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Concept Design of an Airboat for Water Hyacinth Vegetation Area Transportation

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Abstract. Water hyacinth (*Eichhornia crassipes*) is an invasive aquatic plant that disrupts ecosystems and obstructs navigation in shallow waters. Conventional vessels with submerged propellers are ineffective in such environments, highlighting the need for specialized designs. This study developed a conceptual design of an airboat capable of operating efficiently in areas covered by water hyacinths. The design adopted the Sister Ship Design method combined with engineering judgment to ensure efficiency in cost, time, and performance reliability. A flat-bottomed hull with hard chines was selected to enhance maneuverability in shallow and vegetation-dense waters, while hydrodynamic analysis emphasized the planing hull principle to minimize drag at higher speeds. The results of the preliminary stability analysis showed that the transverse metacentric height (GMt) reached 0.17 m, exceeding the minimum requirement of the International Maritime Organization (IMO) and confirming adequate safety and operability. Overall, the design proved suitable for transportation and operational activities in water areas dominated by water hyacinth vegetation and demonstrates the potential of airboats as sustainable solutions for shallow-water environments.

keywords: airboat, water hyacinth, transportation, concept design.

Introduction

Water hyacinth (*Eichhornia crassipes*) is an aquatic plant known for its invasive nature and rapid growth rate, which if not controlled can disrupt the balance of aquatic ecosystems. Several studies have shown that these plants can cover more than 60% of the surface of water bodies such as rivers and lakes and contribute to a decrease in dissolved oxygen levels that are important for aquatic life. In addition, the presence of water hyacinth in large numbers of results in a decrease in species diversity in the aquatic habitat. The presence of this plant also has a negative impact on various sectors such as irrigation systems, water traffic, and tourism, resulting in significant economic losses in the affected areas (Ajithkumar et al., 2021; El-Chaghaby et al., 2022; Harun et al., 2021; Maulidyna et al., 2021; Sotolu, 2012). The management of excess water hyacinth can be done through various approaches, including mechanical, biological, and utilization of these plants for industrial needs (Malik, 2007; Yigermal & Assefa, 2019). Mechanical approaches are carried out by manual uprooting or the use of heavy equipment to reduce the population. Biologically, control can be done by utilizing natural enemies such as the *Neochetina eichhorniae* beetle which has been proven to effectively suppress its growth (Prasetyo, 2024). In addition, water hyacinth also has the potential to be used as compost, biogas energy source, animal feed, and handicraft material,

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thus providing economic benefits while reducing its ecological impact (Gopalakrishnan et al., 2000).

Although various modes of water transportation have progressed, there are still operational constraints in water areas covered by water hyacinth growth, because conventional ships with submerged propeller propulsion systems cannot function optimally in these environments. Brewer (1997) suggests that the utilization of vessels with special technology such as airboats is the right approach to reach shallow water areas that cannot be traversed by ordinary ships (Brewer, 1997). An airboat is a water transportation unit driven by a large air fan mounted on the deck, so it does not rely on an underwater propulsion system. This design allows for high mobility in difficult water terrains, such as muddy, shallow and aquatic vegetation-infested areas, without the risk of mechanical interference due to snagging. Research conducted by Dale et al. (2002) showed that airboats perform efficiently in cleaning aquatic plant-covered water areas, with lower fuel consumption than outboard vessels, which are prone to snagging by water hyacinth roots (Dale et al., 2002). In addition, a study by Dissanayake and Gunarathna (2020) also showed that airboats proved effective in various operations, including flood management, shallow water navigation, and rescue activities (Dissanayake & Gunarathna, 2020).

Many design method have been proposed to study and impoved the methodology design of ship. Several common approaches are used in ship design methods that include various strategies according to the technical, economic, and operational needs of the ship. First, Parent Ship or Sister Ship Design is a method that adapts the design of an existing ship that is proven to function well. This approach is efficient to reduce cost and design time and minimize the risk of failure (Papanikolaou, 2014a). Second, Optimization-Based Design utilizes optimization algorithms, such as genetic algorithm or multi-objective optimization, to derive the best performing design based on specific criteria such as fuel consumption, speed, or payload efficiency (Ang et al., 2019). Third, Rule-Based Design is an approach that follows technical guidelines and regulations set by international classification societies such as IMO, IACS, and ABS, and is standard in ensuring the safety and seaworthiness of ships (Rawson & Tupper, 2001). Fourth, Simulation-Driven Design relies on numerical analysis techniques such as Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) to iteratively evaluate the performance and strength of ship structures prior to production (Andrews & Erikstad, 2015; Ma & Mahfuz, 2012). The ship design process is traditionally divided into several stages, i.e. conceptual (preliminary) design, basic (class) design, and detailed design. Each stage has its own purpose and scope, which is generally carried out sequentially, but is often depicted in a spiral to reflect the iterative nature of the process (Perez-Martinez & Perez Fernandez, 2023).

This research will discuss the design of airboats used for shallow waters with water hyacinth vegetation. The airboat design method used in this research uses the Sister Ship Design method. This research contributes to a deeper understanding of the sister ship design method which is crucial in the design process of safer ships. The structure of this paper is as follows: Section 2 literature review, introduces the sister ship design method and airboat. In section 3, the design method process, and section 4, the discussion. Conclusions are summarized in Section 5.

2. Literature Review

Airboats are characterized by a flat-bottomed hull and powered by a large air propeller, typically driven by an automotive or aircraft engine mounted at the stern. This propulsion system generates aerodynamic thrust like that of an aircraft, offering a fundamental advantage in that no components are submerged below the waterline. As a result, airboats minimize the risk of damage from underwater obstacles such as submerged logs, rocks, or aquatic vegetation. This feature makes them highly adaptable for shallow waters, marshlands, and flood-prone areas where conventional vessels face significant limitations. From a design perspective, the flat-bottomed hull provides lateral stability at low speeds but reduces comfort and seaworthiness in wavy conditions. Consequently, the airboat design reflects a deliberate trade-off between manoeuvrability in extreme environments and performance in open waters. The design of airboat can be seen in Figure 1.

With technological advancements, the functional role of airboats has expanded beyond traditional transportation. They are widely deployed in shallow-water security patrols, flood-related search and rescue operations, as well as aquatic research and resource management activities. Their ability to operate in areas inaccessible to conventional vessels enhances their operational value. From an ecological standpoint, airboats have also been integrated into aquatic weed management strategies, particularly against invasive species such as water hyacinth (*Eichhornia crassipes*). This plant forms thick mats that obstruct navigation, reduce dissolved oxygen levels, and disrupt aquatic ecosystems. The capacity of airboats to glide over dense vegetation enables the application of both mechanical and chemical control methods—such as large-scale cutting or herbicide spraying—in areas previously inaccessible. Hence, airboats are not only transportation devices but also strategic instruments for ecosystem management.

Figure 1 Airboat series (gtoaorboats.com)

In parallel, the concept of Sister Ship Design (SSD) highlights a different yet complementary dimension of naval architecture. SSD is an analogy-based design methodology that builds on the operationally proven data of a parent or sister vessel to inform the development of a new design. The main advantages of this approach include cost efficiency, accelerated design processes, and reduced uncertainty in performance validation (DAVID G.M. WATSON, 1998; Papanikolaou, 2014). SSD is particularly valuable during the preliminary design stage, where principal dimensions, general arrangement, and propulsion systems can be derived from a reference vessel and then adapted to new requirements.

Moreover, SSD enables the direct utilization of existing experimental datasets, such as towing tank tests or numerical simulations conducted for the parent ship. This contributes to higher confidence in the validation of new designs while opening opportunities for data-driven innovation, where modifications can be systematically guided by empirical evidence rather than trial-and-error. Accordingly, SSD not only accelerates design and production but also supports the sustainability of the shipbuilding industry by capitalizing on accumulated knowledge in a structured manner.

Taken together, both the case of airboats and the practice of Sister Ship Design exemplify how innovations in maritime technology can be strategically directed toward broader objectives. Airboats demonstrate adaptability in extreme operational environments and relevance to environmental management, while SSD illustrates efficiency and sustainability in engineering processes. These perspectives collectively underscore the importance of integrating technology, environmental considerations, and design efficiency as fundamental pillars in the advancement of modern water transportation systems.

3. Method

The conceptual stage of ship design is a critical phase, as the initial decisions made at this stage largely determine the overall direction of the design development. At this point, fundamental parameters such as ship type selection, principal dimensions, general arrangement, and propulsion system must be accurately defined, as they have a direct impact on cost, performance, and operational feasibility. However, the availability of complete experimental data or numerical simulations is often limited in this early stage, making engineering judgment a central element in the decision-making process (Andrews, 2021). In the context of ship design, engineering judgment refers to the evaluation and selection of design parameters based on professional experience, historical references, and technical intuition. Its application includes estimating principal dimensions according to payload capacity, selecting hull forms with proven efficiency, determining preliminary power and speed requirements without extensive simulations, and analyzing trade-offs between stability, spatial requirements, and operational performance.

This study used the Sister Ship Design (SSD) method, an analogy-based approach in which a reference or parent vessel serves as the primary basis for the new design (Adnyani et al., 2019). The principal dimensions of the parent ship are used as the foundation for developing a new design of similar type, while allowing for modifications to accommodate specific needs. It is important to note that SSD cannot be applied directly without verification; instead, it requires thorough assessments of hull form similarity, dimensional proportions, stability characteristics, and hydrodynamic performance. Thus, the method combines the efficiency of utilizing proven designs with the flexibility of adaptation to ensure relevance to new requirements and regulatory frameworks.

In addition to SSD, this study also incorporated hydrodynamic considerations specific to airboats, which operate on the principle of a planing hull. Planing occurs when a vessel reaches sufficiently high speeds such that hydrodynamic lift becomes more dominant than buoyancy. Under these conditions, flat-bottomed or V-shaped hulls enable the vessel to skim over the water surface with reduced resistance. The hydrodynamic transition can be described as follows: at low speeds, the vessel operates in displacement mode supported by buoyancy; at intermediate speeds, it enters a semi-displacement mode where lift is partially generated by hull shape; and at high speeds, the vessel fully transitions into planing mode, with hydrodynamic lift carrying most of the vessel's weight. Key factors such as optimal trim angle (3–5°), chine geometry, and lift coefficient significantly influence planing efficiency and stability.

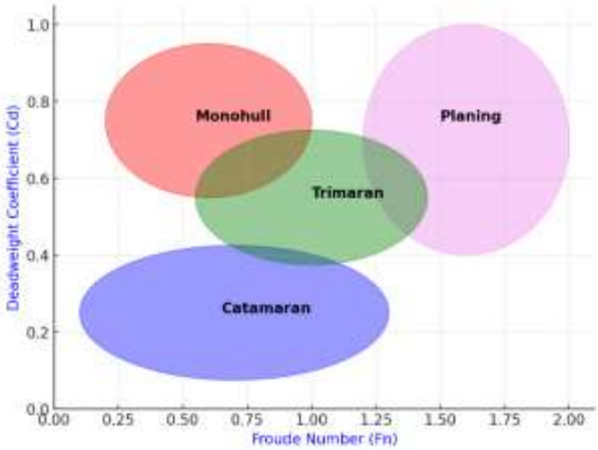

Figure 2 Cd and Fn Number (dmsonline.us)

The relationship between the Froude Number (Fn) and the Deadweight Coefficient (Cd) provides a fundamental framework for understanding the performance of different hull types, including monohulls, catamarans, trimarans, and planing hulls. In Figure 2, can be seen the relations of Cd and Fn. The Froude Number is a dimensionless parameter defined as the equation bellow

$$F_n = \frac{V}{gL} \quad (1)$$

Where:
V is vessel speed (m/s),
g is gravitational acceleration (m/s^2), and
L is the vessel's characteristic length (m)

Monohull displacement vessels typically operate at low Fn with high Cd, making them suitable for large-capacity vessels with low to moderate speeds. Catamarans and trimarans generally occupy an intermediate Fn range with moderate Cd, offering advantages in lateral stability and speed efficiency. By contrast, planing hulls operate at high Fn values (≥ 1.2) with moderate Cd, demonstrating their ability to generate significant hydrodynamic lift that allows high-speed surface skimming.

These characteristics are particularly relevant for airboats, which utilize flat-bottom or shallow-V hulls in combination with air-propeller propulsion to minimize underwater drag, enabling operations in shallow waters, marshlands, and dense aquatic vegetation such as *Eichhornia crassipes* (water hyacinth). The airboat design leverages the hydrodynamic transition from displacement to planing mode, where most of the vessel's weight is supported by hydrodynamic lift rather than buoyancy alone. The decision to classify the airboat as a planing hull reflects the application of engineering judgment in the conceptual design stage, as this choice balances limitations in payload capacity with the essential requirements of speed, maneuverability, and operational flexibility in extreme environments. Accordingly, the Fn–Cd framework not only illustrates performance differences among hull types but also provides strong technical justification for employing a planing hull configuration in airboat design rather than displacement monohulls or multihulls.

In the ship design concept, checking the stability of the vessel is a crucial step to ensure its safety and operational reliability under various loading and environmental conditions. Stability assessment at this stage serves as an early indicator of whether the proposed design can meet the minimum safety standards and regulatory requirements. At the concept design stage, a preliminary stability analysis is generally carried out using empirical or simplified analytical approaches, which allow designers to quickly evaluate the vessel's response to heeling moments, weight distribution, and external forces such as wind and waves. This early evaluation does not provide detailed performance outcomes, but it plays a significant role in identifying potential design flaws and guiding subsequent refinements in the hull form, arrangement of weights, and placement of superstructures. By conducting this initial stability check, naval architects can reduce the risk of costly design revisions in later stages and ensure that the vessel concept is feasible before advancing to more sophisticated computational analyses or model testing. In this study, the preliminary stability analysis use the equation 1-8.

$$GM_T = KM_T - KG \quad (1)$$

$$\frac{KG}{D} = 0.63 \ to \ 0.70 \quad (2)$$

$$KM_T = KB + BM_T \quad (3)$$

$$\frac{KB}{T} = 0.90 - 0.36\,CM \quad (4)$$

$$CM = 0.977 + 0.085\,(CB - 0.60) \quad (5)$$

$$BM_T = \frac{I_T}{V} \quad (6)$$

$$C_I = \frac{I_T}{LB^3} \quad (7)$$

$$C_{WP} = \frac{(1+2\,CB)}{3} \quad (8)$$

Where:

GM_T Transversal Metacentric Height; KM_T Transversal Keel to Metacentric Height; KG Keel to Gravity Height.

D is ship depth

KB Keel to Bouyancy Height; BM_T Transversal Centre of Buoyancy to the Metacentre

T is ship draft; CM Midship Area Coefficient

CB Coefficient Block

I_T Moment of Inertia; V displaced volume' (L x B x T) (where L is the length, B is the beam, and T is the draught)

C_I Moment of Inertia coefficient; C1 = 0.1216 C_{WP} – 0.0410.

By integrating the Sister Ship Design method with engineering judgment, this study aims to produce an airboat design that is not only efficient in terms of time and cost but also reliable in performance. Furthermore, this combination enables validation grounded in historical experience while simultaneously allowing innovative adaptation to specific operational requirements, thereby resulting in a more comprehensive and sustainable design.

4. Results and Discussion

In this study using the parent design method, where the ship data that will be the ship's sister has the following main sizes, the main dimensions can be seen in Table 1.

Table 1 Airboat Main Dimensions

Item	Value
Length Overall (LoA)	6.09 m
Beam (B)	2.59 m
Height of Midship (H)	0.37 m
Ship Draft (T)	0.15 m
Speeds (Knots)	25 Knots

The initial stage in the ship design process is the reconfiguration of the hull form and the arrangement of equipment or commonly referred to as the general plan. This step is crucial to ensure that the reference vessel used is appropriate and can serve as a reliable basis for subsequent design stages. In practice, this redesign phase often requires considerable time, particularly when the available data is incomplete or limited. Nevertheless, design theory provides an approach known as engineering judgment design. This method emphasizes the role of the designer’s expertise in evaluating trade-offs and making informed decisions throughout the design process. By drawing upon professional experience, prior knowledge, and existing information, engineers can formulate solutions that are both effective and feasible. Furthermore, engineering judgment allows designers to avoid repeating past errors by reflecting on historical design failures and their implications. In the field of naval architecture, such judgment is indispensable for generating reliable, efficient, and innovative ship designs.

The conceptual stage of ship design constitutes a pivotal phase in shaping the vessel’s overall characteristics, particularly through the definition of hull geometry. The hull is the dominant structural element that determines hydrodynamic performance, stability, and operational capability. As illustrated in Figure 3, the airboat hull is developed using the parent ship design method, which adapts proven geometries to new design requirements. This type of hull is characterized by a relatively shallow draft and limited wetted surface area, thereby reducing hydrodynamic resistance under calm water conditions. However, resistance tends to increase significantly when the hull is exposed to waves, as the area in contact with the water surface expands. The airboat hull, with its flat-bottom configuration, provides superior buoyancy and facilitates manoeuvrability in shallow waters, while also minimizing drag and the risk of hull abrasion. The bottom profile is typically flat or nearly flat and, in some designs, slight chines are incorporated along the hull sides to enhance stability without markedly increasing draft. Moreover, the broader flat-bottom form is particularly advantageous in aquatic environments where vegetation frequently covers the water surface, as it reduces entanglement and improves operability.

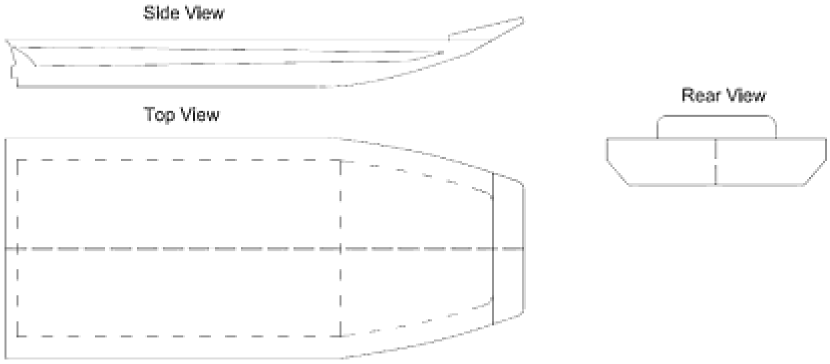

Figure 3 The Hull Design

According to the regulations established by the *International Maritime Organization (IMO)* in the *2008 Intact Stability Code*, the initial metacentric height (GM_0) shall not be less than 0.15 m for all loading conditions (International Maritime Organization, 2008). This requirement serves as an international benchmark to ensure that vessels possess sufficient initial stability to withstand external disturbances at small heel angles. The calculation results indicate that the transverse metacentric height (GMt) of the airboat is 0.17 m, which exceeds the minimum threshold, the value of stability calculation can be seen in Table 2. Consequently, it can be concluded that the airboat hull design complies with the IMO requirement and does not fall into the category of *tender* vessels, which are characterized by excessively low stability and a tendency to heel easily under the influence of wind or waves.

Table 2 Stability Calculations

No	Parameter	Value
1	Froude Number (Fn)	1.67
2	Coefficient Block (CB)	0.60
3	Water Plane Area Cofficient (C_{WP})	0.73
4	Moment of Inertia coefficient (C_1)	0.05 m^4
5	Moment of Inertia (I_T)	0.76 m^4
6	Transversal Centre of Buoyancy to the Metacentre (BM_T)	0.32 m
7	Midship Area Coefficient (C_M)	0.98
8	Keel to Bouyancy Height (KB)	0.08 m
9	Transversal Keel to Metacentric Height (KM_T)	0.40 m
10	Keel to Gravity Height (KG)	0.23 m
11	Transversal Metacentric Height (GM_T)	0.17 m

According to the International Maritime Organization (IMO) Intact Stability Code (2008), the minimum transverse metacentric height (GM_0) required for small vessels shall not be less than 0.15 m in all loading conditions. This standard serves as a global reference to ensure that ships have adequate initial stability to resist heeling moments due to environmental or operational forces such as wind, passenger movement, or uneven load distribution. In this study, the preliminary stability analysis was carried out for three different loading conditions (load cases), there are:

- Loadcase 1 – Lightship condition: the vessel is empty without cargo or passengers, representing the minimum displacement condition.
- Loadcase 2 – Partial load condition: the vessel operates with 50% of the maximum payload, simulating typical operational conditions.
- Loadcase 3 – Full load condition: the vessel is fully loaded with passengers, cargo, and fuel, representing the maximum displacement condition.

Table 3 Results of preliminary stability analysis in three loading conditions

No	Loadcase	Displacement (m^3)	KG (m)	KMt (m)	GMt (m)	Stability Criteria (IMO ≥ 0.15 m)	Status
1	Lightship	0.72	0.22	0.40	**0.18**	≥ 0.15 m	**Pass**
2	Partial Load	0.83	0.23	0.40	**0.17**	≥ 0.15 m	**Pass**
3	Full Load	0.96	0.24	0.39	**0.15**	≥ 0.15 m	**Pass**

The results show in Table 3 that in all loading variations, the GMt value remains equal to or greater than 0.15 m, which complies with IMO stability requirements. The lowest GMt value of 0.15 m occurs under the full-load condition, where the center of gravity rises due to the added payload. However, even in this extreme case, the vessel maintains sufficient righting ability to recover from small heel angles. In contrast, under lightship and partial load conditions, the GMt values reach 0.18 m and 0.17 m respectively, indicating better transverse stability and stiffer motion responses. A GM value lower than the threshold, particularly below 0.15 m, significantly increases the risk of instability. Under such conditions, the vessel's righting arm (GZ) at small heel angles (0–15°) becomes insufficient, thereby heightening the possibility of permanent heeling or even capsizing (Barrass & Derrett, 2006). In extreme cases, if the center of gravity (G) lies above the metacenter (M), GM becomes negative, rendering the vessel unable to return to an upright position (International Maritime Organization, 2008). Conversely, ensuring a GM value greater than or equal to the minimum requirement provides an essential safety margin against free surface effects in tanks, cargo shifts, and the risk of *parametric rolling* in waves ((France et al., 2003; Kobylinski & Kastner, 2003). Therefore, achieving a GMt of 0.17 m is not only an indicator of normative compliance with IMO standards but also evidence that the airboat hull design can support adequate safety and seaworthiness during operation. This underscores the critical importance of conducting stability evaluations at the early design stage, as these assessments directly influence the determination of the *general arrangement* and subsequent structural planning. Moreover, fulfilling IMO stability criteria from the outset enhances the reliability of the vessel and supports safe and efficient operation, as highlighted by recent studies on the significance of stability in modern ship design (Kim & Roh, 2025).

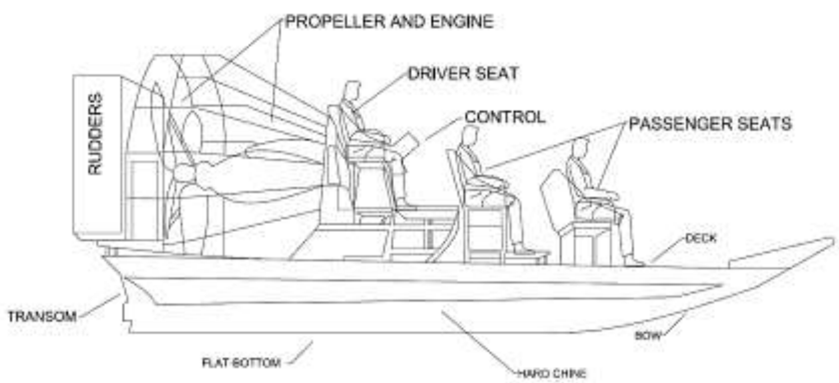

Figure 4 Airboat general arrangement

The general arrangement (GA) of an airboat is designed to integrate its key components in a manner that ensures operational efficiency, safety, and stability. As shown in Figure 4, the arrangement includes the propulsion system, rudders, driver and passenger seats, and hull features. The propeller and engine, enclosed in a protective steel cage, are located ahead of the rudders at the stern, functioning similarly to an aircraft thrust system to generate forward motion without underwater propellers (Han et al., 2014). The driver's seat, positioned in front of the engine with direct access to the control system, provides optimal visibility and maneuverability, while passenger seats are arranged along the deck to maintain balance and safety (Savitsky, 2006). From a structural perspective, the flat-bottom hull allows effective navigation in shallow waters (Müller et al., 2015), while hard chines enhance stability and control at higher speeds (Gerr, 1992). The tilted transom contributes to aerodynamic efficiency, supporting the vessel's performance in dynamic operating conditions (Thien et al., 2015). Overall, the GA reflects a deliberate integration of functional, structural, and safety considerations, making the airboat suitable for shallow-water operations while accommodating both crew and passengers effectively (Barrass & Derrett, 2006).

The selected design configuration—comprising a flat-bottomed hull with hard chines and an air-propeller propulsion system—is particularly suitable for operation in water areas dominated by water hyacinth vegetation. The absence of underwater propulsion components eliminates the risk of entanglement by dense roots and stems, allowing continuous movement through thick vegetation mats. Moreover, the flat-bottomed hull minimizes draft and maximizes lift, enabling the vessel to glide over shallow and obstructed surfaces without becoming grounded. The air-propeller thrust system provides multidirectional control and sufficient power to traverse stagnant or low-oxygen zones where conventional propeller-driven vessels fail to operate. These characteristics collectively make the airboat an optimal solution for transportation, surveillance, and aquatic vegetation management in water bodies heavily infested with *Eichhornia crassipes*.

5. Conclusion

This study demonstrates that the preliminary design of an airboat can be efficiently developed through the application of the parent ship (sister ship) design method, supported by engineering judgment and designer experience. This approach proves effective for generating initial drawings and defining fundamental parameters during the early stages of design. A flat-bottomed hull with hard chines was selected as the primary hull form, as it offers advantages in maneuverability and adaptability in shallow or vegetation-dense waters.

The stability analysis results, with a transverse metacentric height (GMt) of 0.17 m, confirm that the proposed design meets the minimum stability requirement of the International Maritime Organization (IMO). This value indicates sufficient resistance against heeling and ensures the airboat's ability to maintain an upright position under external loads such as wind or uneven passenger distribution. Therefore, the design is considered safe and operationally reliable for field implementation in challenging aquatic environments.

For further research, it is recommended to conduct detailed hydrodynamic simulations and experimental model testing to validate the performance of the proposed hull form under dynamic conditions. Future work may also explore material optimization for lightweight construction, noise reduction from the air-propeller system, and the integration of hybrid or electric propulsion to enhance environmental sustainability and operational efficiency.

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