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Designing A Foldable Boat for Flood Disaster Victim Evacuation

Tegar Intifalda[1*] , Dzaky Al Dzikri[2] , Rizky Maulana Saputra[3]
Institut Teknologi Indonesia, Indonesia
Email: tegarintifalda@gmail.com
*Correspondence

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ABSTRACT

Since the last 5 years, there have been 679 flood disaster fatalities from 2019 - 2023 and 4,246 total flood disaster events from 2019 - 2023. There are 5 types of boats used by BNPB to evacuate flood disaster victims with high prices, and several boats need to be filled with air before evacuating flood disaster victims. Although BNPB has prepared boats. However, there are still many casualties due to flood victims. Therefore, this research is a solution to assist in the evacuation of flood victims in the form of designing a folding boat as a tool for evacuating flood victims. This research was conducted to obtain predetermined specifications and determine the Maxsurf Resistance and Stability analysis. The Pahl and Beitz method with QFD is used to meet these needs. Then, the boat specifications were obtained: DWT; 416 kg or 0.416 Ton, boat dimensions (pxl); 3.115x1.584, folding boat price Rp. 5,404,100 (without engine) and Rp. 23,005,575 (with engine), passenger capacity can load at least 4 people, Cb; 0.842, boat mass; 33.8 kg, and IMO Standard; Pass. The results of Maxsurf Resistance with a speed of 6 knots using the Holtrop Resistance method of 275.42 N and Holtrop Power of 1.14 hp so that more than 1.14 hp engine power is needed, a 5 HP L HD5F Outboard Engine weighing 21 kg is obtained. The simulation results of 6 conditions in Maxsurf Stability have passed the test of the IMO Standard.

Introduction

Flood disasters have been a recurring and devastating issue in Indonesia, claiming 679 lives and causing widespread destruction across 4,246 events from 2019 to 2023 (Indonesian Disaster Information Data, 2023). Despite efforts by the National Disaster Management Agency (BNPB) to deploy boats for evacuation, existing solutions reveal critical shortcomings. The current boats are expensive, cumbersome, and often impractical, with some requiring inflation before use—a process that consumes valuable time during emergencies. This inefficiency contributes to preventable fatalities during floods, especially in scenarios where rapid deployment is crucial to saving lives (Ajiij & Supriyatna, 2024).

Given these challenges, there is an urgent need for innovative and accessible solutions. This research addresses the gap by designing a cost-effective and practical foldable boat specifically tailored for flood evacuation. By incorporating compact storage, ease of deployment, and stability under varied conditions, this design aims to enhance the effectiveness of disaster response efforts. The study employs the Pahl and Beitz method with QFD to meet the specified technical and functional requirements, ensuring the design aligns with real-world needs. This development represents a significant step forward in reducing flood-related casualties and improving disaster readiness across vulnerable regions.

There are 5 types of boats used by BNPB to evacuate flood victims. All types of boats have the same disadvantages: they are impractical and expensive, and some boats need to be filled with air before evacuating flood victims. BNPB (National Disaster Management Agency) has prepared boats to evacuate flood victims. However, there are still many casualties due to flood victims. Therefore, this research is a solution to assist in evacuating flood victims by designing a folding boat as a tool for evacuating flood victims.

Maxsurf Resistance

The Maxsurf calculation approach used in this study is the Holtrop Method because the Holtrop Method is appropriate for use on ships with a significant block coefficient (Cb) ranging from 0.7 to 0.9. Holtrop (Lewis, 1988), put forward the statistical analysis results of the resistance and propulsion tests of 191 models with varying types of *ships carried* in the Dutch MARIN model test laboratory. Holtrop concluded that 95% of the experiments he conducted produced a quite accurate formula.

Maxsurf Stability

Ship stability analysis is closely related to the safety aspects of the ship. The International Maritime Organization (IMO), as an international maritime organization, issues regulations in the form of stability rules that must be met by a ship. Some of the rules that must be met by ships as ship stability requirements according to the provisions and provisions of IMO (International Maritime Organization) Code A.749 (18) Chapter 3 - *Design Criteria Applicable to All Ships,* which requires the following: (Maxsurf, 2023b)

1. Section A.749 (18), Chapter 3.1.2.1:
   a. Area in the region under the GZ curve at a tilt angle of 0° - 30° (deg) > 3.151 m.deg.
   b. Area in the region under the GZ curve at a tilt angle of 0° - 40° (deg) > 5.157 m.deg.
   c. Area under the GZ curve at a tilt angle of 30° - 40° (deg) > 1.719 m.deg.
2. Section A.749 (18), chapter 3.1.2.2: maximum GZ values occurring at angles of 30° - 180° (deg) > 0.2 m.
3. Section A.749 (18), chapter 3.1.2.3: angle at maximum GZ value > 25° (deg).
4. Section A.749 (18), chapter 3.1.2.4: Initial GM value at angle 0° (deg) > 0.15 m.

Block Coefficient

According to Rawson & Tupper (2001), the block coefficient is the ratio of the displacement volume to the volume of a rectangular block with equal sides. Based on Budi Santoso research in 2009, the block coefficient is the ratio between the volume of the ship's body below the water surface and the block's volume formed by the block's length, width, and height. The block coefficient can also be determined by considering the ship's speed, where fast ships generally have a small Cb and vice versa, while ships with low speed have a large Cb. The block coefficient can be expressed by a formula as follows:

$$\boldsymbol{Cb = \frac{V}{L \times B \times d}} \quad (1)$$

Dead Weight Tonnage (DWT)

According to Sutini (2020), Dead Weight Tonnage (DWT) is the ability of a ship to be loaded with loads such as cargo, fresh water, fuel, supplies, lubricating oil, passengers, crew, and others, up to a certain draft and in liquids with a specific density as well. The formula for Dead Weight Tonnage (DWT), namely:

$$\begin{aligned} DWT &= (\,Load\ Displacement - Light\ Displacement)x\ 1,000 \\ Light\ Displacement &= L\ x\ B\ x\ light\ draft\ x\ Cb \\ Load\ Displacement &= L\ x\ B\ x\ load\ draft\ x\ Cb \end{aligned} \quad (2)$$

Draft

According to Fajar , a Dr(2020)aft ship is a series of numbers that are applied or attached (welded or just painted) on the hull of the ship on the right and left at the front (*forward*), in the middle (*midship*) and at the back (*after*), where these numbers indicate the depth of the part of the ship that enters into sea or river water. The formula for the draft, namely:

$$\boldsymbol{d = \frac{\left(\frac{m}{\rho}\right)}{\left(\frac{l}{p}\right)} \times 3} \quad (3)$$

Method

This research follows the Pahl & Beitz design method, which is a systematic approach to product development. The method consists of the following stages:

1. Clarification of Task: In this initial stage, the requirements for the foldable boat are clearly defined based on the needs of flood disaster evacuation. This involves identifying critical design criteria, such as lightweight structure, compact storage, stability, and cost efficiency. The study also incorporates data from existing evacuation boats to establish benchmarks for the design.
2. Conceptual Design: Various design concepts are generated and evaluated against the criteria established in the first stage. This includes brainstorming potential mechanisms for folding and assembly while ensuring the boat's stability and resistance in floodwaters. Concepts are compared using Quality Function Deployment (QFD) to ensure that user needs are directly addressed in the design process.
3. Embodiment Design: In this stage, detailed specifications of the boat are developed, including dimensions, materials, and mechanisms for folding. Maxsurf Resistance and Stability software is used to analyze the boat's performance. Specifically:(Rachman et al., 2020)
    - Maxsurf Resistance Analysis: This uses the Holtrop method to calculate the resistance and required propulsion power at various speeds. Given the boat's high block coefficient (Cb = 0.842), the Holtrop method is particularly suitable, as it is optimized for vessels with significant displacement.
    - Maxsurf Stability Analysis: The design's stability is evaluated under six different loading conditions, ensuring compliance with IMO (International Maritime Organization) standards. The results verify that the design maintains safety and stability with varying passenger loads.
4. Detailed Design: The final design incorporates findings from the Maxsurf analysis. Detailed drawings and specifications of the foldable boat and its mechanisms are prepared. The design is optimized to balance performance, manufacturability, and cost-effectiveness.
5. Implementation and Testing: Prototype manufacturing and testing (if applicable) are outlined to validate the design's real-world performance against the theoretical analysis. This step involves refining the design based on test feedback to ensure it meets practical demands.

Research Flow Chart

The following is a research flow chart for the design of a folding boat using the Pahl & Beitz design method:

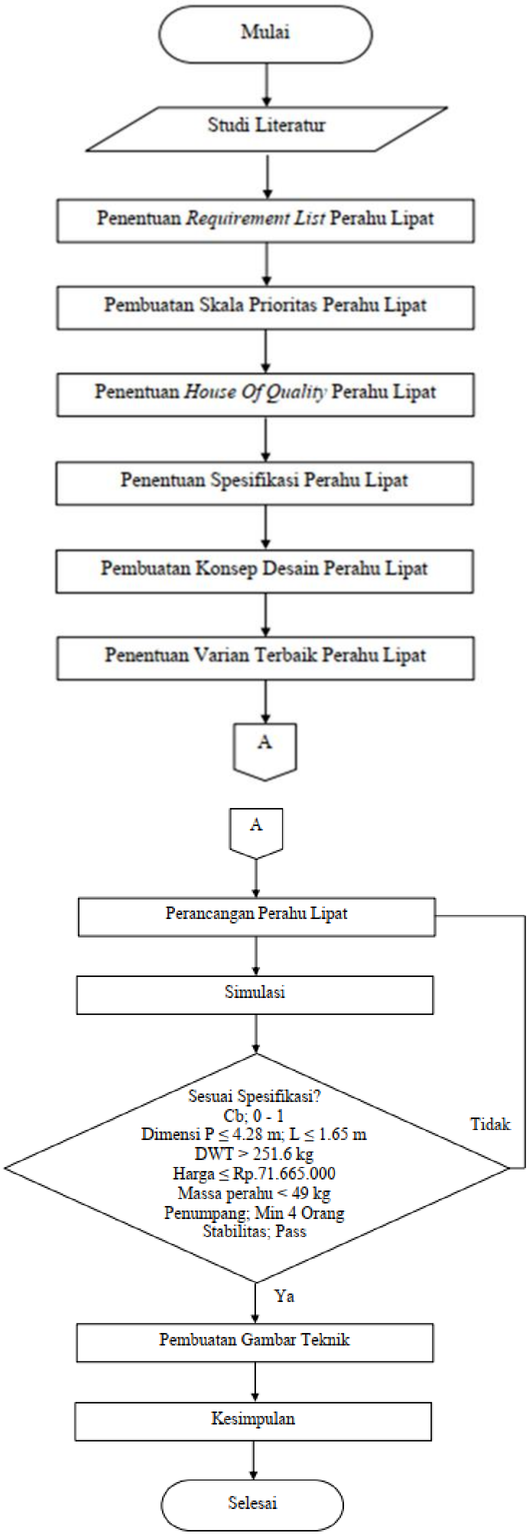


Figure 1. Research Flow Chart

Results and Discussion

The design of a folding boat must meet predetermined specifications.

Folding Boat Design

The folding boat design has been made and meets the following specifications:

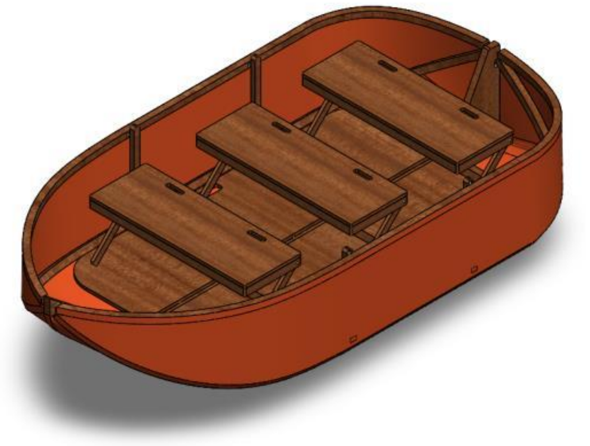


Figure 2. Folding Boat

Table 1. Folding Boat Specifications

Measurement	Value	Units
Dimension (pxlxt)	3.115 x 1.551 x 0.572	m
3 Kursi Lipat	15.08	Kg
Perahu Lipat	82.4	Kg
Block coeff. (Cb)	0.842	-
Material	Kayu Mahoni + Plastel 8820	-

Folding Boat Mechanism

The folding mechanism of the folding boat will be described as follows:

Figure 3. Folding Boat Mechanism 1

Figure 4. Folding Boat Mechanism 2

Figure 5. Folding Boat Mechanism 3

Figure 6. Folding Boat Mechanism 4

Figure 7. Folding Boat Mechanism 5

Folding Chair Design

Based on Anthropometry data, the popliteal length is 394.2 mm and the popliteal height is 417.6 mm. The design of the folding chair is adjusted to the needs of Indonesian adult male anthropometry. The folding chair design is as follows:

Figure 8. Folding Chair

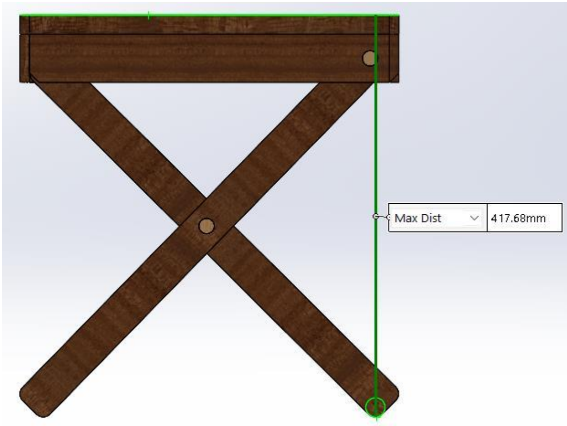


Figure 9. Folding Chair Popliteal Height Dimension

Figure 10. Folding Chair Popliteal Length Dimension

Maxsurf Resistance

Based on Purwo and Iswadi's research in (2024), "Designing a Rubber-Coated Fiber Glass Boat for Flood Disaster Evacuation" for a speed variation of 6 knots. Therefore, in this research, the speed variation starts from 0 - 6 knots. Maxurf Resistance software is required to get Holtrop Resistance and Holtrop Power. The method used is the Holtrop method because the Holtrop method is appropriate for use on ships that have a large block coefficient (Cb), which ranges from 0.7 to 0.9. The following are the results of the Maxsurf Resistance analysis.

Table 2. Speed Variation

Knot	Holtrop Resist (N)	Holtrop Power (hp)
1	11.92	0.008
2	41.74	0.058
3	89.29	0.185
4	217.39	0.6
5	261.67	0.903
6	275.42	1.14

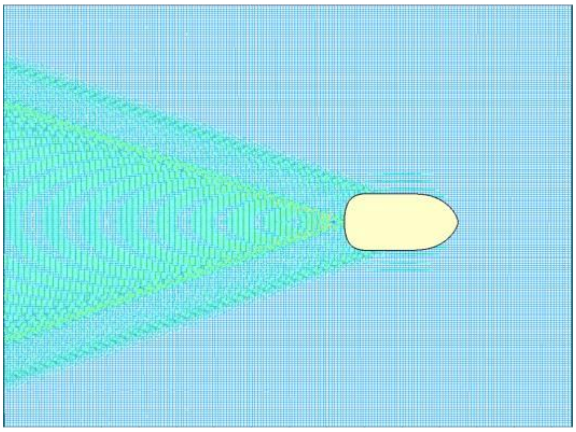


Figure 11. 1 knot speed

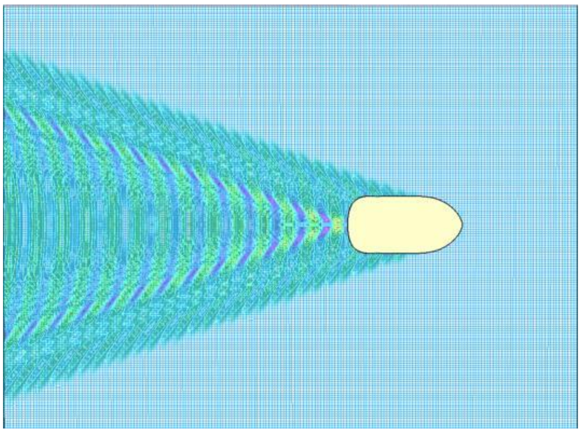


Figure 12. 2 knots speed

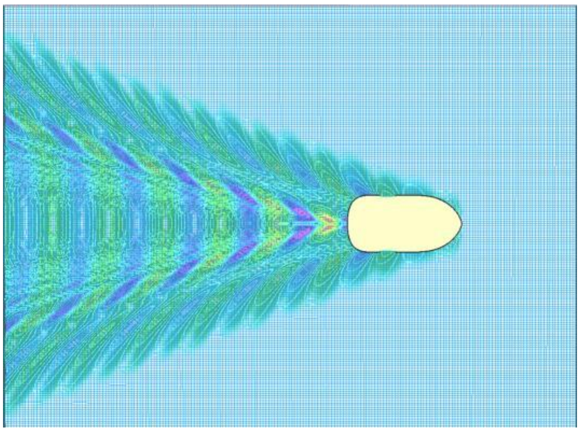


Figure 13. 3 knots speed

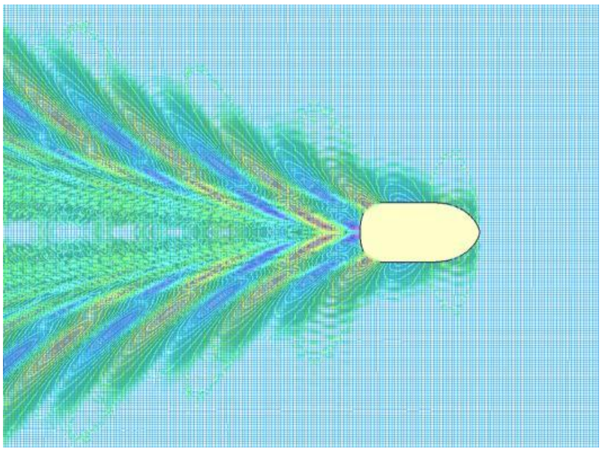


Figure 14. 4 knots speed

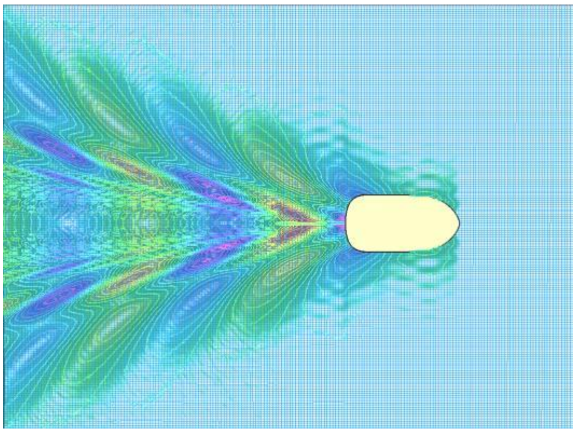


Figure 15. 5 knots speed

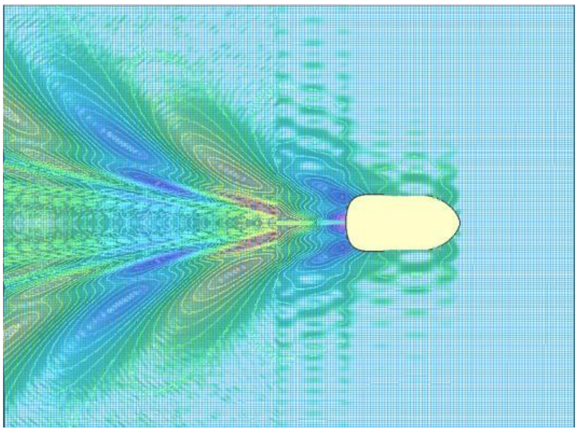


Figure 16. 6 knots speed

Maxsurf Stability

Based on Purwo and Iswadi's research in (2019), "Designing a Rubber-Coated Fiber Glass Boat for Flood Disaster Evacuation" for a speed variation of 6 knots. Therefore, the speed variation starts from 0 - 6 knots in this research. Maxurf Resistance software is required to get Holtrop Resistance and Holtrop Power. The method used is the Holtrop method because the Holtrop method is appropriate for use on ships that have a large block coefficient (Cb), which ranges from 0.7 to 0.9. The following are the results of the Maxsurf Resistance analysis.

1. Condition 1 - folding boat + folding chair + boat engine + engine operator

Table 3. Condition 1

Condition	Criteria	Value	Units	Actual	Status
1	Area 0 to 30 (>)	3.151	m.deg	14.5863	Pass
	Area 0 to 40 (>)	5.157	m.deg	21.2327	Pass
	Area 30 to 40 (>)	1.719	m.deg	6.6464	Pass
	Max GZ at 30 or greater (≥)	0.2	m	0.671	Pass
	Angle of maximum GZ (≥)	25	meg	41.8	Pass
	Initian GMt (≥)	0.15	m	4.245	Pass

2. Condition 2 - folding boat + folding chair + boat engine + engine operator + 1 passenger

Table 5. Condition 2

Condition	Criteria	Value	Units	Actual	Status
2	Area 0 to 30 (>)	3.151	m.deg	12.715	Pass
	Area 0 to 40 (>)	5.157	m.deg	18.5043	Pass
	Area 30 to 40 (>)	1.719	m.deg	5.7893	Pass
	Max GZ at 30 or greater (≥)	0.2	m	0.583	Pass
	Angle of maximum GZ (≥)	25	meg	38.2	Pass
	Initian GMt (≥)	0.15	m	3.068	Pass

3. Condition 3 - folding boat + folding chair + boat engine + engine operator + 2 passengers

Table 6. Condition 3

Condition	Criteria	Value	Units	Actual	Status
3	Area 0 to 30 (>)	3.151	m.deg	11.3813	Pass
	Area 0 to 40 (>)	5.157	m.deg	16.6324	Pass
	Area 30 to 40 (>)	1.719	m.deg	5.2512	Pass
	Max GZ at 30 or greater (≥)	0.2	m	0.527	Pass
	Angle of maximum GZ (≥)	25	meg	37.3	Pass
	Initian GMt (≥)	0.15	m	2.405	Pass

4. Condition 4 - folding boat + folding chair + boat engine + engine operator + 3 passengers

Table 7. Condition 4

Condition	Criteria	Value	Units	Actual	Status
4	Area 0 to 30 (>)	3.151	m.deg	10.1353	Pass
	Area 0 to 40 (>)	5.157	m.deg	14.9724	Pass
	Area 30 to 40 (>)	1.719	m.deg	4.837	Pass
	Max GZ at 30 or greater (≥)	0.2	m	0.527	Pass
	Angle of maximum GZ (≥)	25	meg	39.1	Pass
	Initian GMt (≥)	0.15	m	1.95	Pass

5. Condition 5 - folding boat + folding chair + boat engine + engine operator + 4 passengers

Table 6. Condition 5

Condition	Criteria	Value	Units	Actual	Status
5	Area 0 to 30 (>)	3.151	m.deg	9.2933	Pass
	Area 0 to 40 (>)	5.157	m.deg	13.8521	Pass
	Area 30 to 40 (>)	1.719	m.deg	4.5588	Pass
	Max GZ at 30 or greater (≥)	0.2	m	0.459	Pass
	Angle of maximum GZ (≥)	25	meg	39.1	Pass
	Initian GMt (≥)	0.15	m	1.645	Pass

6. Condition 6 - folding boat + folding chair + boat engine + engine operator + 5 passengers

Table 7. Condition 6

Condition	Criteria	Value	Units	Actual	Status
6	Area 0 to 30 (>)	3.151	m.deg	8.6748	Pass
	Area 0 to 40 (>)	5.157	m.deg	13.0396	Pass
	Area 30 to 40 (>)	1.719	m.deg	4.3648	Pass
	Max GZ at 30 or greater (≥)	0.2	m	0.44	Pass
	Angle of maximum GZ (≥)	25	meg	39.1	Pass
	Initian GMt (≥)	0.15	m	1.43	Pass

Block Coefficient

To get the block coefficient value, complete data is needed to calculate the block coefficient. Data was obtained in volume (displaced) of 1,903 m^3, boat length of 3,115 m, boat width of 1,551 m, and boat draft of 0.47. From these data, then, enter the Cb calculation.

There is a difference that shows the accurate level of simulation in Maxsurf. Manual calculations get a Cb value of 0.838, while simulation calculations in Maxsurf get a Cb value of 0.842. So, the difference between manual calculations and simulation calculations in Maxsurf is 0.004. The block coefficient value is always in the range of 0 to 1.

Deadweight Tonnage (DWT)

To get the Deadweight Tonnage (DWT) value, complete data is needed to calculate Deadweight Tonnage (DWT). Data is required on boat length, boat width, drafts such as light draft and load draft, Cb, and freshwater density of 1000 kg/m^3. From this data, then enter the Deadweight Tonnage (DWT) calculation. So, the folding boat design can be loaded with a load of 416 $kg\ atau$ 0.416 Ton (Machfudin & Mujahid, 2018).

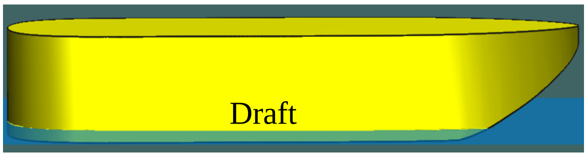
Draft

To get the draft value, complete data is needed to calculate the draft. Data on cargo load, boat length, boat width, and freshwater density of 1000 kg/m are required^3. From these data then enter the draft calculation.

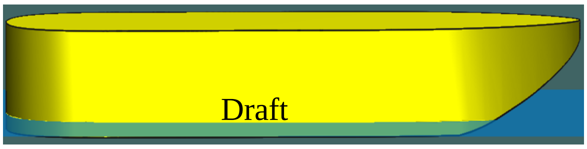
Table 8. Draft

Condition	Draft
1	0.113 m
2	0.153 m
3	0.191 m
4	0.223 m
5	0.27 m
6	0.308 m

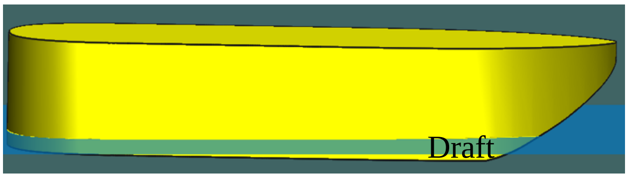
Condition 1 - Draft 0.113 m



Condition 2 - Draft 0.152 m



Condition 3 - Draft 0.191 m



Condition 4 - Draft 0.223 m

Condition 5 - Draft 0.27 m

Condition 6 - Draft 0.308 m

Based on the safe limit of 0.47 m. So, the results of each condition are at a safe and stable level. This means the folding boat design is safe and according to the specified specifications.

Conclusion

Then the boat specifications are obtained: DWT; 416 kg or 0.416 Ton, boat dimensions (pxl); 3,115 × 1,551, folding boat price Rp. 5,404,100 (without engine) and Rp. 23,005,575 (with engine), passenger capacity can load at least 4 people, Cb; 0.842, boat mass; 82.4 kg, and IMO Standard; Pass

The results of Maxsurf Resistance with a speed of 6 knots using the Holtrop Resistance method of 275.42 N and Holtrop Power of 1.14 hp so that more than 1.14 hp engine power is needed, a 5 HP L HD5F Outboard Engine weighing 21 kg is obtained. The simulation results of 6 conditions in Maxsurf Stability have passed the test of the IMO (International Maritime Organization) Code A.749 (18) Chapter 3 - Design Criteria Applicable to All Ships.

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