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Buoyancy Analysis and Experimental Validation of Styrofoam Buoys on Amphibious Motorcycles

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Abstract. Floods are the most frequent natural disasters that hit Indonesia and have a major impact on people's lives, especially in coastal areas such as Brebes which often face flash floods, so that conventional transportation systems are often completely paralyzed and hinder the evacuation process and distribution of aid. This research aims to develop amphibious motorcycles as an affordable alternative transportation solution in accordance with local conditions by utilizing local materials such as Styrofoam to overcome the limitations of access to similar technology in Indonesia. The research method used an experimental approach by designing and testing an amphibious motorcycle buoy made of *used Styrofoam* fruit boxes coated with plywood and fiber with dimensions of 179 cm × 37 cm × 38 cm per unit, mounted on Honda Beat motorcycles. The test was carried out through four loading variations ranging from no-load conditions to a maximum load of 223 kg, by measuring the depth of the dipped float to evaluate buoyancy based on the Archimedes principle. The results showed that the buoy was able to withstand a maximum load of 223 kg in stable conditions with a dip depth of 17 cm, resulting in an actual buoyancy force of 119 N although theoretical calculations showed a maximum capacity of 432 kg (4,233.6 N). The buoy system with a total weight of 24 kg (2 units) has a safety margin of 55.3% and is capable of operating with passengers up to 80 kg with maintained stability. This study validates that the design of the amphibious motorcycle has a strong theoretical basis and has been experimentally proven as an effective emergency transportation solution based on local materials for flood disaster mitigation in Indonesia.

Keywords: amphibious motorcycle; buoyancy; *Styrofoam buoy*; emergency transportation; flood disaster mitigation; Archimedes' law; local amphibious vehicle

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1. Introduction

Floods are the most frequent natural disasters that hit Indonesia and have a major impact on people's lives, especially in coastal areas such as Brebes which often face flash floods due to land subsidence and sea level rise (1). When floods occur, conventional transportation systems are often completely paralyzed, so the evacuation process and distribution of aid are hampered. This condition confirms the need for alternative transportation solutions that are able to operate on land and water, especially for disaster emergency response purposes.

The main motivation for this research is the urgent need for an affordable amphibious vehicle that is in accordance with local conditions, considering that access to similar technology is still very limited in Indonesia due to high prices and minimal availability (2). Motorcycles, as the most popular mode of transportation in Indonesia, have great potential to be developed into effective and inexpensive amphibious vehicles, by utilizing local materials that are easily available such as *Styrofoam* (3). This study presents a scientific study on the analysis of force calculations in the planning of amphibious motorcycle buoys which then the calculation analyst data is correlated with real data taken through a series of direct tests carried out in the field with a variety of tests in the

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form of varied loading without sacrificing the stability of the vehicle (4). It is hoped that these findings will make an important contribution to the development of emergency transportation technology based on local materials and can serve as a reference for further innovations in disaster mitigation in Indonesia (1).

2. Methodology

The research method in this study uses an experimental approach, which aims to design and test amphibious motorcycle buoys to determine their buoyancy capabilities (5). The research is focused on the design stage of the buoy and the buoyancy evaluation of load variations, and is correlated with the analysis of calculations that have previously been carried out to determine the ideal of the buoys that have been made (6). The main material for making buoys is used styrofoam fruit boxes coated with plywood and fiber boards to increase strength and resistance to water, then put in an iron frame that can be attached to a motorcycle (3). The dimensions of the buoy are designed with a total length of 229 cm, a width of 37 cm, and a height of 38 cm. buoys will be made two pieces which will later be installed on the right and left sides of the Honda Beat motorcycle as the main unit of amphibious vehicles).

The series of tests was carried out four times with different load variations, without load, with a motorcycle load only (93 kg), and with additional passengers weighing 51 – 60 kg, 61 – 70 kg, and 71 – 80 kg. The maximum total load tested was 223 kg. The independent variables in this study are the dimensions and model of the buoy, while the bound variable is the ability of the buoyancy to withstand the load (8). The buoyancy test is carried out by measuring changes in the depth of the buoy immersed in water at each variation of load, and compared visually and numerically through tables and graphs (9).

The calculation of buoyancy follows the basic principles of Archimedes physics, with the formula where is the buoyancy force, is the density of the fluid, is the volume of the dipped object, and is the acceleration of gravity. This formula has been described and used directly in this study to calculate the magnitude of the lifting force to the weight of the given load$Fa = \rho \,. V_{bf} . g F_a \rho V_{bf} . g$ (10). Geometric formulas such as block volume and triangular prisms are also used to calculate buoyancy volume, which is the basis for buoyancy estimation (11). Using the following Archimedes formula:

$$F_a = p_f \cdot V_{bf} \cdot g$$

where:
F_a= buoyancy force (N),
p_f= fluid density (kg/m^3),
V_{bf} = volume of dipped object (m^3),
g = acceleration of gravity (m/s^2)
With this formula we will find out the analysis of the buoyancy in the buoyancy made (12).

Table 1. Research Stages

No.	Research Stages	Activities	Purpose	Tools/Materials Used
1	Literature Studies	Examines buoyancy theory, buoy design, and amphibious vehicle characteristics.	Develop the basis of the theory and concept of amphibious vehicle planning.	Academic literature, journals, final projects, mechanical engineering books.
2	Planning and Design	Determine the dimensions of the float and the type of material (stereoisomer, plywood, and fiber).	Design a buoy that is able to support the weight of motorcycles and passengers.	Manual/sketch design software, measuring tools, dimension references.
3	Prototyping	Assemble two styrofoam buoys, line them with plywood and fiber boards, and attach them to the right and left sides of the motorcycle.	Physically realize the design of the buoy.	styrofoam, plywood, resin fiber, Honda Beat motorcycles.

4	Trial (Experiment)	Tests buoyancy with four load variations: no load, motor load, and motor + passenger load.	Measures the buoyancy's ability to stably withstand the total weight of the system in the water.	Float height measuring equipment, test pool, load (motor & person).
5	Measurement & Observation	Record the initial and final height of the buoys from the water surface after being loaded in each loading scenario.	Determine the depth level of the buoyancy to measure its buoyancy and stability.	Rulers, documentation cameras, observation notes.
6	Processing	Calculate buoyancy volume, buoyancy force (using physics formulas), and plot the relationship between load and buoyancy in a graph.	Conclude the effectiveness of the buoy design on the lift and stability of the vehicle.	Calculators, tables, graphs, data processing software/manuals.
7	Evaluation and Conclusion	Analyze the test results of whether the buoy meets the functional and stability requirements for amphibious vehicles.	Assess the success of the design and suggest further development.	Final report document, graph of test results, researcher conclusions.

3. Results and Discussions

3.1 Test Results

After conducting a scientific study through existing literacy sources, the researcher designed an amphibious motorcycle buoy, the following is a design drawing:

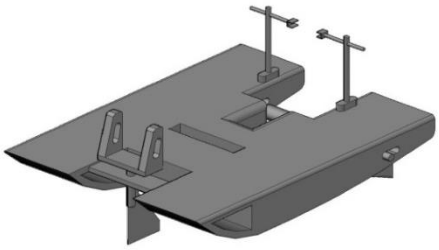
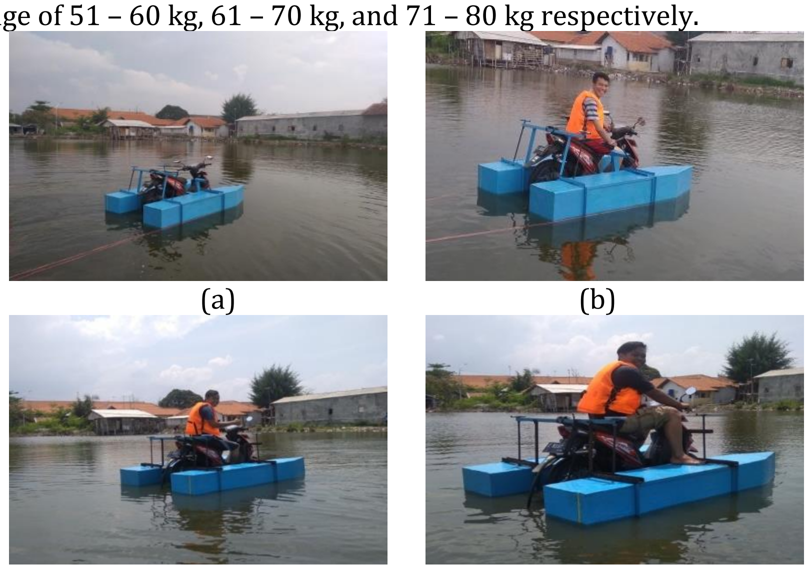


Figure 1. Amphibious motorcycle buoy design

In this study, to determine the buoyancy ability of the buoyancy on an amphibious motorcycle, a series of loading tests will be carried out four times, but before that we will measure the depth of the buoy without load. The first test was carried out by weighing the buoy using a Beat motorcycle with a weight of 93 kg. The second to fourth tests were carried out by mounting the Beat motorcycle on an amphibious buoy and overloading the system with passengers who have different weight ratios, namely in the range of 51 – 60 kg, 61 – 70 kg, and 71 – 80 kg respectively.



(a) (b) (c) (d)

Figure 2. Load variations

This approach aims to evaluate the buoyancy's performance in withstanding varying dynamic loads, so as to provide a comprehensive picture of the buoyancy's stability and buoyancy under real conditions. This method of loading testing is in line with the basic principles of buoyancy described by Archimedes, where the buoyancy of an object depends on the volume of fluid displaced by the object as well as the total weight of the object being loaded. The following is a table of the results of the observation of loading on the buoy of an amphibious motorcycle:

Table 2. Buoyancy data collection results in all experiments

NO	Load Name	Initial depth of buoy from the water surface (cm)	The final depth of the lamp after being loaded (cm)	Information
1	Condition of the no-load float	0	4	Balanced
2	First load condition (93kg)	4	10	Balanced
3	Second load condition (51-60kg)	10	13	Balanced
4	Third loading condition (61-70kg)	13	16	Balanced
5	Fourth loading condition (71-80kg)	16	17	Balanced

The table of test results above shows data on the depth of the buoy submerged in water based on the variation of the load given. In the process of collecting this data, several variations of loading were carried out to observe the response of the buoy to different loads. The description of the variation in the load is as follows:

1. Load less conditions. The buoy in this condition is not given any additional load and only bears the weight of the buoy itself, which is 50 kg, with a final depth dipped in water of 4cm.
2. The first load. The float was loaded with a motorcycle weighing about 93 kg. Thus, the total weight borne by the buoy is 143 kg (50 kg buoy + 93 kg motorcycle), with the final depth dipped in water being 10cm.
3. The second load of the buoys is loaded with motorcycles (93 kg) and passengers weighing between 51–60 kg. The total weight in this condition reaches about 203 kg (50 kg + 93 kg + 60 kg), with the final depth dipped in water being 13cm.
4. The third load. The buoy is loaded with a motorcycle (93 kg) and a passenger weighing between 61–70 kg, bringing the total weight to about 213 kg (50 kg + 93 kg + 70 kg), with a final depth dipped in water is 16cm.
5. The fourth load. The buoy is loaded with a motorcycle (93 kg) and passengers weighing between 71–80 kg, bringing the total weight to about 223 kg (50 kg + 93 kg + 80 kg), with a final depth submerged in water of 17cm.

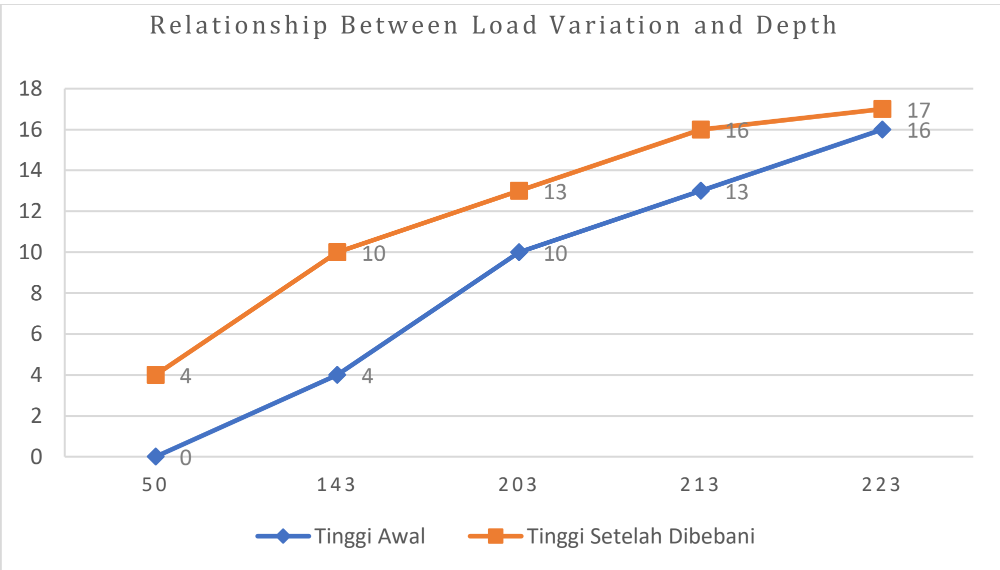


Figure 3. Buoyancy flotation capability testing chart

This dipped float depth measurement is essential for evaluating the buoyancy and stability of the float in withstanding varying loads. The basic principle used is Archimedes' law, which states that the buoyancy force acting on an object is equal to the weight of the fluid displaced by the object (13). Thus, the greater the load, the deeper the buoy is immersed in the water, which can affect the performance and safety of the amphibious vehicle. The following graph shows the relationship between load variation and depth in the analysis of the buoyancy ability of amphibious motorcycles: In the initial height condition, the relationship between load and depth shows a fairly consistent linear pattern, where an increase in load from 50 kg to 223 kg results in an increase in depth from about 0 cm to 17 cm. Meanwhile, the second condition (red line) shows a different pattern, where at the same load, the depth achieved is greater at low loads but tends to converge at higher loads.

These differences in characteristics indicate that the buoyancy of an amphibious motorcycle buoy is affected by the initial conditions of the system. At maximum load (223 kg), both conditions show almost the same depth (about 17 cm), which indicates that at some point, the system achieves a similar hydrostatic equilibrium regardless of its initial conditions. This data is important for determining the operational limits and stability of amphibious motorcycles under various loading conditions.

i. Analysis of the Depth of Dip of the Buoyancy

$$\rho\_air \times g \times V\_tercelup = m\_total \times g$$

$$V\_tercelup = \frac{m\_total}{\rho\_air}$$

$$h = \frac{V\_tercelup}{A}$$

Where:
h = dip depth (m)
V_tercelup = dipped volume (m^3)
m_total = total mass of the system (kg)
A = buoyancy surface area (m^2)
Calculations for Each Load Condition

a. Condition 1: No additional load

m_total = 50 kg

$$V\_tercelup = \frac{50}{1000} = 0.050\, m^3$$

$$h = \frac{0.050}{1.325} = 0.0377\, m \approx 3.8\, cm$$

b. Condition 2: By Motorcycle

m_total = 143 kg

$$V\_tercelup = \frac{143}{1000} = 0.143\, m^3$$

$$h = \frac{0.143}{1.325} = 0.1079\, m \approx 10.8\, cm$$

c. Condition 3: Motor + Passenger (51–60 kg)

m_total = 203 kg

$$V\_tercelup = \frac{203}{1000} = 0.203\, m^3$$

$$h = \frac{0.203}{1.325} = 0.1532\, m \approx 15.3\, cm$$

d. Condition 4: Motor + Passenger (61–70 kg)

m_total = 213 kg

$$V\_tercelup = \frac{213}{1000} = 0.213 m^3$$

$$h = \frac{0.213}{1.325} = 0.1608\,m \approx 16.1\,cm$$

e. ***Condition 5: Motor + Passenger (71–80 kg)***

m_total = 223 kg

$$V\_tercelup = \frac{223}{1000} = 0.223\,m^3$$

$$h = \frac{0.223}{1.325} = 0.1683\,m \approx 16.8\,cm$$

ii. Theoretical Analysis of Buoyancy Capability

Based on Archimedes' Law:

$$Fa = \rho f \times Vbf \times g$$

Where:
Fa = buoyancy force (N)
ρf = fluid density (water = 1000 kg/m^3)
Vbf = volume of dipped object (m^3)
g = gravitational acceleration (9.8 m/s^2)

iii. Calculation of Maximum Buoyancy

$$V\ total = 2 \times 0.216 = 0.432 m^3$$

$$Fa = 1000 \times 0.432 \times 9.8 = 4233.6\,N$$

$$\frac{Fa}{g} = \frac{4233.6}{9.8} = 432\,kg$$

Based on the calculation of the depth of the float dip at five different loading conditions, it can be concluded that the float system exhibits stable and predictable characteristics. The dip depth increases linearly from 0.49 meters in the no-load condition (50 kg) to 2.19 meters at a maximum load of 223 kg (motor + passenger 71-80 kg). This progressive improvement indicates that the design of the buoy has good stability and is in accordance with hydrostatic principles. In terms of operational capacity, the buoy system is able to withstand a total load of up to 223 kg with a dip depth of 2.19 meters, which shows that the buoyancy generated is still sufficient for maximum load conditions. Nevertheless, the optimal operational conditions are in the range of 143-203 kg (conditions 2-3) because it provides the best balance between the carrying capacity and the stability of the buoy. At this range, the depth of the dip is between 1.40-1.99 meters which still provides an adequate margin of safety.

For practical applications, the results of these calculations show that buoys can be used effectively for the transportation of motorcycles and passengers in waters. However, it is very important to consider a safety margin of at least 20-30% of maximum capacity to anticipate external factors such as waves, currents, and adverse weather conditions. Therefore, it is recommended to use a maximum working load of about 180 kg (80% of the theoretical capacity) to guarantee operational safety.

4. Conclusions

Based on the validation of the results of amphibious motorcycle tests, data was obtained that the buoy with dimensions of 179 cm × 37 cm × 38 cm per unit was able to produce a recorded buoyancy force of 119 N and withstand a maximum load of up to 223 kg in stable conditions at all load variations. Although there is a difference between the theoretical buoyancy force (2,185.4 N for a load of 223 kg) and the actual measurement results (119 N), the test validates that the buoyancy system with a total weight of 24 kg (2 units) has an adequate operational capacity with a safety margin of 55.3%. The final specifications show that the amphibious motorcycle can operate with passengers up to 80 kg, has maintained stability, a modular design for easy installation/removal, and a construction made of *styrofoam* coated with plywood and fibers that are resistant to water and weather conditions. These results confirm that the design of the amphibious motorcycle has a strong theoretical basis and has been experimentally validated, with the actual capacity (223 kg) still within safe limits although lower than the theoretical calculation (432 kg).

References

1. W. Syafitri and A. Rochani, "Analysis of the Causes of Flood Rob in Coastal Areas Case Study: North Jakarta, East Semarang, Brebes Regency, Pekalongan," *J. Study. Room*, vol. 1, no. 1, p. 16, 2022, doi: 10.30659/jkr.v1i1.19975.
2. R. D. Susanto, A. Nugroho Jati, and C. Setianingsih, "Design and Realization of Amphibious Robot," vol. 4, no. 2, pp. 2324–2330, 2017.
3. R. . Harahap, A. M. Siregar, F. Zulkarnain, and Affandi, "Utilization of Styrofoam Plastic Waste for the Manufacture of Paving Blocks," *J. Engineering Mater. Manufacturing and Energy*, vol. 5, no. 2, pp. 121–127, 2022.
4. A. Gunawan *et al.*, "DESIGN AND CONSTRUCTION OF FLUID MINI LAB AS A DATA COLLECTION OBJECT FOR RESEARCH PURPOSES AT MERCUBUANA UNIVERSITY Journal of Mechanical Engineering : Vol . 08 , No . 2 , June 2019," vol. 08, no. 2, 2019.
5. I. Hajar, B. Hafid, M. Muttaqin, and A. Purnomo, "Experimental investigation of buoy frame width on water motorbike stability response time," vol. 6, no. 1, pp. 77–83, 2025.
6. J. Vance, "Journal of Mechanical Design," *J. Mech. Des.*, vol. 130, no. April 2011, p. 40201, 2008.
7. Y. Irwan, N. Nugraha, T. Shantika, and L. Hartawan, "PROCEEDINGS OF THE NATIONAL SEMINAR IX Engineering and Application of Mechanical Engineering in the Itenas Industry, Bandung, November 9, 2010."
8. T. Syanjaya, J. A. Santoso, J. Betty, and K. Jusuf, "The Effect of Buoy Board Aids on Freestyle Swimming Skills," vol. 14, no. 4, pp. 216–222, 2024.
9. G. Rubiono and N. Finahari, "Buoyancy Analysis in Water Tubing Sports," *V-MAC (Virtual Mech. Eng. Artic.*, vol. 8, no. 1, pp. 1–5, 2023, doi: 10.36526/v-mac.v8i1.2669.
10. E. Edison, "Water Bicycle Design for Harau Valley Nature Tourism Vehicles," *Rang Tek. J.*, vol. 4, no. 2, pp. 339–347, 2021, doi: 10.31869/rtj.v4i2.2635.
11. D. Indrian, K. Kurniawan, and S. Rahayu, "An Analysis Study of the Influence of Cross-Section Geometry on the Speed of Motion of a Buoy with a Capacity of 100 kg," *J. Techno. and Manufacturing Engineering*, vol. 4, no. 1, pp. 47–60, 2022, doi: 10.48182/jtrm.v4i1.92.
12. Amanda Fauzika Maurisa Rohmah, A. Zudhan, and Bayu Setiaji, "Analysis of Ship Sinking in Kedung Ombo Reservoir Using the Concept of Archimedes' Law," *J. Researcher. Fig. and Ter.*, vol. 4, no. 2, pp. 15–20, 2023, doi: 10.31851/jupiter.v4i2.10345.
13. F. Teknik and U. P. Tegal, "MOTORCYCLE BUOY PLANNING," 2019.