BACHELOR THESIS – ME234804

ELECTRIC OUTBOARD PERFORMANCE ANALYSIS USING PROPELLER VARIATIONS BASED ON EXPERIMENT

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INSTITUT TEKNOLOGI SEPULUH NOPEMBER
SURABAYA
2024

TUGAS AKHIR – ME234804

ANALISA PERFORMA MESIN TEMPEL LISTRIK MENGGUNAKAN VARIASI BALING-BALING BERBASIS EKSPERIMENT

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APPROVAL SHEET

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Submitted to fulfil one of the requirements
For obtaining a bachelor degree in engineering at
Undergraduate Study Program of Marine Engineering
Department of Marine Engineering
Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember Surabaya

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KEMENTERIAN PENDIDIKAN, KEBUDAYAAN, RISET, DAN TEKNOLOGI INSTITUT TEKNOLOGI SEPULUH NOPEMBER FAKULTAS TEKNOLOGI KELAUTAN DEPARTEMEN TEKNIK SISTEM PERKAPALAN

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Here is the declare that the Final Project titled "**ELECTRIC OUTBOARD PERFORMANCE ANALYSIS USING PROPELLER VARIATIONS BASED ON EXPERIMENT**". This bachelor thesis is the original work and has been written in accordance with the established rules of scientific writing. Taken full responsibility for the content of this project.

Should any discrepancy arise concerning the originality of this work in the future, I understand and accept the consequences as outlined in the relevant regulations from Institut Teknologi Sepuluh Nopember Surabaya.

Surabaya, 1 August 2024

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ABSTRACT

ELECTRIC OUTBOARD PERFORMANCE ANALYSIS USING PROPELLER VARIATIONS BASED ON EXPERIMENT

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Abstract

The demand for electric vehicles including electric outboard motors, is on the rise due to growing environmental concerns. To optimize the performance of electric outboards, propeller selection particularly propeller pitch, is crucial. This study experimentally evaluated the impact of varying propeller size 7,8 x (8, 9, and 12) inch on the performance of an electric outboard motor. Through both laboratory and direct field tests, measurements of water flow velocity and Δ v as proxies for thrust, energy consumption, boat speed, and vibration levels were conducted. The objective was to identify the optimal propeller pitch that maximizes propulsive efficiency, minimizes energy consumption, an operational cost at the real condition. Results indicated that an electric outboard using propeller pitch of 8, produced the highest water flow velocity and Δ v, implying the greatest thrust also the change of fluid momentum. At the direct field tests using real boat corroborated these findings, with the 8-pitch achieving an average speed of 10 km/h and a roundtrip time of 3.48 minutes. The 8 pitch also exhibited the highest energy consumption at 0.31366 kWh only for laboratory testing. However, at the instalment on real patrol boat electric outboard generates the optimum operational cost. This can be happened due to 8 pitch generates highest speed at the same endurance of battery in every treatment, that's influenced the distance that can be travel automatically longer than the other propeller pitch. So, the operational cost is lowest directly proportional with the performance. For the, vibration levels were minimal across all pitches only 0,3 and 0,4, suggesting no structural damage based on ISO 8503-1. These findings hold significant implications for the selection of electric propulsion systems in small vessels, especially for patrol boats.

Keywords: Electric outboard, Experiment based, Performance, Propeller Pitch

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ABSTRAK

ELECTRIC OUTBOARD PERFORMANCE ANALYSIS USING PROPELLER VARIATIONS BASED ON EXPERIMENT

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Abstrak

Perkembangan permintaan kendaraan listrik, termasuk mesin tempel listrik semakin meningkat seiring dengan meningkatnya kepedulian lingkungan. Untuk mengoptimalkan kinerja mesin tempel listrik diperlukan pemilihan baling-baling, khususnya pitch baling-baling. Penelitian ini dilakukan berbasis eksperimen dengan mengevaluasi pengaruh variasi pitch baling-baling 7,8 x (8, 9, dan 12) terhadap kinerja mesin tempel listrik. Melalui pengujian laboratorium dan lapangan langsung, pengukuran kecepatan aliran air dan Δv sebagai implementasi untuk daya dorong, konsumsi energi listrik, kecepatan perahu, dan tingkat vibrasi diproduksi. Tujuannya adalah untuk mengidentifikasi pitch baling-baling optimal yang memaksimalkan efisiensi propulsi, meminimalkan konsumsi energi, dan biaya operasional dalam kondisi nyata. Hasil menunjukkan bahwa motor tempel listrik dengan pitch baling-baling 8 menghasilkan kecepatan aliran air dan Δv tertinggi, yang berarti daya dorong dan perubahan momentum fluida terbesar. Pengujian lapangan langsung menggunakan perahu patrol mendukung temuan ini, dengan pitch 8 mencapai kecepatan rata-rata 10 km/jam dan waktu tempuh pulang pergi 3,48 menit. Pitch 8 juga menunjukkan konsumsi energi tertinggi sebesar 0,31366 kWh hanya pada pengujian laboratorium. Namun, saat dipasang pada kapal patroli, motor tempel listrik menghasilkan biaya operasional optimal. Hal ini terjadi karena pitch 8 menghasilkan kecepatan tertinggi dengan daya tahan baterai yang sama pada setiap perlakuan, yang mempengaruhi jarak tempuh menjadi lebih jauh dibandingkan dengan pitch baling-baling lainnya. Dengan demikian, biaya operasional terendah berbanding lurus dengan kinerja. Untuk tingkat vibrasi, semuanya minimal hanya 0,3 dan 0,4 mm/s, menunjukkan tidak ada kerusakan struktural berdasarkan ISO 8503-1. Temuan ini memiliki implikasi penting untuk pemilihan sistem propulsi pada mesin tempel listrik terkhusus kapal kecil, terutama kapal patroli.

Kata kunci: Berbasis eksperimen, Mesin tempel listrik, Performa, *Pitch* baling-baling,

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The author anticipates that this research will contribute to the advancement of the Indonesian maritime industry and offer valuable insights to its readers. Recognizing the potential for improvement, the author welcomes constructive criticism and suggestions for future research endeavors.

Surabaya, 22 July 2024

Yonathan Iwangsa Sima

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LIST OF ABBREVIATIONS

ICE	:	Internal Combustion Engine
ICOb	:	Internal Combustion Outboard
NZE	:	Nett Zero Emission
RPM	:	Rotation Per Minute
SDGs	:	Sustainable Development Goals
GT	:	Gross Tonage
BC	:	Before Century
CPP	:	Controllable Pitch Propeller
FPP	:	Fixed Pitch Propaller

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LIST OF SYMBOLS

T	: Thrust (N)
D	: Propeller Diameter (m)
v	: Velocity of incoming flow. (m/s)
Δ v	: Additional velocity, acceleration by propeller. (m/s)
ρ	: Density of the fluids. (kg/m3)
t	: Thrust Deduction Factor
Vs	: Velocity of incoming flow
P	: Power (Watt)
n	: Rotational speed of the propeller.
L	: Length (m)
P	: Pitch Propeller (m)
P	: Power (kW)
RPM	: Rotation Per Minute
I	: Current (Ampere)
V	: Voltage (V)
L	: Length (km)
L max	: Max. Distance (km)
Rms	: Root Mean Square
AH	: Capacity Battery
kWh	: Energy consumption in every hour

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The Net Zero Emission (NZE) program, which mandates industrial and developed nations to achieve net zero emissions by 2050, has spurred the development of new regulations in various countries concerning the use of energy sources that generate emissions. (Aprilianto & Ariefianto, 2021). The adoption of renewable energy aligns perfectly with Sustainable Development Goals (SDGs) focused on clean energy access. This specific SDG has three key targets: ensuring universal access to affordable, reliable, and modern energy services for all. By 2030, it aims to significantly increase the share of renewable energy in the global mix and double the global rate of improvement in energy efficiency. Expanding renewable energy infrastructure in developing countries is expected to foster positive environmental, social and economic growth. Therefore, transitioning from traditional fossil fuels like petroleum and coal to alternative sources is crucial. Renewable energy offers a compelling solution – not only does it minimize environmental damage, but it also guarantees long-term energy security. (Desti, 2022)

Driven by concerns about air pollution from fossil fuels, society is beginning to shift from traditional energy sources towards renewable alternatives. This transition is evident in the marine transport sector, where outboard engines traditionally powered by fossil fuels are being replaced by electric models. The increasing reliance on fossil fuels has demonstrably contributed to air pollution, prompting governments to explore fuel savings and reduce fuel subsidies. While this may initially lead to higher operational costs for boat and ship owners using outboard engines, the long-term benefits are significant. Electric engines not only address the issue of air pollution but also offer quieter operation, further reducing environmental impact.

In Indonesia, the vast majority of motorized fishing boats are classified as "small scale," typically using electric outboards. This dominance of small boats aligns perfectly with the ideal application of outboard drive motors. Legal definitions, as outlined in Law Number 45 of 2009 (amendment to Law Number 31 of 2004 concerning Fisheries), categorize small-scale fishermen as those using vessels up to 5 Gross Tonnage (GT) for their daily livelihood. This translates to a staggering number: out of 394,630 motorized fishing boats in Indonesia, an estimated 335,510, or 85%, fall under the small-scale classification.

Electric outboards offer several advantages over combustion outboards, making them an attractive choice for environmentally conscious boaters. Electric outboards utilize electricity as their power source, producing zero emissions and minimizing their environmental impact. This aligns with the growing demand for sustainable practices in the marine industry.Electric outboards operate significantly quieter than combustion outboards, reducing noise pollution and creating a more peaceful boating experience. This tranquility also benefits marine life, as excessive noise can disrupt their natural behavior and communication. Electric outboards require less maintenance compared to combustion outboards. Their simpler design eliminates the need for regular oil changes, reducing the burden on both the user and the environment. Electric outboards offer lower long-term operational costs due to the relatively lower price of electricity compared to fossil fuels. This advantage becomes even more pronounced considering the rising costs of traditional fuels.. (İşler, 2023).

While electric outboards offer environmental and operational benefits, achieving optimal performance still requires careful propeller selection. Speed, a critical factor for successful boat operations, depends on both the distance travel and energy consumption. To maximize efficiency and speed, three key propeller aspects influence performance: diameter, rotational speed, and pitch. for the propeller pitch, this refers to the theoretical distance a boat would move forward in one complete propeller rotation. It significantly impacts speed and efficiency.

The growing popularity of electric outboards for small and medium-sized boats can be attributed to their eco-friendly nature and affordability. But to get the most out of these engines in terms of performance and efficiency, choosing the right propeller is crucial. A key factor impacting propeller performance is pitch, which refers to the theoretical distance a boat would travel forward with each complete rotation of the propeller. In essence, propeller pitch has a significant bearing on both the speed and energy consumption of an electric outboard engine.

The operation of this electric powered outboard has a propeller drive system. (Habib et al., 2021). Optimization of a propeller pitch can be done through a calculation process. On the propeller there are leaf angles which are made in such a way as dippers which utilize the flow of water passing through the hull of the ship or what is commonly known as the propeller pitch. Ship speed can be achieved due to the thrust of the ship's propulsor. (Firmansyah et al., 2012)

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This research investigates the impact of propeller pitch variation on the performance of an electric outboard motor, specifically the Cerano E301 with a 3kW engine. The study aims to quantify the effects of different propeller pitches such as propeller pitch 8, 9, and 12 on three key performance variables such as water velocity rate, boat speed, and energy consumption and vibration by the electric outboard system.

1.2 Problem Statement

Following a comprehensive literature review on optimizing propeller pitch for electric boats, three key factors have emerged:

1. How does the use of propeller variations affect the water velocity rate and Δ v as the implemented of thrust on the electric outboard based on laboratory testing?
2. How does the propeller variations effect the speed of a boat using an electric outboard based on sea trial?
3. How does the propeller variations effect on the electric outboard energy consumption on laboratory testing and the real boat operational also for its cost estimated?
4. How does the use of propeller variations effect on the vibration?

1.3 Research Objective

Research objective of this research are:

1. To know the effect of propeller variations for the water velocity and Δ v as the implemented of thrust on electric outboard as the performance based on experiment.

2. To know the effect of propeller variations for the speed on the boat based on experiment.
3. To know the effect of propeller variations on the electric outboard energy consumption in laboratory testing comparing the real boat operational and its cost estimated.
4. To know the effect of propeller variations on the vibration based on open water testing.

1.4 Scope of the Study

This research will focus on specific aspects to achieve the established objectives. Some limitations applied to the study include:

1. This research does not mention how to design the electric machine or modify the electric outboard.
2. The electric outboard used 3kW as the powered machine.
3. This research only mentions about the relation between pitch will influence the produce of water velocity rate, speed of boat, energy consumption and operational cost, also vibration.
4. This research doesn't mention how to EPM, because of the specificity of the propeller outboard already provided by manufacture in market.
5. Sea trial using small boat which is patrol boat.
6. The the size of propeller that used is 7,8 x 8, 7,8 x 9, 7,8 x 12 inch.

1.5 Research Benefit

Benefits that can be obtained from writing this bachelor thesis are:

1. The result will be the references for educational purposes especially in electrical outboard theme.
2. To help the society to decrease the used of fossil fuel with the mission for decreasing emission and support the SDG's also reduce the emission impact in marine field.
3. As the final item for graduating college for the specific benefits.
4. As the form of manifestation of systematic and complex thinking especially in marine field.
5. To help and support the company as the mission to develop and mass production.

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CHAPTER 2

LITERATURE STUDY

2.1 Introduction

This chapter explains the mapping of several previous studies that are relevant to this research, as well as the theoretical bases that relate to and support solving the problems in this research. The related sub-study contains the results of previous research regarding electric outboard. This research is grounded in a comprehensive review of both basic theory and literature review. The theoretical foundation is built upon core concepts gleaned from relevant textbooks, while the literature review draws upon insights from previous research on optimizing electric boat propeller pitch.

2.2 Bibliometric

First step to do the research is looking for the related study like the figure 2.1 below:

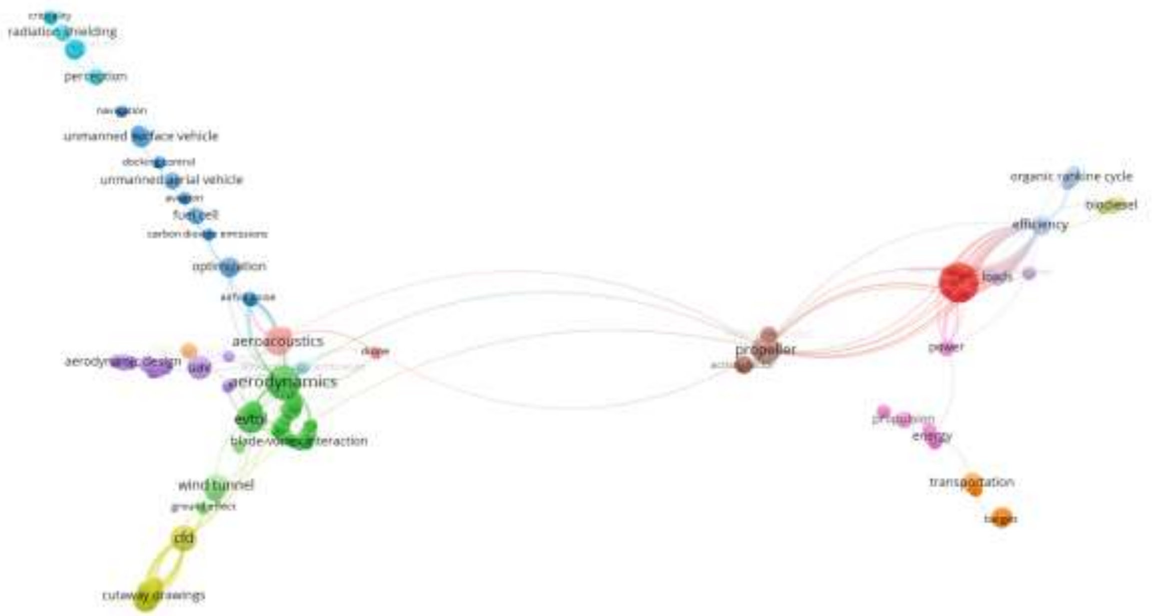


Figure 2.1 Bibliometric

From the figure above, there are the relation between the method to getting performance of engine and also propeller. But there is a lot gap between them. Especially for electric outboard performance analysis using propeller variation or the effect of propeller variations on the electric outboard performance based on experiment. Taken more than 400 journal that related with this research. But this research is still rare. Known if the electricity source that used in the driven or prime mover thing are still new. The society just start move from the conservative energy to the newest energy.

2.3 Basic Theory

Basic theory gotten from book as supporting the research especially for electric outboard driven and also propulsor system. Here is the basic theory for this research:

2.3.1 Electric Motor

In the era of technological modernization, energy has become an important need for humans. This energy can be converted into electrical energy which can then be converted into other energy. Electrical energy is the main energy needed for electrical equipment. Because electrical energy can be changed or converted to other energy. Electrical energy can be converted into light energy through lamps, it can also be converted into other energy. Electrical energy is energy stored in electric current (Ampere) and voltage or electric potential difference (Volt) in terms of requirements for electric power consumption in Watts (W). (Widiarto, 2024)

An electrical energy distributed from an electrical voltage source (for example a battery or batteries) is the same as the electrical energy absorbed by resistance R (for example a lamp or other electrical equipment).The amount of electrical energy provided by an electrical voltage source is equal to power multiplied by time, which is meant by time, namely the length of time the voltage source supplies electrical power). (Widiarto, 2024) To calculate the energy provided by an electricity source, it is formulated as:

$$P = V * I \quad (2.1)$$

When

P = Power (Watt)

I = Current (Ampere)

(Widiarto, 2024)

Battery is a device that can store energy, generally electrical energy in the form of chemical energy. Energy charging can be done repeatedly if the energy runs out. (Widiarto, 2024). Identified all the major components of an Electric Vehicle (EV) and it's important to understand how they work together. The component of battery such as battery, battery charging cable system, battery management system, and etc. (Dhameja, 2002)

The discovery of electromagnetic induction, a cornerstone of electric motor technology, is credited to Michael Faraday around 1831. While James Clerk Maxwell later formalized the laws of electricity, Faraday's earlier work with his rotating homopolar motor in 1831 is recognized as the world's first electric motor. (Dr. Jianfeng Yu, 2011)

The induction motor, a more practical design, emerged later with contributions from two inventors: Galileo Ferraris in 1885 and Nikola Tesla in 1887. Notably, the induction motor became the workhorse of industry, paving the way for automation, a significant development of the 20th centuries. Today, the induction motor remains a dominant force in industrial applications. (Dr. Jianfeng Yu, 2011)

Electric motors are machines that convert electrical energy into mechanical energy. They achieve this through the interaction of a magnetic field generated by the motor itself and an electric current flowing through wires wrapped around the motor's shaft. This interaction produces a force, called torque, that causes the shaft to rotate. This rotational motion can then be used to power a vast array of applications. (Kim, 2017)

There are several types off electric motor, for the example is Direct Current (DC) and Alternating Current (AC) motor. (Kim, 2017). Here is the difference between direct current motor and alternating current motor:

Table 2.1 Differences Between Motor DC and AC (Kim, 2017)

DC	AC
Difficult construction	Simple Construction
Power source from DC current	Power source from AC current
DC uses a device called a Brushed and Commutator to flow current from the current source to the armature coil / power rotor.	Does not require Brused and Commutator.
The interaction of magnetic fields and electric currents where the magnetic field generated by the stator interacts with the electric current in the rotor, producing a repulsive force that rotates the rotor.	Electromagnetic induction in which the alternating magnetic field generated by the stator induces voltage and electric current in the rotor, producing a repulsive force that rotates the rotor.
DC motors are used for tools that require speed control.	Used for tools that require large amounts of power
What moves is the armature coil while the magnetic field remains in the same direction	The magnetic field moves so that it moves the armature coil.

Based on the phase, there are two type of motor AC. Motor AC one phase and three phases. Here is the difference between them

Table 2.2 Differences Between Motor AC 1 Phase and 3 Phase

Feature	Motor AC 1 Phase	Motor AC 3 Phase
Phase	1 Phase	3 Phase
Construction	Simple	Complex
(Thrust)	low	High
Speed control	limited	Easy
Efficiency	low	High
Aplication	Low power	High Power

2.3.2 History of Propulsor System

The origins of marine propulsion technology can be traced back to a remarkable invention by Archimedes between 287 and 212 BC. Made a device, known as the Archimedean Screw Pump, was designed to efficiently transfer water from a lake to irrigation canals in Syracuse, Sicily. (Adji, 2006)

As early as the 15th century, the ingenious mind of Leonardo da Vinci (1452-1519) had already envisioned the principles of screw propulsion, sketching out designs that resembled modern helicopter rotors. Centuries later, in 1661, British inventors Toogood and Hayes patented their ground breaking concept of using helical surfaces, inspired by Archimedean screws, to function as propellers. This innovative approach further gained traction in 1680 when English physicist Robert Hooke proposed the application of Archimedean screws for ship propulsion systems. (Adji, 2006)

Around 1802-04, American inventor C. Stevens utilized a screw propeller, similar in design to modern propellers, to power a 7.5-meter twin screw steamer. In 1828, Scottish farmer R. Wilson successfully demonstrated the principles of the screw propeller. (Adji, 2006)

The year 1836 marked a turning point in the history of marine propulsion as two significant advances in screw propeller technology emerged. English farmer P. Smith made history by becoming the first to implement a screw propeller in practical application. Its innovative design featured a single-bladed wooden propeller capable of rotating in both directions, offering enhanced maneuver ability and efficiency. (Adji, 2006)

Concurrent with Smith's breakthrough, Swedish engineer J. Ericsson unveiled the forerunner of the contrarotating propeller. This ingenious concept involved two wheels with three helical blades rotating in opposite directions, further optimizing propulsion efficiency and reducing vibration. (Adji, 2006)

In 1839, Smith took his screw propeller technology to the next level by equipping his 237-ton vessel with Archimedes screw props. This bold move proved to be a resounding success, marking a pivotal moment in the transition from paddle propulsion systems to screw propulsion systems. (Adji, 2006)

Smith's successful application of screw propellers heralded a new era in marine engineering. The superior performance and efficiency of screw propellers over paddle wheels led to their widespread adoption, revolutionizing maritime transportation. (Adji, 2006)

Steam power and advancements in screw propeller technology went hand-in-hand during the 1840s and 1850s, paving the way for their effective use. This era witnessed a landmark achievement in 1845, when the Great Britain became the first ship equipped with screw propellers to conquer the Atlantic Ocean. The success of this voyage highlighted the superiority of screw propulsion. The trend continued with engineer John Thornycroft's design in 1880. His propellers remarkably resembled the form of propellers used today, further solidifying screw propulsion as the dominant marine technology. (Adji, 2006)

The period between 1880 and 1970 saw a relative stability in basic propeller designs. However, the landscape shifted significantly in the later decades (1970s-1990s) due to external pressures. (Adji, 2006)

The "fuel crisis" and growing environmental concerns, particularly regarding noise, vibration, and emissions, triggered a renewed focus on propeller design and stern configurations. This resulted in the exploration of unconventional propeller shapes, pushing the boundaries of marine propulsion technology. (Adji, 2006)

2.3.3 Types of Propeller

There are several types of propeller, for the example is fixed pitch propeller and Controllable pitch propeller. Fixed Pitch Propellers (FPPs) and Controllable Pitch Propellers (CPPs) are two common types of propellers employed in marine vessels. Each possesses distinct advantages and disadvantages, and the selection of the appropriate propeller type for a specific vessel hinges on a multitude of factors, including vessel type, intended application, and operational conditions. (Carlten, 2010)

a. Fixed Pitch Propeller

   Fixed pitch propellers (FPPs) are characterized by their non-adjustable pitch angle. They excel in scenarios involving constant speeds, demonstrating superior efficiency under these conditions. Due to their simplicity and cost-effectiveness, FPPs are widely used in recreational boats and other vessels with unclear propulsion requirements (Carlten, 2010)

   Propeller with fixed pitch (fixed pitch propeller). Propellers with a fixed pitch (fixed pitch propeller, FPP) is usually used for large ships with relatively low rpm and torque produced high, more economical fuel use, noise or vibration minimal, and minimal cavitation, usually designed sequentially individuals so that they have special characteristics for certain ships will have optimum efficiency values. (Fauzirahman et al., 2018)

b. Controllable pitch Propeller

   Controllable pitch propellers (CPPs) offer the advantage of a variable pitch angle, allowing for adjustments to suit specific operational needs. This adaptability makes them more efficient across a wider range of speeds compared to FPPs. As a result, CPPs are commonly found in vessels that demand high maneuverability, such as tugboats and cruise ships. (Carlten, 2010)

   Propeller with controllable pitch propellers). Propeller with variable pitch, (controllable pitch propeller, CPP) is a ship propeller with the propeller leaf stroke being able to be changed accordingly with needs, for example for low rpm a large pitch is usually used and for high rpm a short pitch is used, or it can be used to push forward and pull the ship backwards. rear, so this can create fuel consumption as effective as possible. (Fauzirahman et al., 2018)

2.3.4 Resistance

The Role of Propeller Design and Propulsion System Planning. To achieve the desired vessel speed, a well-planned propulsion system is crucial. This involves selecting the appropriate propeller type, shaft diameter, and prime mover (engine) to generate the necessary thrust to overcome the vessel's resistance. The next step is propeller Design which is the critical step. The design of the propeller is a critical step in this process. It begins with understanding the key dimensions of the vessel and then calculating the total resistance using appropriate methods, such as the Harvard method. (Siswantoro)

The next step is engine selection by matching power to performance. Next, the required engine power (BHP) is determined. This represents the power transmitted from the engine to the propeller to generate thrust. Based on the calculated BHP and desired vessel speed, the appropriate engine is selected. Then propulsion system planning to getting ensuring optimal performance. Effective propulsion system planning involves carefully considering the interaction between the propeller, shaft, and engine. The goal is to optimize the system to achieve the desired vessel speed while ensuring efficient operation and minimizing fuel consumption. (Siswantoro)

2.4 Literature Review

Literature review gotten by the previous research here is the literature review. A literature review is a comprehensive summary and critical evaluation of existing literature on a specific topic. It is a commonly used tool in academic works such as dissertations, theses, scholarly articles, and research papers. The primary purpose of a literature review is to provide a holistic overview of the current state of knowledge on a particular subject and to demonstrate how new research contributes to this body of knowledge.

2.4.1 Related Study

Research related to electric outboard propulsion systems has been conducted to explore various aspects of their design, efficiency, and performance. This includes studies on battery technology, motor efficiency, propeller design, control systems, and overall system integration. Additionally, research has focused on environmental impacts, such as emissions reduction and noise mitigation, as well as economic factors such as cost-effectiveness and market acceptance.

Based on (Reabroy et al., 2015) in terms of performance of the electric outboard engine. Research has been carried out related to research on electric outboards, system assembly and direct performance tests on small boats. Thirdly, the testing focuses on assessing the performance of the system when integrated into a boat. To accomplish these objectives, the development of the electric outboard motor and its drive system was undertaken, with a small utility boat chosen as the subject for performance testing.

Based on (Habib et al., 2021) Research was carried out on the effect of the tilt of the propeller shaft on the speed or thrust of the "ketinting" boat. The slope is placed based on the following figure:

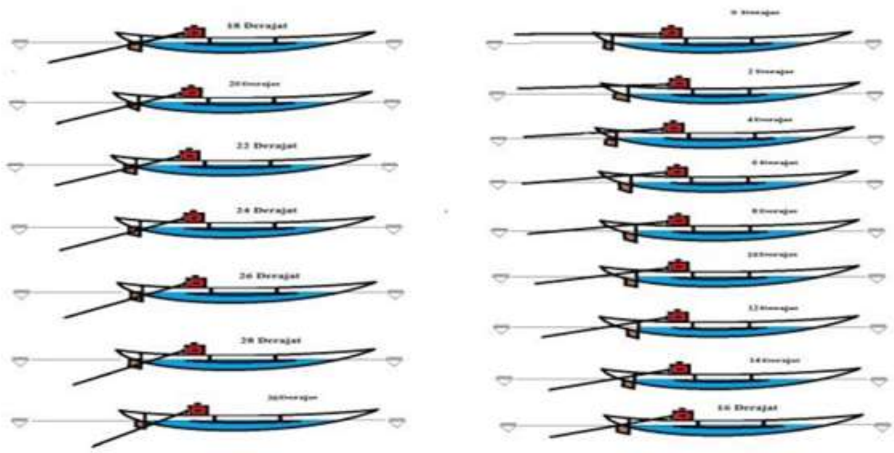


Figure 2.2 Test the effect of shaft tilt on ship performance (Habib et al., 2021)

By the figure 2.1, The thrust and speed of the “ketinting” boat are influenced by the tilt position of the propeller shaft used. (Habib et al., 2021)

Also in the research by (AslamShaikh, 2014). The material of the blade affect the performance of propeller such as:

Table 2.3 Material of Propeller

No	Material	Description
1	Aluminum	Aluminum is the most popular material for propeller of the outboard.
2	Stainless Steel	Stainless steel is the strongest material used for outboard made thinner for better efficiency. The repair cost of stainless steel propellers is approximately double the cost of the same propeller made of aluminum.
3	Plastic and Composite	Plastic and composite material propellers flex considerably under high loads and cannot be repaired if damaged, but they are good on trolling motors and low horsepower outboards.
4	Manganese Bronze	Manganese bronze propellers are reasonably priced and repairable. Manganese bronze propellers can cause corrosion on aluminum surfaces if used in salt water.
5	Cast Copper Alloys	These materials are used when propellers are manufactured by casting process. Casting shall be performed in dry moulds using degassed liquid metal. The casting process shall be supervised in order to prevent eddies occurring. Special devices or procedures shall be in place to ensure that no slag can enter the mould.

As environmental awareness continues to grow among the population, the emergence of electric outboard motors has gained significant attention. In contrast to conventional gasoline outboard engines, electric outboard engines offer numerous advantages, including reduced maintenance expenses, minimal noise levels, enhanced efficiency, and emission-free operation.(Eng, 1973)

Related Research has also examined the underwater radiated noise produced by electric outboard motors and its potential impact on marine life, including dolphins. Studies have compared the acoustic characteristics of electric outboard motors to traditional combustion engines, noting differences in frequency spectrum and sound pressure levels. While electric motors generally produce lower levels of underwater noise compared to their combustion counterparts, they still emit sound that can affect marine mammals like dolphins. (Gaggero et al., 2024)

By the control system, based on (Bonafilia, 2015), This research is based on a digitalization simulation for the control system where previously the steering was carried out manually, now a kind of electric steering has been created.

The realm of electrical outboards is abuzz with exciting developments, offering a cleaner, quieter, and more sustainable alternative to their gasoline-powered counterparts. But the story of these electric marvels goes beyond just recent advancements. Let's embark on a journey through time, exploring the fascinating history of electrical outboard research and its promising future. Basically, electric outboard technology tends not to have been done by much research before. One reason is because this is technology that tends to be new.

2.4.2 Outboard

The outboard motor designed outside of transom as a propulsion system. This outboard consists several parts such as motor engine, propeller, and etc. (Eng, 1973). Here is the example figure of the outboard:

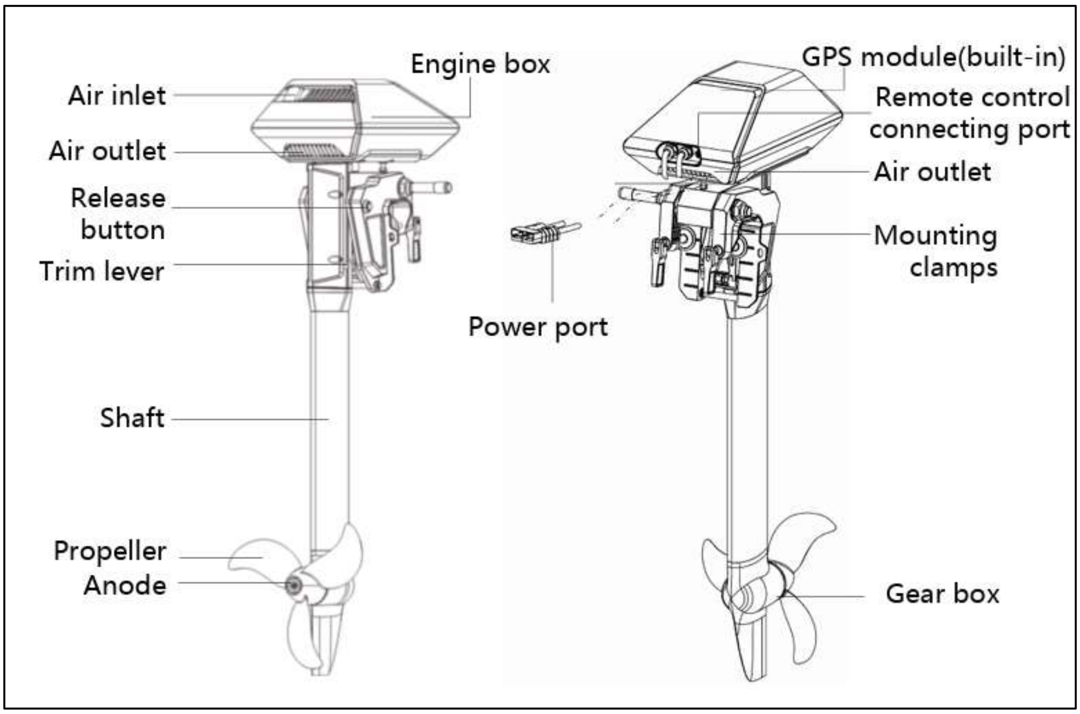


Figure 2.3 Outboard (Eng, 1973)

There are two types of outboard based on the power supply, they are internal combustion outboard and electric outboard. Here is the description of both:

2.4.2.1 Internal Combustion Outboard

An internal combustion outboard (ICOB) is a type of outboard motor that uses an internal combustion engine to power the propeller. The most common type of ICOB uses a gasoline engine, but there are also diesel and even hydrogen-powered models available. At the beginning, two stroke engine dominates the market, but because of two stroke engines not too efficient and produce high pollutant. The researcher starts to develop four stroke engines as well as the new one that makes the equipment has high efficiency and less pollution. (Eng, 1973).

2.4.2.2 Electric Outboard

Care more about protecting the environment, electric outboard motors are gaining popularity. Unlike complicated gas-powered engines, electric ones are simpler, driving the propeller directly from the motor itself. This electric motor has several benefits such as easy upkeep, limited noise, high efficiency, and zero emission. (Eng, 1973)

Early electric outboards were like whispers on the water, limited in power by bulky and heavy batteries. Think golf carts, not speedboats. These "trolling motors" typically sported

0.5kW to 1kW and ran on just one or two lead-acid batteries. But the tide is turning, Thanks to lithium battery technology, which packs up to seven times the punch of traditional batteries, a new wave of electric outboards is surging forward. These powerhouses can reach up to 4kW, offering a smooth, quiet ride with significantly more muscle. Buckle up, boaters, the electric revolution is here. (Eng, 1973)

2.4.3 Propulsion system

When a ship moves at a certain speed, it will experience the drag force of the water, and to overcome this force a pushing force is needed which is quite large from the drive system. Propulsion system or drive system is a system that is very influential in ship movement.

Here are the components of propulsion system:

1. Main engine
2. Propulsor
3. Transmission system

2.4.4 Parameter Affecting the Outboard Propeller Performance

Propeller is a propulsor that is often used on commercial ships. The main parts of the propeller are Hubs and blades. These two parts form a unit which when combined becomes a propeller. The blade or propeller has two parts, namely the face and the back. The back is the surface of the propeller that is visible from the shaft side, while the opposite side is called the face. The front edge of the propeller leaf is called the leading edge, while the other side is called the trailing edge. (Khozin et al., 2016)

Think of a spinning fan, but instead of circulating air, it propels itself forward. That's the essence of a propeller! Its curved blades resemble miniature wings, pushing water or air backward due to a pressure differential between the front and back surfaces. This "push" generates thrust, a force that propels boats, airplanes, and even underwater vehicles. (AslamShaikh, 2014). Here is the variable of propeller of electric outboard.

2.4.4.1 Diameter

The propeller diameter has a big impact on performance. Usually a larger propeller will have a higher efficiency, as it catches more incoming fluid and distributes its power and thrust on a larger fluid volume. (AslamShaikh, 2014). The diameter of a propeller is a critical geometric factor that determines its ability to absorb and deliver power, ultimately influencing the amount of thrust available for propulsion. In most cases, except for high-speed vehicles exceeding 35 knots, propeller diameter is directly proportional to efficiency. This means that larger diameters typically result in higher efficiency. However, in high-speed vessels, larger diameters lead to increased drag. (Gatete et al., 2018)

For conventional vessels, even a small increase in diameter can result in a significant rise in thrust and torque load on the engine shaft. Consequently, larger diameters lead to slower propeller rotation speeds, constrained by structural limitations and engine capacity. Determining the optimum propeller diameter involves employing various empirical formulas.(Gatete et al., 2018)

In high-speed boat, larger diameters are advantageous in mitigating cavitation issues. By reducing the rotational speed of the propeller, forward movement can still be achieved. Slower rotation decreases pressure imbalances on the blades, reducing inflow forces and subsequently lowering cavitation occurrences. Thus, for a given engine output or desired forward speed, a larger diameter propeller allows for slower rotation and decreased cavitation effects. (Gatete et al., 2018)

The diameter of propeller is the range from tip to tip of the propeller Here is the figure of propeller:

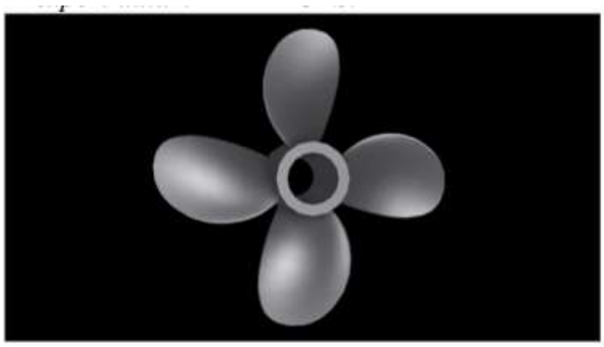


Figure 2.4 Propeller (Lumbanraja et al., 2021)

2.4.4.2 Propeller Pitch

Pitch is the translation distance traveled by the propeller in one round. (Khozin et al., 2016). Propeller pitch defines the theoretical distance the propeller would travel in one revolution through water. (Habib et al., 2021) However, due to the propeller being fixed to a shaft, it doesn't physically move forward itself; rather, it impels the ship forward. The actual distance the boat moves forward in one rotation is typically less than the pitch value. In high-speed vessels, pitch ranges typically between 9 inches to 24 inches. (Gatete et al., 2018)

The influence of propeller pitch on thrust can vary depending on specific conditions and requirements. Generally, propellers with a higher pitch tend to produce higher speeds or thrust compared to those with a lower pitch. However, in certain scenarios, a propeller with a higher pitch may generate lower thrust than one with a lower pitch.(Khozin et al., 2016)

This phenomenon can be attributed to the rotation rate of the propeller. Propellers with a lower pitch typically rotate at a faster speed, leading to a greater displacement of water from behind the propeller. This increased water displacement, in turn, contributes to higher thrust generation. (Khozin et al., 2016)

2.4.4.3 Number of Blade

Blades, the twisted fins or foils extending from the propeller hub, play a crucial role in determining the torque output of a propeller. The shape of the blades and the speed at which they rotate influence the amount of torque generated. When selecting the number of blades for a propeller, it is essential to avoid resonance, as the blade count affects the frequency and intensity of vibrations during operation. (Gatete et al., 2018)

There's a significant relationship between propeller diameter, blade area, and blade number. A larger diameter typically requires fewer blades, while a larger blade area requires more blades. Increasing the number of blades can decrease sheet cavitation on the suction side by reducing the load per blade. However, it may also lead to increased root cavitation due to reduced clearance between blades. Therefore, careful consideration is advised when determining the appropriate. (Gatete et al., 2018)

2.4.5 Parameter Performance of Propeller

There are several parameter performances by propeller such as thrust and torque. Here is the definition of that parameter:

2.4.5.1 Thrust

Thrust which is used to overcome the overall resistance that occurs on the ship so that the ship can move at a certain speed or at its service speed. Propeller is a driving machine used to steer a ship. The working principle of a propeller propulsion device is thrust on a ship that rotates in the water driven by an engine so that it gets a force lift or lifting force acting on the propeller blade. (AslamShaikh, 2014)

Based on (AslamShaikh, 2014), here is the formula for the Thrust

$$T = \dot{m} * \Delta v \tag{2.2}$$

Where:

T : Thrust (N)

$\dot{m}$: Mass flow rate (m)

Δ v : Additional velocity, acceleration by propeller. (m/s)

(Habib et al., 2021)

2.4.6 Power Supply

Power by the electric motor impact by the range and speed during the operational. Larger range and speed the runtime of electric outboard, larger power consumable of dynamo. Here is the table of power that produce by the electric outboard against Speed, runtime, and Range.

Power(W)	Speed(mph)	Runtime (hh:mm)	Range (mile)
500	4	18:00	72
1000	5	9:00	45
2000	6.7	4:30	30.2
3000	8	3:00	24
4000	11.5	2:15	25.9
5000	13.5	1:50	24.7
6000	15	1:30	22.5

Figure 2.5 Power of Electric Outboard Against Speed, Runtime, and Range in General (*EPropulsion Test Ride Report*, 2019)

2.4.7 Consumable Energy

Electrical energy consumption is measured in kilowatt-hours (kWh). This unit shows the amount of electrical energy used in one hour. The higher the kWh consumption, the more electrical energy used. The kWh consumption of an electric outboard engine can vary depending on several factors, as mentioned previously: engine power, speed, load, sea conditions, engine efficiency, battery condition and driving style. (Satria et al., 2017)

The other factors of consumable energy for electric outboard is by the propulsor. The types, material, diameter, number of blade and the pitch propeller. Especially for propeller pitch, propeller pitch is the angle of inclination of the propeller blade to the propeller axis. A larger propeller pitch will produce greater thrust, but also requires more power. Conversely, a smaller propeller pitch will produce less thrust, but require less power.

The impact of propeller pitch on energy consumption by an electric outboard motor is influenced by several factors:

- Speed: At lower speeds, a higher propeller pitch generally results in lower energy consumption. Conversely, at higher operating speeds, a lower propeller pitch typically leads to lower energy consumption.
- Load: When carrying a heavier load, a higher propeller pitch can translate to lower energy consumption. However, at lower loads, a lower propeller pitch is often more energy-efficient.
- Environmental Conditions: Calm water conditions favor lower propeller pitch for optimal energy usage. In contrast, choppy or wavy waters may benefit from a higher propeller pitch to maintain efficiency.

The formulas to calculating the energy consumption, especially for electric outboard. Using the formula as simple as this formula:

$$kWh = P\ (kW)\ x\ t\ (hours) \quad (2.3)$$

Where:

kWh = Consumable Energy (kWh)

P = Power (kW)

t = time (hour)

2.4.8 Cost of Electricity

Based on electricity cost by the PLN in Indonesia, here is the cost estimated in every kWh

PENETAPAN

PENYESUAIAN TARIF TENAGA LISTRIK *(TARIFF ADJUSTMENT)*

JULI - SEPTEMBER 2024

NO.	GOL. TARIF	BATAS DAYA	REGULER		PRA BAYAR (Rp/kWh)
			BIAYA BEBAN (Rp/kVA/bulan)	BIAYA PEMAKAIAN (Rp/kWh) DAN BIAYA kVArh (Rp/kVArh)	
1.	R-1/TR	900 VA-RTM	*)	1.352,00	1.352,00
2.	R-1/TR	1.300 VA	*)	1.444,70	1.444,70
3.	R-1/TR	2.200 VA	*)	1.444,70	1.444,70
4.	R-2/TR	3.500 VA s.d. 5.500 VA	*)	1.699,53	1.699,53
5.	R-3/TR	6.600 VA ke atas	*)	1.699,53	1.699,53
6.	B-2/TR	6.600 VA s.d. 200 kVA	*)	1.444,70	1.444,70
7.	B-3/TM	di atas 200 kVA	**)	Blok WBP = K x 1.035,78 Blok LWBP = 1.035,78 kVArh = 1.114,74 ****)	-
8.	I-3/TM	di atas 200 kVA	**)	Blok WBP = K x 1.035,78 Blok LWBP = 1.035,78 kVArh = 1.114,74 ****)	-
9.	I-4/TT	30.000 kVA ke atas	***)	Blok WBP dan Blok LWBP = 996,74 kVArh = 996,74 ****)	-
10.	P-1/TR	6.600 VA s.d. 200 kVA	*)	1.699,53	1.699,53
11.	P-2/TM	di atas 200 kVA	**)	Blok WBP = K x 1.415,01 Blok LWBP = 1.415,01 kVArh = 1.522,88 ****)	-
12.	P-3/TR		*)	1.699,53	1.699,53
13.	L/TR, TM, TT		-	1.644,52	-

Catatan :

*) Diterapkan Rekening Minimum (RM):
RM1 = 40 (Jam Nyala) x Daya tersambung (kVA) x Biaya Pemakaian.

**) Diterapkan Rekening Minimum (RM):
RM2 = 40 (Jam Nyala) x Daya tersambung (kVA) x Biaya Pemakaian LWBP.
Jam nyala : kWh per bulan dibagi dengan kVA tersambung.

***) Diterapkan Rekening Minimum (RM):
RM3 = 40 (Jam Nyala) x Daya tersambung (kVA) x Biaya Pemakaian WBP dan LWBP.
Jam nyala : kWh per bulan dibagi dengan kVA tersambung.

****) Biaya kelebihan pemakaian daya reaktif (kVArh) dikenakan dalam hal faktor daya rata-rata setiap bulan kurang dari 0,85 (delapan puluh lima per seratus).

K : Faktor perbandingan antara harga WBP dan LWBP sesuai dengan karakteristik beban sistem kelistrikan setempat ($1,4 \leq K \leq 2$), ditetapkan oleh Direksi Perusahaan Perseroan (Persero) PT Perusahaan Listrik Negara.

WBP : Waktu Beban Puncak.
LWBP : Luar Waktu Beban Puncak.

Figure 2.6 Cost Electricity in Indonesia (PLN)

2.4.9 Vibration

The vibrational characteristics of a machine can depict the desired and undesired movements within its components, making vibration measurement and analysis valuable for diagnosing machine conditions. For instance, worn gears can cause vibrations with high amplitudes at frequencies corresponding to the toothmesh frequency (RPM multiplied by the number of gear teeth). Similarly, rotational unbalance can lead to vibrations at high levels at the shaft RPM frequency itself. Using this technique, a rotating machine can be monitored at specific positions to assess its condition. The primary goal is to safeguard the machine, predict potential failures, and reduce maintenance costs.(Bagus Setyawan & Sufiyanto, 2013)

Here is the example of the vibration can detect the broken part of the engine or machinery

Figure 2.7 Failure Caused of Machinery Part(Bagus Setyawan & Sufiyanto, 2013)

Electric outboard motors (EOMs) are increasingly gaining popularity due to their environmentally friendly and efficient nature. However, vibration remains a persistent issue that can detract from the overall boating experience and potentially damage the motor itself. The world of vibration measurement encompasses a diverse array of units and terminologies, each serving a specific purpose in characterizing the intricate nature of these oscillations. Understanding these concepts empowers engineers and technicians to effectively assess the health and performance of machinery, ensuring their safe and reliable operation. (Bagus Setyawan & Sufiyanto, 2013)

The Root Mean Square (RMS) value is commonly used to classify the severity of vibrations in a machine. This RMS value measures the effective energy used to generate vibrations in a machine.(Bagus Setyawan & Sufiyanto, 2013)

CHAPTER 3

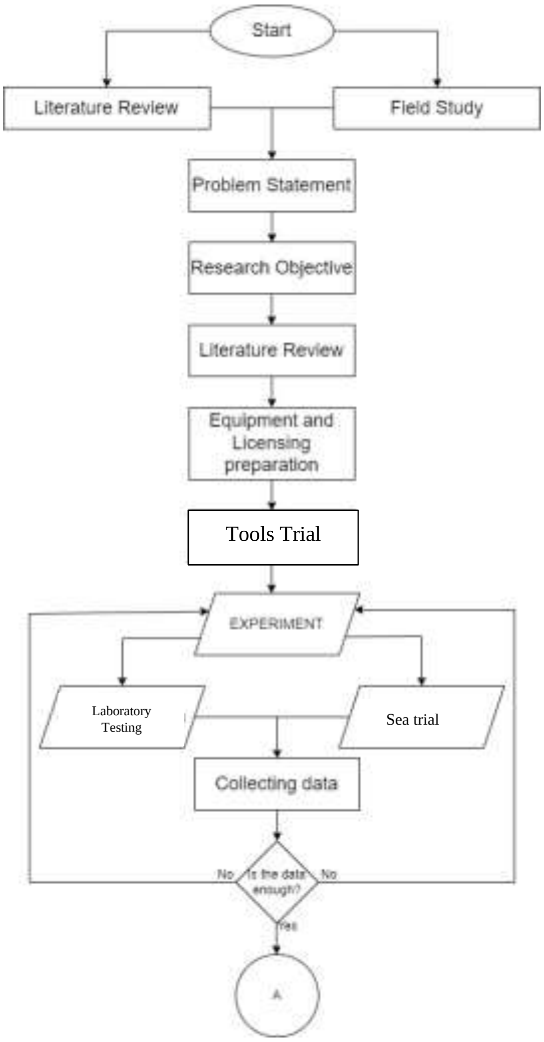
RESEARCH METHODOLOGY

3.1 Introduction

This study relies on direct experimental methods, emphasizing the collection of primary data. Primary data gotten by the two of experimental method. There are laboratory testing and also direct field trial testing. Additionally, secondary data sources, obtained from online resources such as research journals and educational materials, supplement the research process by enriching understanding, serving as references, and aiding in problem-solving efforts.

3.2 Flowchart

Creating a flowchart for a research process involves breaking down the steps from start to finish. Below is a figure flowchart for the research project:



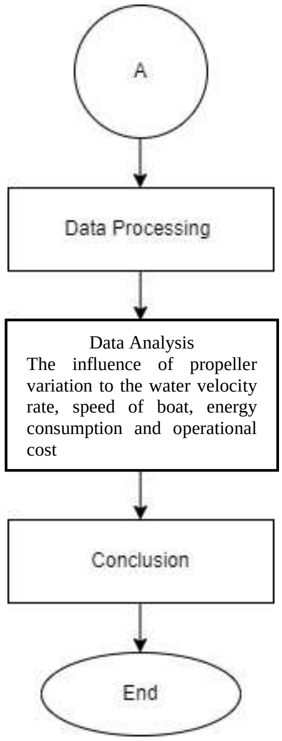


Figure 3.1 Flowchart of the Research (Personal Documentation)

3.3 Experimental Design

3.3.1 Independent Variable (Control Variable)

Independent Variable (Control Variable): This is the factor that the researcher actively changes or controls. It's the cause or the element being manipulated to see its effect on something else. In your example, the propeller pitch (8, 9, and 12) is the independent variable. The researchers are changing the pitch to see how it affects the performance of the electric outboard motor.

- Propeller Pitch: The pitch of the propeller, defined as the distance a propeller would advance in one revolution if it were moving through a solid medium. In this study, three propeller pitches (8, 9, and 12) are used as the independent variable.
- Power Input: The constant power input to the electric outboard motor, maintained throughout the experiments. It can be adjusted by the current input which

1. Laboratory testing for average water velocity and delta-V, the current input is: 6, 12, 24, 36, 48, 60, 72, 84, and 90 Ampere.
2. Laboratory Testing for Energy consumptions, the current input is: 24, 60, and 90 Ampere.
3. Sea trial testing for speed and time to travel the power input is periodic in 60 and 90 ampere round-trip

- Distance: is the distance during trip which is 1,2 km.

3.4.2 Dependent Variable

Dependent Variable: This is the factor that the researcher measures and expects to change in response to the independent variable. It's the effect or the outcome being observed due to the manipulation of the independent variable. In this case, the performance metrics (water flow velocity, thrust, travel time, etc.) are the dependent variables. The researchers are measuring these metrics to see how they are affected by the different propeller pitches. There are performance metrics, the performance metrics of the electric outboard motor, including:

- Water Flow Velocity: The velocity of the water flowing through the propeller, measured in meters per second (m/s).
- Delta-v: The difference in water velocity before and after the propeller, measured in m/s.
- Thrust: The propulsive force generated by the propeller, measured in Newtons (N).
- Travel Time: The time taken by the boat to travel a specified distance, measured in seconds (s).
- Average Boat Speed: The average speed of the boat during the trial, measured in m/s.
- Energy Consumption: The electrical energy consumed by the motor during the trial, measured in watt-hours (Wh).
- Operational Cost: The estimated cost of operating the motorbike for a given travel distance, measured in currency units.

3.4.3 Other Variables

In these are factors that may also influence the dependent variable, but the researchers are trying to keep them constant or control for them. They are not the main focus of the study, but they could affect the results if not controlled. In this example, power input, boat characteristics, and environmental conditions are other variables. The researchers likely kept the power input constant throughout the experiment and tried to minimize the influence of boat characteristics and environmental conditions by conducting the trials under similar conditions.

- Boat Characteristics: The physical characteristics of the boat, such as hull shape, weight, and drag coefficient, which can influence the performance of the propeller.

3.4 Steps

There are two types of experiment method that is the way to taking the parameter data, laboratory testing and direct field testing. Here is the description of that two experiment methods:

3.4.1 Laboratory Testing

Laboratory testing aims to analyse the water flow produced by each propeller variation under different power inputs by battery. To achieve this, an electric outboard with the following specifications was used:

Table 3.1 Electrical Drive Specification

No	Specification	
1	Model	Cerano E301
2	Rated Voltage	64V
3	Rated Output Power	3Kw
4	Rated Running Speed	5500
5	Gear Position	Forward/Reverse
6	Type of Cooling	Nature Cooling
7	Gear Ratio	27:13
8	Battery Capacity	100Ah
9	Rated Voltage	64V

Here is the figure of Electric outboard that used:

Figure 3.2 Cerano Electric Outboard (Cerano Product Guide)

Due to the research used the propeller variations. Here is the propeller variations which is the propeller with size 7,8 x pitch. The pitch of propeller is 8,9, and 12. Here is the figure of the propeller variation

Figure 3.3 Propeller Variation 7,8 x 8 ; 7,8 x 9; and 7,8 x 12 (Personal Documentation)

Here is the parameter data taken by laboratory testing:

a. Water Velocity Rate Based on Laboratory Testing

The results of the water velocity tests conducted with electric outboards using propellers with pitches of 8, 9, and 12. There are 11 points of data taken with 3 height variations such as 20 cm, 40 cm, and 60 cm from base. Water velocity data recorded by flow watch or water velocity meter. This data, which will be displayed in a table format, will serve as the foundation for further analysis in sub-chapter 4.3. There, graphs will be utilized to analyse and compare the performance achieved with these different propeller variations.

To understand the effectiveness of different propellers in generating water flow, the schematic details the data collection methods employed during open water testing. The testing focused on measuring water velocity rates under controlled conditions.

Figure 3.4 Water Velocity Data taken (Personal Documentation)

Here are the steps to getting the water velocity rate based on laboratory testing:

1. Set up the schematic tools such as the figure above

2. the flow watch put in eleven point of data taken in several height variations (20, 40, and 60) cm from base.
3. Water velocity data taken (m/s)
4. Repeat in propeller variation which is propeller pitch 8, 9, and 12 with power input as the control variable such as current input (6, 12, 24, 36, 48, 60, 72, 84, and 90) Ampere
5. Record the data and analysis

b. Energy consumption

The energy consumption analysis will be presented as a graph depicting the relationship between power and consumption. The analysis will explore how variations in current input, such as 24 amperes (low throttle), 60 amperes (mid throttle), and 90 amperes (high throttle), affect power consumption. The electric outboard was operated for 10 minutes with each power input variation for each propeller variation. The magnitude of the battery capacity reduction will serve as data for the energy consumed by the electric outboard with these propeller variations. Once the data on kilowatt-hours (kWh) is obtained, a cost analysis can be conducted.

Figure 3.5 Cerano Electric Outboard Running to Getting Energy Consumption (Personal Documentation)

The data can be obtained from the display on the BMS application. The reduction is in Ah capacity. Here is an example of the documentation:

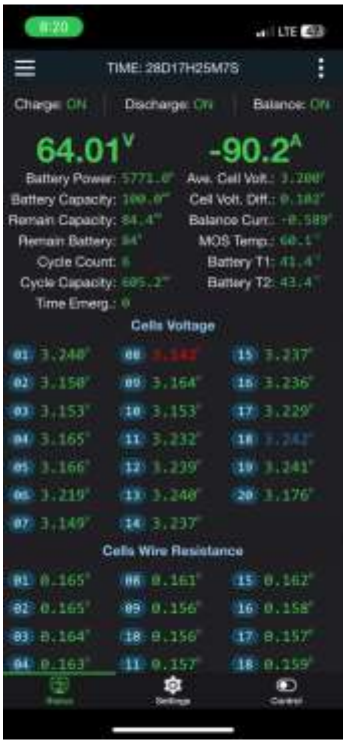


Figure 3.6 BMS Applications for Data Electric Recorder (Personal Documentation)

Here are the steps to getting the Energy consumption based on laboratory testing:

1. Set up the schematic tools such as the figure above.
2. Running the electric outboard in 10 minutes in different propeller with current input (24, 60, and 90) ampere as the control variable.
3. Energy consumption data taken in (AH)
4. Repeat in propeller variation which is propeller pitch 8, 9, and 12
5. Record the data and analysis

c. Vibration

The vibration of the engine that used propeller variation can be analyse as the table and graph of power input vs vibration in every propeller pitch variation. For the example is the same current input 24, 60, and 90 amperes in every propeller pitch which are 8,9, and 12.

Figure 3.7 Vibration Data Taken (Personal Documentation)

Here are the steps to getting the Energy consumption based on laboratory testing:

1. Set up the schematic tools such as the figure above
2. Running the electric outboard in different current input (24, 60, and 90) ampere as the control variable
3. Vibration data taken (mm/s)
4. Repeat in propeller variation which is propeller pitch 8, 9, and 12
5. Record the data and analysis

3.4.2 Sea Trial Experiment

Following the open water testing, a real boat trial was conducted on the waters of Kalimas Surabaya. This trial involved a Satpol PP rescue boat with the following specifications:

Table 3.2 Boat Specification

No	Specification	
1	Model	ZPRO 420
2	Type	Armada 420A
3	LOA	4,2 m
4	Inside Length	3,03 m
5	Inside Wide	0,93
6	Maximum Power	35HP
7	Passengers	8 Person
8	Maximum Payload	850kg
9	Nett Weight	85kg

Here is the Figure of the boat ZPRO 420 as an object to experiment:

Figure 3.8 Rescue Boat ZPRO420 (Tokopedia)

a. Speed of Boat Based on Sea Trial

The boat that used in this trial is military rescue boat from Satpol PP Surabaya. The electric outboard installed propeller pitch variations such as pitch 8, 9, and 12. The next section will present a table and graph analysing the speed achieved by a real boat equipped with an electric outboard motor using propellers of varying pitches. The data will compare the roundtrip travel time and average speed achieved with each propeller variation. Here is the documentation of this trial:

Figure 3.9 Boat Trial to Getting the Actual Speed of Boat using Cerano E301 Electric Outboard

Here are the steps to getting the speed of boat based on direct field testing:

1. Set up the schematic tools such as the figure above
2. Running the boat system with 600m distance depart and 600m arrive which is 1,2 km round trip

3. Use the treatment like different current input in 300m such as using current input 60 Ampere for the first 300m, then push it with 90 Ampere throttle for the next 300m
4. Repeat in depart and arrive
5. Repeat the same treatment using different propeller variation which is propeller pitch 8, 9, and 12
6. Record the time to travel in round trip and average speed.

b. Operational Cost by the Operational Boat that used Cerano E301 Electric Outboard

By the trial, taken parameter data to estimate operational cost such as speed of boat, endurance of battery, maximum distance until battery is empty and energy consumption during several treatment. The treatment is using different propeller pitch (8,9, and 12)

Here are the steps to getting the several parameters to getting the cost based on operational activity of boat based on direct field testing:

1. Set up the schematic tools of direct field testing
2. Running the boat system with 600m distance depart and 600m arrive which is 1,2 km round trip
3. Use the treatment like different current input in 200m such as using current input 24 Ampere for the first 200m, then push it with 60 and 90 Ampere throttle for the next 200m
4. Repeat in depart and arrive
5. Repeat the same treatment using different propeller variation which is propeller pitch 8, 9, and 12
6. Record the speed in km/h
7. calculate the duration of battery until empty
8. calculate the maximum distance until the battery is empty
9. calculate the charge in a day
10. calculate the energy consumption in a day
11. projection of cost estimated in a year

3.5 Hypothesis

In this sub-chapter, the existing problems and hypotheses will be explained. The following are the problems in this research, namely:

1. How does the variations of propeller influence the water velocity rate and Δ v as the implemented of thrust produced by the electric outboard drive?
2. What is the influence and comparison of propeller variations on the speed of boat that using electric outboard ?
3. What is the influence comparation of propeller variations on the energy consumption at laboratory testing and real operational testing also its operational cost of boat that used electric outboard?
4. What the influence and comparation propeller variations on vibration during operational of electric outboard?

The given hypothesis is explained as follows:

1. The variations of propeller influences the water velocity rate as the implemented of thrust. Higher or lower of propeller pitch, higher or lower value of water velocity rate. Higher velocity rate similar with high value of thrust.
2. The variations of propeller influence the speed of boat. Higher or lower pitch, higher or lower speed of boat.
3. The variations of propeller influence the energy consumption. higher or lower propeller pitch greater energy consumption and operational cost. Higher or lower propeller variation greater energy consumption and operational cost
4. The variations of propeller influence the vibration. Higher or lower propeller variation greater or lower vibration.

In proving this hypothesis, several methods are carried out as follows:

1. To prove hypothesis number 1, the graph is needed in the form of water velocity rate or delta-v against the power input for every propeller pitch
2. To prove hypothesis number 2, the graph in the form of propeller variations against the speed of boat is needed.
3. To provide the hypothesis number 3, the graph in the form of propeller variations against the energy consumptions is needed. Not only that, the graph in the form of propeller variations against the operational cost is needed.
4. To provide the hypothesis number 4, the graph in the form of propeller variations against the vibration is needed.

3.6 Literature Review

The literature review in this study serves the purpose of acquiring fundamental theories relevant to the research topic and gathering additional supportive information. Extensive literature searches were conducted utilizing various sources, including books, journals, and previous theses, accessed through platforms such as ScienceDirect, ResearchGate, and the MPP Laboratory database.

The literature review process involved critically evaluating and analysing the selected sources to extract key insights and findings related to analyse the performance of outboard such as the speed and energy consumption. These sources encompassed a wide range of scholarly materials, ensuring a comprehensive understanding of the theoretical foundations, methodologies, and advancements in the field.

3.7 Research Method

The research method used the experimental method found at PT. Braja, with 3 experiments which include:

1. Laboratory testing to getting actual electric outboard performance such as water velocity rate that produce by electric outboard with pitch propeller variations as the implementation of thrust.
2. Sea trial testing to getting actual electric outboard if the equipment assembly at the real boat to getting the speed as the comparation data.
3. Laboratory and trial testing to getting energy consumption also compare it with operational cost of boat by the electric outboard with propeller variation.
4. Vibration Testing to getting the value of vibration in every single propeller pitch that installed at the electric outboard.

3.8 Data Collecting

The data collection process for this research will be divided into three parts, as it involves gathering data from three different cases. The first case, the data from laboratory testing which is the water velocity rate, energy consumption, and vibration that produce by electric outboard using propeller variations. The second case will involve obtaining data as the real experiment by the running the engine with trial method. The data that will be gains, such as speed of boat, time to tavel, and operational cost.

3.8.1 Case 1 – Laboratory testing to Getting Water Velocity Rate

In this case, the open water testing aimed to getting the factor to found the data that influence the water velocity rate such as voltage, current, power, and also RPM. This open water testing using BMS application as the display for record the variable of power. Not only that, the tachometer also used for RPM recorder. The RPM between engine and output by propulsion system are different. This testing also can used to getting the energy consumption for each propeller variation.

3.8.2 Case 2 – Direct Field Trial to Getting the Speed and Operational Cost

In this case which is sea trial testing using real boat to getting the real speed of boat using propeller variation. The electric outboard will be installed in real boat. Then the boat will be operated in the throttle variation such as 60 ampere current input and 90 Ampere current input. Then the data will be compared in every propeller variation.

3.8.3 Case 3 – Energy Consumption

In order to getting the energy consumption variables, using propeller variation also can be the solution. For the example the data can be gotten at laboratory and also at real boat operation. The boat that installed electric outboard round trip operated in same condition. Same condition means same boat, same burden, and same environment. Then the variables of energy consumption gotten.

3.8.4 Case 4 – Vibration

In order to getting the vibration variables using propeller variations, the engine running in several power input that can be adjusted. The data can be taken at the laboratory testing / open water testing.

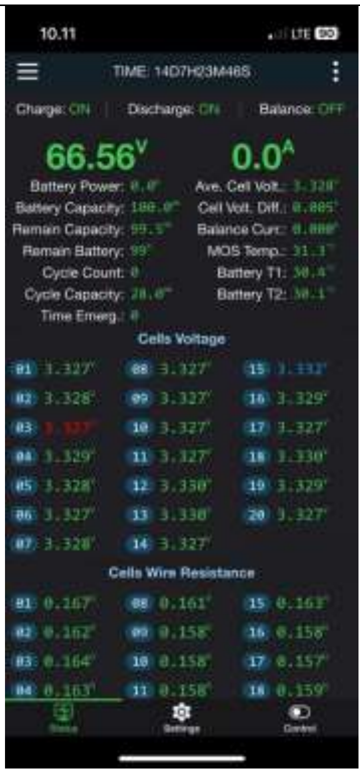
3.9 Tools

At this stage, tools and materials will be prepared before conducting the experiment. The tools and materials needed to carry out this experiment are as follows:

Table 3.3 Tools and Function for this Experiment Project

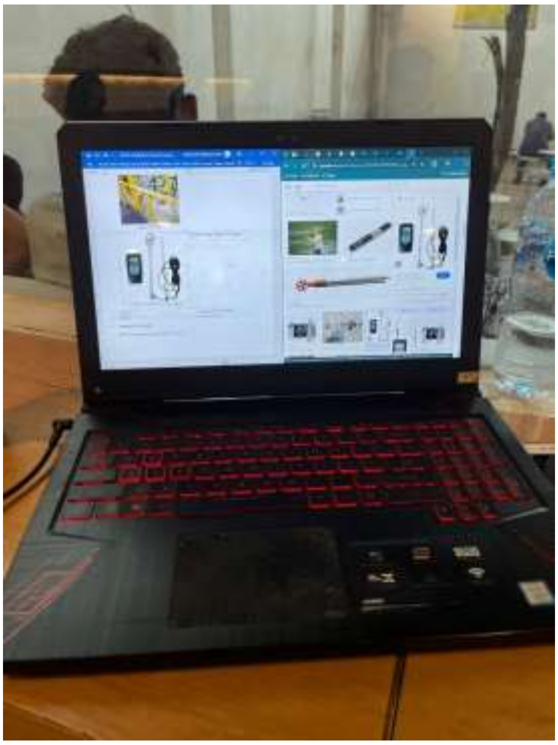
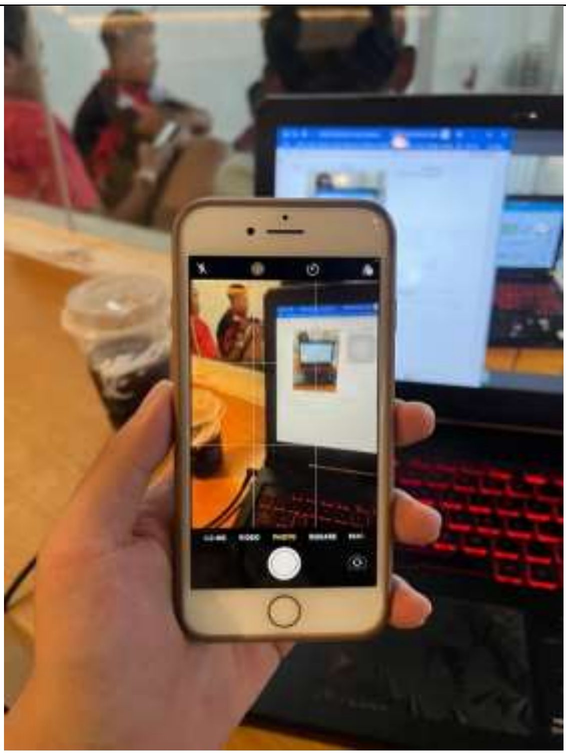
<table>
<tr><th>No</th><th>Name</th><th>Function</th></tr>
<tr><td>1</td><td>
Figure 3.10 Electric Outboard Cerano (Personal Documentation)</td><td>As the object for researched</td></tr>
<tr><td>2</td><td>
Figure 3.11 Propeller (Personal Documentation)</td><td>As the object to research (variation). There are three size, propeller pitch 8, 9, and 12</td></tr>
</table>

No	Name	Function
3	 Figure 3.12 Flow Watch (Personal Documentation)	As the Water Velocity Recorder
4	 Figure 3.13 Circulating Tank	As the test side for laboratory test

No	Name	Function
5	 Figure 3.14 Stand(Personal Documentation)	As a seat or handle for the outboard engine so that the engine does not shake
6	 Figure 3.15 BMS App (Personal Documentation)	Power variable recorder

No	Name	Function
	 Figure 3.16 Military Rescue Boat (Personal Documentation)	As the object to sea trial
7	 Figure 3.17 GPS Speedometer(Personal Documentation)	As the speed recorder

No	Name	Function
8	 Figure 3.18 Tachometer	As the RPM recorder
9	 Figure 3.19 Vibration Meter	As the vibration data recorder

No	Name	Function
8	 Figure 3.20 Laptop (Personal Documentation)	Used to data treatment.
8	 Figure 3.21 Camera (Personal Documentation)	Documentation

3.10 Research Schematic

There are two types experiment in this research which are laboratory or open water testing and also Direct Boat trial. Here is the figure of research schematic:

A. Laboratory Testing

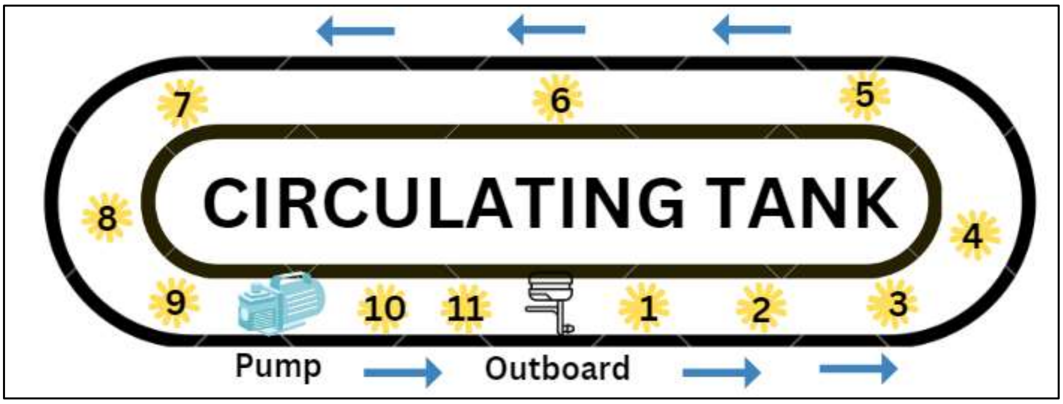


Figure 3.22 Laboratory Schematic (Personal Documentation)

Based on the figure 3.22 above the outboard installed in the middle of point 1 and 11. There are water pump in the middle of point 9 and 10 to make an additional flow. The water has the counter clock wise flow. The number of points such as point 1, 2, 3 until 11 is the point to take the data of water velocity rate.

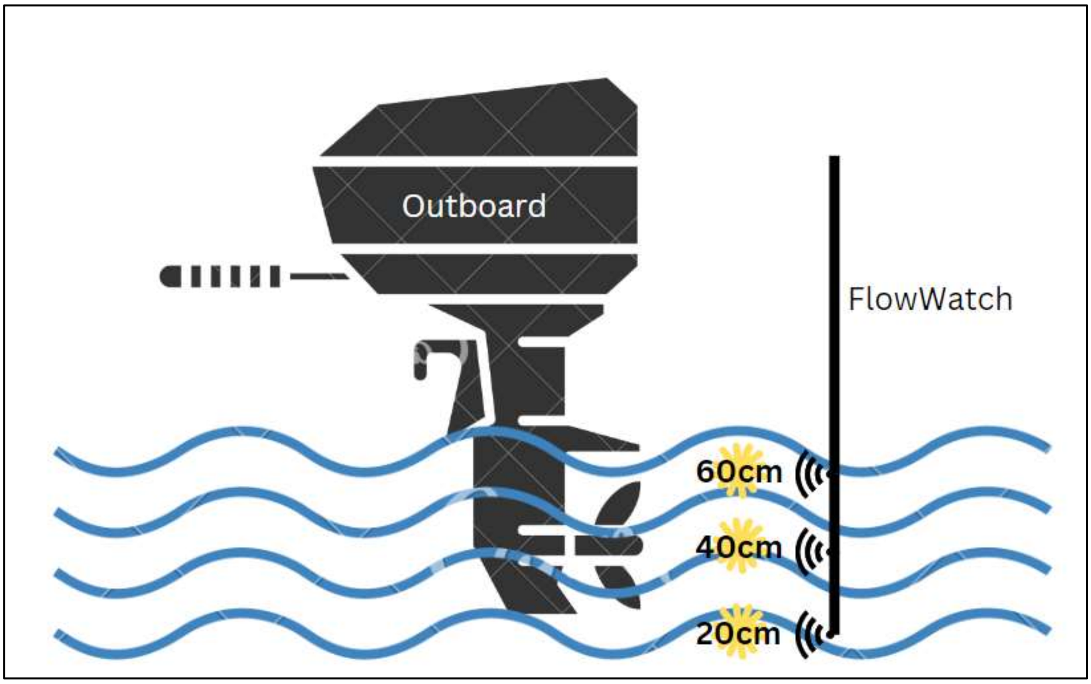


Figure 3.23 Height Variation of Water Velocity Taken (Personal Documentation)

Based on the Figure 3.23 Above, the data taken by using height variation. 20, 40, and 60 cm from base. Using water velocity meter. The data taken from every pitch propeller such as propeller pitch 8, 9, and 12.

Open water testing serves a trial purpose: measuring water velocity rate, capturing energy consumption and vibration data for each pitch propeller which is propeller with pitch 8,9, and 12.

B. Sea Trial

Figure 3.24 Direct Trial (Personal Documentation)

As illustrated in Figure 3.15, the sea trial aimed to evaluate the impact of variable propeller pitch on speed. Different propeller pitches were tested during the trial. Data, including average departure and arrival speeds for each propeller pitch as well as round trip times, was recorded using an online GPS system as shown in Figure 3.17.

Figure 3.25 GPS App (Personal Documentation)

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

Chapter 4 presents the results of an experimental analysis on electric outboard performance. The analysis examines the impact of propeller variations (pitch 8, 9, and 12) on performance. Data was collected through two methods, open water testing and real-boat trials with the electric outboard installed. The first stage of testing, focusing on open water performance, was conducted at the MMS laboratory of the ITS Department of Marine Engineering. Subsequently, the trial boat underwent testing on Kalimas Surabaya.

4.2 Data of Performance Testing

This section presents the data collected during the experiment. The data includes water velocity rates, actual boat speeds, and energy consumption measurements for the electric outboard motor equipped with propellers of varying pitches (8, 9, and 12).

4.2.1 Water Velocity Rate Based on Laboratory Testing

The open water testing yielded valuable data on water velocity rates, a key performance parameter for electric outboards.

Table 4.1 Water Velocity Rate from Electric Outboard that Installed Propeller with Pitch 8

DATA ELECTRIC OUTBOARD														
PITCH 8" (m/s)														
No	**P(Watt)**	**RPM**	**Height**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	**384**	1500	20 cm	0,3	0,3	0,5	0,3	0,2	0,2	0,2	0,2	0,2	0,6	0,2
			40 cm	1,5	0,5	0,5	0,3	0,2	0,2	0,2	0,2	0,2	0,3	0,3
			60 cm	0,3	0,3	0,3	0,3	0,2	0,3	0,3	0,2	0,3	0,3	0,3
2	**768**	2400	20 cm	0,3	0,6	0,6	0,4	0,3	0,4	0,3	0,3	0,3	0,4	0,3
			40 cm	1,9	0,8	0,5	0,4	0,3	0,3	0,3	0,3	0,3	0,4	0,3
			60 cm	0,3	0,6	0,5	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3
3	**1536**	3800	20 cm	0,4	0,6	0,8	0,5	0,4	0,5	0,4	0,4	0,4	0,5	0,4
			40 cm	2,6	1	0,5	0,5	0,3	0,3	0,4	0,4	0,4	0,6	0,4
			60 cm	0,6	0,5	0,5	0,5	0,5	0,3	0,4	0,4	0,4	0,5	0,5
4	**2304**	4300	20 cm	0,4	1,1	0,9	0,6	0,4	0,6	0,5	0,5	0,5	0,6	0,4
			40 cm	3,1	1,1	0,9	0,6	0,5	0,4	0,5	0,5	0,5	0,6	0,5
			60 cm	0,7	0,5	0,8	0,6	0,6	0,5	0,5	0,5	0,5	0,6	0,6
5	**3071**	5200	20 cm	0,4	1	1	0,6	0,6	0,5	0,5	0,5	0,5	0,6	0,6
			40 cm	3,3	1,2	0,8	0,6	0,5	0,5	0,5	0,5	0,5	0,7	0,6
			60 cm	1,5	0,5	0,8	0,6	0,6	0,5	0,6	0,5	0,5	0,6	0,6
6	**3840**	6400	20 cm	0,4	1,1	1,1	0,6	0,6,	0,6	0,6	0,6	0,6	0,6	0,6
			40 cm	3,4	1,2	0,8	0,6	0,5	0,6	0,5	0,5	0,6	0,8	0,7

DATA ELECTRIC OUTBOARD														
PITCH 8" (m/s)														
No	**P(Watt)**	**RPM**	**Height**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
			60 cm	1,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,7	0,7
7	**4608**	7000	20 cm	0,4	1,3	1,2	0,7	0,6	0,6	0,6	0,7	0,6	0,7	0,7
			40 cm	3,5	1,2	0,9	0,5	0,6	0,6	0,7	0,7	0,7	0,9	0,8
			60 cm	1,6	0,6	0,6	0,6	0,6	0,6	0,6	0,7	0,6	0,8	0,7
8	**5376**	7414	20 cm	0,7	1,3	1,2	0,7	0,7	0,7	0,7	0,6	0,6	0,8	0,6
			40 cm	3.3	1,8	0,8	0,7	0,6	0,6	0,5	0,6	0,6	0,7	0,8
			60 cm	0,8	0,8	0,6	0,6	0,7	0,5	0,5	0,6	0,6	0,6	0,7
9	**5760**	7600	20 cm	0,6	1,7	1,3	0,8	0,8	0,7	0,7	0,6	0,6	0,8	0,7
			40 cm	3,1	2,2	1,2	0,7	0,8	0,6	0,6	0,6	0,6	0,8	0,8
			60 cm	0,8	0,7	0,8	0,8	0,7	0,7	0,6	0,6	0,6	0,7	0,8

Table 4.2 Water Velocity Rate from Electric Outboard that Installed Propeller with Pitch 9

DATA ELECTRIC OUTBOARD														
PITCH 9" (m/s)														
No	**P(Watt)**	**RPM**	**Height**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	**384**	1467	20 cm	0,3	3	0,4	0,3	0,2	0,2	0,2	0,2	0,2	0,4	0,3
			40 cm	1,4	0,6	0,3	0,2	0,2	0,2	0,2	0,2	0,2	0,4	0,3
			60 cm	0,3	0,4	0,3	0,2	0,2	0,3	0,3	0,2	0,3	0,4	0,3
2	**768**	2387	20 cm	0,3	0,4	0,5	0,4	0,3	0,3	0,3	0,3	0,3	0,4	0,4
			40 cm	1,6	0,8	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,4	0,3
			60 cm	0,3	0,3	0,4	0,3	0,3	0,3	0,3	0,3	0,3	0,4	0,4
3	**1536**	3100	20 cm	0,3	0,8	0,8	0,4	0,4	0,4	0,4	0,4	0,4	0,5	0,5
			40 cm	2,5	0,8	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,5	0,4
			60 cm	0,7	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,5	0,5
4	**2304**	3989	20 cm	0,3	0,9	0,9	0,5	0,5	0,6	0,5	0,5	0,5	0,6	0,6
			40 cm	3	0,9	0,4	0,4	0,4	0,5	0,5	0,5	0,5	0,6	0,5
			60 cm	0,8	0,4	0,4	0,5	0,5	0,5	0,5	0,5	0,5	0,6	0,6
5	**3071**	5014	20 cm	0,3	1,2	0,9	0,7	0,5	0,7	0,6	0,6	0,6	0,7	0,7
			40 cm	3,2	1,6	0,7	0,6	0,6	0,4	0,5	0,6	0,6	0,7	0,6
			60 cm	0,7	1,2	0,9	0,6	0,7	0,5	0,6	0,6	0,6	0,7	0,7
6	**3840**	6497	20 cm	0,4	1,2	1	0,7	0,6	0,7	0,7	0,6	0,6	0,8	0,7
			40 cm	3,3	1,7	0,9	0,6	0,7	0,6	0,7	0,7	0,7	0,7	0,7
			60 cm	0,8	0,9	0,6	0,7	0,6	0,5	0,6	0,7	0,7	0,7	0,7
7	**4608**	6855	20 cm	0,5	1,6	1,1	0,7	0,7	0,6	0,7	0,7	0,7	0,7	0,8
			40 cm	3,4	1,8	1	0,6	0,6	0,4	0,7	0,7	0,7	0,9	0,8
			60 cm	0,7	0,7	0,6	0,7	0,7	0,4	0,7	0,7	0,7	0,7	0,7
8	**5376**	7300	20 cm	0,6	1,6	1,2	0,8	0,8	0,7	0,7	0,6	0,5	0,8	0,7
			40 cm	3	1,7	0,8	0,7	0,6	0,6	0,5	0,7	0,5	0,8	0,8
			60 cm	0,8	0,6	0,5	0,6	0,6	0,5	0,5	0,6	0,6	0,7	0,8
9	**5760**	7449	20 cm	0,8	1,8	1,3	0,7	0,5	0,4	0,5	0,5	0,5	0,5	0,9
			40 cm	2,9	1,5	0,6	0,7	0,5	0,5	0,5	0,5	0,5	0,8	0,8

DATA ELECTRIC OUTBOARD														
PITCH 9" (m/s)														
No	**P(Watt)**	**RPM**	**Height**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
			60 cm	0,8	0,4	0,5	0,6	0,3	0,4	0,4	0,5	0,5	0,7	0,8

Table 4.3 Water Velocity Rate Produced by Electric Outboard using Propeller Pitch 12

ELECTRIC OUTBOARD DATA'S														
PITCH 12" (m/s)														
No	**P(Watt)**	**RPM**	**Height**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	**384**	1411	20 cm	0,3	0,6	0,4	0,2	0,2	0,1	0,2	0,2	0,2	0,6	0,4
			40 cm	1,3	0,6	0,3	0,1	0,1	0,2	0,1	0,2	0,2	0,3	0,3
			60 cm	0,1	0,1	0,3	0,1	0,2	0,2	0,2	0,2	0,1	0,2	0,3
2	**768**	1800	20 cm	0,3	0.8	0,5	0,3	0,3	0,3	0,3	0,3	0,3	0,8	0,5
			40 cm	1,9	0,6	0,3	0,2	0,3	0,3	0,3	0,3	0,3	0,4	0,3
			60 cm	0,3	0,3	0,1	0,1	0,3	0,3	0,3	0,2	0,3	0,2	0,1
3	**1536**	3100	20 cm	0,3	1,1	0,8	0,4	0,4	0,3	0,3	0,4	0,3	0,9	0,5
			40 cm	2,3	0,8	0,5	0,4	0,3	0,3	0,4	0,4	0,3	0,5	0,4
			/60 cm	0,3	0,3	0,4	0,3	0,3	0,3	0,3	0,3	0,4	0,5	0,5
4	**2304**	3600	20 cm	0,5	1,5	1,1	0,7	0,6	0,5	0,3	0,3	0,4	1,1	0,6
			40 cm	2,8	0,8	0,6	0,6	0,7	0,6	0,4	0,4	0,3	0,7	0,5
			60 cm	0,4	0,1	0,3	0,2	0,3	0,3	0,4	0,4	0,3	0,1	0,6
5	**3071**	4100	20 cm	0,6	1,4	1,1	0,7	0,6	0,6	0,4	0,4	0,4	0,9	0,7
			40 cm	3,1	1	0,8	0,5	0,4	0,4	0,4	0,4	0,4	0,8	0,6
			60 cm	0,6	0,3	0,3	0,4	0,4	0,4	0,4	0,4	0,5	0,8	0,6
6	**3840**	4500	20 cm	0,6	1,5	1,2	0,7	0,6	0,5	0,5	0,5	0,5	0,6	0,6
			40 cm	3,2	1	0,7	0,3	0,4	0,4	0,4	0,4	0,5	0,8	0,6
			60 cm	0,4	0,3	0,5	0,5	0,4	0,4	0,5	0,5	0,5	0,8	0,8
7	**4608**	4800	20 cm	0,7	1,5	1,3	0,6	0,6	0,6	0,5	0,5	0,6	0,5	0,6
			40 cm	3,3	1,2	0,9	0,5	0,5	0,5	0,5	0,5	0,5	0,8	0,7
			60 cm	0,6	0,1	0,2	0,4	0,6	0,4	0,4	0,4	0,4	0,7	0,7
8	**5376**	5800	20 cm	0,6	1,5	1	0,7	0,7	0,4	0,4	0,4	0,5	0,5	0,7
			40 cm	2,9	0,9	0,8	0,5	0,6	0,4	0,3	0,5	0,4	0,4	0,8
			60 cm	0,4	0,4	0,5	0,2	0,8	0,4	0,3	0,4	0,5	0,5	0,7
9	**5760**	6500	20 cm	0,8	1,8	1,3	1	0,7	0,5	0,4	0,4	0,5	0,5	0,9
			40 cm	2,8	1,5	0,8	0,6	0,7	0,5	0,5	0,4	0,4	0,8	0,8
			60 cm	0,8	0,4	0,6	0,5	0,6	0,3	0,4	0,4	0,4	0,7	0,8

From the data at the table 4.1, 4.2, and 4.3 shows that the height 40cm from base produce the highest value. So, the data can be shows only for point 40 cm from base like the table below:

Table 4.4 Water Velocity on Height 40 cm from Base (Pitch 8) in m/s

Water Velocity on Height 40 cm from Base (Pitch 8) in m/s													
No	**P.in**	**RPM**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	384	1616	1,5	0,6	0,5	0,3	0,2	0,2	0,2	0,2	0,2	0,3	0,3
2	768	2400	1,9	0,8	0,5	0,4	0,3	0,3	0,3	0,3	0,3	0,4	0,3
3	1536	3800	2,6	1	0,5	0,5	0,3	0,3	0,4	0,4	0,4	0,6	0,4
4	2304	4300	3,1	1,1	0,9	0,6	0,5	0,4	0,5	0,5	0,5	0,6	0,5
5	3072	5200	3,3	1,6	0,8	0,6	0,5	0,5	0,5	0,5	0,5	0,7	0,6
6	3840	6500	3,4	1,7	0,8	0,6	0,5	0,6	0,6	0,6	0,6	0,8	0,7
7	4608	7000	3,5	1,8	0,9	0,5	0,6	0,6	0,7	0,7	0,7	0,9	0,8
8	5376	7414	3,3	1,8	0,8	0,7	0,6	0,6	0,5	0,6	0,6	0,7	0,8
9	5760	7600	3,1	1,5	0,9	0,7	0,6	0,6	0,6	0,6	0,6	0,8	0,8

Table 4.5 Water Velocity on Height 40 cm from Base (Pitch 9) in m/s

Water Velocity on Height 40 cm from Base (Pitch 9) in m/s													
No	**P.in**	**RPM**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	384	1467	1,4	0,5	0,3	0,2	0,2	0,2	0,2	0,2	0,2	0,3	0,3
2	768	2387	1,6	0,8	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,4	0,3
3	1536	3000	2,5	0,8	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,5	0,4
4	2304	3989	3	0,9	0,4	0,4	0,4	0,5	0,5	0,5	0,5	0,6	0,5
5	3072	5014	3,2	1,4	0,7	0,6	0,6	0,4	0,5	0,6	0,6	0,6	0,6
6	3840	6497	3,3	1,6	0,9	0,6	0,7	0,6	0,7	0,7	0,7	0,8	0,7
7	4608	6855	3,4	1,7	1	0,6	0,6	0,4	0,7	0,7	0,7	0,9	0,8
8	5376	7300	3	1,7	0,8	0,7	0,6	0,6	0,5	0,7	0,5	0,8	0,8
9	5760	7549	2,9	1,5	0,6	0,7	0,5	0,5	0,5	0,5	0,5	0,8	0,8

Table 4.6 Water Velocity on Height 40 cm from Base (Pitch 12) in m/s

Water Velocity on Height 40 cm from Base (Pitch 12) in m/s													
No	**P.in**	**RPM**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	384	1411	1,3	0,6	0,3	0,1	0,1	0,2	0,1	0,2	0,2	0,3	0,3
2	768	2400	1,6	0,6	0,3	0,2	0,3	0,3	0,3	0,3	0,3	0,4	0,3
3	1536	3100	2,3	0,6	0,3	0,4	0,3	0,3	0,4	0,3	0,3	0,4	0,4
4	2304	3550	2,8	0,8	0,5	0,4	0,3	0,3	0,4	0,4	0,3	0,5	0,5
5	3072	4000	3,1	0,8	0,6	0,4	0,4	0,4	0,4	0,4	0,4	0,6	0,6
6	3840	4500	3,2	0,8	0,6	0,6	0,7	0,6	0,4	0,4	0,3	0,7	0,6
7	4608	4700	3,3	0,9	0,7	0,5	0,4	0,4	0,4	0,4	0,4	0,8	0,7
8	5376	5800	2,9	1	0,8	0,5	0,4	0,4	0,4	0,4	0,4	0,8	0,8
9	5760	6400	2,8	1,2	0,8	0,6	0,5	0,5	0,4	0,5	0,5	0,7	0,8

Table 4.1 until 4.3 provides the data for calculating the average water velocity rate at various current inputs (amperes) and propeller submersion depths. The aims of average just to know the distribution of water flow in the system. For example, data point number 1 shows an RPM of 1500 at 6A current input for the measurement taken directly behind the

propeller (point 1). The corresponding water velocity rates at depths of 20cm, 40cm, and 60cm from the base are 0.3 m/s, 1.4 m/s, and 0.3 m/s, respectively. The average of these water velocity using the following equation:

$$\frac{v1 + v2 + v3}{3} = m/s \qquad (4.1)$$

Where:

v1 = water velocity in height 20 cm from base (m/s)

v2 = water velocity in height 40 cm from base (m/s)

v3 = water velocity in height 60 cm from base (m/s)

So, the result of water velocity for number 1 with ampere input (6A) point 1 is =

$$\frac{0{,}3 + 1{,}3 + 0{,}4}{3} = 0{,}67\ m/s$$

Here is the all data of water velocity rate after calculated:

Table 4.7 Water Velocity in Average Produced by Propeller Pitch 8

Water Velocity Rate PITCH 8 (m/s)														
No	**P (Watt)**	**RPM**	**RPM Prop**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	384	1500	722,22	0,67	0,37	0,43	0,30	0,20	0,23	0,23	0,20	0,23	0,40	0,27
2	768	2400	1155,56	0,73	0,67	0,53	0,37	0,30	0,33	0,30	0,30	0,30	0,37	0,30
3	1536	3800	1829,63	1,20	0,70	0,60	0,50	0,40	0,37	0,40	0,40	0,40	0,53	0,50
4	2304	4300	2070,37	1,40	0,90	0,87	0,60	0,50	0,50	0,50	0,50	0,50	0,60	0,53
5	3072	5200	2503,70	1,73	1,13	0,87	0,60	0,57	0,50	0,53	0,50	0,50	0,63	0,60
6	3840	6500	3129,63	1,80	1,20	0,83	0,60	0,57	0,60	0,57	0,57	0,60	0,70	0,67
7	4608	7000	3370,37	1,83	1,10	0,90	0,60	0,60	0,60	0,63	0,70	0,63	0,80	0,73
8	5376	7414	3569,70	1,60	1,30	0,87	0,67	0,67	0,60	0,57	0,60	0,60	0,70	0,70
9	5760	7600	3659,26	1,50	1,53	1,10	0,77	0,77	0,67	0,63	0,60	0,60	0,77	0,77

Table 4.8 Water Velocity in Average Produced by Propeller Pitch 9

Water Velocity Rate PITCH 9 (m/s)														
No	**P (Watt)**	**RPM**	**RPM Prop**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	384	1467	706,33	0,67	0,43	0,33	0,23	0,20	0,23	0,23	0,20	0,23	0,40	0,30
2	768	2387	1149,30	0,83	0,50	0,40	0,33	0,30	0,30	0,30	0,30	0,30	0,40	0,40
3	1536	3000	1444,44	1,20	0,67	0,53	0,40	0,40	0,40	0,40	0,40	0,40	0,50	0,50
4	2304	3989	1920,63	1,37	0,73	0,57	0,47	0,47	0,53	0,50	0,50	0,50	0,60	0,60
5	3072	5014	2414,15	1,40	1,20	0,83	0,63	0,60	0,53	0,57	0,60	0,60	0,70	0,70
6	3840	6497	3128,19	1,50	1,27	0,83	0,67	0,63	0,60	0,67	0,67	0,67	0,73	0,73
7	4608	6855	3300,56	1,53	1,37	0,90	0,67	0,67	0,47	0,70	0,70	0,70	0,77	0,77
8	5376	7300	3514,81	1,47	1,30	0,83	0,70	0,67	0,60	0,57	0,63	0,53	0,77	0,80
9	5760	7549	3634,7	1,47	1,23	0,80	0,67	0,43	0,43	0,47	0,50	0,50	0,67	0,87

Table 4.9 Water Velocity in Knot Produce by Propeller Pitch 12

Water Velocity Rate PITCH 12 (m/s)														
No	**P (Watt)**	**RPM**	**RPM Prop.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	384	1411	722,22	0,63	0,47	0,30	0,20	0,20	0,20	0,20	0,20	0,20	0,33	0,30
2	768	1800	866,67	0,8	0,47	0,37	0,30	0,30	0,30	0,30	0,30	0,30	0,40	0,40
3	1536	3100	1492,59	1,07	0,73	0,57	0,37	0,33	0,30	0,33	0,37	0,33	0,63	0,50
4	2304	3600	1733,33	1,30	0,80	0,67	0,50	0,53	0,47	0,37	0,37	0,33	0,63	0,60
5	3072	4100	1974,07	1,37	0,90	0,73	0,53	0,47	0,47	0,40	0,40	0,43	0,83	0,63
6	3840	4500	2166,67	1,33	0,93	0,80	0,50	0,47	0,43	0,47	0,47	0,50	0,73	0,73
7	4608	4800	2311,11	1,47	0,93	0,80	0,50	0,57	0,50	0,47	0,47	0,50	0,67	0,67
8	5376	5800	2792,59	1,43	0,93	0,77	0,47	0,70	0,40	0,33	0,43	0,47	0,47	0,77
9	5760	6500	3129,63	1,47	1,23	0,90	0,70	0,67	0,43	0,43	0,40	0,43	0,67	0,87

4.2.2 Speed of Boat Based on Sea Trial Experiment

Real boats were used as test subjects to evaluate the performance of electric outboards equipped with different propeller variations, particularly focusing on pitch variations. Performance was measured by averaging roundtrip times or calculating the time to travel a specific distance at an average roundtrip speed. To ensure consistent results, all experiments were conducted under identical conditions. This included matching water velocity or flow (e.g., in the Kalimas River, Surabaya).

4.2.2.1 Time to Travel

Based on the experiment gotten time to travel of real boat used difference propeller witch pitch 8, 9, and 12. Time to travel gotten by the round trip which is time depart and arrive like shows as the illustrate below:

To illustrate the data collection process for travel time, let's consider the example of a propeller with a pitch of 8. The documentation for this specific test is shown in the figure below.

- **Time to Depart**

Figure 4.1 Time to Depart of Boat that used Electric Outboard with Propeller Pitch 8 (Personal Documentation)

So, the time to depart of boat that used electric outboard with propeller pitch 8 is 1,26 minutes

- **Time to Arrive**

Figure 4.2 Time to Arrive of Boat that used Electric Outboard with Propeller Pitch 8 (Personal Documentation)

So, the time to arrive of boat that used electric outboard with propeller pitch 8 is 2,22 minutes

The time to travel for electric outboard that installed another propeller which are pitch 9 and 12 will be shown at the table 4.

4.2.2.2 Speed of Actual Boat

Based on the experiment gotten the of speed of the real boat used difference propeller with pitch 8,9, and 12. For the example, taken data from propeller pitch 9 in speed of depart and arrive because there is flow factor in here like the figure below:

- **Speed used Propeller Pitch 9 (Depart)**

Figure 4.3 Speed to Depart of Boat that used Electric Outboard with Propeller Pitch 9 in 60 Ampere of current input (Personal Documentation)

Figure 4.4 Speed to Depart of Boat that used Electric Outboard with Propeller Pitch 9 in 90 Ampere of current input (Personal Documentation)

So, the speed to depart of boat that used electric outboard with propeller pitch 9 in 60 amperes of current input is 10 km/s. The speed to depart of boat that used electric outboard with propeller pitch 9 in 90 amperes of current input is 11 km/h

- **Speed used Propeller Pitch 9 (Arrive)**

Figure 4.5 Speed to Arrive of Boat that used Electric Outboard with Propeller Pitch 9 in 60 Ampere of current input (Personal Documentation)

Figure 4.6 Speed to Arrive of Boat that used Electric Outboard with Propeller Pitch 9 in 60 Ampere of current input (Personal Documentation)

So, the speed to arrive of boat that used electric outboard with propeller pitch 9 in 60 amperes of current input is 7 km/s. The speed to arrive of boat that used electric outboard with propeller pitch 9 in 90 amperes of current input is 8 km/h.

The data for electric outboard that installed another propeller which are pitch 8 and 12 will be shown at the table 4.7 below.

Following the collection of data on travel times and speeds achieved by a real boat equipped with an electric outboard motor using propellers of varying pitches, the data will be presented in a table format.

Table 4.10 Data of Time to Travel and Speed Based on Sea Trial

Data of Time to Travel and Speed							
No	Propeller	Time to Travel (Minutes)		Speed (km/h)			
				Depart		Arrive	
		Depart	Arrive	3840 Watt	5760 Watt	3840 Watt	3840 Watt
1	Pitch8	1,26	2,22	11	12	8	9
2	Pitch 9	1,5	3,85	10	11	7	8
3	Pitch 12	2,16	4,58	9	10	6	7

4.2.3 Energy Consumption Based on Laboratory Testing

Energy Consumption by the electric outboard displayed by the BMS application. The experiment used ampere variation such as 24, 60, and 90 amperes current input for every pitch of propeller such as pitch 8, 9, and 12. Then the engine running for 10 minutes then the data’s recorded by the display on BMS Application.

The following equation calculates the difference between the initial and final battery capacities (in ampere-hours).

$$AH\ Capacity = AH'' - AH' \tag{4.1}$$

Where:

AH’’ = Capacity After Running (AH)

AH’ = Capacity Before Running (AH)

Here is the data for the energy consumption recorded. Taken the data from propeller pitch 12 for the example as the figure and calculation below:

- **24 Ampere**

Figure 4.7 Battery Capacity for 24 Ampere in Pitch 12 Propeller Before Running

Figure 4.8 Battery Capacity for 24 Ampere in Pitch 12 Propeller After Running

So the energy consumption for 24 ampere variation in propeller pitch 12 is :

$$77{,}7\ AH - 73{,}6\ AH = 4{,}1\ AH$$

- **60 Ampere**

Figure 4.9 Battery Capacity for 60 Ampere in Pitch 12 Propeller before Running

Figure 4.10 Battery Capacity for 60 Ampere in Pitch 12 Propeller After Running

So the energy consumption for 60 Ampere foe propeller pitch 12 is:

$$94\ AH - 86{,}1\ AH = 9{,}9\ AH$$

- **90 Ampere**

Figure 4.11 Battery Capacity for 90 Ampere in Pitch 12 Propeller Before Running

Figure 4.12 Battery Capacity for 90 Ampere in Pitch 12 Propeller After Running

So, the energy consumption for the 90 Ampere variation in propeller pitch 12 is

$$84{,}4\ AH - 69{,}4\ AH = 15\ AH$$

Following the data collection on energy consumption of the electric outboard motor with different propeller variations, the results will be presented in Table 4.4. The data considers various operating conditions, including different power input.

Table 4.11 Energy Consumption Electric outboard

No	**Propeller variations**	**Energy Consumption**		
		P (Watt)	**Running Time**	**AH**
1	Pitch 8	1536	10 minutes	4,1
		3840	10 minutes	10,4
		5760	10 minutes	15,2
2	Pitch 9	1536	10 minutes	4,1

No	Propeller variations	Energy Consumption		
		P (Watt)	**Running Time**	**AH**
		3840	10 minutes	10,1
		5760	10 minutes	15,1
3	Pitch 12	1536	10 minutes	4,1
		3840	10 minutes	9,9
		5760	10 minutes	15

4.2.4 Vibration

Electric outboard produce small noise and vibration but still can recorded by the vibration meter. Vibration by the electric outboard displayed by the vibration meter display. The experiment used ampere variation such as 24, 60, and 90 amperes current input for every pitch of propeller such as pitch 8, 9, and 12. Here is the data of vibration produce by several propeller pitch:

Table 4.12 Vibration Data

Vibration Data				
No	**Pitch**	**Current Input (A)**	**Power Input (Watt)**	**Vibration (mm/s)**
1	Pitch 8	24	1536	0,3
		60	3840	0,3
		90	5760	0,4
2	Pitch 9	24	1536	0,3
		60	3840	0,4
		90	5760	0,4
3	Pitch 12	24	1536	0,4
		60	3840	0,4
		90	5760	0,4

4.3 Data Calculation

Subchapter 4.3 is the data calculation from the data at the subchapter 4.2 above. This sub chapter shows the calculation in every supporting parameter to analyse such as the delta-v, average water velocity rate, energy consumption and etc. The data after calculation will shows as the table to make easier in analysis.

4.3.1 Δv Based on Open Water Testing

As described of Δ v signifies the difference in water velocity before it enters the propeller (point 11) and the velocity after it exits (point 1). This difference is crucial as a larger Δ v corresponds to a higher thrust value. In simpler terms, the greater the acceleration the propeller imparts to the water (Δ v), the stronger the force (thrust) generated to propel the boat. Here is the equation for the delta-v

$$\Delta v(m/s) = v1(m/s) - v11(m/s) \tag{4.3}$$

$$Where$$

$$\Delta v = perubahan\ nilai\ water\ velocity\ (m/s)$$
$$v1 = water\ velocity\ after\ blade\ (m/s)$$
$$v11 = water\ velocity\ before\ blade\ (m/s)$$

Based on the equation above, take the example in propeller pitch 8 number 1 with power input is 384 with RPM engine 1500 that produce v1 = 1,5 m/s and v11 = 0,2 m/s. So, here is the calculation of Δv:

$$\Delta v = 1{,}5\ \frac{m}{s} - 0{,}2\,\frac{m}{s}$$

$$\Delta v = 1{,}3\ m/s$$

So, the value of Δv in propeller pitch with current input 6A is 0,4 m/s

Bases upon the calculations described above, the results obtained by analyzing the entire data set will be presented in the table below.

1. **Pitch 8**

Table 4.13 Δ v For Pitch 8

DELTA V PITCH 8					
No	**P. In**	**RPM**	**v1**	**v11**	**Δ v**
1	384	1616	1,5	0,3	1,2
2	768	2400	1,9	0,3	1,6
3	1536	3800	2,6	0,4	2,2
4	2304	4300	3,1	0,5	2,6
5	3072	5200	3,3	0,6	2,7
6	3840	6500	3,4	0,7	2,7
7	4608	7000	3,5	0,8	2,7
8	5376	7414	3,3	0,8	2,5
9	5760	7600	3,1	0,8	2,3

2. **Pitch 9**

Table 4.14 Δ v for Pitch 9

DELTA V PITCH 9					
No	**P. In**	**RPM**	**v1**	v11	Δ v
1	384	1467	1,4	0,3	1,1
2	768	2387	1,6	0,3	1,3

DELTA V PITCH 9					
No	**P. In**	**RPM**	**v1**	v11	Δ v
3	1536	3000	2,5	0,4	2,1
4	2304	3989	3	0,5	2,5
5	3072	5014	3,2	0,6	2,6
6	3840	6497	3,3	0,7	2,6
7	4608	6855	3,4	0,8	2,6
8	5376	7300	3	0,8	2,2
9	5760	7549	2,9	0,8	2,1

3. **Pitch 12**

Table 4.15 Δ v for Pitch 12

DELTA V PITCH 12					
No	**P. In**	**RPM**	**v1**	**v11**	**Δ v**
1	384	1411	1,3	0,3	1
2	768	2400	1,6	0,3	1,3
3	1536	3100	2,3	0,4	1,9
4	2304	3550	2,8	0,5	2,3
5	3072	4000	3,1	0,6	2,5
6	3840	4500	3,2	0,6	2,6
7	4608	4700	3,3	0,7	2,6
8	5376	5800	2,9	0,8	2,1
9	5760	6400	2,8	0,8	2

4.3.2 Average of Water Velocity Based on Laboratory Testing

By the table 4.7, 4.8, and 4.9 gotten the average value in every point of power input. The reason why used the calculate the average, it's just because this tank is a system, the water distributes or separate in the system. For the example is the number 1 in propeller variation pitch 8 with power input 384 watt. Here is the calculation for average water velocity meter point 1:

$$Average\ Water\ Velocity\ (\frac{m}{s}) = \frac{v1 + v1 + v3 + \cdots vn}{n} \tag{4.4}$$

$$Average\ Water\ Velocity\ 1\ (\frac{m}{s}) = \frac{0,67 + 0,37 + 0,43 + \cdots 0,32}{11}$$

$$Average\ Water\ Velocity\ 1 = 0,32\ m/s$$

So, the value of average water velocity for number 1 propeller pitch 8 with 384watt power input is 0,32 m/s.

The next value, the same calculation method used previously to determine the values for all points with each propeller pitch. The resulting data can be presented in a table format as shown below:

Table 4.16 Average Water Velocity Rate for Electric Outboard with Propeller Pitch 8

Average Water Velocity Rate PITCH 8															
No	**P (Watt)**	**RPM**	**RPM Prop**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Avg**
1	384	1500	722,22	0,67	0,37	0,43	0,30	0,20	0,23	0,23	0,20	0,23	0,40	0,27	**0,32**
2	768	2400	1155,56	0,73	0,67	0,53	0,37	0,30	0,33	0,30	0,30	0,30	0,37	0,30	**0,41**
3	1536	3800	1829,63	1,20	0,70	0,60	0,50	0,40	0,37	0,40	0,40	0,40	0,53	0,50	**0,55**
4	2304	4300	2070,37	1,40	0,90	0,87	0,60	0,50	0,50	0,50	0,50	0,50	0,60	0,53	**0,67**
5	3072	5200	2503,70	1,73	1,13	0,87	0,60	0,57	0,50	0,53	0,50	0,50	0,63	0,60	**0,74**
6	3840	6500	3129,63	1,80	1,20	0,83	0,60	0,57	0,60	0,57	0,57	0,60	0,70	0,67	**0,79**
7	4608	7000	3370,37	1,83	1,10	0,90	0,60	0,60	0,60	0,63	0,70	0,63	0,80	0,73	**0,83**
8	5376	7414	3569,70	1,60	1,30	0,87	0,67	0,67	0,60	0,57	0,60	0,60	0,70	0,70	**0,81**
9	5760	7600	3659,26	1,50	1,53	1,10	0,77	0,77	0,67	0,63	0,60	0,60	0,77	0,77	**0,88**

Table 4.17 Average Water Velocity Rate for Electric Outboard with Propeller Pitch 8

Average Water Velocity Rate PITCH 9															
No	**P (Watt)**	**RP M**	**RPM Prop**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	Avg
1	384	1467	706,33	0,67	0,43	0,33	0,23	0,20	0,23	0,23	0,20	0,23	0,40	0,30	**0,32**
2	768	2387	1149,30	0,83	0,50	0,40	0,33	0,30	0,30	0,30	0,30	0,30	0,40	0,40	**0,40**
3	1536	3000	1444,44	1,20	0,67	0,53	0,40	0,40	0,40	0,40	0,40	0,40	0,50	0,50	**0,53**
4	2304	3989	1920,63	1,37	0,73	0,57	0,47	0,47	0,53	0,50	0,50	0,50	0,60	0,60	**0,62**
5	3072	5014	2414,15	1,40	1,20	0,83	0,63	0,60	0,53	0,57	0,60	0,60	0,70	0,70	**0,76**
6	3840	6497	3128,19	1,50	1,27	0,83	0,67	0,63	0,60	0,67	0,67	0,67	0,73	0,73	**0,82**
7	4608	6855	3300,56	1,53	1,37	0,90	0,67	0,67	0,47	0,70	0,70	0,70	0,77	0,77	**0,84**
8	5376	7300	3514,81	1,47	1,30	0,83	0,70	0,67	0,60	0,57	0,63	0,53	0,77	0,80	**0,81**
9	5760	7549	3634,7	1,47	1,23	0,80	0,67	0,43	0,43	0,47	0,50	0,50	0,67	0,87	**0,73**

Table 4.18 Average Water Velocity Rate for Electric Outboard with Propeller Pitch 8

Average Water Velocity Rate PITCH 12															
No	**P (Watt)**	**RPM**	**RPM Prop.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Avg**
1	384	1411	722,22	0,63	0,47	0,30	0,20	0,20	0,20	0,20	0,20	0,20	0,33	0,30	**0,29**
2	768	1800	866,67	0,8	0,47	0,37	0,30	0,30	0,30	0,30	0,30	0,30	0,40	0,40	**0,38**
3	1536	3100	1492,59	1,07	0,73	0,57	0,37	0,33	0,30	0,33	0,37	0,33	0,63	0,50	**0,50**
4	2304	3600	1733,33	1,30	0,80	0,67	0,50	0,53	0,47	0,37	0,37	0,33	0,63	0,60	**0,60**
5	3072	4100	1974,07	1,37	0,90	0,73	0,53	0,47	0,47	0,40	0,40	0,43	0,83	0,63	**0,65**
6	3840	4500	2166,67	1,33	0,93	0,80	0,50	0,47	0,43	0,47	0,47	0,50	0,73	0,73	**0,67**
7	4608	4800	2311,11	1,47	0,93	0,80	0,50	0,57	0,50	0,47	0,47	0,50	0,67	0,67	**0,69**
8	5376	5800	2792,59	1,43	0,93	0,77	0,47	0,70	0,40	0,33	0,43	0,47	0,47	0,77	**0,65**
9	5760	6500	3129,63	1,47	1,23	0,90	0,70	0,67	0,43	0,43	0,40	0,43	0,67	0,87	**0,75**

4.3.3 Time to Travel and Speed of Boat that used Electric Drive Based on Trial

Based on the table at the subchapter 4.2 above, there are two type of calculation here such as time to travel and also Average speed

4.3.3.1 Time to Travel

Based on the experiment gotten time to travel of real boat used difference propeller witch pitch 8, 9, and 12. Time to travel gotten by the average round trip with this equation:

$$Time\ to\ depart + time\ to\ arrive = Time\ to\ travel(minutes) \quad (4.5)$$

To illustrate the data collection process for travel time, let's consider the example of a propeller with a pitch of 8. The documentation for this specific test is shown in the figure below.

Figure 4.13 Time to Depart of Boat that used Electric Outboard with Propeller Pitch 8 (Personal Documentation)

Figure 4.14 Time to Arrive of Boat that used Electric Outboard with Propeller Pitch 8 (Personal Documentation)

$$1{,}26\ (minutes) + 2{,}22\ (minutes)\ =\ 3{,}48\ minutes$$

So, the average of time to travel by the boat with electric outboard that used propeller pitch 8 is 3,48 minutes. The data for electric outboard that installed another propeller which are pitch 9 and 12 will be shown at the table 4.7 below.

4.3.3.2 *Speed of Actual Boat*

Based on the experiment gotten the average of speed of the real boat used difference propeller with pitch 8,9, and 12. The speed gotten by the average round trip with this equation:

$$\frac{Speed\ to\ Depart\ + Speed\ to\ Arrive}{2} = Average\ Speed \qquad (4.6)$$

For the example, taken data from propeller pitch 9 like the figure and calculation below:

- **Propeller Pitch 9 Depart**

Figure 4.15 Speed to Depart of Boat that used Electric Outboard with Propeller Pitch 9 in 60 Ampere of current input (Personal Documentation)

Figure 4.16 Speed to Depart of Boat that used Electric Outboard with Propeller Pitch 9 in 90 Ampere of current input (Personal Documentation)

$$\frac{10(km/h) + 11\ (km/h)}{2} = 10{,}5\ km/h$$

So, the average of speed to depart of boat that used electric outboard with propeller pitch 9 is 10,5 km/h

- **Propeller Pitch 9 Arrive**

Figure 4.17 Speed to Arrive of Boat that used Electric Outboard with Propeller Pitch 9 in 60 Ampere of current input (Personal Documentation)

Figure 4.18 Speed to of Boat that used Electric Outboard with Propeller Pitch 9 in 60 Arrive Ampere of current input (Personal Documentation)

$$\frac{7\ (km/h) + 8\ (km/h)}{2} = 7{,}5\ km/h$$

So, the average of speed to Average of boat that used electric outboard with propeller pitch 9 is 7,5 km/h.

The data for electric outboard that installed another propeller which are pitch 9 and 12 will be shown at the table 4.7 below.

Following the collection of data on travel times and speeds achieved by a real boat equipped with an electric outboard motor using propellers of varying pitches, the data will be presented in a table format.

Table 4.19 Result of Total Time to travel and Average Speed

No	Pitch Propeller Variation	Result					
		Time to Travel			Speed (km/hour)		
		Round trip (minutes)		Total Time (Minutes)	Round Trip (km/hour)		Average Speed (km/hour)
		Depart	Arrive		Depart	Arrive	
1	8	1,26	2,22	**3,48**	11,5	8,5	**10**

No	Pitch Propeller Variation	Result					
		Time to Travel			Speed (km/hour)		
		Round trip (minutes)		Total Time (Minutes)	Round Trip (km/hour)		Average Speed (km/hour)
		Depart	Arrive		Depart	Arrive	
2	9	1,5	2,35	**3,85**	10,5	7,5	**9**
3	12	2,16	2,42	**4,58**	9,5	6,5	**8**

4.3.4 The Effect of Propeller Variations on the Comparation of Speed at Laboratory and Direct Trial Testing

Taken the data with current input 60 and 90 then can be average in both of Laboratory and direct field testing as the conclusion of this comparation. Here is the data:

Table 4.20 Comparation Speed Laboratory vs Direct Field Testing

Comparation Speed Laboratory vs Direct Field Testing			
No	**Propeller**	**Laboratory (m/s)**	**Direct Field (m/s)**
1	Pitch 8	3,25	2,777778
2	Pitch 9	3,1	2,5
3	Pitch 12	3	2,222222

4.3.5 The Effect of Propeller Variation on Energy Consumption Based on Laboratory Testing

To determine the energy consumption of the electric outboard motor in this experiment, the difference in battery capacity before and after operation was measured, either in a laboratory setting or during open water testing. For example, in the first data set for a propeller pitch of 8 and a power input of 1536, the battery consumption was 4.1 AH. The kWh value can be calculated using the following formula:

$$kWh = \frac{(AH * V) * Time\ to\ Running(hour)}{1000} \tag{4.7}$$

So,

$$kWh = \frac{(4{,}1\ AH * 64V) * 0{,}166\ Hour}{1000}$$

$$kWh = 0{,}0437$$

The other data of energy consumption can be shows at the table 4.17.

Using the same calculation, the other data of cost can be show at the table 4.17 bellow:

Table 4.21 Energy Consumption

ENERGY CONSUMPTION						
No	**Propeller variations**	**P Input (Watt)**	**Running Time**	**AH**	**V**	**kWh**
1	Pitch 8	1536	10 minutes	4,1	64	**0,04374**
		3840	10 minutes	10,4	64	**0,11096**
		5760	10 minutes	15,2	64	**0,16217**
2	Pitch 9	1536	10 minutes	4,1	64	**0,04374**
		3840	10 minutes	10,1	64	**0,10775**
		5760	10 minutes	15,1	64	**0,1611**
3	Pitch 12	1536	10 minutes	4,1	64	**0,04374**
		3840	10 minutes	9,9	64	**0,10562**
		5760	10 minutes	15	64	**0,16003**

4.3.6 Relation of speed, battery capacity, operational and Cost Estimation

This section aims to establish a correlation between the generated speed, battery capacity, real-world operational parameters (distance, usage duration), and the projected monthly and even annual cost estimation. The maximum water velocity data will be extracted from power inputs of 1536, 3840, and 5760 for each propeller pitch. As an example, consider a Satpol PP patrol boat that makes three round trips per day, with each round trip covering a distance of 2 km. This implies that the Satpol PP patrol boat would travel a total of 6 km per day. The battery capacity is 100AH, which translates to 6.4 kWh. The primary data is presented in the table below.

Table 4.22 Cost Parameter Factor

No	Pitch	I	V	P(Watt)	Vs m/s	vs (km/h)	AH	kWh	Working distance/day (km)
1	8	24	64	1536	2,80	10,08	100	6,4	6
		60	64	3840	3,40	12,24	100	6,4	6
		90	64	5760	3,10	11,16	100	6,4	6
2	9	24	64	1536	2,60	9,36	100	6,4	6
		60	64	3840	3,30	11,88	100	6,4	6
		90	64	5760	2,80	10,08	100	6,4	6
3	12	24	64	1536	2,60	9,36	100	6,4	6
		60	64	3840	3,00	10,80	100	6,4	6
		90	64	5760	2,80	10,08	100	6,4	6

The subsequent step involves calculating the battery's endurance, which represents the duration for which the battery can power the device at each speed until it is fully discharged. This calculation is based on the following formula:

Using a propeller with a pitch of 8 as an example, and considering varying current inputs of 24A or power inputs of 1536W, the approximate battery life until depletion is:

$$Duration\ (h) = Max\ Capacity\ of\ Batery(AH)\ :\ Current\ Input\ (A) \quad (4.8)$$

So,

$$Duration\ (h) =\ 100\ AH\ :\ 24\ A$$

$$Duration\ (h) =\ 4{,}1\ hour$$

Once the battery life has been determined for the specified power inputs, the next step is to calculate the maximum distance that can be achieved. Here's the calculation for the maximum attainable distance:

Using a propeller with a pitch of 8 as an example, and considering varying current inputs of 24A or power inputs of 1536W, the resulting speed is 10.08 km/h and the battery life is 4.1 hours. Consequently, the maximum distance that can be covered until the battery is fully discharged is as follows:

$$L\ max\ (km) = v\ \left(\frac{km}{h}\right) *\ Duration\ (h) \quad (4.9)$$

$$L\ max\ (km) = 10{,}08\ \left(\frac{km}{h}\right) *\ 4{,}1\ (h)$$

$$L\ max\ (km) = 42\ km$$

Consequently, the farthest distance that can be traveled until the battery is fully discharged at a steady speed of 10.08 km/h is 42 km

Having determined the maximum attainable distance, the next step is to calculate the number of charges required per day based on the boat's daily operations and battery capacity. Here's the calculation for the number of daily charges based on boat operations using the data for a propeller pitch of 8, a power input of 1536W, a speed of 10.08 km/h, and a maximum distance of 42 km:

$$Charge\ in\ a\ day = \frac{Operational\ Distance\ in\ a\ day\ (km)}{maximum\ distance\ (km)} \quad (4.10)$$

So,

$$Charge\ in\ a\ day = \frac{6\ (km)}{42\ (km)}$$

$$Charge\ in\ a\ day = 0{,}143$$

Therefore, during Satpol PP boat operations, the battery will be charged to 14.3% of its capacity.

Having determined the number of charges per day, the next step is to calculate the daily energy consumption in kWh based on the number of daily charges. Using the same example as before, where the number of daily charges is 0.143 times, the kWh value is calculated by multiplying the number of daily charges by the maximum battery capacity, as follows:

$$kWh = Max\ Capacity(AH) * Charge\ in\ a\ day \quad (4.10)$$

So,

$$kWh = 6kWh * 0{,}143$$

$$kWh = 0{,}9143\ kWh$$

Having obtained the energy consumption value, the next step is to determine the operational cost. This is done by multiplying the daily energy consumption (kWh) by the electricity price per kWh. The non-subsidized PLN price of IDR 1699 per kWh is used. Here's the calculation of the kWh cost based on the electricity price per kWh:

$$Electric\ Cost\ in\ a\ day = kWh\ in\ a\ day * Rp\ 1699$$

$$Electric\ Cost\ in\ a\ day = 0{,}9143\ kWh * Rp\ 1699$$

$$Electric\ Cost\ in\ a\ day = Rp\ 1.553$$

After that, monthly and annual costs are projected with a working time of 5 working days a week. Which means one month has 22 working days. So Cost in a month and year can be presented as follows:

$$Electric\ Cost\ in\ a\ month = Rp\ 1.553 * 22\ days$$

$$Electric\ Cost\ in\ a\ month = Rp\ 34.174$$

So,

$$Electric\ Cost\ in\ a\ year = Rp\ 1.553 * 12\ month$$

$$Electric\ Cost\ in\ a\ year = Rp\ 410.000$$

So, the cost that should be spent in a month is Rp 34.174 and in a year is Rp 410.000.

The other result for every propeller pitch and power input can be shown as this table:

Table 4.23 Cost Estimation

No	Pitch	I	P	vs	Duration	D max	L	Charge	kwh	Cost	Cost	Cost
		A	Watt	Km/h	h	km	km	Per-day		/day	/month	/year
1	8	24	1536	10,08	4,17	42,0	6	0,143	0,914	Rp 1.553	Rp 34.174	Rp 410.090
		60	3840	12,24	1,67	20,4	6	0,294	1,882	Rp 3.198	Rp 70.359	Rp 844.303
		90	5760	11,16	1,11	12,4	6	0,484	3,097	Rp 5.261	Rp115.751	Rp1.389.015

COST ESTIMATION												
No	**Pitch**	**I**	**P**	**vs**	**Duration**	**D max**	**L**	**Charge**	**kwh**	**Cost**	**Cost**	**Cost**
		A	Watt	Km/h	h	km	km	Per-day		/day	/month	/year
2	9	24	1536	9,36	4,17	39,0	6	0,154	0,985	Rp 1.673	Rp 36.803	Rp 441.635
		60	3840	11,88	1,67	19,8	6	0,303	1,939	Rp 3.295	Rp 72.491	Rp 869.888
		90	5760	10,08	1,11	11,2	6	0,536	3,429	Rp 5.825	Rp128.153	Rp1.537.838
3	12	24	1536	9,36	4,17	39,0	6	0,154	0,985	Rp 1.673	Rp 36.803	Rp 441.635
		60	3840	10,80	1,67	18,0	6	0,333	2,133	Rp 3.625	Rp 79.740	Rp 956.877
		90	5760	10,08	1,11	11,2	6	0,536	3,428	Rp 5.825	Rp128.153	Rp1.537.838

4.4 Data Analysis

Sub-chapter 4.2 presents various tables summarizing the data collected during the experiment. The data can be calculated in sub-chapter 4.3 then shows as the table after that the data can be shows as the using a series of graphs, similar to the one shown below.

4.4.1 The Effect of Propeller Variation on Water Velocity Rate Based on Laboratory Testing

This subchapter, graphs are generated from the calculations of the impact of propeller variation on water velocity rate. Two types of analyse were conducted: the influence of propeller variation on delta v and the impact of propeller variation on the mean water velocity rate produced by the electric outboard motor. An analysis of the findings is presented below:

4.4.1.1 The Effect of Propeller Variation on Δv

After gotten the data of **Δv** in every pitch of propeller with different current input, then the data can be shows as the graph below:

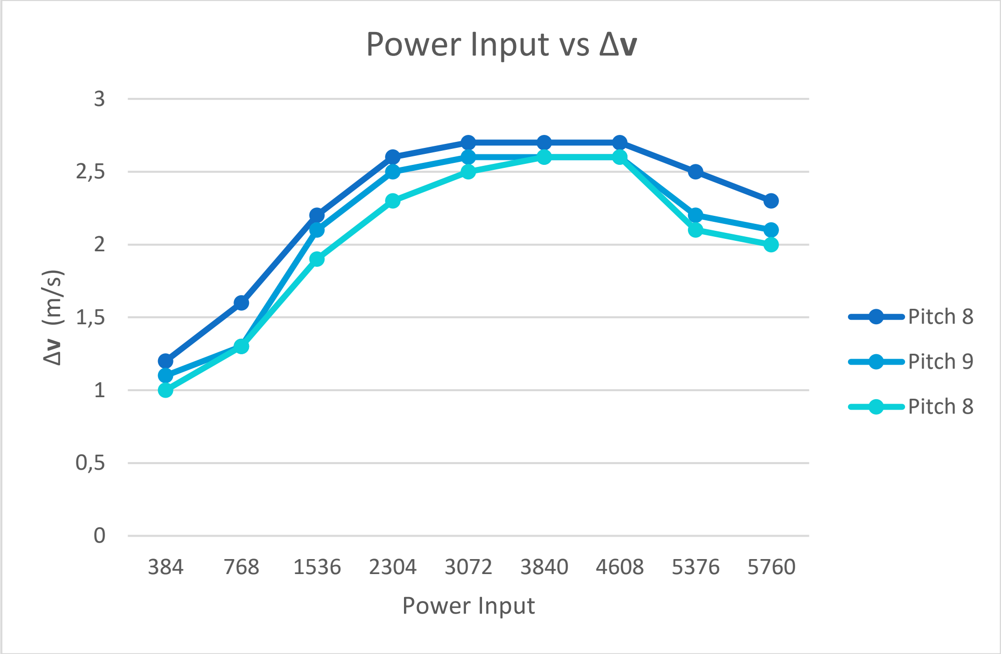


Figure 4.19 delta v vs Power Input

Figure 4.19 illustrates the changes in water momentum achieved by different propeller pitches. Higher power input, higher the value of $\Delta\, v$. The results indicate that Propeller Pitch 8 exhibits the highest change in momentum. This means to the 8-pitch propeller installed on the Cerano electric outboard producing the greatest thrust value among the tested propellers. Consequently, a propeller with a pitch of 8 appears to be the most suitable choice for maximizing speed, based on the data presented.

This is in accordance with the thrust formula where the difference in $\Delta\, v$ and thrust values is directly proportional to the thrust value.

$$T = Mass\ flow * \Delta\, v$$

Based on that equation, higher $\Delta\, v$ will produce higher thrust. For the example in the treatment of power input 384 watt. Propeller pitch 8 produce 1,2 m/s $\Delta\, v$, Propeller pitch 9 produce 1,1 m/s $\Delta\, v$, and propeller pitch 12 produce 1 m/s $\Delta\, v$. In other words that the propeller with pitch 8 produce higher value of $\Delta\, v$, which means propeller with pitch 8 during the operational on laboratory testing produce higher thrust. This value also in the increasing of power input by the throttling.

4.4.1.2 The Effect of Propeller Variations on Water Velocity

After gotten the data of water velocity only at height 40 cm. Here is the analysis graph that can be taken.

a. Water Velocity for Electric Outboard with Propeller Pitch 8

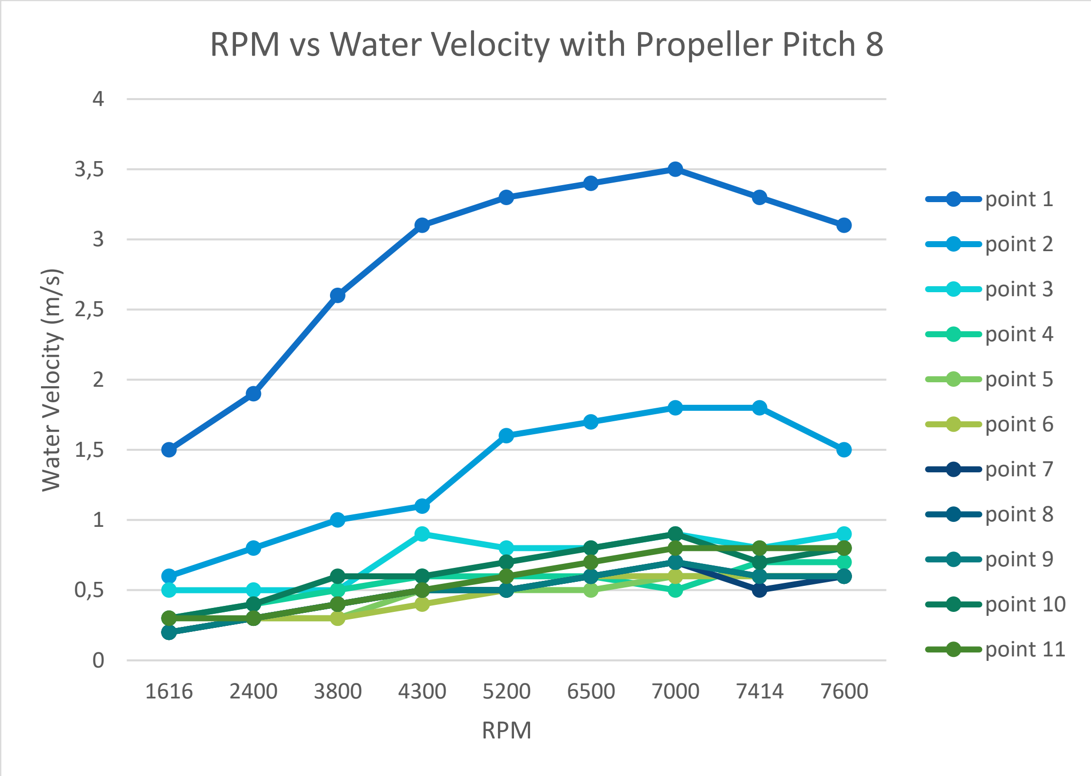


Figure 4.20 RPM vs Water Velocity with Propeller Pitch 8

There is a general positive correlation between RPM and water velocity. As the RPM increases, the average water velocity also tends to increase. This is intuitive, as a higher RPM implies that the propeller is pushing more water, leading to a greater flow velocity. There is a general positive correlation between RPM and water velocity. As the RPM increases, the average water velocity also tends to increase. This is intuitive, as a higher RPM implies that the propeller is pushing more water, leading to a greater flow velocity. Higher RPM values lead to a tendency for increased water velocity. The graph indicates that point 1 has the highest water velocity. This is likely because point 1 is located 20 cm behind the propeller, where the transfer of water from the blades is most pronounced. Points 5, 6, 7, 8, and 9 show relatively stable values because the water flow has already reached a steady state at these locations. Points 10 and 11 exhibit higher values compared to points 5 through 9 due to the presence of an additional pump that increases water flow installed before point 10.

b. RPM vs Water Velocity for Electric Outboard with Propeller Pitch 9

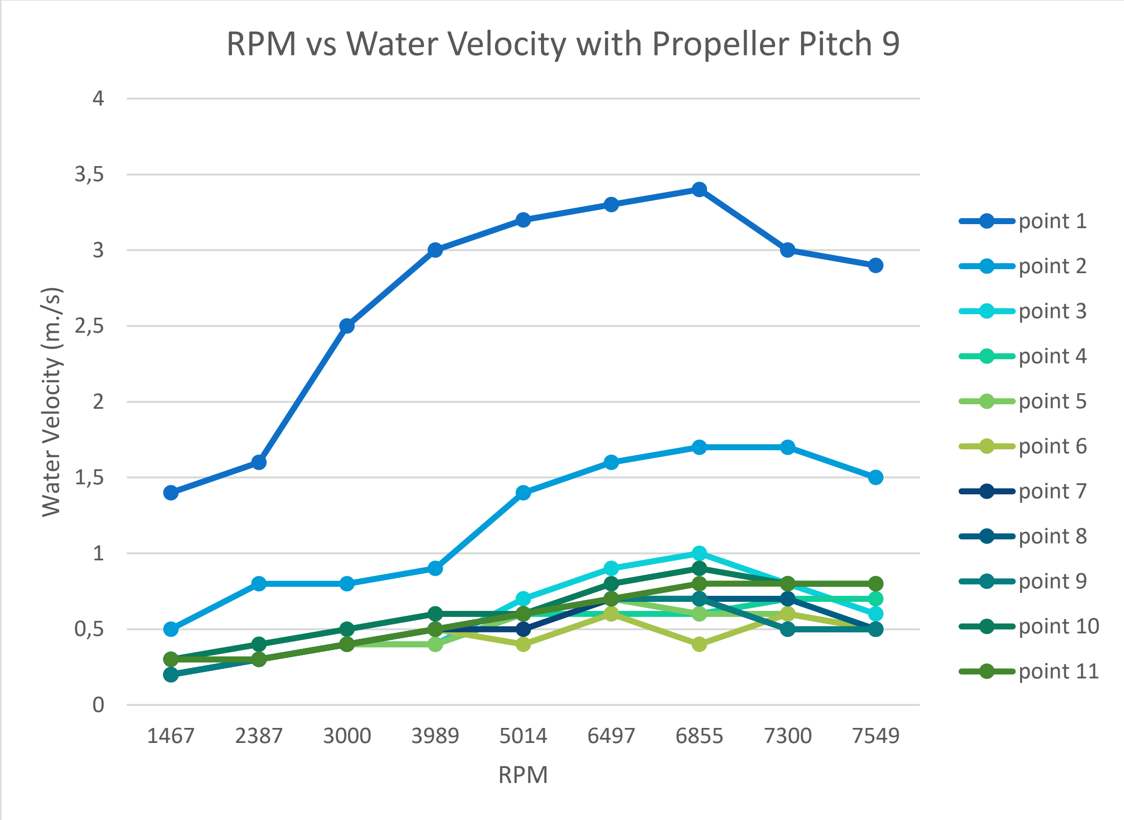


Figure 4.21 RPM vs Water Velocity with Propeller Pitch 9

There is a general positive correlation between RPM and water velocity. As the RPM increases, the average water velocity also tends to increase. This is intuitive, as a higher RPM implies that the propeller is pushing more water, leading to a greater flow velocity. There is a general positive correlation between RPM and water velocity. As the RPM increases, the average water velocity also tends to increase. This is intuitive, as a higher RPM implies that the propeller is pushing more water, leading to a greater flow velocity. Higher RPM values lead to a tendency for increased water velocity. The graph indicates that point 1 has the highest water velocity. This is likely because point 1 is located 20 cm behind the propeller, where the transfer of water from the blades is most pronounced. Points 5, 6, 7, 8, and 9 show relatively stable values because the water flow has already reached a steady state at these locations. Points 10 and 11 exhibit higher values compared to points 5 through 9 due to the presence of an additional pump that increases water flow installed before point 10.

c. RPM vs Water Velocity for Electric Outboard with Propeller Pitch 12

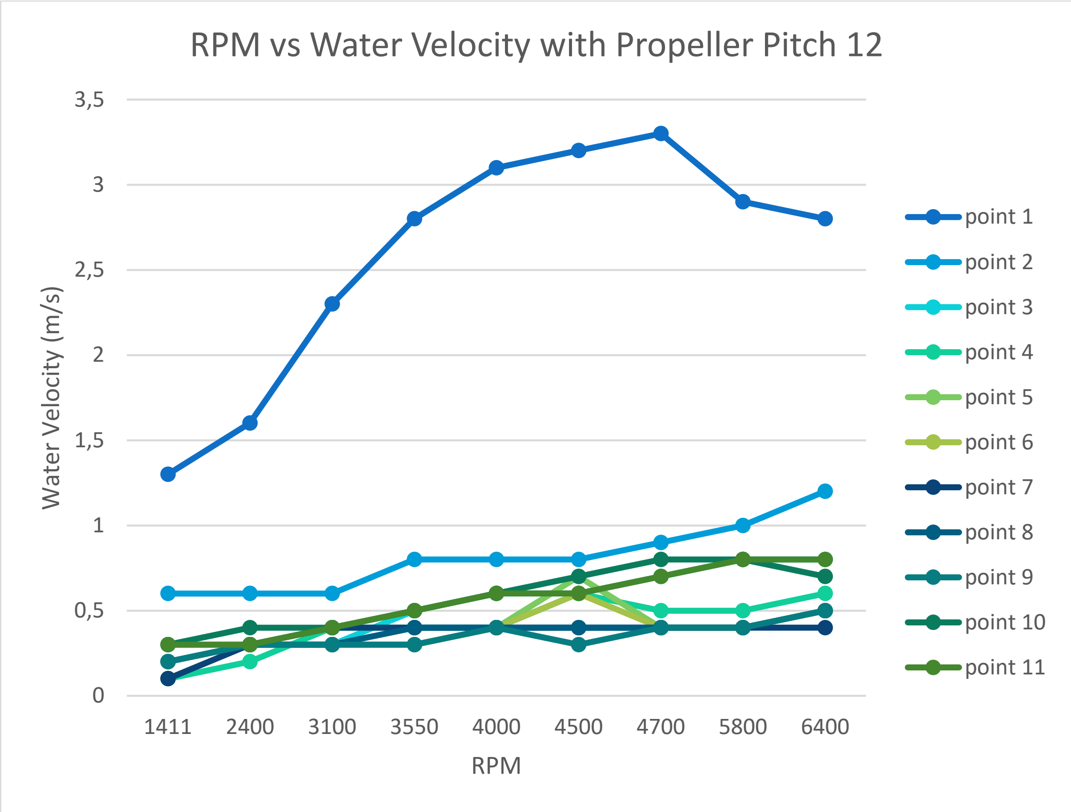


Figure 4.22 RPM vs Water Velocity with Propeller Pitch 12

There is a general positive correlation between RPM and water velocity. As the RPM increases, the average water velocity also tends to increase. This is intuitive, as a higher RPM implies that the propeller is pushing more water, leading to a greater flow velocity. There is a general positive correlation between RPM and water velocity. As the RPM increases, the average water velocity also tends to increase. This is intuitive, as a higher RPM implies that the propeller is pushing more water, leading to a greater flow velocity. Higher RPM values lead to a tendency for increased water velocity. The graph indicates that point 1 has the highest water velocity. This is likely because point 1 is located 20 cm behind the propeller, where the transfer of water from the blades is most pronounced. Points 5, 6, 7, 8, and 9 show relatively stable values because the water flow has already reached a steady state at these locations. Points 10 and 11 exhibit higher values compared to points 5 through 9 due to the presence of an additional pump that increases water flow installed before point 10.

d. The Effect of Propeller Variations to the RPM vs Water Velocity

Here is the graph of conclusion of the water velocity from different variations of propeller in RPM vs Water velocity.

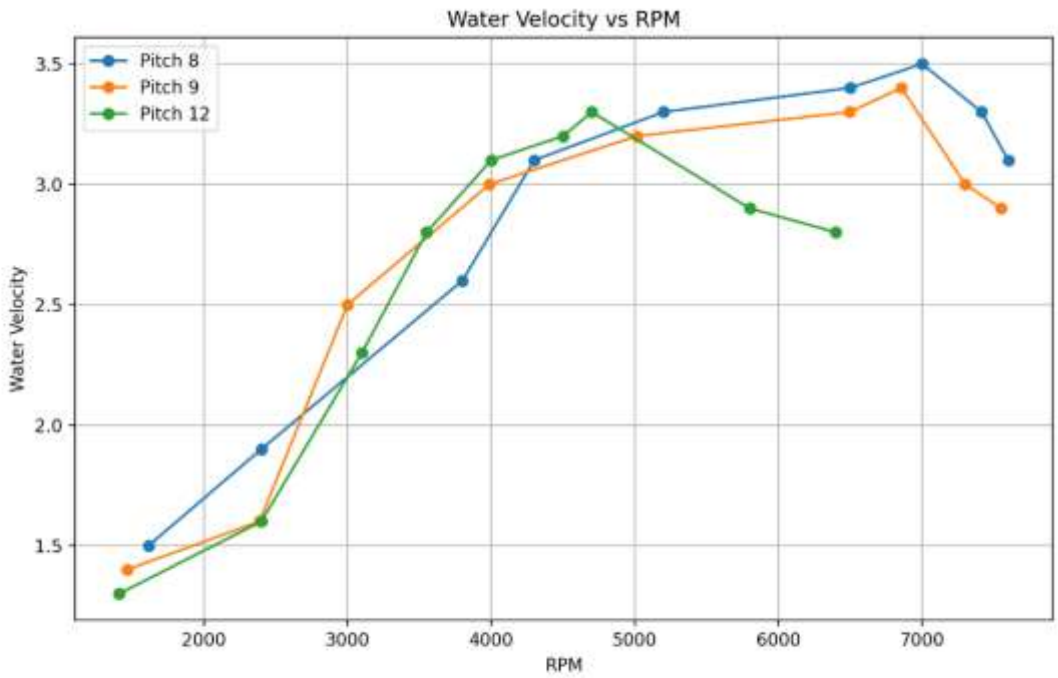
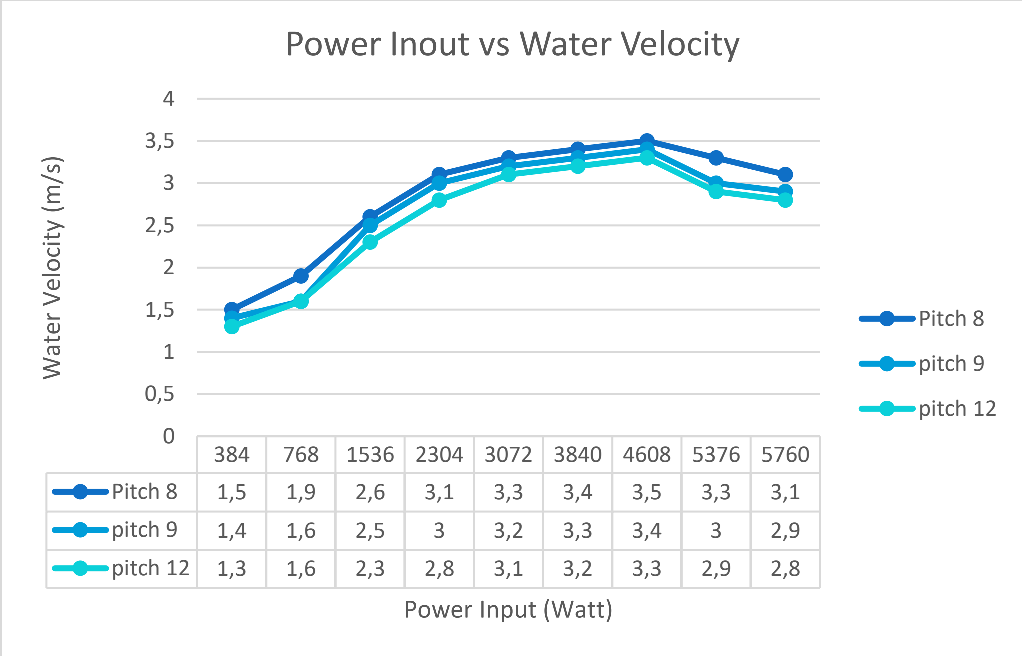


Figure 4.23 RPM vs Water Velocity

The graph in Figure 4.23 illustrates the relationship between propeller revolutions per minute (RPM) and generated water velocity for three varying pitch angles (8, 9, and 12 degrees) in an electric outboard motor. As the input power increases, the RPM also increases. Generally, the graph shows that water velocity rises with increasing RPM; however, the rate of increase varies depending on the pitch angle. For a pitch of 8 degrees, water velocity significantly increases until reaching a peak around 7000 RPM, followed by a slight decline. This suggests that a pitch of 8 degrees can produce higher water velocities at higher RPMs, but efficiency might decrease at the highest RPMs due to factors like cavitation. With a pitch of 9 degrees, water velocity also increases with RPM but reaches its maximum at a lower RPM compared to a pitch of 8 degrees. This indicates that a pitch of 9 offers a good balance between water velocity and efficiency at lower RPM ranges. For a pitch of 12 degrees, the initial increase in water velocity is substantial, but the rate of increase slows down and eventually plateaus. This suggests that a pitch of 12 degrees provides higher torque at lower RPMs, but the maximum attainable water velocity is lower compared to pitches of 8 and 9 degrees.



	384	768	1536	2304	3072	3840	4608	5376	5760
Pitch 8	1,5	1,9	2,6	3,1	3,3	3,4	3,5	3,3	3,1
pitch 9	1,4	1,6	2,5	3	3,2	3,3	3,4	3	2,9
pitch 12	1,3	1,6	2,3	2,8	3,1	3,2	3,3	2,9	2,8

Figure 4.24 Power Input vs Water Velocity

Figure 4.24 illustrates the relationship between water velocity and power input for electric outboards equipped with propellers of varying pitches (8, 9, and 12). The graph reveals a positive correlation, where increasing power input leads to a corresponding increase in water velocity for each propeller pitch. In simpler terms, the greater the power input, the higher the resulting water velocity, suggesting a direct proportionality between the two.

Figure 4.24 further reveals that among the propellers tested (pitches 8, 9, and 12), propeller pitch 8 exhibits the steepest upward trend in water velocity as power input increases. This suggests that for a given power input, a propeller with a pitch of 8 produces the highest average water velocity, translating to the greatest achievable speed. Conversely, propellers with a pitch of 12 show the least increase in water velocity with increasing power input, resulting in the lowest achievable speed/thrust.

4.4.1.3 The Effect of Propeller Variations on Average of Water Velocity

After gotten the average value of water velocity in every variation above that shows as the table 4.16, 4.17, and 4.18. The table below presents the relationship between RPM (Revolutions Per Minute) and water velocity rate for each propeller pitch installed on the Cerano Electric Outboard. A corresponding graph is shown below to further visualize this relationship.

The reason why needed to analyse using average of water velocity is there is unbalance distribution of water velocity at the system. The At the graph shows that there is Non-uniform distribution or the fluid flow generated by the propeller is not uniform across the entire pipe or channel cross-section. Velocities tend to be higher near the center of the flow (close to the propeller) and lower near the walls. Not only that but also turbulence intensity. The level of turbulence in the water flow can vary depending on the height and flow conditions. Turbulence affects fluid mixing and momentum transfer, thereby influencing the flow velocity

a. RPM vs Average Water Velocity for Electric Outboard with Propeller Pitch 8

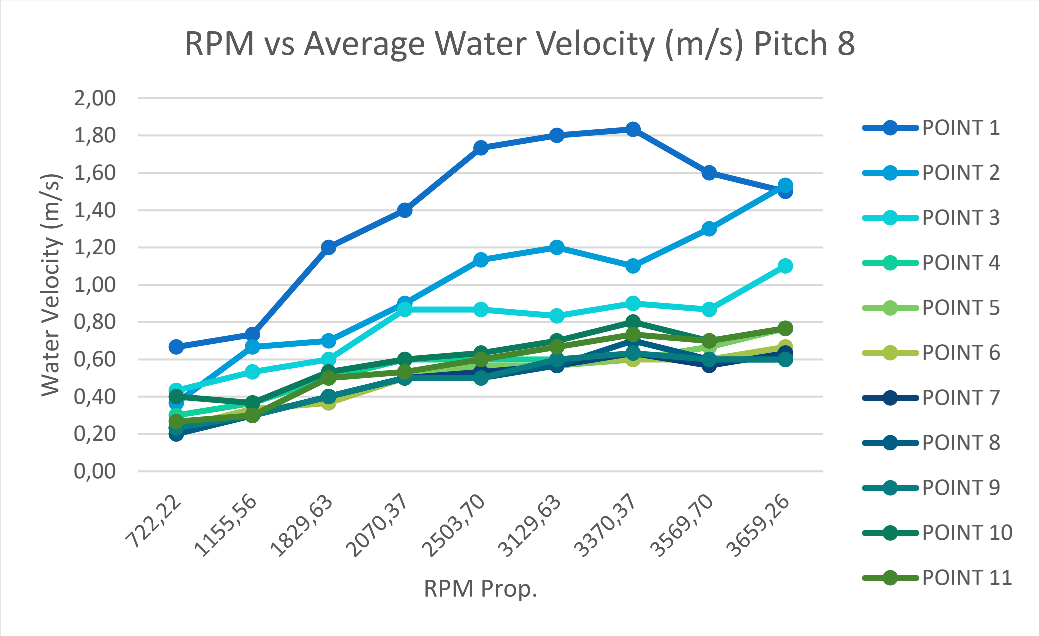


Figure 4.25 RPM vs Water Velocity (m/s) in Propeller Pitch 8

The graph reveals a positive correlation between RPM and average water velocity. Higher RPM values lead to a tendency for increased water velocity. The graph indicates that point 1 has the highest water velocity. This is likely because point 1 is located 20 cm behind the propeller, where the transfer of water from the blades is most pronounced. Points 5, 6, 7, 8, and 9 show relatively stable values because the water flow has already reached a steady state at these locations. Points 10 and 11 exhibit higher values compared to points 5 through 9 due to the presence of an additional pump that increases water flow installed before point 10.

b. RPM vs Average Water Velocity Rate (m/s) for Electric Outboard with Propeller Pitch 9

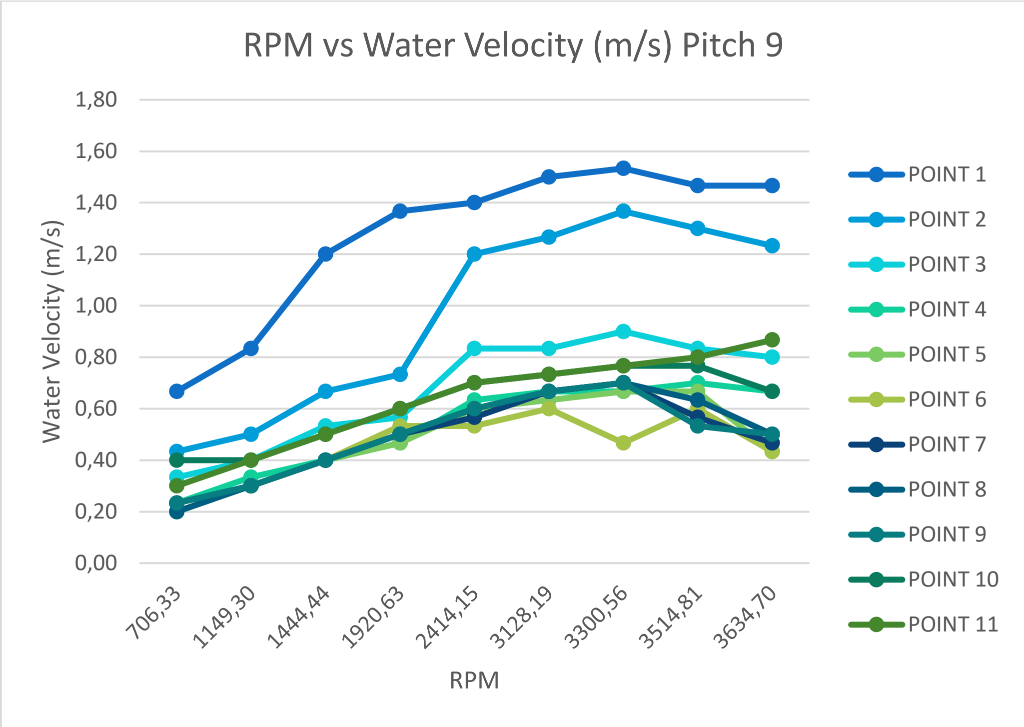


Figure 4.26 RPM vs Water Velocity (m/s) in Propeller Pitch 9

The graph reveals a positive correlation between RPM and average water velocity, with higher RPM values leading to increased water velocity. Point 1, located 20 cm behind the propeller where water transfer is most pronounced, exhibits the highest velocity. Points 5 through 9 show stable values due to steady flow, while points 10 and 11 have higher values likely due to the additional pump installed before point 10.

c. RPM vs Average Water Velocity Rate (m/s) for Electric Outboard with Propeller Pitch 12

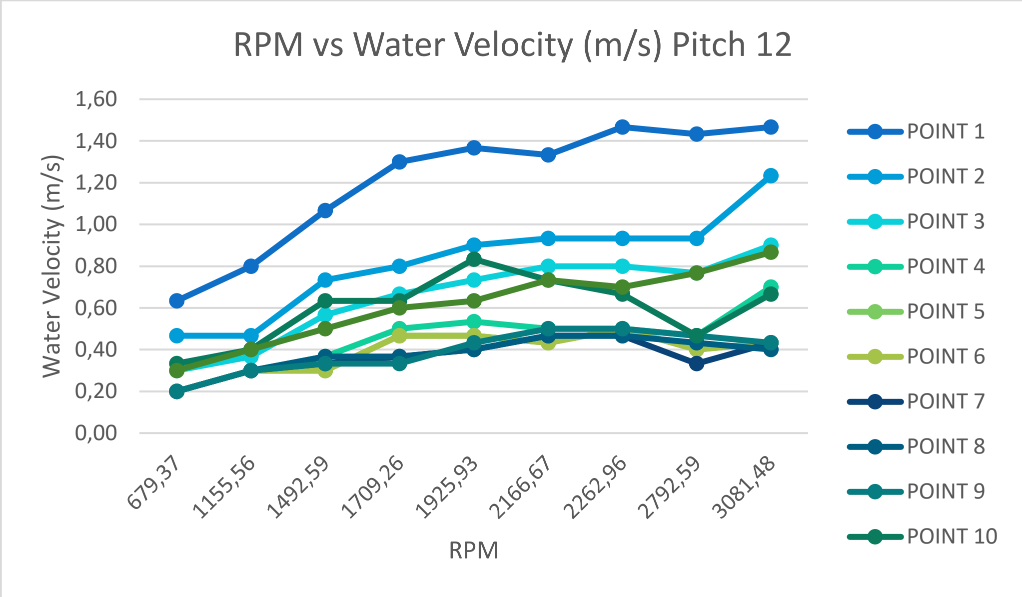
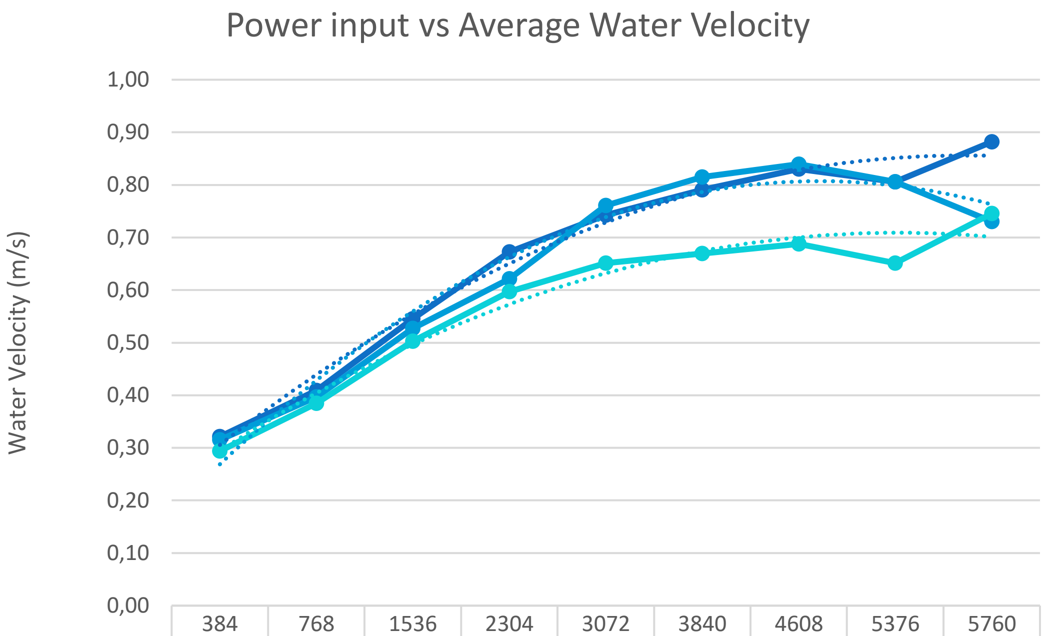


Figure 4.27 RPM vs Water Velocity (m/s) in Propeller Pitch 12

The graph reveals a positive correlation between RPM and average water velocity, with higher RPM values leading to increased water velocity. Point 1, located 20 cm behind the propeller where water transfer is most pronounced, exhibits the highest velocity. Points 5 through 9 show stable values due to steady flow, while points 10 and 11 have higher values likely due to the additional pump installed before point 10.

d. **The Effect of Propeller Variations to the Average Water Velocity in Power Input vs Average Water Velocity**



	384	768	1536	2304	3072	3840	4608	5376	5760
PITCH 8	0,32	0,41	0,55	0,67	0,74	0,79	0,83	0,81	0,88
PITCH 9	0,32	0,40	0,53	0,62	0,76	0,82	0,84	0,81	0,73
PITCH 12	0,29	0,38	0,50	0,60	0,65	0,67	0,69	0,65	0,75

Figure 4.28 Comparation of Water Velocity for Pitch 8, 9, and 12

Figure 4.28 illustrates the relationship between average water velocity and power input for electric outboards equipped with propellers of varying pitches (8, 9, and 12). The graph reveals a positive correlation, where increasing power input leads to a corresponding increase in water velocity for each propeller pitch. In simpler terms, the greater the power input, the higher the resulting water velocity, suggesting a direct proportionality between the two.

Figure 4.28 further reveals that among the propellers tested (pitches 8, 9, and 12), propeller pitch 8 exhibits the steepest upward trend in water velocity as power input increases. This suggests that for a given power input, a propeller with a pitch of 8 produces the highest average water velocity, translating to the greatest achievable speed. Conversely, propellers with a pitch of 12 show the least increase in water velocity with increasing power input, resulting in the lowest achievable speed/thrust.

The At the graph shows that there is Non-uniform distribution or the fluid flow generated by the propeller is not uniform across the entire pipe or channel cross-section. Velocities tend to be higher near the center of the flow (close to the propeller) and lower near the walls. Not only that but also turbulence intensity. The level of turbulence in the water flow can vary depending on the height and flow conditions. Turbulence affects fluid mixing and momentum transfer, thereby influencing the flow velocity. So the value of average need to shown.

4.4.2 The Effect of Propeller variation on Speed of Boat Based on Sea Trial

Table 4.19 presents data on round-trip boat travel times and average speeds (km/h) achieved using different propellers. This data can be analyzed by creating a graph as shown below.

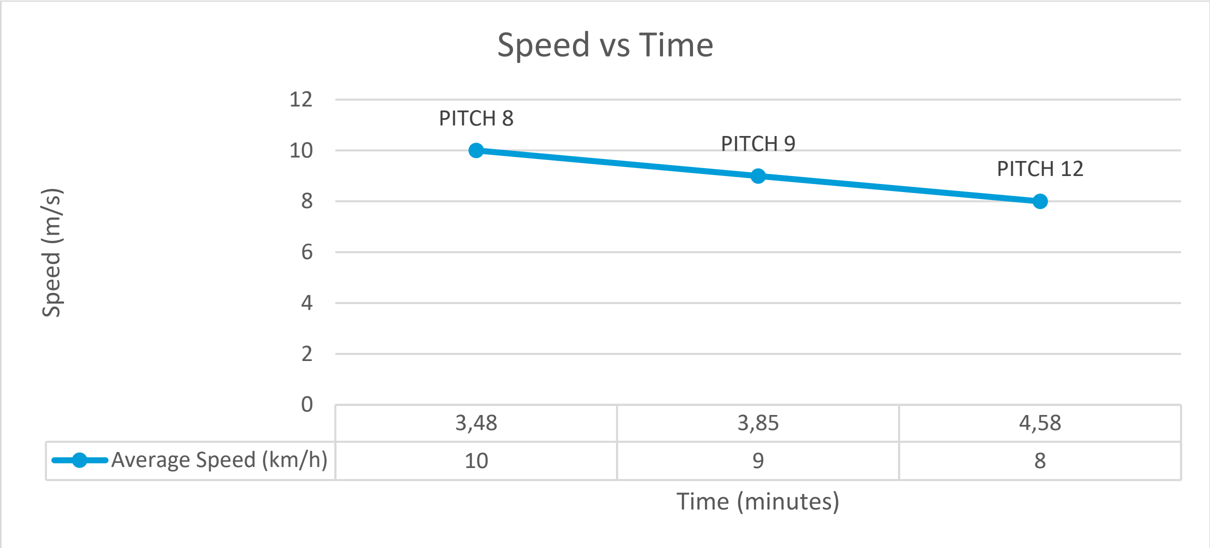


Figure 4.29 Time vs Speed

The graph of speed versus time (shown above) indicates that the electric outboard with a variable pitch propeller of 8 achieved the fastest roundtrip time of 3.48 minutes and the highest average speed of 10 km/h. In simpler terms, a propeller with a pitch of 8 installed on the Cerano E301 electric outboard is the most recommended option for patrol boats. This is because patrol boats prioritize fast operation, and the propeller with a pitch of 8 delivers the quickest results.

The electric outboard equipped with a propeller pitch of 12 achieved a travel time of 4.58 minutes and an average speed of 8 km/h. However, due to this slower performance, a propeller pitch of 12 is not recommended for patrol boats used by Satpol PP. The reason why propeller with pitch 8 gotten the best result than the other is propeller with lowest pitch will produce higher RPM.

4.4.3 The Relation Between Water Velocity Rate on Laboratory and Direct Field Testing

After gotten the result of the speed in laboratory and sea trial or direct field trial, here is the graph to compare both of result that can be analyse

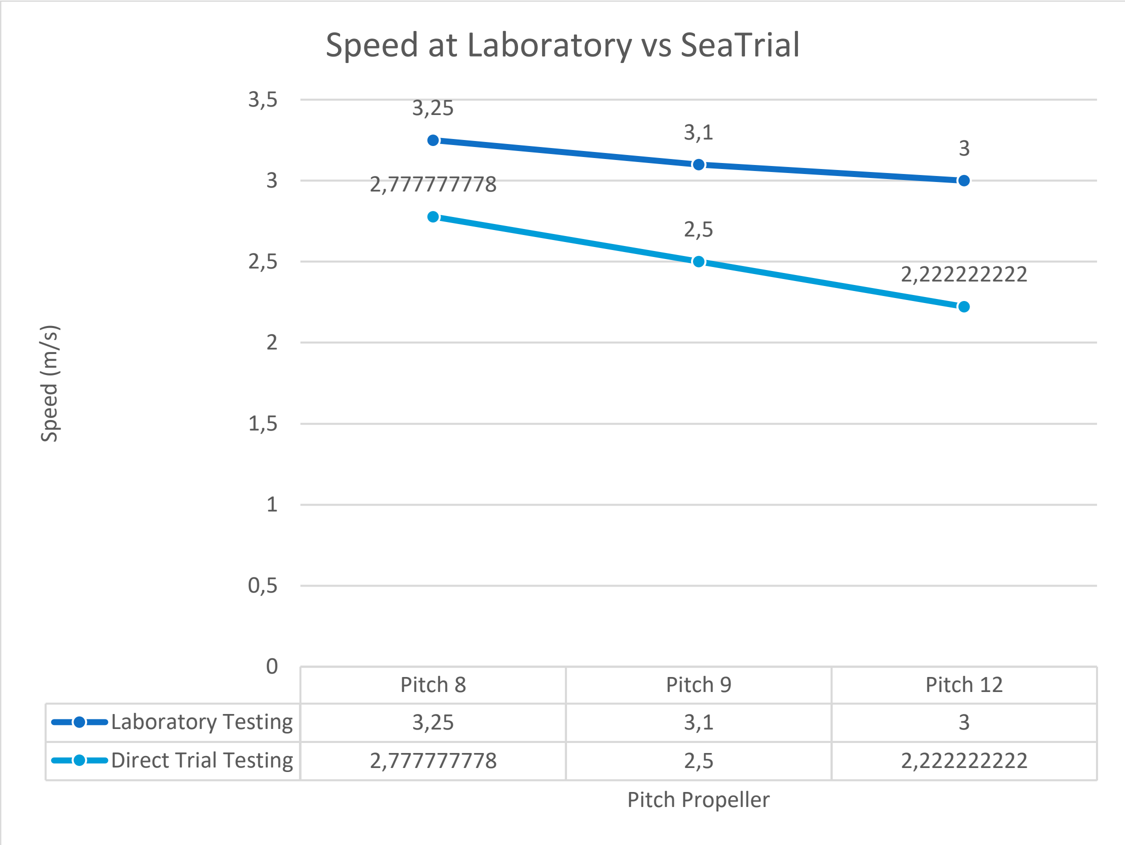


Figure 4.30 Laboratory vs Direct Field Trial Speed

Figure 4.30 compares the velocities obtained from laboratory testing and sea trials for various propeller pitches (8, 9, and 12). Velocities were measured in meters per second. Generally, laboratory test results yielded higher velocities compared to field trials for all pitch values. This velocity discrepancy increased with increasing pitch. Potential causes for these differences include environmental conditions and loading. Field trials are subject to various environmental factors like wind, waves, and currents, which can impede a vessel's performance and reduce speed. Laboratory tests, conducted under controlled conditions, are free from such disturbances, resulting in more consistent and measurable data.

Additionally, boat in field trials carry additional loads like fuel, passengers, and equipment, increasing drag and reducing speed. Laboratory models are typically unladen, leading to lower drag. Notably, both laboratory and field tests converged on a similar finding, lower pitch propellers generally resulted in higher speeds. This is attributed to the larger volume of water displaced by lower-pitch propellers. To achieve the same speed as a higher-pitch propeller, a lower-pitch propeller must rotate faster, displacing more water and generating greater thrust. Value of speed in laboratory vs direct field of propeller pitch 8 is (3,25 vs 2,78) m/s. Pitch 9 is (3,1 vs 25) m/s and Pitch 12 is (3 vs 2,22) m/s.

4.4.4 The effect of Propeller Variations to the Energy Consumption Based on Laboratory Testing

Once the energy consumption is calculated in kWh, the cost of the consumed energy can be determined by multiplying it by the price per kWh. For this experiment, Assumed the price of electricity provided by PLN (*Perusahaan Listrik Negara*) is Rp 1.699,00 per kWh. Therefore, the cost of energy consumption for a propeller pitch of 8 with a power input of 1536 watts would be:

$$Cost = kWh * Rp\ 1.699{,}00$$

$$Cost = 0{,}04373 * Rp\ 1.699{,}00$$

So,

$$Cost = Rp\ 74{,}00$$

Using the same calculation, the other data of cost can be show at the table 4.17 bellow:

Table 4.24 Energy Consumption and Cost

Energy Consumption										
No	**Propeller variations**	**P Input (Watt)**	**Running Time**	**AH**	**V**	**kWh**	**Cost**		**Total Cost/0,5 hour**	
1	Pitch 8	1536	10 minutes	4,1	64	0,04374	Rp	74	Rp	538
		3840	10 minutes	10,4	64	0,11096	Rp	189		
		5760	10 minutes	15,2	64	0,16217	Rp	276		
2	Pitch 9	1536	10 minutes	4,1	64	0,04374	Rp	74	Rp	531
		3840	10 minutes	10,1	64	0,10775	Rp	183		
		5760	10 minutes	15,1	64	0,1611	Rp	274		
3	Pitch 12	1536	10 minutes	4,1	64	0,04374	Rp	74	Rp	526
		3840	10 minutes	9,9	64	0,10562	Rp	179		
		5760	10 minutes	15	64	0,16003	Rp	272		

Based on the table above, taken the graph power input vs consumable energy in kWh. The table shows as the figure above:

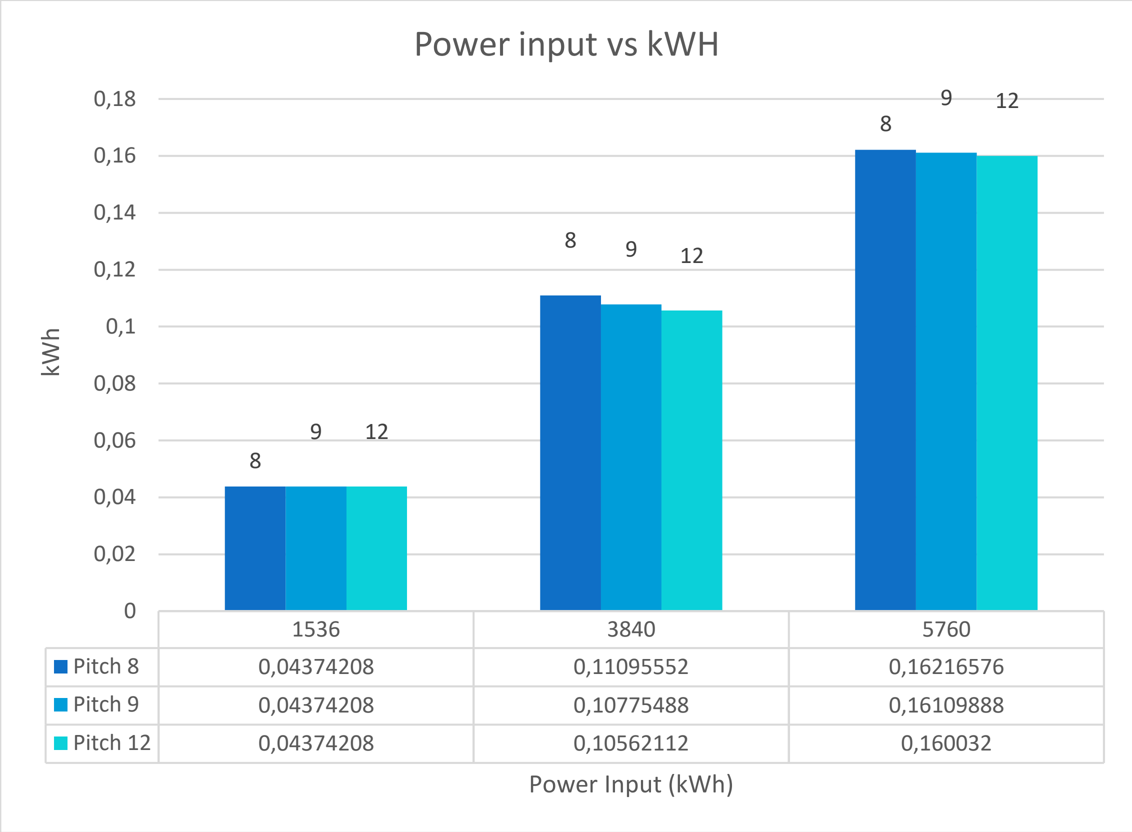


Figure 4.31 Power input vs kWh

As evident from the graph, energy consumption increases in direct proportion to the power input. Propeller pitch 12 exhibits lower fuel consumption compared to propeller pitches 8 and 9. At a power input of 3840 watts, propeller pitch 12 consumes 0.106 kWh of energy, which is lower than the consumption of propeller pitch 8 (0.110 kWh) and propeller pitch 9 (0.108 kWh). Similarly, at a power input of 5760 watts, propeller pitch 12 consumes 0.160 kWh of energy, which is lower than the consumption of propeller pitch 8 (0.162 kWh) and propeller pitch 9 (0.161 kWh). Higher energy consumption higher cost also. This is because propellers with higher pitch require fewer revolutions, leading to lower energy consumption.

4.4.5 The Relation of Speed, Duration and Distance to the Operational Cost of Electric Outboard using Propeller Variation

To taking the several factor such as speed, energy consumption, and cost analysis as a conclusion. Here is the correlation between all the factor.

COST ESTIMATION

No	Pitch	P	vs	Duration	L max	L	Charge	kwh	Cost	Cost	Cost
		Watt	Km/h	h	km	km	Per-day		/day	/month	/year
1	8	1536	10,08	4,17	42,0	6	0,143	0,914	Rp 1.553	Rp 34.174	Rp 410.090
		3840	12,24	1,67	20,4	6	0,294	1,882	Rp 3.198	Rp 70.359	Rp 844.303
		5760	11,16	1,11	12,4	6	0,484	3,097	Rp 5.261	Rp115.751	Rp1.389.015
2	9	1536	9,36	4,17	39,0	6	0,154	0,985	Rp 1.673	Rp 36.803	Rp 441.635
		3840	11,88	1,67	19,8	6	0,303	1,939	Rp 3.295	Rp 72.491	Rp 869.888
		5760	10,08	1,11	11,2	6	0,536	3,429	Rp 5.825	Rp128.153	Rp1.537.838
3	12	1536	9,36	4,17	39,0	6	0,154	0,985	Rp 1.673	Rp 36.803	Rp 441.635
		3840	10,80	1,67	18,0	6	0,333	2,133	Rp 3.625	Rp 79.740	Rp 956.877
		5760	10,08	1,11	11,2	6	0,536	3,428	Rp 5.825	Rp128.153	Rp1.537.838

Based on the table above, taken the graph as below:

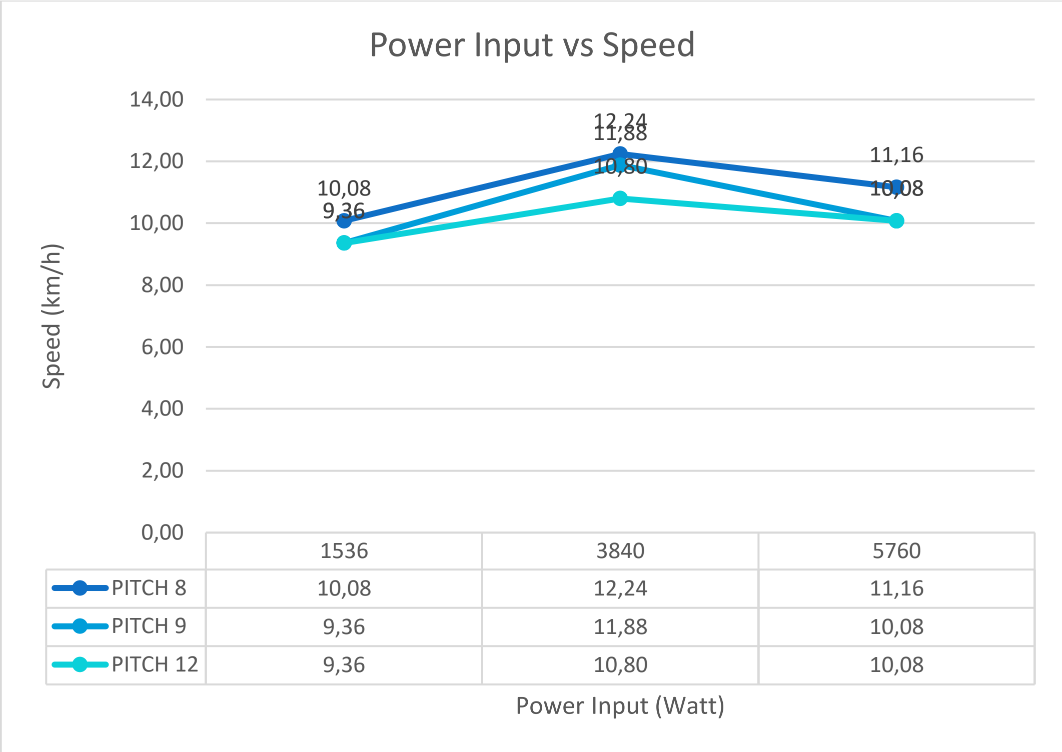


Figure 4.32 Power Input vs Speed

Based on the graph above, the increase of power input, increase of speed also. From the graph, propeller with pitch 8 dominate the more speed in every single power input. It makes the propeller with pitch 8 will get the maximum distance in the same operation or same treatment like the graph below:

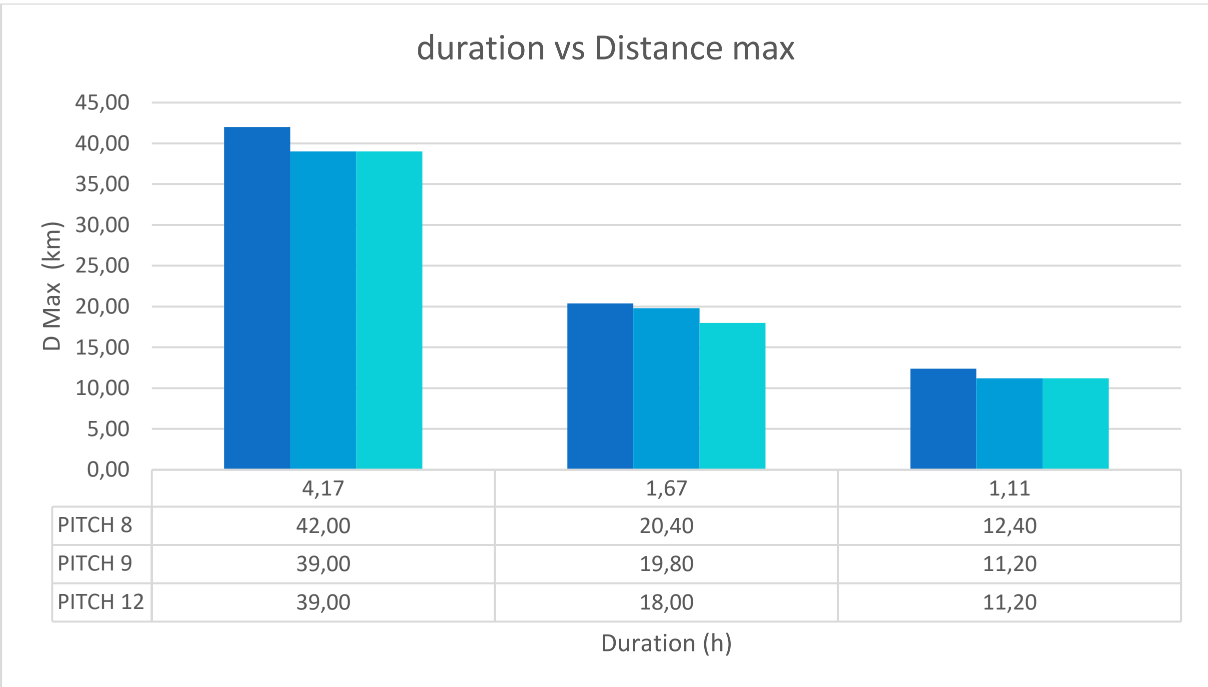
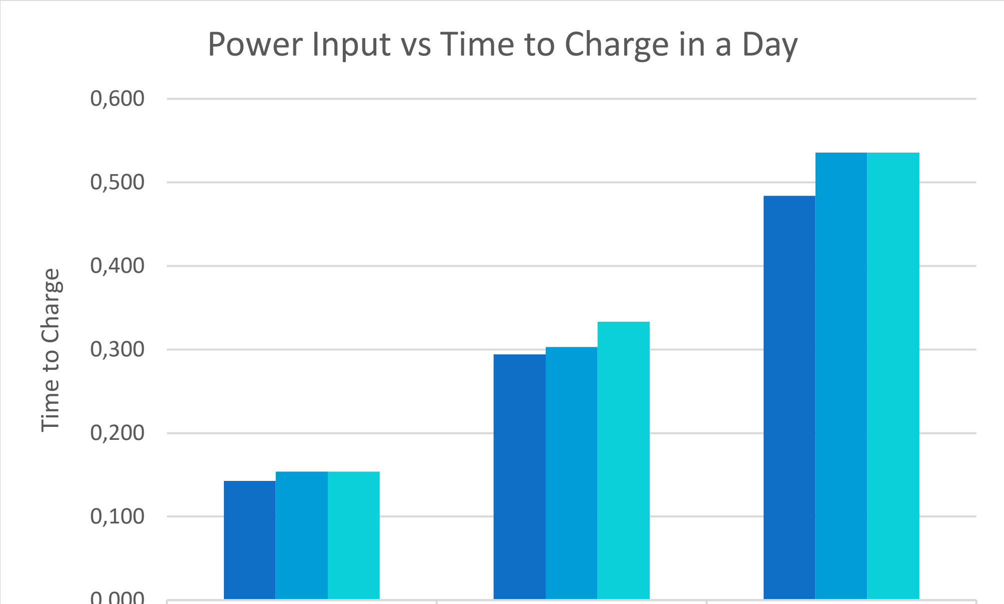


Figure 4.33 Duration of Battery vs Maximum distance

From the graph above, the same power input makes the endurance or make the duration of battery life same in every treatment. For the example with power input 1536 watt, the battery will alive in 4,17 hours. But speed that produce by propeller variation will different it can influence the maximum distance. For the example propeller pitch 8 with endurance of battery is 4,17 and speed 10,08 km/h will made 42 km for the distance. Different with propeller pitch 9 that with endurance of battery is still same in 4,17 hours, only get the distance max in 39 km.

After gotten the graph of Endurance of the battery, next is the graph of power input vs the time to charge in a day using the operational distance in a day over the maximum distance until the battery is empty. Here is the graph



	1536	3840	5760
PITCH 8	0,143	0,294	0,484
PITCH 9	0,154	0,303	0,536
PITCH 12	0,154	0,333	0,536

Figure 4.34 Power Input vs Time to Charge in a Day

Based on the graph 4.34 above, higher power input, higher the time to charge. Propeller with pitch 8 gotten the value of time to charge lower than the other propeller pitch. For the example propeller with pitch 8 in power input 1536 watt need the time to charge 0,143 times in a day. In other side the propeller with pitch 9 and 12 need the time to charge 0,154 times in a day. It can be happened because the propeller with pitch 8 produce higher speed than the other propeller.

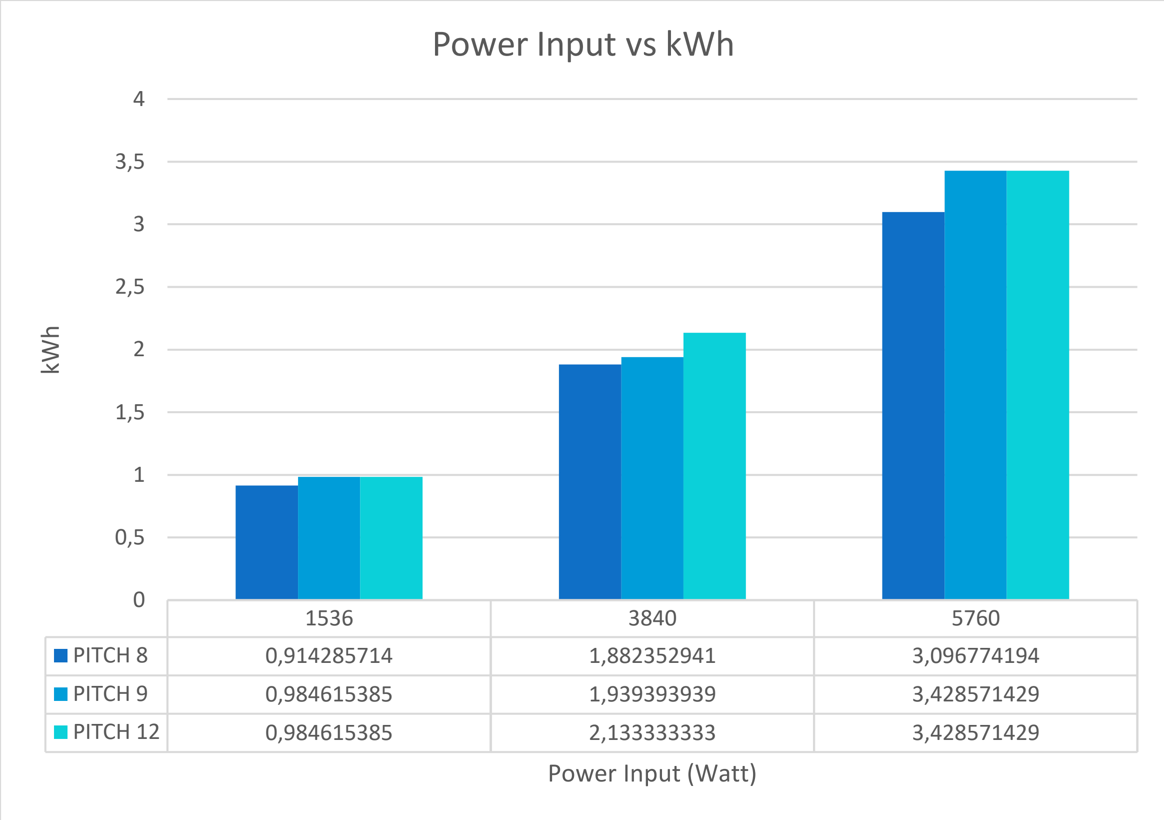
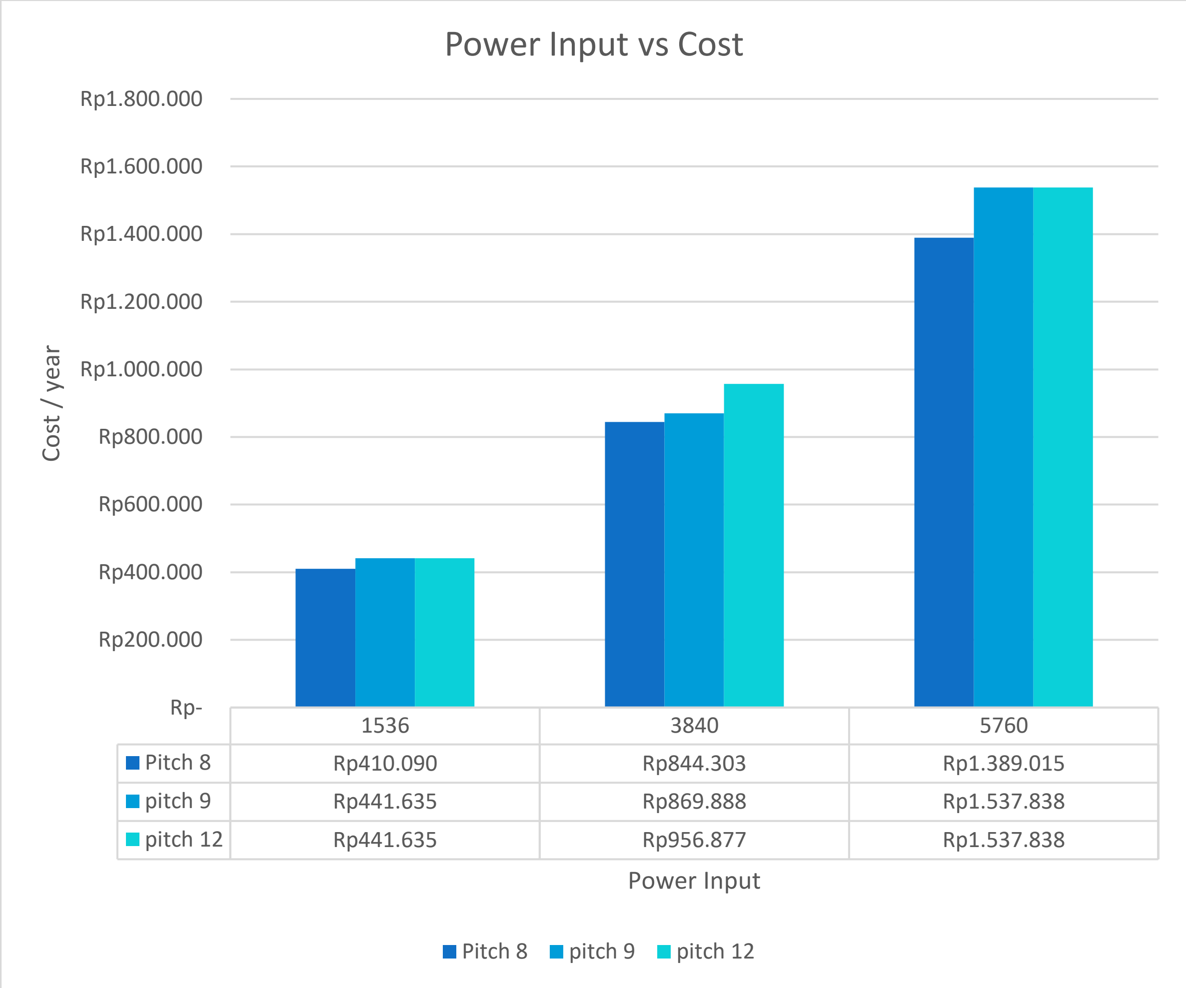


Figure 4.35 Power Input vs kWh

Based on the graph above, higher power input higher the kWh. There is the relation between time to charge and consumable energy. Low time to charge, lower energy consumable energy. During the operational, propeller with pitch 8 gotten the lowest value of consumable energy in kWh. It can be happened because of propeller with pitch 8 have the fastest speed, longest distance in the same endurance of battery and distance of operational.



	1536	3840	5760
Pitch 8	Rp410.090	Rp844.303	Rp1.389.015
pitch 9	Rp441.635	Rp869.888	Rp1.537.838
pitch 12	Rp441.635	Rp956.877	Rp1.537.838

Figure 4.36 Power Input vs Cost in a year

The graph reveals a positive correlation between power input and estimated cost. This implies that higher power input demands higher operational expenses. Among the power input values considered, 1536 watts stands out as the most economical option. Pitch 8 emerges as the most efficient and cost-effective propeller, consistently producing the lowest cost across all power inputs. At a power input of 1536 watts, the annual cost is IDR 410,090. For a power input of 3840 watts, the annual operational cost is IDR 844,303. And with a power input of 5760 watts, the annual cost reaches IDR 1,389,015. This efficiency is attributed to Pitch 8's ability to generate the highest speed, enabling it to cover a greater distance using the same battery duration and capacity.

4.4.6 The Effect of Propeller Variation on Vibration Based on Laboratory Testing

Here is the graph of the effect of propeller variations on the vibration

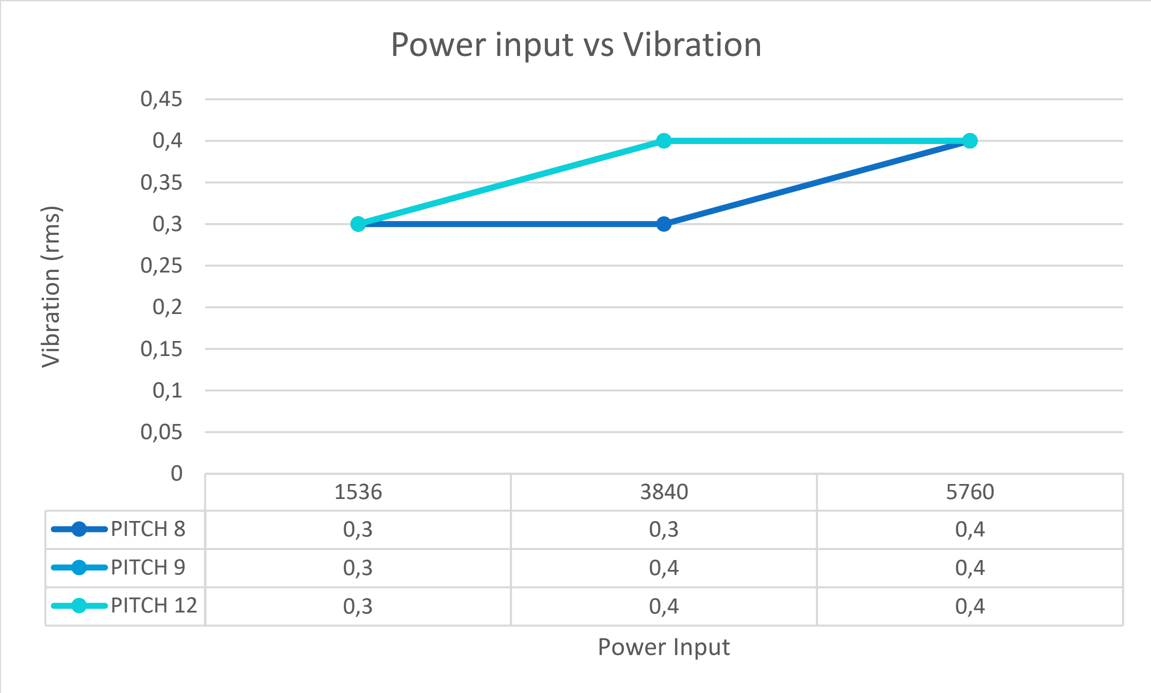


Figure 4.37 Power input vs Vibration in Every Propeller Pitch

Figure above presents a compelling analysis of the relationship between power input, vibration, and propeller pitch during operational conditions. As expected, a higher power input leads to a corresponding increase in vibration levels. This phenomenon is consistent with the fundamental principles of mechanical vibrations, where energy input directly influences the intensity of vibrations.

Generally, propellers with smaller pitch angles tend to produce less vibration compared to those with larger pitch angles. This is because propellers with smaller pitch angles cut through the water at a shallower angle, resulting in a smoother and more consistent thrustInterestingly, the study revealed that the choice of propeller pitch does not exhibit a significant impact on vibration levels. This observation can be attributed to the inherent characteristics of electric motors, which generally produce smoother and less noticeable vibrations compared to combustion engines. Electric outboards, in particular, are renowned for their low vibration profiles, making them a popular choice for applications that demand quiet and smooth operation.

The study further highlights that vibration in electric outboards is more likely to arise from component failures, such as bearing damage. This emphasizes the importance of regular maintenance and inspections to ensure the optimal performance and longevity of electric outboard motors.

CHAPTER 5

CONCLUSION

5.1 Conclusion

Taken conclusion of this research

1. The research reveals a compelling relationship between propeller pitch and water flow velocity and Δ v. For the water velocity rate and average water velocity rate, among the tested pitches (8, 9, and 12), pitch 8 producing the highest water velocity. This phenomenon can be attributed to the varying RPM levels generated under constant power input. Pitch 8 generates the highest RPM, leading to the observed velocity advantage. It is important that water flow velocity directly correlates with thrust, the propulsive force generated by the propeller. The propeller with the highest Δ v gap also exhibits the highest thrust output which is propeller pitch 8. Consistent with experimental results and calculations, pitch 8 emerges as the top performer in terms of Δ v and, consequently, thrust. This observation aligns with the principle of momentum conservation, which states that a higher momentum difference translates to a higher thrust value.
2. The direct or the direct field testing as the prove of laboratory testing confirmed the positive correlation between propeller pitch, travel time, and average boat speed. pitch propeller 8 achieved the fastest roundtrip time of 3.48 minutes and a maximum average speed of 10 km/h. These results highlight the 8-pitch propeller as the optimal choice for patrol boats, which prioritize rapid response times. In contrast, the electric outboard with a pitch propeller 12 recorded a travel time of 4.58 minutes and an average speed of 8 km/h. This slower performance renders the 12-pitch propeller unsuitable for patrol boats, where speed is a critical factor. The superior performance of the 8-pitch propeller can be attributed to its ability to generate higher RPM due to its lower pitch angle especially for this research. Then the laboratory and sea trial generate same result which is propeller pitch 8 produce highest speed.
3. The study revealed a clear relationship between propeller pitch and energy consumption. At the laboratory testing higher power input higher value of energy consumption. Higher propeller pitch lower energy consumption. The 12-pitch propeller demonstrated the lowest energy consumption due to its lower rotational speed compared to the 8 and 9-pitch propellers. The study analyzed the impact of propeller pitch (8, 9, and 12 inches) on an electric outboard boat's operational cost. Key factors examined included battery power input, endurance, boat speed, range, energy consumption, and overall cost. Results showed that while battery endurance remained consistent across different power inputs, the 8-inch propeller consistently outperformed its counterparts in speed and range. Given the patrol boat's operational distance, the 8-pitch propeller demonstrated the lowest energy consumption and subsequently, the lowest annual cost. Compared to the 9 and 12-inch propellers, the 8-pitch propeller option proved to be the most cost-effective and efficient choice for the patrol boat application. So, the energy consumption in laboratory and real operational boat difference result because of operational condition.

4. Generally, propellers with smaller pitch angles tend to produce less vibration compared to those with larger pitch angles. This is because propellers with smaller pitch angles cut through the water at a shallower angle, resulting in a smoother and more consistent thrust. With value of vibration at propeller pitch 8 in several treatment is 0,3 mm/s, 0,3 mm/s, 3 mm/s. in other side propeller with pitch 9 and 12 generates (0,3, 0,4, 0,4) mm/s and (0,4, 0,4 ,0,4) mm/s. Based on ISO 8503-1, the vibration usually used for detecting the damage of the part at machinery. 0,3 and 0,4 is the small vibration that inform there is no damage or failure at the electric outboard.

5.2 Recommendation

Given the focus of this research on testing the performance of an existing electric outboard motor, the employed experimental methods, despite their limitations, have yielded satisfactory results. However, to achieve even more precise outcomes, EPM calculations through simulations would be necessary. Unfortunately, such an approach is impractical for testing electric outboards due to the physical constraints of the existing equipment and the inability to modify specifications within a short timeframe. Therefore, for future research closely related to this study, it is recommended that simulations be conducted for data comparison.

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ATTACHMENT

Attachment 1 Water Velocity Data Taken Based on Laboratory Testing

From the experiment taken the data of water velocity rate, for the example is in the data of water velocity rate for propeller pitch 8 number 2 with current input 12 ampere in the data point 1 with height 40 cm from base. Gotten the value of water velocity rate is 1,6 m/s.

Figure 5.1 Water Velocity Data Taken (Personal Documentation)

Figure 5.2 Water Velocity Data Taken (Personal Documentation)

Figure 5.3 RPM Data Taken

Attachment 2 Vibration Data Taken

Not only the water velocity rate, but also the vibration produced by the electric outboard using propeller variation also taken in this open water testing. Here is the documentation of vibration data taken:

Figure 5.4 Vibration data Taken

Attachment 3 Time to Travel and Speed of Boat Based on Sea trial

Taken the data of time to travel and speed of boat based on sea trial as the figure below:

Figure 5.5 Sea Trial

Here is the documentation during the sea trial to getting the one of parameter performance which is speed of boat and time to travel using propeller variation:

Figure 5.6 Electric Outboard Instalation (Personal Documentation)

Figure 5.7 Boat Trial

Figure 5.8 Changed of Propeller Variations

Here is the documentation and calculation for the Time to Travel and Speed data Taken:

A. Time to travel

- **Pitch 9**

Figure 5.9 Time to Depart of Boat that used Electric Outboard with Propeller Pitch 9 (Personal Documentation)

Figure 5.10 Time to Arrive of Boat that used Electric Outboard with Propeller Pitch 9 (Personal Documentation)

So, the average of time to travel by the boat with electric outboard that used propeller pitch 8 is:

$$1{,}50\ (minutes) + 2{,}35 \ = \ 4{,}25\ minutes$$

- **Pitch 12**

Figure 5.11 Time to Depart of Boat that used Electric Outboard with Propeller Pitch 12 (Personal Documentation)

Figure 5.12 Time to Arrive of Boat that used Electric Outboard with Propeller Pitch 12 (Personal Documentation)

So, the average of time to travel by the boat with electric outboard that used propeller pitch 8 is:

$$2{,}16\ (minutes) + 2{,}42\ =\ 4{,}58\ minutes$$

B. Speed of Boat

a. Pitch 8

- Propeller Pitch 8 Depart

Figure 5.13 Speed to Depart of Boat that used Electric Outboard with Propeller Pitch 8 in 60 Ampere of current input (Personal Documentation)

Figure 5.14 Speed to Depart of Boat that used Electric Outboard with Propeller Pitch 8 in 90 Ampere of current input (Personal Documentation)

$$\frac{12\ (km/h) + 10\ (km/h)}{2} = 11\ km/h$$

So, the average of speed to depart of boat that used electric outboard with propeller pitch 8 is 11 km/h

- **Propeller Pitch 8 Arrive**

Figure 5.15 Speed to arrive of Boat that used Electric Outboard with Propeller Pitch 8 in 90 Ampere of current input (Personal Documentation)

Figure 5.16 Speed to arrive of Boat that used Electric Outboard with Propeller Pitch 8 in 60 Ampere of current input (Personal Documentation)

$$\frac{9\ (km/h) + 8\ (km/h)}{2} = 8{,}5\ km/h$$

So, the average of speed to arrive of boat that used electric outboard with propeller pitch 8 is 8,5 km/h

b. Pitch 12

- **Propeller Pitch 12 Depart**

Figure 5.17 Speed to Depart of Boat that used Electric Outboard with Propeller Pitch 12 in 60 Ampere of current input (Personal Documentation)

Figure 5.18 Speed to Depart of Boat that used Electric Outboard with Propeller Pitch 12 in 90 Ampere of current input (Personal Documentation)

$$\frac{9\ (km/h) + 10\ (km/h)}{2} = 9{,}5\ km/h$$

So, the average of speed to depart of boat that used electric outboard with propeller pitch 12 is 9,5 km/h

- **Propeller Pitch 12 Arrive**

Figure 5.19 Speed to Arrive of Boat that used Electric Outboard with Propeller Pitch 12 in 90 Ampere of current input (Personal Documentation)

$$\frac{6\ (km/h) + 7\ (km/h)}{2} = 6{,}5\ km/h$$

The data indicates that the average arrival speed for the boat equipped with the electric outboard and a propeller pitch of 12 is 6.5 km/h.

C. Energy Consumption

a. Pitch 8

- 24 Ampere

The data for 24 amperes in propeller pitch 8 recorded by before and after running in 10 minutes. Here is the documentation

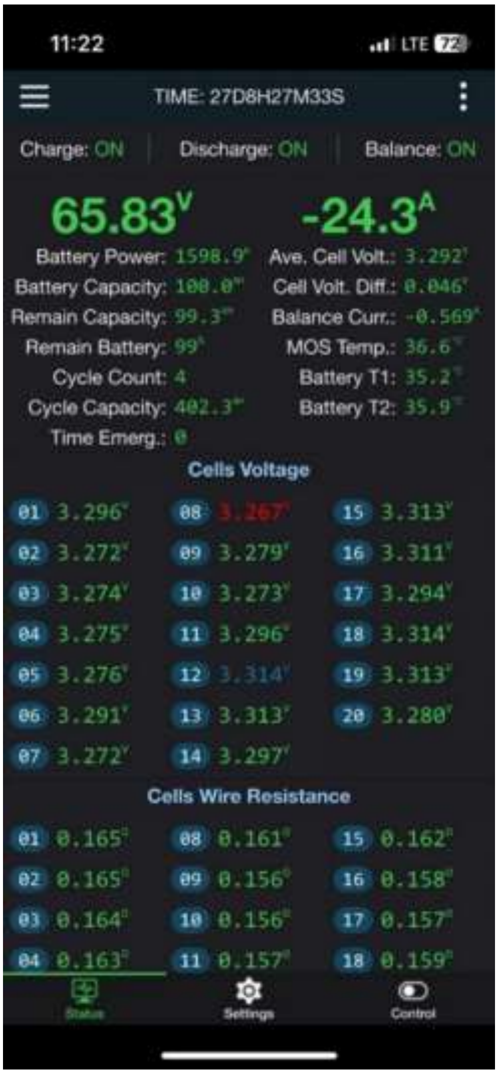

Figure 5.20 Battery Capacity for 24 Ampere in Pitch 8 Propeller Before Running

Figure 5.21 Battery Capacity for 24 Ampere in Pitch 8 Propeller After Running

By the Figure above, the result gotten by the different of initial and last of capacity of battery in ampere hour. So the energy consumption is

$$99{,}3\ AH - 95{,}2\ AH = 4{,}1\ AH$$

- **60 Ampere**

Figure 5.22 Battery Capacity for 60 Ampere in Pitch 8 Propeller Before Running

Figure 5.23 Battery Capacity for 60 Ampere in Pitch 8 Propeller After Running

$$94\ AH - 83{,}6\ AH = 10{,}4\ AH$$

- **90 Ampere**

Figure 5.24 Battery Capacity for 90 Ampere in Pitch 8 Propeller Before Running

Figure 5.25 Battery Capacity for 60 Ampere in Pitch 8 Propeller After Running

$$81{,}4\ AH - 66{,}2\ AH = 15{,}2\ AH$$

b. Pitch 9

- **24 Ampere**

Figure 5.26 Battery Capacity for 24 Ampere in Pitch 9 Propeller Before Running

Figure 5.27 Battery Capacity for 24 Ampere in Pitch 9 Propeller After Running

$$99{,}2\ AH - 95{,}1\ AH = 4{,}1\ AH$$

- **60 Ampere**

Figure 5.28 Battery Capacity for 60 Ampere in Pitch 9 Propeller Before Running

Figure 5.29 Battery Capacity for 60 Ampere in Pitch 9 Propeller After Running

$$95\ AH - 83{,}9\ AH = 10{,}1\ AH$$

- **90 Ampere**

Figure 5.30 Battery Capacity for 90 Ampere in Pitch 9 Propeller Before Running

Figure 5.31 Battery Capacity for 90 Ampere in Pitch 9 Propeller After Running

$$82{,}4\ AH - 67{,}3\ AH = 15{,}1\ AH$$

AUTHOR BIODATA

Yonathan Iwangsa Sima with nickname Iwang was born on October 4, 1999, as the youngest of three siblings. The Author is the son of Lilik Cholifah and Wing Aryono. The educational journey began at SDN Temas 1 Batu for elementary school, followed by SMPN 1 Batu and SMAN 1 Batu for middle and high school. After two years of studying at Universitas Brawijaya, decided to pursue a degree in Marine Engineering at Institut Teknologi Sepuluh Nopember Surabaya in 2020. With a student number of 5019201168, with successfully completed the undergraduate studies in four years.

During the studied in Marine Engineering, The author is active in several organizational activities, both internal and external. Examples include HIMASISKAL and Jazziner. In addition to his studies, Yonathan Iwangsa Sima is also a dedicated and hardworking individual who actively contributes to his family's well-being through his business endeavors. This demonstrates his commitment to both academic achievement and financial responsibility.