MEC-E1004 - Principles of Naval Architecture D 11.12.2020

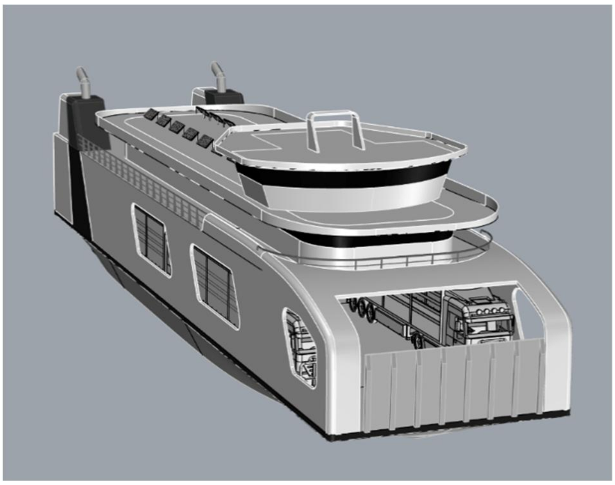
Group 5

Tuomas Toriseva

Gustavo A. Alarcon

Juho Salminen

Amazona SaFerry Concept



Contents

1 DESIGN CONTEXT 6

1.1 Design Mission and Objectives 7

1.2 Design Variables 8

1.3 Innovations 9

1.4 Boundaries 10

1.5 Design Parameters 10

1.6 Design Constraints 10

2 REFERENCE SHIP 12

2.1 Ship Category 12

2.2 Literature Review 13

2.3 Reference Vessel 15

2.3.1 Benchmarking study of reference vessels 15

2.4 Main Dimensional Statistics 18

2.5 Conclusion 18

3 MAIN DIMENSIONS 19

3.1 Constraints for Vessel Dimensions 19

3.1.1 Length 19

3.1.2 Required cargo capacity 19

3.1.3 Physical constraints 19

3.1.4 Environmental Constraints 20

3.1.5 Draught 20

3.1.6 Beam 20

3.1.7 Hull resistance 20

3.2 Ship Dimensional Assessment 20

3.3 Analysis of the Reference Ship 22

3.3.1 L/B Ratio 22

3.3.2 Length in terms of car space 22

3.3.3 Breadth in terms of car space 22

3.3.4 L/D Ratio 22

3.3.5 B/T and B/D Ratios 22

3.3.6 T/L Ratio 23

3.4 Normand's Number 23

3.5 Conclusion 25

4 HULL FORM AND HYDROSTATICS 26

4.1 Preconditions for the Hull Form Design......26
4.1.1 Stem profile......26
4.1.2 Mid ship section and Parallel mid-body......26
4.1.3 Stern profile......28
4.2 Lines Plan and Sectional Area Curve......28
4.3 Hull Form Analysis......30
4.4 Calculation of Hull Hydrostatics......33
4.4.1 Waterplane area Aw......33
4.4.2 Midship area Am......34
4.4.3 Volume (displacement)......35
4.5 Conclusion......37
5 GENERAL ARRANGEMENT......38
5.1 Preconditions for the General Arrangement Design......38
5.1.1 Fire zone division......38
5.1.2 Watertight bulkheads......39
5.1.3 Fore peak collision bulkhead......39
5.1.4 Double bottom......40
5.1.5 Minimum bow height......40
5.2 Description of the General Arrangement......41
5.2.1 Double bottom......41
5.2.2 Tanktop......42
5.2.3 RoRo decks......42
5.2.4 Passenger decks......43
5.2.5 Bridge deck......44
6 SHIP STRUCTURES......45
6.1 Regulatory Assessment......45
6.1.1 Minimum hull section modulus......45
6.1.2 Hull bending strength......45
6.1.3 Hull shear and buckling strength......46
6.2 Material Selection......46
6.3 Ship Main Section Strength......48
6.3.1 Ship specific challenges......48
6.3.2 Midship section......49
6.3.3 Structural continuity......51
6.3.4 Hull girder ultimate strength......53
6.3.5 Framing system......53

6.4 Conclusion....53
7 POWER AND MACHINERY....54
7.1 Operating Profile....54
7.2 Ship Resistance and Propulsion Power....57
7.3 Propulsion and Power Generation....62
7.3.1 Power generation....62
7.3.2 Propulsion system....64
7.3.3 Bow thruster....66
7.3.4 Auxiliary Machinery....67
7.4 Machinery Arrangement....68
7.5 Conclusion....70
8 WEIGHT AND STABILITY....71
8.1 Classification of the Ship Systems....71
8.2 Lightship Weight Estimation....75
8.2.1 Rough preliminary weight assessment....75
8.2.2 Further developed weight assessment....77
8.3 Deadweight and Displacement....82
8.4 Discussion....83
9 ECONOMIC ASSESSMENT....84
9.1 Shipbuilding Cost Analysis....84
9.1.1 Nallikari-Nieminen 1990 Ship Building Cost Estimation Method....84
9.1.2 NSFI/Levander Ship Building Cost Estimation Method....86
9.1.3 Ümran Bilen et al. January 2018 Ro-Pax Market Analysis....88
9.1.4 Market Price Estimates....92
9.2 Economic Key Performance Indicator Analysis....93
9.2.1 Improving economic KPIs....95
9.3 SWOT Analysis....95
REFERENCES....98
LIST OF APPENDICES....100

Project Team

Gustavo A. Alarcon – BEng Civil Engineering (2011- 2015), MSc Mechanical Engineering, previous experience in steel box girder bridges and concrete structures. Inspection of structural elements (e.g. welds, stiffeners, TCBs, etc.).

Tuomas Toriseva – MSc, Mechanical Engineering (2011). Currently working in Meyer Turku shipyard in machinery design Specialized in propulsion systems and main engine auxiliaries.

Juho Salminen – B.Eng. Automotive Engineering (2020), M.Sc. Mechanical Engineering (2020-). Previous experience: aerodynamics team member/leader on Formula Student team and mechanical design engineer for Scania SOE bus production.

1 DESIGN CONTEXT

This design focuses on concept design of a Ro-PAX style vessel which will focus on first round of the design spiral of ship design. Our project has three main goals: improved maneuverability compared to old traditional ferries sailing on Amazon; improve efficiency of the vessel as a whole and improve safety of vessel and passengers on board.

In the Amazon Basin alone in the year 2011/12, there were over 400 fluvial accidents, and over 50% of these accidents were caused by subpar vessels operating in the area, collision with banks, obstacles on water and/or other vessels, onboard fires, piracy, vessels running aground and incorrect (over)loading of vessels. The area lacks recent infrastructure and the Manaus and Tefe ports are difficult to access. Some renovation works were carried out but are still subpar when compared to more modern ports such as the port of Santos (SP) or port of Paranagua (PR).

This report is structured in in the same format as the design spiral drawn from Evans Sequential cyclical approach to ship design. For this 10-week design, we have followed the outside of the design spiral, starting by setting the mission requirements, then going into more detail towards lines & body plan, all the way to cost estimates. Each main design stage is separated by chapters in this report. Further detailed analysis is to be carried out in the future following this report.

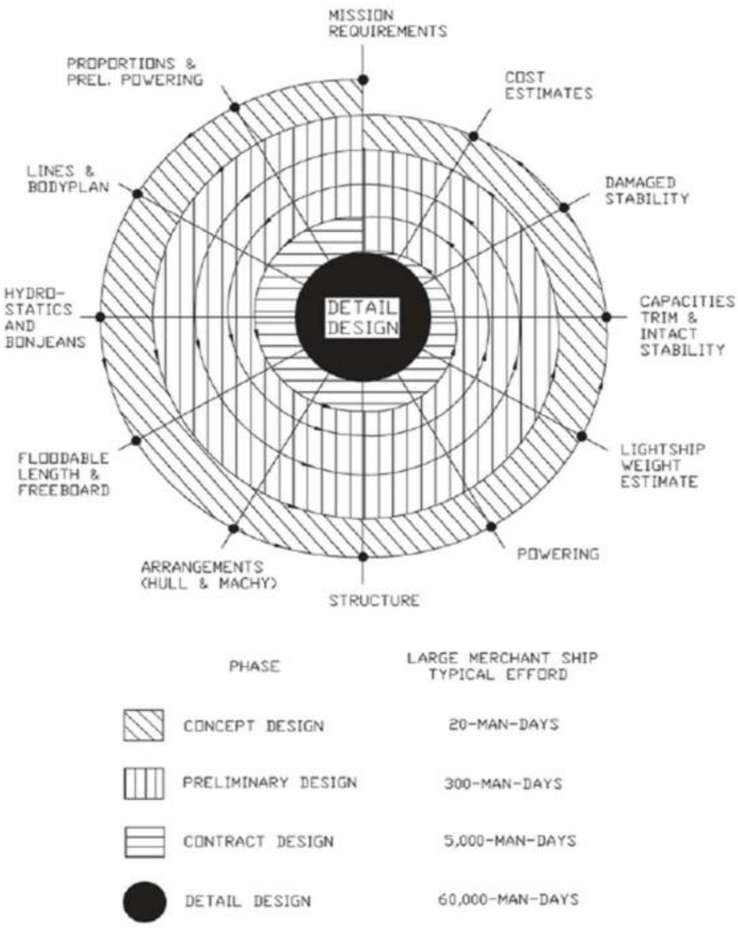


Figure 1 Ship Design Spiral. [1]

1.1 Design Mission and Objectives

There have been many ferry accidents in recent years in Manaus-Amazon area in Brazil, which are caused by natural phenomenon such as heavy rain and winds as well as human error with collisions with houses and other vessels. The Ro-Pax vessels operating in the Amazon River are old and consequently safety, reliability and environmental friendliness is out of date.

The mission of this project is to develop modern Ro-Pax ferry specialized for operation between Manaus and Tefe on the Amazon River in Brazil, see Figure 2. The vessel key characteristics will be chosen to ensure safe, economical and efficient operation in the route without compromising the performance and cargo capacity compared to existing vessels.

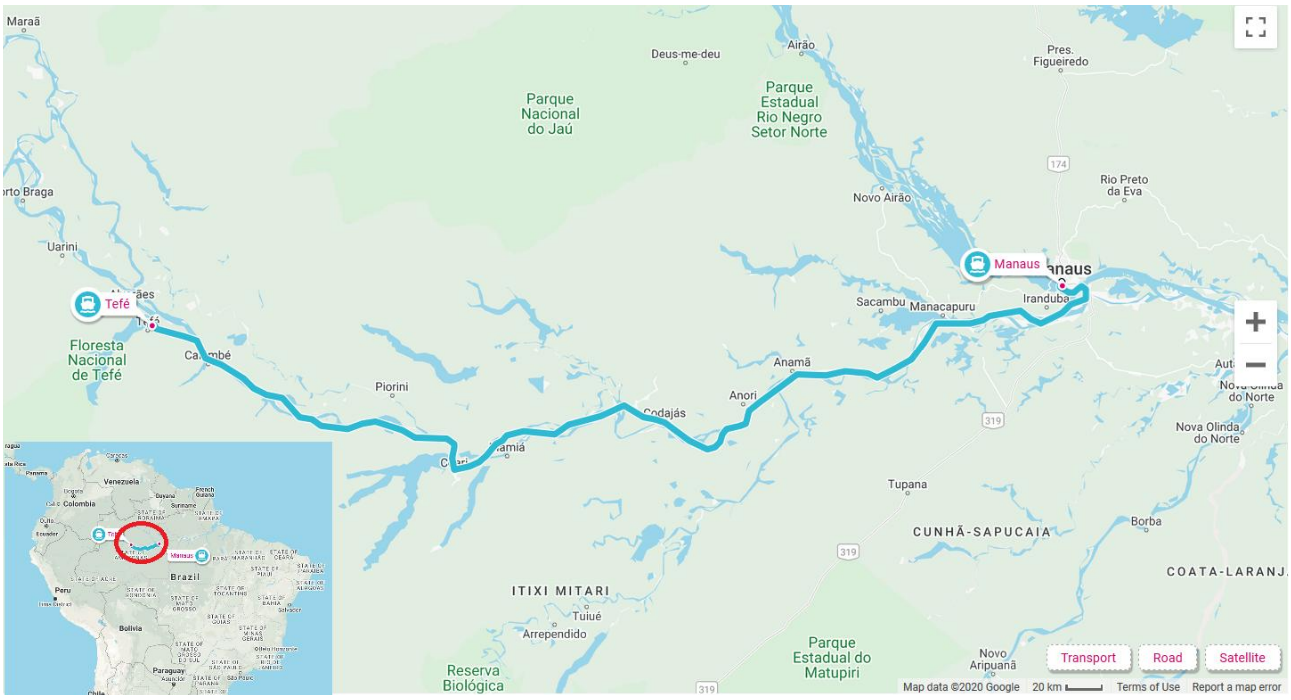


Figure 2 Vessel will be designed to operate route between Manaus and Tefe (total 523 km) on the Amazon River in Brazil.

The existing vessels on the route are old fashioned so passenger and car capacity as well as other design variables need to be examined critically. Reference vessel for the design in terms of passenger capacity and cargo could be FB M.MONTEIRO II (Figure 4) which is a typical Ro-Pax ferry operating in Amazon route. In addition, benchmarking of other vessels operating on the route will be executed.

As such, our team got together to design a ferry that is above all, safe and efficient to transport passengers from Manaus to Tefe. In line with the current tendency for sustainable choices, we have also planned for an environmentally safe ferry, keeping in mind the CO_2 reduction of 50% by 2050 as per IMO goals. We have also considered several vessels in the market, and when looking at the Efficiency Propulsion Design Index (EPDI) of these vessels on the image on right, we can see that there are three well defined groups, one for high speed crafts, one for slow and small ferries (circled in blue) and the larger group for conventional RoPAX vessels. We designed our ferry in the hopes of having a competitive EPDI when looking at the conventional ferryboats, and we have done so by carefully analysing and selecting our options in terms of environmentally friendly propulsion systems.

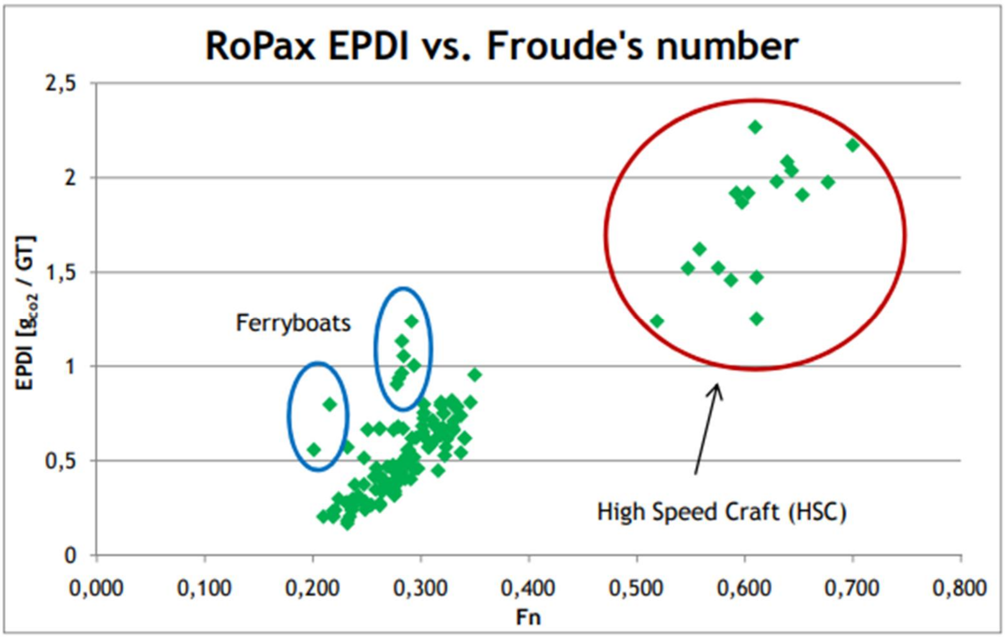


Figure 3 - RoPAX Efficiency Propulsion Design Index (EPDI) vs. Froude's Number analysis - Deltamarin Ltd. - "Study on tests and trials of the Energy Efficiency Design Index as developed by the IMO"

Additional targets include 20% reduction in energy consumption (per cargo capacity) and 30% reduction on emission level (CO2, NOx, SOx, and particles) compared to reference vessel. Implementation of new innovative technologies such as azimuth propulsion systems & electric/hybrid power plant is considered. Goal is to obtain same performance in speed but to achieve time savings by efficient maneuvering and unloading/loading passengers and cars.

Figure 4 Example of river ferries currently operating in the area: FB M.MONTEIRO II. [2]

1.2 Design Variables

The following design variables will be examined during the project to ensure fit for purpose of the vessel:

Cargo capacity

- Number of passengers
- Lane meters
- DWT
- GT

Ship characteristic

- Main dimensions and weight

- Stability, buoyancy, center of gravity, etc.
- Construction materials
- Maneuverability of vessel under certain conditions
- Vessel speed and need for propulsion power
- Accessibility / Entertainment / Features in vessel / Services
- Number of cabins vs. cargo and entertainment spaces

Economic

- Life span of the vessel
- Maintenance costs
- Operating costs
- Amount of crew

1.3 Innovations

Following innovations will be examined during the project development:

- As target is to improve stability, maneuverability and control, Azimuth propulsion system would be very natural choice as ferry equipped with azimuth thrusters would not need rudder as thrusters can rotate 360 degrees. That would enable more accurate controlling characteristics, smaller turning circle and in overall, more agile ship.
- In addition, system would be more reliable and enable better performance. Environmental point of view Azimuth propulsion system is also more efficient and as environmental issues are important factor when designing this new ferry, Azimuth thrusters would be preferable choice for ferry's propulsion system.
- Also, considerations about alternatives perhaps would still be needed as while Azimuth-system would look like an ideal choice, it is much more expensive than traditional fixed thrusters with rudders. Other alternatives to make ship easier to maneuver and almost as efficient as Azimuth thrusters could also be an option.
- Ship safety also consists other things than only ship controlling characteristics. Hull should be designed so that it could withstand forces in case of collisions probably bit more than just regulations as on Amazon river there is risk for pirate attacks or collisions with other traffic. That could be done by simulation software by calculating how much force we want the hull to withstand and then do FEM-simulations with these parameters. Longitudinal bulkheads could perhaps be used. As ship is Ropax ferry, transverse bulkheads are not an option inside the car deck.
- Low emissions
    - Full electric ferry with chargeable batteries is be impossible as longest range what electric ferry can do is approximately one tenth of a range this ferry should go in one journey.
    - Some sort of hybrid system solution could be investigated. For example, hybrid system where electric is used when approaching and leaving ports might be possible to implement.
    - LNG also a possibility. Maybe combine LNG and hybrid power.
    - Possibility for hydrogen ship in the future. LNG or gasoline powered engine and maybe there could be conversion to hydrogen later when it is possible.
    - Waste energy recapturing system to collect additional energy for batteries in case ship will be hybrid.
    - Batteries would bring extra weight and lower Center of Gravity (KG). Lower KG would increase ferry's stability.

1.4 Boundaries

Boundaries to be taken into account in the design:

Building cost

- If ship will use Azimuth propulsion system and hybrid power, cost of manufacturing and design is very high. With more traditional propulsion system costs could be reduced but overall performance of the ferry would not be as great. With normal MDO-powered engine without any hybrid systems emissions also would be higher but with efficient engines still lower than old ferries travelling the route.

Maintenance cost

- Maintenance for Azimuth propulsion system could potentially be more affordable as it reduces parts needed for propulsion system. On the other hand, repairing damages or malfunctions could be more expensive.

Voyage costs

- With hybrid ferry, voyage costs are lower when there is savings in energy consumption and using electric is usually more affordable than fossil fuels.
- LNG might be more expensive or cheaper than MDO depending on world market price of oil and taxation of those energy sources. Price difference for LNG and MDO for one voyage could be calculated if needed.

1.5 Design Parameters

Factors affecting the performance of the design:

- Fuel Price - although we are trying to mitigate against these costs by designing a highly efficient electric/hybrid ferry.
- Materials (steel, aluminum, other innovative materials)
- Environmental Conditions and restrictions – Amazon river, etc – This part of the world is known for heavy, random rainfall. There are no apparent "dry" and "wet" seasons as the rainfall in the area seems to be a year-round event. This is in fact one of the causes of several fluvial accidents in the area. This is regarded as the main design affecting constraint that the team will have to consider, as it cannot be controlled and the design must account for such events and the events resulting from the rainfall
- Operating speed and hull form of the vessel to be such that they will minimize wave making that disturbs inhabitants in riverbanks. Operating and building costs to enable competition with existing low-cost old vessels currently operating in the route.
- Main dimensions such as draught, beam and length need to be taken into special consideration in river conditions.
- Fluvial distance from Manaus to Tefe - 523km Trajectory (i.e length of journey and conditions) 523km and rainfall all year round

1.6 Design Constraints

The vessel will be designed to fulfill the latest international and national rules and requirements:

- IMO SOLAS and MARPOL conventions

- National: Ship will sail under The Brazilian Flag
- Classification society: Lloyd's Register
- Local regulations will be examined

Delivery date for the vessel will 2024, keel laying on 30.5.2023 and contract date 18.9.2020 which will determine the applicable revision of rules and regulations.

One significant design constraint is infrastructure and hydro structure of the places. The main route of the ferry is to be Manaus – Tefe, however, many communities along the way do not have necessary infrastructure to receive large vessels, and therefore means of getting of the ferry and transported to the river banks might need to be designed.

The depth of the river is one of the constraints in designing a vessel in amazon. Depth of Amazon the river is between 20m to 100m. Therefore, minimum of 20 meter or even 15m can be a design constraint considering the seasonal draught.

Maneuverability of the vessel in a river should be as easy as possible for the crew and because of hars weather conditions the speed limitation for the vessel might need to be implemented. Considering the possible accidents in the Amazon River, safety regarding collisions with other vessels must be considered in hull design as it is common reason for accidents and capsizings.

When choosing propulsion machinery and technology, limitations of local infrastructure in terms of availability of different fuels (i.e. LNG, HFO, MGO) as well as shore connections for battery charging needs to be considered.

2 REFERENCE SHIP

2.1 Ship Category

Based on our design challenge, we are required to design a Ro-Pax ferry to be used in the Amazon River, mostly to be used in the Manaus – Tefe route. The Manaus-Tefe route is actually an upper stretch of the Amazon River called Solimoes River. The main challenge we are trying to overcome is the increase in efficiency of the vessel, as well as reduction in harmful emissions and increased safety of passengers on board. We would also like to design a vessel that would contribute positively to the community as well, as this area is very important to the economy of Brazil and to the world given the proximity to the Amazon rainforest.

To start this project, the team carried out extensive literature review on the current conditions of the existing ferries and vessels that utilize this inland waterway. We found that this route is utilized as a commuting route, for passengers to get from villages/town/cities to other places, as well as transportation of goods in/out of the country. Some of the literature review is described further in Section 0 below. In summary though, there have been many fluvial accidents in the area, and the main reasons behind this is the poor instrumentation on ships, ever changing riverbanks (vary with weather, time of day, etc.), and congestion in the waterway (i.e. many vessels at once in narrow sections).

In order to tackle these issues and to come up with our design, we decided to look at vessels that are similar to our conceptual ideas. This is further described in Section 0 below. To identify suitable reference ships, we first classified our own ship into the categories studied in class. As such, the following classifications have been attributed to out vessel:

General category

General category is a more general way of classifying ships, based on general mission of the ship and what it is designed to be. Therefore, our ship has been classified as a: *Passenger Inland Waterway Self-Propelled Vessel*

This classification comes from the fact that this is a ferry whose primary mission is to transport people and vehicles from Manaus to Tefe. The ferry may be design for sea-going activities for any future purposes, but the main use is to be a self-propelled passenger vessel.

Cargo based category

Cargo based category is a way of classifying ships based on their cargo. As a ferry that is also designed for sea-going activities, the following classification has been given: *Ro-Pax Vessel / Roll-On/Roll-Off Cargo*

Mission based category

Mission based category is a method of categorizing ships on what they are intended to do. Our ferry is to be designed such that it allows for roll-on / roll-off of vehicles and for the transport of passengers from point A to B in inland waterways. This is likely to become a commercial ship, in which passengers purchase tickets to be transported from A to B, therefore, the classification is: *Commercial Ship/Vessel types*

Technology based category

We are considering designing this Ro-Pax ferry as a MDO monohull passenger ship, which we believe would be the best design for a vessel for this particular use. Displacement vessels generally provide more comfort for the passengers in a sense that it allows the vessel to travel more smoothly through the waters at the expense of speed, but given the operational environment, speed is not a major design requirement. Efficiency is also increased in displacement hull vessels.

Operation based category

The operational area/environment in which the vessel is supposed to operate in. For this particular vessel, though we have considered limited sea-going capabilities, its primary function is to operate in inland waterways; therefore, the following classification has been given: *Inland waterway vessel*

As such, the vessel is not expected to encounter large waves or any marine interfaces; however, it will be expected to interact with/against riverbanks, other vessels, structures and thunderstorms.

Limiting factory based

The categorizing of ships based on design limits, for example maximum weight, height, capacity, etc. Our classification for our vessel under this basis would be: *Space limited ships*

This classification comes from the fact that the ferry will have a limit on the amount of passengers and vehicles it can carry. However, it could be argued that it could also be classified as a size limited ship, since the operational environment will also dictate the suitable dimensions of the ship.

Hull no. Based

The categorizing is based on the hull of the ship only. As this is planned to be a monohull ship, the given classification would be: *Monohull(single hull)*

Market based

The categorizing of ships based on the market to which the ship is thought to be operating in/for. As a ferry of commercial use, the following classification has been given: *Niche market* (not expecting major luxury and great number of passengers/cargo).

2.2 Literature Review

As there has been major incidents which has happened to RO-RO ships and most notably Ro-Pax ferries there could be assumption that Ro-Pax ships are more dangerous than other ships. Ro-Pax ferries cargo loss rate per thousand ships seems to be same on a same figure compared to all ships. [3]

However, Ro-Ro ships still have the reputation as dangerous ships. IMO's Ro-Ro safety improvement report says that in Lloyd's Register there has been almost 4600 registered deaths resulted by accidents at sea between a 5-year period which started in 1989. One third of those deaths happened in accidents occurred on Ro-Ro ships even though Ro-Ro ships makes only small segment of all ships sailing on sea. Based on this we could make conclusion that accidents involving Ro-Ro ships are not more frequent than other ships but risk for disastrous accidents are far higher [3]. So based on that we could conclude that while Ro-Ro's are not more vulnerable to accidents than other ships in general, major accidents are more common and they might have bad reputation as sinking of Estonia, The Herald of Free Enterprise, MV Sewol and MV Le Joola have been worldwide headlines on newspapers and even topic of movies.

One reason for reputation is also that Ro-Pax-ship has already one disadvantage what comes by the nature of the ship. To make access for cars to drive through the ship it makes it impossible to have transversal bulkheads above tank top so subdivisions created by bulkheads are not possible to do. Transverse bulkheads are useful way to improve ship safety as with them stability and water tightness of the ship are much better if ship is flooding as flooding is limited to only a small section of ship. [4]. Transverse bulkheads also improve safety in case of fire too, as fire would not spread to other sections of the ship as easily [5].

With that in mind. Quick flooding is not the only problem with Ro-Pax design. In situation of breach or flooding, water progress full length of the ship and it will lose buoyancy and its stability more easily. [4]

Another problem with Ro-Pax ship is maintaining stability on extreme conditions. As they are having quite high depth to draft ratio, they are quite sensitive to heeling moments. High velocity crosswind, waves or unbalanced loading of cargo could cause problems and at worst-case scenario, even ships capsizing. [4], [5]

As Ro-Pax ships needs to have cargo doors in stern and bow it is another weakness for them. Stern doors are close to waterline as loading cargo conveniently is major reason for Ropax ship success and low doors enable that. Also rising doors and car deck ship would have higher KG etc.

Problem with low cargo doors is that even though the door itself would have great structural strength and would not be a weak part of the ship's structure there is still danger for human error. If door is not locked properly and ship moves away from the port, there is large risk that water would fill the ship's cargo deck.

Bow doors have even larger risk as high loads from waves, corrosion and fatigue could affect bow door's strength and its structural rigidity, especially on joints. Estonia's sinking in 1994 was caused by detached bow door [4]. In addition, like stern doors, also human error is factor causing risks for bow doors too as capsizing of Herald of Free Enterprise was caused by flooding through open bow doors during the start of the journey.

Luckily there have been developments to prevent capsizing. Tu Delft has developed air bags, which are Inflatable bracelets. Idea is that when ship is sinking due to unbalanced cargo or damage or opening on the hull, "airbags" would deploy and balance the ship so it would prevent capsizing. Model testing of the device have been done with scaled Ro-Pax ship model and results has been promising but there is still challenges ahead as airbags needs to inflate quickly and find correct location for them in Ship's superstructure. [6]

2.3 Reference Vessel

The Ro-Pax and passenger ferries currently operating on the route Manaus-Tefe are considerably old and ship data is difficult to obtain. Consequently, group has benchmarked also new modern and innovative passenger ferries to explore new technologies and find new suitable design for the ferry.

2.3.1 Benchmarking study of reference vessels

Aurora Botnia

Aurora Botnia is new modern Ro-Pax ferry for Wasaline currently under construction in RMC shipyard in Finland. The vessel will have a hybrid power generation system, as well as an electric propulsion system rarely used in car and passenger ferries. At the moment the ferry can be considered as the most environmentally friendly large Ro-Pax ferry under construction. [7]

Figure 5 Aurora Botnia [7]

MV Alfred

MV Alfred is 85m long catamaran vehicle-passenger ferry built by Strategic Marine Vietnam, for family-owned Scottish ferry operator Pentland Ferries. MV Alfred is planned to operate in the rough waters of the Pentland Firth, between Gills Bay on the Scottish mainland and St Margaret's Hope, Orkney, with a transit time of around one hour. Entry into service is planned for later this year and, the vessel will significantly expand the operator's capacity on the route, carrying up to 430 passengers and 98 cars, or 12 lorries with 54 cars. [8]

Figure 6 MV Alfred [8]

DAMEN ROPAX 6716

Damen Ro-Pax 6716 is an innovative “standard ferry” design from Damen shipyard that can be customized according to shipowner needs. It has mono hull structure and uses steel as hull and superstructure material. Propulsion system enables good maneuvering capabilities and low emissions. [9]

Figure 7 Damen ROPAX 6716 [9]

MV Jadran

MW Jadran is typical Ro-Pax ferry operating in coast of Croatia in route Split—Stari Grad. Vessel has similar features required by Amazon river ferries.

Figure 8 MV Jadran [10]

Leao de Juda V

Leao de Juda V represents existing design and reference level of Amazon Ro-Pax ferries. However, it has been difficult to find reliable data on the vessel characteristics.

Figure 9 Leao de Juda V [11]

2.4 Main Dimensional Statistics

The comparison of main dimensions of the chosen reference vessels can be found from Appendix 1. Froude numbers vary between 0,23-0,29 which are common values for low speed ferries.

2.5 Conclusion

Damen ROPAX 6716 is selected as a final reference vessel because it represents well productized modern passenger ferry design. All the main information for the vessel is easily available which is important fact when trying to meet the technical complexity and features of the reference vessel. The concept of Amazona SaFerry can be developed on the basis of reference vessel and customized to meet the environmental conditions of Amazon river. Some factors such as fuel option compared to the reference vessel need to be considered during the design phase as there are limitations in the infrastructure in the operating region.

3 MAIN DIMENSIONS

3.1 Constraints for Vessel Dimensions

The main limiting factor in deciding the dimensions for our ship comes from the environment in which it will be operated on, and some physical constraints as well. We have decided that ship will have 500 passengers/crew members and it could take 40 cars and those are first constraints where we start to shape the ship.

3.1.1 Length

Length of the vessel could be approximately 60-80 meters based on pictures from Tefe's port which looked like there is no infrastructure for much larger vessels. Exact length will be determined via calculations using Normand's number and statistical approach. Also fit the amount of passengers we want should be plausible with this length.

3.1.2 Required cargo capacity

- 500 passengers which would equal to approximately 50 tons (gets added to deadweight).
- Cargo load would be 40 saloon cars as we have estimated to have 220 lane meters. We have approximated that one car weighs 1.5 tons so 40 cars would equal 60 tons but as lorries could weight approximately 50 tons we have settled that amount of lorries ship would carry is 4 to 6 depending on weight of the lorries but total weight of vehicles ship is supposed to carry would be up to 400 tons.
- Overall cargo capacity then should be up to 450 tons.
- Safety factor of course should be in consideration and we would think that safety factor could be in the lines of 2 which would equal approximately deadweight of 900 tons.

3.1.3 Physical constraints

- Shipyard facilities won't be that big of a problem as ship's size is not more than 80 metrers of length and under 20 meters breadth. Ships could be manufactured in Brazil for example Sao Paulo's Santos docks could potentially have shipyard where ship will be built. It also would be convenient and good for Brazilian economy to support local industry. Also manufacturing price wouldn't be that high compared to Finland or Germany.
- Amazon is a wide river, and it has enough depth, so draft is not going to be an issue on a ship sized like this. Also, breadth is not limited by river's width.

Figure 10 Route from Manaus to Tefe.

- Port in Tefe is probably limiting constraint for length and width. Based on pictures Tefe won't have infrastructure for large passenger ships, so it seems that at ship maximum dimensions lies somewhere around 18 meters of breadth and 80 meters of lenght.

3.1.4 Environmental Constraints

- Rain season. Thunderstorms are possible in rain seasons but still ship sails in river conditions, so it doesn't have to necessarily withstand open sea condition waves and winds. That's why draft/length ratio won't be as important than in some other ships.
- Breadth. There might be strong currents in Amazon river, so stability is important. Increasing breadth will increase stability of the ship.

3.1.5 Draught

- Draught from reference vessel is 3.3 meters which seems suitable for our ship too.
- This draft will enable slightly larger propellers to increase maneuverability of the ferry.
- Draft/length ratio and slamming at seas are not as important factor as ferry is not sailing on open seas so weather conditions and waves in open sea does not need to be taken account. That is why we can have relatively high draft/length ratio.

3.1.6 Beam

As we wanted to load 40 cars and we have approximately 220 lane meters we would need to have 4 different lines for cars if our ship is approximately 55 meters long. That would mean that one line would be approximately 2.5 meters wide so even large lorry could fit there. Steel structure is at least couple of meters thick on both sides. That would mean approximately 15-16-meters wide beam.

3.1.7 Hull resistance

- L/B ratio will relatively low so hull resistance is going to be quite high based on this. Hull resistance could be lowered by adding some underwater fins or some similar solutions to make wetted surface more hydrodynamic.
- Air resistance is negligible so superstructure's design is not going to be that important when thinking about resistance of the ship.
- Hull resistance should be calculated carefully by CFD-simulations on detailed design phase. Information gained from CFD could be used to decrease water resistance of the hull.

3.2 Ship Dimensional Assessment

We have attempted to generate main dimensions for this ship by using both the empirical and statistical methods, as well as a more direct approach for some dimensions. Scaling down/up the reference ship has also provided some insight into the project's dimensions. We have also been a bit critical of the chosen reference ship, as some of the ratios are outside the normal accepted ranges. This is discussed further in the report.

Our reference ship is the Damen RoPax 6716 Passenger & Car Ferry, and the main parameters are shown in Figure 11 and Table 1. In Table 1 part of the dimensions are estimated based on available data and pictures. In evalution of displacement, rule of thumb estimates for hull, machinery and outfitting weight is used.

GENERAL

Yard number	539319	
Hull material	Steel	
Basic functions	Passenger Car Ferry	
Flag	Timor Leste	
Classification	+1A R0 Ferry A BWM(T) BIS	

DIMENSIONS

Length o.a.	67.30	m
Beam mld.	16.00	m
Depth	4.70	m
Draft	3.30	m

TANK CAPACITIES

Fuel oil	82	m3
Fresh water	38	m3
Sewage	12	m3
Ballast water	450	m3

Figure 11 Damen RoPax 6716 Passenger & Car Ferry main data. [9]

Table 1 Estimated main dimensions for the reference vessel Damen RoPax 6716 Passenger & Car Ferry.

Damen 6716 RoPax Passenger & Car Ferry		
Dimension	Value	
Length (Lpp)	64	m
Breadth (B)	16	m
Draft (T)	3.3	m
Freeboard	1.4	m
Depth (D)	4.7	m
L/B	4.00	
L/D	13.62	
B/T	4.85	
T/L	0.05	
B/D	3.40	
Block Coefficient	0.63	
Displacement	2195	tons
Fn	0.21	

At the initial stage of the design, it is assumed that the best approach for the ferry design is to assume this is a “deadweight carrier”, as such; the following requirements are the main governing factors in deciding the dimensions of the ship:

● Deadweight - this refers to the measure of the capacity of the ship to carry cargo, provisions, passengers, crew, vehicles, etc.

● Speed - Given the tricky route in which this vessel will be operating in, we have decided that this ferry will not be designed for speed, but for comfort and efficiency. As such, we are limiting the operating speed to 12 knots. The speed of the reference vessel are 10 knots so we wanted it to be still bit faster than our reference ship which has actually really low speed for ferry.

● Range - The route from Manaus to Tefe is 523km, with stops along the way, and no refueling facilities. This means that the ship must be able to carry enough fuel for a round-trip, and additional fuel as a factor of safety.

The following parameters can be used to carry out a check on the design:

- Capacity
- Stability
- Freeboard

We have first carried out a simple rule of thumb analysis on our reference ship, as described in following chapter.

3.3 Analysis of the Reference Ship

3.3.1 L/B Ratio

L/B = 64.3/16 = 4.00

The Length-breadth ratio L/B is typically 4 – 10 and our reference ship has it inside the target area. L/B has influence on hull resistance, hence power. L/B tends to be larger for faster ships, but this ferry wasn't designed for speed. Calm water resistance is sensitive to hull length, and a L/B of 4 could be acceptable since the river does not generally present treacherous waters relatively speaking.

3.3.2 Length in terms of car space

The reference ship states a limit of 60 cars in 264 lane meters. Using the rule of thumb that each car takes requires 6 m of lane meters, the ship is well outside this rule of thumb. In this reference design, each car takes 4.4 lane meters. Drawings indicate 6 lanes, with different lengths and widths. Longest lane has 12 cars, each car space is assumed to be 5 m in length with varying widths, but an average area of 11.5 m^2 per car space.

We have used 5,5 lane meters for one car so we can be sure that we can fit enough cars. Original plan is to have four different lines for cars. We have used 13,75 m^2 per car space.

3.3.3 Breadth in terms of car space

Breadth of our reference ship is 16 meters. It has 4 different lines for vehicles and one line is approximately 2.5 meters wide but it also appears to have longitudinal bulkhead.

So if breadth for our ferry would be when wall thickness would be 2.5 meters

B = (4*2.5) + (2*2.5) = 15 meters. This means we would have approximately 15 meters of breadth.

3.3.4 L/D Ratio

L/D = 64/4.7 = 13.62

The Length-Depth ratio is typically 10 – 18. The length-depth ratio affects the strength of the hull girder. The reference vessel is well within the range that as a rule of thumb satisfies strength of the hull.

3.3.5 B/T and B/D Ratios

B/T = 16.0/3.3 = 4.85

B/D = 16.0/4.7 = 3.40

An increased in breadth generally translates into increased stability, as such, both the breadth-draft and breadth-depth ratios affect the transversal stability of a ship. The higher the ratio, the higher the stability of the ship. Decrease in *B* generally translates into reduced resistance, but since this ship is designed for relatively calm waters, a decrease is acceptable.

3.3.6 T/L Ratio

T/L = 3.3/64 = 0.05

It is observed that *T* should be as large as possible, in order to allow larger propeller and increase efficiency of ship. This is however governed by the operating conditions of the route. The Manaus – Tefe route changes drastically according to the seasons, and the depth of river can be as low as 6m, which affects the value of the designed *T*. Larger *T* also minimizes slamming effect of ship navigating in rough waters. Generally speaking, *T/L* ratios of 0.035 - 0.05 provide good comfort and is generally the industry rule of thumb.

Typical C_b values at fully loaded drafts

Ship Type	Typical C_b Fully Loaded	Ship Type	Typical C_b Fully Loaded
ULCC	0.850	General cargo ship	0.700
Supertanker	0.825	Passenger liner	0.575–0.625
Oil tanker	0.800	Container ship	0.575
Bulk carrier	0.775–0.825	Coastal tug	0.500

Medium-form ships (C_b approx. 0.700), full-form ships (C_b > 0.700), fine-form ships (C_b < 0.700).

Figure 12 Typical block coefficient C_b values for different type of vessels.

Based on values shown in Figure 12, required displacement and weight estimation, it is assumed that as a passenger ship, the C_b for the reference ship is 0.63. This will also be used for our design.

C_b is the ratio of underwater volume of the vessel and the volume of a rectangular block in the dimensions of the vessel. This number has an effect on the buoyancy of the vessel, the higher the coefficient, the higher the buoyancy. It also affects resistance and speed. The higher the coefficient, the lower the speed and increased resistance.

3.4 Normand's Number

We used Norman's approach to determine the final constraints of our ship using our initial values as targets what we would like to achieve. The Normand's number approach is defined as a factor by which the change in one or various weight components is multiplied to give the change in the total displacement of a ship as follows:

$$N = \frac{d\Delta}{dW} = \frac{\Delta}{\Delta + (W_H + W_O) + \frac{2}{3}(W_M + W_F)} \quad (1)$$

where

W_H is the hull weight of the reference ship,

W_O is the outfitting weight of the reference ship,

W_M is the machinery weight of the reference ship, and

W_F is the fuel weight of the reference ship.

The displacement of the new vessel can be calculated when Normand's number from (1) is known:

$$\Delta_{new} = \Delta + NdW \quad (2)$$

We used first reference vessel Damen 6716 Ropax which had approximately 700 tons of deadweight. After getting values from there, we did calculate new ship data from there using draft of 3.3 meters, block coefficient of 0.6 and we added 150 tons of deadweight which gave us 850 tons of deadweight being our target.

Calculation of Normand's number and displacement of the new vessel are shown in Table 3. The length and breadth is been increased to obtain increased displacement and deadweight 850 tons. Also hull block coefficient is decreased from 0.63 to 0.6 to reduce the resistance and obtain speed increase from 10 kn of reference vessel to 12 kn of the new vessel.

Table 2 Calculation of vessel dimensions with Normand's number.

Damen RoPax 6716

Item	Reference Ship data
Lpp (m)	64
B (m)	16
T (m)	3,3
CB	0,63
Density of water	1,025
Δ (tonne)	2195
Hull weight W_H (tonne)	700
Machinery Weight W_M (tonne)	300
Outfitting weight W_O (tonne)	500
Fuel weight W_F (tonne)	0
Deadweight (tonne)	695
L/B	4,23

Fuel weight included in deadweight

Normand's no. (N)	2,761

Amazon SaFerry, added 150t deadweight

Item	New Ship data
L (m)	74,85
B (m)	17,70
T (m)	3,3
CB	0,6
Δ (tonne)	2623
Deadweight (tonne)	850
L/B	4,23

The dimensional coefficients of the Amazona SaFerry are shown in Table 3.

Table 3 Amazona SaFerry preliminary dimensions.

Dimension	Value	
Length (Lpp)	74.85	m
Breadth (B)	17.7	m
Draft (T)	3.3	m
Freeboard	2.8	m
Depth (D)	6	m
L/B	4.23	
L/D	22.68	
B/T	5.36	
T/L	0.04	
Block Coeff.	0.58	
Displacement	2623	tons
Fn	0.22	

3.5 Conclusion

After careful consideration what ship dimensions would be and what ship's deadweight target it was decided to use dimensions gained from Normand's number calculations to determine the new ship's dimensions as they are very close to our original preliminary numbers and they have at least some scientific and mathematical proof behind them. Additional dimensions which are not visible on table are freeboard height which will be 2.8 meters from waterline as we decided to keep depth at 6 meters. If there is need for changes later in the design phase we will make then if they are necessary.

Our vessel will be larger than the reference vessel, which is expected since we want to increase deadweight capacity and have more efficient equipment for it. Block coefficient was reduced further to reduce resistance, and bulbous bow has been introduced to reduce wave-making and environmental effects. The dimensional ratios are well within the industry's practices which gives us confidence at this stage that our dimensions are reasonable to proceed with the design.

4 HULL FORM AND HYDROSTATICS

4.1 Preconditions for the Hull Form Design

In the following paragraphs the targets and general features of the hull form design are discussed.

4.1.1 Stem profile

The Froude number of the vessel (*Fn*=0.22) is in the area where wave making resistance starts to be significant. Thereby it is decided to use bulbous bow shape to decrease the residuary resistance. It is noted that selection will increase the hull building costs but, on the other hand, it will have relatively low payback time as the required propulsion power can be reduced. Lower propulsion power will mean lower operating costs and have decreasing impact to the machinery investment cost. As bulbous bow also reduces waves created by ship it helps to reach target that our ferry would disturb local habitants less.

V-type of bow shape with bulb is selected as it provides good stability and wide deck area for RoRo cargo. The shape of bow needs to be raked to increase deck area and make space for the loading ramp in the bow.

By using, V-shape bow, the waterline can be widened and volume above waterline can be maximized. V-type bow will reduce the frictional resistance and have reduced building cost compared to U-shape bow.

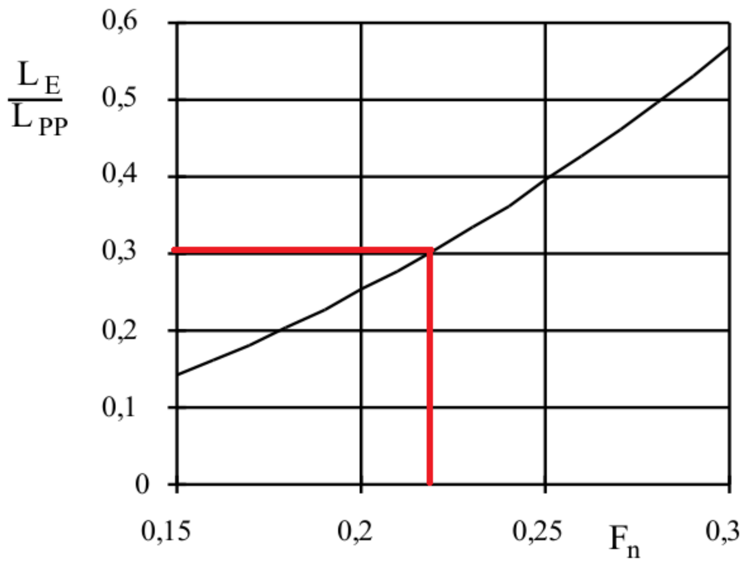


Figure 13 Entrance length to length between perpendiculars ratio related to Froude number. [12]

As per Figure 13, the length of entrance Le in sectional area curve with Froude number *Fn* = 0.22 is to be around 30 % of the length between perpendiculars *Lpp*.

4.1.2 Mid ship section and Parallel mid-body

Conventional flat bottom with vertical sides and a rounded bilge is used in the mid ship section to have lower building costs and provide space for diesel electric power plant in tank top.

Common recommendations for feasible prismatic coefficient in relation to Froude number are shown in Figure 14. These are based on suggestions and recommendations by Raw-son and Tupper (2001), Jensen (1994), Taylor (1943), Dubrovsky and Lyakhovitsky (2001) and Saunders (1957). [13]

Based on reference curves and *Fn* = 0.22, the prismatic coefficient of the vessel should be in the range of C_p = 0.67-0.74 for majority of suggestions. Also values for C_p in the range of 0.51-0.54 can be accepted as suggested by Rawson and Tupper and Taylor.

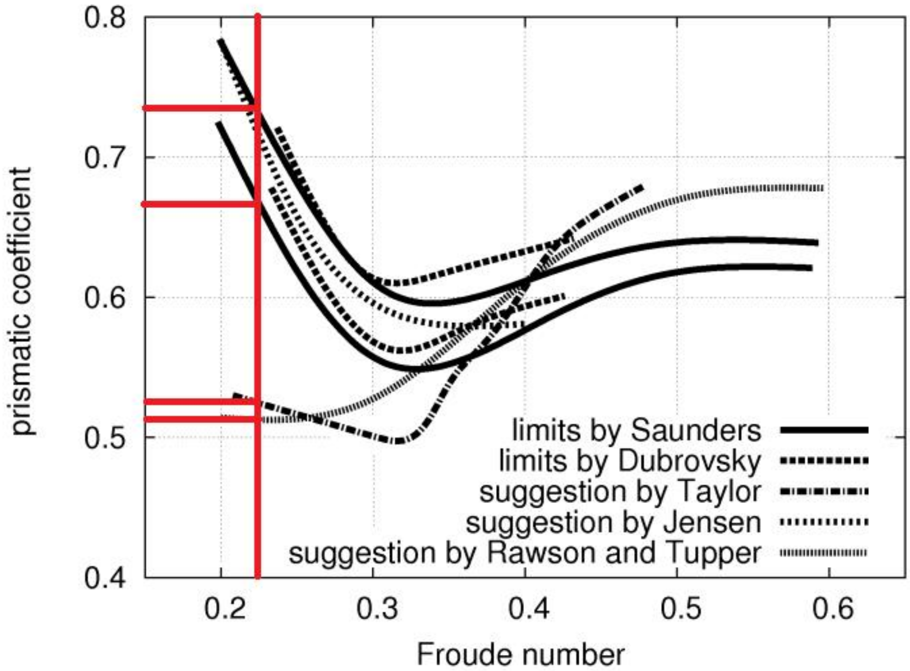


Figure 14 Recommendation for prismatic coefficients a function of Froude number. [13]

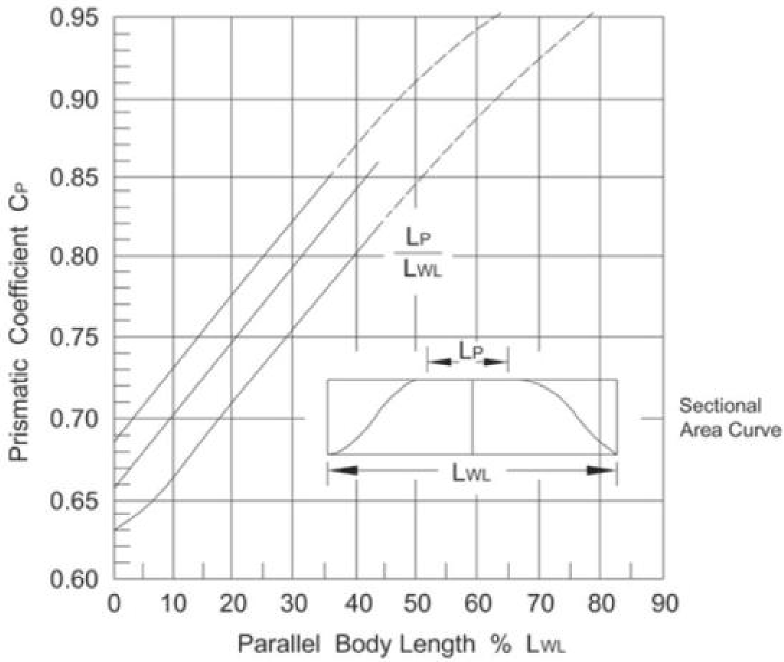


Figure 15 Parallel body length vs. prismatic coefficient. [14]

The length of the parallel mid-body depends on chosen prismatic coefficient as per Figure 15. With prismatic coefficient $C_p < 0.7$ the length of the parallel mid body can be estimated already at this point to be less than 10 % of the waterline length.

4.1.3 Stern profile

Transom stern is used as it provides large water plane area and increased stability in still water. This stern shape can increase stern slamming but it is not considered as a significant risk in river operation. As *Fn* < 0.3, the stern should be above waterline. The stern shape is optimized for operation of two azimuth unit and homogenous wake field to propellers, as the stern appendices before propeller are not needed.

4.2 Lines Plan and Sectional Area Curve

To get the main characteristics clear, the first version of hull shape is defined with *04. T4_Hull Lines.xlsx*- excel sheet. In the shape of the hull, it is needed to take into account the integration to car deck both in stem and stern. The stern bottom shape should enable implementation of azimuth thrusters so the angle of rise near the aft perpendicular should not be too steep. Main dimensions and coefficients of the hull are shown in Table 4.

Table 4 Main dimensions and hull form coefficients.

Ship type:	Passenger Ferry, 2 propellers		
Loa	80,1	[m]	From lines
Lpp	74,9	[m]	Given data
Lwl	77,8	[m]	From lines
B	17,7	[m]	Given data
T	3,3	[m]	Given data
D	6,0	[m]	Given data
Displacement Volume (Vol):	2 594	[m3]	Hull + Skeg
Displacement Weight (Displ)	2 594	[ton]	1,025*Vol
Hull Volume to Upper Deck	5906	[m3]	
Speed (V):	12,0	[kn]	Given data
Froude Nr. (Fn):	0,22		
Hull form coefficients:			
L / B	4,23		
L / D	12,48		
B / T	5,36		
Slenderness ratio:	5,67		Lwl/Vol^(1/3)
Block coefficient (CB):	0,593		Vol / Lpp*B*T
Midship area (Am):	58,1	[m2]	From SAC
Midship area coefficients (CM):	0,994		Am/B/T
Prismatic coefficient (CP):	0,597		CB/CM
Waterplane area (Aw):	1059	[m2]	From SAC
Waterplane area coefficients (CW):	0,800		Aw/Lpp/B
LCB:	-1,1 %		From SAC
KB	1,84		From SAC
BM	8,34		From SAC
KM	10,18		From SAC

As our ship had already determined length between perpendiculars, breadth, depth, draft and speed we needed to start figuring out all other necessary measures and hull lines for our ship's hull. After careful consideration and iterations, the section area curve was defined (Figure 16).

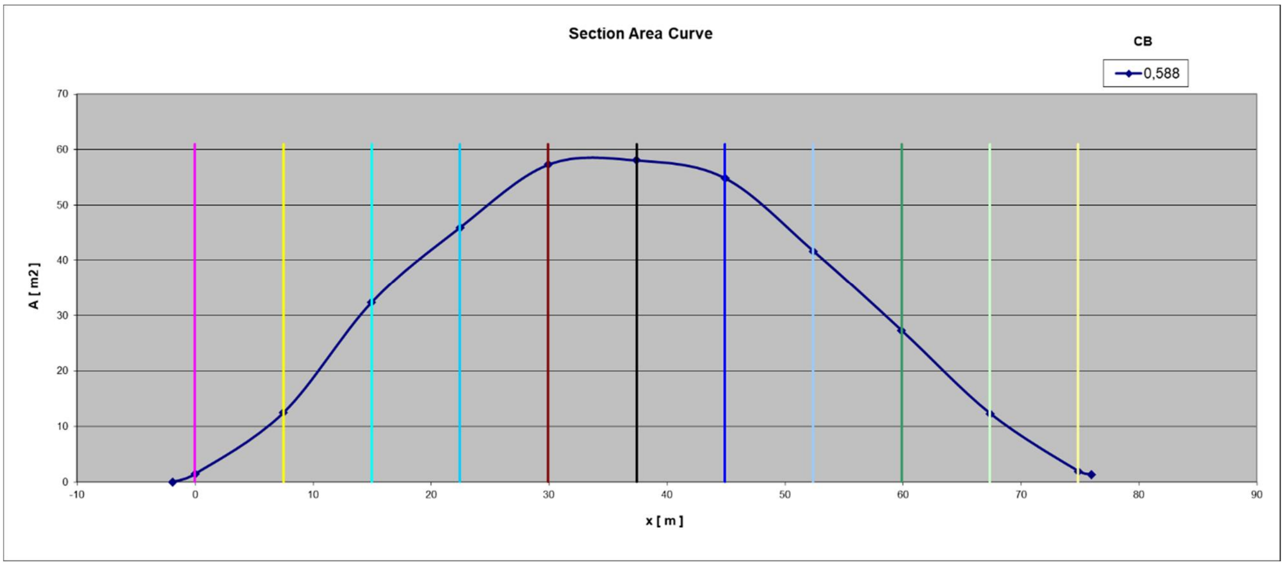


Figure 16 Section Area Curve of Amazona SaFerry.

Waterline curve of ship's hull affects the ship's buoyancy, handling characteristics and for example water resistance of the ship. That is why waterline needed to be optimized so that it would have sensible shape fitting our needs. Half breadth plan of the vessel is presented in Figure 17. Waterline curve shape looks good and it was iterated many times to get final shape.

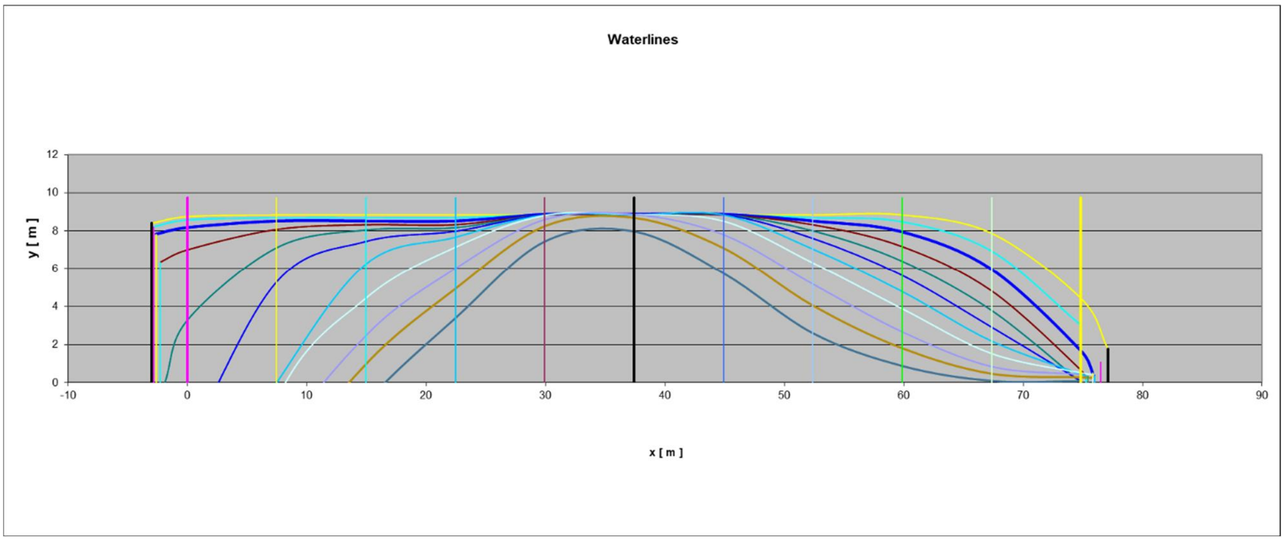


Figure 17 Half breadth plan of Amazona SaFerry.

Profile of ship hull has been determined by calculations and spreadsheet and is shown in Figure 18. Ship hull's length overall is 80.1 meters and shape close to normal Ropax ship shape. In addition, it has bulbous bow that was decided to use in earlier phase of the design. This is also how waterline length were determined as waterline is on 3.3 meters.

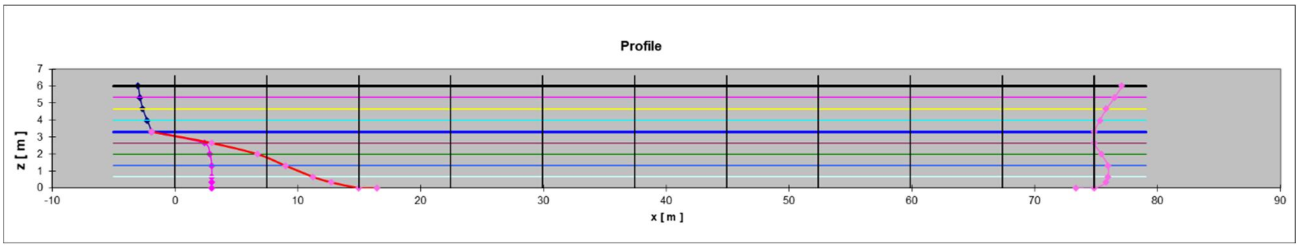


Figure 18 Profile of Amazona SaFerry hull.

Body plan of the vessel is shown in Figure 19.

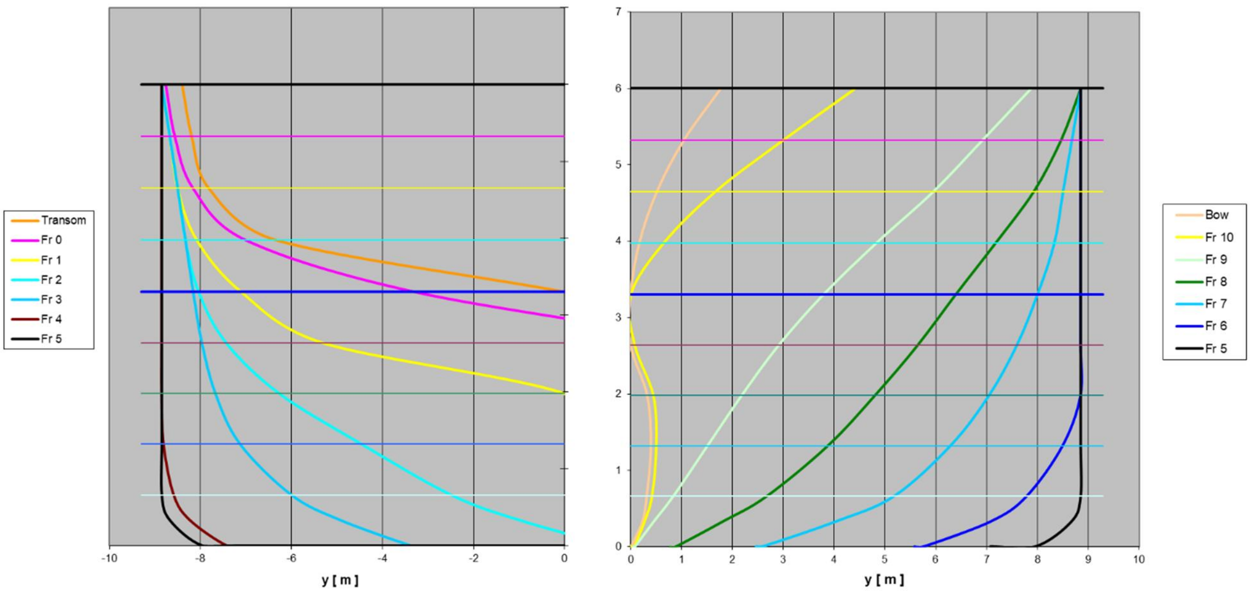


Figure 19 Body plan, bow and stern.

After we managed to get our ship's hull shape, next step on hull design is to try to optimize the hull lines, measures and information on DelftSHIP. (?)

4.3 Hull Form Analysis

The hull shape and its main coefficients were presented in Table 4. In this paragraph, the main coefficients are discussed and compared to original target of the design and statistical data.

Displacement **Δ**: Based on Normand's number and deadweight capacity increase of 150 tons, the displacement of the vessel was specified to be Δ = 2623 tons. For the actual hull shape the displacement was calculated to be Δ = 2594 tons which is very near to the original target.

Block coefficient C_B: Block Coefficient of our vessel was reduced further to 0.593. This is a direct result of us changing the hull lines such that the hull is smoother to reduce resistance of the hull. The result is a reduced block of coefficient, which translates to increased speed of the vessel, and reduced displacement as shown above.

Waterplane Area C_W: Refers to the degree of the fullness of the waterplane area in relation to the referred rectangle box of length *L* and breadth *B*. This was calculated to be 0.8, which is a relatively high number. This high number may affect negatively the ship's resistance, and lower C_w generally is favorable hydrostatically speaking. However, this will be calculated further in hydrostatic calculations and it is something to be aware of.

Prismatic coefficient C_p: The prismatic coefficient C_p was calculated to be 0.597 which is in line with suggestions and recommendations presented in section 1 of this report.

Length of entrance L_e: This refers to the length from the forward perpendicular to the forward end of parallel mid-section, or simply the maximum section, see Figure 20. The selection of the Length of Entrance affects the generation of bow waves, thus it affects wave resistance. We wanted to move the midship area towards the aft of the vessel as much as possible to optimize hull resistance, and as shown in section 1, we have chosen to utilize the relationship between the ratio L_e/L_{pp} and Froude's number. With a Froude's number of 0.22, the estimated Le is to be 38% of the L_{pp} length, which in turn has been calculated to be around 28.5 m. This actually puts the midship area closer to the forward part of the vessel, but as we have maximized this ratio, it is believed to be acceptable. In addition, this ship is not considered a fast ship, and the lower designed speed reduces need for higher L_e/L_{pp} ratio as for smaller ships wave resistance is not significant.

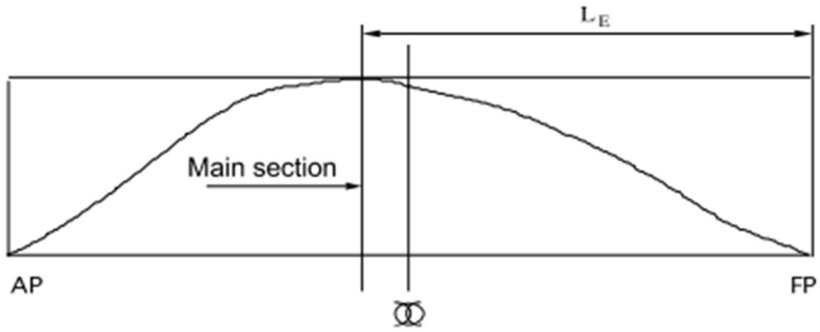


Figure 20 Length of entrance L_e definition.

Length of parallel midbody: Refers to the length over which the midship section remains unchanged. Similarly, for smaller ships, the wave resistance part is not entirely significant and increasing the parallel midbody is not of utmost importance as per Figure 15. With a C_p of 0.593, the parallel body length in percentage is 0%, i.e our ship does not have a parallel middle body. This means it will be more challenging to build this ship in terms of physical construction.

LCB: Longitudinal Center of Buoyancy. Refers to the longitudinal centroid of area under the curve (Section Area Curve). Generally speaking, the optimal value for LCB tends to place it closer to the stern of the vessel, however, as per available literature (systematic experiments and numerical investigations), for vessels with Froude number between 0.22 - 0.25 (which is the case with our design, Fn = 0.22) the optimum position is around amidship, slightly towards the forward. Therefore, LCB of the hull was calculated to be -1,1% with block coefficient C_B = 0.59 which is in line with typical values for hull form, see Figure 21. And additionally using an approximate optimal LCB position vs. Froude Number graph shown in Figure 22 we can validate the result.

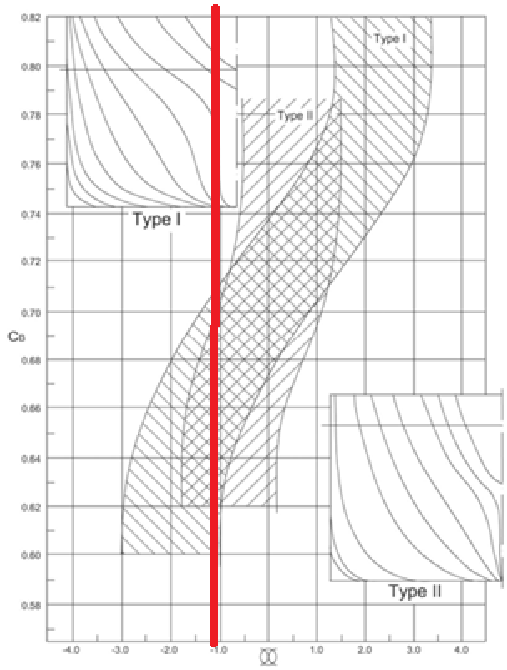


Figure 21 *Vessel LCP vs. typical LCB as a function of C_B and hull form type. [14]*

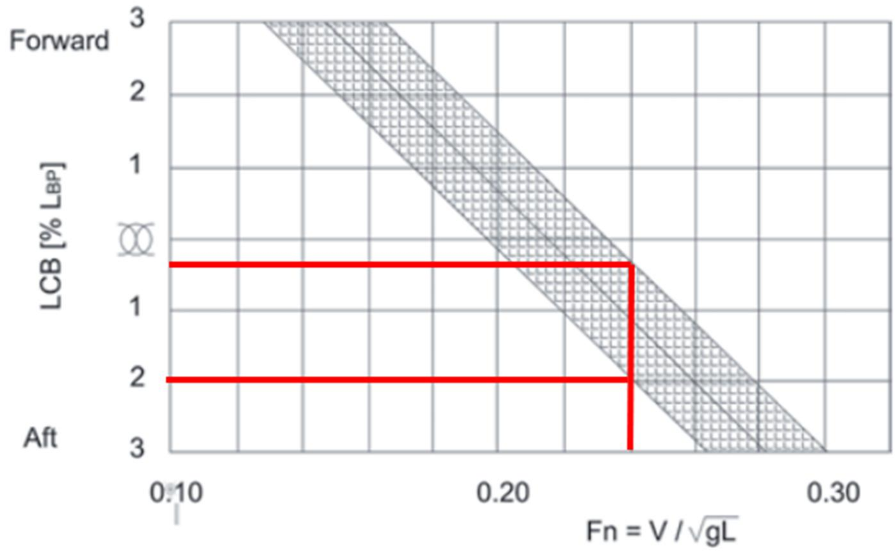


Figure 22 *Approximate optimal longitudinal position of center of buoyancy vs. Fn as per Guldhammer–Harvard. [15]*

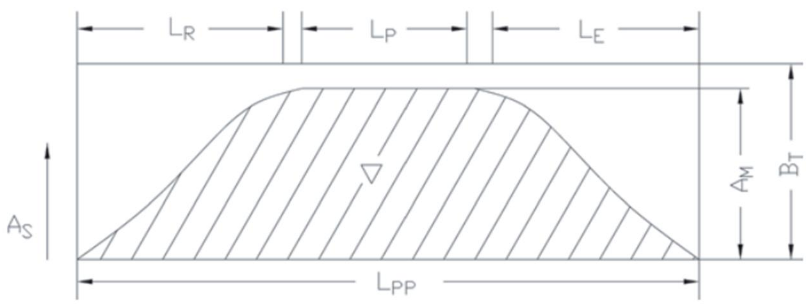


Figure 23 *Breakdown of Sectional Area Curve and definitions.*

Sectional Area Curve (SAC): Directly related to defining LCB, L_p, L_e and L_r as discussed above and The calculated recommended section area curves are shown below. The section area curve of the vessel is in the range of recommended values for C_B = ~0.6, see Figure 13 below. As our vessel has a C_B of 0.59, its sectional area should closely match that of the recommended C_B-0.6 curve. Some minor changes are observed, but it does seem to be a close match, validating the SaFerry SAC shown in Figure 16.

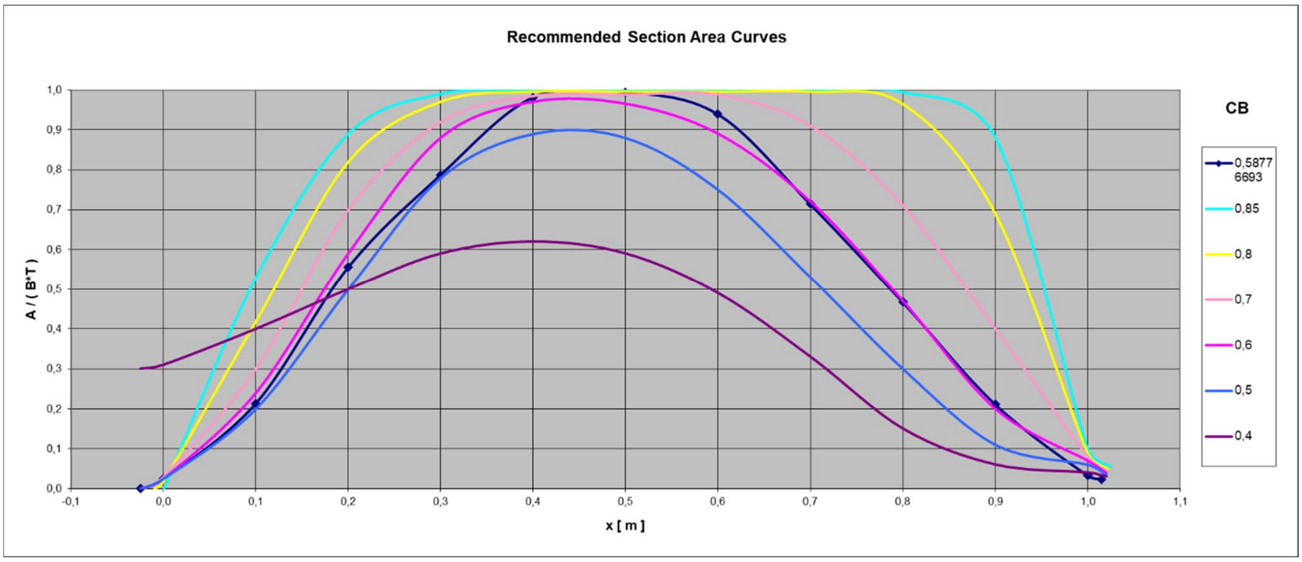


Figure 13 *Recommended SACs vs. actual SAC of SaFerry.*

4.4 Calculation of Hull Hydrostatics

The main initiative for the project is to create modern, energy efficient and safe ferry that fulfils the current rules and requirements for passenger ships. The hydrostatic calculations are applied to the hull to verify the floatation and stability properties.

Because hull is very complex shape, exact analytical calculation of the dimensions cannot be done but numerical estimations are used. Excel sheet *05. T4_Simpson Intergration-1_Amazon SaFerry.xlsx* is used in the calculation. Interval of s = 10 is used in the calculations (area divided to 10 parts).

4.4.1 Waterplane area Aw

For the calculation of waterplane area Simpson I rule is applied:

$$A = \frac{s}{3}(y_0 + 4y_1 + 2y_2 + 4y_3 + 2y_4 + \cdots + 2y_{n-2} + 4y_{n-1} + y_n \quad (3)$$

Moment of area respect to x-axis can be integrated with Simpson I rule:

$$M_{area} = \sum_n y_n k_n R_n \quad (4)$$

LCF distance from aft perpendicular can be calculated as follows:

$$x_c = \frac{M_y}{A} \quad (5)$$

Table 5 Calculation of Aw and LCF.

Length	74,9	m
Intervals:	10	-
Spacing, s:	7,49	m

Frame	x-coordinate	1/2 ordinates	SM	Product for area	Lever @ Frame 0	moment of area	
		y_n	k_n	$y_n * k_n$	R_n	$y_n * k_n * R_n$	
[-]		[m]	[-]	[m^2]	[m]	[m^3]	
0	0	3,3	1	3,3	0	0,0	
1	7,49	7,1	4	28,4	1	28,4	
2	14,98	8,0	2	16,1	2	32,2	
3	22,47	8,2	4	32,6	3	97,9	
4	29,96	8,9	2	17,7	4	70,8	
5	37,45	8,9	4	35,4	5	177,0	
6	44,94	8,9	2	17,7	6	106,2	
7	52,43	8,0	4	32,0	7	223,9	
8	59,92	6,4	2	12,8	8	102,2	
9	67,41	3,8	4	15,2	9	136,4	
10	74,9	0,0	1	0,0	10	0,0	
			S	211	m^2	975	m^3

WPA	898	m2
LCF From fr0	34,593	m

As per Table 5, waterplane area (Figure 15) results in *Aw* =898 m2 which is in line with *Cw* and rectangular area of beam vs. length of the vessel. Longitudinal center of floatation is a slightly towards aft from amidship. Waterplane area curve is shown in Figure 24.

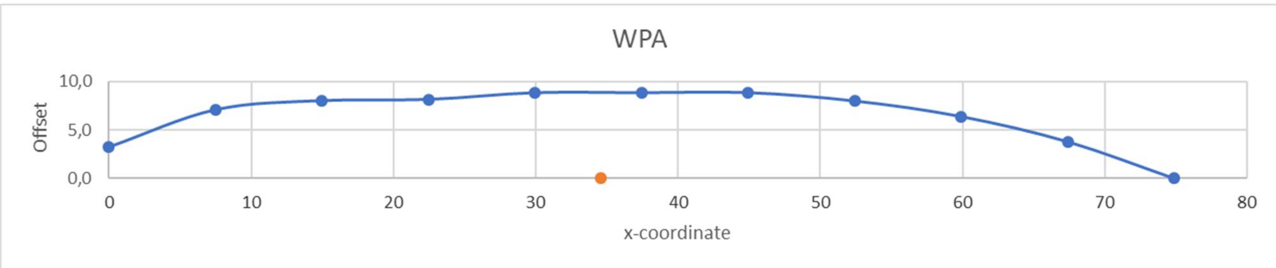


Figure 24 WPA curve.

4.4.2 Midship area Am

For the calculation of midship area and moment of area Simpson I rule (3, 4) is applied. Center of area is calculated with (5).

Table 6 Calculation of Am and center of CSA.

Maximum draft	3,3	m
Intervals:	10	-
Spacing, s:	0,33	m

WL	Z-coordinate	1/2 ordinates	SM	Product for area	Lever @ Frame 0	moment of area	
		y_n	k_n	$y_n * k_n$	R_n	$y_n * k_n * R_n$	
[-]		[m]	[-]	[m^2]	[m]	[m^3]	
0	0	0,0	1	0,0	0	0,0	
1	0,33	8,7	4	34,7	1	34,7	
2	0,66	8,9	2	17,7	2	35,4	
3	0,99	8,9	4	35,4	3	106,2	
4	1,32	8,9	2	17,7	4	70,8	
5	1,65	8,9	4	35,4	5	177,0	
6	1,98	8,9	2	17,7	6	106,2	
7	2,31	8,9	4	35,4	7	247,8	
8	2,64	8,9	2	17,7	8	141,6	
9	2,97	8,9	4	35,4	9	318,6	
10	3,3	8,9	1	8,9	10	88,5	
			S	255,9	m^2	1326,8	m^3

Cross sectional area	56,3	m2	
Center of CSA	1,711	m	above keel

As per Table 6, cross sectional area at midship section (Figure 16) area results in A_m = 56.3 m2 which is in line with midship area coefficient C_m = 0,994 and rectangular area of beam vs. draught of the vessel. Center of CSA is 1,7 m above keel. Station curve for midship section underwater part is shown in Figure 25.

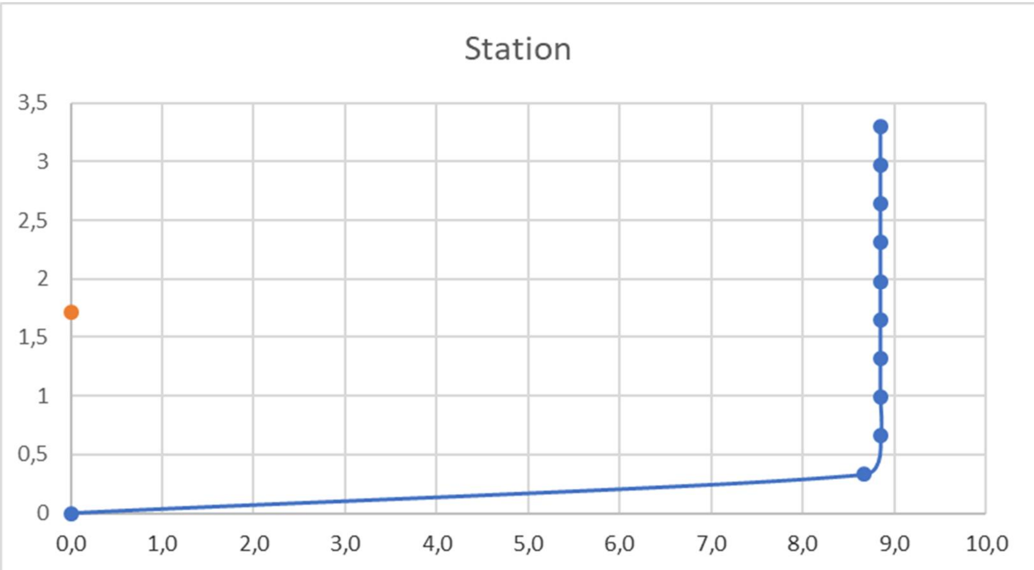


Figure 25 Station curve for midship section (discrete).

4.4.3 Volume (displacement)

For the calculation of vessel displacement, Simpson I rule is applied for volume calculation:

$$V = \frac{s}{3}(A_0 + 4A_1 + 2A_2 + 4A_3 + 2A_4 + \cdots + 2A_{n-2} + 4A_{n-1} + A_n \quad (6)$$

Moment of volume respect to x-axis can be integrated with Simpson I rule:

$$M_{volume} = \sum_n A_n \, k_n R_n \quad (7)$$

Table 7 Calculation of hull volume (displacement) and LCB based on cross section areas.

Length	74,9	m
Intervals:	10	-
Spacing, s:	7,49	m

Frame	x-coordinate	Cross-sectional area	SM	Product for volume	Lever @ Frame 0	moment of volume
		A_n	k_n	$A_n * k_n$	R_n	$A_n * k_n * R_n$
[-]		[m^2]	[-]	[m^3]	[m]	[m^4]
0	0	1	1	1	0	0
1	7,49	12	4	50	1	50
2	14,98	32	2	65	2	130
3	22,47	46	4	184	3	551
4	29,96	57	2	115	4	458
5	37,45	58	4	232	5	1161
6	44,94	55	2	110	6	658
7	52,43	42	4	167	7	1167
8	59,92	27	2	55	8	437
9	67,41	12	4	49	9	444
10	74,9	2	1	2	10	19
		0	S	1029	m^3	5077 m^4

Volume	2570	m3
Density of water	1	t/m3
Displacement	2569,552798	t
LCB from fr0	36,945	m

Table 8 Calculation of hull volume (displacement) and KB based on waterline areas.

Maximum draft	3,3	m
Intervals:	10	-
Spacing, s:	0,33	m

WL	Z-coordinate	WPA	SM	Product for volume	Lever @ keel	moment of volume	
		y_n	k_n	$y_n * k_n$	R_n	$y_n * k_n * R_n$	
[-]		[m^2]	[-]	[m^3]	[m]	[m^4]	
0	0	420,3	1	420,3	0	0,0	
1	0,33	543,2	4	2172,9	1	2172,9	
2	0,66	634,2	2	1268,4	2	2536,8	
3	0,99	684,0	4	2735,8	3	8207,5	
4	1,32	733,7	2	1467,4	4	5869,8	
5	1,65	768,7	4	3074,8	5	15374,1	
6	1,98	803,7	2	1607,4	6	9644,2	
7	2,31	881,3	4	3525,2	7	24676,5	
8	2,64	958,9	2	1917,8	8	15342,8	
9	2,97	1009,2	4	4036,7	9	36330,7	
10	3,3	1059,5	1	1059,5	10	10594,5	
			S	23286,3	m^3	130749,7	m^4

Volume	2561,5	m3	
KB	1,853	m	above keel

As per Table 7 and Table 8, the hull volume *V* = 2560-2670 m3 by calculating from either cross sectional areas and water plane areas. It is to be noted that this calculation excludes skeg which ads approximately 20 m3 to the total displacement of the vessel. LCB is calculated to be 36.9 m from aft perpendicular (fr0) and KB 1.85 m above keel.

4.5 Conclusion

Shaping the hull form and hydrostatics was iterative process and it took a while to finalize Amazona SaFerry's final hull form. First we did get preliminary dimensions by using Normand's number method which gave us lenght, breadth, draft, block coefficient and deadweight.

After that we put these values in use to get our hull lines and section area curve. It was iterative process and we did many iterations to get our final hull form from many different options. After getting the final hull form we have approximately same block coefficient, volume and displacement than with Normand's number approach before hull form interations so our hull shaped like we want to have based on numerical values. Froude's number for our vessel is 0.22 which is very suitable for Ropax ferry like Amazona SaFerry.

Hull hydrostatics were determined by Simpson's integration method and by using hull line drawings and previous calculations. After calculation process we received our cross sectional areas and waterplane areas and our final hull form has thus been finalized. Our Dispalcement is still around what we originally get from Normand's number approach so we are satisifed with the results and we can continue to the next phase of design which is general arrangment of Amazona SaFerry.

5 GENERAL ARRANGEMENT

As defined in section DESIGN CONTEXT, the vessel will be designed to fulfill the latest international and national rules and requirements:

- IMO SOLAS and MARPOL conventions
- National: Ship will sail under The Brazilian Flag
- Classification society: Lloyd's Register
- Local regulations will be examined

Delivery for the vessel will be in December 2024, keel laying on 30.5.2023 and contract date 18.9.2020 which will determine the applicable revision of rules and regulations.

5.1 Preconditions for the General Arrangement Design

This paragraph describes the general rules and regulations that have been taken into account in the general arrangement design.

5.1.1 Fire zone division

Rules considering passenger ship division to fire zones are given in SOLAS Part C. As the number of passengers exceeds 36, the vessel needs to be divided in fire zones as follows: [16]

2.2.1.1.1 In ships carrying more than 36 passengers, the hull, superstructure and deckhouses shall be subdivided into main vertical zones by "A 60" class divisions. Steps and recesses shall be kept to a minimum, but where they are necessary they shall also be "A 60" class divisions.

2.2.1.2 As far as practicable, the bulkheads forming the boundaries of the main vertical zones above the bulkhead deck shall be in line with watertight subdivision bulkheads situated immediately below the bulkhead deck. The length and width of main vertical zones may be extended to a maximum of 48 m in order to bring the ends of main vertical zones to coincide with watertight subdivision bulkheads or in order to accommodate a large public space extending for the whole length of the main vertical zone provided that the total area of the main vertical zone is not greater than 1,600 m^2 on any deck. The length or width of a main vertical zone is the maximum distance between the furthermost points of the bulkheads bounding it.

If assuming beam of B = 17.7 m, the maximum length of 48 m is more limiting than area of 1600 m^2 for the length of one main vertical zone. However, when considering the length of the vessel Loa = 80.1 m, watertight compartment division and passenger safety, it is reasonable to divide the vessel more than two fire zones.

2.2.1.4 Where a main vertical zone is subdivided by horizontal "A" class divisions into horizontal zones for the purpose of providing an appropriate barrier between a zone with sprinklers and a zone without sprinklers, the divisions shall extend between adjacent main vertical zone bulkheads and to the shell or exterior boundaries of the ship and shall be insulated in accordance with the fire insulation and integrity values given in table 9.4.

2.2.1.5.1 On ships designed for special purposes, such as automobile or railroad car ferries, where the provision of main vertical zone bulkheads would defeat the purpose for which the ship is intended, equivalent means for controlling and limiting a fire shall be substituted and specifically approved by the Administration. Service spaces and ship stores shall not be located on ro-ro decks unless protected in accordance with the applicable regulations.

Due to division of compartments, it is decided to divide the vessel to five main vertical zones to increase the passenger safety. Fire casualties are common accidents in the Amazon area ferries. The design is such that fire in one main vertical zone will not paralyze the vessel and at least one propulsion unit and engine room remains always available (safe return to port). Passenger spaces are also divided to vertical zones and passengers can be always evacuated to the intact zones in case of fire casualty.

In Amazon river the distance to land and thereby vessel redundancy is not as critical as in ocean going vessels but it is decided to use these rules as a design basis in reasonable extent to meet the safety targets of the ferry.

Additionally the bulkhead between engine space (deck 1) and passenger deck (deck 2) are considered as A-class fire resistant and RoRo space forms main horizontal fire zone with extensive fire suppression systems.

5.1.2 Watertight bulkheads

The rules considering number of watertight bulkheads is given in Lloyd's Register Rules and Regulations. The ships are to have a collision bulkhead, an after peak bulkhead and a watertight bulkhead at each end of all main and auxiliary machinery spaces. Additional watertight bulkheads are to be fitted so that the total number of bulkheads is at least in accordance with Table 9. [17]

Table 9 Minimum number of bulkheads. [17]

Length, L_R, in metres	Total number of bulkheads	
	Machinery amidships	Machinery aft *see* Note
$L_R \leq 65$	4	3
$65 < L_R \leq 85$	4	4
$85 < L_R \leq 90$	5	5
$90 < L_R \leq 105$	5	5
$105 < L_R \leq 115$	6	5
$115 < L_R \leq 125$	6	6
$125 < L_R \leq 145$	7	6
$145 < L_R \leq 165$	8	7
$165 < L_R \leq 190$	9	8
$L_R > 190$	To be considered individually	

Note With after peak bulkhead forming after boundary of machinery space.

When *Loa* = 80.1, the minimum number of bulkheads is 4 including the aforementioned compulsory bulkheads.

Based on the structural arrangement and increased safety requirements of the ferry, it is decided to divide the hull to six watertight compartments numbered from 1 to 6 starting from bow. Additionally there is longitudinal watertight and A-class fire resistant bulkhead between starboard and port azimuth units to provide redundancy in case of casualty in other steering gear room.

Deck 1 between engine spaces (tanktop) and RoRo space is the watertight bulkhead deck.

5.1.3 Fore peak collision bulkhead

The collision bulkhead is to be positioned as detailed in Table 10.

Table 10 Collision bulkhead position distance of collision bulkhead aft of fore end of L R, in metres. [17]

Arrangement	Length L_R, in metres	Minimum	Maximum
(a)	≤ 200	$0,05L_R$	$0,08L_R$
	> 200	10	$0,08L_R$
(b)	≤ 200	$0,05L_R - f_1$	$0,08L_R - f_1$
	> 200	$10m - f_2$	$0,08L_R - f_2$

Symbols and definitions

- f_1 = $G/2$ or $0,015L_R$, whichever is the lesser
- f_2 = $G/2$ or 3 m, whichever is the lesser
- G = projection of bulbous bow forward of fore perpendicular, in metres

Arrangement (a) A ship that has no part of its underwater body extending forward of the fore perpendicular

Arrangement (b) A ship with part of its underwater body extending forward of the fore perpendicular, (e.g. bulbous bow)

When *Loa* = 80.1 m (≤200 m) and bulbous bow (arrangement b), following min and max positions are obtained: [17]

$G = 1,5\,m$ From lines drawing

$$f_1 = \min\left(0.015L_R, \frac{G}{2}\right) = \min(1.20, 0.53) = 0.53$$

$$min = 0,05L_R - f_1 = 3,5\,m \quad (8)$$

$$max = 0,08L_R - f_1 = 5,9\,m$$

5.1.4 Double bottom

As per Lloyd's Register Rules and Regulations [18], passenger vessels need to have be fitted with a double bottom extending from the collision bulkhead to the after peak bulkhead, as far as this is practicable and compatible with the design and proper working of the ship. Where a double bottom is required to be fitted, its depth at the centerline is to be taken as the greater of the following:

$$a.\, d_{DB} = 28B + 205\sqrt{T}\; mm = 868\; mm$$

$$b.\, d_{DB} = 50B\; mm = 885\; mm \qquad d_{DB} = min.\, 885mm \quad (9)$$

$$c.\, d_{DB} = 760\; mm$$

In Amazona SaFerry, the height of the double bottom is further increased to 1200 mm from rules minimum requirement. This is to allow for greater tank space, increase longitudinal strength and protection in case of grounding, which is one of the main hazards in the environment this vessel is going to operate in.

5.1.5 Minimum bow height

Minimum bow height can be determined based on ICLL Regulation 39. The bow height (F_b), defined as the vertical distance at the forward perpendicular between the waterline corresponding to the assigned summer freeboard and the designed trim and the top of the exposed deck at side, shall be not less than: [19], [20]

$$F_b = \left(6075\left(\frac{L}{100}\right) - 1875\left(\frac{L}{100}\right) + 200\left(\frac{L}{100}\right)\right)\left(2.08 + 0.609C_B - 1.603C_{wf} - 0.0129\left(\frac{L}{d_1}\right)\right) \quad (10)$$

where

The length (L) shall be taken as 96% of the total length on a waterline at 85% of the least moulded depth measured from the top of the keel (ICLL Regulation 3). As taken from lines drawing at moulded depth d_1 = 5.1 m and multiplying with 96% we get:

$$L = 78 \text{ m} \tag{11}$$

The block coefficient C_{Bf} at moulded depth d_1 = 5.1m:

$$C_{Bf} = 0.58 \tag{12}$$

The waterplane area coefficient C_{wf} forward of L/2:

$$C_{wf} = \frac{A_{wf}}{\frac{L}{2}B} = 0.71 \tag{13}$$

We get minimum bow height of F_b = 3768 mm. The sheer at the vessel bow needs to be increased from standard freeboard (2.7m) to fulfill the regulations.

5.2 Description of the General Arrangement

When we started do design general arrangement, we decided that there is no accommodation below waterline and below car decks. In addition, because we have limited space, we cannot have sleeper cabins for every passenger so we wanted to use bed arrangement from passenger train coach to maximize the amount of beds passengers could use. There is also large passenger deck with comfortable chairs and canteen/bar to have some passenger activities on board. Profile view is shown in Figure 26. General arrangement is shown in Appendix 2.

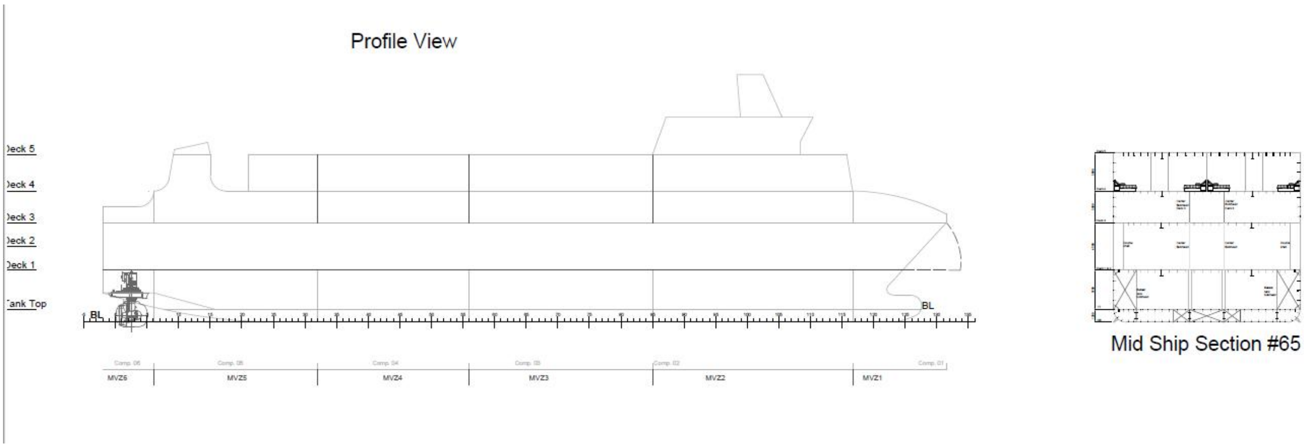


Figure 26 Amazona SaFerry general arrangement.

5.2.1 Double bottom

Like in previous section it was described, our ferry has double bottom as its lowest possible "deck". Double bottom was carefully calculated and designed and result fulfill all necessary regulations and is safe solution for our vessel. Double bottom has been made benefit for various different tanks: Fuel oil, ballast, sewage, fresh water and bilge. All medias are divided to several compartments to have redundancy in case of flooding or fire casualty to enable safe return to port even if one compartment/tank is destroyed. Arrangement is shown in Figure 27.

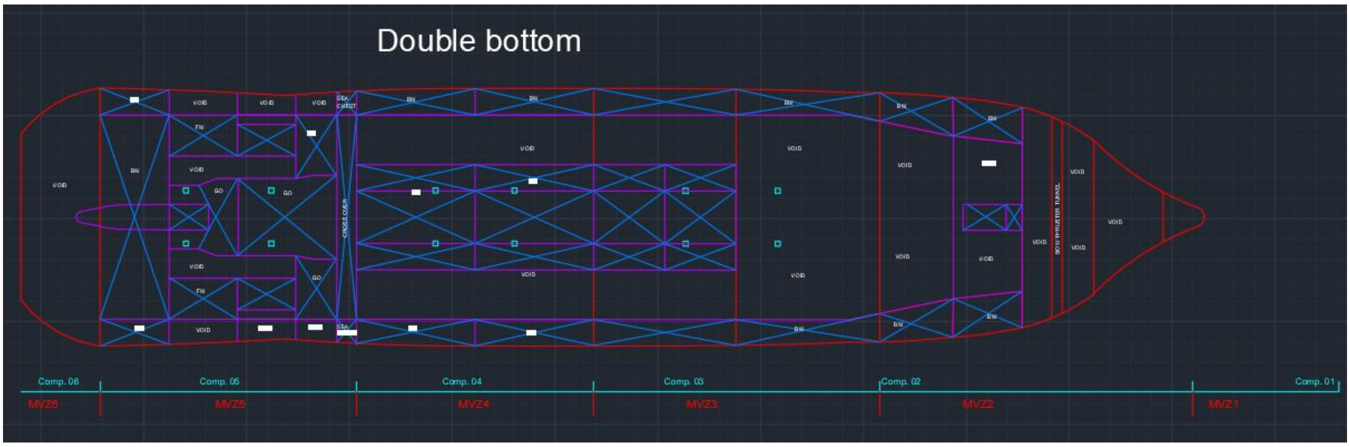


Figure 27 Double bottom and tank arrangement.

5.2.2 Tanktop

Engine rooms and propulsion systems rooms are at the tanktop. We have decided to use diesel electric propulsion power so diesel engines are used as generators for propulsion system's electric motors. Also as hybrid system is a possibility we have reserved space for batteries in the tanktop.

As propulsion system, we are going to have azimuth thrusters and even though ABB's Azipod thruster system is the most famous one we also should check other options so we inquired Kongsberg, ABB and Steerprop and asked what kind of products they could offer for us so we would know how much space we are going to need for the propulsion system. All three manufacturers replied to our inquiries and offered propulsion system from their catalogue. Steerprop's offer was their SP 14 CRP thruster, Kongsberg's offer was Azimuth Thruster US 155S P14 PM FP and ABB offered their Azipod CO861. Final decision what propulsion system we are going to use will be made when focusing more on propulsion and power generation.

At tanktop (Figure 28) we have longitudinal bulkhead dividing steering gear rooms at the aft. Then there is aft engine room and fore engine rooms where generators will be placed. Inside engine rooms, there is also small main switchboard rooms including electrical power distribution (main switchboards, propulsion drives). Towards the bow of the ship, there is also room for passenger/crew luggage and storage space.

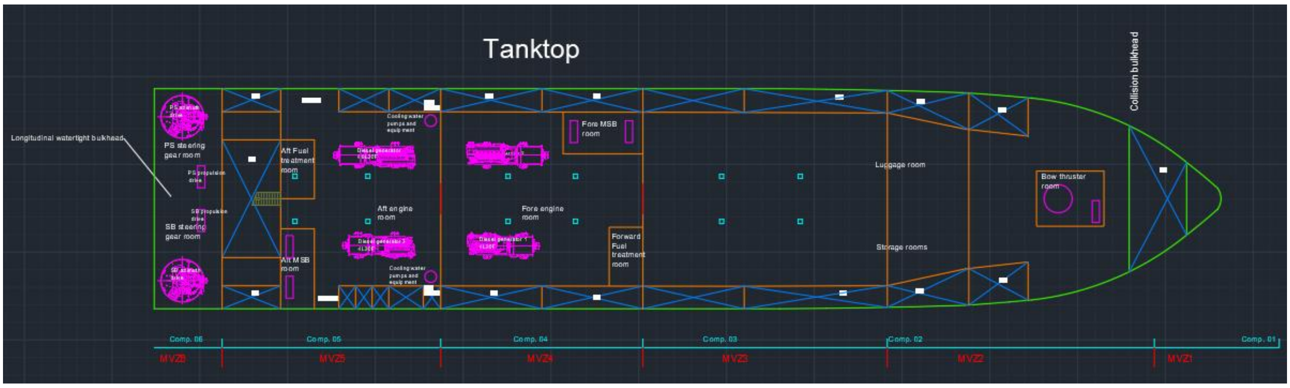


Figure 28 Tank top.

5.2.3 RoRo decks

First and second actual decks are one car deck as car deck is requiring space for two floors as it needs to fit lorries. Deck has 4 different lines for cars consisting of 220 meters of line altogether. In the middle of the ship there is longitudinal bulkheads to bring more rigidity. Inside the bulkhead there is elevators and stairs.

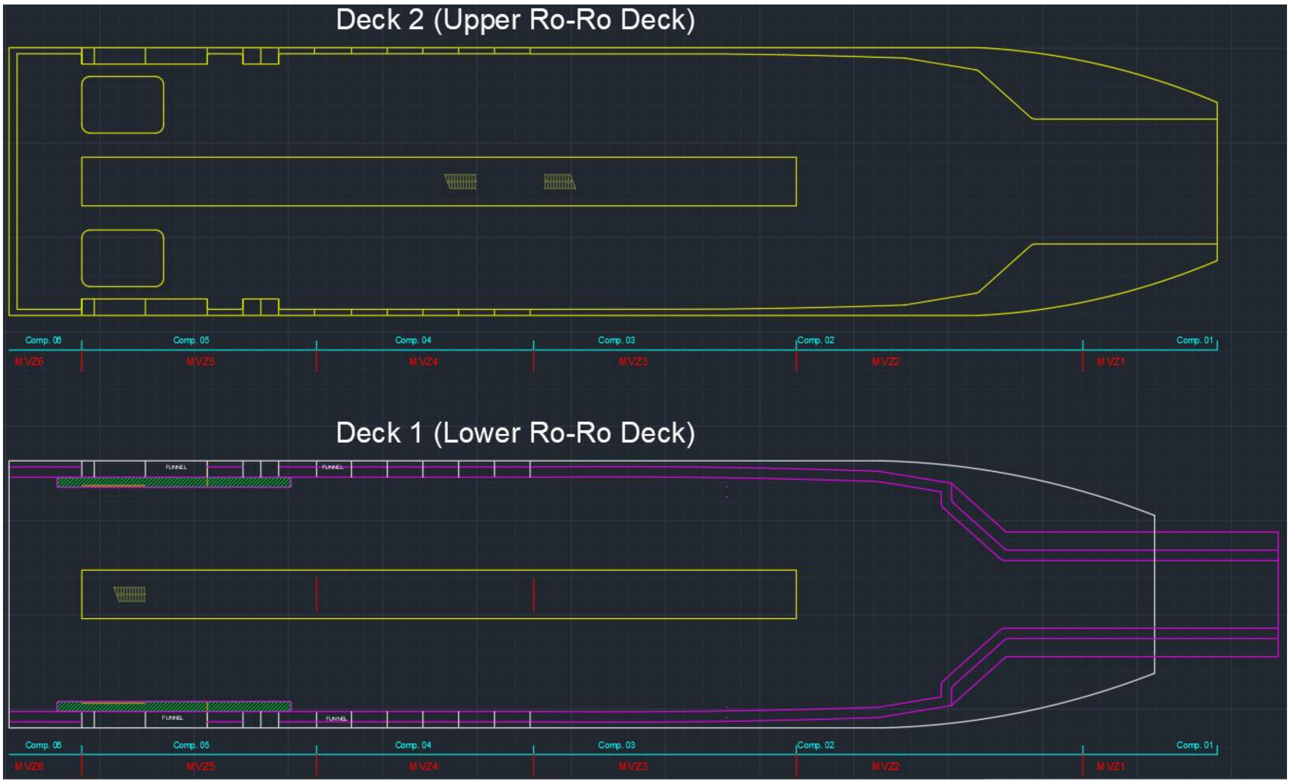


Figure 29 Ro-Ro decks (Deck 1&2.)

5.2.4 Passenger decks

Third deck is passenger deck (Figure 30). It has cantine/bar, comfortable passenger seats, toilets and also third deck has mooring decks. Total number of passenger seats the ship has is approximately 460 so in theory ship could fit slightly over 500 passengers as some passengers are using sleeping cabins on deck 4. Total amount of passengers is limited to 480.

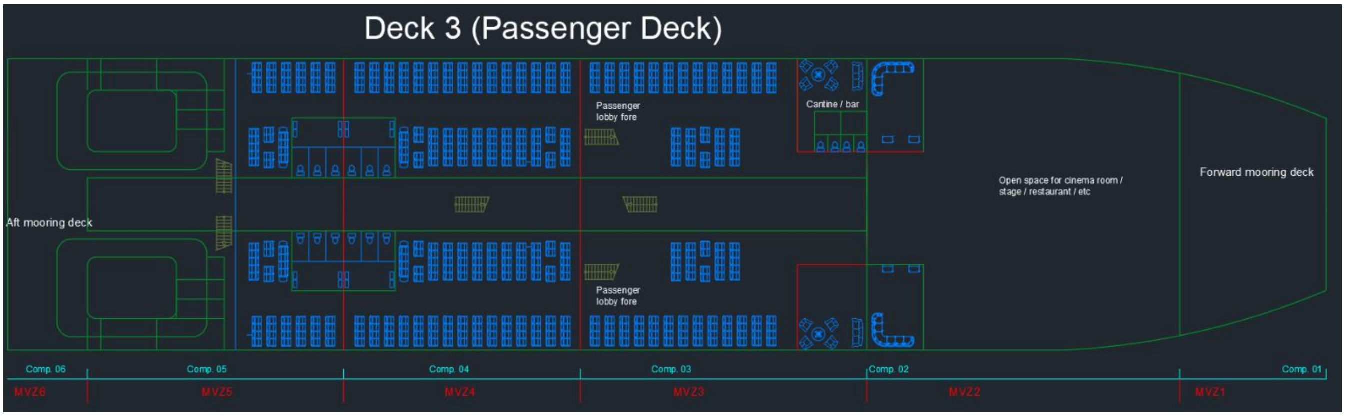


Figure 30 Passenger deck (deck 3).

Deck 4 (Figure 31) is passenger/crew accommodation deck. There are approximately 120 beds in cabins. On passenger deck, beds are arranged like passenger train coaches have them. Double deck beds in each cabin. At the fore of the ship, there is couple larger cabins for ship's crew. This is the last deck of the ship where passengers are allowed to be.

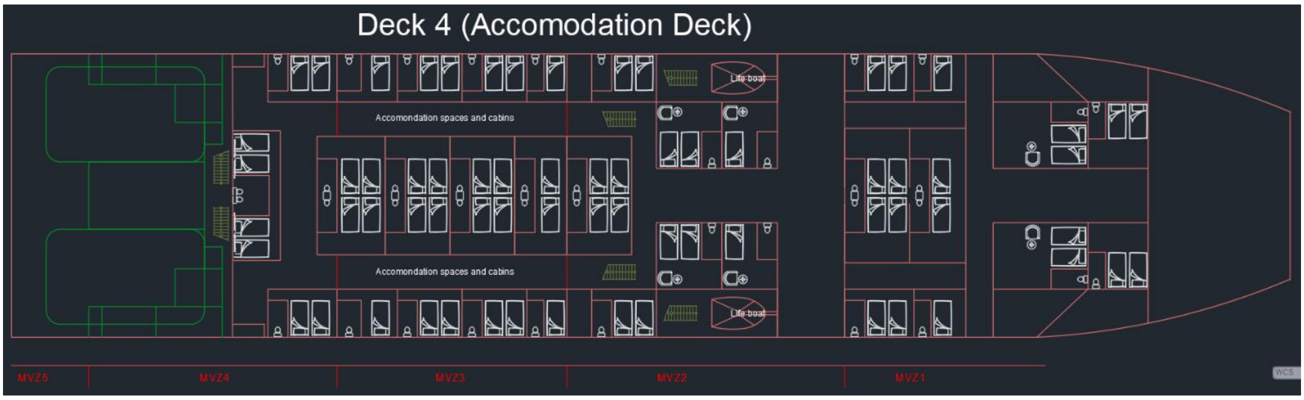


Figure 31 Accomodation deck (Deck 4).

5.2.5 Bridge deck

Fifth and last actual deck is Bridge Deck (Figure 32) which is the ship's navigation deck. We have tried to design bridge deck so there would be good visibility everywhere around the ship to improve safety when sailing on Amazon River to prevent collisions with other ships, rocks or debris and that ship is easier to handle when approaching ports. All thruster control systems are located at Bridge deck. In the aft side of the bridge is located the safety center of the ship

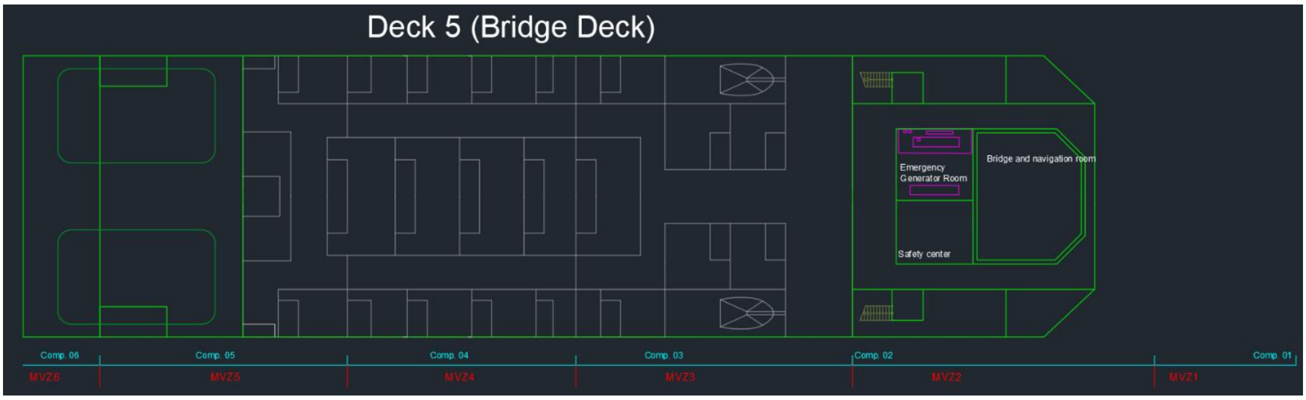


Figure 32 Bridge deck (Deck 5).

6 SHIP STRUCTURES

6.1 Regulatory Assessment

The structural requirements of ship hull girder are defined in Lloyd's Register Rules and Regulation Part 3. In this project we are defining the ship concept so mainly the primary level of structural assessment is considered and partly qualitatively. The rules and regulations are assessed in order to verify that the most important global properties of the hull are meeting the classification society requirements. These are the longitudinal (bending) strength, shear strength and hull girder ultimate strength.

6.1.1 Minimum hull section modulus

The hull section modulus at midship is the main characteristic in calculation of longitudinal strength of the hull. As per Lloyd's Register Rules and Regulations [23], the hull midship section modulus about the transverse neutral axis, at the deck or the keel, is to be not less than:

$$z_{min} = f_1 k_L C_1 L^2 B(C_b + 0.7) 10^{-6} \text{ m}^3 \quad (14)$$

where ship service factor f_1 is to be specially considered depending upon the service restriction and in any event should be not less than 0.5. For unrestricted sea-going service f_1 = 1. Our ferry is operating in river conditions where weather and wave induced loads are limited so it is used:

$$f_1 = 0.7 \quad (15)$$

Wave bending moment factor for ship L = 80.1 m (L < 90 m):

$$C_1 = 0.0412L + 4.0 = 7.3 \quad (16)$$

Material factor k_L = 0.72 for steel with specified minimum yield stress 355 N/mm^2 [24]. Block coefficient C_b = 0.58, beam B = 17.7 m so we get minimum section modulus for our ferry:

$$z_{min} = 0.535 \text{ m}^3 \quad (17)$$

As per rules, the scantlings can be gradually reduced towards bow and aft of ship but minimum section modulus needs to be maintained within 0.4L amidships.

6.1.2 Hull bending strength

The permissible combined (still water plus wave) stress for hull vertical bending, σ, is given by [23]:

$$\sigma = \frac{175}{k_L} N/mm^2 = 243\ N/mm^2 \quad (18)$$

The appropriate hogging or sagging design hull vertical wave bending moment at amidships is given by the following:

$$M_w = f_1 f_2 M_{wo} \quad (19)$$

where

$$f_2 = -1.1 \quad \text{for sagging (negative moment)} \quad (20)$$

$$f_2 = \frac{1.9C_b}{(C_b + 0.7)} = 0{,}861 \quad \text{for hogging (positive moment)}$$

The longitudinal distribution factor, C_2, of wave bending moment is to be taken as follows:

- 0 at the aft end of L

- 1,0 between 0,4L and 0,65L from aft
- 0 at the forward end of L

For the midship section $C_2 = 1$ so we get:

$$M_{wo} = 0.1C_1C_2L^2B(C_b + 0.7) = 106114 \text{ kNm} \tag{21}$$

And consequently the appropriate hogging or sagging design hull vertical wave bending moment as follows:

$$M_w = f_1 f_2 M_{wo} \begin{cases} -81708\ kNm\ (sagging) \\ 63955\ kNm\ (hogging) \end{cases} \tag{22}$$

These values are used in calculation of max allowed bending stress of the midship section.

6.1.3 Hull shear and buckling strength

As per Lloyd's Register Rules and Regulations, the design shear forces and stresses for the hull are presented in [25]. For ships with length *L* greater than 65 m, the shear forces on the hull structure are to be investigated and so the analysis should be covered in design of our ferry.

Similarly, the requirements for the buckling strength of hull are presented in [26]. These requirements apply to plate panels and longitudinals subjected to hull girder compression and shear stresses based on design values for still water and wave bending moments and shear forces.

As only qualitative analysis of hull strength is performed at this project, it is only noted that the data for all analysis is available for in detail study of hull strength but no in detail strength calculations are performed. However, it is recognized that these calculations are essential in the design process and should not be forgotten.

6.2 Material Selection

Hull is the most important part of the ship's structural rigidity and strength. Choosing correct hull material is therefore very important so we have taken a careful consideration of it and done research for good suppliers and proper material choices.

First, we want the hull to withstand collisions with other vessels or collisions with rocks, ground, or collision with platforms during mooring. In addition, we want material to be affordable, easy to manufacture and easy to get from the supplier. As S355 steel is one of the most used and popular steels and we feel it is also suitable for our use we searched S355 shipbuilding steels to pick the best one for our use.

What we found and picked as hull's material was SSAB's D36HS steel, see Figure 33. It is hot rolled, easy to mold, exceeds many classification requirements including Lloyd's Register which we are using on Amazona SaFerry's classification. It is also available with mechanical properties we seek.

Dimension range

SSAB Multisteel HSD is available in thicknesses of 5.00 - 150.00 mm.
SSAB Multisteel HSE is available in thicknesses of 5.00 - 150.00 mm.
(If PC is involved in the combination max thickness is 100 mm.)

Mechanical Properties

Thickness (mm)	Yield strength (min MPa)	Tensile strength (MPa)	Elongation A_5 (min %)
5.00 - 100.00	355	490 - 620	21
100.00 - 150.00	355	490 - 600	21

The mechanical properties are tested transverse to the direction of rolling.

Impact Properties

Steelgrade	Thickness	Test temperature	Min. impact energy (full size specimen 10x10 mm)
SSAB Multisteel HSD	5.00 - 50.00 mm	-20 °C	34 J
SSAB Multisteel HSD	50.01 - 70.00	-20 °C	41 J
SSAB Multisteel HSD	70.01 - 150.00	-20 °C	50 J
SSAB Multisteel HSE	5.00 - 50.00	-40 °C	34 J
SSAB Multisteel HSE	50.01 - 70.00	-40 °C	41 J
SSAB Multisteel HSE	70.01 - 150.00	-40 °C	50 J
EN 10025-2 S355K2+N	5.00 - 150.00	-20 °C	40 J

The impact test is made longitudinally to the rolling direction in compliance with society rules and EN 10025-2.

Chemical Composition (ladle analysis)

C (max %)	Si (max %)	Mn (max %)	P (max %)	S (max %)	Nb (max %)
0.18	0.50	1.60	0.025	0.020	0.05

Carbon Equivalent Values

Condition	If only hull structural steel	If only hull structural steel	If S355K2+N is in the combination	If S355K2+N is in the combination
Thickness (mm)	5.00 - 60.00	60.01 - 150.00	5.00 - 60.00	60.00 - 150.00
CEV (max %)	0.45	0.49	0.45	0.47

Figure 33 SSAB HS multisteel specification sheet. [27]

As ship's calculation sheet was assuming that we would use same material on superstructure, we are using A36HS steel also on superstructure's frame. However, on plates of the superstructure we could use aluminum, as it is much more lightweight and more corrosion resistant so superstructure plates could be assumed to last longer without corrosion being issue and it could be assumed that Brazil ship maintenance might be not on a level than for example in Northern Europe. This would'be a less of a problem, as aluminum is easier to maintain than steel.

The grade of Aluminum 5083 would be preferred for superstructure's plates, if aluminum will be used. It is excellent to weld, has great corrosion resistance, is easy to drill and cut and it has surface of good quality. In addition, it is relatively affordable. Advantage of using aluminum on superstructure's plating is also that it enables us to have lower center of gravity which enables ship to be more stable and better handling characteristics.

ALUMIINISEOKSET

	Tiheys	Si	Fe	Cu	Mn		Mg		Cr		Zn	Ti	Muut	
Nimi	g/cm3	Max	Max	Max	Min	Max	Min	Max	Min	Max	Max	Max	Min	Al (Loput)
EN AW-5083	2,66	0,4	0,4	0,1	0,4	1	4	4,9	0,05	0,25	0,25	0,15	0,15	True

ALUMIININ OMINAISUUDET

		Lämpöjohtavuus	Lämpölaajentumiskerroin	Sulamispiste		Kimmomoduuli	Sähkönjohtavuus
Seos	Tila	W/m*K	µm/(m*K)	Min	Max	KN/mm2	%IACS
EN AW-5083	Hx2	117	23,8	580	640	71	28,5
EN AW-5083	Hx4	117	23,8	580	640	71	28,5
EN AW-5083	Hx6	117	23,8	580	640	71	28,5
EN AW-5083	Hx8	117	23,8	580	640	71	28,5
EN AW-5083	Hx9		23,8	580	640	71	
EN AW-5083	O	117	23,8	580	640	71	28,5

Figure 34 Alumeco Al 5083 specification sheet. [28]

Furthermore, there could be option which unfortunately we couldn't validate via calculations was that also superstructure's extrusions could be aluminum. That material would be aluminum 6082 as it is more strong material than 5083 and it's not as big of a problem that it is not as great for machining or drilling, cutting etc. as it still has good welding abilities. Aluminum extrusions would lessen the weight of the ship more, so it could have larger deadweight or be more efficient and have lower KG. Unfortunately as our group's resources are so limited, as of now, we cannot select this idea to be on our ship right now but in the future developments this idea could be taken further.

6.3 Ship Main Section Strength

To verify that our vessel satisfies the structural requirements, the structural arrangement was determined taking into special account the continuity of the structure and adequate local and global strengths. In this assignment, the midship section modulus and bending stress was calculated and compared to the class requirements as well as material ultimate (yield) strength. For the shear and buckling strength, only qualitative methods are used.

6.3.1 Ship specific challenges

The main structural issue we encountered with this vessel was designing for the car deck. As there needs to be enough room for vehicles to enter/manoeuvre inside of this vessel, we were not able to add structural members that would otherwise impede vehicles from coming in and out of the vessel. As such, an open deck had to be designed, and essentially, what the car deck becomes is a "shoe box". The idea was to treat it as simply supported beam, i.e top of car deck supported on both ends by structural members, thus allowing, "beam" to span the whole breadth of car deck. In doing that however, it became apparent that to support the superstructure and further bulkheads on decks above, more supporting structural elements were needed and therefore the idea of creating a box within a box surged. To support the transversal bulkheads from superstructure above, the car deck was given further transversal bulkheads that follow the line of the bulkheads above but do not go the whole length of the vessel. This ensures vehicles have enough room for transport and structurally solves the issue mentioned. This however adds an obstacle to car movement and perhaps big lorries would not be able to manouvre inside of the vessel. The team is now considering the possibility of adding a "back door" to the vessel that way vehicles can simply drive through the whole vessel, thus eliminating the need for major manouvre.

6.3.2 Midship section

Longitudinal bending strength needs to be greater than the stresses caused by deflections on the structure of the ship. These deflections occur as the ship suffers hogging and sagging effects caused by waves, loads, etc. At midship, the hull girder experiences the greatest longitudinal bending moment, and that is why (for the purposes of this course) we will only be analyzing the midship section. As seen in section 1 above, the ship's maximum allowable bending stress at midship is calculated, and the longitudinal bending strength of the hull must be designed such that it satisfies the max allowable bending stress values.

To verify that our vessel satisfies the classification rules, we assigned materials and dimensions to the ship elements. It was decided that bottom and shell plates would have a thickness of 15mm (AH36 Steel) and inner deck plates and bulkheads would have a thickness of 9mm (AH36 Steel). The midship section of the vessel including deck heights can be seen in Figure 35 and Appendix 3.

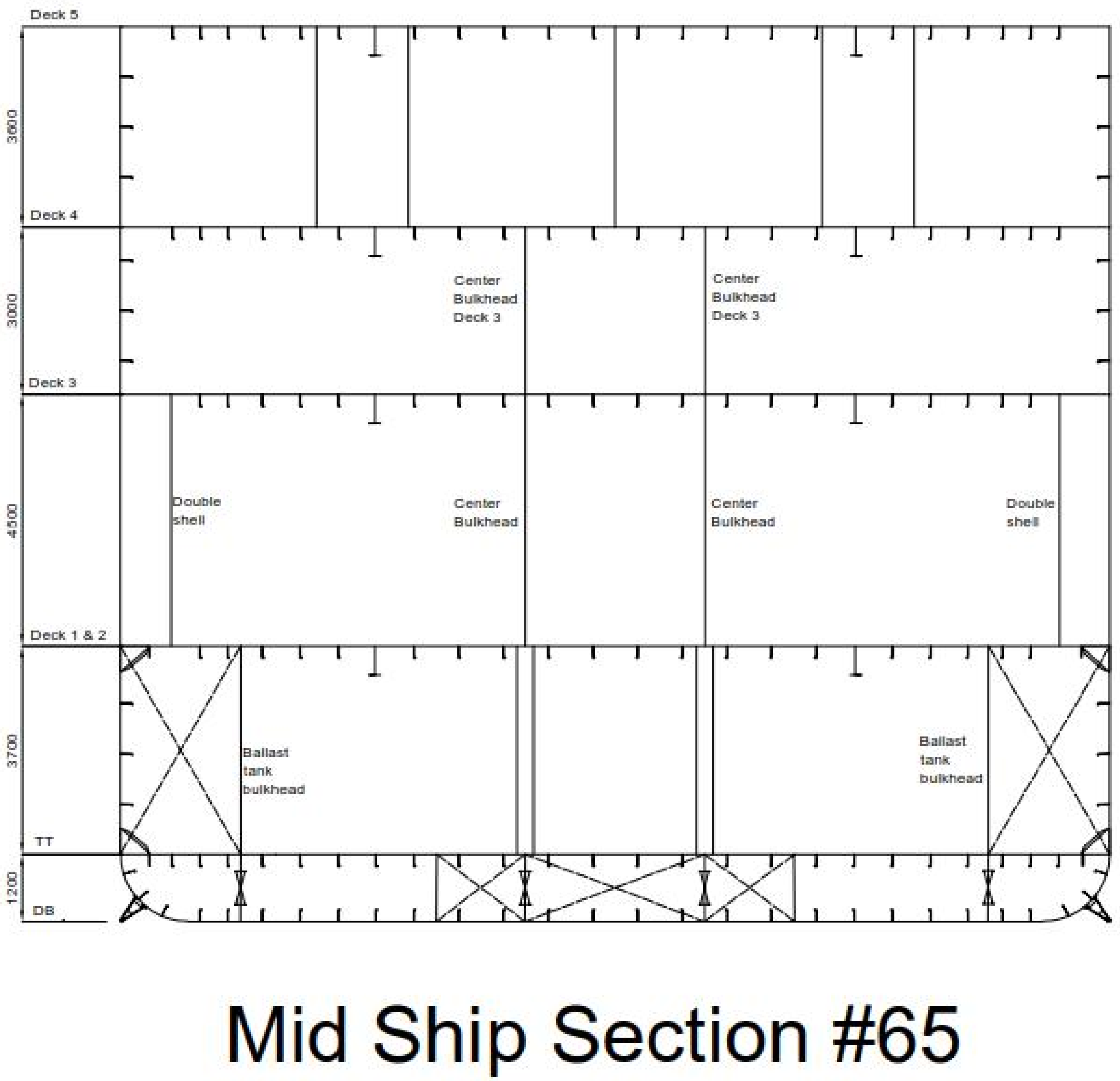


Figure 35 Amazona SaFerry, midship section structural arrangement.

The section modulus was calculated with T7_Section Modulus excel calculator using the main structural member data as an input:

- Deck and bulkhead thickness
- Deck and bulkhead heights

The calculation spreadsheet is shown in Appendix 2. Longitudinal stiffeners and other local reinforcements were not taken into account in the section modulus calculation.

Two scenarios were calculated. In the first scenario whole hull girder including the superstructure was assumed to be load bearing element, see the results in Table 11. Hogging or sagging design hull vertical wave bending moment as per equation (9) was used in calculation of hull maximum bending stress.

In the second scenario only hull structure up to bulkhead deck was assumed as load bearing element as per Table 12. This would be the case if adequate strength for the car deck and public area could not be applied. The same bending moment (equation 9) was used in the calculation.

Table 11 Study A: Calculation of hull section modulus and longitudinal bending stress. Assumed whole cross section as load bearing element.

Item	Number of parts	Breadth	Depth	Height	Area	1. Moment	2nd Moment @ centroid	2nd moment @BL
	n	b	d	h_j	A=n*b*d	S=A*h_j	i=n*b*d^3/12	I_s=A*h_j^2
[-]	[-]	[m]	[m]	[m]	[m^2]	[m^3]	[m^4]	[m^4]
Tank Bottom	1	17.7	0.012	0.0060	0.212	0.001	2.55E-06	7.65E-06
Tank top	1	17.7	0.006	1.197	0.106	0.127	3.19E-07	1.52E-01
Deck1 (RoRo)	1	17.7	0.012	4.894	0.212	1.039	2.55E-06	5.09E+00
Deck3	1	17.7	0.006	9.397	0.106	0.998	3.19E-07	9.38E+00
Deck4	1	17.7	0.006	12.397	0.106	1.317	3.19E-07	1.63E+01
Deck5	1	17.7	0.006	15.997	0.106	1.699	3.19E-07	2.72E+01
Outer shell	2	0.012	4.900	2.45	0.118	0.288	2.35E-01	7.06E-01
Ballast tank bulkhead tanktop +double bottom	2	0.006	4.900	2.45	0.059	0.144	1.18E-01	3.53E-01
Double shell elements + Center bulkhead deck 1/2	4	0.006	4.500	7.15	0.108	0.772	1.82E-01	5.52E+00
Middle stiffners + stiffners deck 1/2	2	0.006	3.000	10.9	0.036	0.392	2.70E-02	4.28E+00
				∑	1.170	6.778	0.562	68.973

Total cross-section		
Ship Depth D	16.00	m
Neutral axis	5.79	m from BL
Elements, i_{tot}	0.56	m^4
Elements, $I_{s,tot}$	68.97	m^4
I_{BL}	69.54	m^4
I	30.27	m^4
Z_{deck}	2.965508244	m^3
Z_{bottom}	5.224780491	m^3

Load and response			
Moment	69008218	Nm	Calculated based on classification rules
σ_{deck}	23.27	MPa	
σ_{bottom}	13.21	MPa	

Table 12 *Study B: Calculation of hull section modulus and longitudinal bending stress. Assumed hull up to bulkhead deck as load bearing element.*

Item	Number of parts	Breadth	Depth	Height	Area	1. Moment	2nd Moment @ centroid	2nd moment @BL
	n	b	d	h_j	A=n*b*d	$S=A*h_j$	$i=n*b*d^3/12$	$I_s=A*h_j^2$
[-]	[-]	[m]	[m]	[m]	[m^2]	[m^3]	[m^4]	[m^4]
Tank Bottom	1	17.7	0.012	0.0060	0.212	0.001	2.55E-06	7.65E-06
Tank top	1	17.7	0.006	1.197	0.106	0.127	3.19E-07	1.52E-01
Deck1 (RoRo)	1	17.7	0.012	4.894	0.212	1.039	2.55E-06	5.09E+00
					0.000	0.000	0.00E+00	0.00E+00
					0.000	0.000	0.00E+00	0.00E+00
					0.000	0.000	0.00E+00	0.00E+00
Outer shell	2	0.012	4.900	2.45	0.118	0.288	2.35E-01	7.06E-01
Ballast tank bulkhead tanktop	2	0.006	4.900	2.45	0.059	0.144	1.18E-01	3.53E-01
						0.000	0.00E+00	0.00E+00
						0.000	0.00E+00	0.00E+00
				Σ	0.707	1.600	0.353	6.298

Total cross-section		
Ship Depth D	4.90	m
Neutral axis	2.26	m from BL
Elements, i_{tot}	0.35	m^4
Elements, $I_{S,tot}$	6.30	m^4
I_{BL}	6.65	m^4
I	3.03	m^4
Z_{deck}	1.149324615	m^3
Z_{bottom}	1.340491051	m^3

Load and response			
Moment	69008218	Nm	Calculated based on classification rules
σ_{deck}	60.04	MPa	
σ_{bottom}	51.48	MPa	

As seen above, the T7_Section Modulus excel calculator has shown hull stresses much lower than the permissible combined (still water plus wave) stress for hull vertical bending, *σ,* of 243 N/mm2 (equation 5) calculated in chapter 1 above. The hull midship section also satisfies the minimum hull section modulus, z, of 0.535 m^3 which was calculated in equation (4). This reveals that our vessel is indeed in accordance with the classification rules.

6.3.3 Structural continuity

The structural continuity is ensured by aligning the main structural members and verifying that each deck has load bearing members that transfer the load between the decks smoothly. This is especially crucial in analysis of shear forces and induced stresses. It can be seen in Figure 36 that the bulkheads are aligned both in longitudinal and transversal direction.

Main stiffening member in the middle of the vessel is the corridor area in the middle of the car deck which is continuing to decks above. This “room” is including the stairs to above decks. Because similar structure cannot be reached in engine room due to lack of space, we have decided to use pillars that are supporting the above decks in engine room and transferring the load between double bottom and car decks.

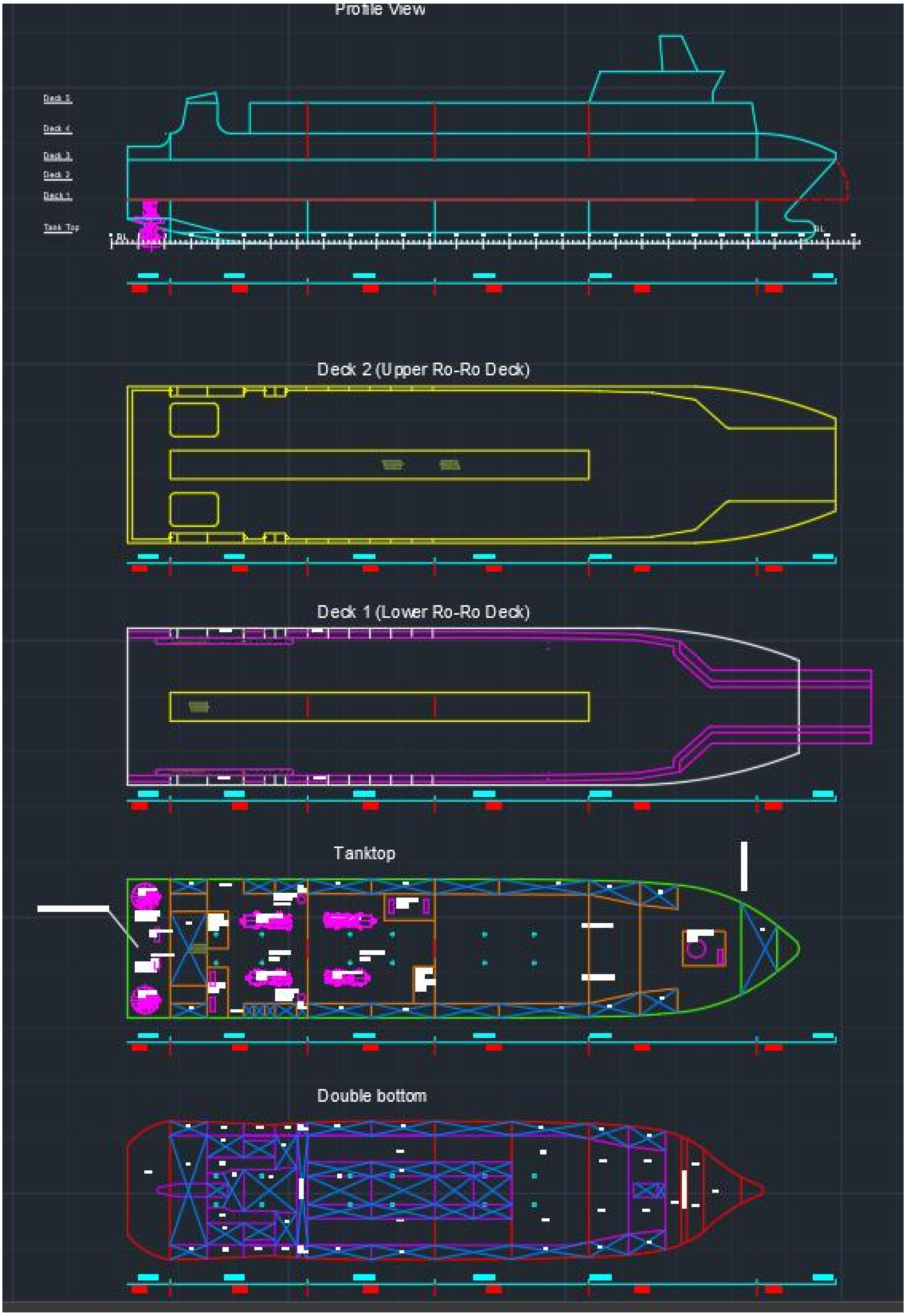


Figure 36 Structural continuity of the ferry.

6.3.4 Hull girder ultimate strength

As it can be seen from the above calculation, the global strength of the hull very good and safety factor to yielding is high. For the analysis of local stress concentrations, more sophisticated methods such as finite element analysis are to be applied.

6.3.5 Framing system

Mixed system – transversal and longitudinal stiffeners / framing system. Longitudinal bulb flats have been used to stiffen the deck plates, and side plates of the hull. Of course, no quantitative studies have been carried out so sizes and position of stiffeners have been approximated only. The idea is to show that buckling of the plates due to loading has been considered and in the final design it will be addressed. Bulkheads also are load bearing structures used transversally as well as longitudinally. Same positioning applies to bulb flat stiffeners.

6.4 Conclusion

In this assignment, qualitative strength assessment for the hull girder was done. The applicable rules where investigated and minimum section modulus for the hull midship section as well as maximum allowed bending stress was calculated.

Material selection was investigated and traditional shipbuilding steel was decided to use in main structural load carrying members because of ease of manufacturing, low cost and good fire resistance. Aluminum superstructure was considered to reduce the lightweight and lower center of gravity of the hull and consequently improve stability.

The midship section was sketched based on the general arrangement concept. Special emphasis was in maintaining the structural continuity of the structure both in longitudinal and transversal directions. The midship section modulus and bending stress was analyzed by using T7_Section Modulus excel calculator. According to the calculations, the bending strength of the hull is in accordance with the classification rules and material strength.

For in detail analysis of the hull structural response and local stress concentrations finite element calculations and 3D-modeling would be needed.

7 POWER AND MACHINERY

7.1 Operating Profile

As described in previous assignments, the mission of our ship is to be RoPax ferry capable of transporting passengers from Manaus, Brazil to Tefé, Brazil. The route is highlighted in Figure 37 below:

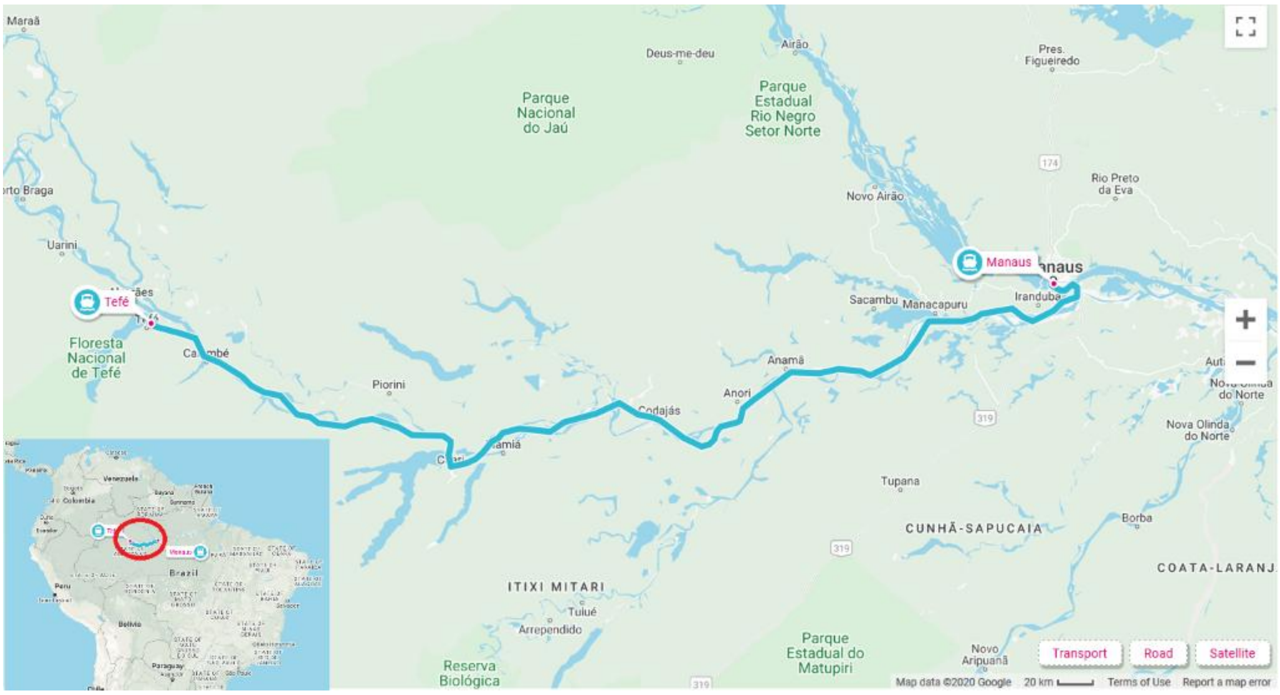


Figure 37 Vessel will be designed to operate route between Manaus and Tefe (approximately 700 km) on the Amazon River in Brazil.

As such, the team has decided the modus operandi of our vessel is similar to those already operating in the area. The vessel will set sail from Manaus, and will stop in points along the Solimões River for passengers to disembark the ferry (onto a dinghy boat or similar) which will transport the passengers to the nearby villages/towns. Each stop is designed to take about 30-45 minutes, in which the Amazon SaFerry will simply wait along the bank line for the dinghy to return. Alternatively, the Amazon SaFerry may continue journey at a much lower speed until dinghy has caught up.

The chosen/designed route then becomes the following:

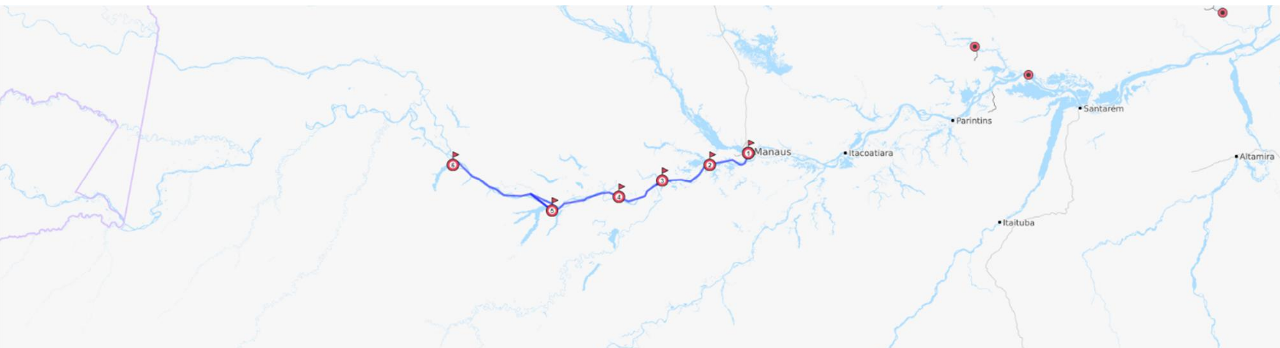


Figure 38 Vessel will be designed to operate route between Manaus and Tefe (approximately 700 km) on the Amazon River in Brazil.

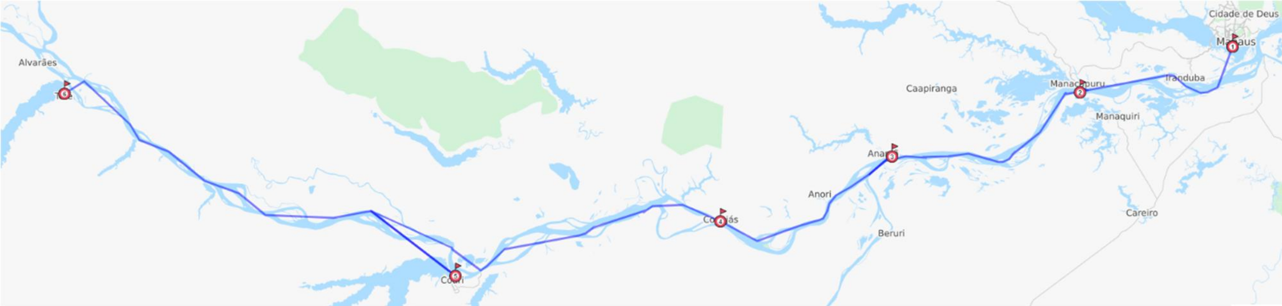


Figure 39 *Vessel will be designed to operate route between Manaus and Tefe (approximately 700 km) on the Amazon River in Brazil.*

Table 13 *Amazon SaFerry Route.*

Amazon SaFerry Route		Estimated Time Taken from last stop (hrs)
Start	Manaus	-
Stop 1	Manacaparu	4
Stop 2	Anamã	6
Stop 3	Codajás	4
Stop 4	Coari	10
End	Tefé	9
-	-	-
Start	Tefé	-
Stop 1	Coari	9
Stop 2	Codajás	10
Stop 3	Anamã	4
Stop 4	Manacaparu	6
End	Manaus	4

The estimated time taken from last stop is based on the vessel maximum designed speed, but it highly expected that the vessel will not maintain the designed maximum speed throughout the whole route due to the environmental restrictions of the route.

Firstly, a large volume of vessels are expected to be travelling along the same route, irrespective of the time of the day.

Secondly, the route itself is a very tricky one, where some areas have a low river depth, moving sandbanks and torrential rainfall. At night, visibility is drastically reduced and considerably more dangerous due to subpar vessels operating in the area, and the threat of river piracy that occurs in those waters.

Lastly, the width of the river changes and in some areas the route gets divided into many different segments due to sandbanks. Depending on the season, heavy rainfall may widen the river, but it may also cover the sandbanks, making the river much shallower in some areas.

As such, the vessel will operate at maximum speed where applicable. Good instrumentation and a good captain with experience of the route will be required to avoid collision regardless of the speed.

As with all vessels, propulsion power is needed for the ship to sail, but as explained, the ship will rarely sail at full speed. That's why ship will have diesel electric propulsion using generators instead of straight diesel engine to thruster propulsion system so generators could be run more efficiently.

In order to create an estimated ship operational profile, the average speed of the ship at each of the 34 hours route (one-way) was estimated. Then, based on the power requirements of the propellers, an engine load (in %) estimate was also calculate and shown on Table 14 below:

Table 14 Approximate engine load.

	Hour	Avg speed p/ hour (knt)	ME_Load (%)
Manaus - Manacaparu	0	0	0
	1	7	43
	2	11	65
	3	11	60
	4	8.5	49
Manacaparu - Anamã	5	6	38
	6	11	65
	7	10	70
	8	11	66
	9	11	65
	10	7	43
Anamã - Codajás	11	6	36
	12	9	54
	13	9	53
	14	6	36
Codajás - Coari	15	6	37
	16	9	53
	17	10	59
	18	10	57
	19	11	65
	20	10	57
	21	10	60
	22	9	55
	23	7	42
	24	5	32
Coari - Tefé	25	6	38
	26	7	41
	27	8	47
	28	8	48
	29	8	49
	30	8	48
	31	8	45
	32	7	44
	33	7	42
	34	5	32

Using the above information, an estimated ship operating profile is then created:

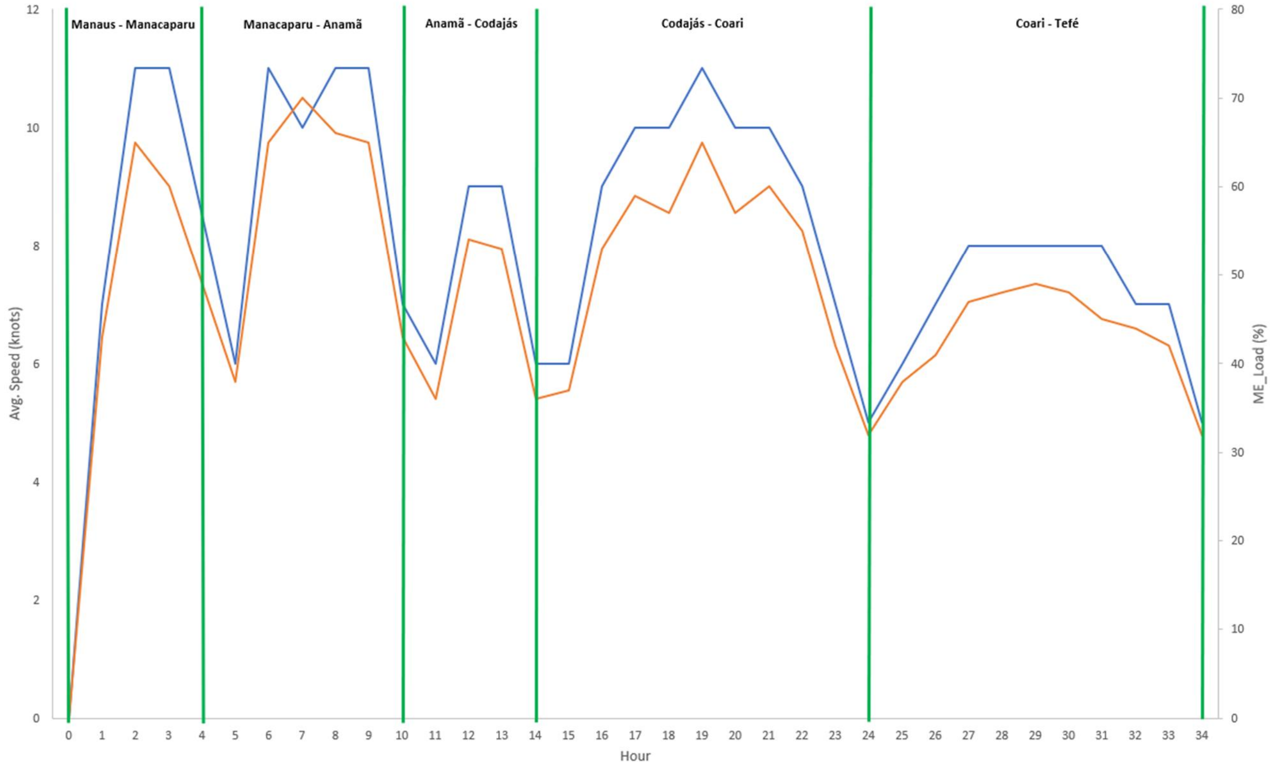


Figure 40 Amazona SaFerry operational profile.

As shown in Figure 40, the expected operating profile of our vessel satisfies the design requirements and allows the vessel mission to be completed. In terms of power profile, at least three main engines are expected to be in operation throughout the voyage and they will not be expected to exceed 90% capacity.

7.2 Ship Resistance and Propulsion Power

The ship total resistance is calculated as a sum of hull viscous resistance, appendages viscous resistance, wave making resistance, bulbous bow resistance, immersed transom resistance and model-ship correlation as follows:

$$R_{total} = R_v + R_{APP} + R_w + R_B + R_{TR} + R_A \quad (23)$$

Additionally air resistance R_{air} is present in ship operation. For Amazon SaFerry, the maximum operational speed is 12 kn and in Amazon river the wind conditions are normally not significant. In case of tropical storm, the vessel will probably stay in port. However, the presence of air resistance is considered as an excess margin in propulsion power calculations.

In this project, *Holtrop and Mennen statistical power prediction method* is used to estimate ship resistance in preliminary level [29]. The principal parameters of the vessel used in calculation are are shown in Table 15.

Table 15 Principal particulars used in power prediction calculation.

PRINCIPAL PARTICULARS				
LBP =	74,850	m	-	Length Between Perpendiculars
B =	17,700	m	-	Beam
T =	3,300	m	-	Average Moulded Draught
lcb =	-1,100	%	-	Longitudinal Centre of Buoyancy as a percentage of LBP - + Foward of 0,5 LBP
Cp =	0,597		-	Prismatic Coefficient
Cb =	0,594		-	Block Coefficient
Cms =	0,980		-	Midship Section Coefficient
Cwp =	0,800		-	Waterplane Area Coefficient
Abt =	1,700	m2	-	Transverse Sectional Area of the Bulb at Fore Perpendicular (See the middle picture below)
Cstern =	10		-	Afterbody form: (see the left picture below)
Tf =	3,300	m	-	Foward draught of the ship
Ta =	3,300	m	-	Stern draught of the ship
hb =	0,000	m	-	Position of the centre of the transverse area Abt above the keel (See the middle picture below)
At =	0,000	m2	-	Immersed part of the transverse area of the transom (See the rigth picture below)
S =	0,000	m2	-	Wetted Surface - If you don't now, input zero and the program

Following parameters are obtained from section 4.2: L_{pp}, B, T, LCB, C_p, C_B, C_{ms}, C_{wp}.

Transversal section area of the bulb at fore perpendicular is calculated from hull lines by Simpson I rule, see Table 16 below. The coordinates of the bulb are taken from hull lines drawing.

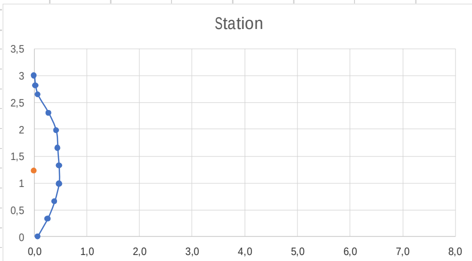
Table 16 Calculation of transversal section area of the bulb at fore perpendicular with Simpson I rule.

Maximum draft	3	m	
Intervals:	10	-	
Spacing, s:	0,3	m	

Input | Calculation

WL [-]	Z-coordinate	1/2 ordinates y_n [m]	SM k_n [-]	Product for area $y_n * k_n$ [m²]	Lever @ Frame 0 R_n [m]	moment of area $y_n * k_n * R_n$ [m³]	
0	0	0,1	1	0,1	0	0,0	
1	0,33	0,3	4	1,0	1	1,0	
2	0,66	0,4	2	0,8	2	1,6	
3	0,99	0,5	4	1,9	3	5,7	
4	1,32	0,5	2	0,9	4	3,8	
5	1,65	0,5	4	1,8	5	9,0	
6	1,98	0,4	2	0,8	6	5,0	
7	2,31	0,3	4	1,1	7	7,6	
8	2,64	0,1	2	0,1	8	1,1	
9	2,82	0,0	4	0,1	9	0,7	
10	3	0,0	1	0,0	10	0,0	
			S	8,6	m²	35,5	m³

Cross sectional area	1,7	m2	
Center of CSA	1,232	m	above keel



Shape of stern is U-shaped sections with Hogner stern so aftbody form parameter C_{stern} = 10. Even keel draught is used in calculation ($T_f = T_a$). The hull form is such that no underwater transom exist and therefore h_b, A_t = 0.

Azimuth thrusters with electric motor are chosen as main propulsion of the vessel. Principals and background for the selection are further explained in later section 7.3. As there is no direct resistance factor for azimuth drive, the appendage resistance is estimated as a combination of strut bossing and shaft brackets (2+2pcs) where strut bossing represents azimuth drive torpedo and brackets the strut of the drive. The wetted area of the azimuth units is estimated from cylinders as corresponding size, see Figure 41.

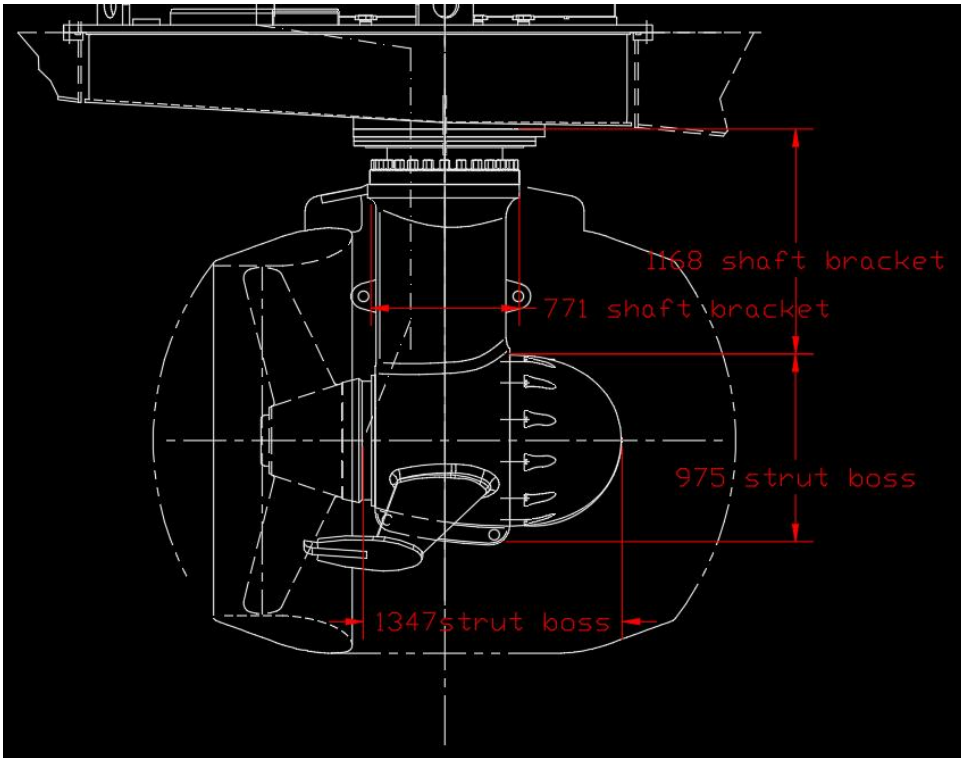


Figure 41 Calculation of wetted area of appendages.

Additionally bilge keels are implemented to the vessel and wetted area calculated accordingly. The resistance factors are shown in Table 17.

Table 17 Appendage resistance factors.

APPENDAGES PARTICULARS					
	1 + K2	**Sapp (m2)**	**Presence**		
Rudder Behind Skeg	1,70	0,00	0	1 + K2 :	Appendage resistance factor - Default
Rudder Behind Stern	1,40	0,00	0	Sapp :	Wetted area of the appendages
Twin-screw balance rudders	2,80	0,00	0	Presence:	1 or 0 (Present or not Present)
Shaft Brackets	3,00	0,46	2		
Skeg	1,80	0,00	0		
Strut Bossings	3,00	1,10	2		
Hull Bossings	2,00	0,00	0		
Shafts	3,00	0,00	0		
Stabilizer Fins	2,80	0,00	0		
Dome	2,70	0,00	0		
Bilge Keels	1,40	12,00	2	**Diameter**	
Bow Thruster	-	-	1	1,50	**m**
Stern Thruster	-	-	0	1,00	**m**

It is to be noted that more in detail CFD analysis and model testing would be needed to obtain more accurate results and optimize the hull geometry.

The propeller size is chosen based on similar reference vessels with similar size and speed. The dimensions are obtained from manufacturers technical proposal for the project. The efficiency of the propeller is estimated and conservative value 0.63 is used in preliminary propulsion power analysis. The propulsion particulars are shown in Table 18.

Table 18 Propulsion particulars.

PROPULSION PARTICULARS				
Z =	4		-	Number of blades
P =	2,13	m	-	Pitch of the propeller
D =	1,80	m	-	Diameter of the propeller
Hp =	1,11	m	-	High of the shaft from keel line
K =	0,1		-	K = 0,2 for single-screw ships or 0,1 for twin-screw ships
eta0 =	0,63		-	Open water efficiency of the propeller
Speeds				
V0 =	1,00	knots	-	Initial Speed
Vf =	12,00	knots	-	Final Speed
WATER PARTICULARS				
Ni =	1,188E-06	m2/s	-	Kinematic Viscosity of Water
rho =	1000	kg/m3	-	Specific mass of water

Based on the calculation the total resistance and required propulsion power is shown in Figure 42 and Figure 43.

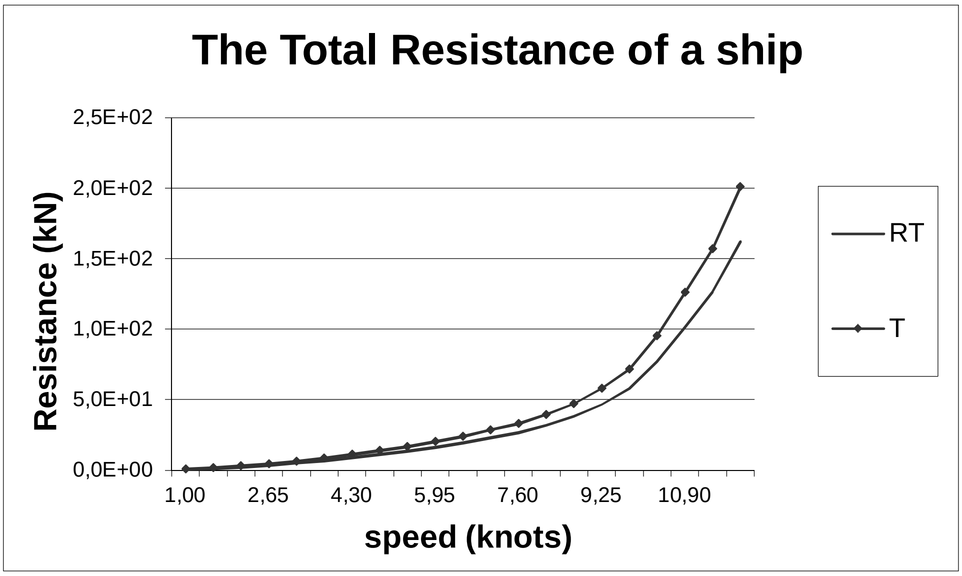


Figure 42 The calculated total resistance of the vessel and propeller thrust.

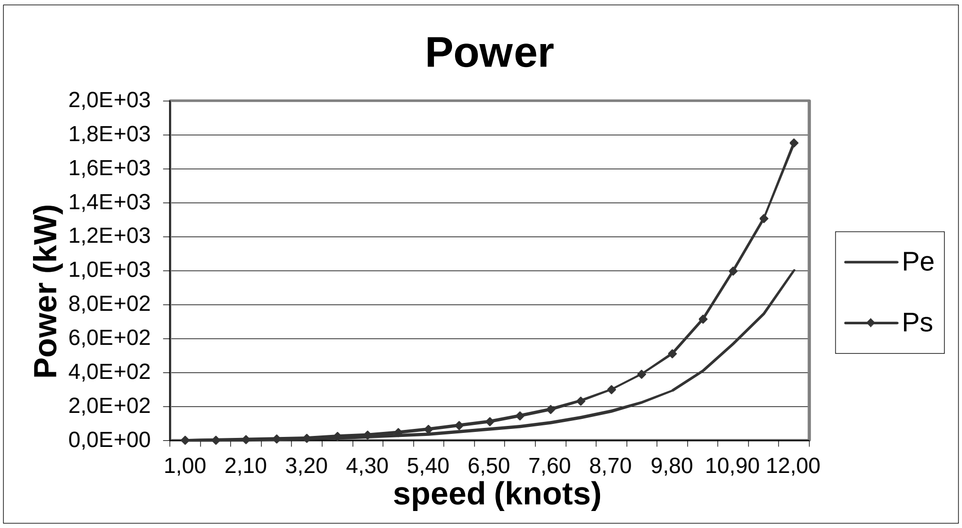


Figure 43 The calculated effective power and required propulsion power.

In case using the azimuth thruster, the efficiency of power transmission (L-drive gear) needs to be taken into account when dimensioning the thruster motor. In Table 19 the needed power at motor output shaft is shown. This is compared to chosen propulsor Kongsberg Azimuth Thruster US 155S P14 PM FP and approximately 15 % margin has been obtained. This is a good margin and gives flexibility in additional resistance caused by find, fouling and heavy weather. The azimuth unit is further discussed in section 7.3.

Table 19 Dimensioning of the propulsion motor.

Speed	Resistance	Thrust	Efective power	Shaft power	Shaft power / unit	Gear efficiency	Required motor output		
Speed (knots)	**Rt (kN)**	**T (kN)**	**Pe (kW)**	**Ps (kW)**	**Psunit (kW)**	**Etagear -**	**Psoutput (kW)**		
1,00	0,6	0,7	0,3	0,5	0,3	0,92	0,3		
1,55	1,3	1,6	1,0	1,8	0,9	0,92	1,0		
2,10	2,3	2,8	2,5	4,3	2,2	0,92	2,3		
2,65	3,5	4,4	4,8	8,4	4,2	0,92	4,6		
3,20	5,1	6,3	8,3	14,5	7,3	0,92	7,9		
3,75	6,8	8,4	13,1	23,0	11,5	0,92	12,5		
4,30	8,8	10,9	19,5	34,1	17,1	0,92	18,6		
4,85	11,1	13,7	27,6	48,3	24,2	0,92	26,3		
5,40	13,6	16,8	37,7	66,0	33,0	0,92	35,9		
5,95	16,3	20,2	49,9	87,4	43,7	0,92	47,5		
6,50	19,3	24,0	64,7	113,3	56,7	0,92	61,6		
7,05	22,8	28,2	82,6	144,7	72,3	0,92	78,6		
7,60	26,7	33,1	104,6	183,3	91,6	0,92	99,6		
8,15	31,7	39,2	132,7	232,7	116,3	0,92	126,4		
8,70	38,0	47,1	170,2	298,5	149,2	0,92	162,2		
9,25	46,7	57,9	222,4	390,0	195,0	0,92	211,9		
9,80	57,9	71,7	291,7	511,6	255,8	0,92	278,1		
10,35	76,8	95,1	408,8	717,1	358,5	0,92	389,7		
10,90	101,6	125,9	569,7	999,5	499,8	0,92	543,2		
11,45	126,6	156,9	745,7	1308,3	654,2	0,92	711,0		
12,00	162,0	200,7	1000,0	1754,8	877,4	0,92	953,7	1100,0	15 %

Kongsberg Azimuth Thruster US 155S P14 PM FP rating

"sea margin"

The power plant dimensioning is presented in Table 20. The hotel and auxiliary load maximum base level is assumed to be 700kW and small increase in relation to propulsion power is assumed as the auxiliary system consumption is higher.

Table 20 Dimensioning of the power plant.

Speed	Required motor output	Propulsion drive effiency	Propulsion load at generator	Hotel + auxiliaries load	Propulsion drive effiency	Total load at engine	SFOC with MDO	MDO density	Consumption
Speed (knots)	**Psoutput (kW)**	**Etadrive -**	**Pinput (kW)**	**Photel (kW)**	**Etagenerator -**	**Ptotal (kW)**	**SFOC (g/kWh)**	**roo (kg/m3)**	**C (m3/h)**
1,00	0,6	0,93	0,6	700,00	0,98	719	200	890	161
1,55	2,0	0,93	2,1	705,00	0,98	725	200	890	163
2,10	4,7	0,93	5,0	710,00	0,98	733	200	890	165
2,65	9,2	0,93	9,9	715,00	0,98	743	200	890	167
3,20	15,8	0,93	17,0	720,00	0,98	756	200	890	170
3,75	25,0	0,93	26,9	725,00	0,98	771	200	890	173
4,30	37,1	0,93	39,9	730,00	0,98	790	200	890	177
4,85	52,5	0,93	56,5	735,00	0,98	812	200	890	182
5,40	71,7	0,93	77,1	740,00	0,98	838	200	890	188
5,95	95,0	0,93	102,2	745,00	0,98	869	200	890	195
6,50	123,2	0,93	132,5	750,00	0,98	905	200	890	203
7,05	157,3	0,93	169,1	755,00	0,98	948	200	890	213
7,60	199,2	0,93	214,2	760,00	0,98	999	200	890	225
8,15	252,9	0,93	271,9	765,00	0,98	1064	200	890	239
8,70	324,4	0,93	348,9	770,00	0,98	1148	200	890	258
9,25	423,9	0,93	455,8	775,00	0,98	1262	200	890	284
9,80	556,1	0,93	598,0	780,00	0,98	1413	200	890	318
10,35	779,4	0,93	838,1	785,00	0,98	1665	200	890	374
10,90	1086,4	0,93	1168,2	790,00	0,98	2008	200	890	451
11,45	1422,1	0,93	1529,1	795,00	0,98	2384	200	890	536
12,00	1907,4	0,93	2050,9	800,00	0,98	2924	200	890	657
				Power plant with 2x4L20DF+2x6L20DF		3600			
				Margin		23 %			

Assumed constant SFOC. In reality consumption depends on engine loading and power plant configuration (number of engines runnign)

From the table it can be seen that there is 23% margin towards the maximum output of the intended power plant. The fuel oil consumption of the power plant at different speeds is very coarse and indicative. It is assumed constant SFOC=200g/kWh but this parameter is changing dynamically depending on engine loading and power plant configuration (number of engines running). The total consumption at full power is approximately 660 l/h.

7.3 Propulsion and Power Generation

7.3.1 Power generation

As main energy source we are using diesel fuel as on Brazil and especially on a smaller port like Tefe there is not necessarily LNG bunker availability. LNG option would also require large changes in local infrastructure which is not foreseen in near future. Therefore, it is decided to choose regular marine diesel oil (MDX, MDA) as the main fuel of the vessel.

Like it is explained in the earlier section, the vessel's operational profile has varying speeds and loading on different parts of the journey we use diesel electric propulsion which enables better efficiency at partial loads than normal mechanical propulsion. For example, in slow speed part of the journeys, arriving different ports etc. the engines can run in more optimal efficiency area. Diesel electric power plant is also convenient in the machinery arrangement wise as the transmission and shaft line would require more space.

We have narrowed our power generation to two options which both have their pros and cons.

First option is that we would use four Wärtsilä 14 gensets with 60Hz frequency. They would produce approximately 3600 Kilowatts of power altogether and are lightweight as one generator weighs approximately 7.5 tons. Problem is that as these are relatively high rpm engines with many cylinders it would mean that reliability is not probably as high compared to engines with lower RPM but larger displacement. This is also estimated to be more expensive option.

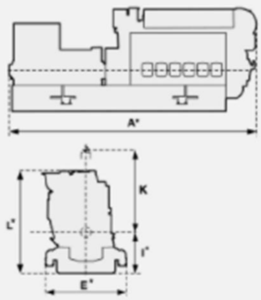
Another option is to use four Wärtsilä 20 Gensets. This means we would have two 4L20 Wärtsilä engines and two 6L20 engines as generators to produce the needed power. Advantage of this option would be that it would provide more reliability as they are larger engines and are used in lower RPM range. Also estimated price would be lower in this case. Downside is that they are twice as heavy as Wärtsilä 14 engines. This option would produce approximately 3600 kilowatts so our need to produce slightly more than 2500 kilowatts are easily exceeded and we would have some reserve power too.

Figure 44 Wärtsilä 20 engine. [30]

After some consideration we will use Wärtsilä 20 gensets on this concept design as the lower price and likely more reliable large displacement engine is fitting on our needs better as one of our targets was also to keep ferry affordable and also relatively easy to maintan.

Wärtsilä 20 generating set		**IMO Tier II or III**	
Cylinder bore	200 mm	Generator voltage	0.4 - 13.8 kV
Piston stroke	280 mm	Generator efficiency	0.95 - 0.96
Cylinder output	185, 200 kW/cyl	Fuel specification	Fuel oil
Speed	900, 1000rpm	700 cSt/50°C	7200 sR1/100°C
Mean effective pressure	27.3, 28.0bar	ISO 8217, category ISO-F-RMK 700	
Piston speed	8.4, 9.3m/s	SFOC 190,3 g/kWh at ISO condition	

Genset 20, Rated power						
	60 Hz				50 Hz	
Engine type	185 kW/cyl, 900 rpm		220 kW/cyl, 1200 rpm		200 kW/cyl, 1000 rpm	
	Eng. kW	Gen. kW	Eng. kW	Gen. kW	Eng. kW	Gen. kW
4L20	740	700	-	-	800	760
6L20	1110	1055	1320	1255	1200	1140
8L20	1480	1405	1760	1670	1600	1520
9L20	1665	1580	1980	1880	1800	1710



Genset 20, Dimensions (mm) and weights (tonnes)						
Engine type	A*	E*	I*	K	L*	Weight*
4L20	4910	1770 1920	990	1800	2338	14.0
6L20	5325	1770 1920 2070	895 975 1025	1800	2243 2323 2373	16.8
8L20	6030	1920 2070	1025 1075	1800	2474 2524	20.7
9L20	6535	2070 2300	1075 1125	1800	2524 2574	23.8

* Dependent on generator type and size.

Figure 45 Wärtsilä 20 genset spec sheet. [30]

In case of emergency (blackout), we have chosen is Wärtsilä 14 12-cylinder emergency diesel generator on fifth deck behind the bridge. Emergency supply is connected to SOLAS required system including steering, navigation and emergency lighting.

Hybrid system is also option which is would reduce the environmental impact of the vessel. Wärtsilä is providing hybrid systems for ships and ferries. As our group's resources are relatively limited as we don't have much manpower we cannot design the whole hybrid system so in case we would have Hybrid solution for our ferry it would come from Wärtsilä with cooperation from Wärtsilä experts and designers to get hybrid system suitable for Amazona SaFerry. It could be for example used when arriving and leaving ports. Based on what Wärtsilä says it could give payback also financially already in four years. [31]

Batteries on hybrid system would be Li-ion batteries and space for them would be below car deck. Charging batteries would happen by plug-in system so it would probably require additional infrastructure on ports but as Amazona SaFerry has lifetime of over 25 years it would be also investment for future and for ferries in the future.

After some evaluation we made decision that right now Amazona SaFerry won’t be equipped with hybrid system but it will be in the future developments and will be something that could possibly be retrofitted afterwards.

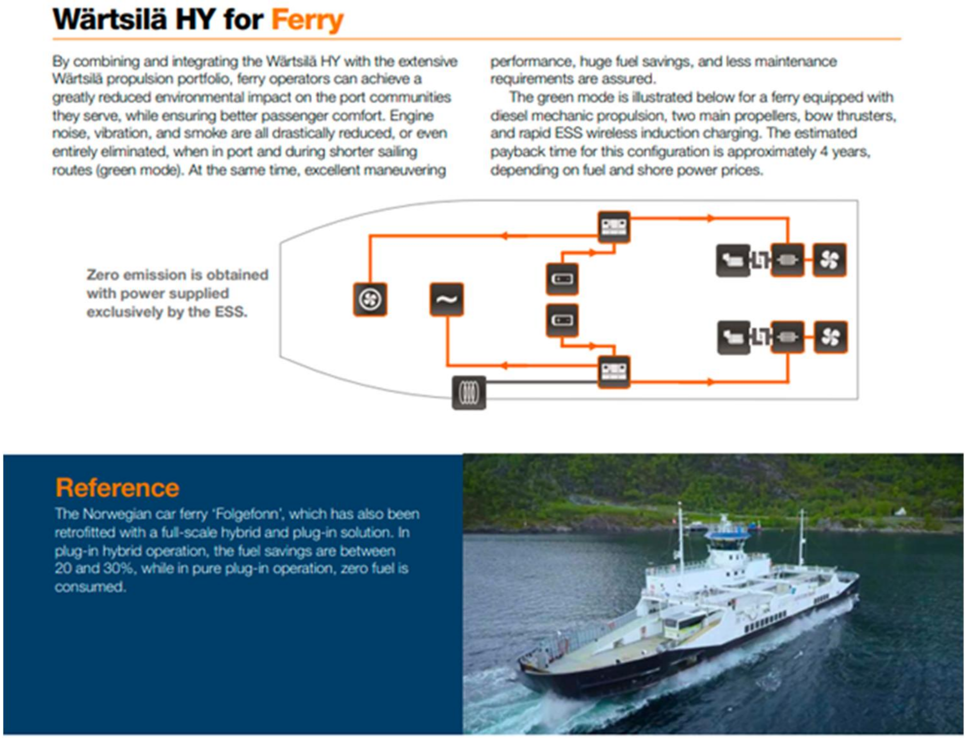


Figure 46 Wärtsilä HY system for Ferry. [31]

7.3.2 Propulsion system

We use two azimuth thrusters as propulsion system. After we received replies to ou inquiries we did meticulous consideration and checking what fits our needs best we have decided that we will go with Kongsberg Kongsberg Azimuth Thruster US 155S P14 PM FP.

It is L-drive azimuth Thruster with vertical PM motor on the top unit and it has bolt-in intermediate part. It can freely azimuth 360 degrees and is controlled by Kongsberg Aquapilot system. In addition, permanent magnet motor which this propulsion system has is best choice because of its efficiency as there is no excitation losses compared to synchronous or asynchronous motors. [22]

Prime mover of it is PM motor and it input power is 1150 kW. Input speed is 720 rpm and propeller’s nominal speed is 258 rpm. Thruster steering speed is 3 rpm and propeller has 1,8m as diameter. Overall weight of the thruster is approximately 16 000 kg and without liquids. [22]

Figure 47 Kongsberg Azimuth Thruster US 155S. [22]

With thruster there comes also Kongsberg Aquapilot navigation system. It is independent control system with integral time dependent back-up controls for one azimuth thruster. It means that each thruster has independent control system so failure on one thruster do not affect controls of the other thruster. All control systems are on easy to handle with controls in simple panels and joysticks so training of the pilots are easy. [22]

Table 21 Konsberg thruster specs. [22]

Prime mover (Kongsberg supply)	: PM Motor
Input power (primary)	: 1150 kW
Input speed (primary)	: 720 RPM
Max. allowable torque on the input shaft	: 15.3 kNm
Total reduction ratio	: 2.786
Propeller speed at nominal rpm	: 258 RPM
Direction of propellers rotation (viewed from the aft)	: Right handed

Table 22 Konsberg thruster weight information. [22]

Weights	
Azimuth thruster, dry weight	: Abt. 15 000 kg
Gravity oil tank	: Abt. 15 kg

Electric steering gear control unit	: Abt. 400 kg
Lubrication pump unit	: Abt. 500 kg
Control equipment	: Abt. 100 kg
Volumes	
Lubrication oil in the unit	: Abt. 1000 l
Gravity tank oil	: Abt. 35 l

Figure 48 Kongsberg aqua pilot system illustration. [22]

7.3.3 Bow thruster

As bow thruster we have choice in place. Our preliminary choice is to use Kongsberg 1300 FP tunnel thrusters. They will have auxillary power of 500 kilowatts and their motor RPM is between 1470-1760 depending on specification. Propeller RPM is 390-467 and they help ship maneuverability when arriving and leaving ports. They are electric powered so for example hybrid system could provide power for them after hybrid system would be implemented.

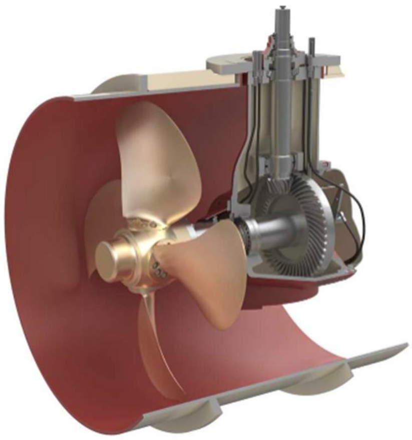


Figure 49 Kongsberg tunnel thruster. [32]

7.3.4 Auxiliary Machinery

In addition to main propulsion there are exist auxiliary systems which are not described here in detail but are vital part of ship machinery:

- Main engine auxiliary systems:
  - Cooling water systems (HT-LT)
  - Lubrication oil separators
  - Fuel oil separator
  - Fuel feed units
- Thruster lubrication oil systems
- Electrical power distribution equipment:
  - Main switchboards and transformers
  - Propulsion variable frequency drives
- Boilers
  - Auxiliary boiler
  - Exhaust gas boilers in engine casing
- Catalyzators and exhaust gas piping in engine casing.
- Bilge and ballast system including pumps
- Engine room ventilation
- Potable and technical water treatment
- Grey and black water system
- Wet and dry garbage collecting system
- Fire fighting systems
- AC system
- Machinery automation system
- Lifting systems
- Mooring systems
- RoRo systems
  - Bow and stern ramps
  - Hatches
  - Side doors

7.4 Machinery Arrangement

Main generator rooms are at the tanktop approximately at the midships. Propulsion system required bit more space so the propulsion system is angled on an certain angle so car deck could be fully utilized and it wouldn't be penetrated by thruster system.

Main generator rooms have been divided by bulkheads so in case of fire or structural breach only one of the generators goes off and not all of them. At the fore of the ship, there is also room for bow thrusters so they are divided on their room for maintenance and for safety reasons.

In front of generator room there is space reserved for batteries and hybrid system if they will be retrofitted on the ship.

On the fifth deck, there is spare generator in case of emergency situations if full blackout happens. Some of the smaller machinery arrangements what we have on ferry have not been modelled on AutoCAD drawings as our resources have been limited so we have decided to focus on main machinery components. The full machinery arrangement concept can be seen in Appendix 4.

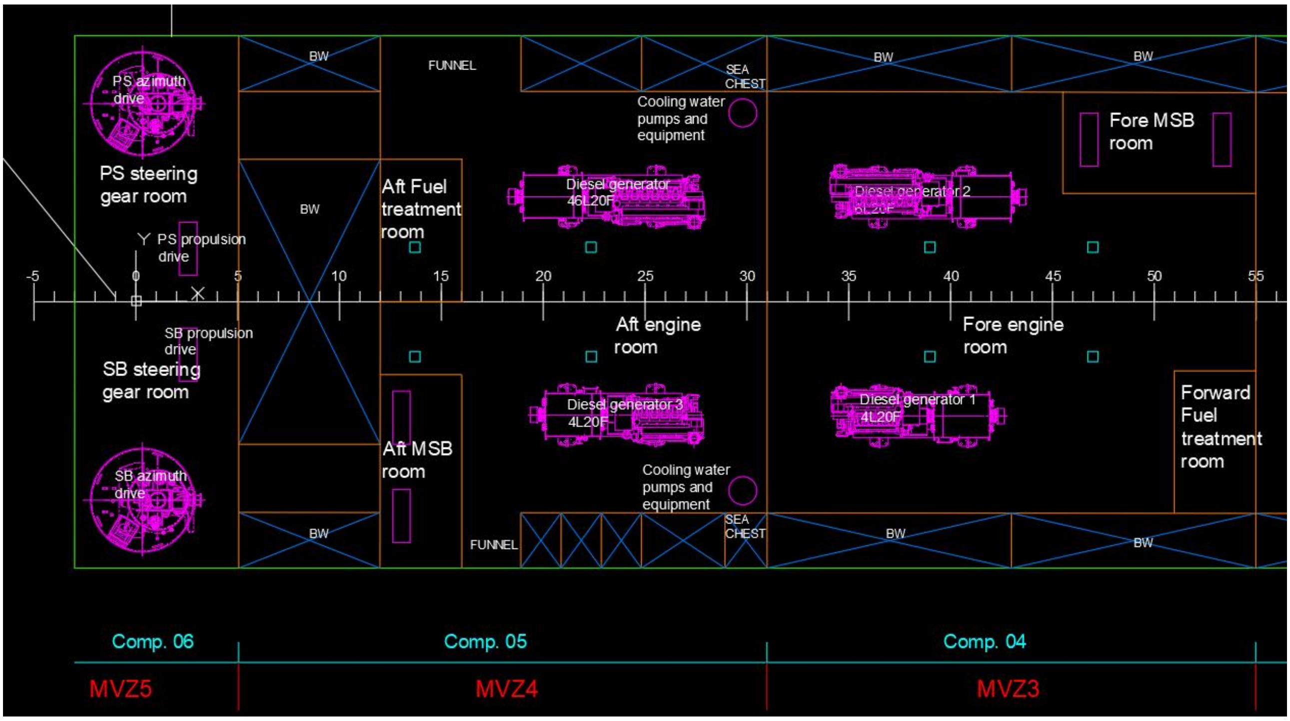


Figure 50 Engine and steering gear rooms at tanktop.

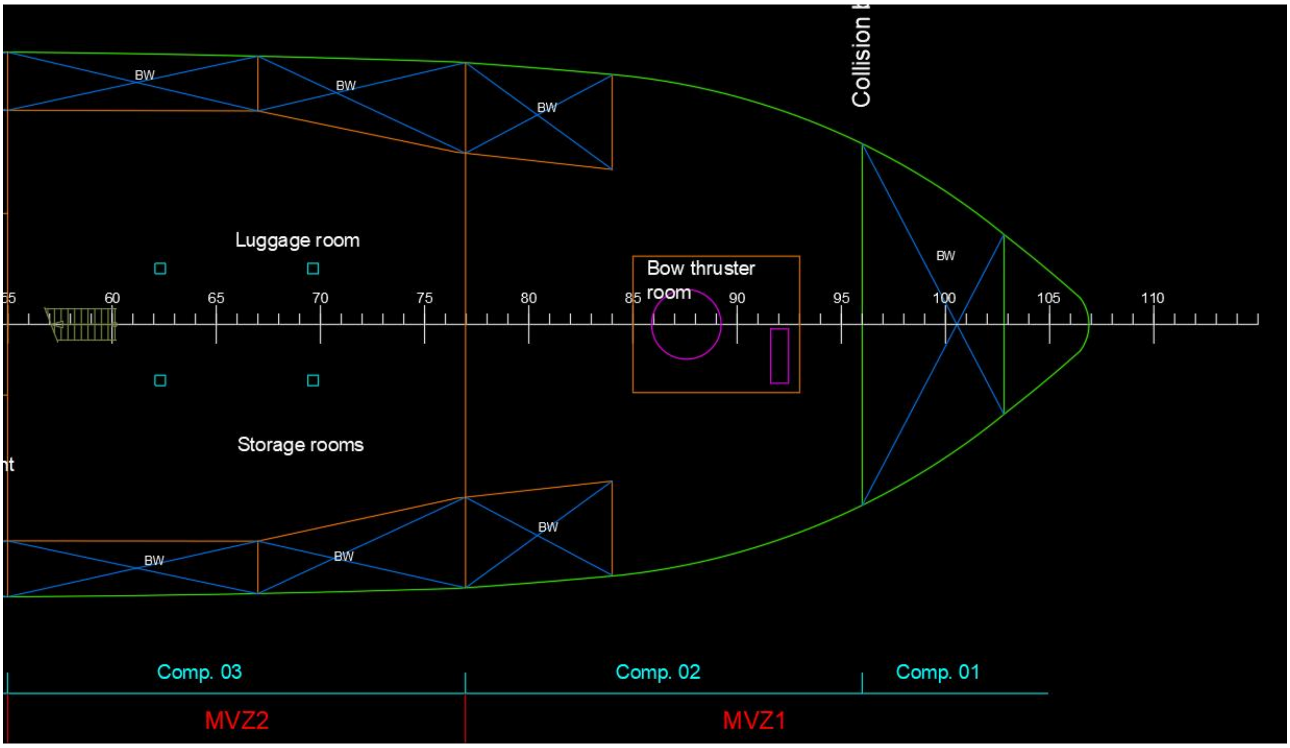


Figure 51 Bow thruster room and luggage/storage spaces.

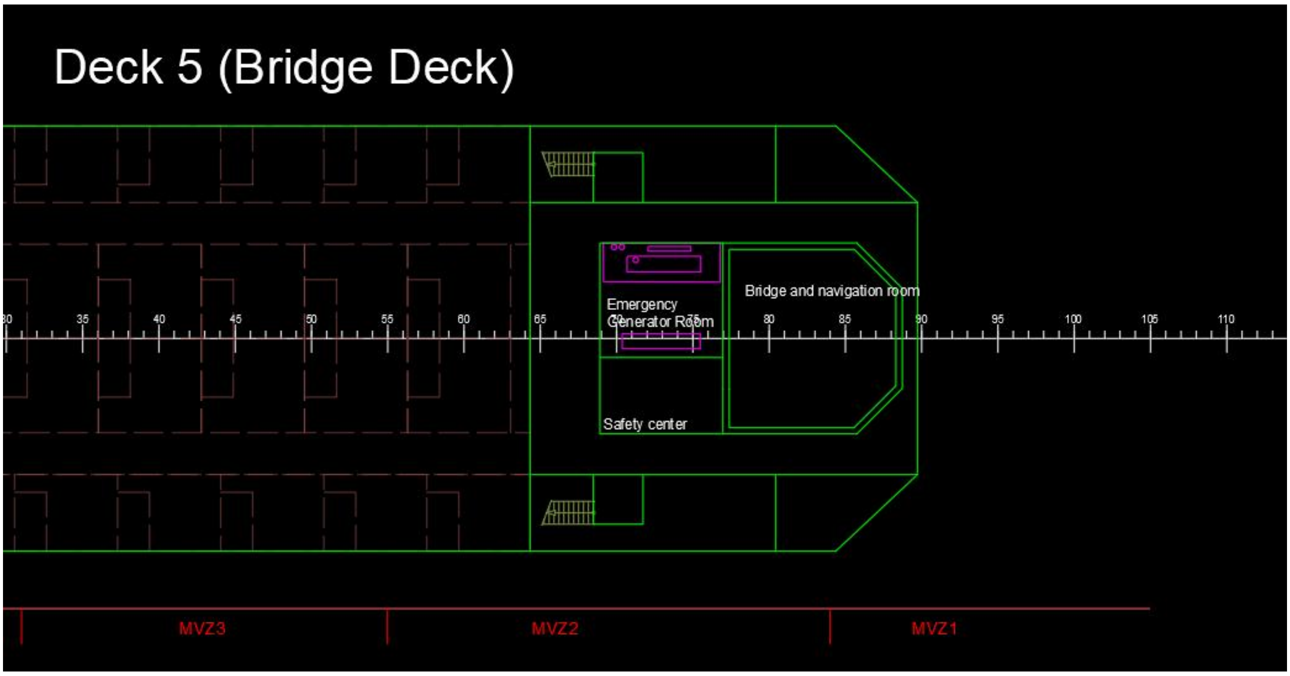


Figure 52 Emergency generator room behind the bridge.

7.5 Conclusion

We have determined ferry's operational profile, what kind of journey it is to sail from Manaus to Tefe and how much time and machinery load our journey will take. Based on our journey's length and profile we have then calculated required power for Amazona SaFerry and how much power we would need for our propulsion system and auxiliary machinery system.

After calculations we have chosen most suitable machinery for propulsion and power generation and considered also hybrid possibility for ferry. Besides those we have done some ideation what other machinery we would need on our ship, for example air conditioning, fire extinguishing. Last we have done machinery arrangement on our ship so we can actually see our chosen components and machines are good fit on our ship and we have determined their locations on decks of the ship.

Overall progress has been good development and we are satisfied how we have managed to determine our ship's operational profile and required power and thus choose suitable machinery. Next and second to last phase of the ship's design will be ship weights.

8 WEIGHT AND STABILITY

8.1 Classification of the Ship Systems

The systems of the Amazona SaFerry are classified by using SFI standard. In each of these systems, a classification number is assigned to each item or group of items of the ship, according to a tree structure. Only 1st and 2nd level are considered at the concept stage of the project.

1 SHIP GENERAL

- *12 MODELS*
  - Scaled models with scale of 1/20 will be made for stability tests
- *15 TRIALS AND TESTS*
  - Seat trials and machinery testing will be conducted in 2023
  - Inspections late 2022 or early 2023
  - Last inspections late 2023

2 HULL

- *20 HULL MATERIALS*
  - Steel S355J10 HA36
  - Aluminum Al 5083
  - All structures will be analyzed in Finite Element Analysis software
- *21 AFT BODY*
  - Aft body designed for two azimuth thrusters and have steering gear rooms and propulsion drivers
- *22 ENGINE AREA*
  - Two engine rooms where is also MSB and fuel treatment rooms, cooling water pumps and equipment. Divided by bulkhead.
  - Includes main diesel generator
- *23 MIDSHIP/GARGO AREA*
  - Cargo area located at tanktop on compartment 3
  - Ro-Ro decks are deck 1 and deck 2. Approximately 240 lane meters by four lanes. Divided by longitudinal bulkhead.
  - Ballast tanks located on tank top at midships.
- *24 FOREBODY*
  - Collision bulkhead and stern thruster located at forebody
- *25 SUPERSTRUCTURE*
  - Superstructure includes decks 1-5.
  - Decks 1 and 2 are Ro-Ro car decks.
  - Deck 3 consists passenger seats, toilets and restaurant. Also mooring deck is deck 3.
  - Deck 4 has accomodation for crew and passengers who has their own cabins. Also lifeboats are in deck 4.
  - Fifth deck is navigation deck which also includes emergency generator room
  - Superstructure materials Steel S355J10 HA36 and Aluminum Al 5083
- *26 HULL OUTFITTING*
  - Hull has Bilge keels
  - Two funnels
  - Sea chests on double bottom

- Bow thruster tunnels at near front perpendicular

- *27 MATERIAL PROTECTION EXTERNAL*
  - Hull will be painted with green, black and white color according to latest regulations. Hull color symbolizes Amazona forest and green values used in designing of Amazona SaFerry.
  - Sharp edges shall be rounded so that edge are at min 2mm.
  - All cuts should be welded on tanks
  - Steel should be sandblasted to grade SA 2,5
  - Surface treatments should be done according to recommendations
- *28 MATERIAL PROTECTION INTERNAL*
  - All sharp edges should be rounded so minimum radius of edge won't fall below the limit of 2mm.
  - All areas should be cleaned from oil, grease and other liquids which do not belong.
  - Surface treatments should be done according to recommendations

3 EQUIPMENT FOR CARGO

- *30 HATCHES*
  - Bow and stern doors. Made from stainless steel. Manholes from tanks.
- *31 Equipment for Cargo*
  - Elevator for cargo from deck 1 to tanktop

4 SHIP EQUIPMENT

- *40 MANOUVERING MACHINERY AND EQUIPMENT*
  - Maneuvering control by Kongsberg Aqua Pilot control system located on deck 5.
  - Kongsberg Azimuth thrusters. No rudder
  - Tunnel thrusters
- *41 NAVIGATION EQUIPMENT*
  - Navigation mast and platform at top deck
  - Bridge at deck 6
- *42 COMMUNICATION EQUIPMENT*
- *43 ANCHORING AND MOORING EQUIPMENT*
  - Mooring equipment at deck 3.
- *44 REPAIR AND CLEANING EQUIPMENT*
  - Repair and maintenance equipments at tanktop storage rooms
- *45 LIFTING AND TRANSPORT EQUIPMENT FOR MACHINERY COMPONENTS*
  - Elevator

5 EQUIPMENT FOR CREW

- *50 LIFESAVING EQUIPMENT*
  - Life vests for passengers deck 3 and 4. Also on bridge deck
  - 2 lifeboats
  - Life rafts
  - First aid and medics at deck 3 restaurant
- *51 INSULATION, BULKHEADS AND PANELLING*
  - Fireproof ceilings structures
  - Fireproof doors according to latest regulations
- *52 INTERNAL DECK COVERING, LADDERS, STEPS, RAILING*
  - Ladders shall be steel

- Accomodation shall have vinyl covers

- *53 EXTERNAL DECKS*
  - Deck covering with paint specified with superstructure color
  - All external deck ladders shall have handrails
- *54 FURNITURE AND INVERTORY*
  - All toilets shall have proper sinks with thermostatic mixing, toilet roll holders
  - Beds shall have dimension of 800x2000mm
  - Seats shall have dimensions according to regulations
  - Entertainment equipment: 52'' TV is fitted at deck 3.
- *57 VENTILATION*
  - Ventilation and air condition system should be made according that
- *58 SANITARY SYSTEM AND EQUIPMENT*
  - Sanitary system will use fresh water.
  - 14 toilets on deck 3. 2 of those toilets are also for disabled persons.
  - Each cabin has own shower and toilet.
  - Piping system use galvanized steel pipes

6 MACHINERY MAIN COMPONENTS

- *60 ENGINES FOR PROPULSION*
  - Four diesel generators. Two Wärtsilä 20 6-cylinder engines and two Wärtsilä 20 4-cylinder engines. Total power output approximately 3600kW.
  - Also possibility for Batteries and hybrid system
- *63 PROPELLERS, THRUSTERS, TRANSMISSION*
  - Two Kongsberg propulsion units. Combined power approximately 2200kW. More information about thrusters found on spec sheet and documents.
  - Bow thrusters at bow. Kongsberg 1300 series tunnel thruster
- *66 EMERGENCY GENERATOR*
  - Located behind the bridge deck
  - Wärtsilä 14 16-cylinder generator. Approximately 700kW of power.

7 SYSTEMS FOR MACHINERY COMPONENTS

- *70 FUEL OIL SYSTEM*
  - Fuel and oil systems and fuel treatment rooms at engine rooms.
- *74 EXHAUST GAS SYSTEM*
  - Funnels starts from tanktop. Two funnels going through ships side walls. Catalyzators included and ship passes every required emission regulations
- *79 AUTOMATION SYSTEM FOR MACHINERY*
  - Engine control room has consoled to monitor systems for propulsion, engines, electric system

8 SHIP SYSTEMS

- *80 BALLAST SYSTEM*
  - Ballast system includes water ballast pumps and ballast hatches and ballast tanks. Ballast water tanks located at double bottom and tank top. Crossover located at double bottom.
- *81 FIRE AND LIFEBOAT SYSTEMS*
  - Two lifeboats located at Deck 4.

    - Alarm bells shall be installed at accommodation passages, engine room, cargo area, galley, emergency generator room and steering gear room, navigation deck, Ro-Ro deck.
    - Sprinkler system at ceiling of every deck
- *85 ELECTRICAL SYSTEMS*
    - All electrical installations and equipment should comply with necessary standards and regulations.
    - Approvals according to requirements
- *86 ELECTRICAL SUPPLY SYSTEM*
    - Electrical plant is powered by main generators or by Emergency generator or hybrid system.
- *88 ELECTRICAL CABLES AND INSTALLATION*
    - The voltage drop on all power and lighting circuits from main bus bars to the final termination point shall not exceed 7% of the nominal voltage, except for DC circuits, where a maximum voltage drop of 11% of the nominal voltage is allowed.
    - All cables, terminals and conductors should have proper installation guides.
    - All cables should be supported by corrosion resistant steel brackets
- *89 ELECTRICAL DISTRIBUTION SYSTEM*
    - All electric equipment shall fulfill needed requirements
    - Explosion proof lights should be provided in gas-hazardous spaces
    - All switches should be grounded accordingly

8.2 Lightship Weight Estimation

Lightship weight is the weight of a ship in metric tons without cargo, fuel, lubricating oil, ballast water, fresh water and feed water in tanks, consumable stores, passengers and crew and their belongings. It includes standard outfitting, inventory according to the List of Inventory, spare parts according to the Class Society requirements and with liquids in engine room systems.

The lightship weight can be distributed in following components:

$$W_{LS} = W_S + W_M + W_O + W_{margin} \quad (24)$$

where :

W_S is the structural weight,

W_M is the propulsion machinery weight

W_O represents the outfitting weight and

W_{margin} is the margin or reserve.

The lightship weight does not include loose container lashing equipment, spare parts in excess of rule requirements, provision stores, crew and effects, fuel oil, diesel oil, lubricating oil, fresh water, ballast water in tanks.

8.2.1 Rough preliminary weight assessment

The first estimate on ship weight is made by using empirical formulas.

Hull (structural) weight is estimated using a formula based on Watson and Gilfillan approach:

$$W_S = KE^{1.36}(1 + 0.5(C_B - 0.7) \quad (25)$$

The block coefficient of the Amazona SaFerry at 80% depth is approximately $C_B = 0.58$.

As per Table 23, the value of coefficient K for Ro-Ro vessels (or passenger vessels) can be estimated as follows:

$$K = 0.031 \pm 0.006 = 0.025 \dots 0.037 \quad (26)$$

Table 23 Coefficient K for different ship types (Thomas, 2003).

Ship type	*K mean*	*K range*	*Range of E*
Tankers	0.032	±0.003	1500 < E < 40 000
Chemical tankers	0.036	±0.001	1900 < E < 2500
Bulk carriers	0.031	±0.002	3000 < E < 15 000
Container ships	0.036	±0.003	6000 < E < 13 000
Cargo	0.033	±0.004	2000 < E < 7000
Refrigerator ships	0.034	±0.002	4000 < E < 6000
Coasters	0.030	±0.002	1000 < E < 2000
Offshore supply	0.045	±0.005	800 < E < 1300
Tugs	0.044	±0.002	350 < E < 450
Fishing trawlers	0.041	±0.001	250 < E < 1300
Research vessels	0.045	±0.002	1350 < E < 1500
RO-RO ferries	0.031	±0.006	2000 < E < 5000
Passenger ships	0.038	±0.001	5000 < E < 15 000
Frigates/corvettes	0.023		

The equipment number *E* can be calculated as follows:

$$E = E_{hull} + E_{SS} + E_{dh} = L(B + T) + 0.85L(D - T) + 0.85\sum_i h_i + 0.75\sum_j h_j \quad (27)$$

We get equipment number:

$$E \sim 2365 \quad (28)$$

Hull weight by using *K* values (26) are:

$$W_S = 911 \ldots 1348\ tonnes \quad (29)$$

The total machinery weight with modern diesel electric engines can be calculated with formula proposed by Watson (*MCR*=3700kW):

$$W_M = 0.72(MCR)^{0.78} = 437\ tonnes \quad (30)$$

The outfitting weight can be estimated with following formula:

$$W_O = C_0 LB \quad (31)$$

where the outfitting weight coefficient is estimated as C_0 = 0.5. The outfitting weight coefficient as a function of the ship type and length shown in Figure 53 does not apply for small ferries (*Lpp* = 80.1). However, it estimated that the amount of outfitting should be something between cargo vessels and passenger vessels of larger size. Thereby we have rough preliminary weight estimate for outfitting weight:

$$W_O = C_0 LB = 533\ tonnes \quad (32)$$

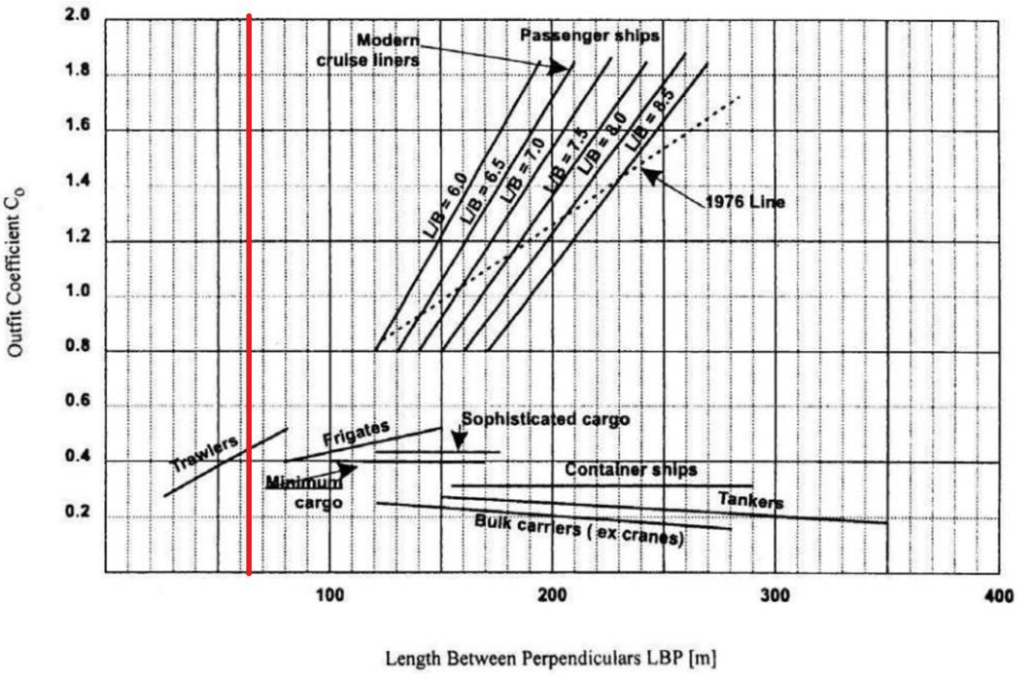


Figure 53 The outfitting weight coefficient C_0 as a function of the ship type and length.

By using values (29), (30) and (32) we get rough lightship weight estimate as follows (depending on factor *K*) without additional safety margin:

$$W_{LS} = W_S + W_M + W_O = 1881 \ldots 2325\ tonnes \quad (33)$$

It is to be noted that the lightship weight is higher than previously assumed and gives small to zero deadweight capacity. Thereby more accurate weight estimation methods are to be used or displacement increased by adjusting block coefficient or main dimensions. When evaluating the result, it is to be kept in mind that the formulas used are not necessarily very accurate with the type of ferry that Amazona SaFerry represents and might lead in too conservative design. The calculation with spread sheet is shown in Table 24.

Table 24 Rough lightship weight estimate by using excel spread sheet 04. T9_Weight estimation.xls.

Ship's main characteristics	
L(m)	74.9
B(m)	17.7
T(m)	3.3
D(m)	12.4
CB	0.58
LCB(m) @AP (m)	36.6261
Lightship weight	
2010.67	
KG_{Light}	
7.558	

Structural weight	
Length of superstructure (m)	58
Height of superstructure (m)	3.5
Length of deckhouse (m)	15.2
Height of deckhouse (m)	3.5
E	2364.702
K	0.025
WS (tonne)	910.76
KG_{hull} (m)	5.694
LCG_{hull} (m)	36.4761

Machinery weight	
MCR (KW)	3700
N (rpm)	900
type of plant	Diesel electric
No of engines	4
cm	0.83
W_M (tonne)	437.049
Height of engine room (m)	5
Height of double bottom (m)	0.7
KG_M (m)	2.205

Outfitting weight	
Co	0.5
W_o (tonne)	662.865
KG_o (m)	13.65

Ship's main characteristics	
L(m)	74.9
B(m)	17.7
T(m)	3.3
D(m)	12.4
CB	0.58
LCB(m) @AP (m)	36.6261
Lightship weight	
2447.84	
KG_{Light}	
7.225	

Structural weight	
Length of superstructure (m)	58
Height of superstructure (m)	3.5
Length of deckhouse (m)	15.2
Height of deckhouse (m)	3.5
E	2364.702
K	0.037
WS (tonne)	1347.92
KG_{hull} (m)	5.694
LCG_{hull} (m)	36.4761

Machinery weight	
MCR (KW)	3700
N (rpm)	900
type of plant	Diesel electric
No of engines	4
cm	0.83
W_M (tonne)	437.049
Height of engine room (m)	5
Height of double bottom (m)	0.7
KG_M (m)	2.205

Outfitting weight	
Co	0.5
W_o (tonne)	662.865
KG_o (m)	13.65

As per Table 24, we also obtained vertical center of gravity for lightship:

$KG_{Light} \approx 7{,}3m$ measured from keel. (34)

8.2.2 Further developed weight assessment

More in detail analysis of the weight has been made by using the existing information on hull and machinery available at this stage of the project.

Hull weight

It is started by manually and roughly calculating the hull weight of our vessel based on some assumptions and general arrangement drawings produced earlier.

One of the assumptions made is that the ship's hull weight is calculated based on the midship's cross-section (Figure 54), which is where the ship is at its maximum breadth and height, and therefore highest amount of material.

Another assumption is that the number of stiffeners and their dimensions have been assumed correctly.

The choice of material remains as AH36 (S355J steel) with known density of 7850 kg/m3.

Finally, another assumption is the rough dimensions of these plates (including thickness), which we would require additional FEM analysis to confirm. Given that the forward end of the ship is significantly slimmer than the midship section, a "mark-up" of 15% has been used to account for the usage of less material for the forward end of vessel. As such, the following calculations have been done:

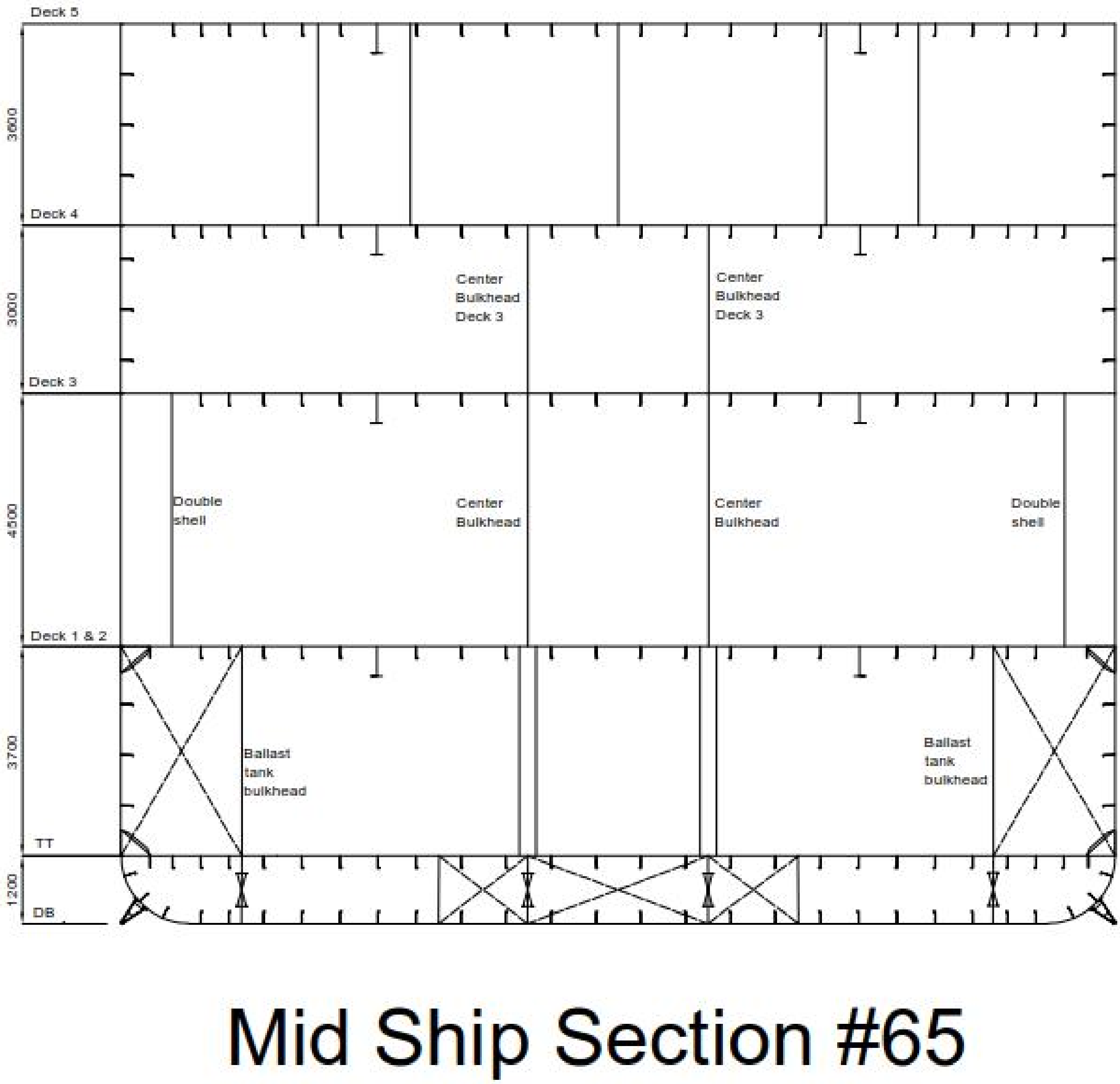


Figure 54 Midship section of Amazon SaFerry.

Figure 55 Profile view of Amazon SaFerry.

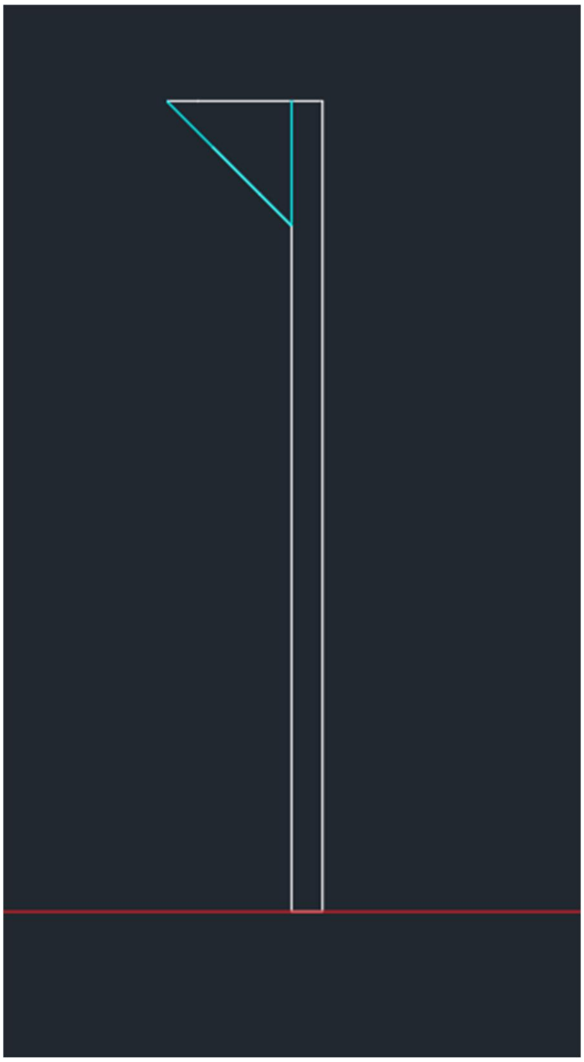


Figure 56 Assumed cross-section of stiffener bulbs.

Table 25 Calculation of the hull steel weight.

Deck	Element	L (m)	B (m)	T (m)	V (m3)	W (kg)	W (tonnes)	
DB	Bottom Flange	80.1	17.7	0.012	17.0	133553.9	134	
	Top Flange	80.1	17.7	0.006	8.5	66777.0	67	
	Left Flange	80.1	1.182	0.012	1.14	8918.7	9	
	Right Flange	80.1	1.182	0.012	1.14	8918.7	9	
TT	Bottom Flange							
	Top Flange	80.1	17.7	0.006	8.5	66777.0	67	
	Left Flange	80.1	3.688	0.012	3.5	27827.5	28	
	Right Flange	80.1	3.688	0.012	3.5	27827.5	28	
1 & 2	Bottom Flange							
	Top Flange	80.1	17.7	0.006	8.5	66777.0	67	
	Right Flange	80.1	4.488	0.012	4.3	33863.8	34	
	Right DS	80.1	4.488	0.006	2.2	16931.9	17	
	Left Flange	80.1	4.488	0.012	4.3	33863.8	34	
	Left DS	80.1	4.488	0.006	2.2	16931.9	17	
3	Bottom Flange							
	Top Flange	80.1	17.7	0.006	8.5	66777.0	67	
	Right Flange	80.1	2.988	0.012	2.9	22545.7	23	
	Left Flange	80.1	2.988	0.012	2.9	22545.7	23	
4	Bottom Flange							
	Top Flange	57.0	17.7	0.012	12.1	95038.4	95	
	Right Flange	57.0	3.582	0.012	2.5	19233.2	19	
	Left Flange	57.0	3.582	0.012	2.5	19233.2	19	
TT	Ballast Tank BH	80.1	3.688	0.006	1.8	13913.8	14	
	Ballast Tank BH	80.1	3.688	0.006	1.8	13913.8	14	
1 & 2	Center BH	47.3	4.488	0.006	1.3	9998.5	10	
	Center BH	47.3	4.488	0.006	1.3	9998.5	10	
	Center TBH	3.15	4.488	0.006	0.1	665.9	1	
	Center TBH	3.15	4.488	0.006	0.1	665.9	1	
5	Top Flange	14.0	17.7	0.006	1.5	11671.4	12	
	Right Flange	14.0	3.482	0.006	0.3	2296.0	2	
	Left Flange	14.0	3.482	0.006	0.3	2296.0	2	
Stiffners		80.1	0.2	0.006	0.132	1037.5	1.0374953	
	0.042	80.1	0.03	0.03				
Stiff. Tot	158				20.9	163924.2	164	
TS BH	1	11.5	17.7	0.009	1.8	14380.8	14	
	2	15.0	17.7	0.009	2.4	18757.6	19	
	3	11.5	17.7	0.009	1.8	14380.8	14	
	4	11.5	17.7	0.009	1.8	14380.8	14	
	5	6.5	17.7	0.009	1.0	8128.3	8	
							1054	tonnes

There is an assumption that the whole ship's weight is based on midship section, which is not realistic. To account for this, total hull weight is multiplied by 0.85 to account for less material usage at forward end of ship, therefore:

Ship Hull Weight:	896		tonnes	

There was a need to reduce the thickness of the plates to 12mm (for outer plates) and 6mm (for inner plates) as there was an absolute need to reduce weight of the lightweight of the ship. This is discussed further in the report, but it is the reason as to why the thickness of plates has changed from that of previous chapters.

As per Table 25, the more accurate estimate for the hull calculated weight is in the same level as previously given by the rule of thumbs formulas. This is basically weight of classification system 2:

$$W_S = 896 \approx 900 \; tonnes \qquad (35)$$

Machinery weight

The weight of the propulsion machinery and engines shown in Table 26 is be estimated more accurately by using the manufacturers data sheets [22], [30] and [32]. These are the weights of classification system 6.

Table 26 Propulsion machinery and power plant weight.

Propulsion machinery and power plant weight

Type	Unit weight [t]	Amount	Total weight [t]
Genset Wärtsilä 4L20F	14	2	28
Genset Wärtsilä 6L20F	16,8	2	33,6
Emergency genset Wärtsilä 12V14F	5,5	1	5,5
Azimuth unit Kongsberg US 155S P14 PM FP	17	2	34
Bow thruster Kongsberg 1300 FP	10	1	10
Total W_{ME}			111

Remaining machinery weight

cm for passenger vessel			0,83
MCR [kW]			3600
Total W_{rem}			256

Total machinery weight

Total W_M			367

From the table we obtain:

$$W_{ME} = 111\ tonnes \quad (36)$$

For the remaining machinery there is no accurate weight information available, so the weight is estimated by using Watson and Gilfillan approach:

$$W_{rem} = c_m(MCR)^{0.7} = 256\ tonnes \quad (37)$$

The total weight of machinery is:

$$W_M = W_{ME} + W_{rem} = 367\ tonnes \quad (38)$$

For the outfitting weight W_o representing the remaining classification systems, the rule of thumb formulas (9) is still used.

The more accurate lightship weight without safety margin is thereby using (12), (15) and (9):

$$W_{LS} = W_S + W_M + W_O = 1523\ tonnes \quad (39)$$

Weight reserve

The vessel is prototype ship with limited experience from designers and available weight information, higher weight reserves are applied at this point of the project. In the preliminary weight calculations, 15 % weight reserve and 1 m reserve in G are applied. Thereby the lightweight used for the ship at this stage is:

$$W_{LS} = W_S + W_M + W_O + W_{margin} = 1{,}15 * 1523\ tonnes = 1752\ tonnes \quad (40)$$

8.3 Deadweight and Displacement

As described in previous assignments, the deadweight of our reference vessel is 750 tonnes. For the vessel, it is wanted that number to be higher due to fuel weight capacity and additional “extra weight” for various entertainment and accommodation purposes. The desired values was 850t deadweight for our vessel.

We have also carried out some deadweight estimation calculations based off industry standards in order to see how far off the values are from rule of thumb values:

The ship’s deadweight is defined as:

$$DWT = DWT_c + DWT_{fo} + DWT_{fw} + DWT_{c\&e} + DWT_{pr} + DWT_{sw} \tag{41}$$

Where DWT_c is the cardo deadweight; DWT_{fo} is the fuel oil weight; DWT_{fw} is the lube oil weight; $DWT_{c\&e}$ is the weight of the crew and their effects; DWT_{pr} is the weight of their provisions and DWT_{sw} is the weight of sewage waste/water storage/treatment.

As such,

$$W_{fo} = SFR * MCR * \frac{range}{speed} * margin \tag{42}$$

therefore,

$$W_{fo} = 0.00019 * 3600 * \frac{700}{6} = 82t + 10\% = 90t \tag{43}$$

Then,

On the basis of using 45 gallons (170L) of fresh water per person per day:

$$W_{fw} = 170 * 400 * 1.5 = 102t \tag{44}$$

Then, weight of crew and their effects can be estimated to be 0.17t per person. Assuming a crew of 20 members:

$$W_{c\&e} = 0.17 * 20 = 3.4t \tag{45}$$

Then, weight of provisions can be estimated to be 0.01t per person per day. Therefore:

$$W_{pr} = 0.01 * 400 * 1.5 = 6t \tag{46}$$

Then, weight of sewage waste/water storage/treatment can be estimated to be 70L of water per person per day, therefore:

$$W_{sw} = 70 * 400 * 1.5 = 42t \tag{47}$$

Then, we will assume lub oil weight to be 30t in accordance with reference vessels, therefore:

$$W_{fo} = 40t \tag{48}$$

And finally, the cargo deadweight, based on worst loading case scenario of 6 cars at 2t and 8 lorries at max weight of 50t:

$$W_{cargo} = (6 * 2) + (8 * 50) = 412t \tag{49}$$

As such, the deadweight requirements of our vessel based on the rough calculation estimates above:

$$DWT = 90 + 102 + 3.4 + 6 + 42 + 40 + 412 \approx 700t \tag{50}$$

Our design hoped to get a deadweight of at least 850t which would satisfy the requirements above and leave out approximately 70t of reserve weight. Ideally, we would get even more reserve weight to have a very safe design, and we will attempt to increase deadweight capacity in further iterations of this design.

We know that displacement = lightweight + deadweight, and as such, we needed to obtain a relatively low value for lightweight in order to maximize deadweight of the vessel (I.e. how much it can carry). From Assignment 3, we had obtained the values for displacement of our vessel (based off reference vessel assumed data) shown in Table 27.

Table 27 Amazona SaFerry main dimensions and coefficients.

Dimension	Value	
Length (Lpp)	74.85	m
Breadth (B)	17.7	m
Draft (T)	3.3	m
Freeboard	2.8	m
Depth (D)	6	m
L/B	4.23	
L/D	22.68	
B/T	5.36	
T/L	0.04	
Block Coeff.	0.58	
Displacement	2623	tons
Fn	0.22	

When we used these values for to calculate our actual allowable deadweight for our vessel, we obtained available deadweight of:

$$DWT = \Delta - W_{LS} = 2623 - 1752\ tonnes = 871\ tonnes \quad (51)$$

This is approximately the target in the beginning of the project. Some design iterations were required to achieved this DW capacity, and the extra 2.5% extra tonnage (in compared to initial design) is added as safety reserve.

8.4 Discussion

The initially obtained deadweight of 211 tonnes was not ideal since we were aiming for 850 tonnes capacity. The explanation for this discrepancy was the fact that we had no information on the reference vessel with regards to block coefficient, machinery weight, outfitting weight, etc. The only information we had was the main dimensions and deadweight, and the rest was basically estimations based on other vessels we did find the information on.

To rectify the issue, we went back to the initial design parameters and altered the block coefficient and increased main dimensions of the vessel. All design calculations and iterations were carried out as above to confirm the validity of new dimensions. Old dimensions and calculations were not included in this report, but it is worth mentioning that this exercise was carried out.

9 ECONOMIC ASSESSMENT

9.1 Shipbuilding Cost Analysis

9.1.1 Nallikari-Nieminen 1990 Ship Building Cost Estimation Method

To start this this cost analysis, the team investigated some different methods of ship building cost estimation, and the first method the team came across is the Nallikari-Nieminen Cost Estimation Method [33].

This method is based on several factors affecting the design of the ship, and then it provides some formulas (seen below) that are based on some of these factors to provide cost estimation. It is worth noting that this method used the Finnish Markka (FIM) as base currency and therefore inflation and conversion rates had to be taken into account in the calculations.

Figure 57 below shows the relevant design parameters for the calculations:

Amazon SaFerry		
Length (m)	L	80.1
Breadth (m)	B	17.7
Power (kW)	P	3700
Height (m)	h	11
Fn	F_n	0.22
# of shaftlines	n	0
DWT (tonnes)	DWT	871
# of crew	n_{crew}	20
Quality	Q	0.05
Vol. of Engine room (m^3)	V_{eng}	1099
Vol. of Cargo Space (m^3)	V_{cgo}	4878.8
Volume of Accomm. (m^3)	V_{acm}	5700
Area of Accom. (m^2)	A_{acm}	1900
Side Profile Area (m^2)	A_{sde}	1158
Mass of Displ. (tonnes)	M_{Disp}	2623

Figure 57 Approximate Amazon SaFerry Design Parameters.

The Finnish Markka ceased to be legal tender on 28th February 2002, but this method was actually developed in 1990, and therefore an inflation and conversion rate taken from sources online are as shown in Figure 58 below:

Currency conversion	
FIM (1990)	€ (in 2019)
1	0.27

Figure 58 FIM (1990) to Euro (2019) conversion rate taking inflation into account. [34]

The Nallikari-Nieminen estimation method consists of 10 equations taking the parameters above into consideration. Since our vessel is a Ro-Pax ferry, it is believed that the main costs and main design parameters are those related to: main dimensions; deadweight (DWT); volume of engine room, volume of cargo/pax space, and volume of accommodation. As such, out of the equations shown below, OKA1, OKA2, OKA8 and OKA10 are the best equations to describe an estimate cost of our vessel, as the variables are related to the most important design parameters in terms of cost.

Nallikari-Nieminen Cost Estimation Method			
		M (FIM)	Price (M€)
OKA1	114.4 + 0.00563 * L * B * h * Fn + 0.00661 * Aacm;	146	39.5
OKA2	83 + 0.00615 * L * B * h * Fn + 0.00661 * Aacm + 465 * Qual	140	37.8
OKA3	73.2 + 0.00802 * P * 1.2(n-1) + 0.00887 * Aacm + 402 * Qual	75	20.1
OKA4	-8.5 + 0.00696 * P * 1.2(n-1) + 0.00224 * Aacc + 536.6 * Qual + 0.00643 * (L*h)^1.36	57	15.3
OKA5	52.3 + 0.00687 * P * 1.2(n-1) + 0.00202 * DWT + 0.944 * Ncrew	42	11.5
OKA6	18.3 + 0.00745 * P * 1.2(n-1) + 0.00239 * DWT + 0.7 * Ncrew + 407.6 * Qual	22	5.9
OKA7	83.1 + 0.00462 * P * 1.2(n-1) + 0.000698 * L * B * h + 0.698 * Ncrew	87	23.6
OKA8	131.7 + 0.00861 * Veng + 0.000538 * Vcgo + 0.00466 * Vacm;	170	46.0
OKA9	7.9 + 0.00821 * P * 1.2^(n-1) + 0.00958 * Veng + 0.000652 * Vcgo + 0.00213 * Vacc	59	15.9
OKA10	0 + 0.00976 * Veng + 0.000576 * Vcgo + 0.00435 * Vacc - 1.1931 * EN	37	10.0
	Geo. Mean	74.4	20.1
	MAX	170	46.0
	MIN	22	5.9
	AVG	89	24.0
	OKA1, OKA2, OKA8, OKA10 AVG	123.4	33.3

Figure 59 Nallikari-Nieminen Cost Estimation for Amazon SaFerry.

As seen in Figure 59, using this method gives us a cost estimate of 33.3M€ - 46M€. These values come from the table above, but in short, equation 8 seems to be the best fitting in terms of variable usage and it is also the equation producing highest cost, which we called our upper margin. The average between the equations that were more closely related to our vessel type (OKA1, OKA2, OKA8 and OKA10) gives us our lower margin cost.

The issue with this cost estimate is that it is an European cost estimate. As our vessel is designed for inland waterways in Brazil, it is assumed that design of the vessel may be done in Finland, but actual construction of the ship may be undertaken in Brazil. As such, materials and labour costs will be drastically reduced and not taken into account in this method.

The following method attempts to bridge this gap between materials and labor costs in different areas:

9.1.2 NSFI/Levander Ship Building Cost Estimation Method

This method is a mix of Levander's ship building cost estimation method and the NSFI method of cost estimation. Levander's method provides coefficient values for certain ship equipment, parts and systems, and the SFI classification allows the team to allocate a certain unit to the classification group. [35]

To start this method, taking into account the cost and labor costs in Brazil, cost of average cost of A36 steel in Brazil was looked at from online sources and estimated to be around 782€ per tonne of the material. The team also looked at average working hours and rates in Brazil. Generally speaking, in Europe, it is estimated labor cost to be 60€ / hr. In Brazil however, this rate is much lower, and although it was estimated to be less than what the team has used as labor costs, the team decided to use 12€ / hr as labor rate to account for some Brazilian design and overhead costs.

Then, the team made an assumption of the cost of the chosen azimuth thrusters and estimated the cost of the engines, as seen in Figure 60. These parts are Finnish made and therefore costs were kept at Euros.

Max Input Power (kW)	RPM	Weight (tonnes)	Cost (EUR)	
2560	750-2000	24	3.5M	
			Estimate	Estimate
3700		33	1M	240€/kW
				240*3700 = 880000 ≈1M

Figure 60 Thrusters, engine and labour cost estimates.

Following from previous report, the SFI classification groups of our vessel were assigned units and unit values based on the design of the ship, general arrangement and mission as shown in Figure 61. The Price €/unit column shows either Levander's coefficient for that SFI group or the team's estimate of costs per unit. For example, Levander's coefficient for Group 2 – Hull is 1561, but the team has substituted that value for the average cost of material per tonne in Brazil in Euro.

NSFI/Levander Cost Estimate Method			Material		Labour				
NSFI Cost Group	**Unit**	Unit Value	Price (€/unit)	Price (M€)	h/unit	hours	€/hr	Price (M€)	Total (M€)
1- General Cost	LWT (ton)	2050	507.15	1.0396575	20	41000	12	0.492	1.5316575
2- Hull	Mass (tonnes)	900	782	0.7038	60	54000	12	0.648	1.3518
3 - Equipment for Cargo	Mass (tonnes)	1000	2500	2.5	30	30000	12	0.36	2.86
4 - Ship Equipment	Gross Volume (m^3)	8000	50	0.4	10	80000	12	0.96	1.36
5 - Equipment for Crew and passenger	Interior Area (m^2)	2000	2000	4	20	40000	12	0.48	4.48
6 - Machinery Main Components	Total Power (kW)	3700	240	0.888	8	29600	12	0.3552	1.2432
7 - Systems for Machinery Components	Engine Room Volume (m^3)	1100	500	0.55	8	8800	12	0.1056	0.6556
8 - Ship Systems	Gross Volume (m^3)	8000	25.36	0.20288	4	32000	12	0.384	0.58688
Total				10.2843375				3.7848	14.069138

	Price (M€)
Construction Costs	14.1
Design Costs	2
Interest of Capital 6%	0.6
Shipyard Profit 10%	1.7
Total Price	18.4

Figure 61 NSFI/Levander Cost Estimate Method for Amazon SaFerry. [35]

Using this method, the overall construction cost estimate of our vessel, taken into account Brazilian material and labour costs, comes down to 18.4M€.

Using the same method, but utilising the European estimate of 60€/hr of labour cost and material unit price of 1561 (as per Levander's method and close to price of tonne of A36 steel), the cost of the vessel is shown to be 35.8M€ (as shown in Figure 62), which is well within the range specified in Nallikari-Nieminen method above, which gives the team some confidence in the results.

NSFI/Levander Cost Estimate Method			Material		Labour				
NSFI Cost Group	**Unit**	Unit Value	Price (€/unit)	Price (M€)	h/unit	hours	€/hr	Price (M€)	Total (M€)
1- General Cost	LWT (ton)	2050	507.15	1.0396575	20	41000	60	2.46	3.4996575
2- Hull	Mass (tonnes)	900	1561	1.4049	60	54000	60	3.24	4.6449
3 - Equipment for Cargo	Mass (tonnes)	1000	2500	2.5	30	30000	60	1.8	4.3
4 - Ship Equipment	Gross Volume (m^3)	8000	50	0.4	10	80000	60	4.8	5.2
5 - Equipment for Crew and passenger	Interior Area (m^2)	2000	2000	4	20	40000	60	2.4	6.4
6 - Machinery Main Components	Total Power (kW)	3700	240	0.888	8	29600	60	1.776	2.664
7 - Systems for Machinery Components	Engine Room Volume (m^3)	1100	500	0.55	8	8800	60	0.528	1.078
8 - Ship Systems	Gross Volume (m^3)	8000	25.36	0.20288	4	32000	60	1.92	2.12288
Total				10.9854375				18.924	29.909438

	Price (M€)
Construction Costs	29.9
Design Costs	2
Interest of Capital 6%	0.7
Shipyard Profit 10%	3.3
Total Price	35.8

Figure 62 *NSFI/Levander Cost Estimate Method for Amazon SaFerry (European labour & material costs).* [35]

9.1.3 Ümran Bilen et al. January 2018 Ro-Pax Market Analysis

This study was aimed at optimization of vessel types that provide the most comprehensive application cases and concept design optimization, namely Ro-PAX vessels. This study concentrated on vessels made after the year 2000, and concentrated on vessels between 140m – 220m in length and only vessels owned by European owners. A total of 116 vessels were analyzed under these parameters, but only 68 had market prices and thus analyzed.

Out of these 68 ferries, the maximum and minimum building costs of this group were identified (Figure 63).

	Building Year	Length (m)	Beam (m)	Draught (m)	dwt (m)	cgt	PAX (no)	Power (kW)	Speed (kn)	Lanes (m)	Price (€)
Min.	2,000	142.6	24.2	5.9	2,900	21,467	600	18,888	14	750	35,360,679
Max.	2,017	215.1	31.5	7.3	10,670	49,332	3,160	67,200	32	4,076	230,000,000

Figure 63 *Max. And Min. Building costs identified in Ro-Pax group study. [36]*

It is worth highlighting that the 35.3M€ in the year 2000 corresponds to just under 50M€ in 2020 and 230M€ in 2017 corresponds to 240M€ in 2020 according to online sources (inflation calculators and the like).

Using the data from the Ro-Pax group, Ümran Bilen et al. carried out price vs. Ship particular analysis, which we have used to see where our vessel fits in, see Figure 64.

Figure 64 *Price € vs. DWT (t) of Ro-Pax group. [36]*

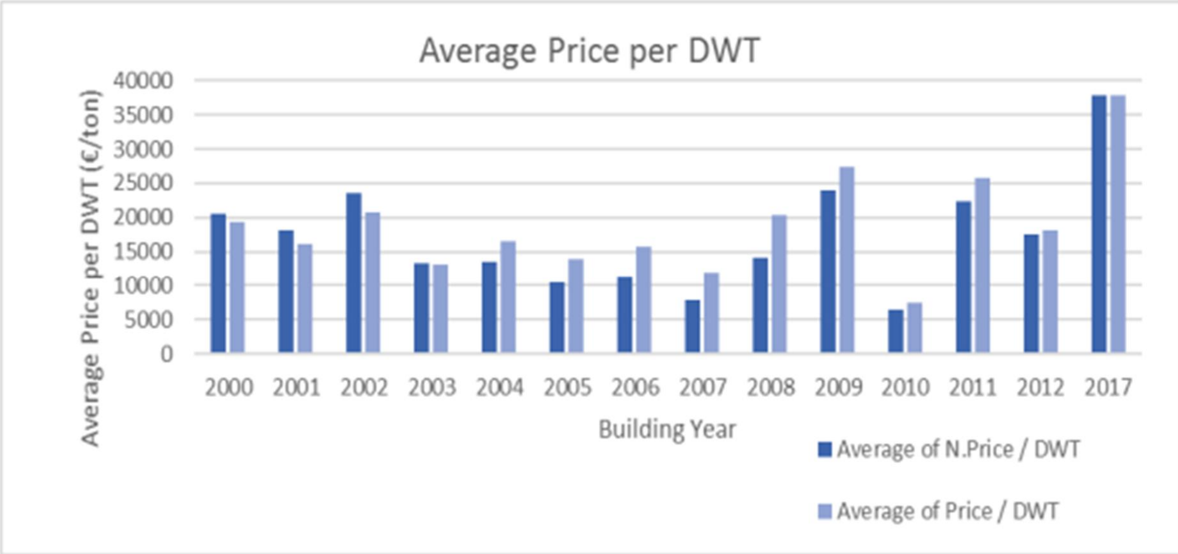


Figure 65 Average Price per DWT. [36]

As seen in Figure 65, the vessels analyzed had greater DWT (t) capacity than our vessel, however, it is possible to see that they were all generally just above or about 50M€, and with an R2 of 0.0109 it really becomes hard to draw definite conclusions of influences of DWT on new building prices as there is too much statistical insignificance.

Using the average price per DWT in 2017 though, a quick calculation would put our vessel in the 32M€ which is more in line with the calculations in sections 1.1 and 1.2. This may be because the 2017 data is more relevant than the year 2000 data for example, where inflation is taken into account.

Figure 66 Market Price € vs. Power (kW). [36]

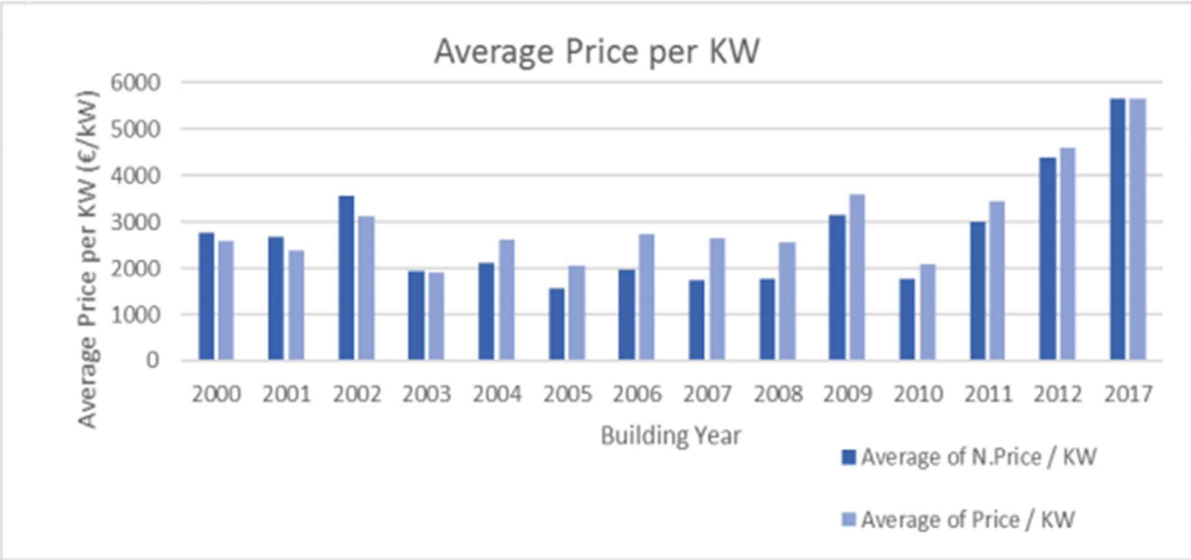


Figure 67 Average Price per kW. [36]

Here so interpolation is required to identify where our vessel would be in relation to the others in this group. Our vessel's power is rated at 3700 kW and would therefore be close to the 50M€ mark, which is an acceptable estimate based on results obtained using the different methods in sections 1.1 and 1.2.

Using the average price per kW in 2017 though, a quick calculation would put our vessel in the 22M€ which is more in line with the calculations in sections 1.1 and 1.2. This may be because the 2017 data is more relevant than the year 2000 data for example, where inflation is taken into account.

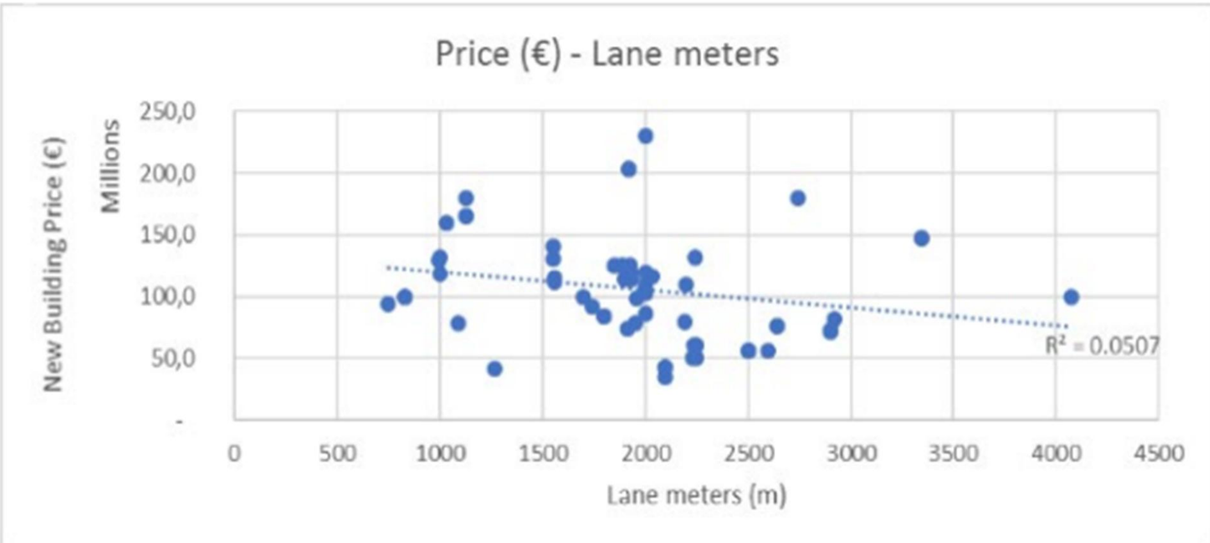


Figure 68 Market Price vs. Lane Meters. [36]

Figure 69 Average Price per Lane Meter. [36]

Again some interpolation is required, but as our vessel was designed to have 240 lane meters, it can be concluded that the market price of such ferry would be (following the pattern above) well above the 100M€, and this is not deemed to be quite accurate and again it may be very difficult to draw reasonable conclusions on price market based on lane meters of vessels in this study, as there is again, there is a lack in statistical significance with a R2 value so low.

Using the average price per lane meter in 2017 though, a quick calculation would put our vessel in the 28M€ which is more in line with the calculations in sections 1.1 and 1.2. This may be because the 2017 data is more relevant than the year 2000 data for example, where inflation is taken into account.

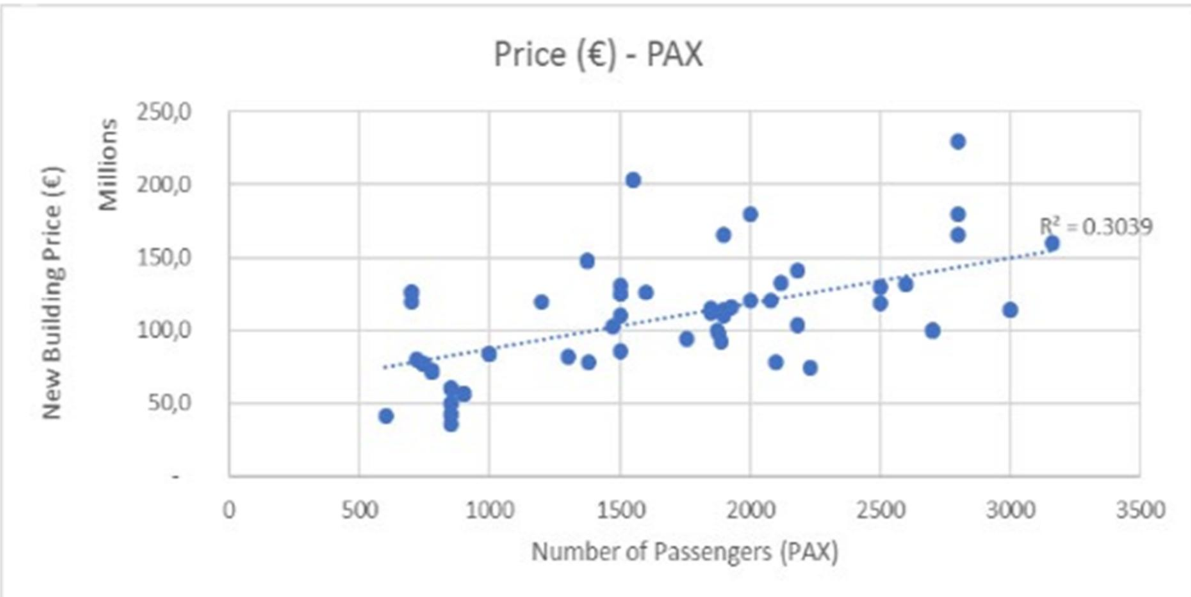


Figure 70 Market Price vs. PAX capacity. [36]

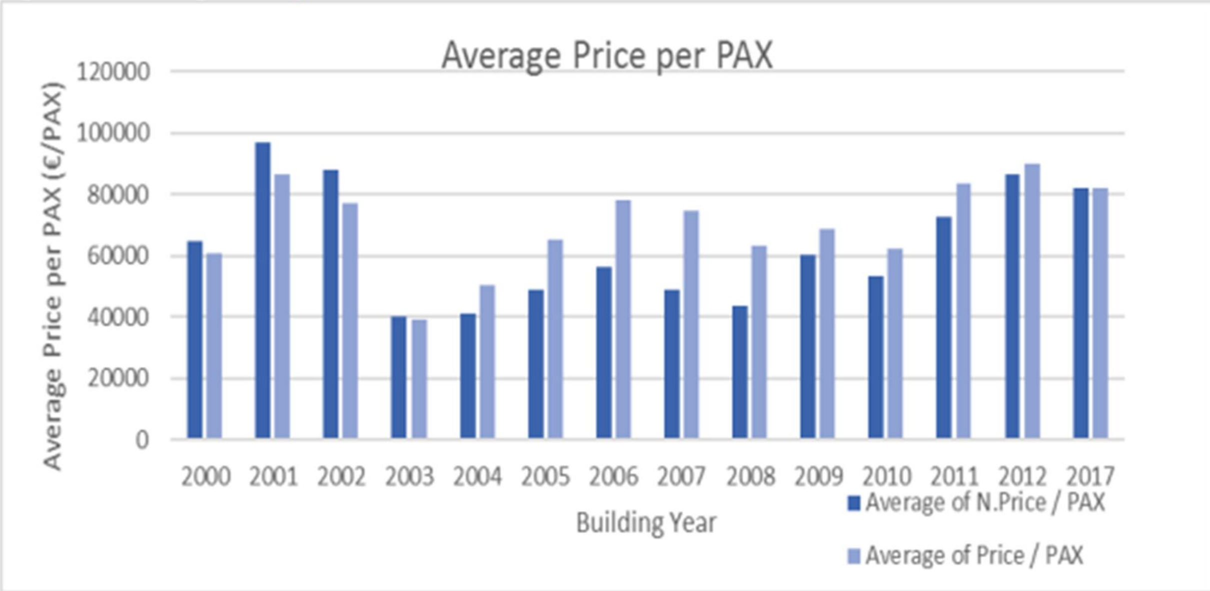


Figure 71 Average price per PAX. [36]

Here, it is possible to interpolate the data once again for our vessel, which was designed for 400 passengers, indicating once again that the price market would be just above the 50M€ mark. The statistical variation is still too great and may be still be difficult to confirm this market price.

Using the average price per PAX in 2017 though, a quick calculation would put our vessel in the 40M€ which is more in line with the calculations in sections 1.1 and 1.2. This may be because the 2017 data is more relevant than the year 2000 data for example, where inflation is taken into account.

9.1.4 Market Price Estimates

Method	Final Price Estimate (M€)	Final Price Estimate (M R$)
Nallikari-Nieminen (max)	46.0	285
NSFI/Levander (Brazilian cost)	18.4	115
NSFI/Levander (European Cost)	36	223
Ro-Pax Market Analysis		
Average Price per DWT	33	204
Average Price per kW	23	145
Average Price per PAX	41	257
AVG (Brazilian Price)	18.4	115
AVG (European Price)	35.8	223

Figure 72 Market Price Estimates from methods discussed.

As seen in Figure 72, from the methods used, it is estimated that our vessel, if built in Brazil under the cost references of Brazilian standards, would cost around 18M€, whereas if built entirely in Finland for example, we would be looking at a vessel that costs around 36M€.

9.2 Economic Key Performance Indicator Analysis

The economic performance of the design is analyzed based on calculated ship cost of 18M€ and Brazilian standard as the ferry is known to be competing in Brazilian market. Analysis of annual income is presented in Table 28. The amount of passengers and cars is based on design targets and occupancy is estimated based on demand on operating route. Ticket prices are compared to market prices currently available on the route.

Table 28 Calculated annual income based on estimated revenue.

Number of pax	500
Occupancy	80 %
Ticket price without taxes	25,00 €
Cabins	40
Occupancy	80 %
Ticket price without taxes	20,00 €
Cars	40
Occupancy	80 %
Ticket price without taxes	20,00 €
Average income per trip (Manaus-Tefe)	11 280,00 €
Annual number of journeys	200
Annual average pax income	2 256 000,00 €
Income from service	480 000,00 €
Total annual income	2 736 000,00 €

Annual operating costs are divided to operation, voyage, cargo handling and capital costs as per Table 29. The manning costs are based on 20 crew members year around operation and Brazilian salary level. Fuel oil consumption has been estimated by using consumption values calculated in assignment 8 and MDO price of 0,5€/l (without taxes and tariffs). Other costs are estimated based on general distribution of costs in same type of vessels.

Table 29 Annual operation costs

Annual operation costs

Mannig costs	80 000 €
Stores and lubricants	26 667 €
Repairs and maintenance	30 476 €
Insurance	22 857 €
General costs	30 476 €
Periodic maintenance	9 524 €

Annual voyage costs

Fuel oil	224 000 €
Port costs	10 000 €
Canal duties	10 000 €

Annual cargo handling costs	50 000 €

Annual capital costs

Interest	50 000 €
Debt reayment	50 000 €

Total annual running costs	594 000 €

In the assessment of economic feasibility, following formulas have been used:

Net present value: $$NPV = -C_0 + \sum_{i=1}^{n} \frac{C_i}{(1+r)^i} \quad (52)$$

Required freight rate (pax): $$RFR = \left[P \frac{r(1+r)^n}{(1+r)^n - 1} + A\right] / C \quad (53)$$

The economic KPIs based on 30 years economic life of ship and required interest rate of 6% are calculated in Table 30 and Appendix 4.

Table 30 Economic KPIs for Amazona SaFerry.

Initial investment	18 000 000	€
Annual running costs	594 000	€
Annual revenue	2 736 000	€
Annual profit	2 142 000	€
Interest rate	6,0 %	
Economic life of ship	30	a
Economic KPI		
Payback period	8,4	a
RFR	24	€/pax
NPV after 30 years	11 484 268	€

Even though the lowest estimate for ship price, 18M€, is used in the calculation, the payback period is extending up to 8.4 years. The required freight rate (RFR) is calculated as €/passenger and is in reasonable level considering the ticket and customer service presented in Table 28. The NPV for 30 years of operation is positive but taking into account the low interest rate and high initial investment it could be higher.

9.2.1 Improving economic KPIs

The economic performance KPIs can be improved basically by:

- Lowering investment cost (ship price)
- Reducing operating costs (fuel costs, crew, maintenance)
- Improving operating efficiency (cargo density)
- Increasing operating profit

In total investment, the optimization of shipbuilding costs plays a significant role. The building costs can be minimized with tendering of shipyards and selecting low cost country where to built the vessel.

The vessel operating costs have tried to be minimized by choosing energy efficient propulsion system and reducing amount of crew with automation. With good maintenance practices and care the economic operating years of the vessel can be extended up to 30 years.

In the design of general arrangement, the cargo density has tried to be optimized and waste space reduced to minimum. The deadweight-displacement ratio of the vessel is large. Also spaces for customer experience have been added with bar and restaurant to provide extra sales.

Ticket prices are dependent on market competition. However, the luxury level and services of the ferry might enable to operate with slightly higher prices than the competitors. It is also to be noted that current vessels operating in the route Manaus-Tefe are old and new vessel would certainly arouse interest of the customers.

9.3 SWOT Analysis

As our mission is to build safe and efficient Ferry from Manaus to Tefe we need to have great handling and controlling characteristics and stable ship with efficient engines and low water resistance and large enough deadweight. These targets have been tried to achieve with Azimuth thrusters, having reliable and modern Wärtsilä Engines as Diesel generators, bulbous bow to reduce water resistance, bow thrusters and modern ship architecture to ensure that ship is still up to date even after 20 years of service.

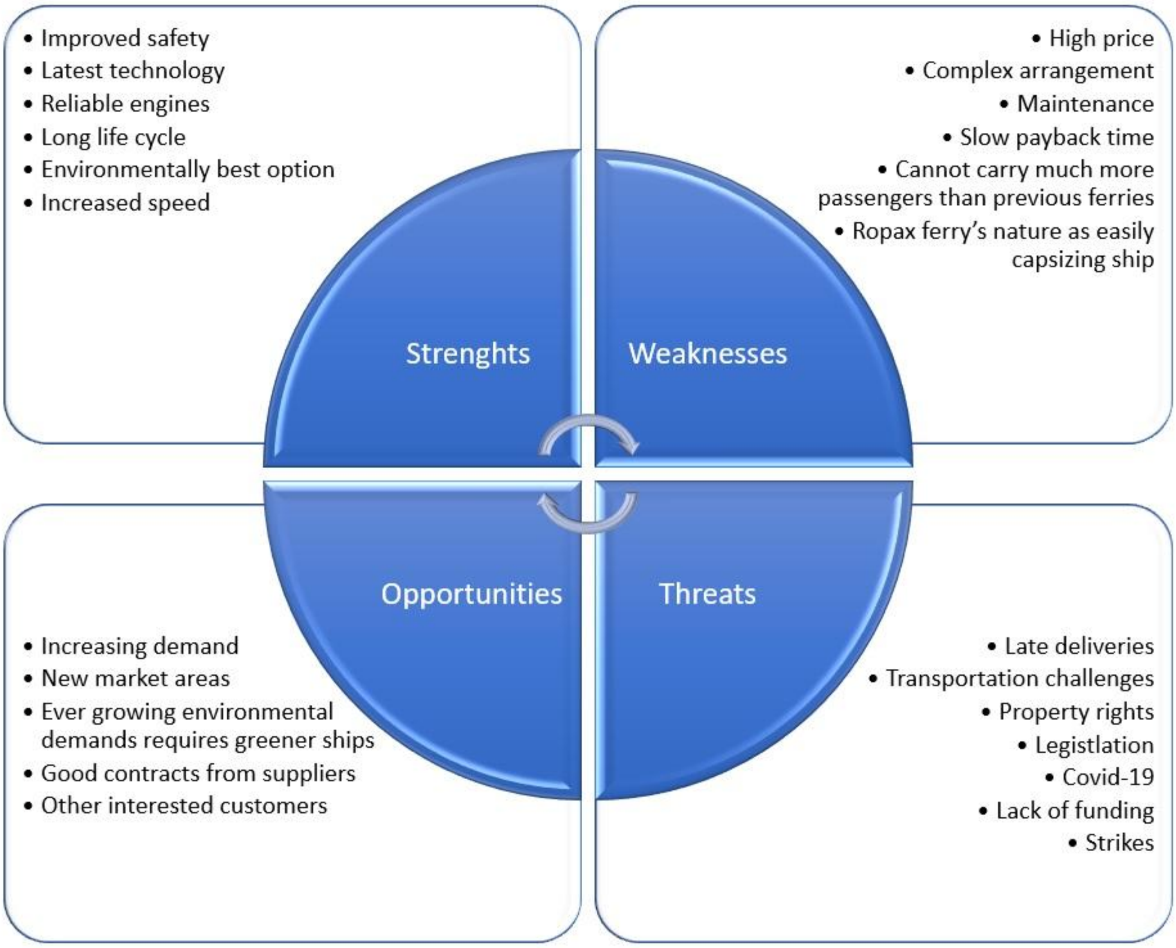


Figure 73 SWOT-analysis of Amazona SaFerry.

Based on SWOT analysis (Figure 73), high price of our ship is definitely most notable weakness of the first round of ship design spiral and our concept design. It needs to be compensated by choosing manufacturing yards in Brazil which on the other hand is very suitable for our ship as it is supposed to do journeys from Manaus to Tefe. Questions arise that is Brazilian shipyards capable to manufacture our high technology Ropax ferry but this is risk which will be needed to take to get unit cost to be on a level that this project is desirable to implement further.

Also as Ropax ferries have nature that they are relatively unstable ships we wanted to address that problem by adding azimuth thrusters, bow thrusters and with bilge keels. Naturally as the price for the ship will be relatively high we wanted the ship to have very long lifecycle so Wärtsilä engines with large displacement per cylinder were good choices for gensets so reliability issues with machinery would not be that large problem. This also eases maintenance which still requires well-trained mechanics and engineers as usual ferries sailing on Amazon are not as advanced than Amazona SaFerry.

But making this ferry modern and high-tech ferry this is also opportunity as if Amazona SaFerry is successful, this concept could gain interest in other parts of the world too. For example, new ferries which would travel on lake Nile, India, Argentina, Paraguay or China could have similar demands and targets. Besides those, as Brazil is one of the most rapidly growing economies in the world it is possible that demand to travel with this ferry would increase and more passengers will use the ferry which would mean more paying customers. That could also lead more orders of the ferry for the same route. Producing more than one ship would lead better deals with suppliers and reduce unit cost so profits would be higher per contract.

Threats to this project could be late deliveries as current Covid-19 situation all over the world is what it is so it potentially could delay deliveries from suppliers, design- or manufacturing process could freeze and then late deliveries would decrease contract price or even worse could be affecting that customer are not required to accept ship if it is too late. Also because of Covid-19 situation ship travelling is in decrease and as we don't know how long it continues it will throw some shades around this project as we cannot be sure how economy and ship industry and travelling react to aftermath of this pandemic.

Legislation could also be one threat as if there is some mistake calculations or design failures that would not enable ship to be qualified and deemed to be safe by qualification society it would delay deliveries or even worse fully overthrow the ship project. This could be avoided by careful design and iterating design as much as it is needed and fixing problems some issues would be found which could prevent qualifications. That's why conducting own tests, calculations and simulations is necessary to proof seaworthiness of the vessel before qualification society will inspect it.

Overall Amazona SaFerry is project which has great potential to make profit and also as environmental issues and safety of ferries sailing on lakes, seas and rivers are important Amazona SaFerry is also in that aspect great concept for ship operators to consider.

REFERENCES

[1] T. Lamb, Ship design and construction, Jersey City: Society of Naval Architects and Marine Engineers, 2003.

[2] [Online]. Available: http://transportebare.blogspot.com/2019/03/navegacao-reis-monteiro-fb-m-monteiro-ii.html.

[3] [Online]. Available: http://www.imo.org/en/OurWork/Safety/Regulations/Documents/RORO.pdf.

[4] [Online]. Available: https://www.marineinsight.com/naval-architecture/ro-ro-ship-design-dangers/ .

[5] [Online]. Available: https://www.marineinsight.com/marine-safety/8-reasons-that-make-ro-ro-ship-unsafe-to-work-on.

[6] [Online]. Available: https://www.delta.tudelft.nl/article/could-airbags-prevent-damaged-ships-capsizing.

[7] [Online]. Available: https://rmcfinland.fi/the-keel-of-wasalines-new-ferry-was-laid-at-rauma-shipyard/.

[8] [Online]. Available: https://www.bmt.org/news/2019/new-85m-ro-pax-cat/.

[9] [Online]. Available: https://products.damen.com/en/ranges/ropax-ferry/drpa-6716.

[10] [Online]. Available: https://www.vesselfinder.com/vessels/JADRAN-IMO-9559119-MMSI-238991940.

[11] [Online]. Available: https://m.facebook.com/Ferryboat.leaodejuda5/?__tn__=C-R.

[12] S. Cheirdaris, "MEC-E1004 Principles of Naval Architecture, Lecture notes," 2020.

[13] M. Haase, "On the macro hydrodynamic design of highly efficient medium-speed catamarans with minimum resistance.," *International Journal of Maritime Engineering,* 2012.

[14] A. Papanikoulau, Ship Design: Methodologies of Preliminary Design, Springer, 2014.

[15] Guldhammer-Harvard, Ship Resistance, 1974 .

[16] "IMO Publications and Documents - International Conventions - SOLAS - International Convention for the Safety of Life at Sea - Chapter II-2 - Construction - Fire protection, fire detection and fire extinction - Regulation 9 - Containment of fire".

[17] "Lloyd's Register Rules and Regulations - Rules and Regulations for the Classification of Naval Ships, January 2018,incorporating Notice No. 1, 2, 3, 4, 5 & 6 - Volume 1 Ship Structures - Part 3 Design Principles and Constructional Arrangements - Chapter 2".

[18] "Lloyd's Register Rules and Regulations - Rules and Regulations for the Classification of Ships, July 2018 - Part 4 Ship Structures (Ship Types) - Chapter 1 General Cargo Ships - Section 8 Double bottom structure".

[19] "Statutory Documents - IMO Publications and Documents - International Conventions - Load Lines, 1966/1988 - International Convention on Load Lines, 1966, as Amended by the Protocol of 1988 - Annex I - Regulations for Determining Load Lines - Chapter III -".

[20] "Statutory Documents - IMO Publications and Documents - International Conventions - Load Lines, 1966/1988 - International Convention on Load Lines, 1966, as Amended by the Protocol of 1988 - Annex I - Regulations for Determining Load Lines - Chapter I - Ge".

[21] [Online]. Available: https://www.wartsila.com/marine/build/engines-and-generating-sets/generating-sets/wartsila-gensets.

[22] Preliminary Technical specification - Kongsberg Azimuth Thruster US 155S P14 PM FP.

[23] Lloyd's Register Rules and Regulations - Rules and Regulations for the Classification of Ships, July 2018 - Part 3 Ship Structures (General) - Chapter 4 Longitudinal Strength - Section 5 Hull bending strength.

[24] Lloyd's Register Rules and Regulations - Rules and Regulations for the Classification of Ships, July 2018 - Part 3 Ship Structures (General) - Chapter 2 Materials - Section 1 Materials of construction.

[25] Lloyd's Register Rules and Regulations - Rules and Regulations for the Classification of Ships, July 2018 - Part 3 Ship Structures (General) - Chapter 4 Longitudinal Strength - Section 6 Hull shear strength.

[26] Lloyd's Register Rules and Regulations - Rules and Regulations for the Classification of Ships, July 2018 - Part 3 Ship Structures (General) - Chapter 4 Longitudinal Strength - Section 7 Hull buckling strength.

[27] [Online]. Available: https://www.ssab.fi/tuotteet/brandit/ssab-multisteel/ssab-multisteel-hs.

[28] [Online]. Available: https://www.alumeco.fi/alumiini/levyt/valssatut-ja-valetut/en-aw-5083/8-x-1020-x-2020-mm/p/394/4284.

[29] H. J. Mennen G.G.J., "A statistical power prediction method," *International Shipbuilding Progress,* vol. Vol.25, 1978.

[30] [Online]. Available: https://www.wartsila.com/marine/build/engines-and-generating-sets/diesel-engines/wartsila-20.

[31] [Online]. Available: https://www.wartsila.com/docs/default-source/product-files/hybrid/wartsila-hy-2018.pdf.

[32] [Online]. Available: https://www.kongsberg.com/maritime/products/propulsors-and-propulsionsystems/thrusters/tunnel-thrusters/standard-tunnel-thruster/#services.

[33] M. &. N. J. Nallikari, Tutkimus laivan omakustannusarvoon vaikuttavista laivateknisistä tekijöistä, TKK, 1990.

[34] ""Value of 2017 Euro Today." Value of 2017 Euro Today - Inflation Calculator," [Online]. Available: www.inflationtool.com/euro/2017-to-present-value?amount=230000000..

[35] K. Levander, "Passenger Ships. Ship Design and Construction," *Society of Naval Architects and Marine Engineers* , vol. 2, 2004.

[36] Ü. e. a. Bilen, "Holistic Optimisation of Ship Design and Operation for Life Cycle D 1.1 Market Analysis.," HOLISHIP, European Union, January 2018. [Online]. Available: ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5b85b131d &appId=PPGMS..

LIST OF APPENDICES

Appendix 1 - Ro-Pax ferry comparison table

Appendix 2 – Amazona SaFerry General Arrangement

Appendix 3 - Amazona SaFerry Midship Section

Appendix 4 - Amazona SaFerry Machinery Arrangement

Appendix 5 - Economic KPIs for Amazona SaFerry

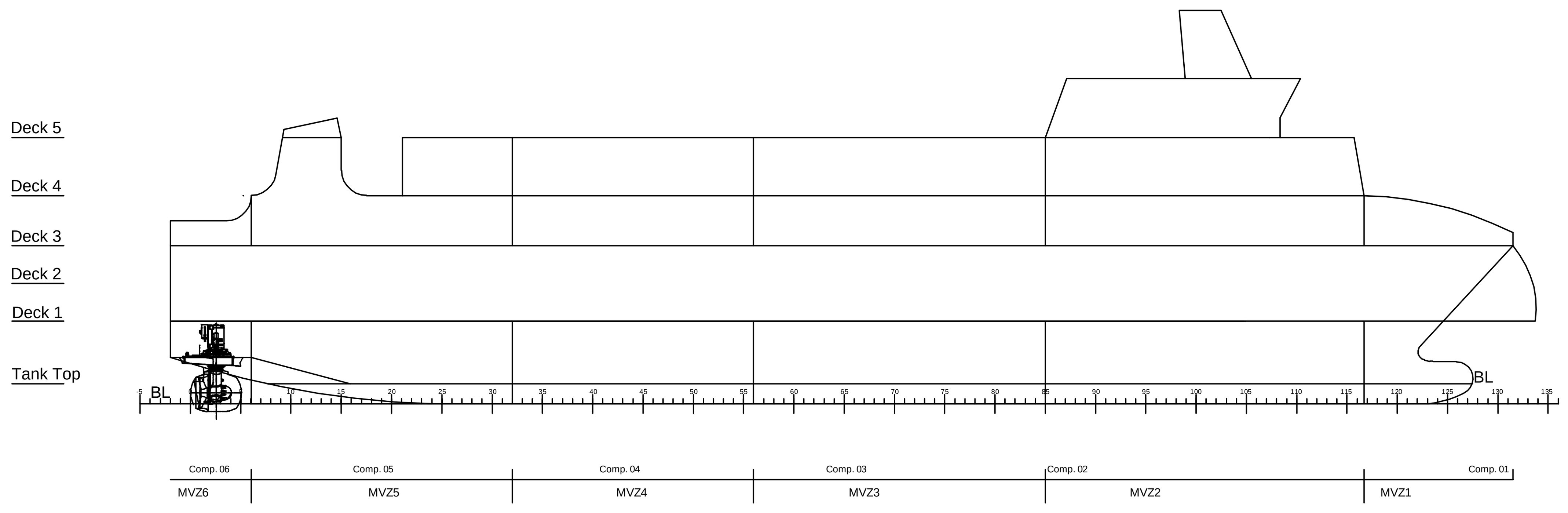
Appendix 1 - Ro-Pax ferry comparison table

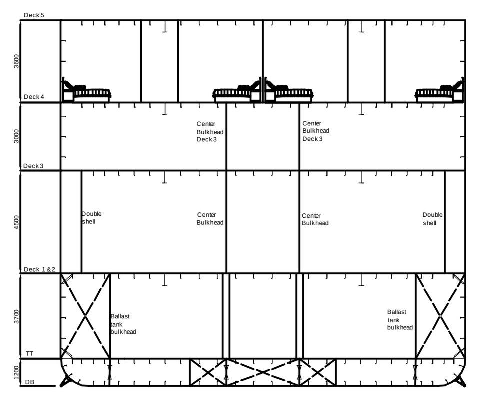
Name of the vessel	Length (m)	Breadth (m)	Draft (m)	Depth (m)	Speed (kn)	Passengers (kpl)	Lane meters (m)	Machinery (kW)	Propellers (kpl)	Dead weight (ton)	Fn	CB	L/D	L/B
DAMEN ROPAX 6616	65,6	16,6	2,6	5,1	12,7	*590*	*Unkown*	*1710*	2	unavailable	0,258		12,9	4,0
Aurora Botnia	150	26,00	6,1		20	*800/1000*	*1500*		2	3500	0,268		-	5,8
MV Alfred	85				16	430		4x749	2	550	0,285		-	-
mv jadran	87	17			13	1200		2148		3193	0,229		-	5,1
Leo de Juda V	66	22			11,4						0,230		-	3,0
Average	90,7	20,4	4,35		14,62	740				2414	0,254			4,5

Name of the vessel	Year of manufacture	Flag	Source
DAMEN ROPAX 6616	2021	TBD	https://products.damen.com/-/media/Products/Images/Clusters-groups/Ferries/Passenger-Car-Ferry/RoPax-Ferry/DRPa-6616/Documents/Damen_RoPax_Ferry_6616_YN234776_DS.pdf
Aurora Botnia	2021	Finland	https://deltamarin.com/references/aurora-botnia-lng-fuelled-ferry/
MV Alfred	2019	UK EURO 'B'	https://www.bmt.org/projects/project/2646/85m-passenger-ferry
mv jadran	2010	Croatia [HR]	https://en.wikipedia.org/wiki/MV_Jadran
Leo de Juda V		Brazil	https://www.fleetmon.com/vessels/leao-de-juda-v_0_2366958/

Appendix 2 – Amazona SaFerry General Arrangement

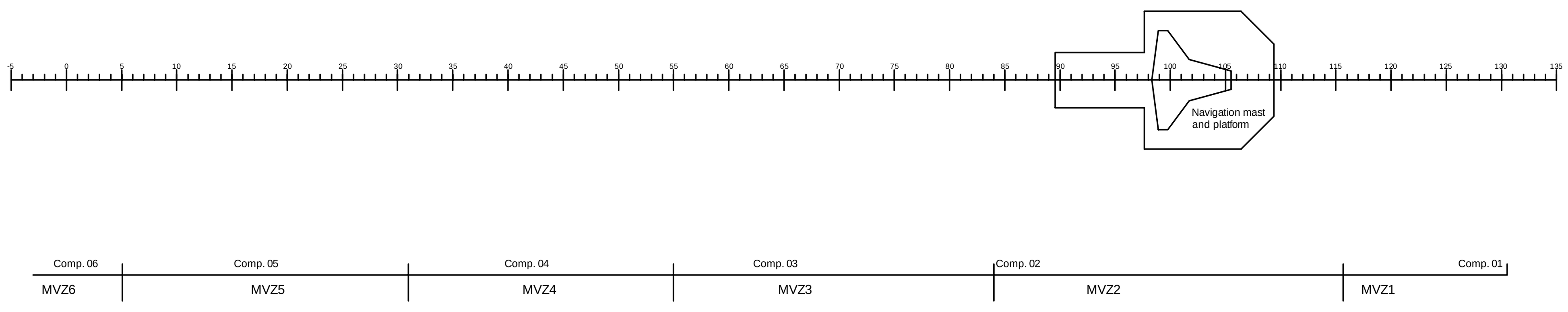
Profile View



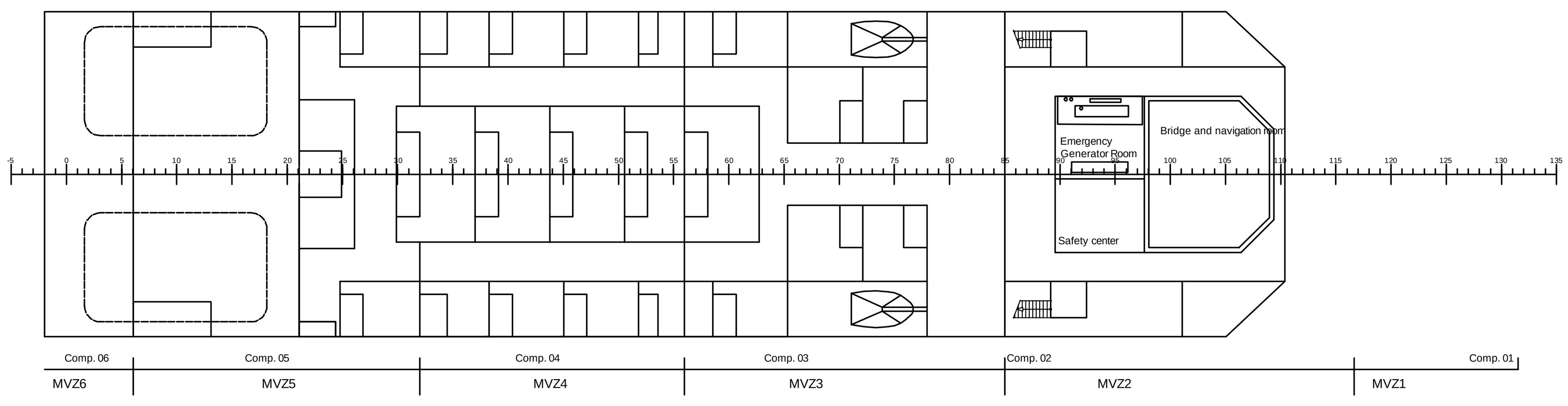


Mid Ship Section #65

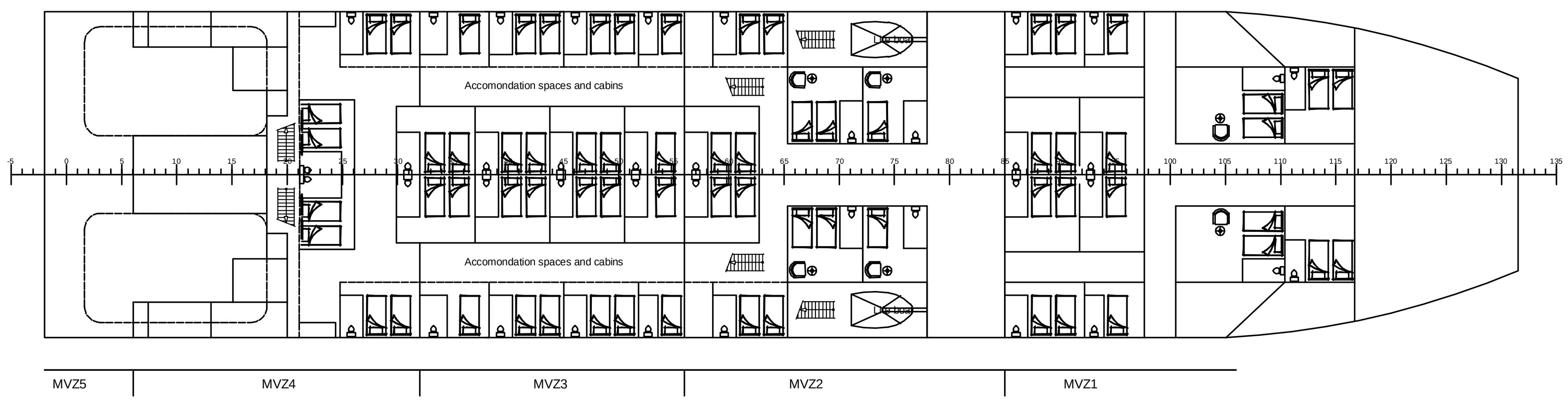
Top Deck



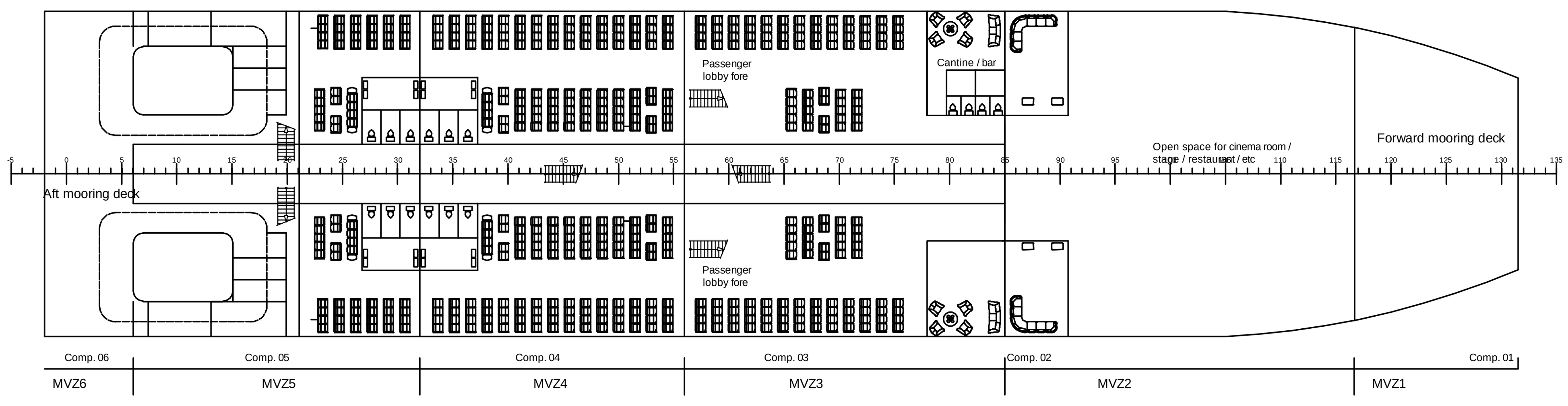
Deck 5 (Bridge Deck)



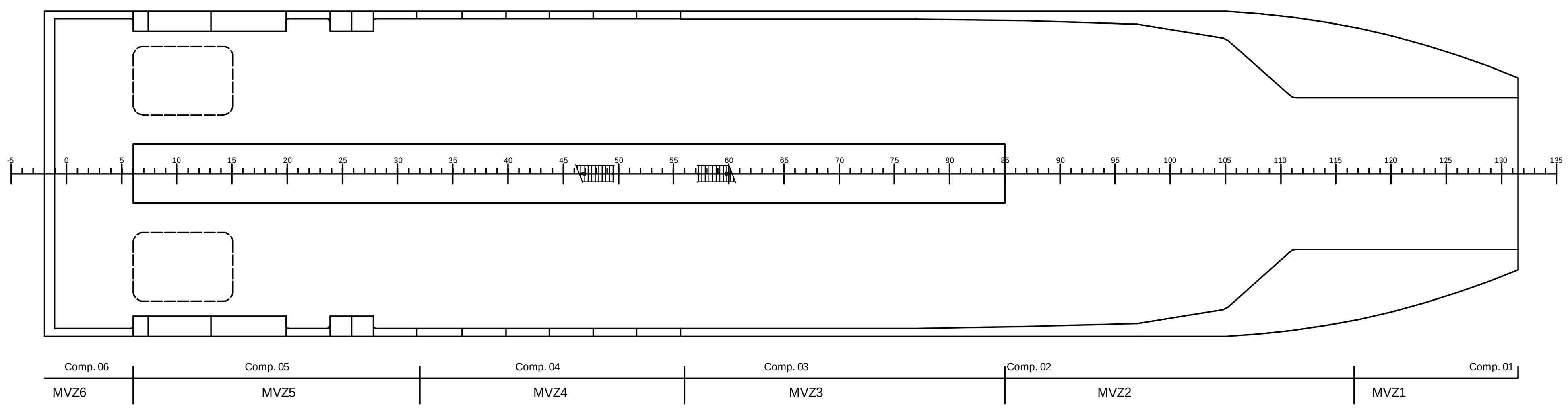
Deck 4 (Accomodation Deck)



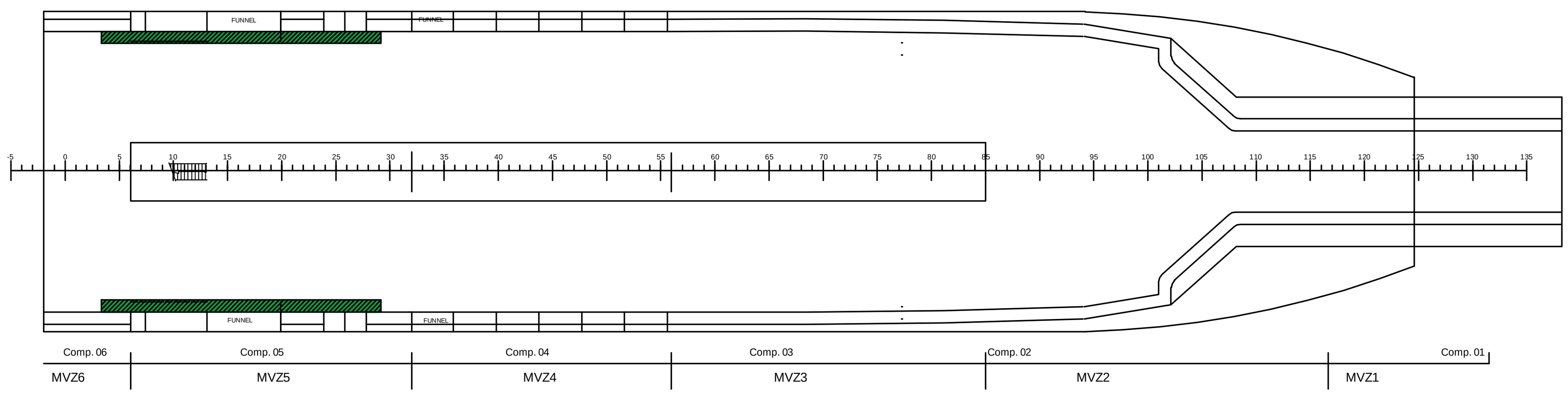
Deck 3 (Passenger Deck)



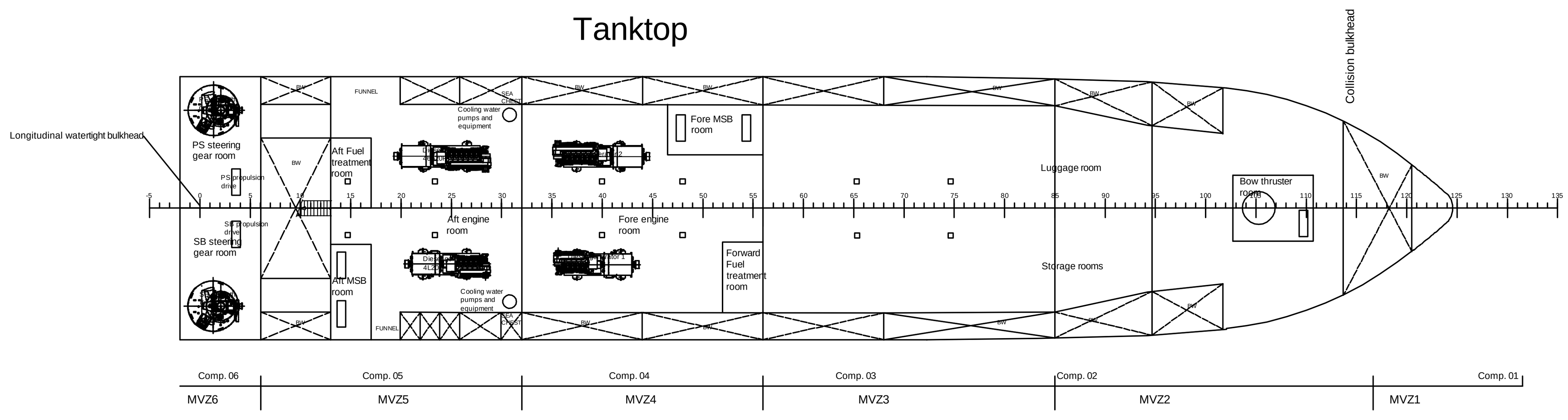
Deck 2 (Upper Ro-Ro Deck)



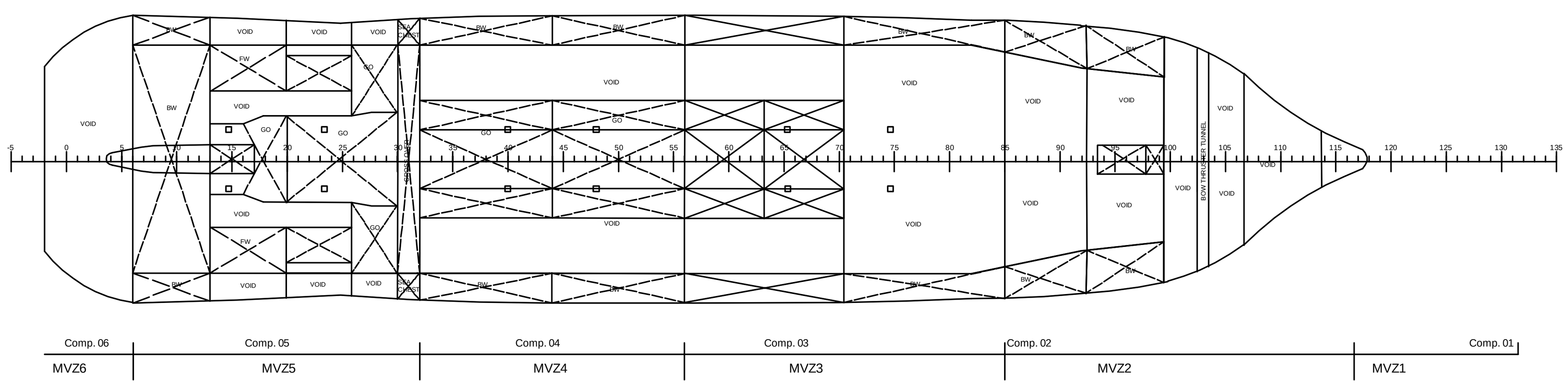
Deck 1 (Lower Ro-Ro Deck)



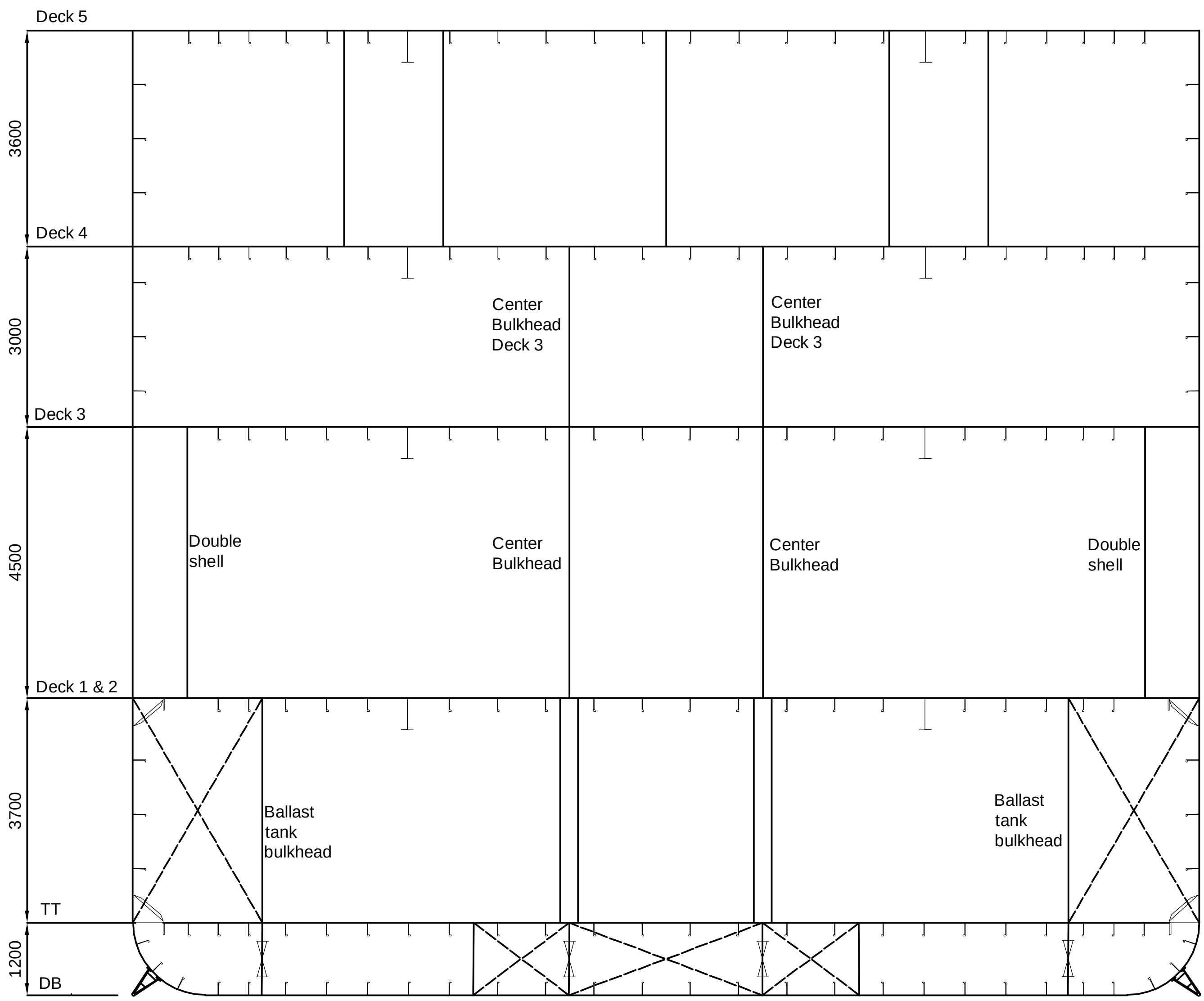
Tanktop



Double bottom



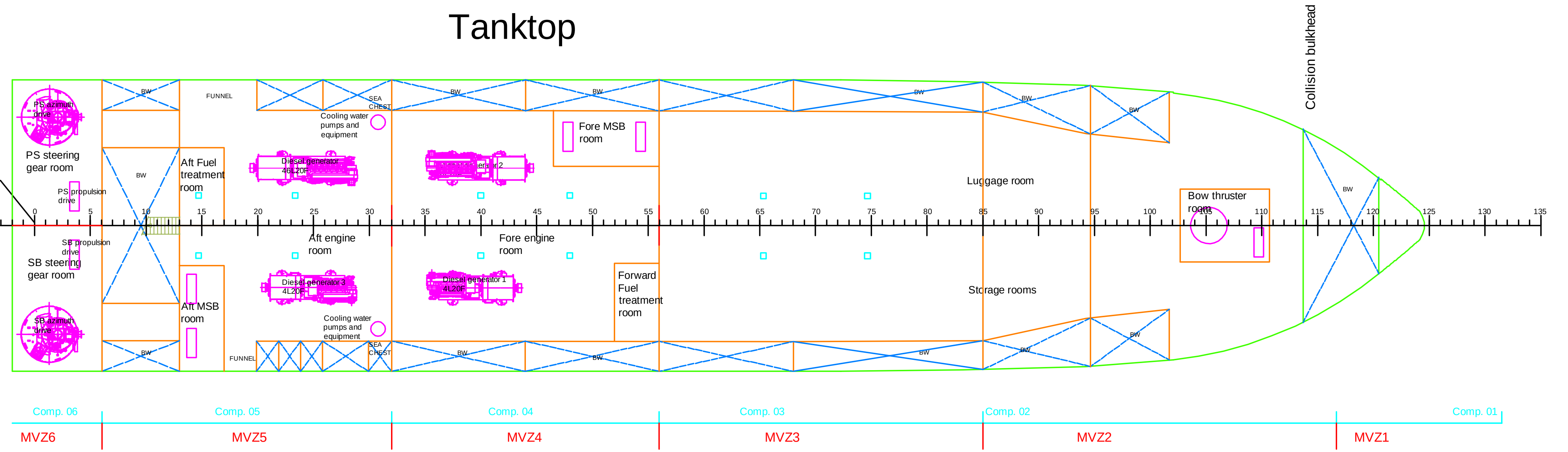
Appendix 3 - Amazona SaFerry Midship Section



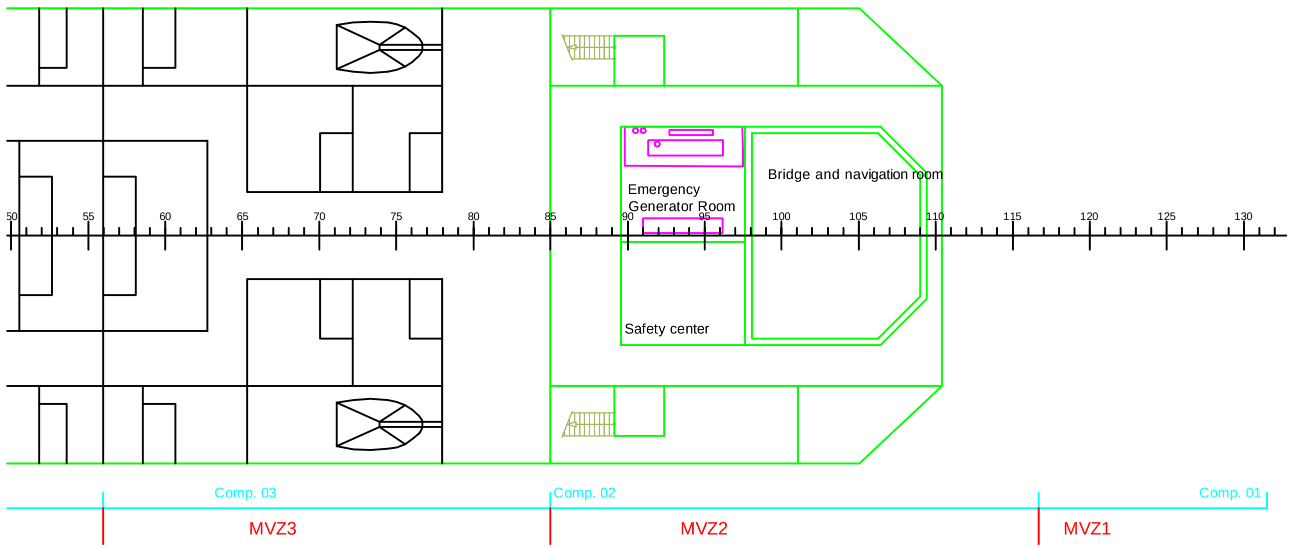
Mid Ship Section #65

Appendix 4 - Amazona SaFerry Machinery Arrangement

Tanktop



Deck 5 (Bridge Deck)



Appendix 5 – Economic KPIs for Amazona SaFerry

Initial investment	18 000 000	€
Annual running costs	594 000	€
Annual revenue	2 736 000	€
Annual profit	2 142 000	€
Interest rate	6,0 %	
Economic life of ship	30	a
Economic KPI		
Payback period	8,4	a
RFR	24	€/pax
NPV after 30 years	11 484 268	€

Year	NPV, annual cash flow	NPV
0	-18 000 000 €	-18 000 000 €
1	2 020 755 €	-15 979 245 €
2	1 906 372 €	-14 072 873 €
3	1 798 465 €	-12 274 408 €
4	1 696 665 €	-10 577 744 €
5	1 600 627 €	-8 977 117 €
6	1 510 025 €	-7 467 091 €
7	1 424 552 €	-6 042 539 €
8	1 343 917 €	-4 698 622 €
9	1 267 847 €	-3 430 775 €
10	1 196 082 €	-2 234 694 €
11	1 128 379 €	-1 106 315 €
12	1 064 508 €	-41 806 €
13	1 004 253 €	962 447 €
14	947 409 €	1 909 856 €
15	893 782 €	2 803 637 €
16	843 190 €	3 646 828 €
17	795 463 €	4 442 290 €
18	750 436 €	5 192 727 €
19	707 959 €	5 900 686 €
20	667 886 €	6 568 571 €
21	630 081 €	7 198 652 €
22	594 416 €	7 793 068 €
23	560 770 €	8 353 838 €
24	529 028 €	8 882 866 €
25	499 083 €	9 381 949 €
26	470 833 €	9 852 782 €
27	444 182 €	10 296 964 €
28	419 040 €	10 716 004 €
29	395 321 €	11 111 324 €
30	372 944 €	11 484 268 €