



Remodeling and Basic Control System Integration on Lifebuoy for Marine Accident Mitigation

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Abstract

A remodeled lifebuoy prototype integrating a self-propulsion and remote-control system was developed to support marine accident mitigation. The design process combined iterative concept development, hydrodynamic comparison, system integration, fabrication, and prototype testing. Three geometrical models—a boogie board, a seabob, and the proposed lifebuoy—were evaluated using Maxsurf: Modeller and Maxsurf: Resistance under the same comparison condition. At the highest plotted speed of 20 knots, the proposed lifebuoy showed a total resistance of 0.3 kN, compared with 0.5 kN for the boogie board and 0.6 kN for the seabob, corresponding to reductions of 40% and 50%, respectively. The corresponding predicted power requirement was 2.868 kW for the lifebuoy, compared with 4.622 kW and 5.255 kW, giving reductions of approximately 38% and 45%, respectively. A physical prototype based on the selected design was fabricated and tested in an outdoor freshwater basin for propulsion, control, and buoyancy. The prototype test confirmed basic propulsion and control operation and evaluated buoyancy under a design payload of up to 70 kg; however, quantitative speed, response-time, endurance, remote-control range, and propulsion-efficiency measurements were not recorded in the present study. The results indicate that hydrodynamic form and wetted-surface area are important design variables, while further controlled experiments are required to validate the simulation quantitatively and assess operational performance.

Keywords: Lifebuoy; Emergency Response; Marine Accident; Basic Control System; Speed and Power Prediction

1. Introduction

Marine transportation is the foundation of the global trade and holding the essential role in the economic development of the world. However, with the rapid change of the global trade, the size of ships and the marine traffic also increased globally, which leads to a higher risk of marine accidents especially in shipping world [1] [2]. When the accident occur, impacts and losses that might be caused is not only in term of economy, but also life and environment [3]. According to the yearly maritime accident case inspections, the total of 23.814 maritime accidents involved injuries and deaths based on the record from 2014 to 2022 [1]. The international maritime organization (IMO), national maritime authority, shipping company, and other stakeholders have given serious attempts to increase the safety of life at sea. Even so, the number of maritime accidents remains high [4]. Even so, it still difficult to avoid the maritime accident to be happened entirely. Thus, reducing and preventing the accidents should be done as the initial effort for preventing loss of life and other casualties [5] [6].

According to marine accident statistics recorded from Japan Transport Safety Board (JTSB), the casualties can be classified into several types, such as: collision, contact, grounding, sinking, flooding, capsizing, fire, explosion, missing vessel, damaging facilities and fatalities [7]. The report shows accidents occur to recreational fishing vessel (11 casualties), followed by cargo ships (3 casualties), passenger ship and fishing vessel (2 casualties) in Japan alone. While others types, such as: tanker, tugboat, pusher, angle ferry-boat, work vessel, non-self-propelled vessel, public service vessel reported to have the least occurrence [7].

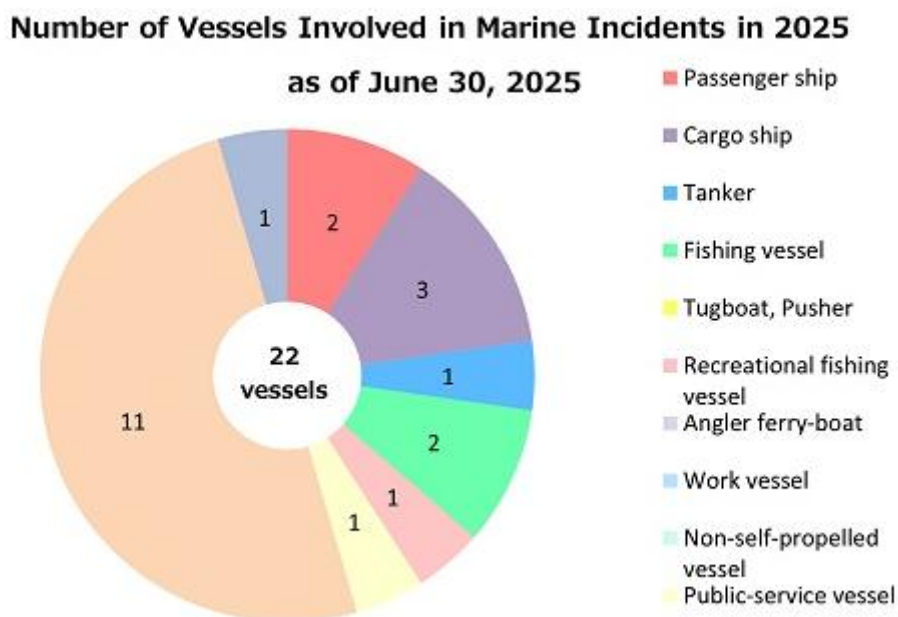


Figure 1. Number of vessels involved in marine incidents as per June 30th, 2025 [7]

As well as report of marine accident world-wide shows bulk carriers (96 casualties), with yachts and special purpose ships (5 casualties) which provided in Figure 3 [8]. According to the statistics provided by JTSB and ILO, type of ships with low mobility show lower amount of accidents due to a shorter shipping route [9]. Hence, those vessels encountered lower amount of ocean dynamics phenomenon, as well as interacting with marine traffic along the way of cruising and also in-and-out activities around the port or harbor [7] [8].

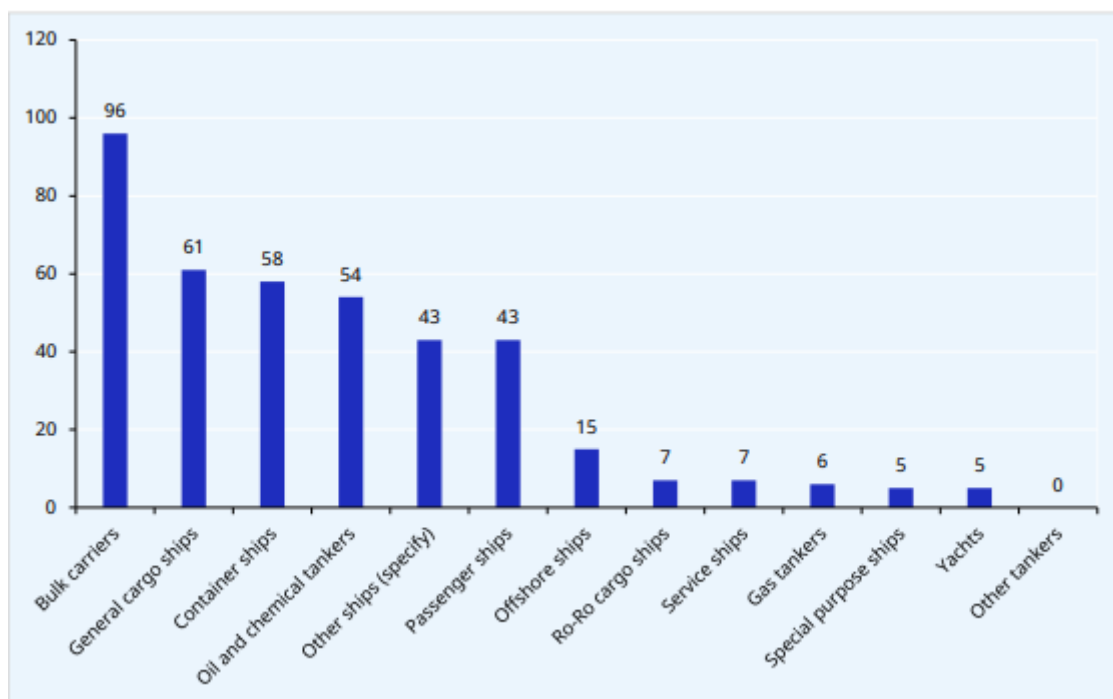


Figure 2. Global marine accident reported by 51 countries in 2023, except for Estonia 2021 and Germany 2021 [8]

Since maritime safety remains high, this topic still being one of the priorities in maritime industry, several equipment to support this matter need to be advanced further to meet the designated criteria and international regulation, such as SOLAS, IMO, Class Society and other specific regulations regarding the maritime industry or to enhance its capabilities while operating. One of the easiest equipment which can be modified or remodeled is Lifebuoy due to its

simple rounded conventional shape. This form allows this equipment can be designed even in a more radical way [10] [11] [12] and also integrated with many kinds of additional or supporting installment, such as thruster, control system, lightings, and other electronics. This availability to go further into the radical and combined with other instruments give Lifebuoy a wider range of design [13]. Furthermore, wider range of design may resulting easier modification, while keeping the main functions, following the regulation requirement and additional values integration. Previous investigations have demonstrated that the risk influential factors (RIF) of marine accidents are specified by uncertainty and complexity due to the dynamics of the ocean itself [14] [15]. Hence, the safety equipment need further advancements. Integrating self-propulsion and remote control system changes not only the arrangement of the equipment, but also procedures of mitigation since the product now owning new functions. The game shifted from only launching the equipment to accelerate and controlling it to target victims. Thus, the success rate of the mission can be improved to a level where not only those who can swim closer to the Lifebuoy who can be saved, but also those who cannot due to injuries, lack of capabilities to move in water, etc. On the other hand, self-propelling and control capabilities also may reduce the time consumes at the life-saving attempt and increasing the number of victims who can be saved.

Nomenclature

C_A	: Correlation Allowance
ΔC_F	: Roughness Factor
k_s	: Roughness Allowance
Re	: Reynolds Number
L_{WL}	: Length of Waterline
I	: Identity Tensor
$X(s, t)$	: Axis of the model's body
x	: General Point
s	: Arc-Length Coordinate
ℓ	: Model Length
$n(s, \theta)$	: Outward unit surface normal
Z	: Total lift force
M	: Total momentum

2. Method

The method of remodeling the product consists of four stages, those are: design, performance measurement, product manufacturing and painting, and prototype test. These whole procedures were done to find the most optimum model based on the performance and ergonomic criteria.

2.1. Design Stage

In this step, the process of design may become a more creative activity since the base model of Lifebuoy itself is considered to be very simple. Thus, many references can be taken into account to help the creative design thinking to provide the best form and accommodate all requirements which there in the marine safety regulation, similarly to the well-known sister ship design method in naval architecture. Ideation of the engineering, in this stage, might come back-and-forth as the model design can be stretched from the most simple and conventional to a quite radical and futuristic one. However, the process is not as ignite so freely as there still several engineering considerations which need to be added as variables in this stage. Although going thoroughly in creative designing activity, the spiral design from watercraft design principle still applied in the process since the product is indeed a marine vehicle. Moreover, the new lifebuoy is going to utilizes as a safety equipment and evacuation tool for victims of marine accident. Therefore, using spiral design approach in creating the design and evaluating it is essential to ensure that the design satisfy the functions required for accomplishing its intended mission.

From numbers of marine safety products which can be found in the market, there are two products which can be used as comparison to create the new Lifebuoy design, namely: boogie board and seabob. These two tools are widely used in surfing and other water sport activities at the beach. However, injuries have been reported occurred when using these equipment which reported in several studies. The injuries includes traumatic mitral valve regurgitation, neck injuries, head injuries, etc. which proved that even the conventional design of marine equipment still requires evaluation and correction in some parts, considering more factors [16] [17]. Thus, this stage then produced three models including boogie board, seabob and the new lifebuoy model, which can be shown as follows:

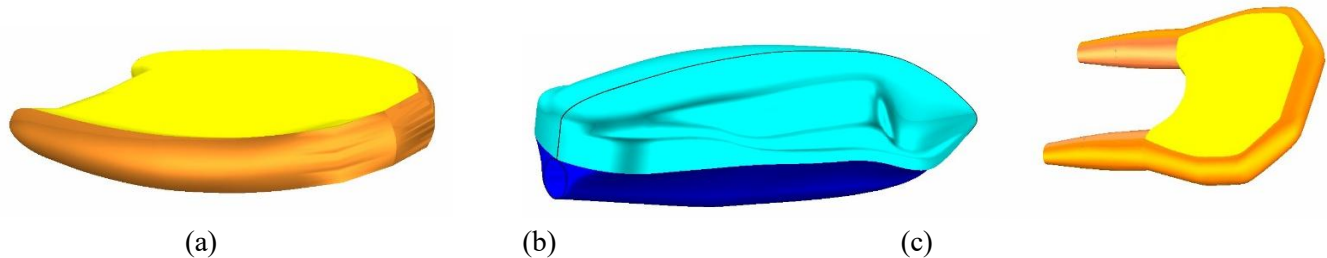


Figure 3. Product 3D models and its comparative products ((a) Boogie Board, (b) Seabob, (c) Lifebuoy)

As presented in **Figure 3**, the ideation of creating the new model flow to a more complex design. With such modifications considering aspects which already mentioned in section 1, paragraph 4, the new design finally be able to be integrated with the designated additional systems.

Table 1. Principal dimensions and physical specifications of the three compared models

Model	Length (m)	Beam (m)	Draft (m)	Design load (kg)	Material / surface
Boogie Board	1.2	1.2	0.10	70 kg	FRP
Seabob	1.2	1.0	0.2	70 kg	FRP
Proposed Lifebuoy	1.2	1.0	0.15	70 kg	FRP

2.2. Performance Measurement

In order to specify the requirement of propulsion system, measurements of the product performance need to be conducted. In this research, the measurement was done using Maxsurf: Resistance design tool which may result the speed and power prediction of the product in term of computer simulation. This software often utilized to measure the total resistance of ships, mainly those which designed using the conventional hull type [18]. There are several methods included in the software to compute, such as: methods for planning hull (Savitsky, Blount and Fox, Lahtharju, etc.), for displacement hull (Holtrop, Compton, Series 60, etc.), Yachts (Delft I, II, and III), Slender Body (including form factor $(1+k)$ and viscous interaction for multihulls). Besides that, correlation allowance (C_A) from ITTC also exist and also the roughness factor (ΔC_F), which can be written mathematically as follows [18]:

$$C_A = \left[105 \left(\frac{k_s}{L} \right)^{\frac{1}{3}} - 0.64 \right] \times 10^{-3} \tag{1}$$

where k_s is the hull roughness, typically have the value of 150×10^{-6} m. While L is the waterline length of the hull in meter. This correlation allowance formulated by ITTC (International Towing Tank Conference). And then,

$$\Delta C_F = 0.044 \left[\left(\frac{k_s}{L_{WL}} \right)^{\frac{1}{3}} - 10 \cdot Re^{-\frac{1}{3}} \right] + 0.000125 \tag{2}$$

where, the Re is the Reynolds number, L_{WL} is the length of waterline and k_s is the roughness allowance (value of 150×10^{-6} m can be used).

Since the whole size of Lifebuoy model is small, a more analytical computing method was chosen rather than the empirical ones. Due to this reason Slender Body method was taken into account to accomplish the simulations of the three models (see **Figure 3**). Moreover, the asymptotic technique used in this method to obtain analytical approximations for fluid flow (especially Stokes flow) around elongated particles, where the particle length is significantly greater than its thickness, allows this method to measure the total resistance of smaller and more slender models better compared to the empirical methods [19] [20]. Thus, in using Slender Body the fluid velocity must be determined and assuming the waterline along the draught $d \ll L$ is mostly straight because the simulation is conditioned in calm water. Hence, the fluid velocity can be written as follows

$$u(x) = \int_0^\ell \frac{f(s)}{8\pi\mu} \cdot \left(\frac{I}{|x-X|} + \frac{(x-X)(x-X)}{|x-X|^3} \right) ds \quad (3)$$

where, I is the identity tensor, $X(s, t)$ is the axis of the body, x is the general point, μ is the fluid viscosity, s is the arc-length coordinate, ℓ is the body length of the model and $f(s)$ is the force density, where

$$f(s) \sim \frac{\ln\left(\frac{\ell}{a}\right)}{4\pi\mu} f(s) \cdot (I + X'X') \quad (4)$$

The slender body surface is divided into discrete elements Γ_k , based on the concept of the slender body method, which treats the body as a series of thin, longitudinal sections. Each section has a simply calculated added mass, and the combined effect along the body's length is integrated to estimate the lift force and moment. Given a quadrature accuracy tolerance ϵ_{quad} , there exists a region $\mathcal{N}_{\Gamma_k}$ around each element where, for target points outside this region, standard quadrature rules (a combination of Gauss-Legendre and periodic trapezoidal methods) are sufficient. For target points within $\mathcal{N}_{\Gamma_k}$, special quadrature rules are applied instead [19] [20]. Hence, we obtain

$$I(x,s) := \int_0^{2\pi} G(x,y(s,\theta)) \sigma(s,\theta) J(s,\theta) d\theta \quad (5)$$

In this approach, asymptotic analysis used to show that the leading-order contribute to the integral for a point x on the surface of the model's body adjacent to position x_{Aft} comes from the force distribution at $|x_{Fore} - x_{Aft}| = O(a)$. Since $a \ll \ell$, the approximation $f(x_{Fore}) \approx f(x_{Aft})$ can be determined [21]. Thus, the net lift force on the body

$$Z = \int_{x_{Aft}}^{x_{Fore}} m_a(x) [-\dot{w} + x\dot{q}] dx + U \int_{x_{Aft}}^{x_{Fore}} \frac{\partial}{\partial x} [m_a(x)(w - xq - U\alpha)] dx \quad (6)$$

where x_{Fore} representing the coordinate of the fore body of the model, and x_{Aft} representing the coordinate of the after body of the model. Similar approach can be used to obtain the approximation of the momentum prediction in slender body method calculation, which can be written as follows

$$M = \int_{x_{Aft}}^{x_{Fore}} x m_a(x) (\dot{w} - x\dot{q}) dx - U \int_{x_{Aft}}^{x_{Fore}} \frac{\partial}{\partial x} [m_a(x)(w - xq + U\alpha)] dx \quad (7)$$

Combined with powering estimation, approximation of effective horse power needed by each model can be obtain through the resistance simulation using Maxsurf: Resistance software to create a comparison in the attempt to find the most optimum model based on these criteria.

2.3. Product Manufacturing and Painting

Continuing to the next step of the overall process of remodeling lifebuoy is the manufacturing and painting stage. These works involves the making of the model based on the blueprint, integrating propulsion system compartments, control system instruments and also painting.



Figure 4. Product Manufacturing and Painting ((a) Body manufacturing, (b) Propulsion system installment, (c) Remote control integration, (d) Painting correction)

The manufacturing of lifebuoy was made in such a way, so the whole system can be installed. For the electrical and control system, there are several instruments which being integrated, including electric speed control, battery, remote receiver, cooling hose that consist of inlet and outlet hoses, lighting instruments, and other wirings. From the calculation of the electrical and propulsion requirements of the product can be obtained. Since the product will be used on water, all of the electrical instruments, including the control system were all placed in a watertight container. This container was made of plastic to reduce the overall displacement of the lifebuoy. In this way, the electrical and control system instruments can be stored within the lifebuoy safely without decreasing the buoyancy of the product significantly. This procedure was attempted to make its lightweight (LWT) as minimal as possible to increase the amount of payload which also increased if deadweight (DWT) increased. Moreover, the product was painted in with bright colors (yellow and orange) to enhance visibility while operating at sea. Although it already equipped with lightings, it is still important to do this in case of emergency where there is a lighting instrument failure which may cause the lights to turn off. Besides that, bright colors psychologically will attract more attention compared to darker colors [22]. Thus, the lifebuoy shall be easier to be recognized from a far and so does the disaster victim on board.

2.4. Prototype Test as Validation

Experiment or test on real field is necessary for every research for validation purposes. This stage not only bringing real-time data, but also ensuring that the product truly can be applied or utilized in real life event. The same reason also motivated us to test out our product prototype prior make it public, to validate our design and simulation as well as finding what's need to be improved to make the product better for commercialization purposes.

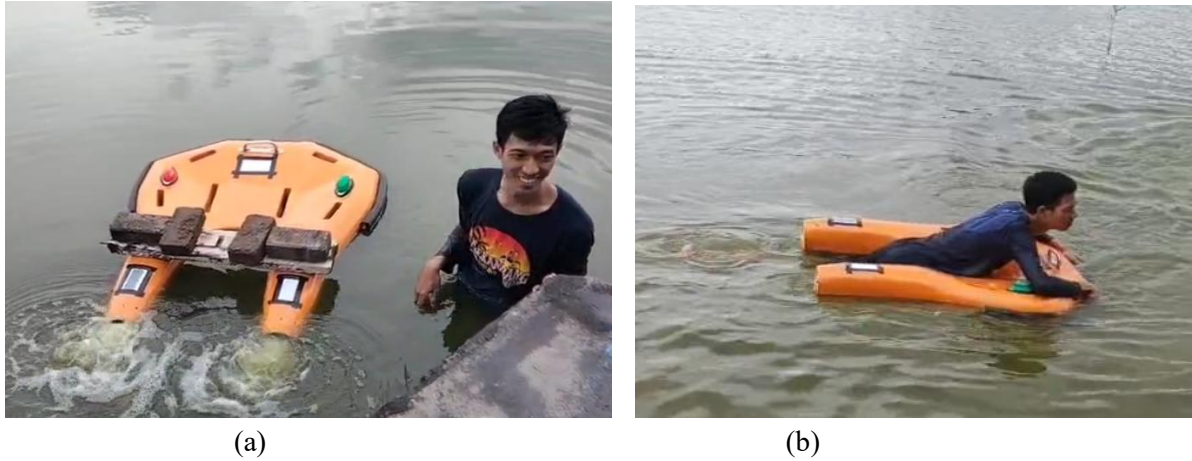


Figure 5. Prototype Test ((a) Propulsion and Control Test, (b) Weight Test)

In prototype test, there are two steps in the conduct, such as propulsion and control test and weight test. The propulsion and control test were done to ensure the propulsion and control system to work well on water, without electrical failures and signal miscommunication due to water contamination from small leakages. The weight test is to examine the product capability to carry the design load (which up to 70 kg) while operating without losing control and its buoyancy. As most of us know, losing buoyancy is crucial while operating at sea since this phenomenon leads to sinking or capsizing which make survival for the disaster victim turns to be impossible. Furthermore, the test were not conducted in the open sea to reduce the involvement of the viscosity and density of salt water to support the buoyancy of the product. In contrast, the prototype test was conducted in an outdoor anthropogenic basin filled with fresh water to test reliability of the product to preserve its buoyant. Here are the prototype general specifications.

Table 2. Prototype General Specifications

Component	Specification
Propulsion motor	Drive: underwater motor, Model 3550, KV 500, Power 600 Watt, Voltage 12-24 V, Thrust 5 Kg, Nylon shell material with aluminum motor cover. Total of 2 units.
Battery	1200 mAH Lithium Battery
Electronic speed controller	F405 V3 3-6S 30 x 30 FC&BLHELIS 60A
Remote control / receiver	Fly Sky FSi6 type, 6 channels, Bandwith 500 KHz, Power 6V : 1,5V, Range: RF 2,4-2,48 GHz.
Lighting	Strobo Warning Light 220 V (Red and Green); 42 LED Waterproof Marine Boat LED Light
Watertight enclosure	Plastic enclosure; FRP composite; 25 cm x 10 cm x 10 cm
Prototype material	FRP composite with three reinforcing layer

3. Results and Discussions

Based on the research which being conducted to remodeling and integrating basic control system in lifebuoy, several results can be obtained from the computer simulation and prototype test. On the simulation, lifebuoy performance was compared to conventional boogie board and seabob with the same size and load capacity. The result shows that seabob produce the biggest resistance compared to the other two products, while lifebuoy make the lowest with boogie board in the middle. This result occur due to the difference of shapes in every product with seabob having more well-rounded form compared to lifebuoy and boogie board which tend to be flatter.

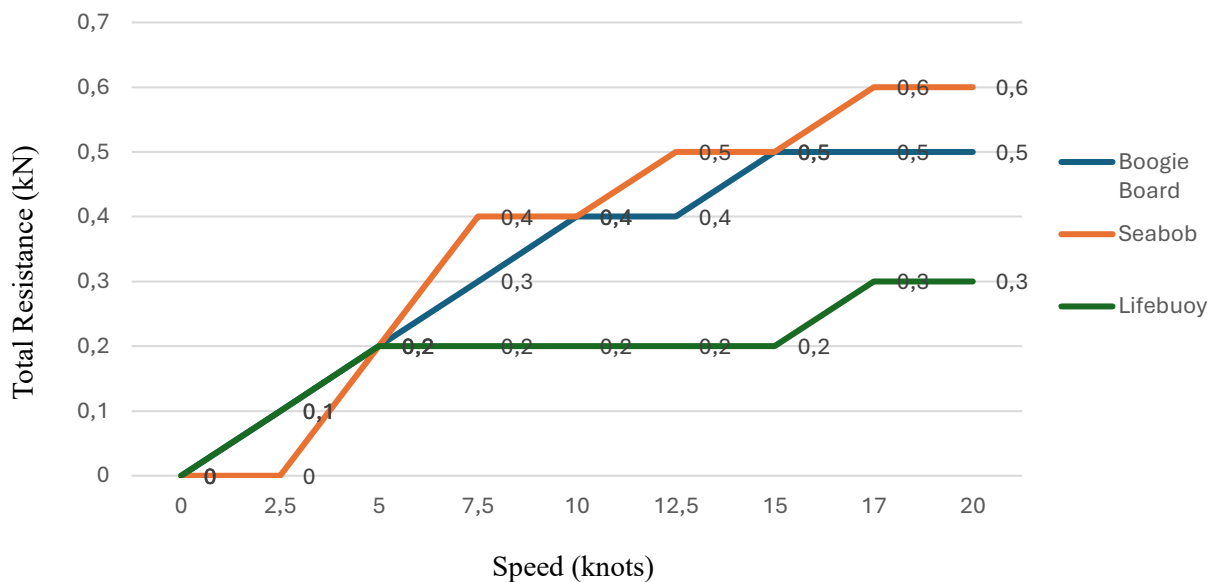


Figure 7. Total Resistance of Lifebuoy, Seabob, and Boogie Board

This thing latter caused the seabob to have more interaction with water due to bigger amount of wetted-surface area (WSA) and resulting more resistance to be produced. This variable can easily be observed visually, like what presented in **Figure 4**. Scientifically, resistance explained as a force which resists the movement of an object during its interaction with fluid. Thus, to reduce the amount of resistance produced by a product when operating is to reduce its contact with a fluid substance (in this case is water) and reducing the wetted-surface area (WSA) is one of the methods to reduce resistance. Besides that, the density of the fluid and number of additional compartments installed in the product also influence the total resistance. As can be seen in the **Figure 4**, boogie board having less well-rounded shape on top, but still produced a quite big amount of resistance between the three. This phenomenon occurred due to most of the body of the product immersed in water. As we know the water have higher density compared to air, even though the simulation was specified to run in fresh water with 1000 kg/m^3 , the amount is still a lot higher than air with only 1.225 kg/m^3 . Contrary, lifebuoy produced the lowest amount due to the lower amount of wetted-surface area (WSA). Although having the similar condition like boogie board, lifebuoy consists of a more streamlined fore and after body. Moreover, lifebuoy have less WSA at the after body compared to boogie board.

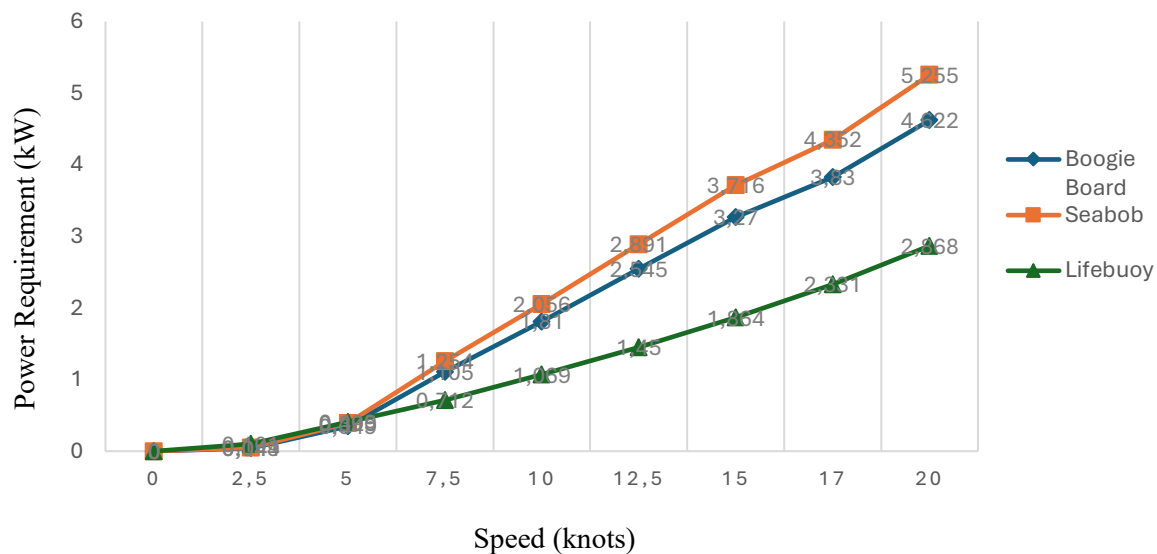


Figure 8. Power Requirement of Boogie Board, Seabob, and Lifebuoy Based on Resistance Calculation

Based on the calculation of total resistance of the three product, the power requirement can be obtained. Since the amount of resistance will always in-line with the power required to move an object or product in the designated speed, of course seabob is the product with the biggest amount of power requirement among all with lifebuoy in the lowest place. Although this is an obvious event, there is a unique phenomenon which needed to be highlighted, that is the phase of power requirement increases in lifebuoy. Compared to the other product, lifebuoy have the least fluctuation in the increase. This indicates a stable of power consumption increases although the increase of its total resistance fluctuate in some parts, specifically at 5 knots and 17 knots. This phenomenon occur due to a more stable fluid flow along the object while interacting with fluids. If we look at the design which presented below,

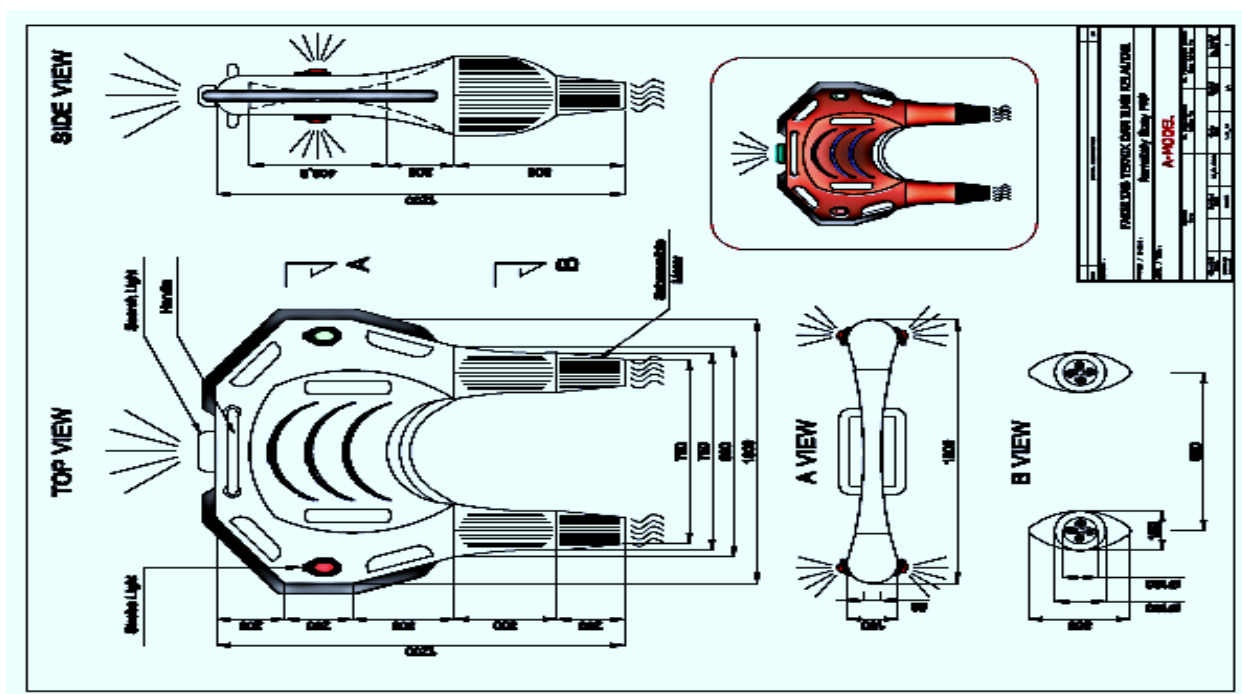


Figure 9. Lifebuoy Design

The product designed in almost approaching the perfect tear drop shape. In the perspective of hydrodynamic, the most ideal shape based on resistance criteria is the tear drop shape due to its streamline curvature which create a more stable transitional flow where the fluid flow have more area to rest prior released at the after body (outlet flow). This

condition then creates less eddies since less turbulence being generated. This fluid flow stability then contribute to a more stable power requirement increases although the amount of total resistance increases fluctuate.

4. Conclusion

In conclusion, the research demonstrates that the lifebuoy outperforms the seabob and boogie board in terms of hydrodynamic efficiency, producing the lowest resistance. The differences in performance are largely attributed to the shapes of the products, with the lifebuoy's streamlined design resulting in less wetted-surface area (WSA) and consequently lower resistance. The seabob, having a more rounded shape, interacts more with the water, creating greater resistance. The boogie board, while less rounded than the seabob, still produces significant resistance due to most of its body being immersed in water. Furthermore, the lifebuoy also shows the most stable power requirement increase compared to the other two products. This stability is linked to its nearly ideal tear-drop shape, which minimizes turbulence and fluid flow instability. As a result, the lifebuoy maintains a more consistent power consumption even as total resistance fluctuates. These findings highlight the importance of shape and WSA in the design of water-based products, particularly in improving efficiency and reducing energy consumption.

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Future Works

Since the experiment of the dummy test of the novel lifebuoy model have been going successfully, in the next step there shall be an attempt to optimize it both the by using numerical investigation and experimenting the dummy model in real-field condition to identify its performance during operation. Moreover, the dynamic of the sea shall draw more variables which can be new considerations for the research before entering the prototyping and finalization stages.

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