Preliminary Design of a Catamaran Ship for Water Tourism in Lake Sunter

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***Abstract*— Lake Sunter is one of Jakarta's water tourism destinations with great potential for development. However, the limited water attractions and lack of supporting infrastructure remain challenges in increasing its appeal to tourists. One possible solution is the development of a tourism vessel based on a stable and efficient catamaran design. This study aims to design a tourism catamaran suited to the characteristics of Lake Sunter's waters. The methodology used in this study includes secondary data analysis to determine the vessel's main dimensions using linear regression and a stability evaluation based on IMO A.749(18) standards. The vessel is designed with main dimensions of L = 3.2 m, B = 1.9 m, H = 1.115 m, and T = 0.4 m, with a passenger capacity of three people. The stability analysis is conducted using Maxsurf software to ensure the design meets safety criteria. The results indicate that the vessel's design meets stability standards under both fully loaded and empty conditions, with a maximum GZ value of 0.43 meters at a 30° heel angle. However, this study has limitations in terms of field validation, exploration of alternative hull designs, and environmental impact analysis regarding the use of fiberglass as the primary material. Therefore, future research is recommended to conduct prototype testing, explore asymmetrical hull designs, and integrate renewable energy sources to enhance the sustainability of this tourism vessel's operations**

Keywords— Catamaran, stability, water tourism, Lake Sunter, Ship Design.
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I. Introduction

Indonesia is a country with a wealth of natural resources, including a diverse range of lake ecosystems. According to sources, the archipelago boasts a total of 840 lakes, varying in size from vast expanses to smaller, secluded bodies of water [1]. The lakes in Indonesia are not only beautiful natural features, but also play a crucial role in supporting human life, meeting both present needs and future goals [1].

Indonesian ecosystems play a significant role in the lives of Indonesians, serving as important reservoirs of resources that are essential for a variety of needs. Lakes, for example, are primary sources of potable water, which quench the thirst of communities and sustain daily life across the nation [1]. Furthermore, they are centers of productivity, fostering the growth of aquatic life that provides a crucial source of protein and minerals for countless individuals [2].

Lakes in Indonesia play a crucial role in the country's power supply and economic development by harnessing natural forces to generate electricity [3]. They also serve as important transportation routes, connecting communities across the diverse Indonesian landscape [4].

In addition to their practical uses, lakes also provide valuable opportunities for leisure and recreation, offering spaces for relaxation, exploration, and enjoyment amidst nature's beauty [5]. Essentially, Indonesia's lakes are complex ecosystems that sustain and enrich the lives of millions, representing the inherent connection between humanity and the natural world [1].

According to its technical definition, a lake is a substantial body of water encircled by land and nestled within a basin. It is a distinct entity, separate from the vastness of the sea, with its waters flowing solely through intricate networks of rivers and streams. Lakes are typically formed over long periods of time as basins are sculpted by geological processes. These basins then retain water from various sources, including rainfall, freshwater springs, seepage from surrounding terrain, and rivers. The combination of these sources contributes to the dynamic equilibrium of these aquatic ecosystems [6].

Furthermore, the proactive cultivation of positive growth within the field of lake tourism is emerging as a beacon of promise for enhancing economic prosperity at both local and regional levels. By recognizing and harnessing the inherent appeal of these tranquil water

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landscapes, communities can unlock a wealth of opportunities for sustainable economic development. By capitalizing on the natural beauty and recreational potential of lakes, regions can effectively position themselves as world-class destinations, attracting visitors from near and far for a wide range of activities, from leisurely boating excursions to exhilarating water sports. In doing so, these communities not only enrich travelers' experiences, but also stimulate the growth of local businesses, from quaint lakeside cafes and charming bed and breakfasts to bustling marinas and adventure outfitters. Moreover, cultivating a vibrant lake tourism sector not only enhances economic prosperity, but also fosters a deeper appreciation of the ecological importance of these vital aquatic ecosystems, promoting their conservation and sustainable management for generations to come [7].

The DKI Jakarta Province stands as a beacon of tourism excellence, drawing countless visitors in search of unparalleled recreational opportunities. Among its myriad attractions lies Danau Sunter 2, a picturesque lake nestled at Jl. Danau Sunter Barat No.2-21, Sunter Agung, Tanjung Priok, North Jakarta City, within the Special Capital Region of Jakarta 14350, Indonesia [8]. Spanning an impressive area of approximately 33 hectares, Lake Sunter 2 serves as a tranquil oasis amidst the urban landscape, its waters fed by a network of drainage systems and surrounded by bustling residential and commercial establishments. Flowing gracefully into the Muara River, the lake not only enriches the local ecosystem but also provides a serene retreat for visitors seeking respite from the city's hustle and bustle [9].

In the year 2023, data released by the BPS DKI Jakarta Province unveiled a remarkable surge in tourism activity, with both domestic and foreign arrivals experiencing an impressive 8% increase compared to the preceding year. This surge underscores the province's enduring allure as a premier destination for travelers, highlighting the diverse array of experiences and attractions it has to offer [10]. Moreover, DKI Jakarta Province's pivotal role in bolstering Indonesia's tourism sector cannot be overstated, with statistics revealing that it contributed a substantial 17.09% to the total number of tourists visiting the country. This significant contribution underscores the province's invaluable position as a cornerstone of Indonesia's tourism landscape, further cementing its reputation as a must-visit destination for travelers from near and far [8].

Lake Sunter, characterized by its urban setting, has great potential for enhancement through the integration of a diverse range of water attractions, strategically designed to capture the interest and engagement of tourists. This assessment emphasizes an objective analysis rather than a subjective viewpoint. Within the tranquil waters of the lake, tourists can enjoy recreational opportunities aboard specially designed boats, allowing them to leisurely explore and appreciate the picturesque landscapes surrounding the lake [11].

Lake Sunter holds great potential as a water tourism destination in the heart of Jakarta. However, its development faces numerous challenges and significant gaps. One of the main issues is the limited availability of water-based attractions. Currently, tourism activities at Lake Sunter are mostly confined to passive pursuits, such as enjoying the scenery, jogging, or fishing, without any dedicated attractions designed to draw the interest of tourists. Additionally, the supporting infrastructure around the lake is inadequate to optimally accommodate visitors' needs. Facilities such as docks for tour boats, spacious parking areas, and public amenities like clean toilets and changing rooms are very limited, which restricts the comfort and experience of visitors [12].

From a management perspective, there appears to be a lack of integrated efforts to incorporate a modern water tourism concept that aligns with urban characteristics and meets the needs of both local residents and tourists. Furthermore, the promotion of Lake Sunter as a tourist destination remains insufficient, limiting its potential to compete with other water tourism destinations, both in Jakarta and in other regions. Another issue is the lack of diversified water attractions that are both appealing and safe, such as family-friendly tour boats or eco-friendly water sports facilities. Therefore, a strategic approach is needed, not only to increase the number of attractions but also to focus on aspects of comfort, safety, and environmental sustainability at Lake Sunter [13].

However, an examination of tourism activities in Jakarta, particularly at Lake Sunter, reveals several shortcomings, most notably the insufficient availability of water-based attractions. In order to address these deficiencies and enrich the tourist experience, it is imperative to consider the introduction of purpose-built water rides that are specifically tailored to tourism activities. For example, the introduction of catamaran-style boats could significantly increase and diversify the range of water-based activities available to visitors, thereby enhancing the overall attractiveness of Lake Sunter as a premier tourist destination [14].

Several previous studies have explored the design of catamaran vessels to support water tourism in various locations. One such study was conducted by Santoso Jurnal [15], this research focused on designing a catamaran vessel tailored to the characteristics of shallow waters and the needs of local tourists in Rowo Jombor, Klaten. Additionally, another study by Kurniawan [16] examined the design of a catamaran vessel for tourism purposes in the Karimunjawa Islands [16], emphasizing stability and operational efficiency. Both studies make significant contributions to the development of tourism vessel designs, particularly for application in waters with unique characteristics, such as urban environments. They prioritize stability, comfort, and efficiency as the main considerations in the design process.

Catamaran vessels are characterized by their distinctive double hulls or demi-hulls, a design feature that not only makes them aesthetically pleasing but also gives them remarkable functionality, particularly in the field of passenger transport. This structural layout provides these vessels with large deck areas , giving passengers ample space to move about and enjoy various recreational activities during their voyage [14]. In addition, the inherent lateral stability of catamarans ensures a stable and comfortable ride for passengers, even in potentially rough sea conditions . This stability factor is paramount in enhancing the overall travel experience, as it significantly reduces the incidence of motion sickness and promotes a sense of security among passengers [14].

One of the key advantages of catamarans, particularly when compared to monohull displacement vessels of similar size, is their superior efficiency. Due to their streamlined design and reduced water resistance, catamarans typically require less power to achieve comparable speeds, resulting in cost savings and environmental benefits [17]. However, it is important to recognize that this efficiency comes with a trade-off, as catamarans generally have a lower payload capacity than their monohull counterparts [18]. This limitation highlights the importance of careful planning and optimization in the design and operation of catamaran vessels to ensure that they meet the specific requirements of their intended applications, such as passenger transport [19].

Delving deeper into the intricacies of catamaran hull design, it becomes clear that there are several different models, each with its own set of characteristics and performance attributes. These include symmetrical designs with twin hulls that are mirror images of each other; asymmetrical configurations with straight interiors, where one hull is larger or differently shaped than the other; and asymmetrical designs with straight exteriors, where the shape and size of the hull varies along its length. Understanding these nuances is critical for engineers and naval architects tasked with designing and optimizing catamarans for specific applications and operating environments [20].

Moving to the context of Sunter Lake in Jakarta, where the focus of this research lies, the aim is to develop specialized tourist boats that take advantage of catamaran design principles. By using fiberglass as the primary construction material for these vessels [21], the aim is to achieve a balance between durability, performance and cost effectiveness, all of which are essential considerations in the context of tourism operations. To ensure the seaworthiness and stability of these tourist vessels, advanced computational methods such as the A.N. Krylov stability calculation method are used to enable engineers to evaluate and optimize vessel design parameters for optimum performance and safety. In addition, sophisticated software tools such as AutoCAD, Maxsurf and SketchUp will be used to conceptualize and visualize the vessel design, facilitating iterative refinement and adaptation to meet the unique requirements of the Sunter Lake tourism industry.

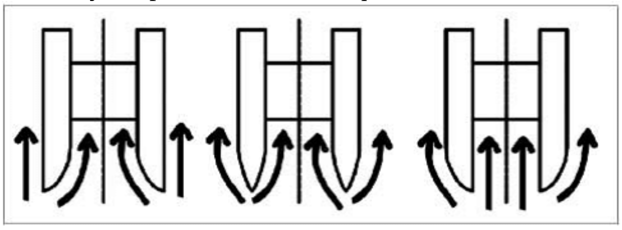

Figure. 1. Catamaran Ship hull shape [22]

II. METHOD

2.1. Data Collection Method

The data collection methodology used for this research relies predominantly on indirect or secondary data collection methods. This approach involves the collection of existing data sources rather than the collection of primary data through direct observation or experimentation. In the context of this study, the data required primarily consists of comparator vessel data, site data relevant to the study area, and ancillary data to support the analysis and findings [23].

The data collection method used relies entirely on secondary data. This data includes comparative vessel data, relevant location data, and other supporting data to support the analysis and design.

It is mentioned that the comparative vessel data was obtained to evaluate and compare the performance, characteristics, and design features of existing catamarans. Location data from Sunter Lake is used to understand water conditions, such as depth, shoreline topography, and other environmental factors that may affect the vessel design. Additionally, supporting data, such as demographic trends of tourists and maritime safety regulations, are also utilized to complement the design analysis.

This method is indirect, as the researchers did not conduct field surveys or primary data collection, such as interviews with users or direct testing on-site. Instead, the data used comes from documents, literature, and other available reference sources, which are then analyzed using software like Maxsurf to theoretically validate the design.

Comparison vessel data is a critical component in evaluating and benchmarking the performance, characteristics and design features of various vessel types, including catamarans. By analyzing existing data on comparable vessels, researchers can gain valuable insights into industry standards, best practices and areas for potential improvement or innovation. This comparative analysis will provide the basis for informed decision-making and optimization in the design and development of tourist boats tailored for use on Lake Sunter [24].

The selection of comparison vessels should be based on several important criteria, such as water conditions similar to those of Lake Sunter, which has shallow depths and calm waters. The comparison vessels used should have dimensions appropriate to the scale and needs of water tourism in the lake, including length, width, and height that allow the vessels to maneuver effectively in restricted waters. Additionally, the passenger capacity of the comparison vessels needs to be considered to ensure that the design meets the needs of the tourists who will use the vessels.

The type of material used in the comparison vessels, such as fiberglass, should also be relevant to the design goals, considering the environment and use of vessels in Lake Sunter that require durable yet lightweight materials.

Furthermore, it is important to clarify the sources of data for the comparison vessels, whether from scientific literature, vessel design catalogs, or operational data from vessels that have operated in similar environments, so that the comparison results can be trusted and valid.

Location data, on the other hand, provides geographic context and spatial information essential for understanding the specific operating environment and conditions of Sunter Lake in Jakarta. This data encompasses various aspects such as water depth, shoreline topography, navigational hazards, and environmental factors, all of which influence vessel design, route planning, and operational considerations. By integrating location data into the research framework, researchers can effectively assess the suitability and feasibility of different design options and strategies within the unique context of Sunter Lake [25].

In addition to comparison ship data and location data, the research also relies on other supporting data to supplement the analysis and enhance the comprehensiveness of the study. This may include demographic data related to tourism trends and preferences, economic data pertaining to the tourism industry's contribution to the local economy, and regulatory data concerning maritime safety standards and environmental regulations. By incorporating a diverse range of supporting data, researchers can gain a holistic understanding of the complex interplay of factors influencing the design, development, and sustainability of tourist boats on Sunter Lake [26].

Overall, the use of indirect data collection methods, coupled with a multi-dimensional approach to data collection and analysis, will enable the researchers to conduct a rigorous and thorough investigation into the optimization of tourist boat design for Lake Sunter. By utilizing existing data sources and integrating diverse data sets, the research aims to generate actionable insights and recommendations to improve the tourist experience and promote sustainable tourism development in the region [27].

2.2. Linear Regression Method

This method uses a graphical representation in which two variables are plotted along a straight line as ratio parameters, which are essential for determining the primary dimensions of the ship. By plotting these variables side by side on a graph, researchers can visually see the relationship between them and gain key insights into the optimal size and proportions required for the ship's design. This approach provides a systematic and quantitative analysis that enables designers and naval architects to identify the most appropriate dimensions that balance factors such as payload capacity, stability, maneuverability and fuel efficiency. By using this method, informed decisions can be made about the key dimensions of the ship, ensuring its suitability for its intended purpose and operating conditions [28].

The method used in linear regression is the Least Squares Method. This method aims to make the errors that occur as small as possible, as shown below. The trick is to square the error (D^2), where;

$$D^2 = \left(y1 - f(x1)\right)^2 + \left(y2 - f(x2)\right)^2 + \left(yn - f(xn)\right)^2 \quad (1)$$

From the regression form :

$$Y = a + bx \quad (2)$$

a and b must be made such that for D^2 to be a minimum, so that:

$$\partial D^2/\partial a = 0 \quad (3)$$

$$\partial D^2/\partial b = 0 \quad (4)$$

$$b = \frac{n\sum xiyi - \sum xi \sum xi}{n\sum xi^2 - (\sum xi)^2} \quad (5)$$

$$a = y - bx \quad (6)$$

After obtaining a and b, enter them into the regression equation y = a + bx. To predict whether the regression line that we have made already has the slightest possible error, it is necessary to calculate the correlation coefficient (r). The correlation coefficient has a value from 0 - 1. The closer the value to 1, the better r. The formula for calculating r is:

$$r = \sqrt{\frac{Dt^2 - D}{Dt^2}} \quad (7)$$

Where :

$$Dt^2 = \sum_{i=1}^{n}(yi - y)^2 \quad (8)$$

$$D^2 = \sum_{i=1}^{n}(yi - a - bxi)^2 \quad (9)$$

2.3. Stability Calculation Method

The A.N. Krylov method is used to determine the stability of the designed ship in accordance with International Maritime Organization (IMO) standards, ensuring strict compliance with industry regulations and safety protocols. When the ship is in its upright position or tilted at an angle denoted by φ, it is subject to two primary forces: the gravitational force exerted by the ship's weight (W) and the buoyancy force (fb), both of which are equal in magnitude but act in opposite directions. The weight of the vessel, measured in Newtons, represents its gravitational pull towards the surface, while the buoyancy force, also measured in Newtons, is equivalent to the displacement force and reflects the volume of water displaced by the submerged hull.

The displacement of the vessel, denoted by the symbol Δ and measured in tones, is a key parameter in determining its buoyancy and overall stability characteristics. In addition, the underwater volume of the hull, known as the volumetric displacement, is represented by the symbol ∇ and provides essential insight into the vessel's hydrodynamic properties and buoyancy distribution.

By using the A.N. Krylov method, designers and engineers can accurately assess the ship's stability under various operating conditions and environmental factors, ensuring the vessel's seaworthiness and compliance with regulatory standards. In addition, the use of advanced stability analysis software such as Maxsurf Stability enhances the accuracy and efficiency of stability calculations, enabling researchers to generate comprehensive and reliable results to inform the design and optimization process. Through careful stability analysis and simulation, potential risks and vulnerabilities can be identified and mitigated, ultimately ensuring the safety and integrity of the designed vessel throughout its operational life.

$F_B = g\Delta = \rho g\nabla$ (10)

The initial metacentric height equals the difference between the metacentric radii and the distance between the centre of buoyancy (B) and gravity G. $GM_0 = BM_0 - GB$ (11)

The transverse metacentre radius at each inclination is also called the metacentre difference.

$r_\varphi = B_\varphi M_\varphi = \frac{dI_{WL}}{d\nabla}$ (12)

The transverse metacentric radius for the upright position is:

$r_0 = BM_0 = \frac{I_{WL}}{\nabla}$ (13)

Where: Iwl = moment of inertia of the waterplane.

The relationship between the two equations is:

$r_\varphi = r_0 + \nabla \frac{dr_0}{d\nabla}$ (14)

The static stability arm can be calculated using the following equation:

$GZ = y_{B\varphi} \cos\varphi + (z_{B\varphi} - Z_B) sin\varphi - GBsin\varphi$ (15)

Where : $y_{B\varphi}, z_{B\varphi}$ are the coordinates of the centre of buoyancy.

The equation $BN = y_{B\varphi} \cos\varphi + (z_{B\varphi} - Z_B) sin\varphi$ is called the righting arm of form, and BC = BG sinφ is called the righting arm of weight. The formula can also calculate GZ:

$GZ = y_{B\varphi} \cos\varphi + Z_{B\varphi} - KGsin\varphi$ (16)

The relationship between GZ and the inclined angle is assumed to be directly proportional for a slight inclination angle. Then the erection moment can be calculated by:

$M_R = g\Delta\, GM_0\varphi$ (17)

The above formula is called the metacentre formula of stability. For all angles of inclination, the erection moment can be calculated by:

$M_R = g\Delta\, GZ$ (18)

The curve of the straightening arm must match the appropriate characteristics. An example of the GZ value at the slope angle $GZ20^0$, $GZ30^0$, $GZ40^0$, $GZ\ ^0m$ must match the slope angle m. The difference between the straightening arm and the angle of inclination is called the generalized metacentre height:

$h_\varphi = \frac{d(GZ)}{d\varphi} = B_\varphi M - y_{B\varphi} sin\varphi + Z_{B\varphi} cos\varphi - KGcos$ (19)

Geometrically, this is equal to the distance between the metacentre M and the projection of G in the direction of the buoyant force, Z

$E_R = \int_0^\varphi M_R\, d\varphi = g\Delta \int_0^\varphi GZ d\varphi$ (20)

III. Results and Discussion

3.1. Determining the main size of the vessel

The process of determining the primary design specifications of a vessel is of paramount importance as it directly influences the balance and overall performance of the vessel. Careful consideration of the ship's dimensions is imperative, as these primary dimensions play a pivotal role in shaping several critical parameters that govern the ship's behavior and functionality. Factors such as stability, maneuverability, speed and efficiency are closely linked to the ship's basic dimensions, underlining the importance of a balanced design approach [19].

To facilitate this crucial aspect of ship design, reference data from existing catamarans provides a valuable guide to determining the optimum size/proportion parameters. By analyzing and benchmarking against established standards and industry norms, designers can gain valuable insight into the proportionality and interrelationship of key dimensions essential to catamaran design. This reference data provides a comprehensive framework for evaluating and refining key size ratios to ensure that the resulting design achieves optimum performance, seaworthiness and safety [18].

Incorporating this reference data into the design process allows designers to leverage established best practices and lessons learned from previous catamaran designs. By drawing on this wealth of knowledge and experience, designers can streamline the decision-making process, mitigate potential design flaws and ultimately deliver a vessel design that meets or exceeds industry expectations[29].

TABLE 1.
CATAMARAN VESSEL COMPARISON DATA

No	Ship Name	L (m)	B (m)	H (m)	T (m)
1	The aqua View	12	05.05	01.08	00.05
2	BT T 405	13.06	07.07	02.07	01.01
3	BT A-307	12.08	06.07	02.04	01.03
4	Bahia 46	04.08	02.04	03.02	01.03
5	Salina 48 Evolution	14.03	07.07	02.08	01.01
6	Nautitch 47	14.05	07.06	3	01.01
7	Yellow Cat II	14.09	06.07	02.02	01.02
8	Fastford	12	04.05	01.08	01.02
9	Whitemorph	14.08	05.04	01.08	01.02
10	Cat Taxi	09.08	05.08	1	00.03

Through meticulous attention to detail and adherence to established standards, the determination of key design parameters lays the foundation for the successful realization of a well-balanced and optimized catamaran vessel. By prioritizing the careful consideration of key size ratio parameters, designers can ensure that the resulting vessel achieves optimum performance, efficiency and safety, thereby enhancing its competitiveness and viability in the maritime industry [30] .

The dimensions of the comparison vessels provide an important foundation for designing a tourist boat that fits the characteristics of Lake Sunter. Comparison vessels such as Aqua View and BT A-307 are larger because they are designed for a higher passenger capacity and a wider water environment. However, these dimensions are used to establish the main dimension ratios (L/B, L/H, and B/T) tailored to the needs of tourist boats on Lake Sunter. For example, considering a smaller passenger capacity (3 people), the study design results in a boat length of 3.2 meters and a draft of only 0.4 meters to ensure the boat remains stable in shallow waters and has good maneuverability.

The dimension ratios of the comparison vessels are also used to verify the proportions of the design. For instance, the length-to-breadth (L/B) ratio of the comparison vessel Aqua View (2.37) serves as a reference to ensure that the ratio in the study design (2.015) remains within a safe range for stability and efficiency. This indicates that although the sizes differ, the design principles of the comparison vessels remain relevant for application in boats on Lake Sunter.

The main ship dimension is expressed as the length to beam (L/B) ratio, which influences parameters such as resistance, maneuverability and cost. The L/B ratio is usually determined using the Watson and Gilfillan formula [31]. To determine width and height, the ratio is compared with the regression method as shown below:

- L/B Ratio

L/B = 0.0115x + 1.976

With the calculation formula above with L = 3.2 m. So calculated L/B = 0.0115x 3.2 + 1.976 = 2.015. So the results L = 3.2 m. B = 1.9 m. and L/B = 2.015

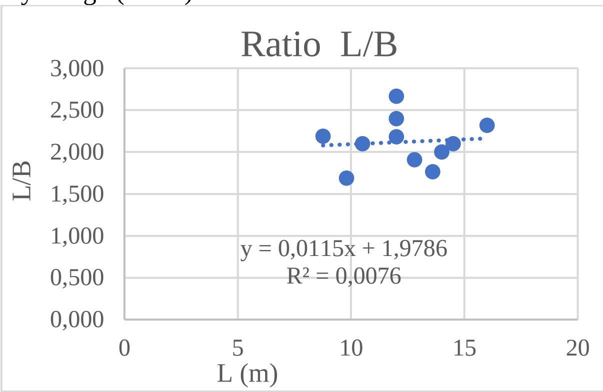

Figure. 2. Ratio L/B

The L/B ratio is an important consideration in ship design because it affects the performance and characteristics of the ship. A larger L/B ratio typically results in a longer and narrower vessel, which can increase the vessel's speed and reduce the drag it experiences. However, a larger L/B ratio can also reduce a ship's stability and make it more difficult to maneuver in tight spaces [29]. The greater the L/B ratio, the greater the ship's resistance. However, the smaller the L/B ratio, the greater the ship's maneuverability. Apart from that, the greater the L/B ratio, the higher the shipbuilding costs. Therefore, the L/B ratio needs to be considered in designing ships to achieve an optimal balance between resistance, maneuverability, stability, and cost [30] .

The Length of the Ship (L) parameter has a direct impact on longitudinal stability and passenger capacity. In this calculation, the ship's length (L) is set at 3.2 meters. If the length is increased by 10% (to 3.52 meters), the length-to-beam ratio (L/B) increases to 1.85, which can enhance speed but reduce maneuverability. Conversely, if the length is reduced by 10% (to 2.88 meters), longitudinal stability decreases, potentially affecting passenger comfort.

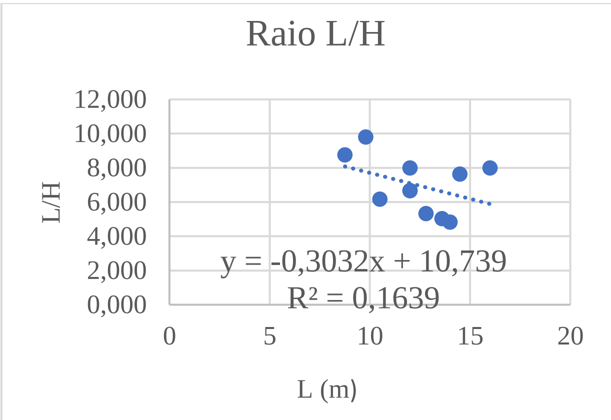

Figure. 3. Ratio L/H

L/B = -0.3032x + 10.739. With the calculation formula above with L = 3.2 m. Then it is calculated that L/h = -0.3032x 3.2 + 10.739 = 9.768. So the result is L = 3.2 m. H = 1.115 m. and L/H = 9.374. The length-to-depth ratio or Length/height (L/H) affects the longitudinal strength of the ship, but this ratio is not significant for small ships.

The beam directly influences transverse stability and deck space. In this design, the beam is set at 1.9 meters. If the beam is increased by 10% (to 2.09 meters), transverse stability improves, but water resistance also increases, reducing efficiency. Conversely, if the beam is reduced by 10% (to 1.71 meters), the ship becomes narrower, but transverse stability decreases, which may lead to heeling when carrying maximum load.

The ship's height affects stability and passenger comfort, especially under lateral wind conditions. With a height of 1.115 meters, stability remains within a safe range. However, if the height is increased by 10% (to 1.227 meters), the ship's center of gravity rises, reducing transverse stability. Conversely, if the height is reduced by 10% (to 1.004 meters), the ship becomes more stable, but the available space for passengers inside the vessel becomes more limited.

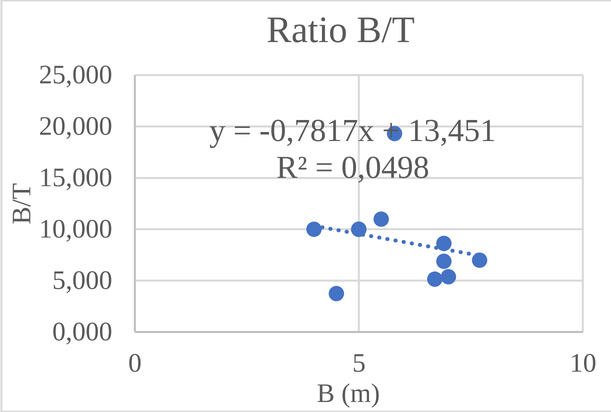

Figure. 4. Ratio B/T

B/T = -0.7817x + 13.451. With the calculation formula above with L = 3.2 m. So it is calculated that B/T = -0.7817x 3.2 + 13,451= 11,966. So you get results. L = 3.2 m. T = 0.4 m and B/T = 11.966. The draft width ratio B/T is an important factor in determining ship stability, and was determined by Watson and Gilfillan . The draft width ratio (B/T) affects ship stability, drag, and wet surface area.

The draft significantly affects buoyancy and stability. In this design, the draft is set at 0.4 meters to accommodate the shallow waters of Lake Sunter. If the draft is increased by 10% (to 0.44 meters), buoyancy improves, but maneuverability in shallow waters may be compromised. Conversely, if the draft is reduced by 10% (to 0.36 meters), the ship becomes easier to maneuver, but buoyancy decreases, affecting passenger capacity.

TABLE 2.
RATIO OF MAIN SIZE PARAMETER

Parameter	Result	Reference	Condition	Remark
L/b1	7.111	Insel & Molland	5.9 - 11.1	Pass
L/H	2.783	BKI	4.828 - 14.8	Pass
B/H	1.652	Insel & Molland	0.7 - 4.2	Pass
S/L	0.406	Insel & Molland	0.19 - 0.51	Pass
S/b1	2.889	Insel & Molland	0.9 - 4.1	Pass
b1/T	1.125	Insel & Molland	0.9 - 3.1	Pass

TABLE 3.
RESULTS OF MAIN SIZES OF SHIPS FROM LINEAR REGRESSION

No	Dimension	Size (m)
1	L	3.200
2	B	1.900
3	H	1.115
4	T	0.400

According to what Paroka [32] has to say, figuring out the primary dimension ratio accurately is essential to controlling ship design in the modern world as well as for future marine projects. Keeping this basic idea in mind, they are easily included into the complex structure of Maxsurf Modeler software once they have obtained the necessary ship measurements. The results of this integration are next carefully examined and analyzed, then carefully arranged and evaluated in Table 3 in order to outline the design for the intended ship model. Using the powerful features of Maxsurf Modeler, this complex procedure involves making use of an already-existing catamaran-shaped ship hull template that the program has wisely provided.

By means of a sequence of painstakingly coordinated modifications and enhancements, directed by the requirements painstakingly specified in Table 3, this template is painstakingly adjusted to match the intended main ship size criteria. With this systematic methodology, theoretical concepts, empirical data, and state-of-the-art computational tools are harmoniously combined to modify the ship model iteratively until it achieves the highest levels of performance, stability, and efficiency. Following the guidelines and legally required standards to

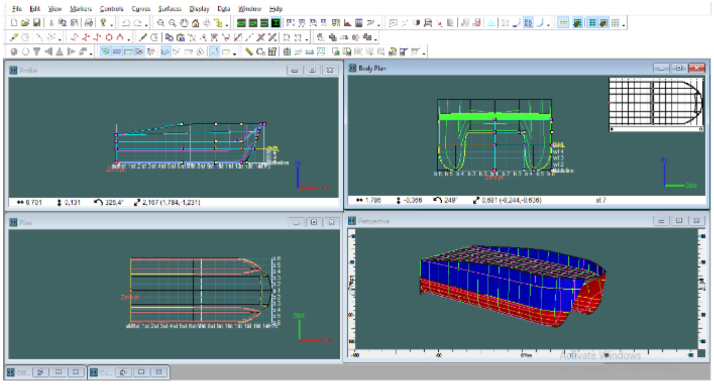

Figure. 5. Lines Design

the letter, this painstakingly planned project results in the creation of a strong and well-balanced ship design that is ready to sail the seas with confidence and dependability in the present and in the future.

When it comes to building boats, catamaran designs have many advantages over other options. Because of the two hulls that catamarans are built with, they are incredibly stable and buoyant, which allows them to glide through even the roughest waters with grace and ease. Because to the increased stability, passengers get a much smoother ride, which gives them comfort and confidence even in rough seas. Moreover, the connecting bridge that spans the gap between the two hulls functions as a multipurpose platform, providing catamarans with a generous amount of extra deck area. This extra deck space helps the ship carry more passengers and makes it easier to provide amenities and recreational areas, which improves the overall comfort and enjoyment of the aboard experience.

Furthermore, the smooth waterline and streamlined shape of catamarans represent a harmonious combination of form and function that yields noticeable gains in speed and fuel efficiency. Through the reduction of drag and enhancement of hydrodynamic performance, catamarans can attain greater speeds while preserving fuel efficiency. This advantageous combination makes them a compelling option for both business and leisure users. All things considered, the numerous benefits that come with catamaran designs—from improved stability and volume to faster speeds and more fuel economy—make them an appealing choice for a wide range of marine activities, from business to leisure cruising.

There are two main hull shape types for catamaran ships: symmetrical and asymmetrical. A symmetrical hull has the same dimensions on each side of its midline, with equal angles of entrance and departure. A symmetrical hull design was chosen as the modeling foundation for this investigation. After the hull modeling process is finished, the vessel's detailed design is captured by creating the 2D Lines Plan image. After that, the image is exported in DXF format, which makes it easier to integrate AutoCAD software with it and process it further. The imported image is carefully refined and enhanced in AutoCAD to create the Catamaran Ship Layout and General Plan. The architectural parameters and design aspects of the vessel are communicated with accuracy and clarity thanks to this iterative approach, which also lays the foundation for further phases of analysis and optimization.

3.2. Line Plans and General Arrangement

After the primary measurements are obtained, they function as a fundamental point of reference for the ensuing phases of ship design. Making use of these measurements, architects carefully construct the ship's structure to meet the requirements. This procedure involves drawing both a general design and a line plan that specify the vessel's architecture and structural support in great detail. High-end software like Maxsurf Modeler is used to carry out this complex design procedure. This advanced software suite provides a wide range of tools and features designed especially for ship design and naval architecture. Through the utilization of Maxsurf Modeler,

TABLE 4
MAIN DIMENSION

No	Main Dimension		
1	LOA	3.200	m
2	LWL	2.893	m
3	B	1.900	m
4	H	1.115	m
5	T	0.400	m
6	bl	1.174	
7	cb	0.505	
8	Cwp	0.881	
9	Cp	0.867	
10	Cm	0.833	
11	Lcb	4.352	
12	Lcf	4.432	
13	Vdisp	1.324	m^3
14	Displacement	1.291	ton
15	Wsa	5.984	m^2

designers may effectively convert their ideas into accurate, three-dimensional renderings, enabling a thorough comprehension of the shape and purpose of the vessel.

This design endeavor's outcomes are carefully documented and provided for examination and analysis. Table 4 provides stakeholders with a thorough understanding of the dimensions, configurations, and performance characteristics of the ship's major design parameters. In order to assess the practicality and effectiveness of the suggested ship design, this tabular presentation is a useful resource that will direct further decision-making procedures and improvement initiatives.

Before developing the general plan, the Maxsurf-generated lines plan is exported to AutoCAD for a detailed 2D representation. In AutoCAD, meticulous refinement smooths out any irregularities, ensuring coherence in the ship's contours. The ship's lines plan includes the body, profile, and view plans, each providing unique design insights. Iterative refinement ensures alignment with intended specifications. Figure 6 showcases the finalized lines plan, serving as a blueprint for the general plan's development. Its accuracy provides guidance for further design iterations.

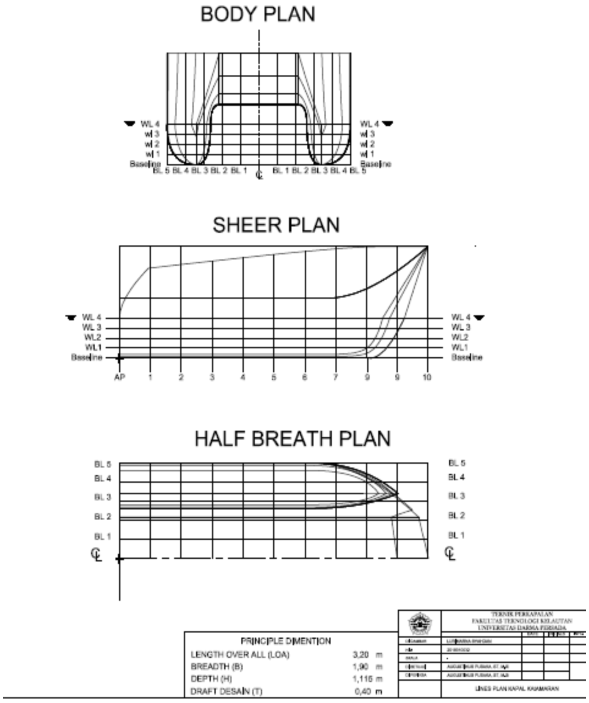

Figure. 6. Lines Plan

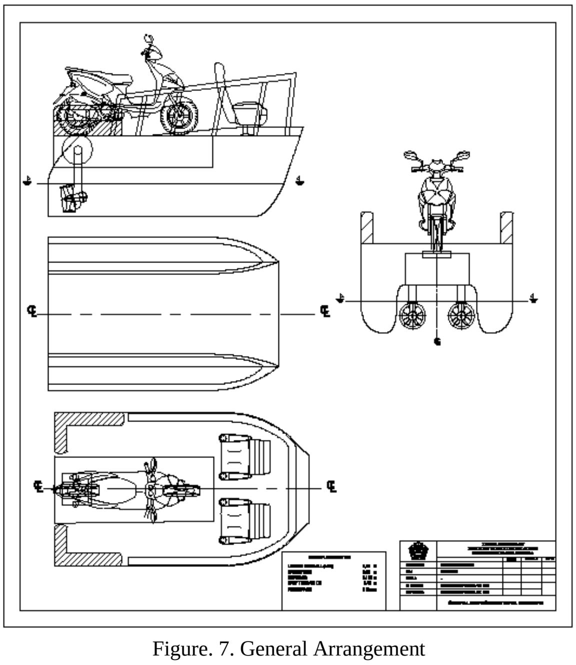

Figure. 7. General Arrangement

3.3. Stability Analysis

The advanced capabilities of the Maxsurf Stability program are used to calculate ship stability. The International Maritime Organization (IMO) publication A.749 (18) Chapter 3 [33] and the Intact Stability (IS) High-Speed Craft (HSC) 2000 Annex 7 Multihull requirements [34] both contain established rules that these calculations closely follow. Examining multiple load case scenarios, each intended to evaluate the vessel's stability under different circumstances, is part of this thorough analysis. Loadcase 1 simulates real-world operating conditions by evaluating stability at the maximum passenger load. On the other hand, Loadcase II simulates reduced occupancy or emergency situations by analyzing stability while the ship is empty of passengers. Through stability calculations across several load case criteria, the stability profile of the vessel is fully understood. By using an analytical method, it is ensured that the ship's design complies with strict safety regulations and standards, protecting against potential dangers and hazards that may arise during operation.

TABLE 5.
RESULT LOADCASE 1 & 2

NO	Heel to Starboard Degree	GZ Loadcase 1 m	GZ Loadcase 2 m
1	0	0	0
2	10	0.273	0.39
3	20	0.455	0.558
4	30	0.432	0.453
5	40	0.311	0.338
6	50	0.185	0.22
7	60	0.065	0.11
8	70	-0.032	0.029
9	80	-0.115	-0.023
10	90	-0.193	-.0.82

The label "pass" indicates that the catamaran successfully satisfies the specified criteria under both Loadcase I and Loadcase II conditions, based on the data shown in Table 5 above. This means that under the given load levels, the vessel exhibits enough stability characteristics to navigate safely and effectively.

The stability analysis results indicate that the ship's design meets the stability standards set by IMO A.749(18) in both fully loaded conditions (Loadcase 1) and without passengers (Loadcase 2). In the fully loaded condition, the GZ max value reaches 0.43 meters at a 30° heel angle, demonstrating the vessel's ability to return to an upright position after tilting due to external influences, such as passenger movement or small waves. This is crucial for ensuring passenger safety and comfort during tourism operations.

However, the ship's stability also presents some operational limitations that need to be considered. At a heel angle approaching 70°, the GZ value nears zero and may become negative, indicating that the ship could lose stability if the load is not evenly distributed or if a significant disturbance occurs, such as passengers accumulating on one side of the vessel. Therefore, during operations, passenger distribution must be carefully monitored to prevent excessive tilting.

Additionally, the analysis shows that the vessel remains stable in calm waters such as Lake Sunter, where currents and waves are minimal. However, under extreme weather conditions, such as strong winds causing heeling, the ship should be operated at a low speed to maintain lateral stability. Operating at excessive speeds under these conditions could increase the risk of unsafe heeling.

In real-world operations, several additional measures can enhance safety, such as:

- Providing training for ship operators to understand stability limitations.
- Installing visual draft indicators on the hull to monitor load distribution in real-time.
- Clearly displaying maximum passenger capacity information.
- Ensuring passengers distribute their weight evenly across the deck.

By considering the stability results and operational mitigation measures, the vessel can be safely operated for water tourism activities in Lake Sunter, as long as environmental conditions and load distribution adhere to the design parameters. This demonstrates that the ship's stability not only supports safety but also provides a sense of security for passengers during their tour.

TABLE 6.
STABILITY CORRECTION OF SHIP IN LOADCASE 1 & 2

Code	Criteria	Value LC 1	Units	Actual LC 1	Actual LC 2	Status LC 1	Status LC 1
A.749(18)Design Ch3 - design criteria applicable to all ships	3.1.2.1.: Area 0 to 30	0.05	m.deg	9,76	12	Pass	Pass
	3.1.2.1.: Area 0 to 40	0.09	m.deg	13.5	16	Pass	Pass
	3.1.2.2.: Max GZ at 30 04 greater	0,2	m	0.43	0.453	Pass	Pass
	3.1.2.4.: Initial GMt	0,15	m	1,6	2.257	Pass	Pass

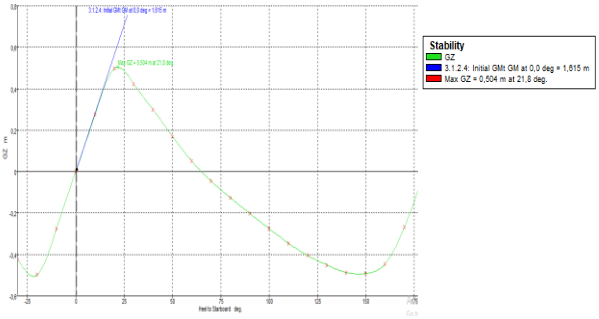

Figure. 8. Angle Stability Loadcase 1

The behavior of the ship at full load (load case I) is analyzed in the GZ value curve shown in Graph 1. The GZ value first rises gradually as the angle increases from 0° to 21.8°, when it peaks and reaches the maximum GZ value of 0.504 m. The GZ value starts to fall after this, signifying a loss of stability. Interestingly, the GZ value goes negative as the angle gets closer to 90°, indicating an unstable state where the ship does not have the restoring moment needed to offset heeling forces. According to Rawson and Tupper (1983) [35], this denotes a major loss of stability. It claim that positive GZ values characterize the stability range, which is generally 0° to 90°, and indicate the vessel's capacity to restore to its initial position following the dissipation of the external force that caused the tilt.

In general, it is imperative to make sure that the region beneath the stability arm curve, which encompasses different ship widths and draft ratios, conforms to the stability standards set forth by the International Maritime Organization (IMO). This commitment minimizes the risk of capsizing and ensures the safety of the crew and passengers by guaranteeing that the vessel maintains appropriate stability across a range of operating situations.

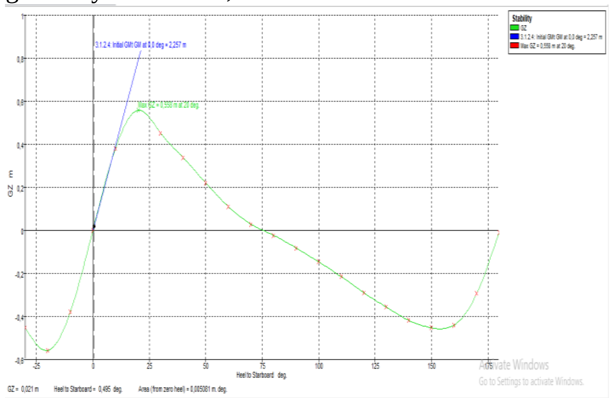

Figure. 9. Angle Stability Loadcase 2

The highest GZ value is found at an angle of 20°, which corresponds to the maximum GZ value of 0.558 m, in graph 9, which shows the empty load condition (load scenario II). Then, as the angle exceeds 20°, the GZ value starts to slowly decrease. This decrease indicates that as the vessel tilts more from the vertical axis, stability may be compromised. A crucial intersection in the vessel's stability profile is shown by the vital point where the GZ value peaks and starts to decline. After this point, the vessel's ability to withstand heeling forces and maintain stability is shown by diminishing GZ values. This result emphasizes how important it is to keep the vessel's stability qualities at their best, particularly when operating under different load situations, in order to guarantee its integrity and safety.

The stability curve (*GZ curve*) can be used to evaluate passenger comfort at various heeling angles, as the *GZ* value reflects the ship's ability to return to an upright position after tilting. At small heeling angles, such as 10–20°, a positive *GZ* value indicates that the ship has good righting capability without causing passengers to feel a significant tilt. Within this range, passenger comfort is maintained, as the experienced inclination does not create a sense of instability.

However, at larger heeling angles, such as 30–40°, *GZ* reaches its maximum value (e.g., 0.43 m for a fully loaded condition in this design), meaning the ship has its highest righting ability. While stability is still maintained, passengers may begin to feel the effects of the tilt, especially if the ship's load is not evenly distributed. This can impact passenger comfort, particularly for individuals who are more sensitive to ship movements.

If the heeling angle exceeds 40° and the *GZ* value begins to decrease, the ship's stability diminishes, and passenger comfort may be significantly affected. At this angle, the ship's movements may feel more extreme, potentially causing discomfort or even risks such as objects sliding on deck or passengers losing balance.

At a heeling angle approaching 70°, the *GZ* value nears zero or turns negative, indicating that the ship is on the verge of losing stability. In such situations, passenger comfort is no longer the primary concern, as the vessel's safety could be compromised. Therefore, it is crucial to ensure that the ship's operational conditions, such as load distribution and speed, are controlled to prevent heeling angles where *GZ* becomes too low.

To maintain passenger comfort, the ship should be operated within conditions that ensure *GZ* remains within a safe positive range, below the maximum heeling angle that produces *GZ max*. The ship operator should also provide guidance to passengers, advising them to remain seated or distribute their positions properly during the journey, especially when heeling occurs due to maneuvers or environmental conditions. Thus, the GZ curve is not only relevant for technical stability analysis but also serves as a guideline for creating a safe and comfortable tourism experience.

IV. CONCLUSION

This study has resulted in the design of a tourism catamaran with the main dimensions of L = 3.2 m, B = 1.9 m, H = 1.115 m, and T = 0.4 m, specifically designed for calm waters such as Lake Sunter. The stability analysis indicates that the vessel meets IMO A.749(18) standards under both load scenarios, with sufficient GZ values to maintain transverse and longitudinal stability. This design is expected to serve as a solution for enhancing the diversification of tourism attractions in Lake Sunter and supporting local economic development through water tourism.

However, this study has several limitations that should be considered. The benchmark vessel data used is entirely based on secondary sources without validation through field testing or prototyping. Additionally, this study does not explore alternative hull designs in depth, such as asymmetrical hulls, which might provide better hydrodynamic efficiency. Furthermore, the environmental impact of using fiberglass as the primary material has not been comprehensively analyzed, particularly in terms of long-term sustainability.

For future research, it is recommended to explore alternative hull designs, including comparisons between symmetric and asymmetric hulls, to optimize stability and efficiency. Additionally, integrating renewable energy sources, such as solar panel installations to support the ship’s power system, could be an innovative step toward sustainable operations. Further research could also include prototype testing in Lake Sunter to evaluate the vessel’s real-world performance, as well as a life cycle assessment (LCA) of fiberglass materials to minimize environmental impact.

Thus, this design is not only a technical solution but also provides a direction for the development of more efficient, environmentally friendly, and sustainable tourism vessels.

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