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Archimedes' Principle Applied to Buoy Design for Measuring Purposes in Offshore Illumination Conditions

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ABSTRACT

Solar cells are becoming so common that every industry except PLN is already using them to produce alternative energy. The more solar cells used, the more light intensity meters are needed to calculate the amount of Illumination in a given area. This research entails constructing or implementing software, calculating the float's balance against the impact of waves, and determining how the float distributes load using the Archimedes principle. Electrical construction and chassis buoyancy are included in the design. When the density of water is greater than the density of the object, namely $\rho_a > \rho_b$ *objects (997 kg/m3 > 46.73 kg/m3), the variables obtained are the total weight of the buoy of 5,044 kg with the distribution of the object force of 49.43 N and the buoyant force of 1046.08 N. then this design produces the required buoyancy force when manufactured and used.*

***Keywords**: Archimedes' principle, buoyancy force, Concept design, Lifebuoy.*

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1. INTRODUCTION

A life vest, also known as a lifebuoy, is an essential safety device on all ships. This method endangers both the victim and the rescuer. As a result, intelligent buoys are made using modern technology, which rescuers can operate via remote control [1]. On the other hand, the existing intelligent buoy system is complicated, especially for women, children and people with disabilities. However, in this study, the buoy will measure light intensity for solar cell applications. The utilisation of solar cells is increasing, so that in every sector already using solar cells to make alternative energy apart from PLN, the more a light intensity meter is needed to calculate how much light intensity is in a place [2]. At this time, the sunlight hits the seabed directly without any obstacles on the beach, but the obstacle to taking measurements is the presence of unstable sea waves, so the lux meter reading is disturbed .

Lifebuoys and other personal flotation devices have been used on watercraft for years. A man overboard (MOB) situation occurs when a person falls from a boat during a water accident. In such a situation, life buoys can be thrown into the water at the individual [3]. Once the lifebuoy has been launched toward the person overboard, it is hoped that the lifebuoy is within the person's reach; if not, it is often more difficult to rescue the person overboard [4]. Nowadays, there are two types of lifebuoy: manual lifebuoy and intelligent lifebuoy. The manual lifebuoy is a conventional device, such as the doughnut-shaped lifebuoy ring [5]. When the victim is close to the rescuer's location, using a manually-operated lifebuoy seems prudent. It is since manual lifebuoys can only reach victims based on the strength of the rescuer throwing them. In certain drowning situations, at least one person may need to descend into the water with the life ring to rescue the victim [6].

Yang Lu et al. conducted research on the low-cost a buoy monitoring tool for offshore fish farming cages. The focus was on low-cost research and simple construction. An artificial intelligence (AI) buoy system measures air quality data autonomously and wirelessly transmits the information to server locations on land. Moreover, the data provides aquaculture staff with real-time information on water quality and enables server-side AI programs to use machine learning techniques to make short-term quality predictions. Specifically, we intend to provide a low-cost design for a simple float system proposed for measuring airspeed by incorporating electronic devices and server-side AI programs. Therefore, its application in the real world will cost 2015 dollars. AI proposes a system for measuring real-time dissolved oxygen, salinity, air temperature, and air velocity data. In addition, the AI buoy system offers short-term temperature and velocity estimates with mean squared errors of 0.021 °C and 0.92 cm/s, respectively. Next, we replaced expensive air velocity measuring devices with inexpensive flow sensor tubes [7]

This experiment produced a Lifebuoy that may be used as a measurement device in offshore illumination condition. This study intends to design a buoy that will act as a platform for monitoring the intensity of light. These findings will be used to create a buoy as a light intensity measuring platform. This study utilises the software design, the calculation of the buoy's equilibrium against the effect of waves, the load distribution of the lifebuoy, and the manufacturing process. Archimedes' principle will be developed and applied in this study. Archimedes' principle is one of the most basic laws of physics and fluid dynamics. According to this theory, an object submerged in a liquid will be lifted with the same force as the liquid it is transporting. This law, which is possibly the most fundamental in hydrostatics, explains the functioning and evolution of a wide variety of natural phenomena. Archimedes' concept is used to explain the isostatic principle, which claims that the earth's crust is balanced by its denser core [8]. Several calculations are performed to obtain the required method's results. The required design consists of obtaining the proper design form and calculating the buoy's displacement to achieve a distributed load [9]. After comprehending the design concept, it is essential to comprehend the types of waves that occur. The majority of ocean waves are wind-driven sea waves [10]. The parameters of ocean waves are the wave period, wavelength, wave height, and wave speed.

2. METHODOLOGY

This investigation takes an experimental approach to the design of a lifebuoy for use as a measuring device in offshore light conditions. The research methodology is depicted in **Figure 1**.

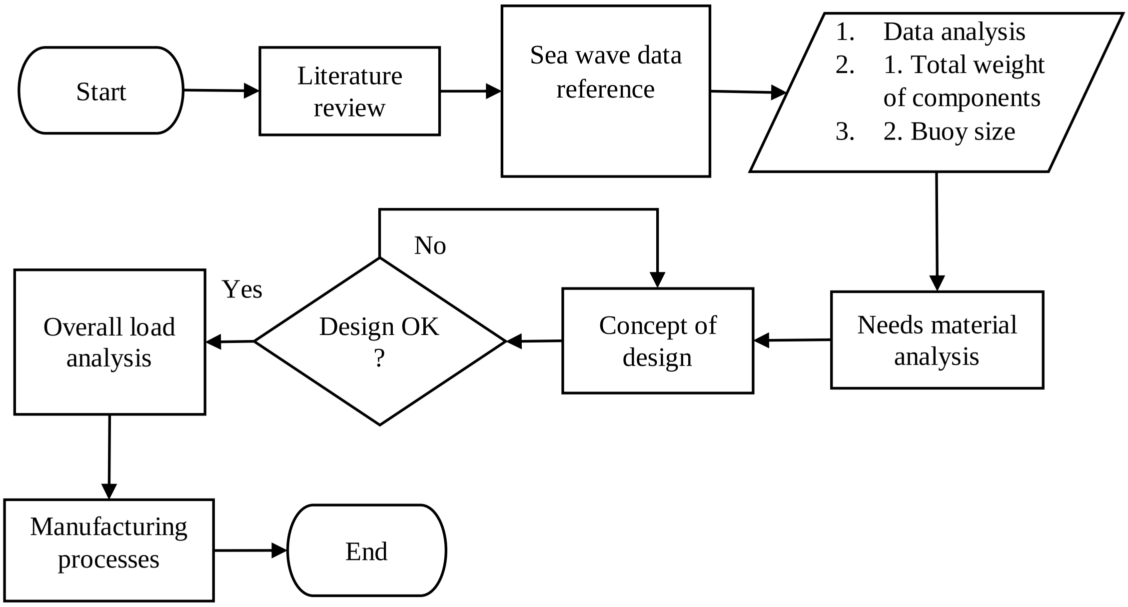


Figure 1. The research flowchart methodology

2.1. *Application of Archimedes theory and the theoretical concept of buoys*

The T wave period is the time it takes for the wave to move between the next two crests or troughs at a given location (seconds). Wavelength (λ) is the horizontal distance between two successive peaks or valleys (meters). The vertical distance between the wave's crest and trough is measured in wave height (H) (meters). To calculate the wave speed (v), divide the wavelength (L) by the wave period (T), then use equation 1 [11].

$$v = \frac{\lambda}{T} \tag{1}$$

Figure 2 illustrates how the length of a sea wave influences which buoy should be used. The buoy to be used has a diameter with a length that adjusts to ocean waves to balance the buoy. To raise the buoy force and float on the sea surface area, the Archimedes principle must be applied, which states that an object partially or completely immersed in a fluid will experience an upward force equal to the weight of the fluid displaced by the object [12]. The Archimedes concept is depicted in **Figure 3**.

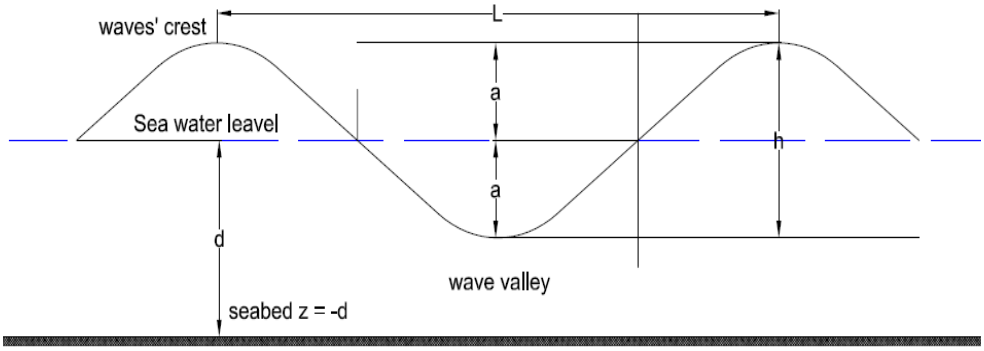


Figure 2. Wave Period schematic

Figure 3 demonstrates the calculation of the buoyancy force using Archimedes' law. Figure 4 can be used to apply the buoyancy equation based on Newton's first law with the restriction that if the item is at rest (equilibrium), the resultant force must be zero. In this lesson, Newton's first rule is illustrated by the expression 2-4[11] [3].

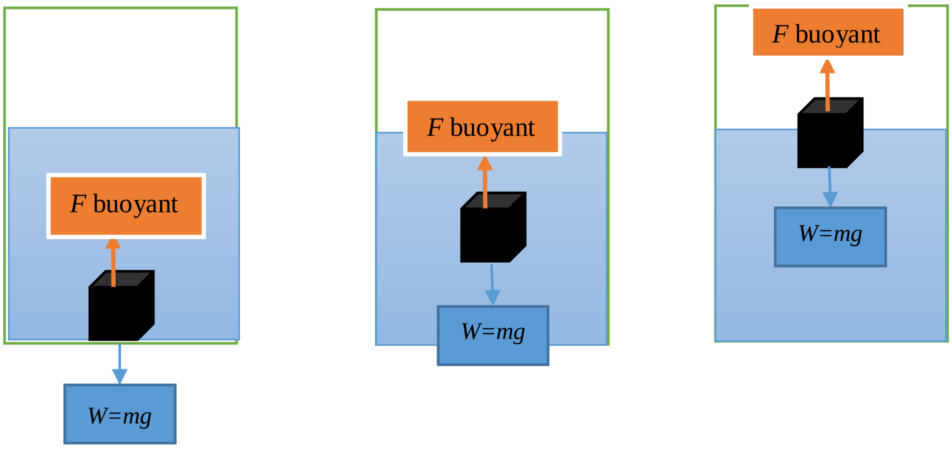


Figure 3. Archimedes concept

$$\sum F = 0 \tag{2}$$

$$Fa - Wb = 0 \tag{3}$$

$$Fa = Wb \tag{4}$$

Look for the relationship between mass and weight of objects;

$$Wb = m \cdot g \tag{5}$$

$$m = \rho \cdot v \tag{6}$$

By entering equation 6 into equation 5, we get the weight of the object in equation 7 [3].

$$Wb = \rho_b \cdot g \cdot v_b \tag{7}$$

Archimedes' law states that the magnitude of the upward force produced by a fluid on an item is equal to the mass of the fluid that the object displaces. For the buoy to float, the upward force, Fa, must be larger than the buoy's weight, *Wb*. [3].

$$Fa > Wb \tag{8}$$

$$\rho_f \cdot g \cdot v_f > \rho_b \cdot g \cdot v_b \tag{9}$$

$$\rho_f \cdot v_f > \rho_b \cdot v_b \tag{10}$$

$$\rho_b = \left(\frac{v_f}{v_b}\right)\rho_f \tag{11}$$

Where F_a, W, V_{bf}, V_b, ρ_f and ρ_b indicate the floating force in Newtons, the object's weight in Newtons, the volume of the item submerged in the fluid in metres cubic, the fluid's density in kilogrammes per cubic metre, and the object's density in kilogrammes per cubic metre. Equation 12 is utilised to calculate the fluid density.

$$\rho_f = \frac{m_b}{h_{bf} \cdot A} \tag{12}$$

Where ρ_f is the density of the fluid (kg/m^3), m_b is the mass of the object in kg, h_{bf} represent the high of the wave in cm and A is the cross-sectional the tube in cm^2.

2.2. *Ocean wave data retrieval*

Ocean wave data retrieval refers to previous research data, specifically rip currents in Pangandaran's coastal waters [13]. Table 1 displays the analysis results based on data on average wave height and wave period with an average speed of 0.8 m/s. **Table 1** shows the equation used to calculate the wavelength.

Table 1. Result of measurement wave

Wave height (Cm)	**Wave-1**	**Wave-2**	**Wave-3**
Min.	17	38	37
Max	80	64	53
Range	63	26	15
Average	48	53	44
Wave period (seconds)	**Wave-1**	**Wave-2**	**Wave-3**
Min.	3.10	6.57	7.39
Max	3.85	8.91	8.45
Range	0.74	2.35	1.06
Average	3.46	7.68	7.78

With measurements on ocean waves, researchers can design an appropriate buoy at the center of gravity so that when the wave period does not make the buoy upside down at the time of data collection. To obtain the total weight of all components, all components are measured by weight and calculate the total weight. The components that must be calculated can be seen in **Table 2**.

Table 2. Weight of component

Part name	**Purpose**
Arduino	Measurement control system controller
LUX Meter	light sensor
Micro SD	Data storage
LCD	Show data
Baterai	Power supply
Papan PCB	Cable jumpers
Box	Electronic system protection box
Sasis	As a support for all components

The center of gravity can be calculated by adjusting the dimensions of the buoy to the period of height and wavelength of the sea. Following the identification of needs and the calculation of all components, the buoy design concept can be determined based on the influence of ocean waves and the total weight so that the buoy is in the center of gravity position. The finite element method and Autodesk Inventor software simulation are used to affect the chassis during load analysis calculations. From the overall weight, simulation at the component's midpoint with the output parameters, namely stress analysis and displacement, can be performed.

3. RESULT AND DISCUSSION

3.1. Period of wave

Table 3 of the inquiry presents the findings of wave height and wave period measurements. The investigation utilises both the wavelength and the average wavelength to calculate the optimal buoy length. Using equation 1, one may determine the wavelength. The information regarding computations is presented in **Table 3**.

Table 3. Average wavelength

Wave		Wavelength (m)	Wave Height (m)
Wave-1	Maximum	2.77	0.40
	Minimum	2.48	0.17
Wave-2	Maximum	6.15	0.53
	Minimum	5.20	0.38
Wave-3	Maximum	6.23	0.44
	Minimum	5.91	0.37

This information indicates that the longest wavelength is 6.22 metres and the shortest is 0.53 metres. To achieve buoyant equilibrium, the buoy must be designed in accordance with the influence of the waves and the entire weight. **Figure 4** lists the overall weight of the components. The area of a cross-section for laying components is determined using the fundamental square formula, L=S2, followed by S=L, so that the total side of the cross-section is 150 mm. The preferred material for the cross section is acrylic, which is lightweight and resistant to damage from ocean waves. **Figure 4** displays the arrangement of each component.

Table 4. The total weight and area of each component.

Component	weight	Large
Arduino	25 gram	3500 mm^2
LUX Meter	10 gram	120 mm^2
Micro SD	18 gram	800 mm^2
LCD	24 gram	3200 mm^2
Baterai	34 gram	560 mm^2
Papan PCB	5 gram	14400 mm^2
Total	**126 gram**	**22580 mm^2**

3.2. Component and calculation force

In order to calculate the overall force of the component when submerged in water, it is necessary to calculate the cost of each component. The buoyancy resulting from Archimedes' law calculation is then obtained. Components that are computed include electrical parts, chassis, and buoys.

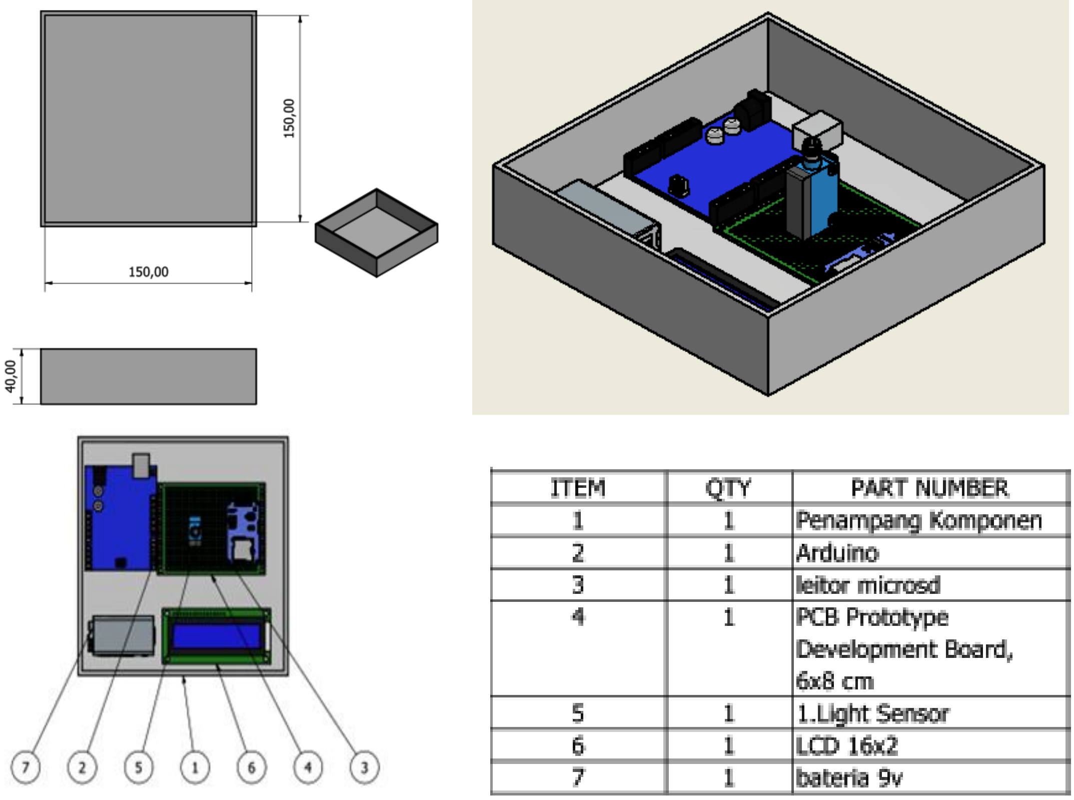
The design was built using the Autodesk Inventor software, which can display the density of the acrylic material used to construct the boxes; the material has a density of 1.06 g/cm^3 without component loads. The density-to-load conversion is expressed in grammes. Then determine the identity using equation 6 [14].

$$\rho = \frac{m}{V}$$

$$1.06\ g/cm^3 = \frac{m}{15 \times 15 \times 4}$$

$$1.06\frac{g}{cm^3} = \frac{m}{900\ cm^3}$$

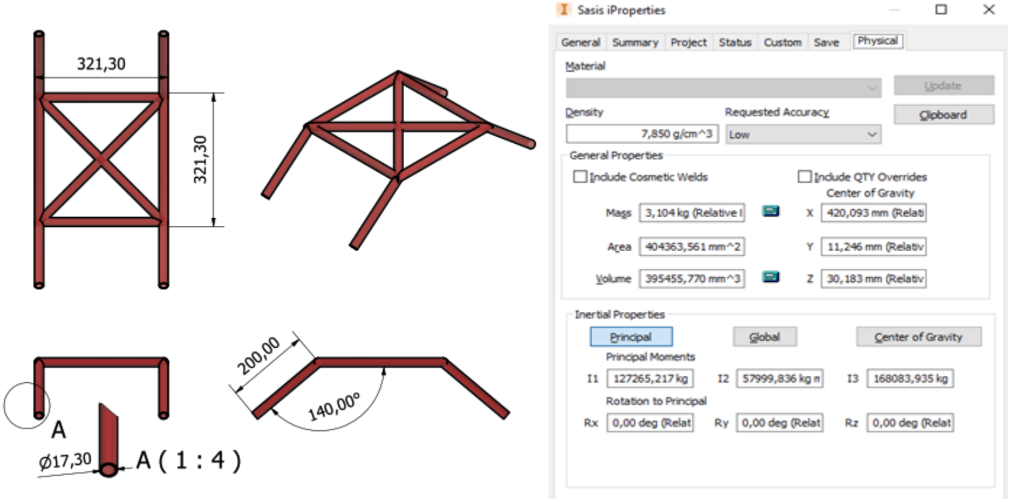
$$m = 1.06\frac{g}{cm^3} \times 900cm^3 = 954\ g \text{ or } 0{,}954 \text{ kg}$$



ITEM	QTY	PART NUMBER
1	1	Penampang Komponen
2	1	Arduino
3	1	leitor microsd
4	1	PCB Prototype Development Board, 6x8 cm
5	1	1.Light Sensor
6	1	LCD 16x2
7	1	bateria 9v

Figure 4. Box Component

The total weight of all electrical components is 126 g + 954 = 1080 g / 1.08 kg. The next step is to calculate the density on the chassis and convert it to a load in grams. **Figure 5** shows the shape of the chassis and the density listed in the design software.



Material

Density: 7,850 g/cm^3

Requested Accuracy: Low

General Properties

☐ Include Cosmetic Welds

☐ Include QTY Overrides

Mass: 3,104 kg (Relative I

Area: 404363,561 mm^2

Volume: 395455,770 mm^3

Center of Gravity

X: 420,093 mm (Relati

Y: 11,246 mm (Relativ

Z: 30,183 mm (Relativ

Inertial Properties

Principal Moments

I1: 127265,217 kg

I2: 57999,836 kg m

I3: 168083,935 kg

Rotation to Principal

Rx: 0,00 deg (Relat

Ry: 0,00 deg (Relat

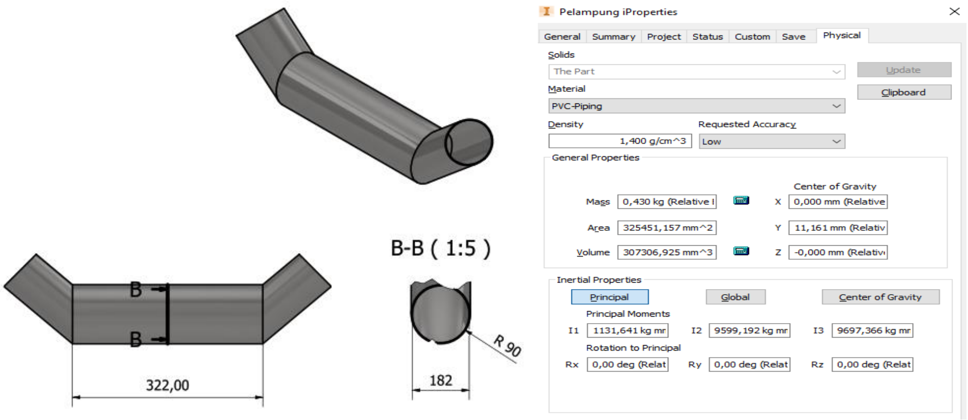
Rz: 0,00 deg (Relat

Figure 5. Chassis and iProperties

Figure 6 displays that the substance weighs 3.104 kg, or 3104 g. Steel SUS 304 was chosen for the chassis because to its superior performance in a harsh environment [15]. The total weight is thus 4.184 grammes or 4.184 kg. If kg is converted to kgf, the result is 4.184 kgf, which is equal to 41.03 N. Figure 7 depicts the buoy's dimensions and design, which will be utilised to support the electrical components of the light intensity measuring apparatus. The buoy is constructed from PVC tubing made of plastic with a total weight of 0.430 kg and a total double buoy type weight of 0.86 kg, providing a force of 0.86 kgf, or 8.4 N. The buoy's total weight and force can then be determined from **Table 4**.

Table 4. Force and weight of component

Component	weight	Force
Box and Chassis	4.184 kg	41.03 N
Buoy	0.860 kg	8.40 N
Total	**5.044 kg**	**49.43 N**



Solids: The Part
Material: PVC-Piping
Density: 1,400 g/cm^3
Requested Accuracy: Low

General Properties

Mass: 0,430 kg (Relative I
Area: 325451,157 mm^2
Volume: 307306,925 mm^3

Center of Gravity
X: 0,000 mm (Relative
Y: 11,161 mm (Relativ
Z: -0,000 mm (Relativ

Inertial Properties

Principal Moments
I1: 1131,641 kg mr
I2: 9599,192 kg mr
I3: 9697,366 kg mr

Rotation to Principal
Rx: 0,00 deg (Relat
Ry: 0,00 deg (Relat
Rz: 0,00 deg (Relat

Figure 6. Buoy design

From the force load, it is feasible to calculate the buoyant force acting upon the buoy. Using the function Fa for the conveyance force and Wb for the buoyant force, it is possible to compute the buoyant force using equation 2-7.

$$Fa > Wb$$

$$Fa = \rho_{fa} \cdot g \cdot A > 49.43\ N$$

$$Fa = 997 \frac{kg}{m^3} \cdot 9.8 \frac{m}{s} \cdot 0{,}107065\ m^3 > 49.43\ N$$

$$1046.08\ N > 49.43\ N$$

Next calculate the density of water and the density of objects

$$\rho_a > \rho_b$$

$$997\ kg/m^3 > \frac{5.004\ kg}{0.107065} = 46.73\ \ kg/m^3$$

$$997\ kg/m^3 > 46.73\ \ kg/m^3$$

According to the force calculation, the buoyant force is greater than the item's force; therefore, the load has a lower force than the buoyant force, allowing this design to be used in the production of offshore buoys where the density of water is more than the density of the floating object. The device will float in water, so this concept can be used to make an offshore buoy for detecting offshore light intensity. **Figure 7** depicts the shape of the design for the offshore buoy.

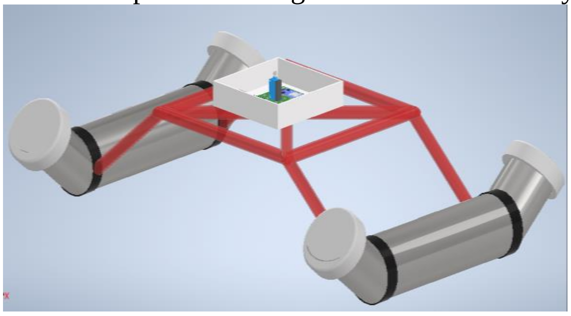


Figure 7. Design of lux meter offshore

3.3. *Ilustration of consept*

Table 3 explains the wave height by measuring the three waves between the minimum and greatest waves. The wave height is depicted in **Figure 8**. This illustrative example demonstrates that the wave height is not consistent, allowing the buoy to swing. As shown in **Figure 9**, a mixture of angles is required for the construction of a catamaran-type buoy to achieve a balanced shape. Using the weight of the concentrated force and the buoyancy provided by the buoy, the existence of a combination angle on the buoy provides a balance force if there are large waves. It can be determined from the distribution of these forces that F load < F floating [3].

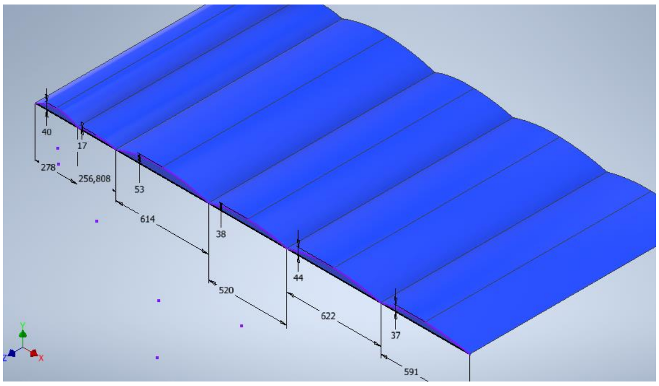


Figure 8. Illustration of wave

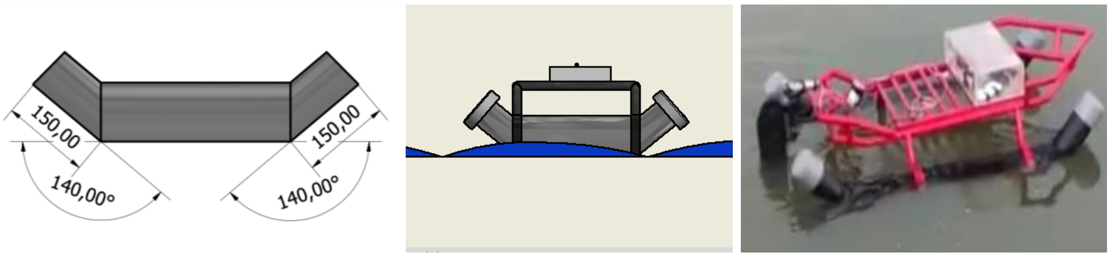


Figure 9. Design of illustrations and comparison of results

4. CONCLUSIONS

Following the completion of this research, the following conclusion can be explained in the form of points:

1. The weight of an electrical system along with the athlete's box is 1.08 kg, the chassis weight is 3.104 kg and the float weight is 0.430 kg, so the total weight of the components is 5.044 kg.
2. According to Archimedes' Law, the magnitude of the buoyant force must be greater than the magnitude of the force on the object to be immersed, so the buoyant force is 1046.08 N and the object force is 49.43 N. As a result, the buoyant force produced can provide buoyancy to this product.
3. The density of water has a magnitude of 997 kg/m^3 and the density of the submerged object is 46.73 kg/m^3 so that the density can provide a buoyant force on the object.
4. This concept can be produced because it has a value of the density of the object that is smaller than the density of water, which is greater because of the effect of buoyancy on this object. with the volume of this object of 107065 cm^3.

AUTHOR’S DECLARATION

Authors’ contributions and responsibilities

The authors contributed significantly to the conception and design of the study. The authors were responsible for data analysis, results interpretation, and discussion. The authors read the final manuscript and gave their approval.

Availability of data and materials

The authors have made all data available.

Competing interests

The authors declare that they have no competing interests.

REFERENCE

[1] I. Wardhana, V. A. Isnaini, R. P. Wirman, N. Novitasari, and O. I. Gunawan, “Rancang Bangun Lux Meter Real Time Berbasis Internet of Things,” *J. Fis. Flux J. Ilm. Fis. FMIPA Univ. Lambung Mangkurat*, vol. 19, no. 1, p. 43, 2022.

[2] L. Paradeshi, M. Mohanraj, M. Srinivas, and S. Jayaraj, “Exergy analysis of direct-expansion solar-assisted heat pumps working with R22 and R433A,” *J. Therm. Anal. Calorim.*, vol. 134, no. 3, pp. 2223–2237, 2018.

[3] P. Mohazzab, “Archimedes’ Principle Revisited,” *J. Appl. Math. Phys.*, vol. 05, no. 04, pp. 836–843, 2017.

[4] S. Thanakodi *et al.*, “A study into the development of a light weight smart life buoy prototype (LWSLB),” *Trans. Marit. Sci.*, vol. 10, no. 2, pp. 383–389, 2021.

[5] A. Collins, “U-SAFE: This Remote Controlled Life Buoy is super fast in saving lives,” 2017. [Online]. Available: https://factschronicle.com/u-safe-this-remote-controlled-life-buoy-is-super-fast-in-saving-lives-4619.html. [Accessed: 20-Jul-2022].

[6] P. Ridden, “Remote-controlled lifebuoy propels itself to save troubled swimmers,” *New Atlas*, 2019. [Online]. Available: https://newatlas.com/dolphin-oceanalpha-remote-electric-lifebuoy/60586/. [Accessed: 17-Jul-2022].

[7] H. Lu *et al.*, “A Low-Cost AI Buoy System for MonitoringWater Quality at Offshore Aquaculture Cages,” pp. 1–15, 2022.

[8] M. I. Maulana, A. Syuhada, and R. Kurniawan, “Experimental study on the effect of flow rate on the performance of two-blade archimedes screw turbine,” *J. Adv. Res. Fluid Mech. Therm. Sci.*, vol. 61, no. 1, pp. 10–19, 2019.

[9] M. Albana, R. Riantini, and I. Munadhif, “Perancangan Dan Pembuatan Prototype Remote Control Buoys Bertenega Baterai Dengan Akuator Propeller,” in *Proceeding 2nd Conf. Saf. Eng*, 2018, pp. 75–80.

[10] O. Sri Suharyo, “Rancang Bangun Alat Pengukur Gelombang Permukaan Laut Presisi Tinggi (a Prototype Design),” *Appl. Technol. Comput. Sci. J.*, vol. 1, no. 1, pp. 18–29, 2018.

[11] R. T. Beyer, A. O. Williams, and A. A. Bartlett, *College Physics*, vol. 28, no. 5. 1960.

[12] Z. Husin, B. Firmansyah, E. Lazuardi, A. Prasetyo, and N. Nurhasanah, “Studi Awal Perancangan Prototipe Remotely Operated Vehicle (Rov),” *J. Mikrotiga*, vol. 1, no. 2, pp. 31–36, 2014.

[13] E. Kusmanto and B. Setyawan, “Arus Rip di Perairan Pesisir Pangandaran , Jawa Barat,” *Ilmu Kelaut.*, vol. 18, no. 2, pp. 61–70, 2013.

[14] S. Sukarman, A. D. Shieddieque, C. Anwar, N. Rahdiana, and A. I. Ramadhan, “Optimization of Powder Coating Process Parameters in Mild Steel (Spcc-Sd) To Improve Dry Film Thickness,” *J. Appl. Eng. Sci.*, vol. 19, no. 2, pp. 1–9, 2021.

[15] Sukarman, C. Anwar, N. Rahdiana, and A. I. Ramadhan, “ANALISIS PENGARUH RADIUS DIES TERHADAP SPRINGBACK LOGAM LEMBARAN STAINLESS-STEEL PADA PROSES BENDING HIDROLIK V-DIE,” *Junal Teknol.*, vol. 12, no. 2, 2020.