Design and analysis of low-cost underwater glider for shallow water

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Abstract. This paper aims to design a low-cost underwater glider to operate in shallow water. The proposed design was developed by manufacturing engineering software. Analysis of the hull using manufacturing engineering software and 3D computer-aided design (CAD). The analysis of hydrodynamics using computational fluid dynamics (CFD). This glider was designed to operate in shallow water, coastal, lake and river for a maximum depth of 10 m and a maximum speed of current 12,96 km/h, or 3,6 m/s. To reduce and minimize the cost to manufacture this underwater glider, the mechanics, electrical, electronics, and power source were using common tools on the market, not on demand. Based on numerical model, the hull pressure had 30,127 psi or 0,2077162 MPa for maximum depth 10 m and max speed 12,96 km/h. Maximum pressure occurs on the nose and behind the wings. This unmanned vehicle was designed to be in 9 compartments. The first compartment and 8th compartment are used for ballast tanks. The others for: mechanics of ballast system, altimeter and attitude controller, payload, battery pack, main controller part, propulsion system, and propulsor.

1. Introduction

Underwater gliders are used in oceanographic research applications such as underwater topography or mapping, environment monitoring and inspection, marine observation, and any other operation including military [1-4]. With this vehicle, a lot of missions or studies of scientists in exploring the sea or underwater become easier, for example, research on marine life, studies of mineral potential, biology and chemistry, and environmental rescue missions. In addition, missions in the military field such as underwater observation and monitoring of the threat of mines, chemical contamination, and radioactivity can also use this vehicle. The capacity of sea gliders to collect data for long durations and travel long distances. Sea gliders are based on buoyancy engines, that change the buoyancy relative to the underwater environment by changing their relative buoyancy to sequentially descend and ascend in saw-tooth gliding patterns [1].

The first underwater glider project was published by Stommel [5] in 1989. This article discusses the imagination and possibilities of using a floating fleet in the sea. Recently, a lot of research projects regarding underwater gliders such as ALBAC glider [6], SLOCUM glider [7], Spray glider [8], Sea glider [9], Libredae XRAY glider [10], Deep glider [11], Folaga glider [12], etc. Underwater glider projects are not limited to a laboratory-scale [5-9] but also on a large scale [10-12] and even commercial [13]. In general, underwater gliders have two kinds of mechanisms to glide downward and upward. The first mechanism uses a payload system [6] and the second way utilizes a buoyancy
engine instead. Most of these gliders [7-9] use the last engine to dive in and dive up due to the simple and low-cost mechanism.

In recent years, myriad studies on gliders at sea scale and still a few research on gliders for applications in shallow waters. Shallow water gliders can be applied to monitor underwater conditions not only on the sea coast but also in rivers, lakes, estuaries, and agricultural cultivation ponds. Shallow water gliders can be applied to monitor underwater conditions not only on the sea coast but also in rivers, lakes, estuaries, and agricultural cultivation ponds. The shallow water glider can be combined with unmanned surface vehicles to monitor the aquatic environment. Shallow water has a complicated working environment for a glider. Gliders for shallow water environments must have the ability to adjust the glider engine quickly to avoid collisions and be able to maneuver swiftly.

Some research projects on gliders in shallow water include: Alvarez et al. created a low-cost underwater vehicle named (Folaga) for shallow coastal areas used for sampling water and is equipped with a global positioning system (GPS) [14], a hybrid between standard oceanographic gliders and self-propelled autonomous unmanned vehicle (AUV) called the Glint'08 experiment designed by Caffaz et al. [15], Page et al. developed (ROUGHIE) a laboratory-scale low-cost glider capable of diving at a depth of 3m, turning tight with a minimum radius of 3m, and 60 hours of endurance [16], a glider that uses a pneumatic buoyancy engine made by Wolek et al. [17], Liu et al. initiated a glider design for shallow water (Enlightens) which can descend to a depth of 3m and turn with a radius of 10m [18]. The majority of these gliders use aluminum and fiberglass as the main material for making the hull. As we know, aluminum has the advantage of being non-corrosive, lightweight, and easy to shape making this material ideal for making hulls from gliders. However, since aluminum currently has a high price, making a low-cost glider is not the right choice. Meanwhile, if the glider uses fiberglass, the price is much cheaper, but if it is related to environmental issues, this material is not suitable for making shallow water gliders. Therefore, this study proposes the design and manufacture of gliders for shallow waters using High Density Polyethylene (HDPE) as the main ingredient for the hull. The advantages of this material have the ability and strength like aluminum but at a relatively cheaper price. In this paper, we will describe the design and architecture as well as analysis of both hull performance, hydrostatic analysis, mechanics, and control device parts.

This paper is organized as follows: Section I introduces sea glider design and architecture; Section II and section III discuss the analysis of hull performance and hydrodynamics, respectively. Section IV exposes plans for the materials, mechanical and control parts. The simulation result presented in section V. Finally, section VI contains the conclusions of this study.

2. Material and Method

In this study, the underwater glider was designed with a total length of 2000 mm, a diameter of 225 mm and a total width including the wingspan of 1220 mm. High Density Polyethylene (HDPE) is used as the main material for the hull of this underwater glider. The underwater glider is equipped with two wings that are installed in the middle of the right and left sides of the body with have the angle of 61.5 degrees relative to the main body of the glider. This prototype has the elliptical front and rear construction to reduce the resistance received when the underwater glider dives. The elliptical front is 315 mm long and the elliptical rear is 350 mm long. While the length of the main body without the elliptical front and rear covers is 1335 mm. Finally, at the rear section of this prototype has a rudder fin with a height of 227 mm and is designed to maintain the stability of the underwater glider when operating. Figure 1 shows the hull design of our underwater glider. To support its operational activities, this underwater glider is divided into 9 compartments. The first and 8th compartment are used as ballast tanks. While the other compartments are used for other components such as: mechanics of ballast system, altimeter and attitude controller, payload, battery pack, main controller part, propulsion system, and propulsor. The detail information can be seen in section five.
There are three main criteria used in this glider simulation, namely: a. floating condition, with a glider water-laden (T or D) of 175 mm, b. Submerged floating condition or in equilibrium condition, at a depth of 5 m, c. fully submerged conditions, at a depth of 10 m. This hydrostatic analysis was carried out to obtain the values of the hydrostatic characteristics of the underwater glider which was developed using the Maxsurf software. Hydrostatic analysis in this study uses 2 criteria, floating conditions and submerged conditions, taking into account the hydrostatic value of a fully submerged glider at any depth, will produce the same hydrostatic value. Figure 2 shows the result of hydrostatic analysis in submerged condition and the result of hydrostatic analysis in floating environment as shown in Figure 3.
Figure 3. Floating condition analysis

The hydrostatic curve at submerged condition can be shown in Figure 4 and while Figure 5 shows the hydrostatic curve analysis at floating condition. Table 1 presented the parameters of hydrostatic analysis of the glider at floating and submerged conditions.

Figure 4. Hydrostatics curve at submerged condition, (developed by simulation of Maxsurf Software, based on hydrostatic data, Basic Ship Theory,[19])

By using the same criteria as mentioned above, namely a. floating condition, with a glider water-laden (T or D) of 175 mm, b. Submerged floating condition or in equilibrium condition, at a depth of 5 m, c. fully submerged conditions, at a depth of 10 m. With one assumption, the Bonjean Curve can be calculated using Maxsurf Software with the results in Table 2 and Figure 6.
| Parameter                  | Floating Conditions | Submerged Conditions |
|---------------------------|---------------------|----------------------|
| Displacement              | 0.0593 T            | 0.0702 T             |
| Volume (displaced)        | 0.058 m³            | 0.068 m³             |
| Draft Amidships           | 0.175 m             | 0.225 m              |
| Immersed depth            | 0.175 m             | 0.225 m              |
| WL Length                 | 2 m                 | 2 m                  |
| Wetted Area               | 0.919 m²            | 1.296 m²             |
| Max sect. area            | 0.033 m²            | 0.04 m²              |
| Waterpl. Area             | 0.32 m²             | 0 m²                 |
| Prismatic coeff. (Cp)     | 0.878               | 0.851                |
| Block coeff. (Cb)         | 0.736               | 0.672                |
| LCB %                     | 0.724               | 0.012                |
| LCF %                     | 0.33                | -1                   |
| KB                        | 0.098 m             | 0.113 m              |

**Table 1.** Hydrostatic values at floating and submerged conditions

**Figure 5.** Hydrostatics curve at floating condition (developed by simulation of Maxsurf Software, based on hydrostatic data, Basic Ship Theory,[19])
3. Result and Discussion

3.1. The Analysis of Hull Performance

The hull resistance is analyzed to determine the velocity in the body and the area traversed by this underwater glider. The resistance analysis is carried out using the Computational Fluid Dynamics (CFD) method. In accordance with the purpose of this design, which is intended for shallow water,

![Bonjean Curve](image)

**Figure 6.** Bonjean curve (developed by simulation of Maxsurf Software, based on hydrostatic data, Basic Ship Theory [19])

| WL/ST | 1   | 2   | 3   | 4   | 5   | 6   | 7   |
|-------|-----|-----|-----|-----|-----|-----|-----|
| 0     | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 0.05  | 0.001016 | 0.003679 | 0.003084 | 0.006156 | 0.006562 | 0.006562 | 0.006562 |
| 0.1   | --  | 0.007162 | 0.011679 | 0.016447 | 0.017042 | 0.017042 | 0.017042 |
| 0.15  | --  | 0.012028 | 0.021111 | 0.02735 | 0.028112 | 0.028112 | 0.028112 |
| 0.2   | --  | --   | 0.028329 | 0.036329 | 0.037284 | 0.037284 | 0.037284 |
| 0.225 | --  | --   | 0.028968 | 0.038514 | 0.039689 | 0.039689 | 0.039689 |

| WL/ST | 8   | 9   | 10  | 11  | 12  | 13  | 14  |
|-------|-----|-----|-----|-----|-----|-----|-----|
| 0     | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 0.05  | 0.006562 | 0.006562 | 0.006562 | 0.006562 | 0.006562 | 0.006562 | 0.006562 |
| 0.1   | 0.017042 | 0.017042 | 0.017042 | 0.017042 | 0.017042 | 0.017042 | 0.017042 |
| 0.15  | 0.028112 | 0.028112 | 0.028112 | 0.028112 | 0.028112 | 0.028112 | 0.028112 |
| 0.2   | 0.037284 | 0.037284 | 0.037284 | 0.037284 | 0.037284 | 0.037284 | 0.037284 |
| 0.225 | 0.039689 | 0.039689 | 0.039689 | 0.039689 | 0.039689 | 0.039689 | 0.039689 |

| WL/ST | 15  | 16  | 17  | 18  | 19  | 20  |
|-------|-----|-----|-----|-----|-----|-----|
| 0     | 0   | 0   | 0   | 0   | 0   | --  |
| 0.05  | 0.006562 | 0.006562 | 0.006525 | 0.004411 | 0.000001 | --  |
| 0.1   | 0.017042 | 0.017042 | 0.016993 | 0.014066 | 0.006371 | --  |
| 0.15  | 0.028112 | 0.028112 | 0.028051 | 0.024329 | 0.013883 | --  |
| 0.2   | 0.037284 | 0.037284 | 0.037204 | 0.032258 | 0.016654 | --  |
| 0.225 | 0.039689 | 0.039689 | 0.039577 | 0.033116 | --   | --  |
with a wavelength less than 19 m and a current strength of about 5 knots. The speed of the underwater glider used for hull analysis is 7 knots or 12.96 km/h.

Figure 7 shows the distribution of the velocity flow rate around the sea glider, simulated by Solidwork Software as Computational Fluid Dynamics method, to determine hydrodynamics characteristic around sea glider while having velocity speed. Based on this analysis, the highest flow rate of 7.8 knots occurred in the front area of the hull. While at the stern, precisely in the propeller area, the flow rate decreased in speed. Figure 7(a) shows the velocity analysis on the side view. Figure 7(b) shows the top view. While the isometric view or 3D view of this analysis can be shown in Figure 7(c).

3.2. The Analysis of Hydrodynamics

Hydrodynamic analysis was developed using the CFD method to determine the pressure that occurs on the body of the glider when it is under the water level. The analysis was carried out at a depth of 10 m below of the water level and to get the value of hydrostatic pressure we used the calculations as follows:

\[
\begin{align*}
\text{Ph total} & = \text{Ph 10 m below the water level} + \text{Ph above the water level} \\
\text{Ph above water/sea level} & = 101325 \text{ pa} / 1 \text{ atm} \\
\text{Ph 10 m below water/sea level} & = \rho \cdot g \cdot h \\
\text{Ph 10 m below of the sea/water level} & = 1025 \text{ kg/m}^3 \cdot 9.8 \text{ m/s}^2 \cdot 10 \text{ m} \\
& = 100450 \text{ pa} \\
\text{Ph total} & = \text{Ph 10 m below the sea/water level} + \text{Ph above the sea/water level} \\
& = 101325 \text{ pa} + 100450 \text{ pa} \\
& = 201775 \text{ pa or 0.201775 MPa or 29.26 psi or 2 atm}
\end{align*}
\]

Based on the calculations above, we conducted the CFD analysis at a depth of 10 meters with a pressure of 2 atm or 0.201775 MPa or 29.26 psi. According to the results of the pressure analysis, it was found that the greatest pressure was occurred at the bow end of the sea glider with a maximum pressure of 2.05 atm or 30,127 psi or 0.2077162 MPa. While the lowest pressure was in the area between the bow to midship and aft to the midship, with the lowest pressure experienced at 1.9 atm or 27.92 psi or 0.192518 MPa as shown in Figure 8. Which are figure 8(a) is an isometric view, figure 8(b) is a side view, and figure 8(c) is a top view. These results will be used for the calculation to meet Rules and Regulation on Biro Klasifikasi Indonesia [20].
3.3. Plans for Materials, Mechanical and Control Parts

The plans for materials, mechanical and control parts on this glider are based on compartment division. The first and eighth compartments will be functioned as tanks with a volume in each of 0.006 m³ or about 6.15 kg and followed by compartments 2-7: altimeter and attitude controller, mechanic of ballast system, payload, main controller, and propulsion system. The last compartment will be functioned as a propulsor compartment and it can be seen in Figure 9. Others, this underwater glider will be equipped with wing on each side, and a rudder fin on the stern, to maintain the stability of this sea glider. The design of the ballast tank on the bow and stern sides is intended as ballast to control the sea glider's operating depth.

The Hull Material will be build by three optional materials. Firstly: HT Pipe, that fulfills JIS K6776, by diameter above 65 mm and working temperatur between 5 through 40 degrees, could withstands pressure up to 1.0 Mpa. Secondly, PVC Pipe, that fulfills JIS, with nominal diameter 8”, could withstands 250 psi or 1,7237 Mpa. Thirdly, HDPE Pipe, with the larger amount with the same diameter. All of these optional material had nominal thickness 4 mm at lowest strength and 9 mm at highest strength. The front and rear cones will be build by casting and forging HT, PVC or HDPE materials, the thickness of hull including front and rear cones will be the same with the nominal thickness of the pipe. The bulkheads that separated compartment, wings and rudder fin will be build from mica (acrylic) materials or materials with similar strenght, and the thickness will be the same thickness with the hull. The bulkhead will have others purpose as internal construction members that support the hull. Figure 9 shows general arrangement of sea glider in isometric view.
The following is the calculation of propulsion for this glider:
Based on the calculation of the engine power that has been carried out, the engine power required by the glider to reach a maximum speed of 3.6 m/s or 12.96 km/h is 0.2178 kW when floating and 0.245 kW when submerged. The calculation details can be seen below (based on Basic Ship Theory Volume 2 [21]):

\[n = 8.33 \quad \text{(Estimated rate per second)}\]
\[k = 0.7 - 0.9 \quad \text{(Coefficient factor)}\]
\[\eta_r = 1.02 - 1.05 \quad \text{(Rotative relative efficiency)}\]
\[\eta_p = 40 - 70\% \quad \text{(Propulsion efficiency)}\]
\[\eta_s = 0.97 - 0.98 \quad \text{(Shaft transmission efficiency)}\]
\[\eta_G = 0.98 \quad \text{(Transmission gear system wheel efficiency)}\]

**Power Calculation of underwater glider while floating:**

Effective Horse Power (EHP) =
\[
= (5.0 \times 0.0593.\frac{3}{2} \times \left(33-0.017 \times L\right)) / (15.000 - 110 \times \sqrt{L})
\]
\[
= 0.085 \text{ kW}
\]

Wake friction (w) =
\[
= 0.5 \text{ c} - 0.05
\]
\[
= 0.5 (0.736 - 0.05)
\]
\[
= 0.318
\]

Thrust Deduction Factor (t) =
\[
k \times w
\]
\[
= 0.9 \times 0.318
\]
\[
= 0.2862
\]

Hull Efficiency (\(\eta_H\)) =
\[
= (1 - t) / (1 - w)
\]
\[
= (1 - 0.2862) / (1 - 0.318)
\]
\[
= 1.0466
\]

Coefficient Propulsif (Pc) =
\[
= \eta_r \times \eta_p \times \eta_H
\]
\[
= 1.02 \times 0.45\% \times 1.0466
\]
\[
= 0.48
\]

Delivered Horse Power (DHP) =
\[
= EHP / Pc
\]
\[
= 0.085 / 0.48
\]
\[
= 0.178 \text{ kW}
\]
Shaft Horse Power (SHP) = \frac{DHP}{\eta_s \eta_b} \\
= \frac{0.178}{0.98} \\
= 0.181 \text{ kw} \quad \text{(Edward V. Lewis. Principle of Naval Architecture)}

Brake Horse Power (scr) = \frac{SHP}{\eta_G} \\
= \frac{0.181}{0.98} \\
= 0.185 \text{ kw} \quad \text{(service continue rating)}

Brake Horse Power (mcr) = \frac{BHP_{scr}}{0.85} \\
= \frac{0.185}{0.85} \\
= 0.2178 \text{ kW} \quad \text{(Surjo Widodo Adjie, Daya motor yang diinstal, Engine Propeller Matching)}

**Power Calculation of underwater glider while submerged:**

Effective Horse Power (EHP) = \frac{(5.0 \Delta \% V^{\frac{3}{2}} (33-0.017L))}{(15.000-110.n.\sqrt{L})} \\
= \frac{(5.0 \times 0.0702.\frac{3}{2} \times 3.6^3 \times (33-0.017 \times 2))}{(15.000-110 \times 8.33 \times \sqrt{2})} \\
= 0.09 \text{ kw}

Wake friction (w) \\
= 0.5 \text{ cb} - 0.05 \\
= 0.5 (0.672) - 0.05 \\
= 0.286

Thrust Deduction Factor (t) = k \cdot w \\
= 0.9 \times 0.286 \\
= 0.2574

Hull Efficiency (\eta_H) = \frac{1 - t}{1 - w} \\
= \frac{1 - 0.2574}{1 - 0.286} \\
= 1.04

Coefficient Propulsif (P_c) = \eta_T \times \eta_T \times \eta_H \\
= 1.02 \times 45\% \times 1.04 \\
= 0.477

Delivered Horse Power (DHP) = \frac{EHP}{P_c} \\
= \frac{0.09}{0.477} \\
= 0.2 \text{ kW}

Shaft Horse Power (SHP) = \frac{DHP}{\eta_s \eta_b} \\
= \frac{0.2}{0.98} \\
= 0.204 \text{ kw} \quad \text{(Edward V. Lewis. Principle of Naval Architecture)}

Brake Horse Power (scr) = \frac{SHP}{\eta_G} \\
= \frac{0.204}{0.98} \\
= 0.208 \text{ kw} \quad \text{(service continue rating)}

Brake Horse Power (mcr) = \frac{BHP_{scr}}{0.85} \\
= \frac{0.208}{0.85} \\
= 0.245 \text{ kW} \quad \text{(Surjo Widodo Adjie, Daya motor yang diinstal, Engine Propeller Matching)}
Among the two calculated power results, 0.2178 kW while floating and 0.245 kW while submerged, the largest value is selected, 0.245 kW. That can be used for the glider when floating operation and submerged operation. Table 3 shows the main engine selection in this study.

| Merk                  | YALU DC Motor            |
|-----------------------|--------------------------|
| Power                 | 0.4021447721 HP          |
|                       | 0.3000000000 kW          |
| Type                  | 24 Volt DC               |
| Piston Stroke         | none mm                  |
| Num of cylinders      | 1,0000000000             |
| SFOC                  | none g/kWh               |
| Weight                | 0,0000020000 ton         |
| Gearbox/ratio         | Worm DC 1:5              |
| Dimension (mm)        | 130                      |
| rpm                   | 2750,0000000000          |
| gerboax ratio         | 5,0000000000             |
| Rpm                   | 550,0000000000           |
| BHP Mcr               | 0,4021447721 Hp          |
| BHP Scr               | 0,3619302949 Hp          |
| SHP                   | 0,3546916890 Hp          |
| DHP                   | 0,3475978552 Hp          |
**Propeller for underwater glider calculation:**
Calculation of Propeller based on the results of Bonjean calculation and Power calculation, thus:

- Ballast Mass = 0.001261 ton
  = 0.0123 M3
- Light Weight Tonnage = 0.04905 ton
  = 0.04785 M3
- Empty Weight = 0.06166 ton
  = 0.06015 M3

Table 4 shows the calculation result of volume and tonnage by water lines.

| Water Lines | Volume (m3) | Disp (Ton) |
|-------------|-------------|------------|
| 0           | 0           | 0          |
| 0.04375     | 0.008636    | 0.008852   |
| 0.0875      | 0.024045    | 0.024646   |
| 0.13125     | 0.041709    | 0.042752   |
| 0.175       | 0.057827    | 0.059273   |
| 0.225       | 0.070244    | 0.072      |

**Interpolation to determine middle of displacement:**

Table 5. Interpolation to determine volume and tonnage at center of propeller

| Water Lines | Volume (m3) | Disp (ton) |
|-------------|-------------|------------|
| 3           | 0.041709    | 0.042752   |
| X           | 0.060152    | 0.061656   |
| 4           | 0.057827    | 0.059273   |

**Maximum diameter of Propeller:**
(calculate maximum prop diameter by inserting interpolation value)

Table 6. Calculation of maximum propeller diameter

| Volume (m3) | Water Lines |
|-------------|-------------|
| 0.041709    | 0.1          |
| 0.032877    | 0.072602     |
| 0.057827    | 0.15         |

**Determination of Propeller**
- Propeller Type = B5-85 (Wageningen B-Screw Series)
- Propeller Diameter = 0.040100011 m
- Blade = 5

(determined by calculation of : Resistance, Propulsion and Steering of Ships, Principles Naval Architecture, Ship Resistance and Propulsion, Burills Diagram, and Wageningen B-Screw Series)
**Calculation of Weight of Materials, Mechanics of Ballast, Propulsor, and Control Parts:**

Below the calculation of light weight (LWT) of underwater glider. Table 7 shows the hull construction, table 8 shows the propulsor specifications, table 9 shows the buoyancy engine specifications, table 10 shows the propeller specifications, table 11 shows the control parts specifications, table 12 and table 13 show the total light weight of underwater glider, including propulsor and propulsor not included. As we can see, LWT maximum is below displacement, it’s mean the use of ballast tank when underwater glider submerged is needed and the remaining is used for payload. Thus ballast 6,15 kg each in total 12,3 kg, could submerge this glider.

**Table 7. The hull construction**

| Nr | Item         | Mat          | ID or OD | OD | Nom Wt/Ft | WP | Std     | WT | L (m) | Wt (kg) |
|----|--------------|--------------|----------|----|-----------|----|---------|-----|-------|---------|
| 1  | Hull         | HT           | 8” or 200 mm | 228 mm | 8.2 | 7,586 kg/m | 1.0 Mpa | JIS K6742/JIS K6776 | 5 to 40 C | 15,172 |
|    | Hull         | PVC          | 7,585”     | 8,625 mm | 0.5 | 8,522 kg/ft | 250 psi 8 Mpa | ASTM D1784 JIS | up to 200 F | 17,044 |
|    | Hull         | HDP          | 8”         | 225 mm | 8.6 | 13,39 kg/m | 6,3 bar | JIS | 5 to 40 C | 26,780 |

**Table 8. The propulsor specifications**

| Nr | Item       | Merk          | Power (W) | RPM | Torque (Nm) | V | I | Wt (kg) | Q | Total Wt (kg) |
|----|------------|---------------|-----------|-----|-------------|---|---|---------|---|------------|
| 1  | Propulsor  | Motor DC      | 300       | 2750 | 1           | 24 | 8,9 | 2       | 1 | 2         |
| 2  | Gear Box   | DC Motor Gearbox 24VDC | 30 | 2 | 24 | 0.2 | 1 | 0.2 |
| 3  | Battery    | S899 12V12ah 6-DZF-12 | 5 | 2 | 10 |
| 4  | Speed Controller | Bracket, Mounted, Cable, Etc | 0.007 | 1 | 0.007 |
| 5  |            |               | 1         | 1  | 1         |

Total Weight

Min 24,272
Ave 26,144
Max 35,880

Total Weight 13,207
### Table 9. The buoyancy engine specifications

| Nr | Item            | Merk         | Power (W) | RPM     | Torque (Nm) | V | I | Wt (kg) | Q | Total Wt (kg) |
|----|-----------------|--------------|-----------|---------|-------------|---|---|---------|---|----------------|
| 1  | Motor           | Motor DC     | 550       | 0,85    | 19500       | 12|   | 0,275   | 1 | 0,275          |
| 2  | Gear Box        | DC Motor     | 1         | 12      | 0,2         | 1 |   | 0,2     |   |                |
| 3  | Battery         | S899 12V12ah | 6-DZF-12  | 5       |             | 5 |   |         |   |                |
| 4  | Speed Controller| PWM 775      |           |         | 0,007       | 1 |   | 0,007   |   |                |
| 5  | Bracket, Mounted, Cable, Etc | | | | | | | | 1 | 1 | 1 |
|    | **Total Weight**| **6,482**    |           |         |             |   |   |         |   |                |

### Table 10. The propeller specifications

| Nr | Item                | Material          | Blade | Diameter (mm) | Weight (kg) | Q | Weight (kg) |
|----|---------------------|-------------------|-------|---------------|-------------|---|-------------|
| 1  | Propeller 5 blade   | Aluminium/Bronze  | 5     | 40            | 0,375       | 1 | 0,375       |
| 2  | Stern Tube          | Steel             |       |               | 0,650       | 1 | 0,650       |
| 3  | Shaft, Connector, Etc | Mica/Acrylic    |       |               | 1,000       | 1 | 1,000       |
|    | **Total Weight**    |                   |       |               |             |   | **2,025**   |

### Table 11. The control parts specifications

| Nr | Item                    | Voltage | DC Current | Memory | Weight (kg) | Q | Wt (kg) |
|----|-------------------------|---------|------------|--------|-------------|---|---------|
| 1  | Arduino Mega Atmega 2560 | 5 V     | 20 mA      | 256 KB | 0,060       | 4 | 0,240   |
| 2  | Box, Connector, Cable, etc |         |            |        | 0,650       | 1 | 0,650   |
| 3  | Antenna (not determined yet) |         |            |        | 0,300       | 1 | 0,300   |
|    | **Total Weight**        |         |            |        |             |   | **1,190**|

### Table 12. Total components and weight

| Nr | Component            | Weight (kg) |
|----|----------------------|--------------|
| 1  | Hull Construction    | 26,144       |
| 2  | Propulsor            | 13,207       |
| 3  | Buoyancy Engine      | 6,482        |
| 4  | Propeller            | 2,025        |
| 5  | Control Parts        | 1,190        |
|    | **Total Weight of Sea Glider** | **49,048** |


| Nr | Component         | Weight (kg) |
|----|-------------------|-------------|
| 1  | Hull Construction | 26,144      |
| 2  | Propulsor         | -           |
| 3  | Buoyancy Engine   | 6,482       |
| 4  | Propeller         | -           |
| 5  | Control Parts     | 1,190       |
|    | **Total Weight of Glider** | **33,816** |

**Table 13. Total components and weight without propulsor**

**Principal dimension and technical specifcation of underwater glider:**
Below the result of Calculation of Sea Glider Parametric, which Displacement 0.00702 T, Light Weight (LWT) 0.049048 T, and Ballast Weight 0.00126075 T, which means the Dead Weight Tonnage and Payload could determined by calculation:

\[
DWT = \text{Displacement} - \text{LWT} = 0.00702 \text{T} - 0.049048 \text{T} = 0.010252 \text{T}
\]

\[
\text{Payload} = DWT - \text{Ballast Weight} = 0.010252 \text{T} - 0.00126075 \text{T} = 0.00899125 \text{T}, \text{or 8.99 kg.}
\]

8.99 kg Payload could carry by sea glider, at floating condition, and at submerged condition, by changing the weight of ballast weight. Which means maximum Payload could determined 24.22 kg at floating condition, if sea glider without Propulsion.

Table 14 shows the Principal Dimension and Technical Specification of the glider:

| Parameter                       | Floating Conditions | Submerged Conditions |
|---------------------------------|---------------------|----------------------|
| Value                           | Unit                | Value                | Unit                |
| Displacement                    | T                   | 0.0593               | T                   | 0.0702               |
| Volume (displaced)              | m³                  | 0.058                | m³                  | 0.068                |
| Draft Amidships                 | m                   | 0.175                | m                   | 0.225                |
| Immersed depth                  | m                   | 0.175                | m                   | 0.225                |
| WL Length                       | m                   | 2                    | m                   | 2                    |
| Wetted Area                     | m²                  | 0.919                | m²                  | 1.296                |
| Max sect. area                  | m²                  | 0.033                | m²                  | 0.04                 |
| Waterpl. Area                   | m²                  | 0.32                 | 0                    | m²                  |
| Prismatic coeff. (Cp)           |                     | 0.878                | 0.851               |
| Block coeff. (Cb)               |                     | 0.736                | 0.672               |
| LCB %                           |                     | 0.724                | 0.012               |
| LCF %                           |                     | 0.33                 | -1                  |
| KB                              | m                   | 0.098                | m                   | 0.113                |
| LWT                             | T                   | 0.049048             | T                   | 0.049048             |
| LWT wo Propulsor               | T                   | 0.033816             | T                   | 0.033816             |
| Ballast Tank Tonnage            | T                   | 0.00126075           | T                   | 0.00126075           |
| Ballast Tank Volume             | M3                  | 0.0012               | M3                  | 0.0012               |
| BHP calculated                  | kW                  | 0.2178               | kW                  | 0.245                |
|                                | HP                  | 0.291957105          | HP                  | 0.328418231          |
3.4. The Simulation Result
Simulations are obtained based on 3-dimensional CAD modelling, as shown in Figure 1 with a diameter of 225 mm and a total length of 2000 mm and then followed by analysis using the CFD method with external flow simulation at a depth of 10 meters under the sea which has a pressure of 201775 pa or 2 atm, a speed of 7 knots or 12.96 km/h, and 318 iterations. Then the simulation results are obtained as below. Table 15 shows the simulation result of flow analysis for this glider.

| Goal Name                  | Unit | Value   | Averaged Value | Minimum Value | Maximum Value |
|----------------------------|------|---------|----------------|---------------|---------------|
| Max Static Pressure        | [atm]| 2.0517  | 2.0517         | 2.0517        | 2.0517        |
| Max Velocity               | [kn] | 7.8408  | 7.8433         | 7.8370        | 7.8492        |
| Max Velocity (X)           | [kn] | 2.9655  | 2.9666         | 2.9572        | 2.9738        |
| Max Velocity (Y)           | [kn] | 3.0108  | 3.0029         | 2.9972        | 3.0108        |
| Max Velocity (Z)           | [kn] | 0.5944  | 0.5556         | 0.4351        | 0.6539        |
| Normal Force (X)           | [N]  | 0.6386  | 0.5807         | -0.0438       | 1.0983        |
| Normal Force (Y)           | [N]  | 666.5824| 666.3090       | 664.3675      | 667.3651      |
| Normal Force (Z)           | [N]  | -15.7138| -15.9461       | -16.3432      | -15.5743      |
| Force                      | [N]  | 667.4078| 667.1455       | 665.1952      | 668.1779      |
| Force (X)                  | [N]  | 0.6501  | 0.5937         | -0.0285       | 1.1133        |
| Force (Y)                  | [N]  | 666.6323| 666.3558       | 664.4183      | 667.4027      |
| Force (Z)                  | [N]  | -32.1583| -32.4429       | -32.8663      | -32.0638      |

Based on the results of this analysis, the largest pressure received by the hull of the sea glider is 2.0517 atm, the maximum velocity is 7.8492 kn, and the maximum force is 668.178 newtons. Meanwhile, the maximum iteration for each main value can be seen in the graphs in Figure 10, Figure 11, and Figure 12. Figure 10 shows the highest static pressure value of 2.098 atm occurs in the third iteration and will have a stable value in the 9th iteration and so on with a static pressure of 2.051 atm. The peak velocity value of 8.79 kn is experienced during the 6th iteration and will become a steady state condition in the 33rd iteration with a velocity value of 7.84 kn as shown in Figure 11. While in Figure 12, the maximum force value of 685.61 N appears in the third iteration and will fluctuate downward in the next iteration.
Figure 10. Iterations for static pressure

Figure 11. Iterations for velocity
4. Conclusions
Based on the CAD design and analysis of the low-cost underwater glider for shallow water that costs about Rp. 30,000,000, the main dimensions of the sea glider are 225 mm in diameter, with a total length of 2000 mm, and wings of 1220 mm. The front shape of the sea glider is designed in an elliptical shape to reduce the resistance received. While the wings and rudder fins are designed to maintain the stability of this glider.

CFD analysis is carried out to determine the coefficients of velocity, pressure, and force that occur in the sea glider area. Using an external flow simulation with a speed parameter of 7 knots and at a depth of 10 meters in the sea, which is then calculated in such a way as to obtain valid values for data input. The simulation results show that the maximum velocity of 7.8 knots and a maximum pressure of 2.05 atm occurs at the end of the bow of the underwater glider.

This glider compartment is designed for 9 compartments, where the first and eighth compartments are used as ballast tanks with a volume of each tank of 0.006 m3 or 6.15 kg, 0.0123 m3 or 12.3 kg in total. While compartment numbers 2 to 7 have the following functions: altimeter and attitude controller, mechanic of ballast system, payload, main controller, and propulsion system, while the last compartment functions as a propulsor.

In order to complete this research in the future, we will consider the following items including analysis of the influence of the angle of the wings and rudder fin on the sea glider, experiments or sea glider model tests, and the design of the control sea glider based on the design that has been carried out in this study, buoyancy engine research instead.

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