Indonesian Journal of Contemporary Multidisciplinary Research (MODERN)
Vol. 5, No. 6, 2026: 969-984

Redesign of Dual Propulsion System on a Kamikaze Submarine for Underwater Speed Optimization

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A R T I C L E I N F O

Keywords: Dual Propulsion System, Propeller Geometric Characteristics, Efficiency, Stability

Received : 15 September
Revised : 20 October
Accepted: 05 November

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A B S T R A C T

This study redesigns a dual propulsion system for a kamikaze submarine to improve underwater speed, propulsion efficiency, and straight-line stability. The research used an experimental engineering approach involving mechanical design, component selection, assembly, and laboratory performance testing. The selected DC 775 motor provided a specific power output of 24.38 W/kg, while a 5.5 cm four-blade propeller was matched to the motor torque characteristics. The New Rain 480A Electronic Speed Control was used to manage motor current, with the system achieving an estimated propulsion efficiency of 55%. Synchronization of the two motors through RPM adjustment improved straight-line motion stability. The proposed configuration also maintained a compact layout and used a standard leak-proof shaft arrangement suitable for the available hull space

INTRODUCTION

Research Background

As the largest archipelagic country in the world with a coastline exceeding 54,000 km, Indonesia faces major strategic challenges in maintaining the sovereignty of its territorial waters. To respond to these challenges, the Indonesian Navy, specifically the Naval Special Warfare Command (Satkopaska), requires the development of an adaptive and asymmetric defense posture. The development of unmanned underwater vehicle technology is increasingly relevant to underwater defense because platform efficiency, endurance, and technological modernization directly affect mission capability. In this context, the development of an expendable unmanned underwater vehicle, or kamikaze submarine, is considered as one potential platform to support underwater missions.

Several previous studies have investigated individual aspects of propulsion systems relevant to underwater vehicles. In Indonesia, (Jaya & Rukmono, 2021) evaluated an efficient AUV propulsion concept using biomimetic fins and reported efficiency improvements of up to 30%. (Guntoro et al., 2021) investigated a dual-motor propeller control system and demonstrated that synchronization between two motors could be maintained using PID control, while (Ayi Al Ma'rif et al., 2023) examined submarine propellers with different blade numbers and demonstrated the importance of propeller configuration in structural performance. Internationally, (Lidtke et al., 2021) showed that AUV propulsion efficiency depends on the interaction between propeller performance and motor–drivetrain efficiency. (Ou et al., 2023) further demonstrated that optimization of a dual contra-rotating motor can improve propulsion efficiency while reducing weight and increasing available internal space in an AUV. These studies indicate that motor characteristics, propeller design, propulsion efficiency, and rotational control are closely related parameters in underwater propulsion systems.

However, the reviewed studies generally focus on individual aspects of the propulsion system. Indonesian studies have mainly addressed propulsion efficiency, propeller characteristics, or dual-motor control separately, while international studies have concentrated on drivetrain efficiency, specialized contra-rotating motors, or hull–propeller hydrodynamic interaction. Within the literature reviewed, limited attention has been given to the integrated experimental evaluation of a compact dual-propulsion system that simultaneously considers hull space availability, motor power density, motor–propeller matching, ESC peak-current capacity, and rotational synchronization. This integration represents the research gap addressed in the present study.

The design of this vehicle faces technical constraints regarding the limited internal space of its slender hull. This restricted volume demands an appropriate balance between motor power and physical dimensions to prevent excessive space requirements while maintaining the targeted vehicle performance. Thrust performance also depends on matching the motor torque and RPM characteristics with the propeller geometry, particularly its diameter

and blade configuration. From the electrical aspect, the Electronic Speed Control (ESC) must be capable of regulating motor power and handling peak-current loads. A dual propulsion configuration is therefore implemented to improve thrust balance and minimize directional deviation through synchronization of the two motor rotations.

Therefore, this research aims to redesign and evaluate the dual propulsion system of a kamikaze submarine by analyzing electric motor power specifications, propeller geometry compatibility, ESC current-handling capacity, and motor rotational synchronization to achieve the targeted underwater speed and straight-line stability. The novelty of this study lies in the integrated evaluation of these mechanical and electrical parameters within the limited hull space using commercially available propulsion components, followed by physical performance testing of the developed dual-propulsion configuration.

Research Formulation

Based on the background above, several problem formulations are concluded as follows:

a. How can the electric drive motor specifications be determined to achieve the target submarine speed while considering power requirements and limited space inside the hull?
b. How can the suitability of the selected propeller configuration be evaluated in relation to the power characteristics and thrust generated by the drive motor to achieve the target vehicle speed?
c. How can the Electronic Speed Control (ESC) capacity and electrical system be determined to support motor power requirements and maintain power distribution in the dual propulsion system?
d. How does the synchronization of the two drive motors in the dual propulsion system affect the achievement of the target speed and the ability of the vehicle to maintain straight-line motion during testing?

Research Objectives

The objectives of this research are as follows:

a. Analyze the electric drive motor power specifications and installation space requirements to determine a motor configuration suitable for the target speed and the limited hull space of the kamikaze submarine.
b. Evaluate the suitability of the selected propeller configuration in relation to the characteristics of the drive motor based on thrust requirements and achievement of the target speed.
c. Analyze the capacity of the ESC and electrical system, including current-carrying capability and voltage drop, to support power requirements in the dual propulsion system.
d. Evaluate the synchronization of the two drive motors in the dual propulsion system based on achievement of the target speed and straight-line motion stability during testing.

LITERATURE REVIEW

Kamikaze Propulsion System

The development of autonomous, asymmetric, "fire-and-forget" defense equipment requires a mature integration between mechanical design and drive systems so that the vehicle can execute missions precisely. The expendable mission characteristics of kamikaze vehicles demand high power consumption efficiency to achieve an optimal operational range. Therefore, performance mapping of the autonomous propulsion system serves as an essential foundation for measuring successful penetration against target objectives.

Research by (Muda & Wellyanto, 2025) examined a hybrid propulsion system (20% solid and 80% liquid) on a kamikaze drone with a range of 280 km using the Computational Fluid Dynamics (CFD) simulation method. The test results showed a mission success rate of 92% with a stable fuel consumption between 0.32–0.38 liters/km and a travel time of 31–34 minutes. These autonomous characteristics prove that directional stability and thrust efficiency are heavily influenced by the drive configuration used.

The relevance of that study to this research lies in the principle of synchronization between mechanical design and autonomous drive systems. Through understanding that long-range performance evaluation, this study adopts the critical urgency of selecting precise propulsion component specifications. This is essential to prevent a decline in the kamikaze submarine's performance due to miscalculations in the early design phase.

Geometry Propeller

The engineering design of unmanned underwater vehicles, such as Autonomous Underwater Vehicles (AUVs), requires complex drive system modeling to accommodate spatial constraints and maneuvering motions. The matching process between the torque capacity of the drive motor and the propeller geometry is the most crucial stage. Mechanical load mismatches risk triggering system failures due to a loss of thrust or the occurrence of overheating phenomena.

(Afif et al., 2016) designed an AUV with a six-propeller configuration driven by DC motors controlled by a PID controller using the Ziegler-Nichols tuning method. Laboratory test results indicated that the speed controller was successfully implemented at values of Kp = 4900 and Ti = 1,25, although the rotational motion response on the physical vehicle still showed deviations from the simulation model. On the other hand, (Guntoro et al., 2021) optimized a twin-rotor dual motor BLDC 930 kV and ESC 20A system using the Chien-Hrones-Reswick (CHR) tuning method, which yielded a steady-state error stability of 0.99%.

Both studies serve as vital references in resolving motor rotation synchronization constraints in the dual propulsion system of the kamikaze submarine. The findings regarding the deviation between simulation data and physical implementation serve as a warning for the author to conduct physical testing meticulously. This evaluation is focused on determining the propeller blade dimensions to match the torque characteristics of the DC 775 motor used.

Hydrodynamics Analysis

Predicting the thrust requirements for a submarine hull moving at a constant speed underwater requires an accurate self-propulsion characteristic analysis. The hydrodynamic interaction between the fluid flow along the hull and the rotation of the propellers at the stern affects the total drag value. A minimal frontal cross-section of the vehicle and an estimation of the blade rotation speed are primary keys to determining the efficiency of the internal hull space.

Research by Çoşgun, (2021) onducted a numerical self-propulsion assessment on a DARPA Suboff generic submarine model using the Reynolds-Averaged Navier-Stokes (RANS) method at speeds ranging from 5.35 to 17.79 knots. The simulation results showed that the propeller rotation speed increased linearly with hull speed, with an increase in viscous pressure in the stern area due to the influence of blade rotation. This numerical validation proved reliable, showing a very small relative error of only about 2% compared to experimental data.

This thrust evaluation methodology is highly relevant for determining the motor power output specifications on the slender hull of the kamikaze submarine. This self-propulsion analysis underlies the author's calculations in establishing the target specific power of the DC 775 motor at 24.38 Watt/kg. This approach was taken to reduce hydrodynamic drag resulting from constraints in battery and electrical component space.

Power Control System

The autonomous operation of an underwater vehicle must account for stability limit regulations and electrical power management reliability. Vertical stability index criteria and system damping ratios are absolute parameters for the vehicle to maintain its operational depth without losing directional control. In addition, the integration of current-regulating components such as an Electronic Speed Control (ESC) is vital to secure the system from electrical load surges.

(Kirikbaş & Bal, 2021) , through a study of the NATO Naval Submarine Code (NSubC) manufacturing regulations, proposed a minimum vertical stability index criterion of 0.2 and a minimum damping ratio of 0.7 to guarantee submarine controllability. Meanwhile,(Jin et al., 2020) developed a tethered 48V DC Hybrid Surface and Underwater Vehicle (HSUV) platform utilizing Way Point and Dynamic Positioning algorithms, which generated an average position error of only 2.03 meters when encountering ocean currents.

This study of regulations and power management architecture forms the foundation for designing the electrical management system on the kamikaze submarine's dual propulsion. The application of peak current control via the New Rain 480A ESC in this study was adopted to ensure the vehicle remains responsive to RPM changes. This step is crucial for maintaining straight-line motion stability while achieving the target system efficiency of 55%.

METHODOLOGY

Research Design

This study is classified as engineering design research, focusing on the development of a Contra-Rotating propulsion system for a Kamikaze Submarine to support underwater sabotage missions. This research aims to deliver innovative technical solutions based on contra-rotating propulsion technology capable of increasing energy efficiency, enhancing maneuvering stability, and reducing the acoustic noise of small submarines in covert operations.

In addition to the propulsion system, the Kamikaze Submarine is designed to be equipped with a weapon payload in the form of explosives/TNT, which can be detonated via impact or remote control. The vehicle also possesses target detection capabilities against enemy ships and real-time coordinate transmission. Therefore, this design is expected to serve as a reliable, ergonomic, and effective combat asset to support successful operational missions and strengthen national naval defense capabilities.

Tools and Materials

In the execution of this research, a number of tools and materials were required as core components to support the design, development, and testing processes of the dual propulsion system on the kamikaze submarine for underwater sabotage missions. Each tool and material served a strategic function in ensuring accuracy, precision, and effectiveness throughout all research phases.

The selection of tools and materials was conducted selectively to support technical requirements, spanning from the assembly process to the testing and performance analysis of the dual drive system. These components were vital to guarantee that the designed system could operate according to the specified objectives and was ready for deployment under actual operational conditions.

Research Design

The research design serves as a systematic operational and conceptual framework that acts as the primary guideline in executing the study. This framework was designed not only to direct the technical processes but also to anticipate various challenges and obstacles that might arise during the course of the research.

Within this framework, potential methodological weaknesses, data limitations, and system implementation challenges were identified. Furthermore, the design includes alternative problem-solving strategies as well as procedures for relevant data collection, processing, and analysis as an integral part of the overall research process.

The following is a general overview of the developed design. This research design will serve as a guide for the researcher in conducting the study and developing the expected system. By designing comprehensively and in detail,

this research is expected to yield an effective, efficient system that aligns with the established research needs and objectives.

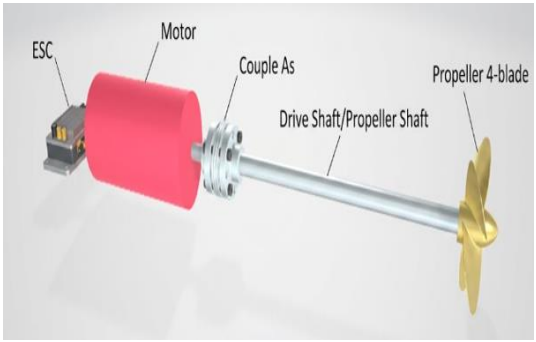


Figure 3.1 Design Dual Propulsion System

Data Collection

The data collection method in this research is divided into two primary complementary phases. Literature Study and Initial Technical Data involves collecting secondary data from technical standards, component manufacturers' datasheets (motor, battery, ESC), and journals related to propeller hydrodynamics. These data are utilized for theoretical design calculations. The output of this phase serves as the research baseline to compare the theoretical performance against the actual performance of the prototype. The data collection methods employed by the author are as follows:

a. The survey method is applied to gather essential qualitative and semi-quantitative information from relevant users or experts.
b. The interview method is used to extract in-depth information and perspectives.
c. The observation method is implemented systematically through the observation of the operational environment.
d. The documentation method is used to compile all relevant technical data throughout this engineering design process.

Through all the executed methods, it is expected to calculate the generated thrust, propulsion efficiency, and design targets, thereby presenting solid conclusions for this research.

Data Processing

The data processing stage begins with a technical comparison between motor power parameters, physical dimensions, and space availability inside the hull through precise clearance calculations. Motor specification data, such as KV rating, torque, and nominal current, are integrated with propeller geometric characteristics (diameter and pitch) using the power matching method to ensure the motor's operating point remains at its highest efficiency without the risk of stalling. In addition, the Electronic Speed Control (ESC) capacity is calculated based on the motor's peak current load, incorporating a safety

margin in accordance with operational standards to guarantee stable power management during the target speed simulation phase.

Subsequently, data processing focuses on analyzing the dynamics of the dual propulsion system by synchronizing the rotational speed (RPM) parameters of both motors to minimize directional deviation of the vehicle. The data obtained from thrust testing are physically processed to validate the system's capability to overcome total hull resistance until achieving a steady-state condition. Testing is conducted to determine the maximum thresholds of all system components when the kamikaze submarine is operated, thereby enabling the anticipation of system failures.

RESEARCH RESULT

Based on the analysis of the propulsion system on the kamikaze submarine, it is established that the selection of the high-power-density DC 775 motor represents the optimal solution to overcome internal space constraints while meeting the target speed based on simulation drag calculations. The synchronization between propeller geometry (pitch and diameter) and motor torque characteristics is proven to be vital in maintaining power management efficiency on the ESC and preventing excessive peak current surges.

Preliminary Planning

The preliminary planning phase of this research is focused on conceptualizing a drive system that integrates the technical specifications of the components with the physical boundaries of the kamikaze submarine hull. The target speed parameter is set above 5 knots, along with a specialized mission profile to calculate the hydrodynamic loads exerted on the vehicle. This planning encompasses an in-depth literature study regarding the selection of dual DC 775 motors as the primary prime movers, initial calculations of the propeller pitch-to-diameter ratio, and the layout mapping of components within the watertight compartment to ensure a balanced weight distribution during underwater operations.

Through this systematic planning approach, the research is directed toward presenting results and solutions relevant to the previously defined problem formulations. Consequently, the outcomes of this study are expected to serve as a reference for the development of underwater vehicle technology, specifically regarding the performance optimization and stability of dual propulsion systems for kamikaze submarines.

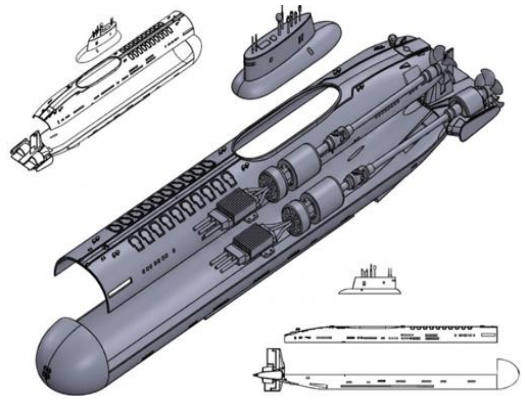


Figure 4.1 Component Design and Layout Optimization Submarine Kamikze.

Figure 4.1 illustrates the integrated component design of the dual propulsion system to be implemented on the Kamikaze Submarine. This dual propulsion system utilizes DC 775 motors, powered by a lithium polymer battery. In its operation, the circuit employs an Electronic Speed Control (ESC) to regulate the power flowing to the motors in accordance with the desired speed.

Table 4.1 Data Dimension Submarine Kamikaze

NU.	ITEM	DIMENSIONS
1	LENGTH	150 cm
2	DIAMETER	19 cm
3	WEIGHT	10,013 Kg
4	Draft (T)	2,3 cm
5	SPEED (Vs)	>5 Knot

Motor Power Specification Sizing

At this stage, calculations are performed to ensure that the utilized DC 775 motor (with its specific KV rating) delivers sufficient power to propel the submarine, which weighs 10.013 kg with a ballast capacity of 4.114 liters, while verifying that all electrical components can fit within the vessel's hull. To determine whether the motor specifications are optimal, an approach based on total electrical power and thrust power estimation is applied.).

1. Power input motor (P_{in})

$$P = V\ x\ I\ x\ n$$

$$P = 11{,}1V\ x\ 20A\ x\ 2$$

$$P = 444\ Watt$$

2. Efficiency power mekanism output (P_{eff}). Efficiency mekanism = 55%.

$$P_{eff} = P_{in}\ x\ \eta$$

$$P_{eff} = 444\ Watt\ x\ 0{,}55$$

$$P_{eff} = 244{,}2\ Watt$$

3. Power-to-weight ratio

$$Ratio = \frac{P_{eff}}{Berat}$$

$$Ratio = \frac{244{,}2\ Watt}{10{,}013\ kg}$$

$$Ratio = 24{,}38\ Watt/kg$$

This figure of 24.38 Watt/kg confirms that the vessel possesses high power capacity for offensive maneuvers (ramming/kamikaze missions).

The thrust required to overcome hydrodynamic resistance (drag).)

1. Speed of 5 knot

$$F_{Drag} = \frac{1}{2}.\rho.v^2.C_{Drag}.A$$

$$F_{Drag} = \frac{1}{2}.1000.(2{,}57)^2.0{,}15.0{,}0132$$

$$F_{Drag} = 500.6{,}6049.0{,}15$$

$$F_{Drag} = 6{,}54\ Newton$$

2. Power mechanism required

$$P_{req} = 6{,}54\ N.2{,}57\frac{m}{s}$$

$$P_{req} = 16{,}81\ Watt$$

The effective power evaluation is 444 Watt > 16,81 Watt.

3. Dual propeller thrust (F_{thrust}).

$$F_{thrust} = \frac{244{,}2\ Watt}{2{,}57\ m/s}$$

$$F_{thrust} = 95{,}02\ Newton$$

With a drag force of 6.54 N and an available thrust of 95.02 N, the 775kV dual motor propulsion system is highly responsive.

To analyze the internal space availability, a recalculation was performed based on the new layout (vertical/inline arrangement).

1. Hull Beam Calculation.

$$L_{Margin} = L_{lambung} - L_{komponen}$$

$$L_{Margin} = 60mm - 55\ mm$$

$$L_{Margin} = 5\ mm$$

The resulting clearance is 5 mm. The width of the New Rain 480A ESC and the Li-ion battery is 45–55 mm.

2. Vertikal Calculation

$$T_{total\ komp} = T_{motor} + T_{ESC} + T_{Baterai}$$

$$T_{total\ komp} = 45 + 25 + 40$$

$$T_{total\ komp} = 110\ mm$$

$$Vertikal = 110\ mm$$

3. Propulsion system overall length

$$Eff_{panjang\ sistem} = \left(\frac{P_{komponen}}{P_{lambung}}\right).100\%$$

$$Eff_{panjang\ sistem} = \left(\frac{300mm}{1500mm}\right).100\%$$

$$Eff_{panjang\ sistem} = 20\%$$

The calculation results show that the length of the propulsion system accounts for 20% of the total ship length. This yields a significant advantage in determining the center of gravity, as the system components can be shifted forward or backward to balance the vessel during operation.

ESC Installation

Ensuring optimal power distribution from the battery to the motor without constraints. The executed voltage drop is 0.16 V, which is exceedingly small, falling below 1% of the 12V system. This indicates that the 120A waterproof cable is highly ideal, as virtually no power is dissipated as heat along the cable, thereby enabling the motor to operate at maximum efficiency.

Current Protection and ESC Capacity Analysis. The New Rain 480A ESC was selected to provide a safety margin. Based on the calculation analysis with a minimum safety factor of 8, the New Rain 480A ESC will never operate close to its maximum threshold

DISCUSSION

Table 4.1 Propulsion System Comparison

Parameter	*Dual Propulsion DC 775)*	*Single Motor Brushless (Coaxial contra rotation)*
Speed	*5 Knot*	*5 Knot*
Hidrodinamic Drag	*Slightly increased (4,5 - 5 N)*	*Low (3,8 - 4,2 N)*
Efectif Power (EHP)	*11,5 - 12,5 Watt*	*9,7 - 10,8 Watt.*
Efficiencyon Propulsion	*55%*	*68%*
Peowr Input Battery	*21 - 22 Watt*	*13 - 15 Watt.*
Mekanism	*Sinkronisasion software ESC.*	*Special system gearbox planetary.*
Manufactur	*Commercial off-the-shelf components*	*High-precision CNC turning*
Maintenance	*Dua poros pararel standart.*	*coaxial dan seal waterproof requires strict inspection*

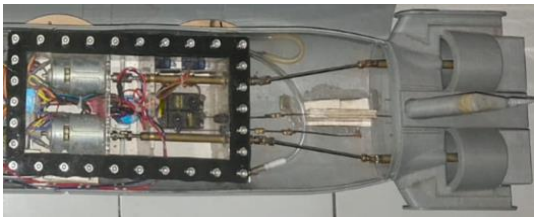


Figure 4.1 Integration of Dual Propulsion System Submarine Kamikze.

Table 4.1 compares the main performance and implementation characteristics of the Dual Propulsion system and the single-motor brushless coaxial contra-rotating configuration. At the same target speed of 5 knots, the coaxial contra-rotating system shows lower hydrodynamic drag, lower effective power requirements, and higher propulsion efficiency. Its propulsion efficiency reaches approximately 68%, compared with 55% for the Dual Propulsion configuration, while the required battery input power is approximately 13–15 W and 21–22 W, respectively.

Conversely, the Dual Motor DC 775 system exhibits a lower efficiency (55%) and higher battery power consumption (21–22 Watts) due to the greater mechanical losses of the brushed motors and the increased hydrodynamic drag of the wetted hull (4.5–5 N); however, it holds an absolute advantage in terms of mechanical practicality, fabrication simplicity using conventional oil seals, cost-effectiveness, and high field reliability owing to its operational redundancy system.

The results of this study are consistent with previous research showing that underwater propulsion performance is determined by a trade-off between propulsive efficiency, mechanical complexity, and system integration. (Lidtke et al., 2021) demonstrated that overall AUV propulsion efficiency is influenced not only by propeller performance but also by motor, drivetrain, and mechanical losses, which supports the lower 55% efficiency obtained by the Dual Motor DC 775 configuration compared with the brushless contra-rotating system. (Ou et al., 2023) reported that an optimized dual contra-rotating motor can achieve higher efficiency and improve internal space utilization; however, this

configuration requires a more specialized motor and coaxial shaft arrangement. Meanwhile, (Guntoro et al., 2021) showed that synchronization of two propeller motors can be effectively controlled by adjusting their rotational response. Therefore, the present Dual Motor DC 775 configuration represents a practical trade-off: although its propulsion efficiency is lower, its simpler parallel-shaft arrangement, commercially available components, and independent motor control provide advantages in fabrication, maintenance, and rotational synchronization.

CONCLUSIONS AND RECOMMENDATION

Conclusions

Based on the results of the planning, design, fabrication, testing, and measurement processes, the DC 775 motor provides a suitable balance between physical dimensions and power output within the limited hull space, with a specific power output of 24.38 W/kg. The use of a larger motor would require a larger component housing, which could increase the frontal area and consequently increase hydrodynamic drag.

At a speed of 5 knots, the dual propulsion system retains reserve thrust that can support maneuvering. The use of a 5.5 cm diameter four-blade propeller provides a configuration that is compatible with the torque characteristics of the DC 775 motor under the tested conditions, enabling the system to achieve the target speed while maintaining sufficient thrust capacity.

The integration of the New Rain 480A ESC and 120A cabling produced an estimated system efficiency of 55%. The low voltage drop measured in the electrical connection indicates limited power loss through the wiring, allowing sufficient electrical power to be delivered to the motor to overcome the hydrodynamic resistance at the target speed.

The dual propulsion configuration also demonstrated stable motor synchronization during testing. With appropriate RPM adjustment between the two motors, the prototype was able to achieve the target speed of 5 knots while maintaining a relatively straight and stable trajectory under the evaluated test conditions.

Recommendations

Based on this Kamikaze Submarine research, the author hopes that in the future, STTAL can continue and further develop this study. This development should not be limited to the propulsion system, but rather extended to all systems, including the hull design, control systems, and weapon systems. The recommendations from the author are as follows:

a. Integrating an automatic control system based on a PID Controller or an IMU (Inertial Measurement Unit) into the vehicle's flight controller. This functions to correct external disturbances (such as underwater currents or waves) in real-time, preventing the vehicle from veering off course.
b. Implementing a passive heat dissipation system (such as a heat sink integrated into the hull that makes direct contact with water / water-cooling) to maintain the optimal performance of the ESC and the DC 775 motor. Additionally, upgrading to higher-specification ESCs is recommended to maximize the performance of the DC 775 motor without triggering automatic cut-offs, as experienced with the current New Rain 480A ESC.
c. Conducting further research on the application of a hydrophobic coating on the component housings or the vehicle's hull to reduce the drag coefficient without altering the physical dimensions of the submarine.
d. Upgrading the battery capacity to determine the optimal ratio between the total vehicle weight, maximum operational range, and the vehicle's response time during final acceleration toward the target.

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