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The Design Concept of an Electric Amphibious Bus as an Alternative Mass Transportation on Rivers and Roads to Overcome Congestion in the Jabodetabek Area

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Abstract

Due to the high growth of vehicles in Jakarta that is not balanced by the growth of roads, the congestion level in Jakarta has been increasing yearly. To overcome the congestion, innovation is needed to utilize the rivers as a means of public transportation. The design uses the spiral design method with a parent design approach. The calculations carried out include the calculation of resistance, calculation of motor power requirements, calculation of longitudinal strength, calculation of construction, calculation of weight, hydrostatic calculation, stability calculation and seakeeping calculation on water vehicles. As for road vehicles, the calculations carried out include wind drag calculation, rolling resistance calculation, incline force calculation, total resistance calculation, torque calculation and electric power calculation. As a result of the calculations and iterations carried out, the technical specifications of the amphibious bus are obtained, including a length of 12.0 m, breadth of 3.0 m, and depth of 3.0 and draught of 0.8 m. This bus is equipped with three movers of waterjet propulsion connected to electric motors with a power of 710 kW each. This bus can carry 51 people with one driver. This bus has good stability when in the water under empty and full load conditions with a level of comfort that meets ISO standards. In addition, this bus can operate up to 359 km for water distances and 501 km for land distances at 40 km/h for water and 60 km/h for land for one battery charging. This bus can also run with a maximum angle of up to 30 degrees.

1. Introduction

The population census conducted by Badan Pusat Statistik in 2020 shows that the population of DKI Jakarta is 10.56 million people [1]. In 2021, the census results showed that the population had increased to 10.64 million [2]. This indicates an increase of 0.78% in the population from 2020 to 2021. Looking at data on the growth of public transportation, particularly city buses, over the same period, there has been a decrease in the number of buses by 0.77% [2]. However, the growth in the number of vehicles in the last five years has reached 3.67% [2]. This vehicle growth has not been accompanied by an increase in the length of roads in Jakarta, which has remained constant at 788,618 km in 2020 and 2021[1][2]. The lack of growth in road infrastructure has contributed to increasing traffic congestion in Jakarta over the years [1].

The high mobility of passengers and goods in the capital city requires safe and comfortable public transportation [2][3]. The availability of such public transportation would reduce congestion and the growth of private vehicles, which has been higher than the growth of roads [1]. In addition to the lack of awareness of road users in following traffic rules, the current state of public transportation could be more satisfactory [2]. This need for public transportation also requires alternative modes of operation, such as on waterways, due to the need for more growth in road infrastructure [4]. Therefore, a design concept for public transportation primarily operates on waterways is needed. The design should also be able to operate safely on roads and be integrated with existing transportation modes.

Haski has planned river transportation as an alternative mode of transportation in DKI Jakarta. The design is a catamaran with 44 people (42 passengers and two crew members). The main dimensions are Length (LBP) = 11.6 m, Breadth (Bm) = 4.5 m, B1 = 1.0 m, Depth (H) = 1.0 m, Draught (T) = 0.4 m, and Speed = 8.0 knots. Economic analysis shows transportation will reach the Break-Even Point (BEP) in the second year. The research recommends further technical study on stability calculation, longitudinal strength of the ship, and propulsion [5].

Setijoprajudo has planned a transportation tool for the West Canal flood. The water transportation route starts from Manggarai-Dukuh Atas-Karet for a distance of 3.4 km. The design constraints include an average water depth of 2.5 meters and a width of 58 meters. Based on the analysis, the waterbus can carry 42 passengers. The hull type for the water bus is a catamaran, as it can operate in limited water bodies such as rivers and lakes. Based on this capacity, the dimensions of the water bus obtained from the regression of the comparison ship are Length (LBP) = 11.6 m; Breadth (Bm) = 4.5 m; Draught (T) = 0.4 m; Depth (H) = 1 m; B1 = 1 m [6].

Rinaldi has designed an amphibious school bus for transporting students on the Kepulauan Seribu Jakarta Utara. The research shows that students can safely cross the sea and operate on land until they reach the school using the Amphibious Water School Bus. The research began by determining the capacity of the school Bus. The capacity of the bus is the number of students in Pulau Untung. After obtaining the payload, the vehicle's main dimension and deadweight were obtained. Subsequently, technical calculations of the amphibious bus were carried out. The calculations included lines plan, general arrangement, and costs. It was concluded that the Amphibious Water School Bus could carry high school students and one driver, with the main dimensions of the ship being Length (LBP) = 14.27 m, Breadth (B) = 2.5 m, Height (H) = 4.0 m, Draught (T) = 1.6 m, and the cost for constructing the platform is Rp 2,393,414,848.59 [7].

Ma'rruf has researched the development of the Banjir Kanal Timur Semarang River as a tourist river transportation. The study aims to analyze whether Banjir Kanal Timur can be used as flood control and river transportation for water tourism in Semarang City. The study results in show that river tourism can use two open speedboats with a length of 8 m, breadth of 2.2 m, and draught of 0.4 m and be integrated with a two-deck open-top shuttle bus. The Operating Cost of the boat is Rp 1,052,717,443 per year, including investment costs, management, and maintenance, with 8eighttrips per day. The tariff charged to each passenger is Rp 18,208 for a trip [8].

Chen has researched an Amphibious Vehicle by Creative Design Using Software OpenSim. In the study, Chen adopts the spiral thinking by creative concept to design amphibious vehicles or ships combined with fluid dynamics and bionics engineering principles. Bionics engineering is the development of accurate mechanical systems by adopting the forms of living beings in certain parts. The design should balance the various aspects of the imagination and creation stage. The aspects are the shape of the vehicle, the hydrodynamic aspect in water and on land, and the power consumption for maneuvering [9].

Based on various studies that have been conducted, there is a research gap in the need for a concept of an amphibious vehicle designed as a mass transportation mode, specifically in the Jabodetabek area. This mass transportation is expected to overcome the increasing traffic congestion in this area. In addition, the design of this mass transportation mode is made to be environmentally friendly, have comfort, reliability, and integration with other mass transportation modes.

2. Methods

The research begins with a literature review and defines the vehicle's mission based on existing design constraints. From the mission, the vehicle concept and dimensions are developed. Next, the concept for the vehicle on the water and land is defined. Several technical calculations are performed to ensure the vehicle is safe and comfortable and to verify that the design meets the vehicle's mission. The resulting vehicle specifications for the water and land are combined to create the amphibious vehicle specification. An operational study of the vehicle is then conducted, and if necessary, the concept and dimensions of the vehicle are redefined. If the study is successful, the lines plan for the vehicle is created, followed by the general arrangement layout and 3D model.

The mission requirement is needed to obtain the philosophy of the vehicle comprehensively. The vehicle's mission is defined at this stage, starting from the route, the number of passengers, and design limitations related to the vehicle's operating environment. These limitations may include the vehicle's size, weight, and efficiency. These requirements will create a concept and design for the vehicle to operate safely and effectively in its intended environment.

After the mission of the amphibious vehicle is obtained, the vehicle's main size and design concept are obtained in this stage. The selection of sizes is planned using the design constraints of the vehicle. The method for determining the main size of the amphibious vehicle uses the spiral design method [10][11]. This vehicle is assumed to be a ship sailing on closed waters. This is done because the vehicle's shipping route is on a river, with relatively low wind speed and wave height [12][13]. Technical calculations are performed to ensure that the designed design has reliability regarding function, safety, safety, and comfort when on the river. The calculations performed include resistance calculations [14], calculation of motor power requirements [14], calculation of longitudinal strength of the ship [15], construction calculation [15], weight calculation, hydrostatic calculation, stability calculation [16] and seakeeping calculation [17]. The calculation is carried out using the Maxsurf Ultimate Student Version software. From various calculations, it will produce the specifications of the water vehicle.

The vehicle is also analogized to a bus running on a road. Longitudinal forces work on this vehicle [18]. The vehicle is planned to be electric-powered, so regulations for electric vehicles [19][20] also need to be considered when designing the vehicle. Technical calculations are carried out to ensure that the design can operate according to the vehicle's mission. The calculations include wind drag, rolling resistance, incline force, total resistance, torque, and electric power calculations [21]. The various calculations will result in the specification of the electric vehicle.

3. Results and Discussion

3.1. Technical Calculation in Water

a. Resistance and Power Prediction in Water

The calculation of resistance performed on this bus uses the Holtrop method [14]. The calculation of resistance is an important aspect of the design process of a water vehicle [23]. This method was chosen because the type of bus is full displacement. This means the bus is not very fast, and there is no planning movement. Resistance calculation is assisted using Maxsurf Resistance Ultimate Student Version software. The result of the resistance calculation is shown in Figure 2.

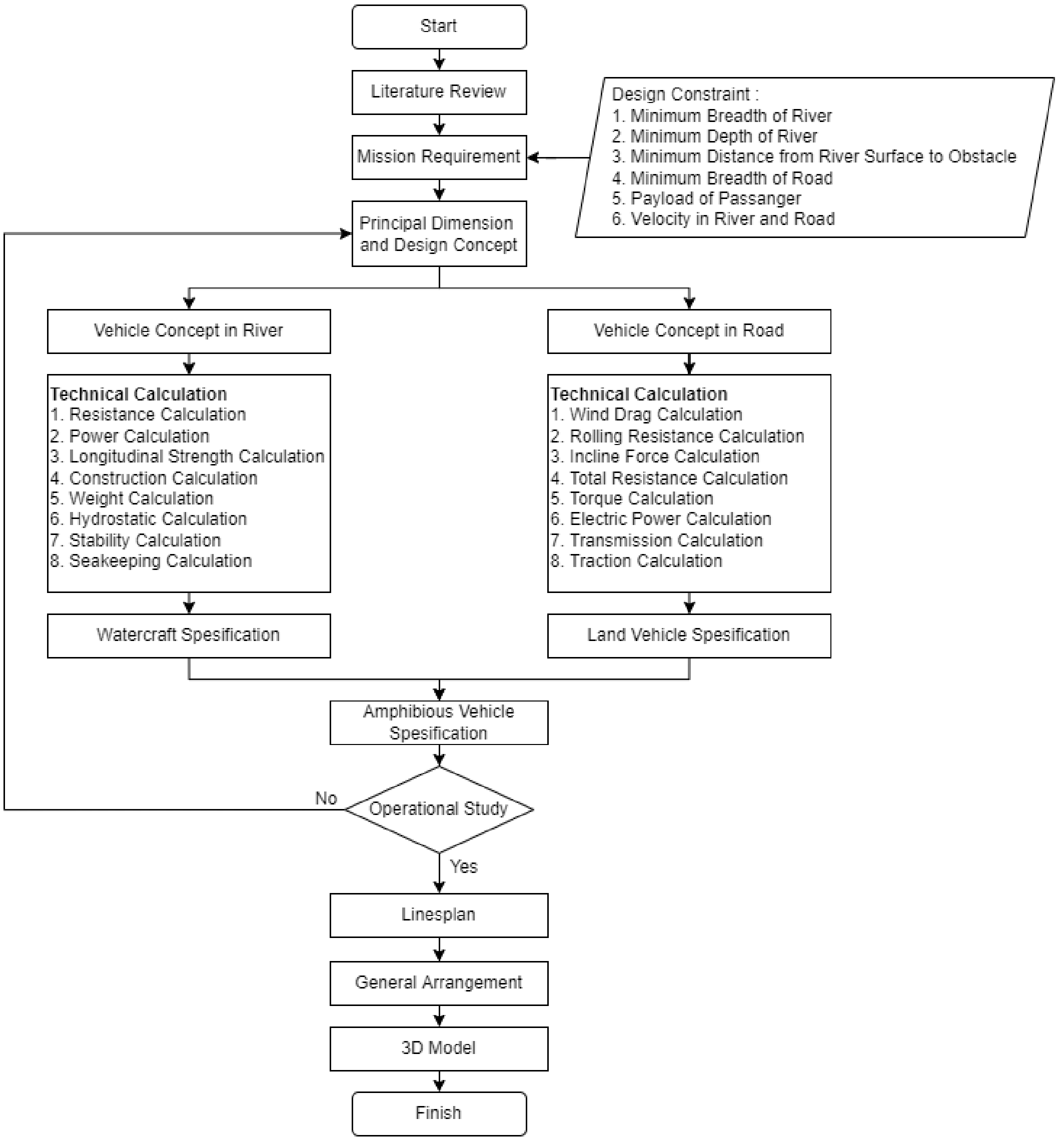


Figure 1. Chart Methodology

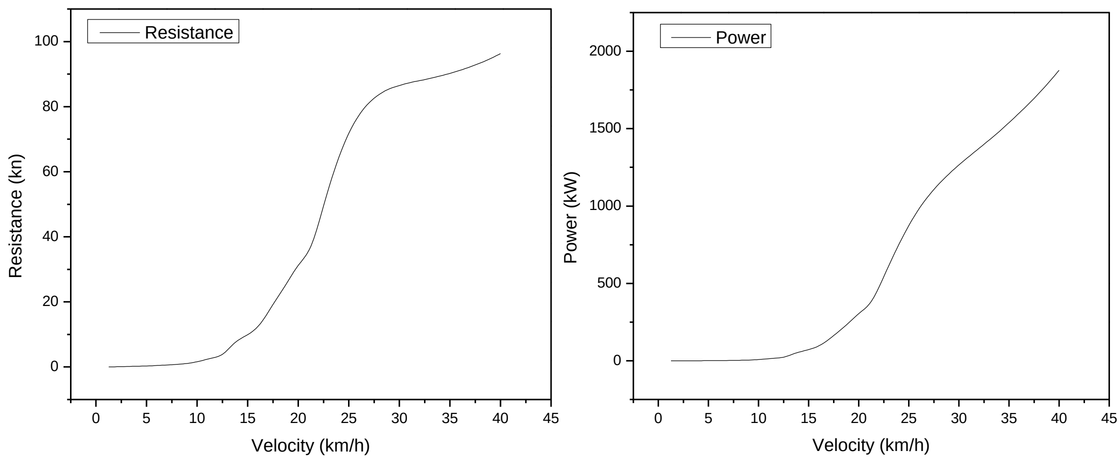


Figure 2. (a) Graph of the relationship between speed and resistance (b) Power Prediction

Figure 2 (a) shows the relationship between bus speed and resistance in a graph. The relationship between the variables is exponential. The resistance of the bus increases with the speed of the vehicle. From the graph, the resistance at the service speed of the bus is 96.421 kN. Figure 2 (b) shows the power prediction. The motor power calculation is obtained from the bus' s maximum speed resistance value. From previous technical calculations, it was found that the resistance value is 96.421

kN. Using an efficiency of 57%, the required motor power is 1883.6 kW. This bus is planned to use an electric motor with water jet propulsion.

b. Construction Calculation

The calculation of the construction dimensions can be seen in Table 1, Table 2 & Table 3. This vehicle is designed using composite material. The vehicle is divided into three areas. The areas are Fore, Midship, and After. The Midship area is located at 0.8L in the middle of the vehicle, while the Fore and After areas are 0.1L forward and 0.1L backward, respectively. This vehicle also has a keel located on the bottom of the vehicle that is located longitudinally. In addition to thickness dimensions, calculations are also carried out for the stiffeners present on the vehicle. The vehicle is designed to have a transverse construction with a distance of 500 mm between each stiffener. The bottom of the vehicle uses a floor construction to strengthen the battery space. The modulus of the stiffener can be seen in Table 2. The thickness calculation results of the lamination can be seen in Table 3.

Table 1. Longitudinal Strength

Calculation	Value	Unit
Modulus	26897	cm^3
Inertia	1355592	cm^4

Table 2. Stiffener Dimension

Part	Specification	Unit
Transverse After	50	cm^3
Transverse Midship	50	cm^3
Transverse Fore	59	cm^3
Side Longitudinal	77	cm^3
Beam	40	cm^3
Bottom Longitudinal	261	cm^3
Floor	208	cm^3
Bulkhead Stiffener	76	cm^3

Table 3. Thickness Dimension

Part	Specification	Unit
Shell After	7	mm
Shell Midship	9	mm
Shell Fore	12	mm
Deck After	7	mm
Deck Midship	7	mm
Deck Fore	7	mm
Bottom Keel	14	mm
Bottom After	9	mm
Bottom Fore	12	mm
Bulkhead	13	mm
Girder	13	mm
Side Girder	8	mm

c. Platform Weight Calculation

The Platform weight is calculated by adding the weight of all components on this vehicle. The weight of the construction is obtained from the calculation of the construction dimensions, while the weight of the passengers is obtained from the average weight of people [25].

The battery weight is obtained by summing up all the battery packs on the amphibious vehicle. Battery specifications can be seen in Table 4. Meanwhile, the weight of the waterjet propulsion and electric motor is obtained from the catalog.

Table 4. Battery Spesification [19]

Parameter	Spesification	Unit
Type	NCA 1860 Li-Ion	
Voltage	100	V
Capacity	300	Ah
Weight	21.5	kg
Height	210	mm
Width	353	mm
Length	700	mm

Table 5. Weight Recapitulation

Component	COG_x [mm]	COG_y [mm]	COG_z [mm]	Quantity	Weight/Qty [kg]	Total [kg]
Construction	7200	0	1500	1	5892	5892
Person	5070	-139	1496	52	63.3	3292
Battery	7260	0	525	100	21.5	2150

Propulsion	1300	0	270	3	480	1440
Electric Motor	5000	0	384	3	1880	5640
Transmission	3000	0	270	3	600	1800

The weight of all components is added up to obtain the vehicle′s total weight. In addition, the center of gravity of each component needs to be calculated based on the arrangement of the vehicle layout. The vehicle′s weight obtained is 20.21 tons, while the center of gravity longitudinally or LCG is 5.45 m, calculated from AP. A summary of weight calculations can be seen in Table 5.

d. Stability Calculation

The stability of the amphibious bus is important for the safety of passengers. Stability calculations can be done using the Maxsurf stability ultimate student version software by entering the components′ weight and center of gravity values in Table 5. The vehicle′s stability is measured by looking at the GZ arm parameter. Some parameters that affect the GZ arm include the position of the load's center of gravity, the hull's shape in the submerged part, the main dimension of the ship, and the ship's displacement [26]. The calculation from the software shows that the value of the GZ arm is positive for various rolling angles. The GZ arm is also positive for various rolling angles at empty loads. This indicates that when the vehicle is empty, it is still stable.

e. Hydrostatic Calculation

The hydrostatic calculation is based on the weight calculation data in Table 5. The calculation is performed using the Maxsurf stability ultimate student version software. The result can be seen in Figure 3. The figure shows the hydrostatic curve of the amphibious bus from the empty condition to the fully loaded condition. The empty weight of this vehicle is 15.1 tons, while the weight when the vehicle is fully loaded is 20.21 tons. From the calculation of the hydrostatic curve, it is found that the empty vehicle is 0.5 meters, while at full load is 0.7 meters. Next, the trim calculation of the vehicle is performed when it is in the water. From the calculation, it is found that the trim is 0.2°.

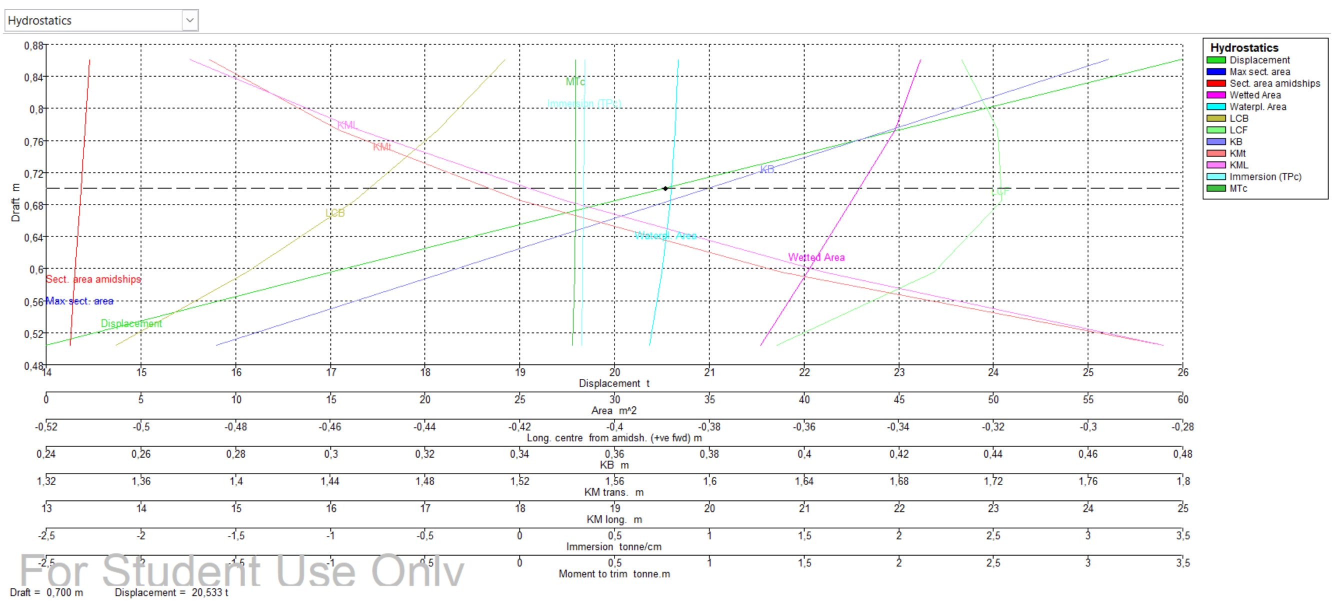
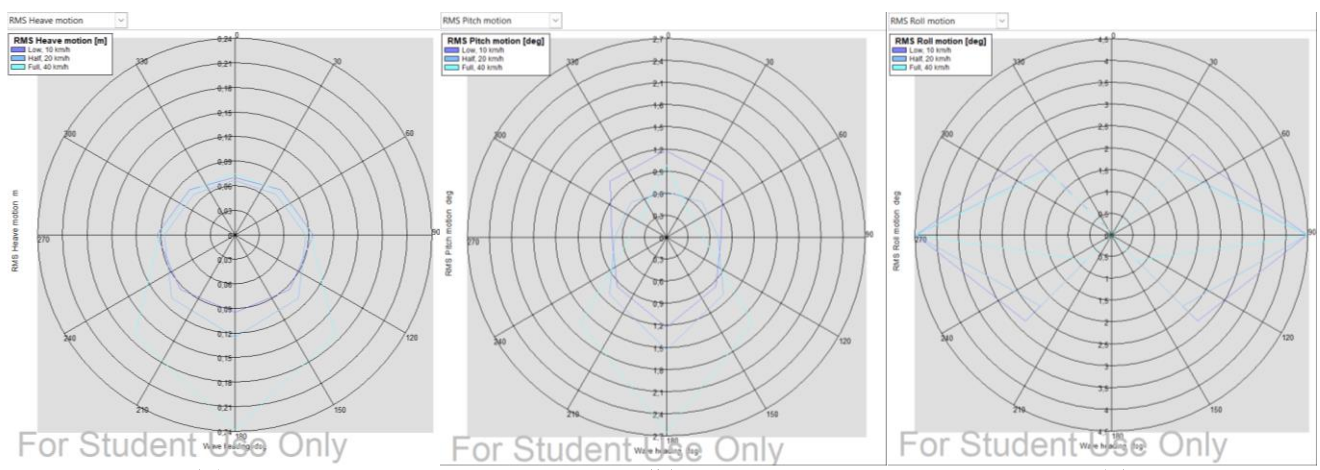


Figure 3. Hydrostatic Curve



(a) (b) (c)

Figure 4. (a) RMS Heave Motion (b) RMS Pitch Motion (c) RMS Rolling Motion

f. Seakeeping Calculation

Seakeeping is the movement of a ship influenced by external forces caused by water conditions. There are six types of ship movement in the water: three translational movements (surging, swaying, heaving) and three rotational movements (rolling, pitching, yawing). However, the movement that can be responded to by the ship is only three movements, namely heaving, pitching, and rolling [27]. The movement of a ship (Seakeeping) is the ability of a ship to stay afloat in any condition. Therefore, this ability is an important aspect of ship design [28]. The comfort of passengers needs to be considered in the design of this vehicle, especially when the vehicle is on the river. To calculate the vehicle′s response to the waves of the river, the Maxsurf motion ultimate student version software is used. Some parameters entered into this software include the heading angle, speed of the vehicle, and wave spectrum. The parameters input is given by data in the North Jakarta River [29].

Figure 4 (a) shows the calculation graph of the RMS heave. The calculation shows that the highest value of RMS heaving occurs at a heading angle of 180° at a speed of 30 km/h. Meanwhile, the lowest value occurs when the vehicle has a heading angle of 0° at a speed of 10 km/h. The maximum response of the heaving movement of the vehicle is 0.14 m, while the minimum value is 0.045 m. Figure 4 (b) shows the calculation graph of the RMS pitch. The calculation shows that the highest value of RMS pitch occurs at a heading angle of 180° at a speed of 30 km/h. Meanwhile, the lowest value occurs when the vehicle has a heading angle of 30° or 330° at a speed of 30 km/h. The maximum response of the pitch movement of the vehicle is 1.4°, while the minimum value is 0.6°. Figure 4 (c) shows the calculation graph of the RMS roll motion of the ship at speeds of 10 km/h, 15 km/h and 30 km/h at each heading angle. The calculation shows that the highest value of RMS roll occurs at a heading angle of 90° or 270° at all speeds. Meanwhile, the lowest value occurs when the vehicle has a heading angle of 0° or 180° at all speeds. The maximum response of the roll movement of the vehicle is 4°, while the minimum value is 0°.

Once known, an analysis of the Motion Sickness Index (MSI) is carried out. The comfort of passengers is measured by the number of passengers who experience seasickness in a given period, based on the ISO-2631/1997 standard. Calculations and simulations are performed at several points on the ship to determine the vertical acceleration that occurs [28]. These locations are in the vehicle′s fore, midship, and after areas. Three limits are used, including a 30-minute exposure limit, a 2-hour limit, and an 8-hour limit. These limits are based on the ISO 2631 standard. From the calculations performed, the value of the MSI of the vehicle is far below the required limit, indicating that the designed vehicle meets the requirements for comfort.

3.2. Watercraft Specification

The specifications of the water vehicle are obtained from the technical calculations performed. The calculations have gone through several iterations to obtain optimal results. The obtained specifications can be seen in Table 6.

Table 6. Watercraft Specification

Measurement	Value	Unit
Length (L)	12.0	m
Breadths (B)	3.0	m
Depth (H)	3.0	m
Draught (T)	0.8	m
Displacement	23.32	ton
Coefficient Block (Cb)	0.826	
LCB from AP	5.5	m
VCG	0.89	m
LCG	5.4	m
Trim	0.2	degree
Propulsion	Waterjet Propulsion	
Power	3x2000	kW
Battery Type	NCA 1860	
Number of batteries	100	
Total Capacity	30	kAh
Frame Spacing	500	mm

3.3. Technical Calculation on Road

a. Calculation of the resistance

The resulting values become the specification of the land vehicle. These values can be seen inTable 7.

Table 7. Technical Calculation for Vehicle

Parameter	Value	Unit
Air Drag Resistance	4445	N
Rolling Resistance	3428	N
Incline Force	99046	N
Total Resistance	106460	N
Torque	42584	Nm
Power	1065	kW
Electric Power	2x710	kW

b. Vehicle Transmission System

The first transmission ratio needs to be calculated first, followed by the calculation of the final transmission ratio. The final transmission ratio is the transmission level used by the vehicle to generate the desired speed. From the transmission calculation, the result can be found in Table 8.

Table 8. Transmission ratio

Gear	Value	V_{base} [km/h]	V_{max} [km/h]
1st gear	15.9	0.33	8.64
2nd gear	1.17	4.51	117.35

c. Vehicle Traction Calculation

Based on the calculations, the first transmission ratio has a larger driving force than the final transmission ratio. This is because the first transmission ratio is used when the vehicle is driving uphill or when the vehicle is starting to move, which requires high torque. Meanwhile, the final transmission ratio is used when the vehicle is driven on a flat road to achieve maximum speed. The traction calculation results can be seen in Table 9.

Table 9. Vehicle Traction

Gear	Traction max [N]	Traction min [N]
1st gear	478378	18399
2nd gear	35227	1355

3.4. Land Vehicle Specification

From the various calculations that have been carried out, the specifications of the land vehicle are obtained. The specifications of the vehicle can be seen in Table 10.

Table 10. Vehicle Specification

Measurement	Value	Unit
Type Electric Motor	OMD IE3-2 Pole	-
Frame Size	355LX2	
Poles	2	
Frequency	50	Hz
Frame	Cast Iron	
Power	2x710	kW
Torque	2x2274	Nm
Rotational	3000	rpm
1st gear ratio	15.9	
2nd gear ratio	1.17	
Tire Diameter	800	mm

3.5. Amphibious Bus Specifications

The amphibious vehicle specifications are obtained from calculating the technical specifications on water and roads. These specifications can be seen in Table 11.

Table 11. Amphibious Bus Specification

Parameter	Value	Unit
Velocity in River	40	km/h
Velocity in Road	60	km/h
Passanger	51	person
Maximum Inclination	30	Degree
Velocity to Inclination	8.6	km/h
Quantity of Electric Motor	3	unit

3.6. Operational Study

The specifications of the amphibious bus will be obtained from various calculations and analyses. These specifications include the following.

Table 12. Operational Study

Parameter	Valu e	Unit
Battery Capacity	30	kAH
Motor Ampere	3.6	A
Duration	8.35	Hour
Maximum Velocity (in Road)	117	km/h
Maximum Velocity max (in River)	43	km
Maximum Distance max (on Road)	918	km

Parameter	Value	Unit
Maximum Distance (in River)	359	km
Charging Times Jakarta – Bogor (in Road)	2	
Charging Times Jakarta – Bogor (in River)	4	

3.7. Lines Plan and General Arrangement

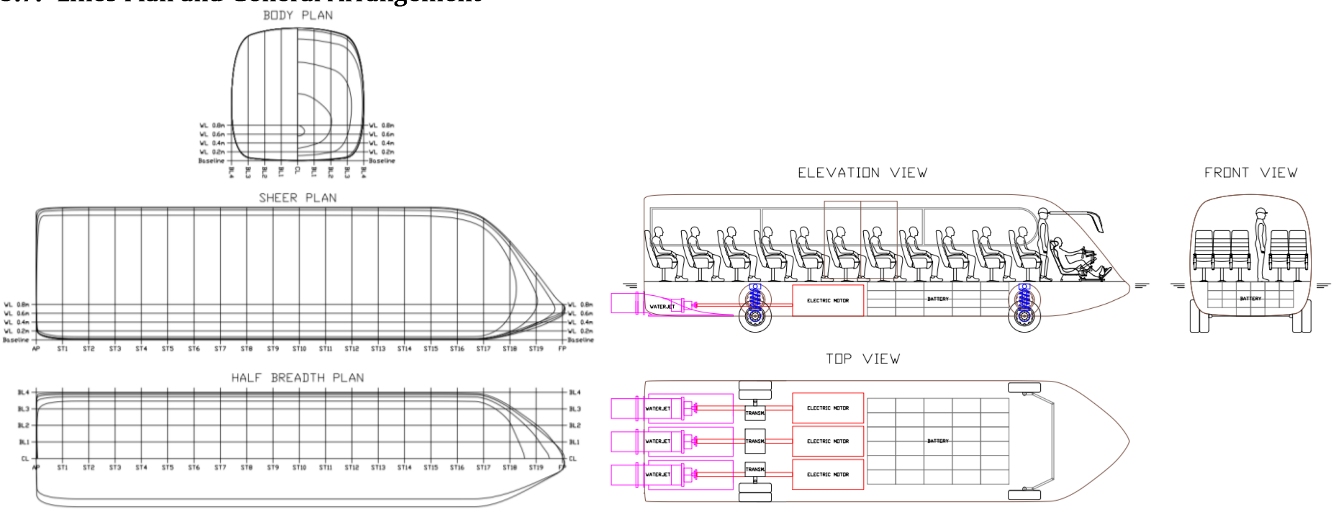


Figure 5. (a) Amphibious Bus Linesplan (b) Amphibious Bus General Arrangement

3.8. Bus Visualization

The visualization of the bus can be seen in the following figure.

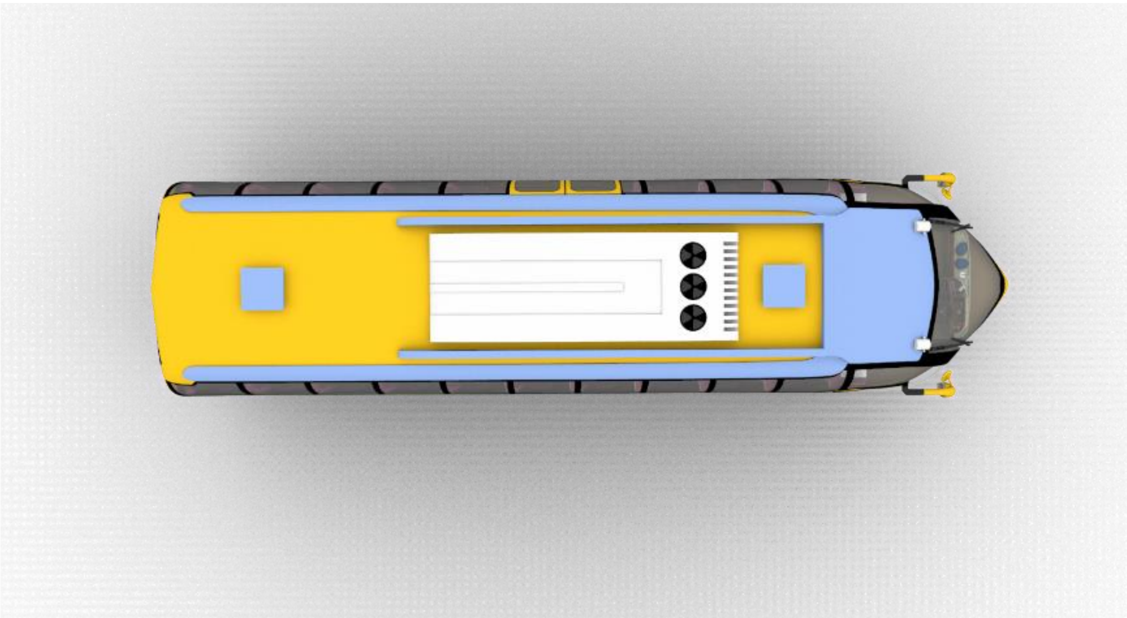


Figure 6. Top View of the Bus

Figure 7. Side View of the Bus

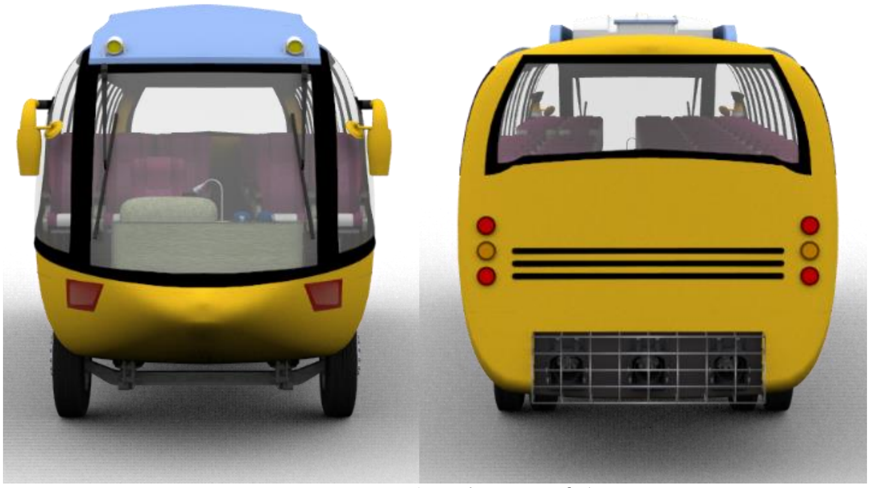


Figure 8. Front and Back View of the Bus

Figure 9. Isometric View of the Bus

3.9. Bus Operation

The operation of the bus can be seen in the following figure.

Figure 10. Land Operation

Figure 11. Water Operation

4. Conclusion

As a result of the calculations and iterations carried out, the technical specifications of the amphibious bus are obtained, including a length of 12.0 m, breadth of 3.0 m, and depth of 3.0 and draught of 0.8 m. This bus is equipped with three movers in the form of waterjet propulsion connected to electric motors with a power of 710 kW each. This bus can carry 51 people with one driver. This bus has good stability when in the water under empty and full load conditions with a level of comfort that meets ISO standards. In addition, this bus can operate up to 334 km for water distances and 501 km for land distances at 40 km/h for water and 60 km/h for land for one battery charging. This bus can also run with a maximum angle of up to 30 degrees.

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