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MEC-E1004 Principles of Naval Architecture

Saimaa Hybrid

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Abstract

This project aims to introduce a novel, zero-emission and futuristic inland waterway vessel to the marine world. The vessel can carry both cargo and passengers to meet the highly fluctuating market demand throughout the year. The vessel was designed with a modular superstructure that can be mounted on the main deck in summer season when the passenger demand is high. While in winter and autumn seasons the superstructure will be removed to allow more payload (timber/general cargo). The proposed design considered only the preliminary design stage and can be regarded as a key step towards the detailed design stage. The vessel iterative design follows the well-known ship design spiral. It commenced with defining the mission requirements and culminated in full preliminary description of main particulars, midship and engine room section, scantling, weight estimation, intact stability analysis and finally economical investigation of the validity of this design.

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Team members

Ahmed Yosri Hassan

I obtained my B.Sc. and M.Sc. degree in Naval Architecture and Marine Engineering from the Faculty of Engineering, Alexandria University, Egypt, in 2016, 2020. After graduation, I have worked with different local marine companies in Egypt, before getting my tenured position as a Teaching Assistant and Researcher at the Naval Architecture Department, Faculty of Engineering, Alexandria University. I have designed different marine units from scratch and made their stability booklet. Currently, besides being a master's degree student at Aalto University, I am working as a free-lancer with two multinational companies DB Schenker and Swiss logistics consulting (marine sectors).

Jonas Korpela

I am a first-year master's student in naval architecture in Aalto University. I obtained my B.Sc. degree in Mechanical Engineering last spring in Aalto University. On my bachelor's thesis I focused on current and future passenger ship design from end user's perspective. This gave me more insights about the whole ship building process, the phases that it includes and the requirements that the customer and the end user may have. I have worked at Meyer Turku shipyard for last three summers in Sales & Design and Naval Architecture departments, so I have some base knowledge about concept design and the whole ship design process from there too. Considering this course project, my strongest asset is probably using of AutoCAD and GA-design.

Akseli Kjellberg

I am a first-year master student in Aalto University, but I am doing my bachelors thesis this autumn. I have studied three years of mechanical engineering at Aalto University and I have been working for two summers for a ship design company. I have experience in machinery design but also some in concept development. I am quite familiar with AutoCAD. My experience will be utilized especially when discussing machinery and equipment.

Oskar Vainionpää

I obtained my B.Sc. degree in Mechanical Engineering last spring here in Aalto University. My Bachelor's thesis focused on the effects of slow steaming in cargo shipping, from machinery to global operational level. With the research I established more in-depth understanding of the maritime sector, which provides an excellent starting point for M.Sc. Studies in Naval Architecture. In work life I have become familiar with different kind of pneumatic machines. This previous experience with machines paired up with the B.Sc. level studies in mechanical engineering and a positive attitude towards maritime sector, can be a great asset for this project.

Li Chen

I work as a project planner for ALMACO Group, being responsible for the planning and scheduling of the company's working scope for a cruise ship manufactured in shipyards in Germany. The working scope includes steel outfitting and accommodation interior installation. I also participate in preparing the project proposal for winning contract for the galley and accommodation working scope in a cruise ship manufactured in China. Earlier, all my working experience are related to project implementation, so I guess I should deepen my knowledge in project management and further my learning in ship design and building industry, hoping to continue on this path when the market becomes a bit warmer.

For this course assignment, I would focus on the economic assessment of the designed vessel and apply the theory and knowledge from the course material and books to the case ferry, so all of us can learn in an efficient way through the collaboration.

Team members' contribution

Each team member has a vital role and constructive impact on the design of Saimaa Hybrid vessel. Ahmed was responsible for example on the Maxsurf analysis, 3D modelling and scantling; Jonas, Akseli and Oskar were responsible for example on the AutoCAD drawings and the economic part while Li was the reporter. The team collaborated equally in the other various remaining parts of this project and often roles were switched between different assignments.

1. Introduction

1.1. Mission requirements

The vessel is intended to operate in Saimaa lake and Canal. Regular route of the vessel is Lappeenranta – Vyborg. The vessel is designed to carry passengers and cargo on the same time, or only cargo depending on the traffic of passengers and cargo. The design aims to have a sustainable vessel that has zero emissions and meets eight sustainable goals (SDGs) of the United Nations; decent work and economic growth, industry innovation and infrastructure, sustainable cities and communities, responsible consumption and production, climate action, life below water, life on land and finally the partnerships for the goals, which can be achieved by the collaboration between Russia and Finland towards clean environment. To achieve the zero-emission target, the vessel will operate by using batteries and hydrogen fuel.

1.2. Market demands

In Saimaa Canal, the total transport volume of cargo was 1.05 million tons in 2019 and 30,000-40,000 tourist passing annually in the 2010s [1]. The constantly growing demand provides opportunities but also places challenges for the ship needed in the future. Saimaa's current passenger ships have served for decades. The two largest passenger ships currently operating in the region are MS Camilla and MS Carelia. MS Camilla is roughly thirty years old and MS Carelia is over fifty years old. Therefore they may have difficulties to meet the needs of potential customers, who require higher quality accommodations and services.

1.3. Goals and limitations

It is important to define the project more carefully to have a better understanding of a feasible design. This part focuses on confining our mission, objectives, different parameters and variables, and of course all the design constraints. Identifying all of these allows us to create a better design to fulfill the mission and objectives.

The current vessels sailable at Saimaa Canal have a maximum capacity of approximately 3,600 DWT and the largest cargo capacity is about 2,500 tons. For importing transport of raw wood, the maximum load is currently approximately 1,400 tons.

It is planned that the Canal locks are extended from 82.5 meters to 93.2 meters length, and the water level is raised from 4.35 meters to 4.45 meters. Therefore, larger ships are capable to operate in the canal in the future. However, if the length of the new vessel exceeds 90 meters, it adds some challenges. It is well known that ships longer than 90 meters are required to have pilotage and larger crews, which might increase the operational cost. The maneuverability of ships longer than 90 meters and wider than 12.6 meters is also considered poor. In addition, the load-carrying capacity is closely in conjunction with the other characteristics of the vessel, which should be taken into consideration when vessels are designed for canals with locks, for instance, maximizing the length of the cargo space would make the bow of the vessel very blunt, which increases fuel consumption. [1]

1.4. Design mission and objectives

Our mission in this project is to create a zero-emission passenger/cargo vessel to lake Saimaa area and the Saimaa canal. The design of the vessel is aimed to be futuristic and an improvement compared to all previous vessels in similar use in the area. Expansion of the Saimaa canal offers a chance to create a larger ship than before, but the passenger demand must be kept in mind. One large exception compared to existing Saimaa area passenger vessels that operate during the summertime, is that our project ship will need ice classification to operate partly in winter.

1.5. Design variables and innovations

The ferry is a small, zero emission vessel and according to its mission and operating profile, it should have a space for approximately 250 passengers. The number of crew onboard shall be around 20. Saimaa Canal dimensions described in design constraints limits the ship dimensions.

As the objective aims a zero-emission type and a hybrid between passenger/cargo vessel, some new design innovations must be used. The propulsion and other powering will be actualized for example with hydrogen fuel cell technology. Operating distances will be quite short, so charging battery technologies could also be an opportunity.

1.6. Machinery design

The propulsion will consist of one shaft line and two electrical motors connected to it via reduction gear. The vessel will also have one bow thruster. The need of propulsion and hotel power is calculated in the upcoming parts. The vessel will also have at least one diesel powered emergency generator.

1.7. Design constraints

Our mission and the location create few design constraints, which we can divide into physical, technical and regulatory constraints. These design constraints must be fully met in order to be able to operate in the Saimaa canal.

1.7.1. Physical

The physical constraints are created by the route, ports and locks in the canal and they limit the dimensions of the ship design. Figure 1 indicates that there are 8 locks between Lappeenranta (Finland) and Vyborg (Russia). In addition, there are 12 bridges of which 7 are movable and 5 immovable/bascule bridges. The immovable bridges set a limit for the maximum air draft. The bascule bridges are illustrated in Figure 2. Bascule bridge increases the voyage time, due to the waiting time for opening the bridges and the other limitation of the bridge's operation. It is noteworthy that, locks are the main limitation of the vessel's breadth, length and draft. Fortunately, there are no sharp turnings that may induce further dimensions limitation to the considered inland waterway vessel.

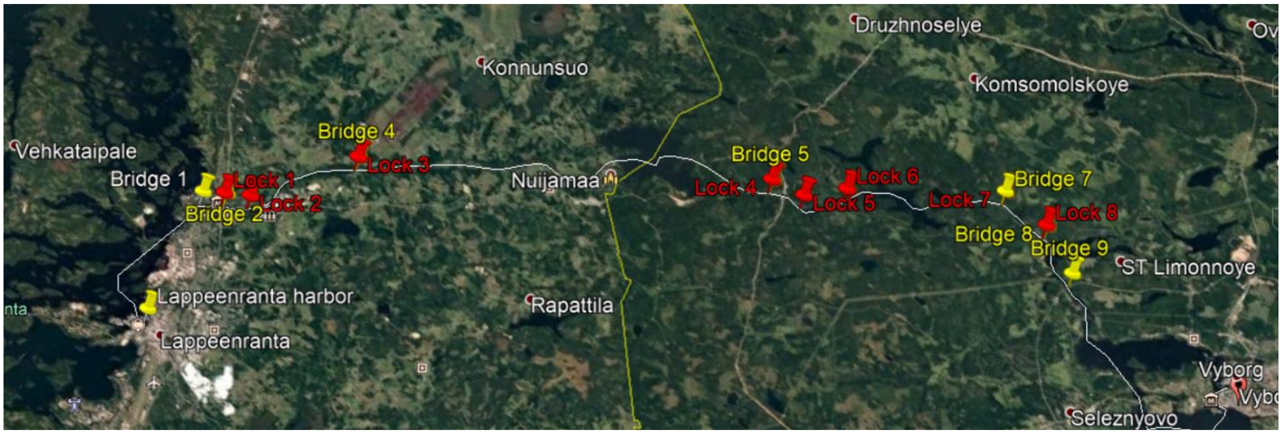

Figure 1 Lock and bridges within the potential voyage path

Figure 2 bascule bridge while a cargo vessel passes through

After taking into consideration all the above, our vessel's physical constraints are:

- Length: 92.5 m

- Beam: 12.6 m
- Draft: 4.45 m
- Air draft: 24.5 m

1.7.2. Technical

The technical constraints are related to our mission. The goal is to design a zero-emission hybrid vessel with operating time of 11 months per year. This limits the design of the machinery (mainly engines) to achieve zero emissions. The multipurpose vessel creates technical difficulties. The vessel must be able to carry passengers and cargo effectively at the same time. Possible solution is to create a modular superstructure to increase efficiency during winter months. Also, since the vessel is operating 11 months per year in the Saimaa Canal, it must be able to operate in icy conditions.

The Saimaa Canal usually freezes before the Saimaa lake; therefore, the design should consider the ice of the canal itself. The canal starts to freeze in December as the other small lakes that are located at the center of Finland. While the ice become thicker in January and February before starting to melt in March to nearly April. The thickness of the ice cover sometimes reaches up to 50 cm, however, it is normally around 25 cm. There are scarce data about the thickness of the ice cover throughout the recent winters, while the very old records of the ice cover may be remarkably conservative due to the global warming [2][3].

Figure 3 Ice covers the Saimaa canal (credential reserved to Aker Arctic Technology)

1.7.3. Regulatory

From the regulatory point of view the vessel must comply with SOLAS convention regarding the safety standards in design, equipment and operation. For example, double bottom is required in all passenger ships. It must also comply with the European, Finnish and Russian legislation. The ship must also comply with the regulations in the Saimaa Canal itself. This limits the top speed to 9 km/h (4.85 knots) in the canal (if draft > 3.9m). With smaller drafts the speed limit is graduated between 9-18 km/h.

1.8. Similar ships operate in the Saimaa canal

Saimaa Canal cruise business:

Karelia Lines, MS Camilla:

334 gross tonnage vessel built in France in 1987 and has the following particulars:

- length 31,2m
- breadth 8,41m
- draught 1,6m
- speed 12kn
- main engines 2x Volvo-Penta, 2x 272kW
- 350 passengers
- 180 seat a la carte restaurant
- bar with a view to the outside
- large sundeck
- 2-hour cruises (43km) starting from Lappeenranta harbor, going through the canal lock and turning back to Lappeenranta after that
- also 3-hour dinner cruises
- normal time of operation is from 2.6. to 6.9.
- 2020 prices for cruise were
    - 22€ adult
    - 10€ kids between 4-14 years
    - 44€ family ticket (2 adults and 2 kids (4-14 years))
    - 18€ pensioners

Figure 4 Karelia Lines ferry MS Camilla

Lappeenrannan Laivat Oy, MS Carelia

393 GT vessel built in West-Germany in 1969 and has the following particulars:

- length 40,92m
- breadth 8,52m
- draft 2,3m
- design speed 14kn (according to Wikipedia 18kn)
- main engines 2x 375kW
- 200 passengers
- tax-free shop
- money exchange
- restaurant and bar
- sundeck
- route: Lappeenranta – Vyborg – Lappeenranta
    - also 3-day cruises
- visa-free
- 1 day cruise costs 69-89€/person
- spends a few hours at Vyborg

Figure 5 MS Carelia ferry

2. Reference ships

Reference ships are a crucial asset when creating a new ship design. Finding well matching reference ships for our project was challenging since there are not any ships in Saimaa region which would carry passengers and also cargo. Many passenger and cargo ships in the area are also several decades old and especially passenger ships are much smaller than our design. Old passenger ships are still a good information considering for example passenger demand, ticket prices and schedule of the route. Examples of these ships are MS Camilla and MS Carelia.

By categorizing our vessel, we can find better reference ships for our design. We can categorize the vessel in various ways. For example, these include: the ship type, mission, applied technology, operational area, design limiting factors, number of hulls, cargo etc.

Below is listed ways to categorize our vessel.

- Ferry (summer)
- Cargo vessel (winter)
- Commercial
- Single hull
- Inland waterway vessel
- Size limited (Saimax)
- Fuel cell / batteries

With these in mind, we searched for reference ships, which are introduced next.

2.1. Suomi 100

The Suomi 100 ship from Ship design portfolio –course in 2018 is a good refence for designing the ship and its passenger accommodations. Suomi 100 is quite close to our ship by its dimensions. Suomi 100 is designed to operate in the Saimaa canal area and Gulf of Finland. The ship has Finnish-Swedish ice classification 1A Super, so it is capable to operate during winter. Although this ship has not been built, it is still a valid reference since it is well specified in the final report. Our group received the report on Suomi 100 ship from the LRK archives.

Suomi 100	
Passenger ship	
Gross Tonnage	3900
Passengers	450
LOA (m)	85,5
LPP (m)	83,5
Beam (m)	12,6
Draft (m)	3,6
Design speed (kn)	10
Max speed (kn)	15
Displacement (m3)	2591
Displacement volume (m3)	2528

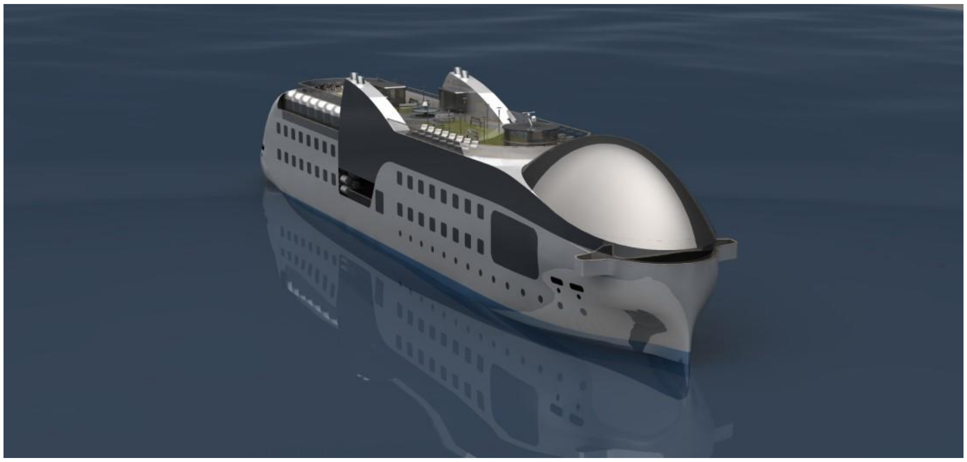

Figure 6 Suomi 100

2.2. Kelt

Our ship will carry bulk cargo like lumber, so it is also important to study Saimaa area cargo ships for reference. Kelt is a Saimax cargo ship built in 2009 so it could be considered relatively modern. Kelt carries general cargo through Saimaa canal. Valuable reference from this ship is for example the cargo capacity and type of the cargo. The ship does not have ice classification so operation in winter is limited.

Kelt	
Cargo ship	
Gross Tonnage	2409
DWT in summer	3750
LOA (m)	82,5
Beam (m)	12,5
Max draft (m)	5
Design speed (kn)	9
Max speed (kn)	15,3
Cargo hold dimensions (m)	54,6x10,3x8,15
Year built	2009

Figure 7 Kelt (cargo ship)

2.3. Reference machinery solutions

Machinery configurations fully complying to our concept have not been built yet. Two options were available, one using azimuth thrusters, and the second using mechanical, one-propeller propulsion with rudder. Both contain advantages and drawbacks.

We will use MF Hilde, as an example, which is a passenger and car ferry currently under construction. It will be delivered in March 2021 and the installation H2 equipment is scheduled for late 2021. The ferry is part of European Flagships project.

MF Hilde will be approximately the same size as our vessel, but its daily operation distance will be 260 km which is significantly greater as our vessel's. The vessel can carry 199 passengers and 60 cars. MF Hilde will have 3 x 200 kW PEM fuel cells and the preliminary hydrogen consumption is announced to be 460 kg/day. The hydrogen is bunkered from shore to ship every night. MF Hilde has also been discussed to have some additional power capacity as battery capacity. [4]

Figure 8 Flagship project MF Hilde

It is also an option to use only batteries to power our vessel, but this option will be studied later. A suitable reference for that machinery solution could be a Finnish road ferry Elektra operating in Turku archipelago. Elektra has 2 x 900 kW propulsion power and 1 MWh battery pack. [5]

3. Main particulars

Choosing correct main dimensions for our ship is crucial for many reasons like stability, technical performance and cost efficiency, cargo and passenger capacity, seaworthiness and strength. Our ship's size is highly limited by the Saimaa canal. Finnish government is planning to expand the canal locks to allow larger vessels go through the canal. After the expansion of the Saimaa canal, the locks are limiting the maximum length of the ship to 92.5 m and beam to 12.6 m. In addition, the canal is relatively shallow and limits our maximum draft to 4.45 m. The route from Lappeenranta to Vyborg also requires going under many bridges which create a maximum air draft of 24.5 m. These limitations act as absolute maximum values for the dimensions and thus should not be exceeded when studying and deciding our ship's main dimensions. Although these limitations are acknowledged in advance and our aim is to create a Saimax size ship according to the expanded canal, it is still important to study reference ships, statistics and regulations before making final decisions on the main dimensions. Our dimensions will be compared to reference ships by using statistical data and empirical formulas to ensure they match requirements.

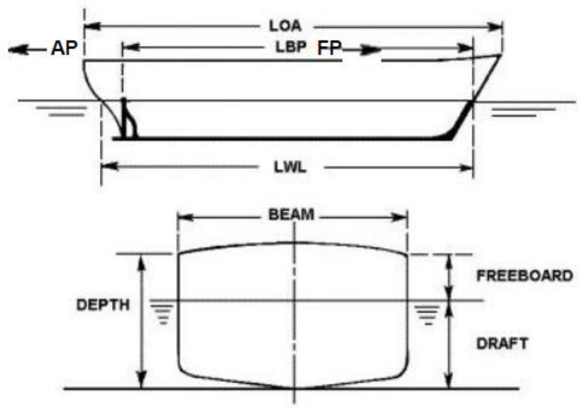

Figure 9 Ship's main dimensions. Photo from the lecture slides.

3.1. Selection of the dimension

There are different methods in literature that can be adopted to select the case study main dimensions. Some of these methods are empirical and others are parametric. The empirical methods are based on statistical data of similar ships; while the parametric depends on the experience of the designer to meet specific and clear objectives of the intended design. In both methods the design should meet the different regulation requirements for safe operation and also it should have realistic and reliable operation and building costs.

3.2. Normand's number method (deadweight estimation)

With the data of reference ships that we have collected earlier, we will be able to calculate the main dimensions of the new ship by applying Normand's number method. The procedure includes four steps:

First, we calculate the displacement of the reference ship based on the main dimensions and block coefficient. Secondly, with the formula, we get the Normand's number. Then based on the limited dimensions of our target design the deadweight change will be calculated using Normand's number.

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However, Normand's number only varies with the size of the ship for most ship types. It is highly recommended that this method is used when determining the displacement or deadweight of a preliminary design. [6] An artificial neural network model was proposed for the purpose of improving the accuracy of the dimensions, using deadweight and vessel speed as the input layer; and length overall, length between perpendiculars, breadth, draught and freeboard being used as the output layer. [7]

Reference ship: Kelt-cargoship is the reference ship employed in this study. Its main dimensions are presented below. Its block coefficient is estimated to be 0.7. Kelt's lightship weight is nearly 423 tons. The Normand's Number of the reference ship is calculated using the following equation

$$N = \frac{d\Delta}{dW} = \frac{\Delta}{\Delta - W_{H+O} - \frac{2}{3}(W_M + W_F)}$$

Target: We plan to design a ship that has the same max breadth (B) and draft (T) of the current operating ships 12.6 m and 4.45 m respectively. The block coefficient (C_b) is assumed not changed and equal 0.7. Therefore, the displacement of the target ship is 3721 tonne. The new deadweight due to the increment of the ship length from 82.5 m to 92.5 m is 3247.9 tonne.

Item	Reference Ship data
L (m)	82.5
B (m)	12.5
T (m)	4.45
CB	0.7
Density of water	1.025
Δ (tonne)	3312.41
Hull weight W_H (tonne)	243
Machinery Weight W_M (tonne)	70
Outfitting weight W_O (tonne)	110
Fuel weight W_F (tonne)	13
Deadweight (tonne)	2889.41
L/B	6.600
Normand's no. (N)	1.141

Item	New Ship data
L (m)	92.50
B (m)	12.60
T (m)	4.45
CB	0.7
Δ (tonne)	3721.30
Deadweight (tonne)	3247.89

Figure 10 Normand's number approach with reference ship Kelt.

3.3. Preliminary design dimensions

The table below illustrates the selected dimensions for our preliminary design. The important ratios between the dimensions are as follows;

- L/D = 8.4 (Typically between 4-10)
- L/B = 6.9 (6,6-10,3)
- B/T = 2,8 (2,3-4,5)

All of them are within the recommended range.

Loa	92.5015	[m]
Lpp	86.45	[m]
Lwl	89.908	[m]
B	12.6	[m]
T	4.45	[m]
D	10.3	[m]
Displacement Volume (Vol):	3177.258	[m3]
Displacement Weight (Displ)	3256.69	[ton]
Hull Volume to Upper Deck	9280.313	[m3]
Speed (V):	12	[kn]
Froude Nr. (Fn):	0.207849	

Figure 11 Preliminary design main dimensions

3.4. Validation of the preliminary dimensions

Since the main dimensions are key to a successful design, we must make sure to get them “right”. A good starting point is to study already existing data. The main advantage of doing so, is the fact that the data is based on delivered and functional ships. With a large sample pool, we can statistically determine regression curves, which give us good references what the ratios between different parameters should look like. Deviating from these curves might indicate that there is something wrong in the design.

3.4.1. Statistical data of collected reference ships

The aim of this section is to compare the dimensions we get with the statistics of similar ships that has nearly the same dimensions than ours and in addition has restricted operational area. Figures below indicates that the selected dimensions are well fitted with the regression curves that correlate the main particulars and ratios of the reference ship statistics and the corresponding selected value/ratio of our preliminary design. The orange point in the figures represents our preliminary design.

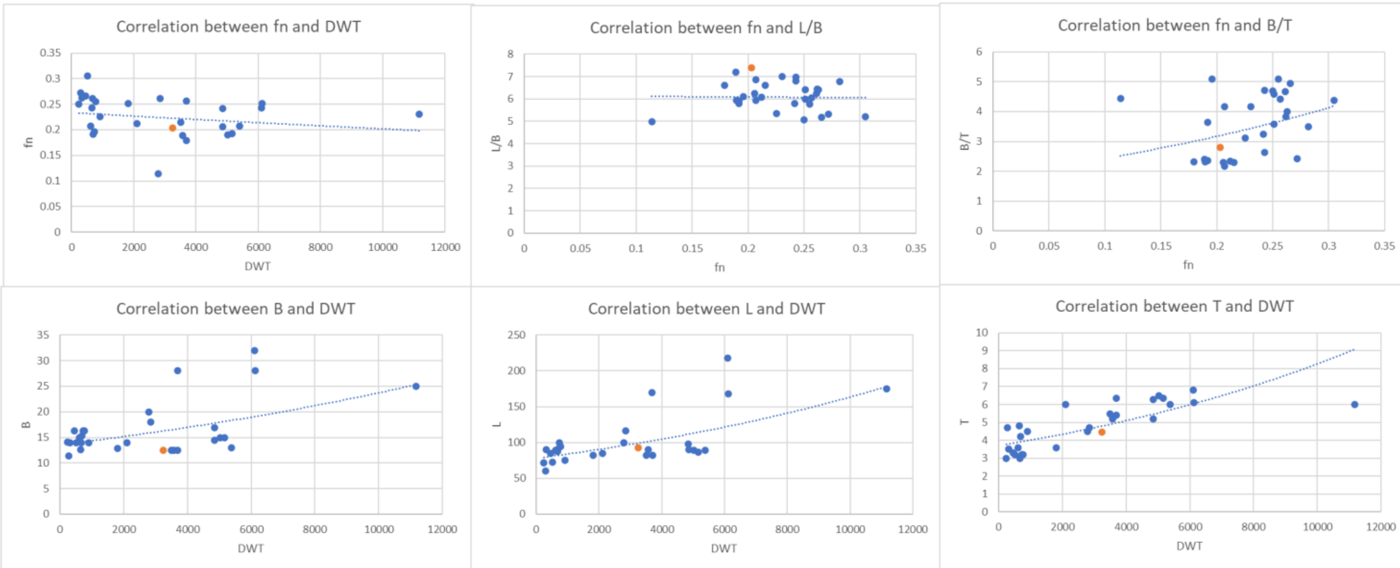

Figure 12 Validation of the selected preliminary design dimension/ratios (Orange point) using similar ship statistics

3.4.2. Comparison with proposed empirical formulas

The obtained dimensions also compared with the available empirical formulas which are listed as follows

$L_{PP} = \Delta^{0.3} V^{0.3} C$ Schneekluth's (1998)

$C_B = -4.22 + 27.8\sqrt{Fn} - 39.1Fn + 46.6Fn^3$ for $0.15 \le \text{Fn} \le 0.32$

$\frac{L}{B} = 4$ for $L \le \frac{30mL}{B} = 4 + 0.025(L - 30)$ for $30m \le L \le 130m$ [Watson & Gilfillan]

$\frac{L_{PP}}{\nabla^{1/3}} = 3{,}33 + 12.5F_n$ (general practice)

The results are showing good agreement with the empirical formulas.

3.5. Speed of the vessel

The speed was selected based on the statistics of reference ships we have collected for our previous assignment. By dividing the square root of the updated length between perpendiculars multiplied by the gravity value (9.81), we calculated the Froude number, which is an important speed measure. The result is around 0.20. Ships with the Froud number between 0.18 and 0.25 are usually considered as a middle speed ship, that have notable wave making resistance. The ship would have shorter aft part and more slender fore part as the slender fore part affects the wave making resistance. Bulbous bow is not always necessary, as bulbous bow only might be important since it decreases angle of entrance and smoothens the fore shoulder for large breadth vessels, which have B/T ratio larger than 3.5. [8] For our Saimaa Hybrid, the B/T ratio will only be around 2.8.

However, as the speed limit in the Saimaa Canal is only 9 km/h (about 4,9 kn) and the canal is a large part of the whole route, we would reduce the speed of Saimaa Hybrid to 4.9 knots while operating in the canal. This will reduce the Froude number to 0.085. With this Froude number, the wave breaking resistance should be ensured not too significant and the hull form should have relatively full bow form and more slender stern. [8] Speed of 4,9 knots is considered very low and setting it as the design speed would reduce the amount of other operational routes. Therefore, the ship will have design speed of 12 knots, since it can also operate other routes during its lifecycle.

4. The form of the ship's bow, stern, and mid-ship areas

The route from Lappeenranta to Vyborg is fairly short (about 60 km). Therefore, the ship is most likely spending a lot of time in the locks and in the ports. In terms of the hull form, the key for successful operation is to optimize the cargo/passenger capacity taking the hydrodynamics into account. Complicated designs are very expensive and in our case the benefits are quite reduced.

A good example of this would be a bulbous bow. It is expensive to manufacture, and there are no real benefits while being in the ports or going through the locks. It works in an optimal way when the speed of vessel is the design speed, which is only possible in the connected lakes of the route. And typically, bulbous bow is more beneficial in higher speeds (Fn 0.15 – 0.23), which we are not able to achieve in the canal. In other words, the bulbous bow is not suitable for our case.

We chose to go with a slightly raked bow shape without the bulb. The bow region is connected with a U-type section, which is preferable when the midship section is full, and to allow the best use of enclosed spaces. The U-section also gives us a wider deck for the passengers. Although U-shape results in higher wave making resistance and larger wave load on the bow, we do not see this as an issue, since the wave making resistance is not significant for slower ships (frictional resistance ~80% of the total resistance) and the expected waves in the canal are very small.

The mid-ship area has a full form. It is rectangular with a normal rounded bilge. This gives us a great deck area and enclosed spaces for cargo. This allows us to use as much of the available space in the locks as possible.

The stern of the ship is transom type with single screw and a rudder. The stern is more slender compared to the fuller bow to prevent flow separation and to give us a good wake. Transom stern offers a greater deck area at the aft, its simple to construct and it allows us to utilize the restricted space in the locks.

4.1. Ship lines and fairness

Line drawings of our ship are sketched with the provided Excel-file. Body plan, half-breadth plan and profile are presented below respectively.

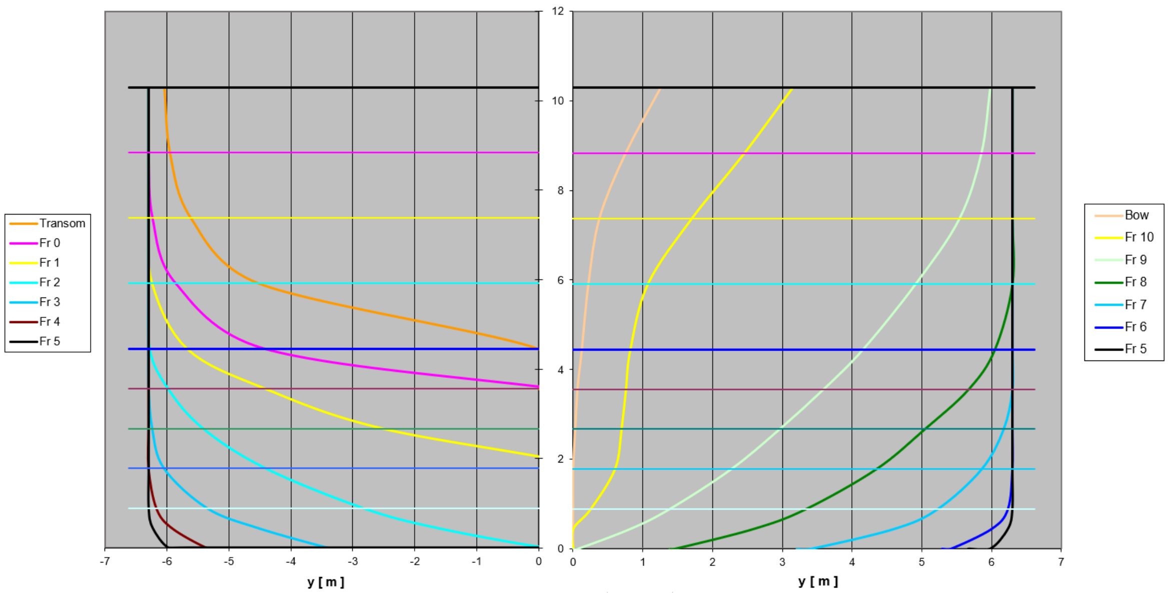

Figure 13 Body plan

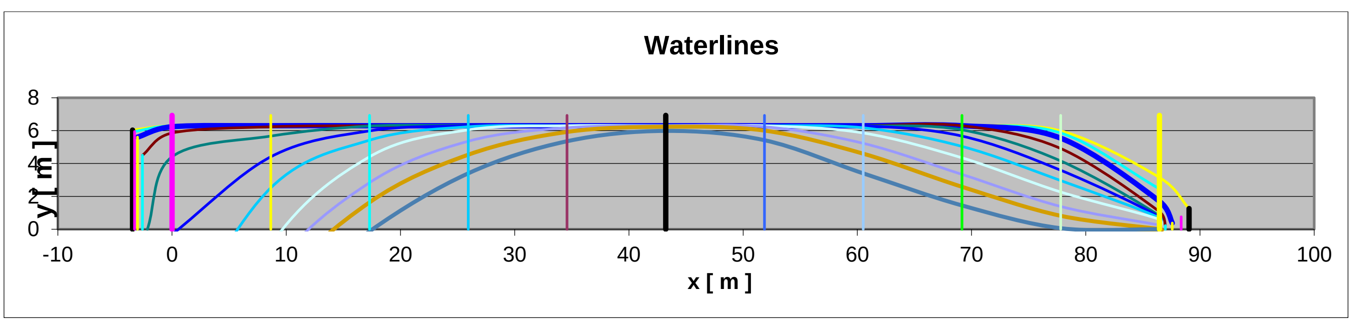

Figure 14 Half-breadth plan

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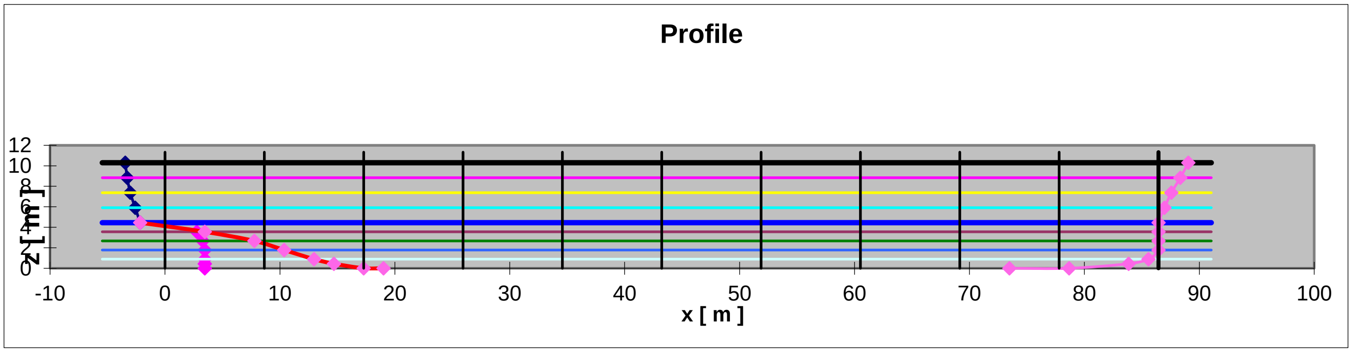


Figure 15 Profile

The sectional area curve is illustrated below:

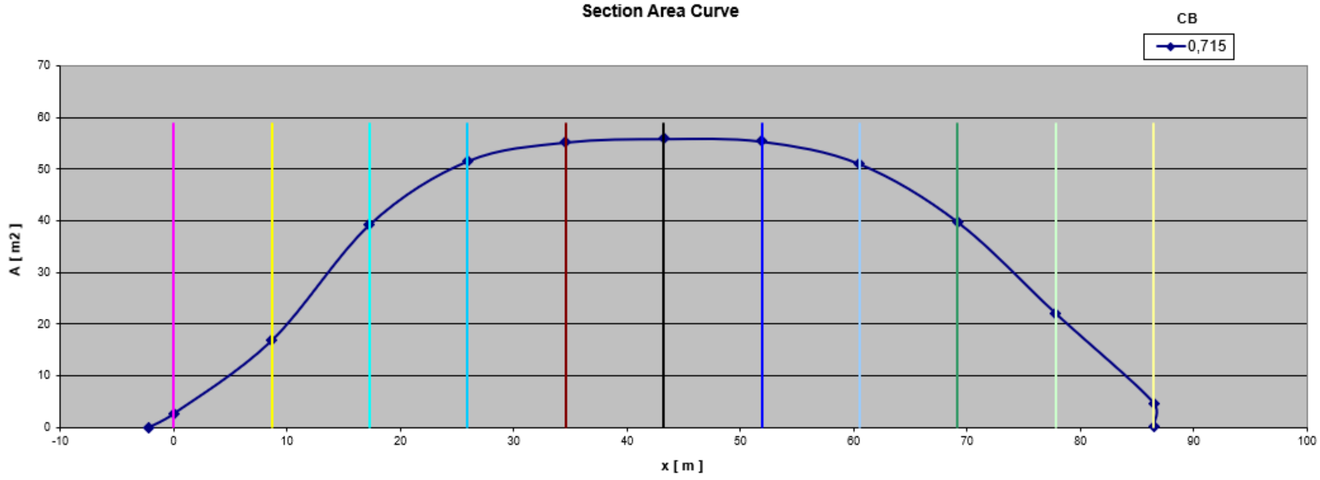


Figure 16 Sectional area curves from Excel.

4.2. Comparing the Excel-values and statistics

In figure below, LCB should be between -0,7 and 1,5 for our C_b value of 0,715. Comparing our C_b value of 0,715 and LCB value of 0,8, we can see that it fits well into the Type 1 area.

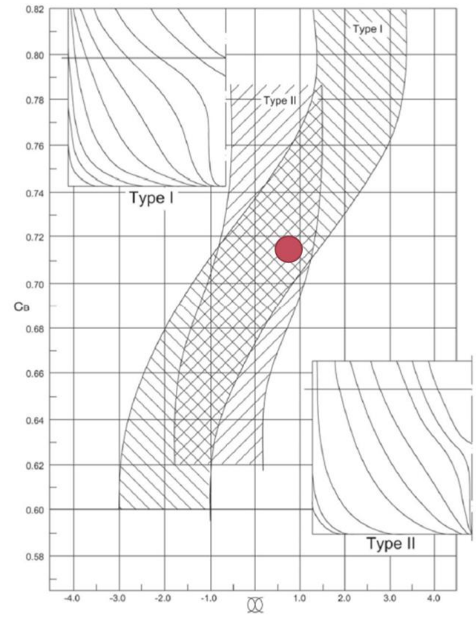


Figure 17 LCB as a function of C_b and hull form type (red point represents our vessel)

In figure below, LCB should be between 0,4 and 2,4 for our C_p value of 0,717. Our LCB value of 0,8 fits well into the wanted area.

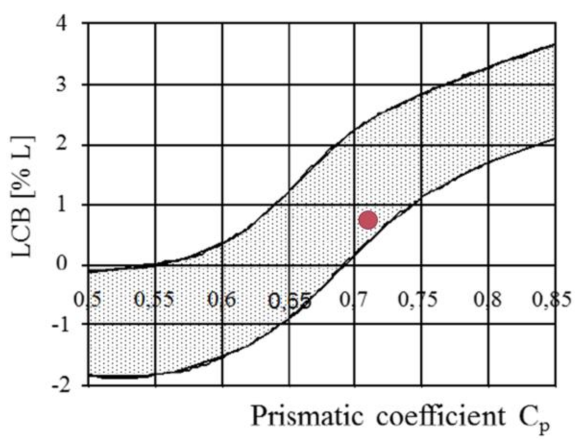


Figure 18 LCB & Cp graph. Photo from the lecture slides (red point represents our vessel).

In figure below, we can see that we match Troost criteria well with our Froude number 0,21 and C_p 0,717.

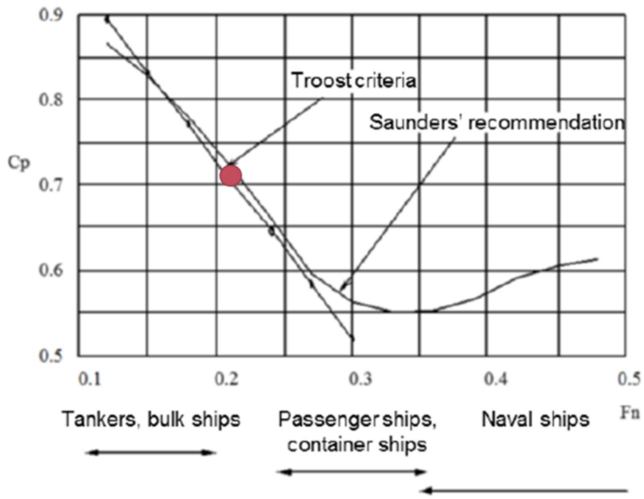


Figure 19 Cp & Fn graph. Photo from the lecture slides (red point represents our vessel).

In figure below, we can see that with our C_p of 0,717 we get parallel body length of about 23% L_{wl}.

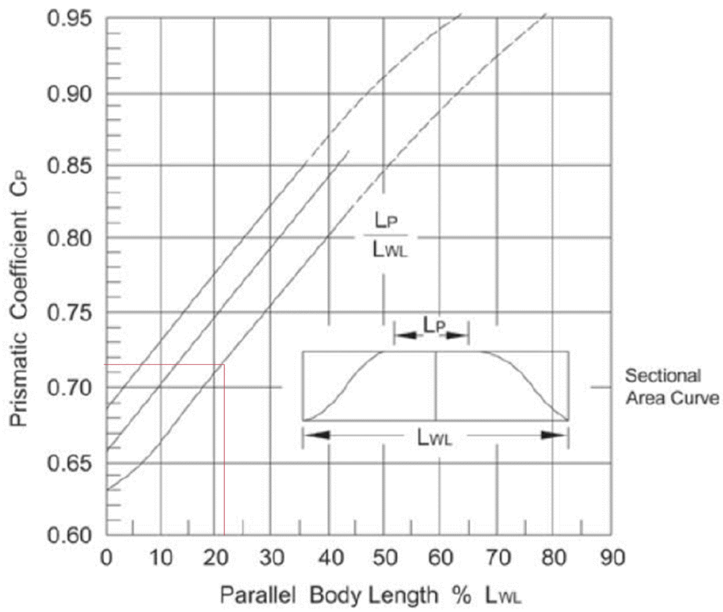


Figure 20 Parallel body length & prismatic coefficient. Photo from the course notes.

From figure below we get Lr-value of 0,41, Lp-value of 0,23 and Le-value of 0,36 with our Cp-value of 0,717. This matches the result of parallel body length from Figure 20.

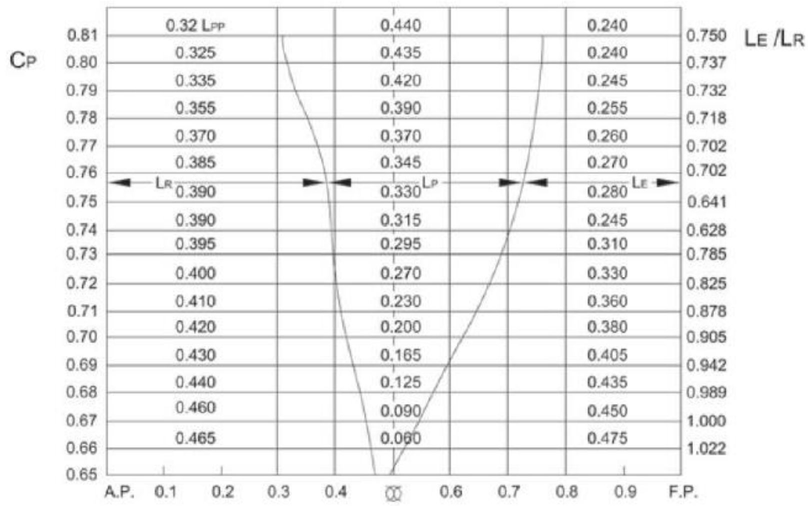


Figure 21 Length of entrance (LE), length of run (LR) and parallel middle body length versus prismatic coefficient. Photo from the course notes.

5. 3D modelling

Based on the assumptions above, we created a 3D model by using Maxsurf, starting from a basis ship model that has nearly the same characteristics. The reference model dimensions are nearly the same as our model, therefore, only few amendments have been made to get exactly our design dimensions. The obtained body plan, profile and half breadth plan were illustrated in Figure 22, Figure 23 and Figure 24 respectively.

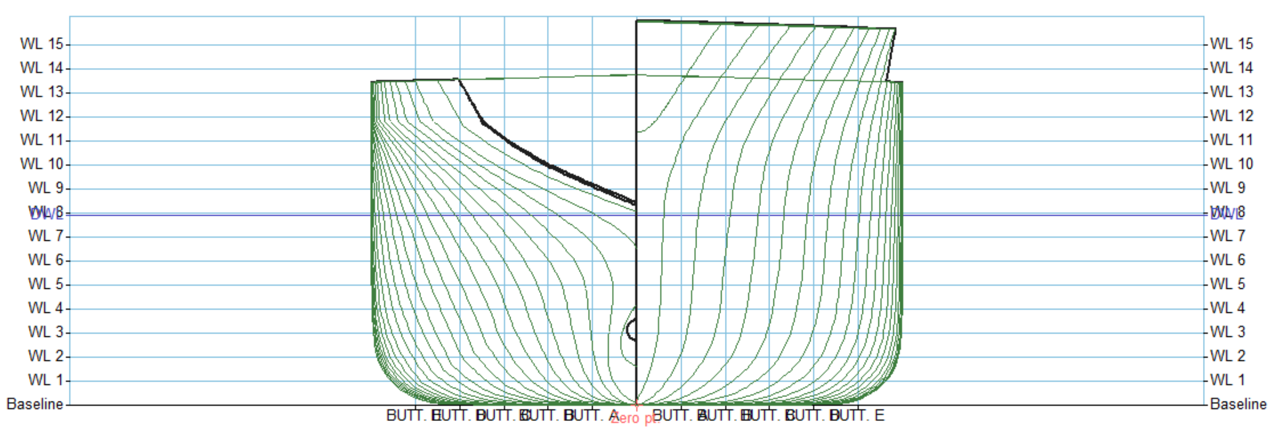


Figure 22 Body plan of the second model

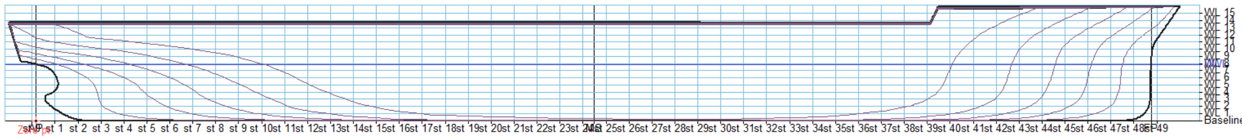


Figure 23: Profile of the second model

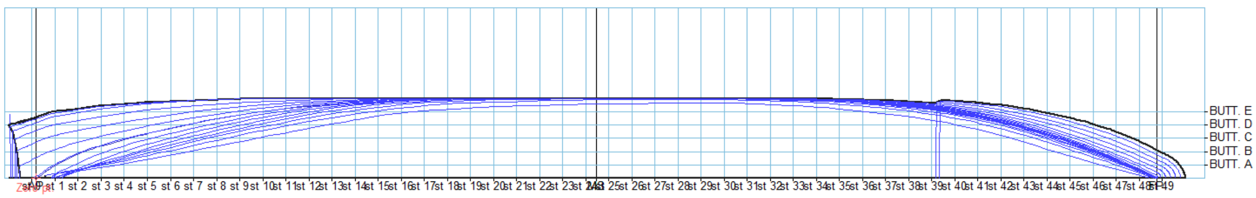


Figure 24 Half breadth plan of the second model

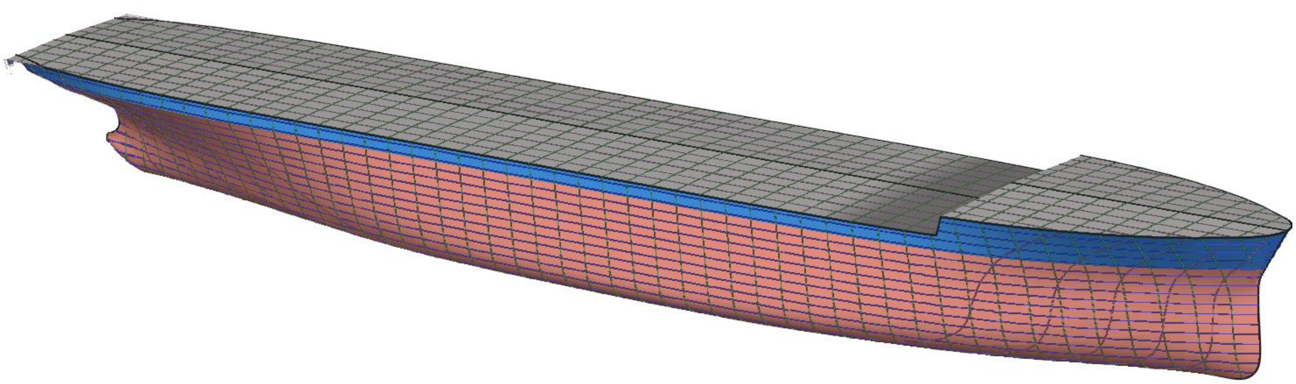


Figure 25 3D of the second model

The lines plot has been attached as an appendix. Also has been illustrted in Figure 26.

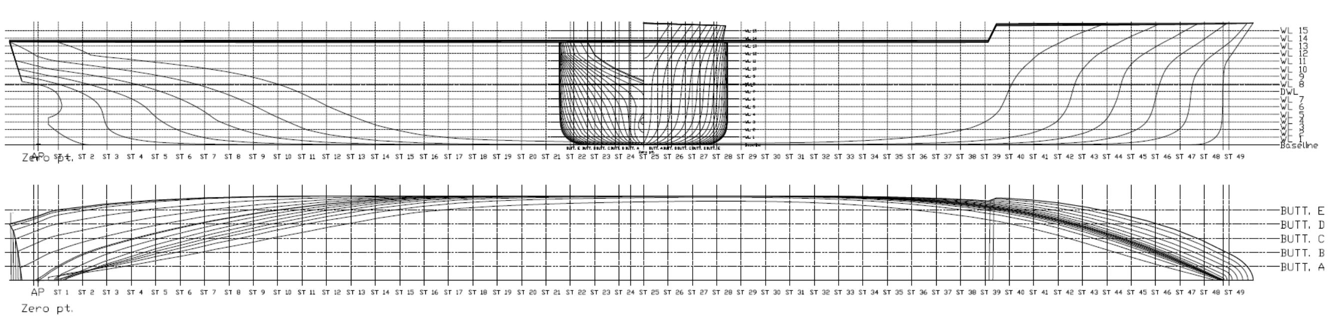


Figure 26 Model 2 Body plan, Half breadth plan and profile

Two hull forms were created and differences between them were compared. The second model was chosen as the final hull form.

Parameter	First model	second model	Difference
Displacement t	3523.0	3550.0	1%
Draft at LCF m	4.5	4.5	0%
WL Length m	88.2	87.3	-1%
Beam max extents on WL m	12.6	12.6	0%
Wetted Area m^2	1407.0	1426.4	1%
Waterpl. Area m^2	987.3	869.6	-14%
Prismatic coeff. (Cp)	0.736	0.724	-2%
Block coeff. (Cb)	0.693	0.708	2%
Max Sect. area coeff. (Cm)	0.945	0.978	3%
Waterpl. area coeff. (Cwp)	0.888	0.791	-12%
LCB from zero pt. (+ve fwd) m	46.5	45.9	-1%
LCF from zero pt. (+ve fwd) m	43.7	44.4	2%
KB m	2.5	2.3	-7%
BMt m	3.4	2.7	-27%
BML m	152.0	112.3	-35%
KMt m	5.9	5.0	-18%
KML m	154.5	114.7	-35%
Immersion (TPc) tonne/cm	10.1	8.9	-14%
MTc tonne.m	59.9	44.5	-35%
Resistance at 12 knot	85.7	89.58	4%

5.1. Previous research

We have discussed two interesting papers in this section. The first that we would like to start with is entitled “An innovative concept for inland waterway vessels” by Alessandro et. al. [9]. The paper is published in the proceeding of technologies and science for the ships of the future conference. It was reported that, in Europe the main constraints when designing inland waterway vessels are somehow environmentally and regulatory. The environmental constraints are the same as discussed in the previous report. While regulatory, the vessel should follow the rules framework of the country, the European Inland Waterway Transport (IWT) [mainly entitled for all types of cargo transportation], the United Nations Economic Commission for Europe (UNECE) and finally the European Union (EU). Currently, those authorities try to improve its regulation to make the inland waterway vessels decarbonized by improving the design and also using zero-emission propulsion system. The paper discussed a new innovational design that follow all that rules and in the same time achieve the zero-emission requirement. The zero-emission was achieved by performing hydrodynamic optimization of the external hull form and in addition using Air Cavity System ACS. The ACS provides a layer of air on the bottom of the unit to reduce the friction resistance, so it requires flat bottom to operate. Alessandro et. al. made a resistance experiment to validate the reduction of resistance using this system and it was concluded that the reduction is about 20% mainly due to the reduction in the friction resistance component. Finally, Bivortix propulsion system is employed to improve the efficiency of the profusion system.

In addition, our group discussed a paper called “Challenges and opportunities of zero emission shipping in smart islands: A study of zero emission ferry lines” [10]. This paper seemed like a logical pick considering our project. In the paper a case study for zero emission ferry lines operating in the coastal area of Croatia was conducted. In the paper, the operating range (55 km) of ferry line 2 is very similar to ours and thus gives a good reference.

The main insight of this paper is that the energy requirements depend on multiple variables. These include the vessel characteristics, voyage requirements and fueling frequency. Where the infrastructure also plays a big role. These factors often rule out the use of batteries. In most cases the practical limits of the batteries are reached before the required energy for the vessel. However, it might be possible in our case since the operating range is quite short and the vessel isn’t too large. Although a better option, or more common approach, is a fuel cell hybrid power system. This could be very effective in our case since the vessel is under low loads when passing through the 8 locks and 9 bridges of the canal. The excess electricity created can be stored into the batteries, and when needed, the maximum power can be delivered with the batteries and the fuel cells together.

It is important to note here that the fuel cell technology for maritime applications is still in the development phase with a technology readiness level of 5 (highest being 9). On a positive note, there are multiple ongoing fuel cell vessel projects while enormous pressure created by the emission regulations is thriving this technology further [11][12][13]. Also, Norway is setting a good example for everyone else by making Norwegian Fjords zero-emission no later than 2026. With proper infrastructure the fuel cell hybrid solution could be feasible solution for our project.

Draft Amidships m	4.439
Displacement t	3721
Heel deg	0.0
Draft at FP m	4.133
Draft at AP m	4.745
Draft at LCF m	4.440
Trim (+ve by stern) m	0.613
WL Length m	95.000
Beam max extents on WL m	12.600
Wetted Area m^2	1505.798
Waterpl. Area m^2	927.949
Prismatic coeff. (Cp)	0.701
Block coeff. (Cb)	0.644
Max Sect. area coeff. (Cm)	0.971
Waterpl. area coeff. (Cwp)	0.775
LCB from zero pt. (+ve fwd) m	-45.014
LCF from zero pt. (+ve fwd) m	-46.444
KB m	2.338
KG fluid m	4.439
BMt m	2.737
BML m	130.882
GMt corrected m	0.635
GML m	128.781
KMt m	5.074
KML m	133.217
Immersion (TPc) tonne/cm	9.511
MTc tonne.m	51.806
RM at 1deg = GMt.Disp.sin(1) tonne.m	41.238
Max deck inclination deg	0.3795
Trim angle (+ve by stern) deg	0.3795

The GZ curve is illustrated below which indicates the ship has max GZ equals 0.7 m (depends on the estimated VCG) and the deck edge emersion is at 26.8 degree

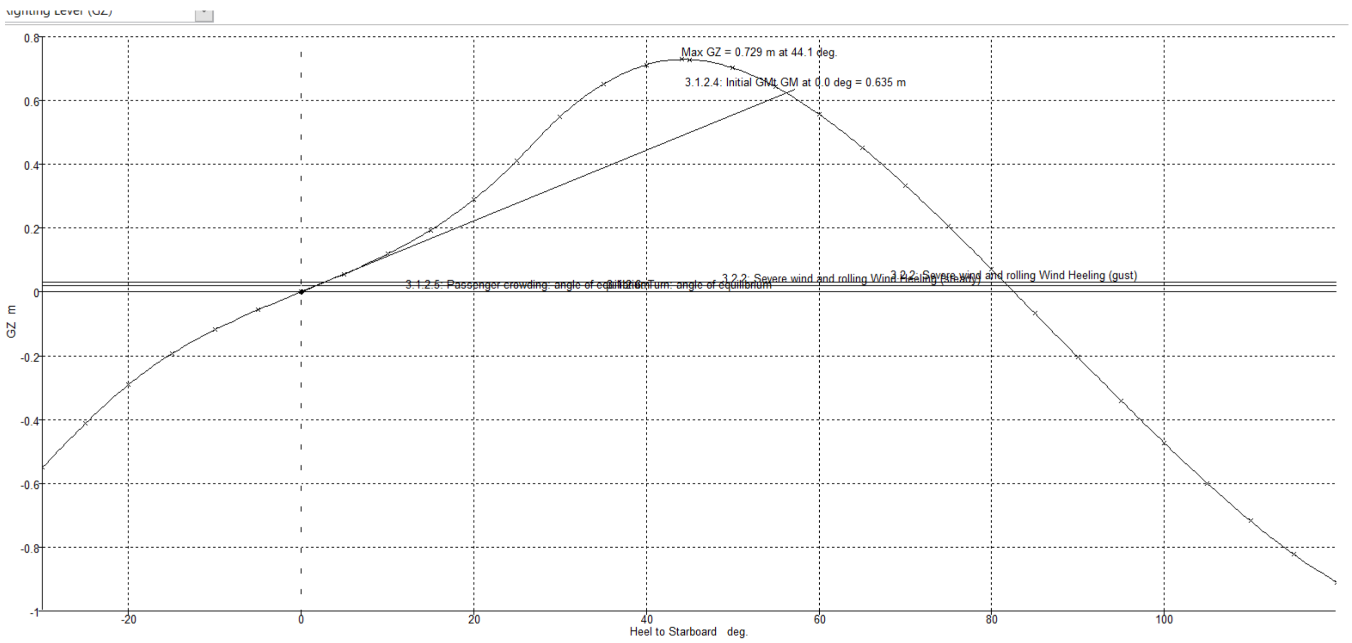


Figure 27 Preliminary Large angle stability GZ curve

The table below indicates that the ship passes all the requirements of IMO A.749(18) Ch3 - Design criteria applicable to all ships with a big margin. That means the proposed ship does not have any problem with the stability.

Code	Criteria	Value	Units	Actual	Status	Margin %
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 0 to 30	3.1513	m.deg	6.7044	Pass	+112.75
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 0 to 40	5.1566	m.deg	13.1465	Pass	+154.95
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 30 to 40	1.7189	m.deg	6.4422	Pass	+274.78
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.2: Max GZ at 30 or greater	0.200	m	0.729	Pass	+264.50
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.3: Angle of maximum GZ	25.0	deg	44.1	Pass	+76.36
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.4: Initial GMt	0.150	m	0.635	Pass	+323.33
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.5: Passenger crowding: angle of equilibrium	10.0	deg	0.0	Pass	+100.00
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.6: Turn: angle of equilibrium	10.0	deg	0.0	Pass	+100.00
A.749(18) Ch3 - Design criteria applicable to all ships	3.2.2: Severe wind and rolling				Pass	
	Angle of steady heel shall not be greater than (<=)	16.0	deg	1.9	Pass	+87.94
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80.00	%	7.20	Pass	+91.00
	Area1 / Area2 shall not be less than (>=)	100.00	%	433.45	Pass	+333.45

6. General Arrangement

This chapter goes through the procedure of designing the general arrangement (Appendix 1.) of the Saimaa Hybrid and aspects with the rules and regulations considered.

6.1. Rules and regulations

During the procedure of designing the GA, we have taken a few general rules and regulations into consideration and we have followed DNV GL classification society's rules.

A-, B- and C- class divisions: The SOLAS chapter II and the FSS Code (Fire Safety System) define the requirements for fire zones and evacuation routes. SOLAS has tables for structural fire protection requirement of bulkheads and decks. The requirements depend on the spaces in question and are different for passenger ships and cargo ships.

Main Fire Zones (MFZ), Main Vertical Zones (MVZ), Main Fire Zone Bulkheads (MFZB): The basic rule is that maximum length of a fire zone is 40 meters, which can be in certain situations extended to 48 meters. The maximum permissible area of one MFZ on one deck is 1,600 m^2. Additionally, the bulkheads between MFZs should not have steps. [14]

Alternative arrangement: Regulations allow for designs and arrangements which are not according to SOLAS requirements, providing an analysis is made that shows the proposed alternative design and arrangements is, with regards to safety, at the same or better level than the SOLAS requirement. For example, an alternative design are lifeboats with a higher than 150-person capacity.

The Safe Return to Port –concept (SRtP) requires redundancy on critical systems, and the GA mainly shows in how the redundancy of propulsion is arranged. Also, a backup bridge and safety center controlling the safety systems are needed. The division into watertight compartments is defined by stability calculations and required subdivision index, but in the concept phase this has been considered by dividing the hull into as many compartments. Possible flooding of compartment is also considered in avoiding longitudinal watertight bulkheads to enable the flooded water to spread evenly in order to avoid listing. When possible considering practicality, the watertight bulkheads are continued also above the bulkhead deck to gain bigger stability range. [15]

6.2. Decks & modular passenger facilities

	Height (mm)	Above base line (mm)
Deck 7		17700
Deck 6	2700	15000
Deck 5	3000	12000
Deck 4	3200	8800
Deck 3	2600	6200
Deck 2	2600	3600
Deck 1	2800	800
DB	800	0

Figure 28 The chosen deck heights for Saimaa Hybrid.

Deck heights are presented above. Highest point on Deck 7 (sundeck) is 19900mm above base line. Deck 4 is the main deck. Deck 5 is embarkation deck for passengers.

Saimaa Hybrid will have a modular superstructure to allow more efficient operation as a passenger ship during summer and as a cargo ship in winter. The modules will contain the public areas for passengers and passenger cabins as well. The modular passenger structure is located on deck 4 and it extends to deck 5. The modules will be removed and stored for winter when operating as a cargo ship to allow larger deadweight for cargo and to allow the use of the four cargo hatches which are located right below the floor of the module on deck 4. For this reason, we have two same views of the ship in different modes (summer & winter) in the general arrangement.

6.3. Cabins

The number and type of cabins are shown in Fig. 31.

Cabin Type	Capacity (Persons)	Amount of cabins	People / cabin type	Maximum people
Passenger				
Family suite	6	4	24	232
Inner cabin	4	12	48	
Window cabin	4	40	160	
Crew				
1 person window	1	10	10	42
2 person window	2	16	32	

Figure 29 Cabin types and amounts for Saimaa Hybrid.

6.4. Watertight bulkheads and zones

The ship is divided into 9 different watertight zones according to the DNV GL requirements for passenger ships. All watertight bulkheads reach from the double bottom to the main deck. The number of WT-bulkheads can be considered high for cargo operation in winter but because the vessel will be classified as a passenger ferry, the passenger ship requirements must be met.

The ship has a forward collision bulkhead according to the DNV GL requirements. Minimum distance from the bow according to DNV GL for the collision bulkhead is 4.5 meters and the maximum 7.5 meters. Saimaa Hybrid’s forward collision bulkhead is 5.8 meters from the bow.

6.5. Fire and evacuation

The ship is divided into 6 main fire zones when operating as a passenger ferry during summer times. Two of these fire zones are the modular passenger areas, which will be removed for winter (MFZ 5&6). In winter operation as a cargo ship, (without the modular passenger facilities) the ship will have 4 main fire zones (MFZ 1-4).

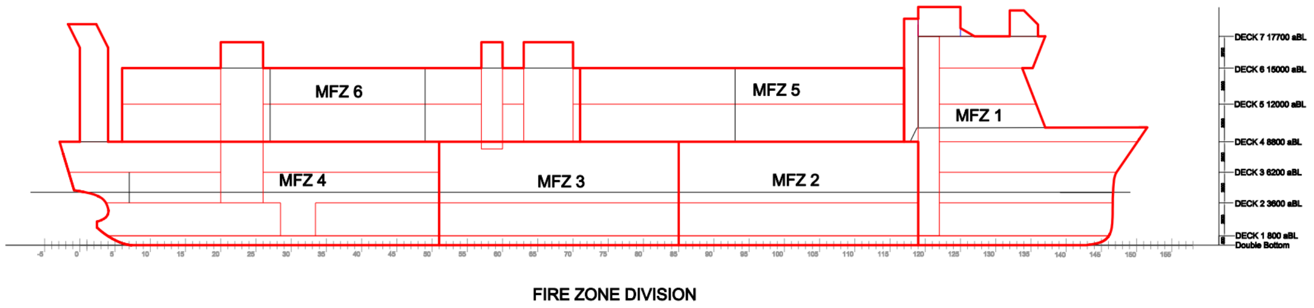


Figure 30 Main fire zones of Saimaa Hybrid

The ship is travelling close to the shore at all times, so lifeboats are not required (approx. 50 kilometers from the shore is the maximum distance after which lifeboats are required). MES rafts are still required, and they are implemented into our GA on deck 4 and 6.

7. Ship Structures

A structure with the building material of the grade B steel was designed for Saimaa Hybrid. The longitudinal framing system with minimum thicknesses of scantlings was selected and is presented with an amidship section drawing. By applying the Section Modulus Calculator, the longitudinal strength, shear strength and hull girder ultimate strength were calculated and validated to meet the structural requirements. The structural continuity is highlighted in the design. The shear force and the longitudinal bending moment were estimated. This discussion underpins the challenge with the modular superstructure part that completes the report.

7.1. Material

It is a common practice to use steel in shipbuilding as it is easier and cheaper in manufacturing, besides with its high strength comparing with other material. There are two types of steel that can be used in shipbuilding, the main difference between them in the ultimate strength. High strength steel sometimes employed in areas that has high bending moment as decks and bottoms to reduce the lightship weight and increasing the payload. The questioned vessel in this study operates usually in a lake and a canal with very small waves, that means the wave bending moment is usually small. Therefore, in case there is no ice strengthening, Grade A steel would be suitable material. However, as the vessel may operate partially in ice condition the grade B steel is selected with yield stress of 240 MPa [16].

7.2. Framing System

There are three systems of framing exist namely the transverse framing system, the longitudinal framing system and the mixed one. The case study here is a hybrid vessel that carry passengers and cargo on the same time, which means strange weight distribution is expected. The strange distribution of the weights may induce high bending moment and therefore, we adopted the longitudinal system, which characterizes by high section modulus and in consequence the ability to carry large moments.

The space between longitudinal is assumed equal 0.5 m while the heavy section is assumed to exist after 3 frames (span 1.5 m).

7.3. Minimum thicknesses of scantlings

Classification societies require minimum thicknesses for the scantling elements to make sure the elements can withstand the loads. DNV GL has defined the minimum thickness as

$$t = a + bL\sqrt{k}$$

Where,

$k = material\ factor$

$a = coefficient\ defined\ in\ tables$

$b = coefficient\ defined\ in\ tables$

Table 1 Minimum net thickness for plating

<table>
<tr><th>Element</th><th colspan="2">Location</th><th>a</th><th>b</th></tr>
<tr><td rowspan="6">Shell</td><td colspan="2">Keel</td><td>5.0</td><td>0.05</td></tr>
<tr><td colspan="2">Bottom and bilge</td><td>4.5</td><td>0.035</td></tr>
<tr><td rowspan="3">Side shell</td><td>From upper end of bilge plating to T_{SC} + 4.6m</td><td rowspan="3">4.0</td><td>0.035</td></tr>
<tr><td>From T_{SC} + 4.6m to T_{SC} + 6.9m</td><td>0.025</td></tr>
<tr><td>Elsewhere</td><td>0.01</td></tr>
<tr><td colspan="2">Sea chest boundaries</td><td>4.5</td><td>0.05</td></tr>
<tr><td rowspan="3">Deck</td><td colspan="2">Weather deck[1),2),3),4)], strength deck[2),3)] and platform deck in machinery space</td><td rowspan="3">4.5</td><td>0.02</td></tr>
<tr><td colspan="2">Boundary for cargo tanks, water ballast tanks and hold intended for cargo in bulk</td><td>0.015</td></tr>
<tr><td colspan="2">Other decks[3),4),5)]</td><td>0.01</td></tr>
<tr><td rowspan="2">Inner bottom</td><td colspan="2">Cargo spaces loaded through cargo hatches except container holds</td><td>5.5</td><td>0.025</td></tr>
<tr><td colspan="2">Other spaces</td><td>4.5</td><td>0.02</td></tr>
<tr><td rowspan="5">Bulkheads</td><td colspan="2">Bulkheads for cargo tanks, water ballast tanks and hold intended for cargo in bulk</td><td rowspan="3">4.5</td><td rowspan="2">0.015</td></tr>
<tr><td colspan="2">Peak bulkheads and machinery space end bulkheads</td></tr>
<tr><td colspan="2">Watertight bulkheads and other tanks bulkheads</td><td>0.01</td></tr>
<tr><td colspan="2">Non-tight bulkheads in tanks</td><td rowspan="2">5.0</td><td>0.005</td></tr>
<tr><td colspan="2">Other non-tight bulkheads</td><td>0</td></tr>
</table>

Table 2 Minimum net thickness for stiffeners and tripping brackets

<table>
<tr><th>Element</th><th>Location</th><th>Net thickness</th></tr>
<tr><td rowspan="3">Stiffeners and attached end brackets</td><td>Tank boundary</td><td>3.0 + 0.015 L_2</td></tr>
<tr><td>Structures in deckhouse and superstructure and decks for vessels with more than 2 continuous decks above 0.7 D from baseline</td><td>4.0</td></tr>
<tr><td>Other structure</td><td>3.5 + 0.010 L_2</td></tr>
<tr><td colspan="2">Tripping brackets</td><td>3.0 + 0.015 L_2</td></tr>
</table>

Table 3 Minimum net thickness for primary supporting members

Element	*a*	*b*
Bottom centreline girder and lower strake of centreline wash bulkhead	5.0	0.03
Other bottom girders	5.0	0.017
Floors	5.0	0.015
Floors in peak tanks	5.0	0.025 [1)]
PSM supporting side shell, ballast tank, cargo tank and hold intended for cargo in bulk [2),3)],	4.5	0.015
Other PSM	4.5	0.01

1) The value of bL_2 does not need to be greater than 5.0.
2) For stringers in double side next to dry space not intended for cargo in bulk, the value of bL_2 does not need to be taken greater than 2.5.
3) Other specific requirements related to ship types are given in Pt.5.

Tables taken from DNV GL Rules for Classification: Ships, Pt.3. Ch.6. Sc3. [17].

The calculation of the thickness and section modulus of the different structural elements were conducted based on the DNV GL design code for ships lower than 100 meters in length. After that they are compared with the minimum requirements and the maximum values were adopted. Figure below illustrates the specification of the main structural elements in our design.

Midship section structural components			
Element	Result from DNV	Adopted	notes
Bottom shell (mm)	6.8	7	
Bottom keel (mm)	11.8	12	
Bilge (mm)	9.0	9	
Inner bottom plating	6.3	6.5	
floors (mm)	5.4	5.5	
Brackets (mm)	6.8	7	
Bottom Long girder (mm)	7.4	7.5	
Bottom Long section modulus (cm^3)	29.7	125*75*10	Unequal leg angles
Side shell	6.4	6.5	
Side long section modulus (cm^3)	21.7	125*75*10	Unequal leg angles
Side stringer section modulus (cm^3)	58.5	150*90*12	Unequal leg angles
Transverse frames	36.1	150*90*9	Unequal leg angles
Deck shell	7.729	8	
Deck long	33.07809375	125x75x10	Unequal leg angles
Deck girder	27.8971875	125x75x10	Unequal leg angles

Figure 31 Amidship section main structural elements specification based on DNV GL rules for ships less than 100m in length

DNV GL describes the specification of the beams using the section modulus, hence the designer should select the shape of the stiffeners that has the same section modulus required by the classification societies. In the figure above, the stiffeners dimensions were selected based on the available steel section in the market (the one adopted here is JFE STEEL SECTIONS FOR SHIPBUILDING catalogue).

7.4. Preliminary cross section drawings

The drawing of the amidship section is illustrated below. As can be seen, the longitudinal system with double bottom has been adopted. The ship has 5 decks at the amidship. The inner bottom and twin deck are loaded by the cargo (required high bearing capacity), while the main deck and the higher ones are only loaded by the superstructure and passengers. That means the load reduces towards the higher deck. Therefore, thickness of the shell and section modulus of the stiffeners in the superstructure can be reduced. In this study only the obtained dimensions from the DNV rules for the structure below the main deck area used. These dimensions do not include the corrosion or owner allowance, neither the reduction of the dimensions due to the reduced loads towards the higher decks.

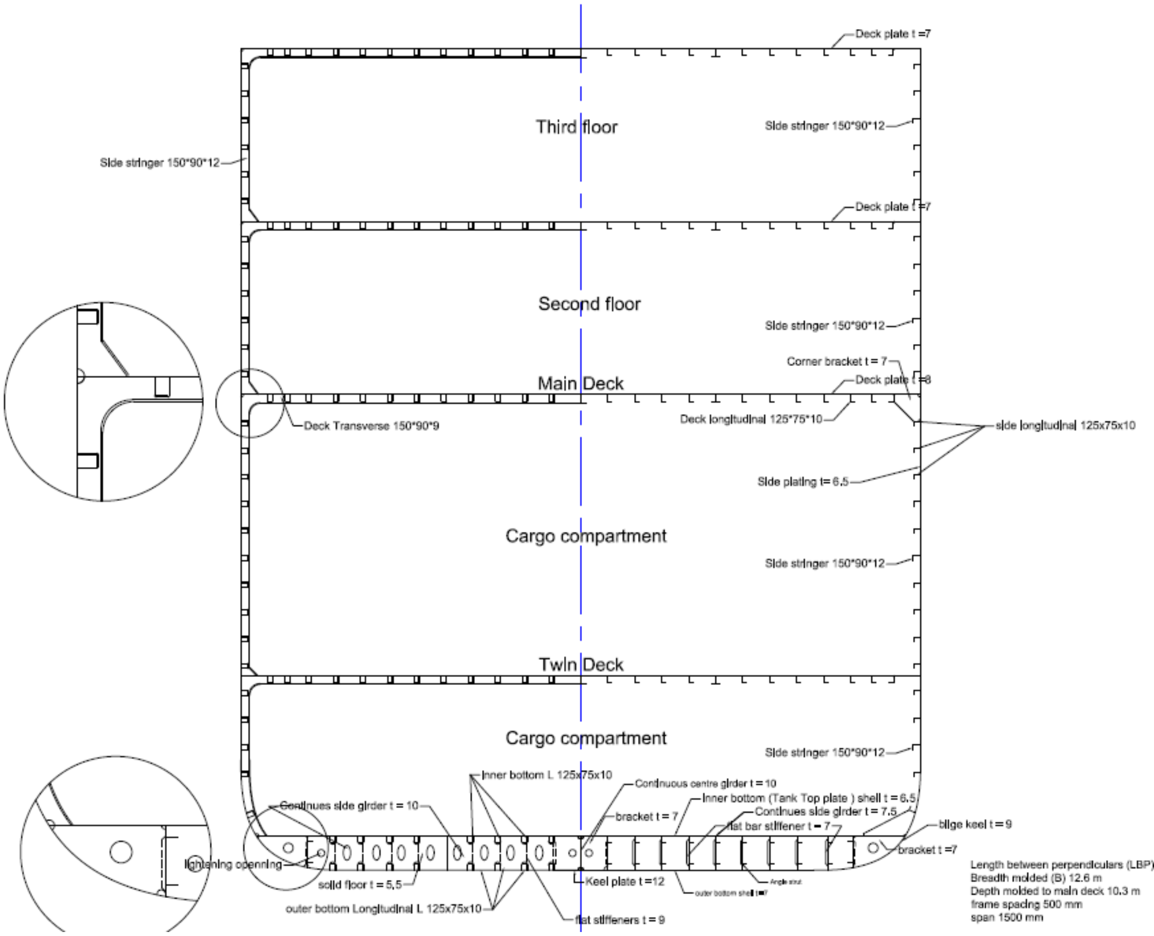


Figure 32 Midship section showing the main specification of the structural component

As we will use fuel cell, which does not contain any moving parts, the stiffening system may not be changed in the engine room. However, in case that the owner for some reason decides to use normal diesel engine instead of the fuel cells, the construction system will change as illustrated in the figure below. As can be seen in this figure it is common to use the transverse system with many heavy girders in the engine room to support the engine and absorb more of its vibrations. It is noteworthy that the cross-section of the diesel engine will not be used in our case and just presented here to amplify the consequence of changing the propulsion system on the ship construction.

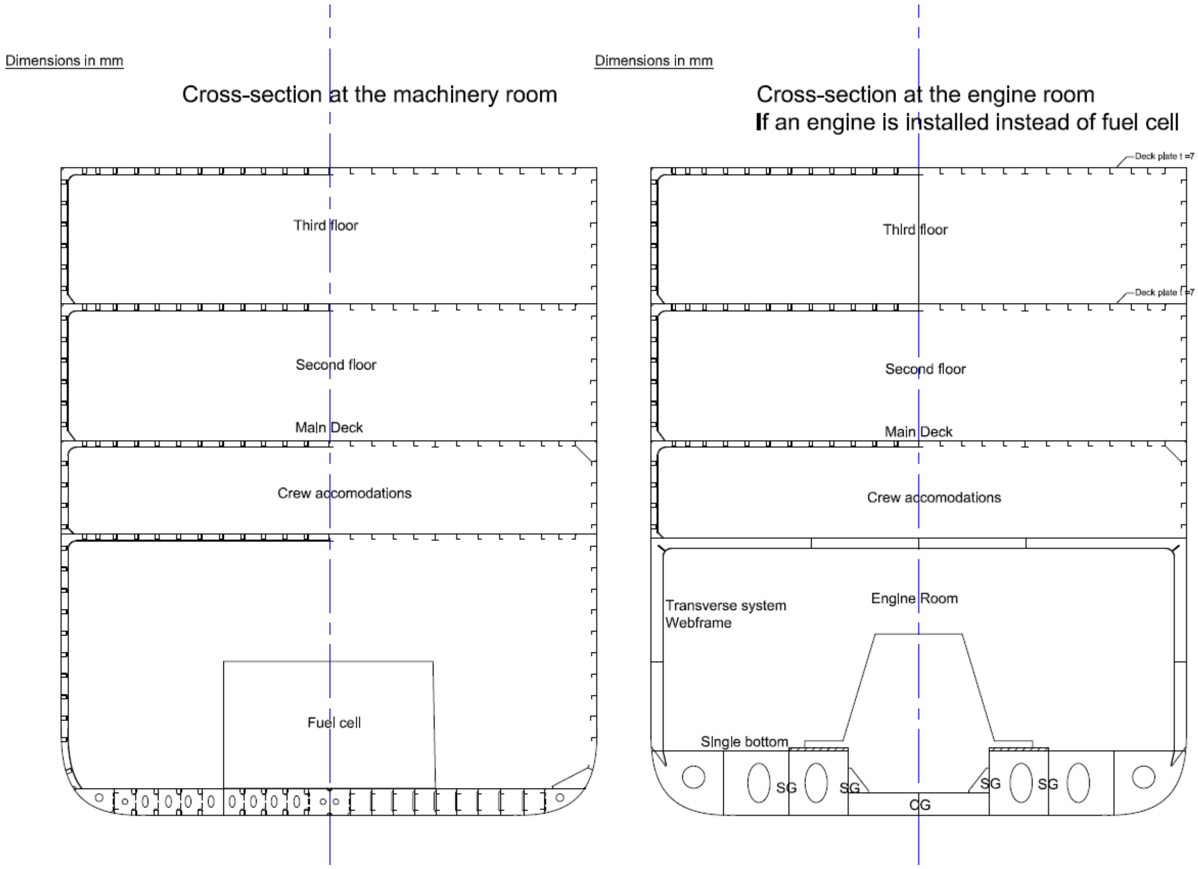


Figure 33 Cross section at the engine room, (Left) adopted cross section for our case study which uses the fuel cell as main source of energy. (Right) The changes in the ship construction if the propulsion system is changed.

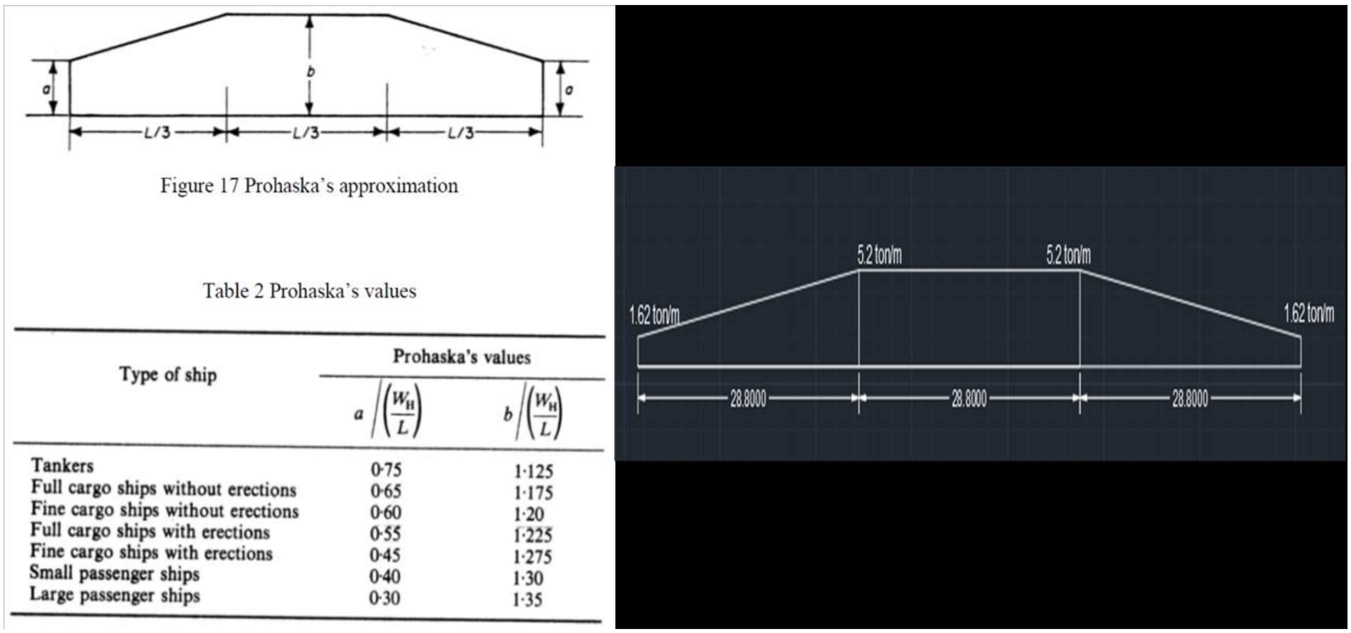
7.5. Structural requirements

Structural requirements are very important in terms of safety. Not following the guidelines may lead to unsafe design or even fatal accidents. The International Association of Classification Societies (IACS) defines the minimum longitudinal (bending) strength, maximum sheer stresses and minimum scantling thicknesses [18]. The ship must fulfill the structural requirements set by the classification society for it to be classified safe for operations.

To make sure our design is suitable, calculations were made. Since, the frame consists of multiple scantlings, idealization was used for the 1st and 2nd moment calculations. Before that, shear stress and bending moments are estimated.

7.6. Shear stress and bending moment

In order to estimate the shear force and the longitudinal bending moment acting on the structure, we must first define the load distribution. The definition of the weight distribution is an iterative process that was not conducted with high accuracy in this report. As a simplification for proceeding with the calculation we assumed that the lightship weight can be described using two items. The first is the hull steel weight W_H, which assumed equal 350 tons and it distribution follows Prohaska's approximation, see figure below. The second load includes all the other remaining load components (including the permanent ballast if any) which assumed equals 100 tons and uniformly distributed thought out the length of the ship.



Type of ship	Prohaska's values $a / \left(\frac{W_H}{L}\right)$	$b / \left(\frac{W_H}{L}\right)$
Tankers	0·75	1·125
Full cargo ships without erections	0·65	1·175
Fine cargo ships without erections	0·60	1·20
Full cargo ships with erections	0·55	1·225
Fine cargo ships with erections	0·45	1·275
Small passenger ships	0·40	1·30
Large passenger ships	0·30	1·35

Figure 34 Hull weight distribution using Prohasak's approximation

After getting the weight distribution and the buoyancy distribution from the hydrostatics, the net load can be obtained by subtracting weight distribution form buoyancy distribution $p = b - w$. Then the net load can be integrated to get the shear force $Q = \int p\,dx$ and integrated again to get the bending moment $M = \int Q\,dx$. These calculations were conducted using Maxsurf and the resulting weight distribution for the ballast condition (without the cargo is illustrated below).

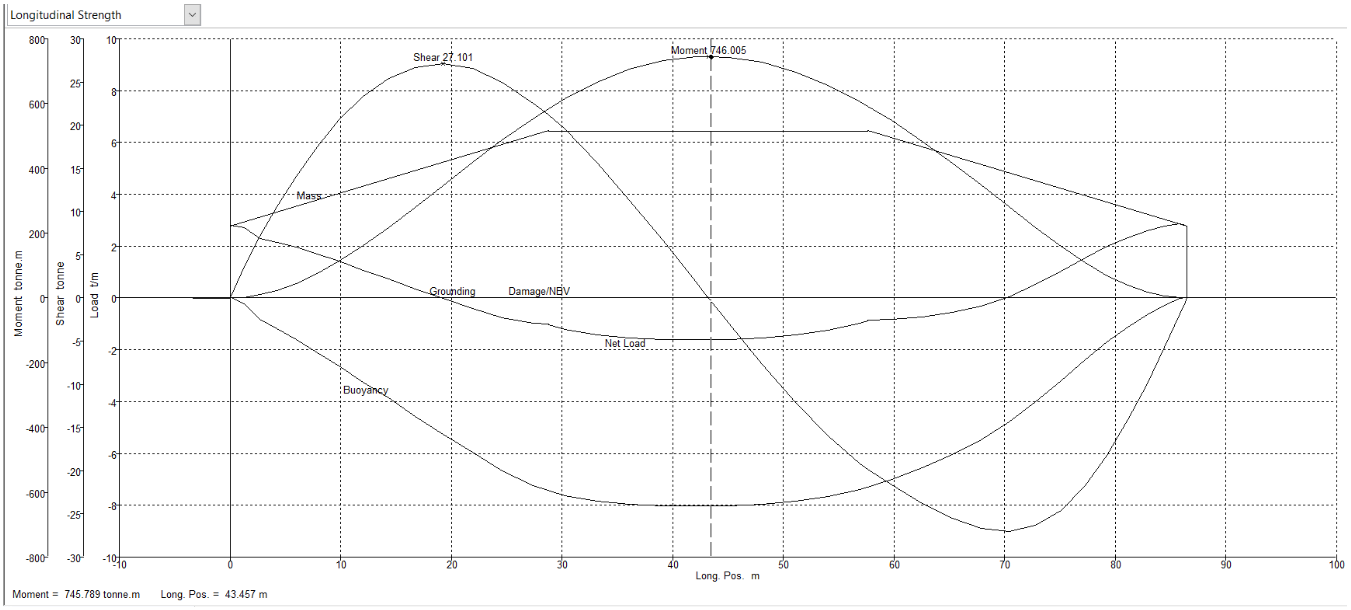


Figure 35 Net load, Shear force and bending moment diagram as obtained from Maxsurf (for ballast condition) Approximation

7.7. Longitudinal strength

In IACS Req. 1989/Rev.9 2019, the minimum hull section modulus is given and the maximum permissible hull girder bending stress [18]. This limits the permissible bending stress to

$$\sigma = \frac{175}{k}\ MPa$$

Where,

$k = material\ factor.$

With common hull structural steel (Grade B) this essentially leads to maximum permissible bending stress of 175 MPa. Comparing this to our results, shows that our design does not exceed this value and therefore fulfills the requirement.

$$\sigma_{Deck} = 1.26\ MPa$$

$$\sigma_{permissible} = 175\ MPa$$

Have to note here that we did not include cargo in the bending moment calculation, nor did we include wave bending moments, since in the canal there are expected to be no waves.

In IACS Req. 1989/Rev.9 2019, the minimum moment of inertia of hull section at the midship is also defined as

$$I = 3CL^3B(C_B + 0.7) * 10^{-8}\ m^4$$

Where,

$C = 10.75 - (\frac{300-L}{100})^{1.5}$ $, for\ \ 90 \leq L \leq 300.$

With our ship design, the moment of inertia of hull section at the midship should not be less than 3.32 m^4. When comparing this to our results, we can see that our design has greater moment of inertia at the midship section, and therefore fulfills the requirement.

$$I = 45.87\ m^4$$

$$I_{min} = 3.32\ m^4$$

7.8. Shear strength

In IACS Req. 1989/Rev.9 2019, the maximum hull girder shear stress along the length L is given as

$$\tau = \frac{110}{k}\ MPa$$

Where,

$k = material\ factor.$

With common hull structural steel (Grade B), this essentially leads to maximum permissible shear stress of

$$\tau_{permissible} = 110\ MPa$$

We did not include any shear stress calculation, since the section in consideration was the midship section where shear stress equals near 0. Different section has to be considered if we want the maximum shear stress values as seen in Figure 35.

7.9. Hull girder ultimate strength

Hull girder ultimate strength is the ships maximum load capacity. After this point the structure starts to collapse. The material starts to yield, plastically (permanently) deform. Since we want to avoid structural collapse, a safety factor is given for the design. In earlier section, the maximum permissible stress is given.

With our material choice, this leads to minimum safety factor of 1.375, if we were to reach the maximum permissible stress.

With our stress results, the factor of safety is

$$FOS = \frac{\sigma_{yield}}{\sigma_{deck}} = \frac{240\ MPa}{1.26\ MPa} = 190.5$$

7.10. Structural continuity

According to DNV GL, attention must be paid to structural continuity. What this essentially means is, that the continuity of strength is to be maintained. “At the termination of a structural member, structural continuity shall be maintained by the fitting of effective supporting structure. Longitudinal members shall be arranged in such a way that the continuity is maintained.” [19]. In plate thicknesses, this means that the transition should be gradual and smooth.

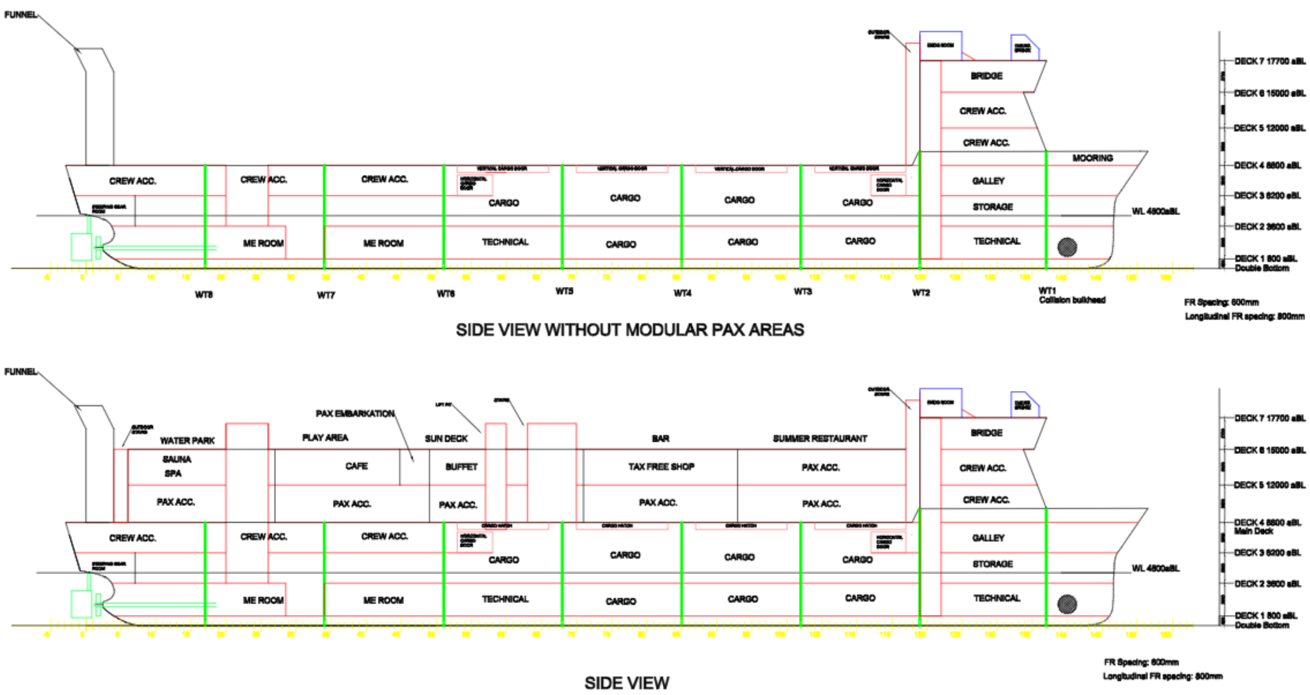


Figure 36 Side view of Saimaa Hybrid

The structural continuity of Saimaa Hybrid can be seen in the Figure above. Structural continuity has been implemented so that main steel bulkheads reach from double bottom all the way to the upmost decks in the vertical same line.

7.11. Ship specific challenges

Main challenge from structural point of view for Saimaa Hybrid are the modular passenger facility areas. As they are not a solid part of the ship, it can be difficult to estimate the structural requirements and their effect on the ship. The modular design on a ship is not very common, and thus there is not as much experience on challenges of such design compared to a traditional one where the ship is one solid structure. The way that in which the modular parts will be attached to the ship must be studied and considered to ensure they are safe and within the limits of requirements. Lifting the five modular blocks from the ship for winter will require heavy equipment.

8. Powering and machinery

This chapter contains the ship's operating profile and estimation of needed powering and machinery solutions.

8.1. Operating profile

On route there are 8 canal locks, so the ship will spend very large part of the trip in the locks. Also, the canal has a speed limit of 9 km/h (approx. 4,85 kn). The lake areas along the route have no speed limit but they make relatively short part of the trip. These limitations mean that there is no need to make the ship very high speed. 12 knots was chosen to be the design speed of the vessel even though it is not possible to cruise this speed for a very long time on this route. If the design speed would have been chosen according to the speed limits in the canal, the ship would have been too slow if at some point of its lifecycle the operational route would change. Speed of 12 kn may be needed more often if the ship will at some point operate on different routes during its lifecycle.

Figure 37 shows the operating profile of the vessel. Departure from Lappeenranta is at 10 o'clock. The route takes approximately 8 hours, so the arrival at Vyborg is at 18 o'clock. She stays 5 hours in the

Vyborg port and departures again at 23 o'clock. Finally, she will arrive back at Lappeenranta at 7 o'clock in the morning, where she will spend 3 hours before departure.

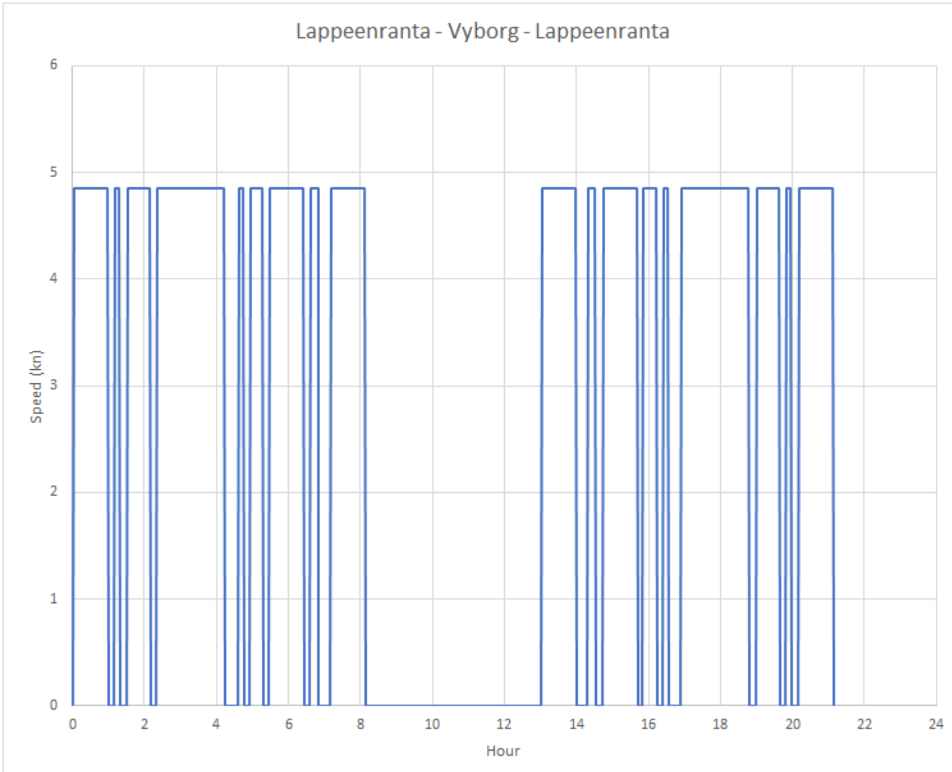


Figure 37 Operating profile

Online data was used to create the operating profile. Google Maps was used to approximate the length of the route, the distances between locks and the connected lakes. Time spent in the locks was approximated by using a time-lapse video of vessel passing through the canal [20]. With this above information combined with the speed limit, the profile was created.

Finnish-Swedish ice classifications have minimum requirements for engine output. The engine output shall not be less than 1000 kW for ice class IA, IB and IC, and not less than 2800 kW for IA Super. Since the ice conditions in Saimaa region will not be very challenging, we chose IC -class for our ship. It means that the ship can manage in easy ice conditions with ice thickness of 0,4 meters. Help from icebreakers is required. The thickness of the ice in waterways cleared by icebreaker may not exceed 0,6 meters for ice class IC. [21]

8.2. Energy source

To achieve the zero-emission target, Saimaa Hybrid will use hydrogen fuel cells as the main energy source. Hydrogen has very high energy density, but it is possible to store only 80 kg of fuel / m3 even with the densest liquid form of hydrogen [22]. Thus, hydrogen requires lot of space, but route from Lappeenranta to Vyborg is rather short (approx. 60 km), so it is not necessary to carry very large amounts of hydrogen onboard since the ship visits ports very often. Other main challenge regarding the hydrogen is its current production, or basically the lack of it. As the availability is low, buying the hydrogen fuel needed for operation could be very difficult at least nowadays. As fuel cell technologies develop and become more common, we may assume that this issue gets easier in the future.

With the current situation we have chosen to couple the fuel cells with batteries. With the hybrid system, less fuel is needed, which is expensive and has low availability. Also, the weight is manageable compared to solution using only batteries. Often the weight limit is reached before the required capacity. Also, fuel cells have poor dynamic response in transient power demands, with batteries we can improve this. This hybrid power system could prove to be very effective. The fuel cell – battery hybrid system may be considered expensive, but essential to be able to achieve the zero-emission target.

8.3. Propulsion system

Saimaa Hybrid has two main electric engines for propulsion, which get the electricity from hydrogen fuel cells or batteries. The ship will have a fixed pitch single-screw propeller with four blades. Four blade propeller is made out of stainless steel alloys and it gives good low-speed handling and performance. It is also cheaper than 5- or 6-blade propeller and its fuel economy can be considered very good. The propeller was chosen to be fixed pitch type because of its cheaper manufacturing cost, installation cost and operational cost. Controlled pitch propeller would provide better maneuverability compared to fixed pitch propeller, but as the ship uses electric engines, the engine loads can be changed rapidly and thus the advantage from controlled pitch propeller would be too low to overcome the difference in cost. Controlled pitch propeller is also much more complex system which increases the chance for malfunction compared to a fixed pitch propeller. The diameter of the propeller was chosen to be 2.5 meters. The ship is equipped with one 70 kW bow thruster with diameter of 1 meter. Rudder is semi-balanced type and located behind the propeller. The rudder area is 10.5 m^2.

8.4. Resistance

The total resistance of the ship is required to determine the propulsion power demand. The total resistance of the ship was estimated using the Holtrop & Mennen method [23].

This gave us the total resistance of the ship as a function of speed, which is presented below (Figure 38**Error! Reference source not found.**). This gives us approximately a total resistance of 90 kN for the design speed.

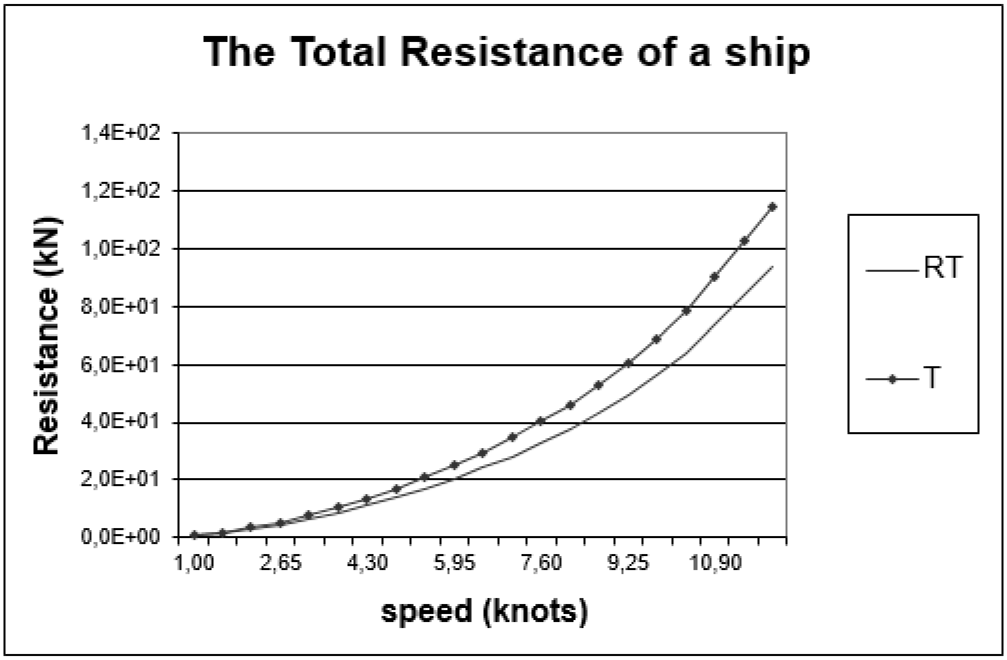


Figure 38 The total resistance of the ship as a function of speed. RT = total resistance. T = propeller thrust.

9.5 Propulsion power

Propulsion power demand is obtained using the Holtrop & Mennen method [23]. Effective power of 570 kW is needed for the design speed of 12 knots, which means that the required shaft power demand is approximately 690 kW. The Finnish-Swedish ice class IC requires the propulsion power to be no less than 1000 kW, so the propulsion power must be chosen according to the requirement. The ship will have two main engines providing 500 kW each, giving the total propulsion power of 1000 kW. With design speed the engine load is 69 %. With 100% engine load our maximum speed is 13 knots according to the figure below. This means our reserve speed is 1 knot.

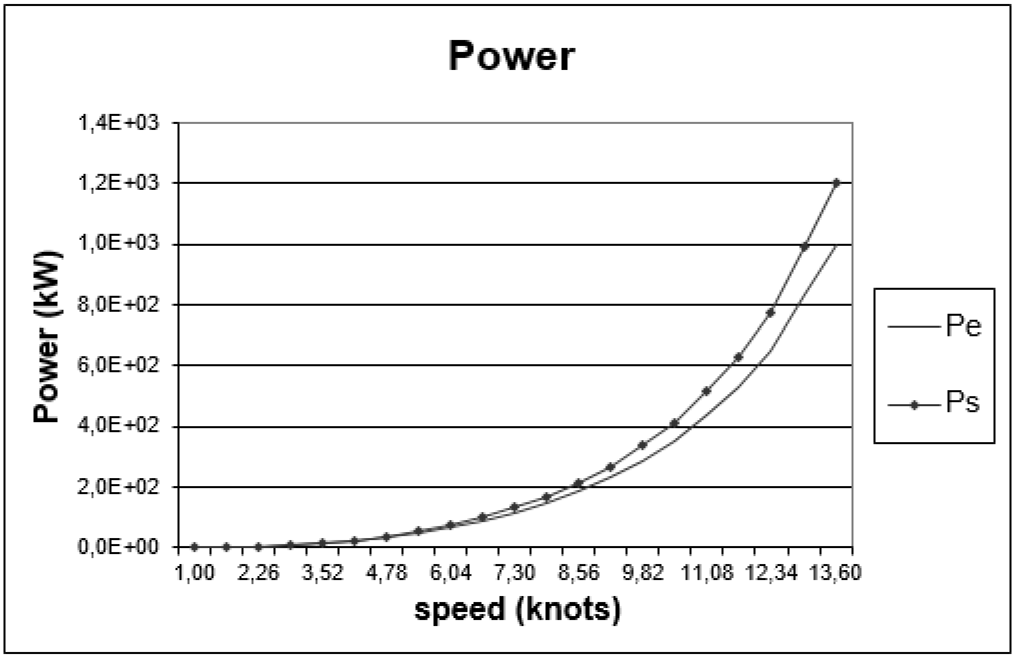


Figure 39 Propulsion power demand as a function of speed

8.5. Hotel power

The hotel power demand is estimated from source [24].

Hotel & aux consumption	kW
Steering	5
Bow thruster	70
Navigation & Communication	5
HVAC	100
Water systems	50
Cabin el. consumption	57,4
Public el. consumption	50
Galley el. consumption	80
Technical	60
Total	477,4

Figure 40 Estimation of the hotel power demand.

The HVAC energy and water system consume big part of the total consumption because there is no excess heat from the engines, so all the air and water need to be heated with electricity.

8.6. Validation using Maxsurf

In order to validate the manual calculated Power using Holtrop method, the Maxsurf resistance package has been employed. Maxsurf resistance can estimate the resistance of our ship using different methods, one of them is the Holtrop method. Holtrop method is one the most common method that can be used to calculate the power and resistance of displacement ships. It has some limitation in the main particulars of the ship, especially the ratios like L/B and B/T.

Figure below illustrates a comparison between the Maxsurf and Excel results. It can be observed that both curves are well coinciding. Also, a slight difference at high speed is noted. It is noteworthy that Maxsurf uses the same concept of the Excel, but the difference may be due to small variation of the inputs.

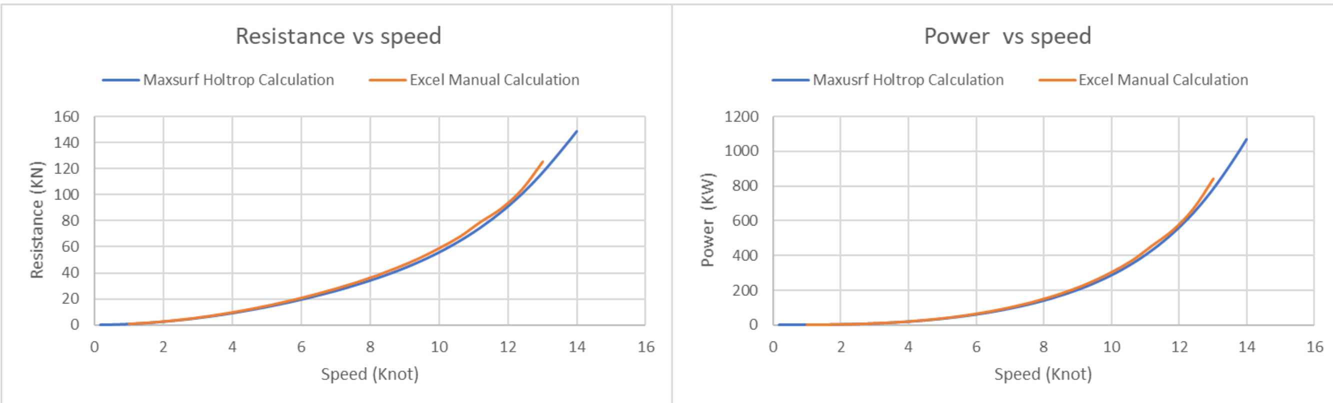


Figure 41 Comparison between results from Excel and Maxsurf.

8.7. Total power

We decided to have 40 x 48 kWh batteries and 3 x 200 kWh fuel cells. The propulsion power is 1000 kW and hotel power 478 kW. This means that our total power demand is 1478 kW.

9. Weight and Stability

The main components and systems of our ship are classified according to the SFI system. Weight estimation calculations are made for the ship in “summer mode”, which means that the modular passenger areas are installed on the ship. Reason for this is that stability is less of an issue when the ship is in winter mode. Also, in winter mode it is possible to have more deadweight than in summer because the modular passenger facilities will be removed.

9.1. SFI main components

2		**Hull**
	20	Hull materials
	25	Superstructure & Deckhouse
3		**Equipment for cargo**
	30	Hatches
	31	Equipment for cargo
4		**Ship equipment**
	40	Steering gear
	40	Bow thruster
	41	Radar
	41	Mast
	41	Other navigation eq
	42	Communication equipment
	43	Anchoring and mooring eq.
	44	Repair & washing equipment
	45	Lifting & transport eq.
5		**Equipment for crew**
	50	Lifesaving equipment
	51	Insulation, panels, bulkheads, doors, side scuttles and windows
	52	Internal deck covering, ladders, steps, railing
	53	External decks
	54	Furniture and inventory
	55	Galley, pantry, prov. and laundry equipment
	56	Transport equipment for crew
	57	Ventilation, aircondition and heating systems
	58	Sanitary system and equipment
6		**Machinery main components**
	60	Main engine
	63	Propeller plant
	63	Reduction gear
	66	Emergency generator
7		**Systems for machinery**
	70	Fuel cell system
	70	Battery pack
	71	Lubricating oil system
	72	Machinery cooling system
	73	Compressed air systems
	79	Automation system for mach.
8		**Ship systems**
	80	Ballast, bilge and drain systems
	81	Fire and lifeboat alarm systems
	81	Firefighting systems
	82	Air and sounding
	83	Special common hydraulic oil systems
	85	Electrical systems, general
	86	Electrical supply system
	87	Electrical common distribution
	88	Electrical cables and installation
	89	Electrical distribution system

Figure 42 The SFI classifications made according to the provided example from Wärtsilä

9.2. Lightship weight estimation

Lightship weight was solved by estimating weights for all different components in our equipment list.

9.3. Equipment list and weights

	Grand total	1387700		
	Without hull & machinery	114900		

2. Hull

Code	Item	Quantity	Weight/item (kg)	Weight*quantity
20	Hull	1	800000	800000
25	Superstructure & Deckhouse	1	350000	350000
			Total	1150000

3. Equipment for cargo

Code	Item	Quantity	Weight/item (kg)	Weight*quantity
30	Hatches	6	2000	12000
31	Equipment for cargo	1	2000	2000
			Total	14000

4. Ship Equipment

Code	Item	Quantity	Weight/item (kg)	Weight*quantity
40	Steering gear	1	1500	1500
40	Bow thruster	1	1500	1500
41	Radar	2	200	400
41	Mast	1	1000	1000
41	Other navigation eq	1	4000	4000
42	Communication equipment	1	500	500
43	Anchoring and mooring eq.	2	3000	6000
44	Repair & washing equipment	1	2000	2000
45	Lifting & transport eq.	1	1000	1000
			Total	17900

5. Equipment for crew

Code	Item	Quantity	Weight/item (kg)	Weight*quantity
50	Lifesaving equipment	6	1000	6000
51	Insulation, panels, bulkheads, doors, side scuttles and	1	15000	15000
52	Internal deck covering, ladders, steps, railing	1	5000	5000
53	External decks	1	10000	10000
54	Furniture and inventory	1	8000	8000
55	Galley, pantry, prov. and laundry equipment	1	5000	5000
56	Transport equipment for crew	1	5000	5000
57	Ventilation, aircondition and heating systems	1	6000	6000
58	Sanitary system and equipment	1	6000	6000
			Total	66000

6. Machinery main components

Code	Item	Quantity	Weight/item (kg)	Weight*quantity
60	Main engine	2	4000	8000
63	Propeller plant	1	6000	6000
63	Reduction gear	1	1500	1500
66	Emergency generator	1	3500	3500
			Total	19000

7. Systems for machinery components

Code	Item	Quantity	Weight/item (kg)	Weight*quantity
70	Fuel cell system	3	5000	15000
70	Battery pack	40	2030	81200
71	Lubricating oil system	1	500	500
72	Machinery cooling system	5	1000	5000
73	Compressed air systems	2	300	600
79	Automation system for mach.	1	1500	1500
			Total	103800

8. Ship systems

Code	Item	Quantity	Weight/item (kg)	Weight*quantity
80	Ballast, bilge and drain systems	1	5000	5000
81	Fire and lifeboat alarm systems	1	500	500
81	Firefighting systems	1	2000	2000
82	Air and sounding	1	500	500
83	Special common hydraulic oil systems	1	2000	2000
85	Electrical systems, general	1	1000	1000
86	Electrical supply system	1	1000	1000
87	Electrical common distribution	1	2000	2000
88	Electrical cables and installation	1	2000	2000
89	Electrical distribution system	1	1000	1000
			Total	17000

Figure 43 Equipment list & weights

9.4. Center of gravity

The center of gravity is an important factor in the ship's stability. Vertical center of gravity of the ship was estimated. Factor K and outfitting coefficient were estimated based on empirical data (Figures Figure 44 & Figure 45).

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		

Figure 44 Factor K for different ship types (taken from lecture notes)

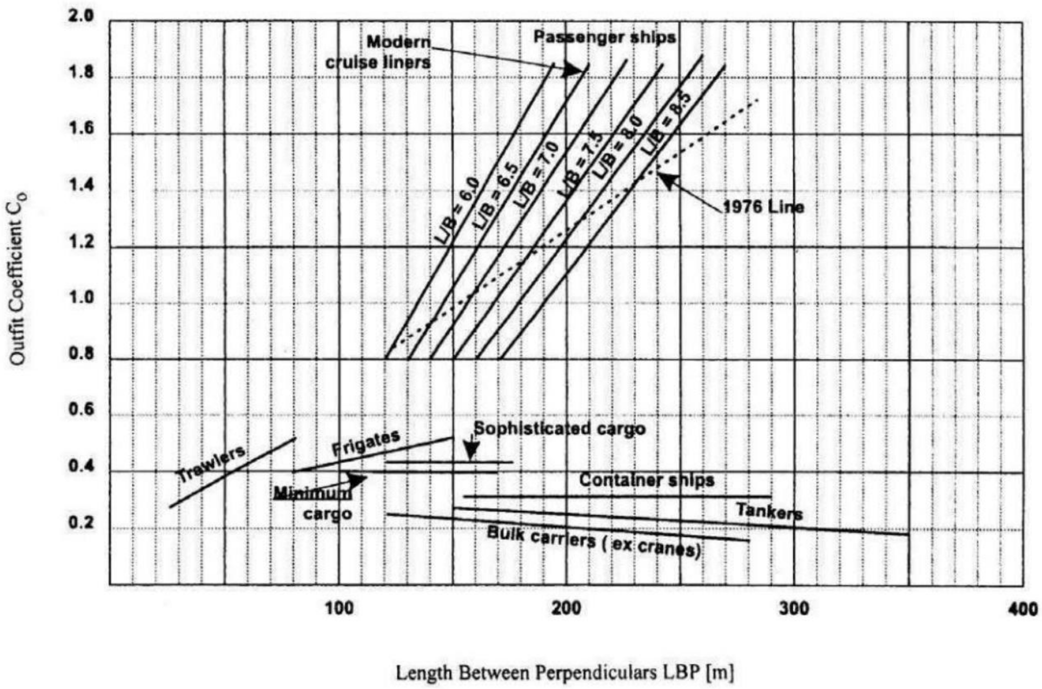


Figure 45 Outfitting coefficient (taken from lecture notes)

Ship's main characteristics	
L(m)	92,5
B(m)	12,6
T(m)	4,45
D(m)	8,8
CB	0,73
LCB(m) @AP (m)	45,5
Lightship weight	
1653,36	
KG_{Light}	
5,321	

Structural weight	
Length of superstructure (m)	66,6
Height of superstructure (m)	6,2
Length of deckhouse (m)	10,8
Height of deckhouse (m)	8,9
E	2342,216
K	0,031
WS (tonne)	1203,71
KG_{hull} (m)	4,265
LCG_{hull} (m)	45,35

Machinery weight	
MCR (KW)	500
N (rpm)	200
type of plant	other
No of engines	2
cm	0,69
W_M (tonne)	100,000
Height of engine room (m)	2,8
Height of double bottom (m)	0,8
KG_M (m)	1,5

Outfitting weight	
Co	0,3
W_o (tonne)	349,65
KG_o (m)	10,05

Figure 46 Lightship weight components & vertical center of gravities

The excel sheet estimated the weights of different components and their vertical center of gravities. As a result, the whole ship's VCG was estimated to be 5.3m.

9.5. Deadweight estimation

The weight of cargo is estimated from cargo hold volume and log wood density. Passenger and crew weights are estimated to be average weight of 80kg/person and 20 kg of luggage per person. Other supplies and their weights are estimated from lecture notes.

	TOTAL WEIGHT (ton)		
	2036		
Cargo weight			
	Quantity	Weight/item (kg)	Weight*quantity
	1	2000000	2000000
		Total	2000000
Hydrogen weight			
	Quantity (m3)	Weight/item (kg/m3)	Weight*quantity
	10	70,85	708,5
		Total	708,5
Lube oil weight			
	Quantity (m3)	Weight/item (kg/m3)	Weight*quantity
	3	800	2400
		Total	2400
Fresh water weight			
	Quantity (m3)	Weight/item (kg/m3)	Weight*quantity
	46,58	1000	46580
		Total	46580
Crew & their effects			
	Quantity	Weight/item (kg)	Weight*quantity
	42	170	7140
		Total	7140
Passengers			
	Quantity	Weight/item (kg)	Weight*quantity
	232	100	23200
		Total	23200
Weight of provisions			
	Quantity	Weight/item (kg)	Weight*quantity
	274	10	2740
		Total	2740

Figure 47 Deadweight estimation

9.6. Displacement

The original displacement that was calculated with Excel earlier was 3626t for the maximum draft of 4.45m. The lightship weight and deadweight estimation done in this chapter gives us a displacement of 3424t.

9.7. Uncertainty and weight reserve

Saimaa hybrid can be classified as a new type ship that has not been built before. The ship combines the characteristics of the general cargo ship and passenger ship on the same time. Therefore, selecting the appropriate coefficient for estimating the different lightweight and deadweight component is quite confusing and may result in underestimated or overestimated weights. In addition, as the ship carries large modular superstructure with high number of passengers, the vertical center of gravity is assumed to be higher than usually in a normal cargo ship. Therefore, we believe that detailed calculation of the weight components is the best method to have an accurate estimation of the lightship weight and deadweight. As this method requires many hours of work and it is also out of the course scope, we just used the highest suggested coefficient of either passenger or general cargo ship. As the uncertainties are higher than normal, we assumed having large reserve weight of 15% of the lightship weight, which equals nearly 250 tons. In case that the center of gravity is higher than required by IMO, a reserve weight at the double bottom tanks may be added to decrease its value. The reserve weight may be added also to the extreme double bottom tanks in the aft or forward of the ship to amend the trim. The location of reserve weights is illustrated in the figure below.

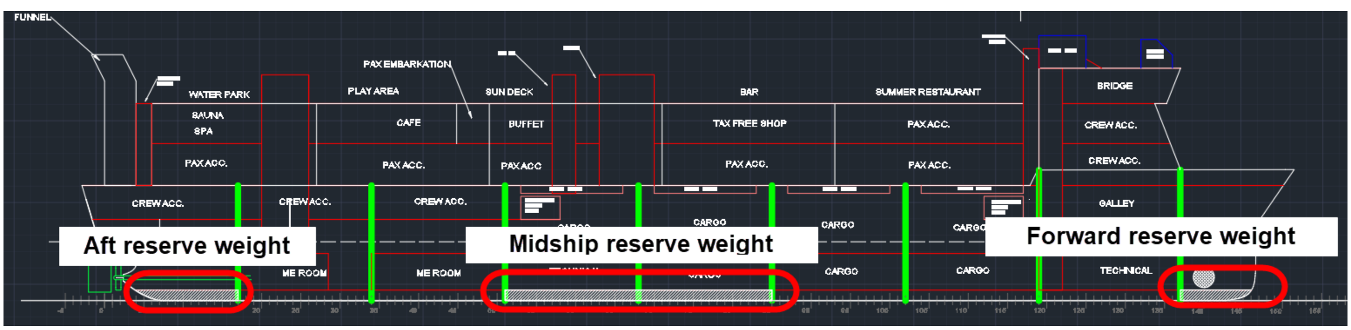


Figure 48 reserve weights location

9.8. Stability and GM

The 3D model that described in **Error! Reference source not found.** was adopted to investigate the large angle stability of the proposed model and ensuring it will pass the IMO criteria applied on all types of ships. The model was created using a basic ship from our database (that has nearly the same dimensions of the case study) which is parametrized to meet our selected dimensions. The profile, body plan and the 3D model of the proposed case study is illustrated in the Figure 26.

Table below illustrates the equilibrium analysis using Maxsurf. The ship has slight trim by aft which can be reduced using reserve ballast tanks at the forward of the ship or by distributing the cargo to shift it VCG towards the aft. The GM_0 is small however, the ship passes all the requirements of IMO. The GZ curve of the fully loaded condition is illustrated in Figure 49.

Equilibrium at fully loaded condition (in summer)	
Draft Amidships m	4.252
Displacement t	3373
Heel deg	0.0
Draft at FP m	4.052
Draft at AP m	4.453
Draft at LCF m	4.250
Trim (+ve by stern) m	0.401
WL Length m	87.271
Beam max extents on WL m	12.599
Wetted Area m^2	1392.248
Waterpl. Area m^2	866.757
Prismatic coeff. (Cp)	0.724
Block coeff. (Cb)	0.676
Max Sect. area coeff. (Cm)	0.973
Waterpl. area coeff. (Cwp)	0.788
LCB from zero pt. (+ve fwd) m	45.476
LCF from zero pt. (+ve fwd) m	44.433
KB m	2.236
KG fluid m	4.392
BMt m	2.827
BML m	117.360
GMt corrected m	0.671
GML m	115.204
KMt m	5.063
KML m	119.595
Immersion (TPc) tonne/cm	8.884
MTc tonne.m	44.162
RM at 1deg = GMt.Disp.sin(1) tonne.m	39.480
Max deck inclination deg	0.2610
Trim angle (+ve by stern) deg	0.2610

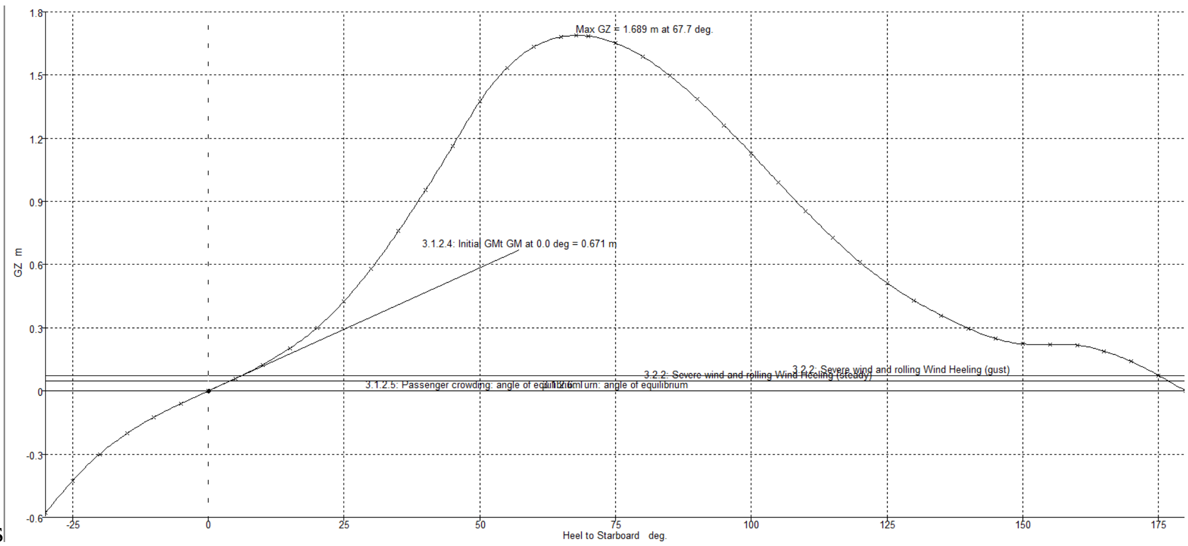


Figure 49 GZ curve of the fully loaded condition in summer (with modular superstructure)

The table below indicates that the ship passes all the requirements of IMO A.749(18) Ch3 - Design criteria applicable to all ships.

Code	Criteria	Status	Margin %
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 0 to 30	Pass	+112.75
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 0 to 40	Pass	+154.95
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 30 to 40	Pass	+274.78
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.2: Max GZ at 30 or greater	Pass	+264.50
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.3: Angle of maximum GZ	Pass	+76.36
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.4: Initial GMt	Pass	+323.33
A.749(18) Ch3 - Design criteria applicable to all ships	3.2.2: Severe wind and rolling	Pass	
	Angle of steady heel shall not be greater than (<=)	Pass	+87.94
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	Pass	+91.00
	Area1 / Area2 shall not be less than (>=)	Pass	+333.45

10. Economic Assessment

Estimating the production cost is a fundamental part of ship design as it steers the process from concept determination to detail specification. Our cost estimation will be carried out in an iterative process: Based on the main parameters, including weight, principal dimensions, size and other general performance parameters.

Another notable consideration is when the operational time of the canal of Saimaa lake is extended to 11 months per year, we expect the target customers served by the ferry in different seasons vary significantly in their needs. Thus, achieving the ferry's convertibility and flexibility in a cost-efficient way would also be one of the important parameters.

This chapter estimates the building costs of the ship. Ship equipment prices are estimated with the SFI classes. We have defined and assessed 3 key performance indicators for our ship, the Net Present Value (NPV), the Internal Rate of Return (IRR) and the Return on Investment (ROI). The improvement of the KPIs are also discussed. The last part of the report SWOT-analyses our concept considering the defined mission, objectives and KPIs.

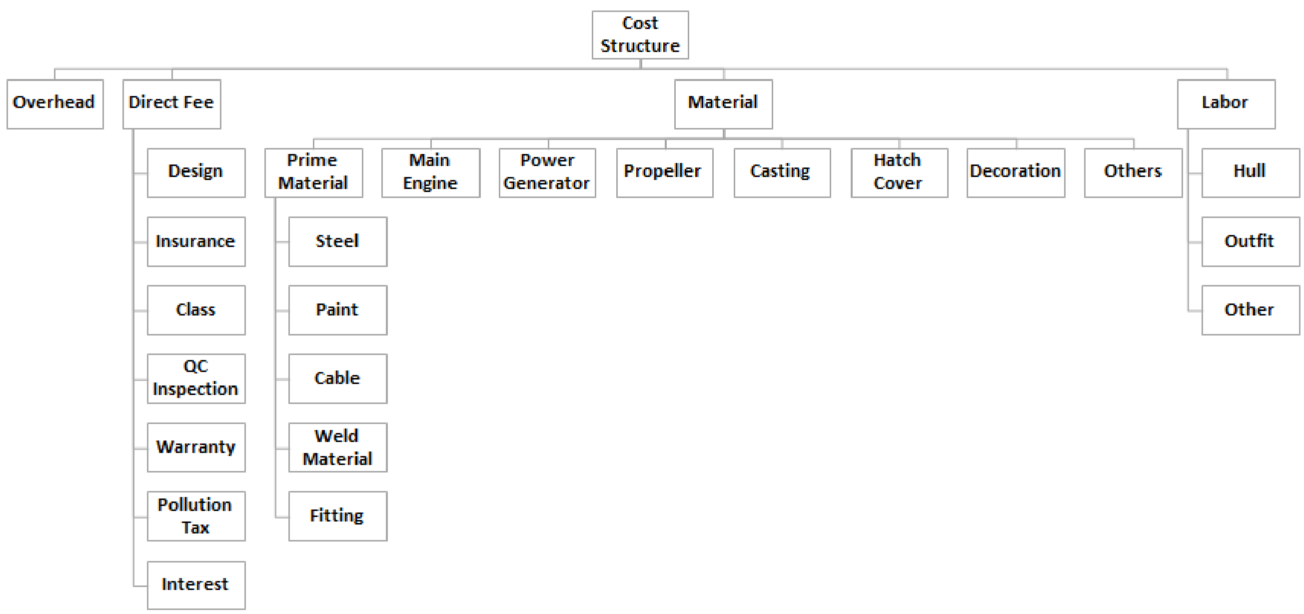


Figure 50 Cost structure

10.1. Rough estimation on the Total Building Costs

Watson (1998) has approximated the cost per weight for the SFI main groups based on statistical data [25]. A rough building cost estimation was conducted based on this (Figure below). The costs are inflation fixed. We did not include estimation for the main group 7, since over 90% of the weight comprises of fuel cells and batteries, which are not common systems. The costs of these systems were evaluated separately.

		$/ton
2	Hull	8000
3	Equipment for cargo	45600
4	Ship Equipment	16800
5	Equipment for crew	29600
6	Machinery main components	32000
7	Systems for machinery components	-
8	Ship systems	51200

Figure 51 Cost per ton for SFI main groups

The battery and fuel cell system costs were estimated based on literature [26][27]. Based on these, we estimated that the battery system and the fuel cell system will cost approximately $1 920 000 and $900 000 respectively. The total cost estimation of $16.57 million is given in figure below.

Code	Item	Quantity	Weight/item (kg)	Weight*quantity	Cost USD
	Grand total	1387700			
	Without hull & machinery	114900			
	Price in USD	16571120			
2. Hull					
Code	**Item**	**Quantity**	**Weight/item (kg)**	**Weight*quantity**	**Cost USD**
20	Hull	1	800000	800000	
25	Superstructure & Deckhouse	1	350000	350000	
			Total	1150000	9200000
3. Equipment for cargo					
Code	**Item**	**Quantity**	**Weight/item (kg)**	**Weight*quantity**	**Cost USD**
30	Hatches	6	2000	12000	
31	Equipment for cargo	1	2000	2000	
			Total	14000	638400
4. Ship Equipment					
Code	**Item**	**Quantity**	**Weight/item (kg)**	**Weight*quantity**	**Cost USD**
40	Steering gear	1	1500	1500	
40	Bow thruster	1	1500	1500	
41	Radar	2	200	400	
41	Mast	1	1000	1000	
41	Other navigation eq	1	4000	4000	
42	Communication equipment	1	500	500	
43	Anchoring and mooring eq.	2	3000	6000	
44	Repair & washing equipment	1	2000	2000	
45	Lifting & transport eq.	1	1000	1000	
			Total	17900	300720
5. Equipment for crew					
Code	**Item**	**Quantity**	**Weight/item (kg)**	**Weight*quantity**	**Cost USD**
50	Lifesaving equipment	6	1000	6000	
51	Insulation, panels, bulkheads, doors, side scuttles and win	1	15000	15000	
52	Internal deck covering, ladders, steps, railing	1	5000	5000	
53	External decks	1	10000	10000	
54	Furniture and inventory	1	8000	8000	
55	Galley, pantry, prov. and laundry equipment	1	5000	5000	
56	Transport equipment for crew	1	5000	5000	
57	Ventilation, aircondition and heating systems	1	6000	6000	
58	Sanitary system and equipment	1	6000	6000	
			Total	66000	1953600
6. Machinery main components					
Code	**Item**	**Quantity**	**Weight/item (kg)**	**Weight*quantity**	**Cost USD**
60	Main engine	2	4000	8000	
63	Propeller plant	1	6000	6000	
63	Reduction gear	1	1500	1500	
66	Emergency generator	1	3500	3500	
			Total	19000	608000
7. Systems for machinery components					
Code	**Item**	**Quantity**	**Weight/item (kg)**	**Weight*quantity**	**Cost USD**
70	Fuel cell system	3	5000	15000	900000
70	Battery pack	40	2030	81200	1920000
71	Lubricating oil system	1	500	500	
72	Machinery cooling system	5	1000	5000	
73	Compressed air systems	2	300	600	
79	Automation system for mach.	1	1500	1500	
			Total	103800	3000000
8. Ship systems					
Code	**Item**	**Quantity**	**Weight/item (kg)**	**Weight*quantity**	**Cost USD**
80	Ballast, bilge and drain systems	1	5000	5000	
81	Fire and lifeboat alarm systems	1	500	500	
81	Firefighting systems	1	2000	2000	
82	Air and sounding	1	500	500	
83	Special common hydraulic oil systems	1	2000	2000	
85	Electrical systems, general	1	1000	1000	
86	Electrical supply system	1	1000	1000	
87	Electrical common distribution	1	2000	2000	
88	Electrical cables and installation	1	2000	2000	
89	Electrical distribution system	1	1000	1000	
			Total	17000	870400

Figure 52 Building cost estimation

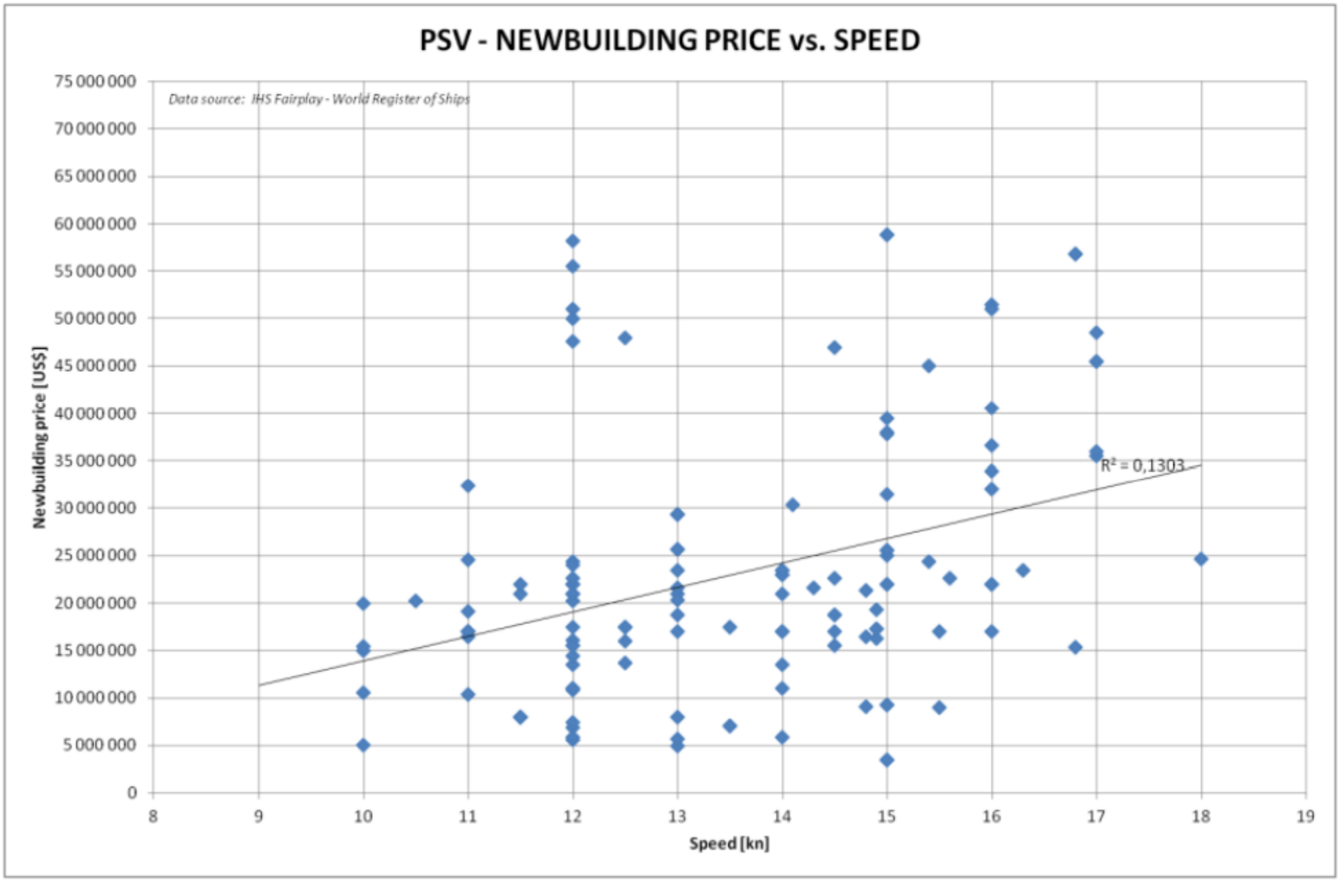


Figure 53 Newbuilding cost vs. Speed (Shetelig 2013) [28]

Another cost estimation done by Shetelig (2013) gives a very similar estimation for a vessel with design speed of 12 knots (Figure above**Error! Reference source not found.**).

10.2. Net present value (NPV)

Incomes were calculated with 75% occupancy for passengers and 90% for cargo. The ship will operate 340 days in a year. 150 days/year with passengers and with 20% cargo (summer mode) and 190 days/year without passengers having 100% cargo (winter mode).

The ship will transport timber. Timber's freight rate is 3,5 cents/m^3/km. Route from Lappeenranta to Vyborg is 60 kilometers long. 90% capacity of cargo means that 1800 tonnes of timber can be transported at a time. This means that volume of timber cargo is 3000 m^3 (timber has a density of 600kg/m^3). In summer mode, the volume of transported timber is 667 m^3, weighting 400 tonnes.

Passenger occupancy was estimated to be 75%, which means that amount of pax is 174. The maximum occupancy is 250. Price of Lappeenranta-Vyborg-Lappeenranta cruise was decided to be 80 $/passenger. It was also estimated that profit of passenger spending onboard during cruise is 80 $/passenger.

Income calculation/a	M $	Cost calculation/a	M $
Passenger fees	1,24236	Labor	1,43276
Passenger spending	2,48472	Maintenance	0,238
Cargo income	1,64934	Hydrogen & electricity	0,476
		Other costs	0,357
TOTAL	5,37642	TOTAL	2,50376

Figure 54 Cost calculations and incomes (with 75% occupancy)

Interest rate	12 %				
		Ship 1			
Year	PW_j (i,n)	Income M $	Costs M $	Net M $	Present value M $
1	0,8929	5,37642	2,50376	2,87266	2,56
2	0,7972	5,37642	2,50376	2,87266	2,29
3	0,7118	5,37642	2,50376	2,87266	2,04
4	0,6355	5,37642	2,50376	2,87266	1,83
5	0,5674	5,37642	2,50376	2,87266	1,63
6	0,5066	5,37642	2,50376	2,87266	1,46
7	0,4523	5,37642	2,50376	2,87266	1,30
8	0,4039	5,37642	2,50376	2,87266	1,16
9	0,3606	5,37642	2,50376	2,87266	1,04
10	0,3220	5,37642	2,50376	2,87266	0,92
11	0,2875	5,37642	2,50376	2,87266	0,83
12	0,2567	5,37642	2,50376	2,87266	0,74
13	0,2292	5,37642	2,50376	2,87266	0,66
14	0,2046	5,37642	2,50376	2,87266	0,59
15	0,1827	5,37642	2,50376	2,87266	0,52
16	0,1631	5,37642	2,50376	2,87266	0,47
17	0,1456	5,37642	2,50376	2,87266	0,42
18	0,1300	5,37642	2,50376	2,87266	0,37
19	0,1161	5,37642	2,50376	2,87266	0,33
20	0,1037	5,37642	2,50376	2,87266	0,30
21	0,0926	5,37642	2,50376	2,87266	0,27
22	0,0826	5,37642	2,50376	2,87266	0,24
23	0,0738	5,37642	2,50376	2,87266	0,21
24	0,0659	5,37642	2,50376	2,87266	0,19
25	0,0588	5,37642	2,50376	2,87266	0,17
				Σ(M $)	22,53
			year 0	Price (M $)	-16,57
		Resales share of the price (%)			80
		Resales value (M $)			13,256
		Resales value today (M $)			0,78
		Total NPV for Ship 1 (M $)			6,74

Figure 55 NPV with interest rate of 12%

NPV has a positive value, so the investment is profitable. The ship is designed for 25 years of operation. The lifecycle could be even longer, since many of the current vessels on the same route are more than 40 years old.

10.3. Internal Rate of Return (IRR)

The internal rate of return can be calculated by setting NPV to zero.

$$NPV = \sum_{i=1}^{n} \frac{C_i}{(1+r)^i} - C_0 = 0$$

This gives us an internal rate of return of 17 %, which indicates that the investment desirable.

10.4. Return on Investment (ROI)

Return on investment can be calculated by diving the annual profits with the initial investment.

$$ROI = \frac{Net\ profit}{Investment} * 100 = 17{,}3\%$$

This gives us ROI of 17,3 % or payback time of 5,8 years, which can be considered good.

10.5. Improvement of the KPI

It is possible to improve the KPI by for example cutting costs or increasing profits. Cost cuttings can be made for example by using Russian workers, which is considerably cheaper than Finnish workforce. Profit can be increased by increasing passenger and cargo demand. Advertising can be a great asset in this, although it is not free either. Finding the "sweet spot" for ticket prices can increase the income as well. Passenger spending onboard may also be increased by adding more selection and adjusting the prices.

10.6. SWOT-analysis

Considering the mission, objectives and KPIs, we have conducted a SWOT analysis on the Saimaa Hybrid project. The biggest strength of Saimaa Hybrid is the convertibility of the vessel as it functions either as a cargo ship or a passenger ship, without idle period throughout four seasons. Another strength is the feature of zero-emission, which will win against competitive ferries by providing the more environmental friendlier option. The weakness mainly lies in the limitation of varieties in the superstructure since it will be built and operated in modules. The weight is a significant concern and therefore affects the selection of building material and the layout of the GA. The opportunity can be found from the increasing attractiveness of Finish nature to tourists from around the world. The location of Saimaa canal and lake area can also possibly make Saimaa Hybrid cruise a popular "side trip" to visit Russia. In addition, the expansion plan of the canal allows the slight increasement in the main dimensions of Saimaa Hybrid in comparison with the current cargo ships operated. Therefore, it is possible to increase the deadweight of the vessel. The threat mainly comes from the transformation of two different ship types. There are no available ships in the market to be reference for manufacturing and operation costs, which might require custom made systems and creative design, which on the other hand implies high risks.

Strength	Weakness
• Convertibility • Zero-emission • KPI's	• Modular superstructure
Opportunity	**Threat**
• Tourism • Russia as a neighbor country • Saimaa Canal expansion	• Technical development

11. Conclusions

The report introduced an innovative idea of a zero-emission inland water way ferry that can carry both cargo and passengers in the same time. To achieve this target and enhance the profitability of the vessel, the superstructure is attached as a modular part. In winter when there is no passengers demand this superstructure with the passenger facilities can be removed to reduce the light ship weight and replace it by tons of payload. The preliminary Saimaa hybrid design was reported which includes the mission and main particulars of the vessel, structure, weight estimation, stability analysis and economic assessment.

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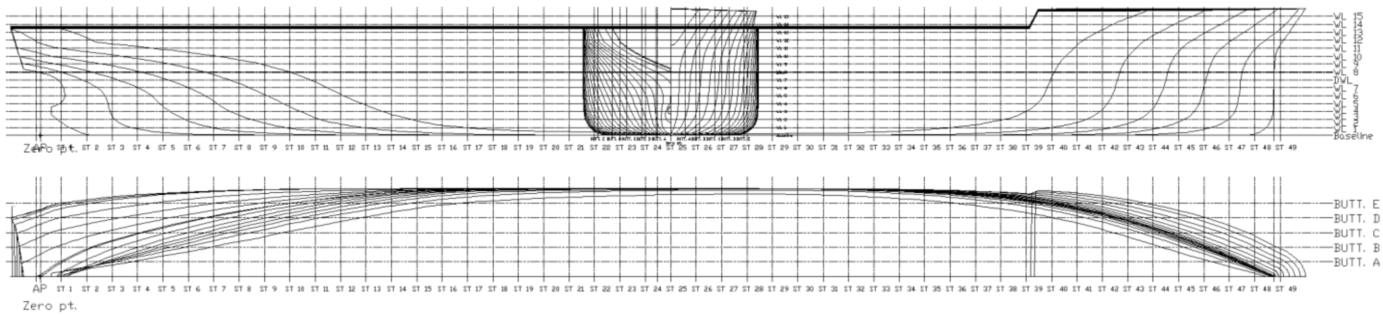
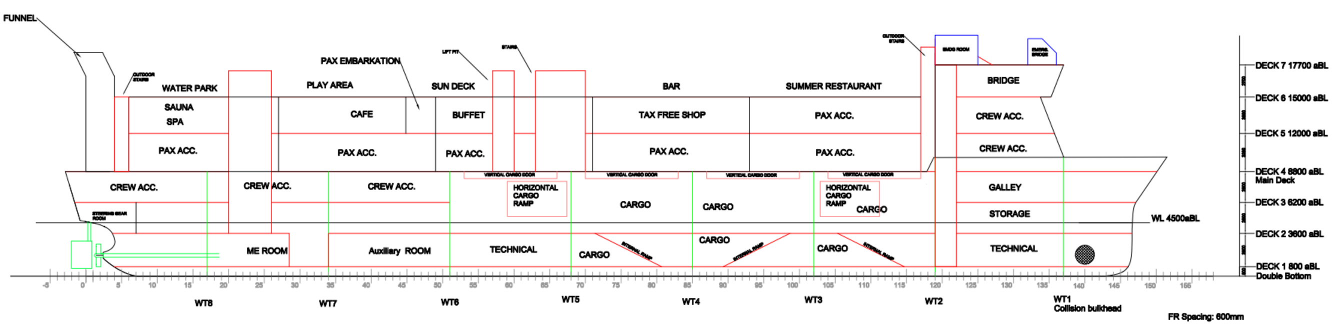
13. Appendices

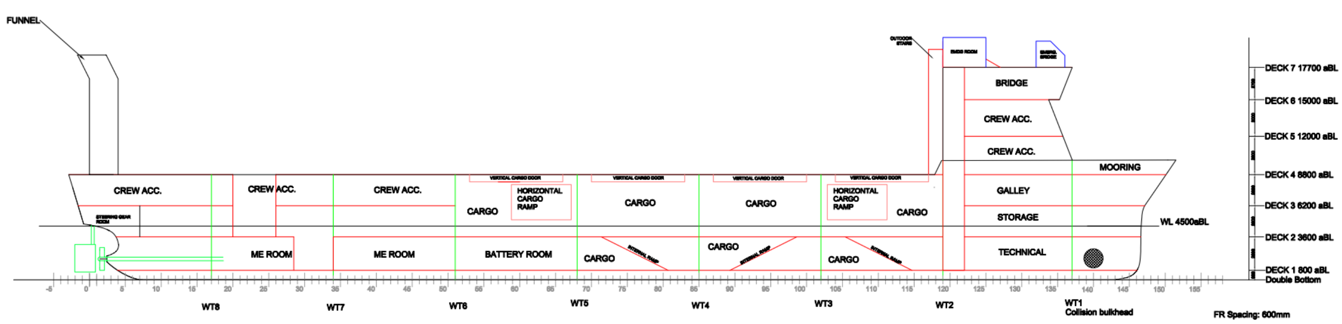
13.1. Saimaa Hybrid lines plan



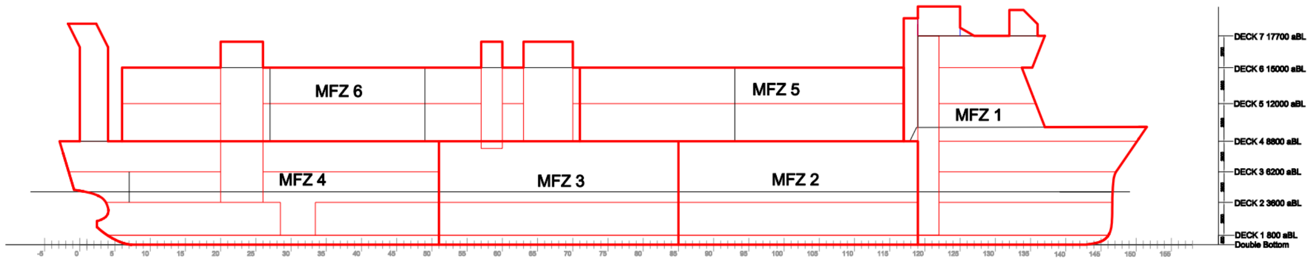
13.2. General Arrangement



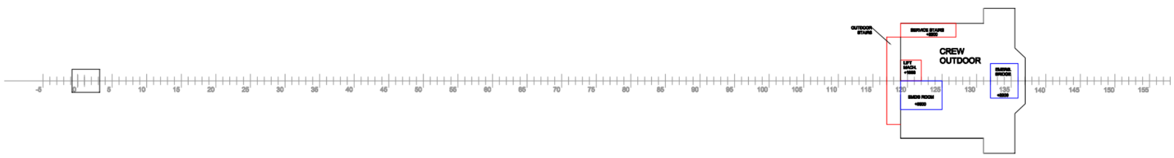
SIDE VIEW



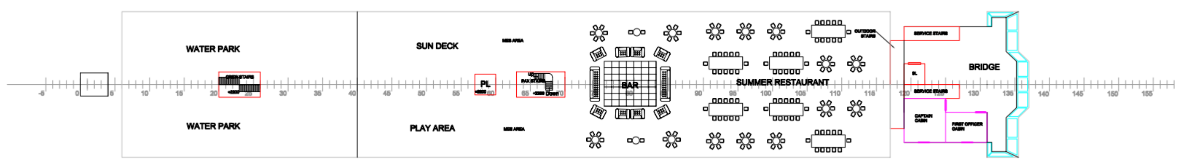
SIDE VIEW WITHOUT MODULAR PAX AREAS



FIRE ZONE DIVISION



DECK 7 17700 aBL



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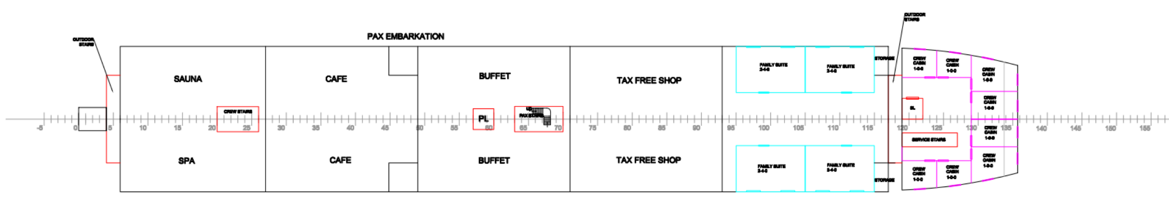
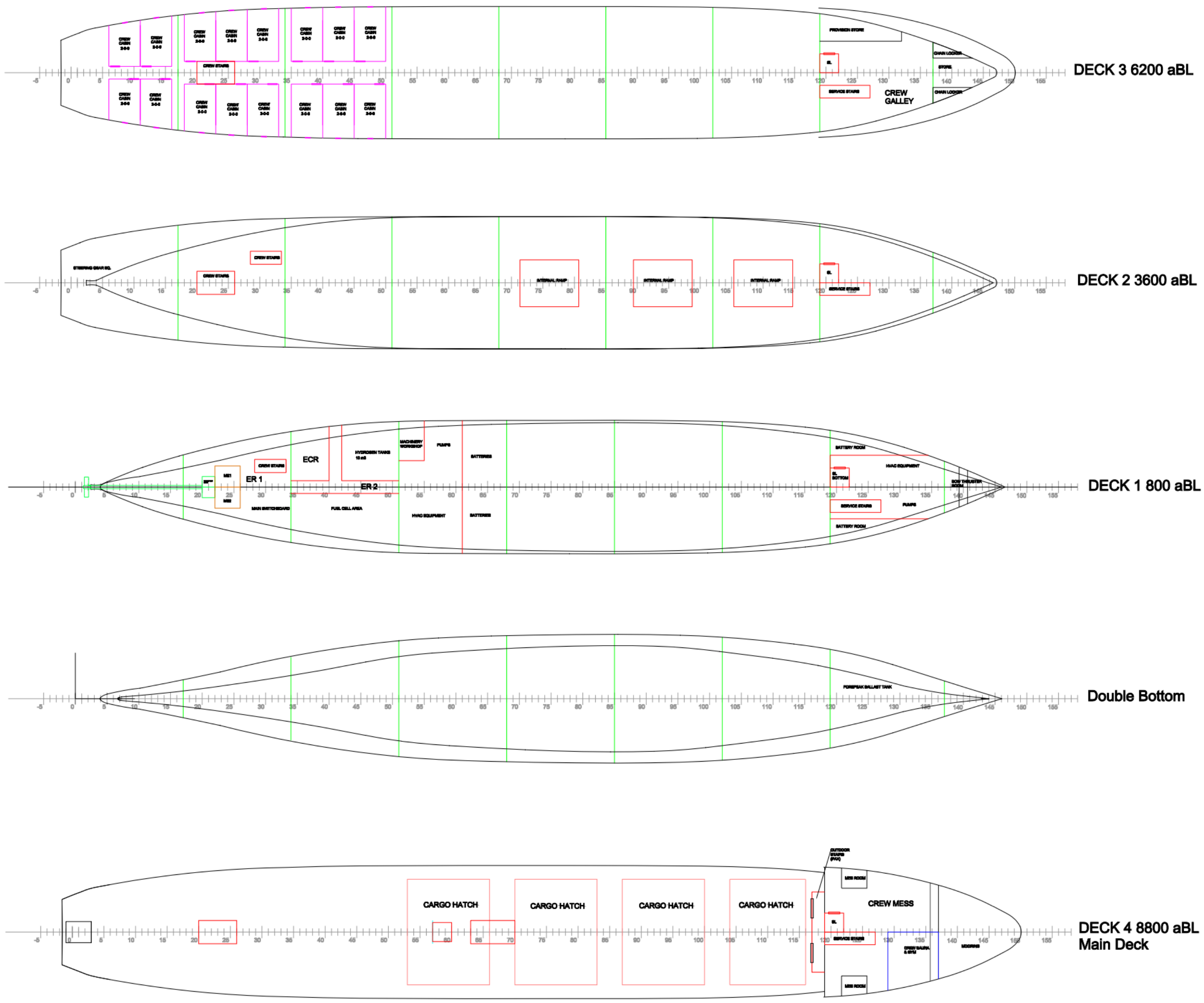


DECK 5 12000 aBL

DECK 4 8800 aBL
Main Deck



MAIN DECK WITHOUT THE MODULAR PAX AREA