

Optimization of Electronic Control for a Monohull Leisure Boat Using Meteorological Data to Enhance Stability and Safety in Coastal Environments

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ABSTRACT

Indonesia's maritime geography offers significant potential for marine tourism but requires transportation systems capable of operating safely under variable coastal environmental conditions influenced by wind and wave variability. This study presents the design and evaluation of a compact monohull leisure boat integrated with an Electronic Remote Control (ERC) system to improve maneuverability and operational safety. The research applies an engineering design approach involving regression-based estimation of principal dimensions, digital hull modeling using Maxsurf, static stability evaluation through righting arm (GZ) analysis, and spatial optimization using a General Arrangement (GA) plan. Five alternative hull geometries were developed and analyzed to identify the most suitable configuration for marine tourism operations. The stability analysis indicates that all hull models exhibit positive righting arm values within the evaluated heel angle range, confirming adequate static stability under typical coastal conditions. Among the evaluated configurations, Model 4 demonstrates the most favorable stability characteristics. The integration of the ERC system further enhances vessel maneuverability and reliability during low-speed navigation and docking, supporting safer marine tourism transportation in coastal waters.

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1. INTRODUCTION

Indonesia is one of the world's largest maritime nations, consisting of 17.508 islands distributed across the equatorial region. The country extends longitudinally from Sabang to Merauke and has a total area of approximately 8 million km², of which nearly two-thirds are marine waters. Indonesia's coastline stretches over 99,000 km, with a total marine area of approximately 3.257 million km² [1]. These geographical characteristics indicate that Indonesia possesses substantial potential in marine and coastal tourism, supported by the diversity of its marine environments and island landscapes. Consequently, the development of marine tourism has become an important national agenda to enhance regional economic growth and optimize the utilization of maritime resources.

According to Law No. 10 of 2009 concerning Tourism, marine tourism, also referred to as water-based tourism, includes tourism and water sport activities supported by facilities, infrastructure, and related services that are commercially managed in marine, coastal, river, lake, and reservoir areas [2]. Furthermore, the Directorate General of Tourism defines marine tourism as tourism activities directly associated with

marine resources both above and below the sea surface, such as swimming, diving, snorkeling, and sailing. The development of marine tourism offers various benefits, including increased regional income, job creation, and support for environmental and cultural preservation [3].

At present, marine tourism transportation in Indonesia is predominantly served by conventional and traditional vessels operating between coastal areas and nearby islands. For example, traditional boats are commonly used to transport tourists to small island destinations such as Pulau Angso Duo in Pariaman [4]. While these vessels provide essential connectivity, their operation often presents limitations in terms of navigational safety, maneuverability, and operational reliability, particularly under varying sea and weather conditions. In addition to traditional vessels, cruise ships are also utilized for marine tourism; however, they require large international-standard port infrastructure and generally operate under fixed travel itineraries, which limit flexibility and reduce access to smaller island destinations [5].

Marine tourism activities in Indonesian waters are highly influenced by near-surface meteorological conditions, including wind variability, wave characteristics, and rapid weather changes commonly observed in coastal and inter-island regions. These environmental factors directly affect vessel motion, maneuverability, and operational safety, particularly for small-scale leisure boats. Consequently, the development of marine tourism transportation systems must consider not only technological and operational aspects, but also environmental conditions governed by meteorological and climatological variability. From this perspective, vessel design and control system integration play a critical role in supporting weather-sensitive marine operations within Indonesia's maritime environment [6][7].

These conditions indicate the need for technological innovation in marine tourism transportation, particularly in the context of vessel safety and operational control. The integration of modern ship design approaches and electronic control technologies offers potential solutions to improve navigational safety and maneuverability. In this regard, the application of an Electronic Remote Control (ERC) system enables electronically assisted vessel operation, allowing improved steering precision and reduced dependence on manual control. Such systems can contribute to minimizing human error and enhancing safety, especially during low-speed maneuvers and near-shore navigation [8].

Accordingly, this study presents the design and development of an electronic remote control-based monohull leisure boat intended to support safer marine tourism transportation in Indonesia. The study focuses on engineering-based vessel design, hydrodynamic considerations, system integration, and prototype evaluation to assess the feasibility and safety performance of the proposed ERC-based leisure boat.

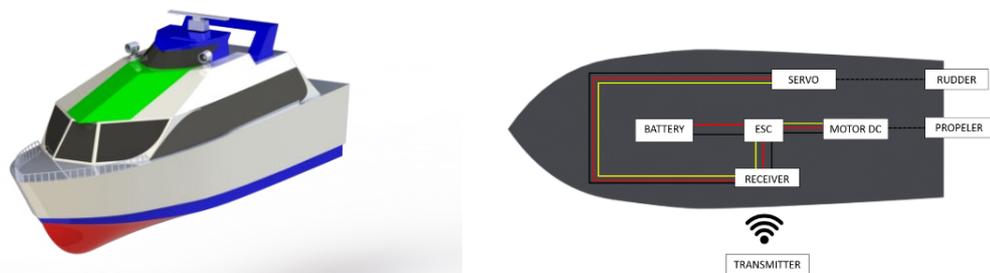


Fig. 1 Conceptual design and system overview of the electric remote control-based monohull leisure boat for marine tourism applications.

2. RESEARCH METHOD

This study employs an engineering design and prototype development methodology to develop a monohull leisure boat integrated with an Electronic Remote Control (ERC) system for marine tourism transportation. The research was conducted through a hull configuration selection, determination of the vessel's principal dimensions using a regression method based on reference data from comparable leisure boats, and hull analysis including hydrostatic and stability evaluation using Maxsurf Stability software. The subsequent stages involved control system integration, prototype fabrication, and overall performance evaluation of the proposed vessel system.

The hull configuration selection process was conducted to determine the most appropriate vessel type for marine tourism operations. Several alternative hull configurations were considered during this stage, including monohull, catamaran, and trimaran designs. The selection was carried out through a literature review examining the hydrodynamic characteristics and operational performance of each hull type. Based on this assessment, the monohull configuration was selected due to its ability to effectively cut through waves, making it suitable for operation in waters with small to moderate wave conditions and enabling stable

navigation on the water surface [9]. In addition, the single-hull configuration provides adequate cargo capacity and contributes to maintaining vessel balance and stability during inter-island tourism operations.

The principal dimensions of the vessel were determined using a regression-based approach derived from reference data of comparable leisure boats. A dataset consisting of several vessels with similar operational characteristics was compiled to establish proportional relationships among the main design parameters. Key parameters considered in the analysis include length overall (LoA), beam (B), depth (D), draft (T), and displacement. Linear regression analysis was applied to examine the relationship between vessel displacement and the principal dimensions, enabling the estimation of appropriate dimensional values for the proposed vessel. The resulting regression equations were then used to determine the preliminary principal dimensions of the monohull leisure boat design based on the average deadweight value as the primary design reference.

The hull design in this study was carried out using Maxsurf software, which was utilized to design and digitally model the geometric form of the vessel. The principal dimensions obtained from the previous stage, including length overall (LOA), beam (B), depth (D), and draft (T), were used as the primary parameters in the hull modeling process. These parameters served as the fundamental inputs for constructing the initial hull geometry within the software environment. The hull modeling process began with the development of the vessel's basic lines plan, consisting of buttock lines, waterlines, and stations, which define the three-dimensional geometric characteristics of the hull. Through this digital modeling approach, the hull form can be systematically developed and refined to represent the intended vessel configuration while maintaining consistency with the predefined principal dimensions.

The hull analysis in this study was conducted using Maxsurf Stability software to evaluate the vessel's stability characteristics based on the hull geometry model developed in the previous design stage using Maxsurf. The analysis process began by importing the hull geometry model along with the principal vessel parameters, including length overall (LOA), beam (B), depth (D), and draft (T), into the Maxsurf Stability environment. Load conditions were then defined to represent realistic operational scenarios, including vessel weight, load distribution, and the position of the vessel's center of gravity. In addition to internal loading conditions, environmental parameters derived from meteorological and oceanographic data were also considered to represent typical coastal operational environments, including wave height and wind speed commonly observed in Indonesian coastal waters. These environmental variables were used to simulate external disturbances that may influence vessel stability during operation.

The analysis was initiated with hydrostatic calculations to obtain key parameters such as displacement, waterplane area, and the center of buoyancy, which serve as fundamental indicators of the vessel's buoyancy characteristics. This stage was followed by a stability analysis to determine important stability parameters, including the metacentric height (GM), the static stability curve or righting arm curve (GZ curve), and the vessel's heel response under various loading conditions. The results of this analysis were used to evaluate the overall stability performance of the vessel and to ensure that the designed hull geometry satisfies the required stability criteria.

In addition to the stability analysis, the Savitsky method was applied as a supplementary approach to estimate resistance characteristics under planing conditions. This method provides an analytical estimation of hydrodynamic resistance and performance parameters for planing hulls, which are commonly used in high-speed leisure boat designs. In this study, the Savitsky method served as a supporting indicator to assess the hydrodynamic feasibility of the proposed vessel design rather than as a detailed performance optimization tool [10][11]. Through this numerical and analytical approach, the evaluation of vessel stability and hydrodynamic characteristics can be conducted systematically prior to physical fabrication or direct experimental testing.

The ERC system was implemented by utilizing electronic communication between the transmitter (Tx) and receiver (Rx) devices. These components were integrated to enable control of propulsion speed and steering direction during the navigation process. The integration process considered compatibility among electronic components, signal communication stability, and control system responsiveness to ensure proper operational performance during testing.

The fabrication process involved constructing the hull structure according to the designed geometry, followed by the installation of the propulsion system, steering mechanism, and electronic control components associated with the ERC system. Particular attention was given to the structural integrity of the hull and the placement of internal components to ensure proper weight distribution and balance. The resulting prototype was then used as a physical model for subsequent experimental testing.

Performance evaluation of the prototype was conducted through a series of functional and operational tests. These tests included buoyancy and balance tests to verify the floating condition and weight distribution of the vessel, maneuverability tests to evaluate steering response and directional control capability, and speed tests to observe the performance of the propulsion system under operational conditions.

3. RESULT AND DISCUSSION

The results of this study focus on several key stages of the vessel development process, including the determination of the principal dimensions of the vessel, the hull design and modeling process, the analysis of hull stability characteristics, and the integration of the Electronic Remote Control (ERC) system. These results illustrate how the proposed design methodology was translated into a functional vessel configuration suitable for marine tourism transportation. The discussion further examines the relationship between hull geometry, weight distribution, and stability performance, as well as the role of the ERC-based control system in supporting maneuverability and operational safety. These aspects are essential considerations in ensuring the feasibility, safety, and reliability of small-scale leisure boats operating in coastal tourism environments.

3.1 Determination of Principal Dimensions

A monohull configuration was selected due to its structural simplicity, predictable hydrodynamic behavior, and suitability for leisure boat operations in low to moderate wave environments. The principal dimensions of the vessel were determined using a linear regression approach based on reference data obtained from comparable leisure boats, providing an initial framework for hull geometry development. In this stage, a dataset of existing leisure boats with similar operational characteristics was compiled to serve as reference data for the regression analysis. The dataset includes several principal parameters commonly used in preliminary ship design, such as vessel length, beam, draft, and displacement. These reference vessel data are summarized in Table 1.

Table 1. Principal Dimensions of Reference Vessels Used for Regression Analysis

No.	Vessel Name	DWT	Length (LoA)	Beam (B)	Depth (D)	Draft (T)
1	Javanese Boat		21	5	2.1	0.6
2	Sport Yacht 170 FT	495	52.4	9.5	3	2.44
3	2009 Palmer Johnson	223	37.9	7.44	2.15	1.98
4	Sport Yacht 120 FT	223	37.9	7.6	2.15	2.1

The collected data were subsequently analyzed using a linear regression method to identify the relationships between displacement and the principal dimensions of the vessels. This approach enables the estimation of appropriate dimensional proportions for the proposed leisure boat design based on empirical trends observed in existing vessels. The resulting regression relationships derived from the reference dataset are illustrated in Fig. 2.

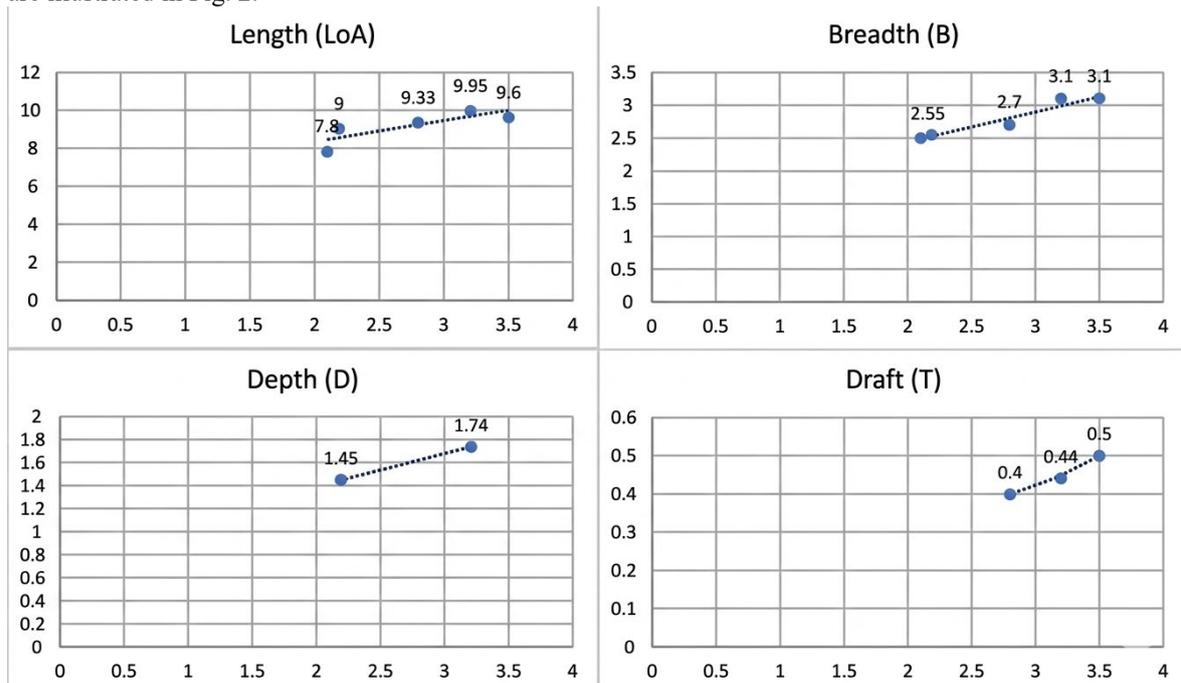


Fig. 2 Linear regression relationships between vessel displacement and principal dimensions (LoA, Beam, Depth, and Draft) derived from reference vessel data.

Based on the regression equations obtained from the analysis, the principal dimensions of the proposed vessel were determined using the average deadweight value as the primary design reference. The resulting regression equations were applied to estimate the appropriate dimensions of the vessel to be developed in this study. The calculated principal dimensions derived from this process are summarized in Table 2 and subsequently serve as the fundamental basis for the hull modeling process and the stability analysis conducted in the following stages of the study.

Table 2. Principal design parameters of the proposed vessel obtained from regression analysis.

Principal Vessel Parameters	Value (cm)
Length (LoA)	60
Beam (B)	22
Depth (D)	14
Draft (T)	5,5

3.2 Hull Geometry Design and Modeling

The hull geometry of the proposed leisure boat was developed using Maxsurf software, which is widely used in naval architecture for digital hull modeling and hydrostatic evaluation. The use of Maxsurf in this study enables the visualization and development of the vessel's three-dimensional hull form based on the principal dimensions determined in the previous stage. Through this software, the hull geometry can be systematically modeled and adjusted to achieve an appropriate balance between hydrodynamic performance, stability characteristics, and structural feasibility [12].

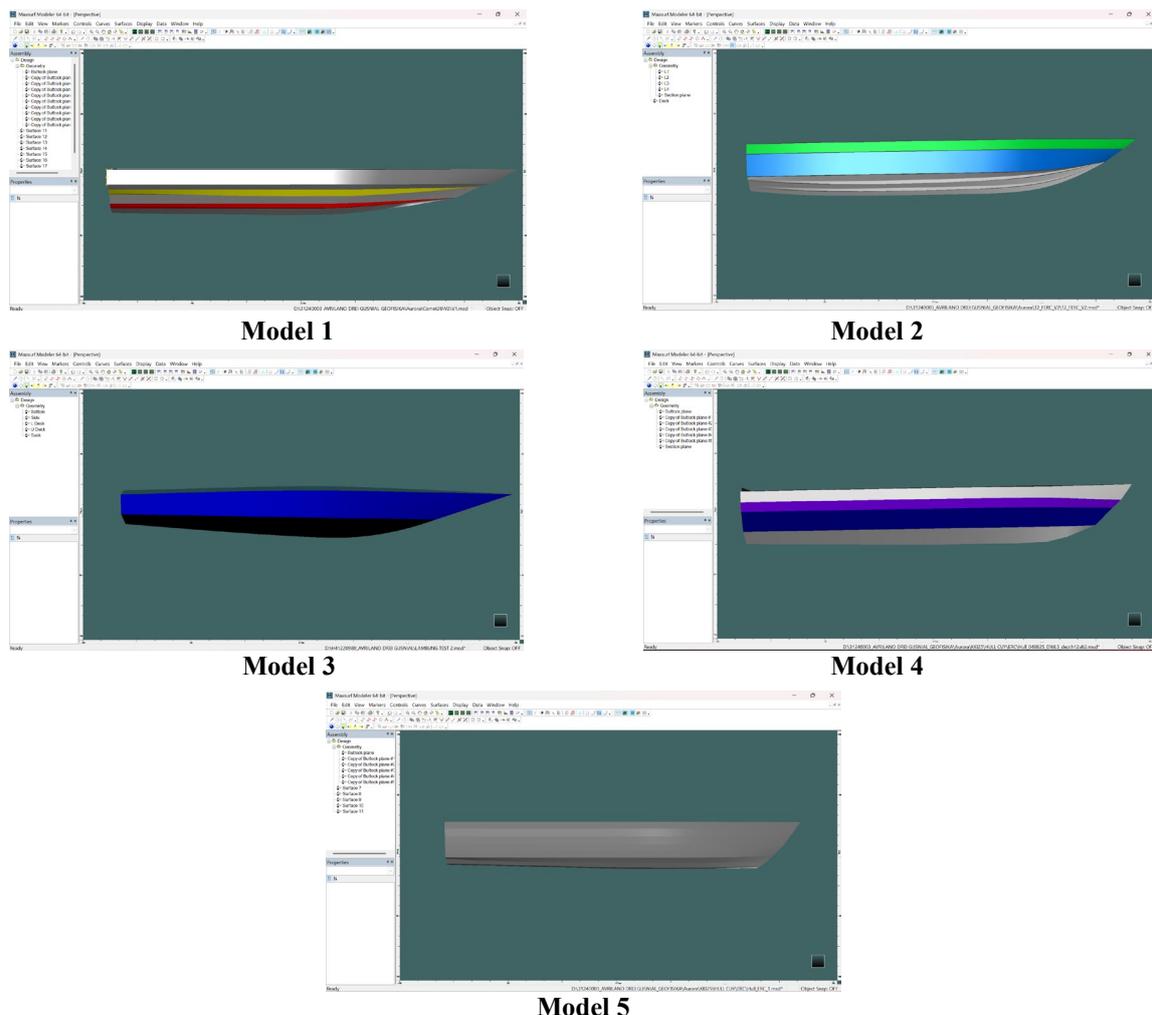


Fig. 3 Variations of hull geometry models developed using Maxsurf

The hull modeling process was initiated by defining the main geometric parameters obtained from the regression-based principal dimension estimation, including the length overall (LOA), beam (B), depth (D), and draft (T). These parameters served as the fundamental constraints for constructing the digital hull surface. The modeling procedure involved the development of the lines plan consisting of stations, waterlines, and buttock lines, which together form the three-dimensional geometry of the hull. This digital modeling process allows detailed control of the hull curvature and overall shape, which are important for determining the vessel's hydrodynamic behavior and stability performance.

Five different hull models were developed during the design stage to evaluate alternative hull characteristics and to identify the most suitable hull configuration for the proposed vessel. Each hull variation was generated by modifying several geometric parameters of the hull form while maintaining the same principal dimensions. The variations primarily focused on differences in hull curvature and sectional shapes, which may influence hydrodynamic resistance, buoyancy distribution, and overall vessel stability.

The five hull configurations were subsequently analyzed and compared to identify the most appropriate hull form for the proposed leisure boat design. The comparison considered aspects such as geometric feasibility, hydrostatic characteristics, and suitability for small-scale marine tourism operations in coastal waters. The modeled hull geometries developed using Maxsurf are presented in Fig. 3, which illustrates the five design variations evaluated in this study.

3.3 Hull Stability Analysis

The static stability performance of the proposed monohull leisure boat was evaluated through numerical analysis to assess its ability to maintain equilibrium under external disturbances. The assessment was conducted by analyzing the righting arm (GZ) values at various heel angles derived from the finalized hull geometry [13]. GZ values were calculated for five hull model configurations to examine their stability characteristics under transverse inclinations. The resulting numerical values are summarized in Table 1, while the corresponding GZ curves are illustrated in Fig. 4, which depict the relationship between heel angle and righting moment and provide a clear visualization of the static stability behavior of each hull configuration.

Table 3. Static Stability (GZ) Values at Various Heel Angles

Degree	Model 1	Model 2	Model 3	Model 4	Model 5
0	0	0	0	0	0
10	0.91	0.95	1.5	1.55	1.07
20	1.53	1.64	2.27	2.39	1.75
30	1.86	2.17	2.74	2.91	2.26
40	2.16	2.65	3.09	3.28	2.76
50	2.51	2.95	3.43	3.55	3.19
60	2.60	3.01	3.49	3.45	3.31
70	2.38	2.81	3.17	2.93	3.10
80	1.87	2.41	2.51	2.15	2.58
90	1.19	1.84	1.67	1.21	1.85
100	0.40	1.15	0.72	0.19	1.01
110	-0.41	0.40	-0.27	-0.84	0.11
120	-1.21	-0.37	-1.23	-1.81	-0.79
130	-1.93	-1.10	-2.11	-2.66	-1.64
140	-2.58	-1.75	-2.86	-3.29	-2.37
150	-3.02	-2.24	-3.39	-3.73	-2.89
160	-3.09	-2.42	-3.51	-3.79	-3.03
170	-2.19	-1.82	-2.62	-2.82	-2.27
180	0	0	0	0	0

The numerical results presented in Table 3 indicate that all evaluated hull models exhibit positive righting arm (GZ) values over the assessed heel angle range, confirming initial static stability of the proposed monohull configuration. For all models, GZ values increase progressively with heel angle from 0° up to approximately 50°–60°, where the maximum righting arm is observed [14]. The range of positive stability for all evaluated models extends approximately up to heel angles close to 100°, where the righting arm

approaches zero. Beyond this point, negative GZ values indicate the loss of restoring capability and the onset of capsizing tendency. This behavior reflects the vessel's increasing restoring moment as transverse inclination develops, which is a desirable characteristic for small leisure craft operating in coastal waters. Beyond the angle corresponding to maximum GZ, a gradual reduction in righting arm magnitude is observed, indicating the onset of decreasing restoring capability at higher heel angles. Among the evaluated configurations, Models 3 and 4 consistently demonstrate higher peak GZ values compared to the other models, suggesting superior transverse stability performance. These numerical trends provide a quantitative basis for assessing hull stability prior to visual interpretation through stability curves and support the suitability of the selected hull geometry for safe marine tourism operations under typical coastal environmental conditions.

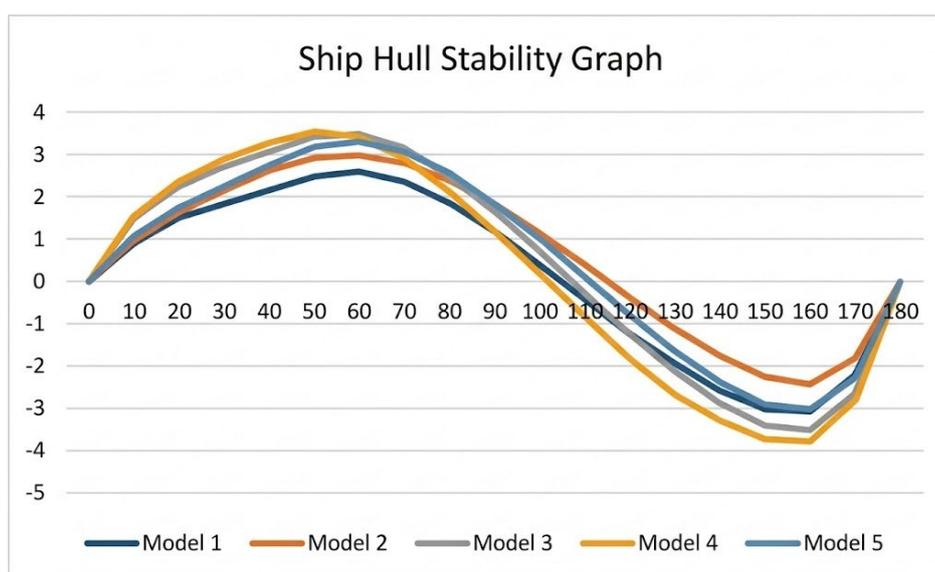


Fig. 4 Static stability curves of the monohull leisure boat

As shown in Fig. 4, all evaluated hull models exhibit a positive righting arm over a wide range of heel angles, indicating that the vessel is capable of returning to its upright position after experiencing heeling forces caused by wave action or maneuvering. The stability curves generally increase to a maximum righting moment at moderate heel angles before gradually decreasing toward larger angles. This trend reflects a stable equilibrium condition and sufficient initial stability, which are essential requirements for leisure boats operating in marine tourism environments [15].

Based on the stability curves obtained from the Maxsurf Stability analysis, Model 4 demonstrates the most favorable stability performance among the evaluated configurations. This is indicated by the highest maximum GZ value, reaching approximately 3.5-3.7 at a heel angle of around 50°-60°. A higher GZ value represents a stronger restoring moment, meaning that the vessel has a greater ability to return to its upright position when subjected to external heeling forces. In addition, the stability curve of Model 4 shows a relatively smooth and consistent variation, indicating a stable and predictable restoring response during increasing heel conditions.

From a meteorological perspective, the selection of Model 4 becomes particularly relevant because marine environmental conditions are strongly influenced by atmospheric factors such as wind speed, wave height, and air pressure variations. Strong winds, typically measured using anemometers in meteorological observations, can generate lateral forces acting on the hull and superstructure, resulting in vessel heel. Furthermore, sea waves generated through wind-sea interactions can induce rolling motions that disturb vessel equilibrium. Under such conditions, vessels require sufficient restoring capability to counteract these disturbances and maintain operational stability.

The stability curve analysis also shows that Model 4 maintains relatively large positive GZ values up to heel angles approaching 100°, indicating that the vessel still possesses the ability to generate restoring moments even under significant inclination. This characteristic is particularly important when the vessel operates under unstable weather conditions, such as strong winds or elevated wave heights that are frequently associated with atmospheric dynamics in coastal environments. The higher maximum stability value of Model 4 suggests that this configuration provides the best resistance to environmental disturbances, thereby reducing the likelihood of stability loss or capsizing compared to the other evaluated hull models.

Based on these considerations, Model 4 was selected as the final hull configuration for the proposed monohull leisure boat design. Its superior restoring capability and wider stability margin indicate that the hull geometry is better suited to withstand environmental disturbances influenced by meteorological variability, ensuring safer and more reliable operation for marine tourism activities in coastal waters.

3.4 Electronic Remote Control System Integration

An Electronic Remote Control (ERC) system was integrated as the primary vessel control mechanism to enhance maneuverability and navigational safety. The ERC architecture consists of a remote transmitter, electronic speed controller, steering servo mechanism, and onboard electronic components that enable responsive control of vessel speed and steering. The application of ERC technology aims to reduce dependence on continuous manual control and mitigate potential human error, particularly during low-speed maneuvers, docking operations, and navigation in confined or near-shore environments. The architecture of the ERC system used in this study is illustrated in Fig. 5.

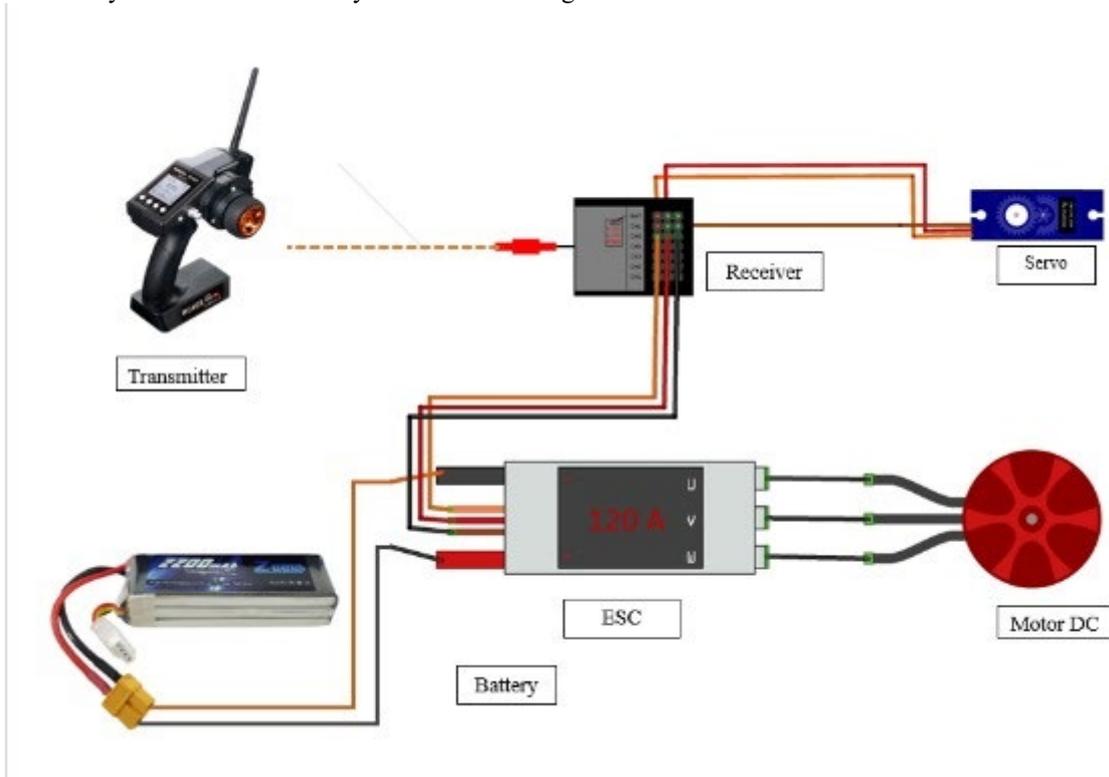


Fig. 5 Architecture of the Electronic Remote Control (ERC) system used for vessel propulsion and steering control.

Table 4. Electronic Component Specifications.

Name	Specification
Battery	2200 mAh 4 cell 6 s
Electronic Speed Controller	120 a
Motor Brushless	2200 Kv 3000 W
Servo	20 Kg
Transmitter	2.4 GHz
Receiver	2.4 GHz

The ERC system operates using a 2.4 GHz radio communication protocol employing Frequency Hopping Spread Spectrum (FHSS), which enhances signal stability and reduces the risk of interference

adaptive platform for marine tourism transportation. The proposed design framework emphasizes operational safety and functional efficiency under environmental conditions influenced by meteorological variability commonly observed in Indonesian coastal and inter-island waters. The General Arrangement Plan confirms a rational distribution of functional spaces and control components, while numerical stability analysis based on righting arm characteristics indicates that the hull configuration provides sufficient static stability within the evaluated heel angle range. The incorporation of an ERC-based control system enhances maneuverability and operational reliability during low-speed navigation and docking, which are critical under variable wind and wave conditions. Beyond its immediate application, the developed vessel concept offers a scalable foundation for safety-oriented and environmentally adaptive marine transportation, supporting the long-term development of sustainable marine tourism in Indonesia.

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