Final Project Report

Team FiPER

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1 Preliminary Design Concept

The purpose of this phase was to generate the main concept. It aimed at analysing the main constraints involved with the project and determining what would be needed of project FiPER. The section outlines the main concept and the constraints involved with designing a polar research vessel.

1.1 Introduction

Polar regions have been in service to global ecosystems and mankind ranging from food and energy to freshwater reservoirs of biodiversity. But these regions have been facing drastic changes at rates that far outpace the rest of the world. Species in the coastal arctic regions are being affected by climate change through coastal erosion, rise of sea levels, ice melt and the altered marine food webs. The rate of climate change has increased at an alarming rate, causing the melting of sea ice and glaciers. This is leading to the rise of sea levels. Research vessels are the primary and most efficient source of oceanographic observations in polar regions for ages to come. More research is likely to be conducted in these environmentally challenging areas for decades.

Research vessels have been fulfilling an important role in conducting research at polar regions enabling detailed research of the oceanic arena for a wide range of purposes. Polar research vessels are designed in such a way that the research keeps on going with minimal interruptions even in harsh environment conditions.

1.1.1 Mission Statement

To provide a platform for polar scientists to identify current and emerging research goals. This polar research vessel (PRV) will aim to help advance earth system science and contribute to better understanding of the Polar Regions. The vessel will be a versatile ocean observing platform with advanced scientific tools and mechanical handling equipment for Polar expeditions, oceanic surveys, observations, explorations, and logistics.

1.2 Design Objectives

The vessel is going to operate on both Arctic and Antarctic regions, so it will have to be able to break ice. The goal of this project is that it will break at least 1,65 m thick ice at a speed of 3 knots. The cruising speed will be 12 knots and the top speed will be approximately 23 knots.

Total installed power will be 38 400 kW with the main power source being diesel. Hydrogen fuel cells will used to supplement the power demand, providing noise and vibration free energy to power the hotel load whilst stationary. The range of the vessel will be 90 days.

In addition to the previously mentioned characteristics which make up the core of the polar research vessel, it will need to be able to carry out research in these regions. In order to do this, it will need to be equipped with special features and tools. First and foremost, the vessel must have excellent sea keeping abilities, and be capable of remaining reasonably stable even in harsh weather. This is crucial to ensure the safety of scientific cargo and allow for research to be conducted on board regardless of the weather conditions.

It also has to have enough cargo hold and space for laboratory working. Scientific cargo hold will be approximately 900 m^3. The laboratory will consist of 500 m^2 of fixed laboratory space, with the option of converting parts of the cargo hold into further laboratory space with modular laboratory units. These reconfigurable laboratory spaces will be able to meet the changing needs in research. Furthermore, there will be communication facilities to transmit collected data to the outside world.

The vessel will feature various research facilities. Among these will be a large moon pool to enable access to the sea, without having to endure the harsh elements of the polar regions. Furthermore, this moon pool will allow the vessel to deploy submersible remote-control vehicles easily, even when surrounded by ice.

Modern polar research also requires agents that operate in the air, and so consequently the vessel will be equipped with various drones. Additionally, it will also feature landing and hangar facilities for two medium sized helicopters. The drones will enable quick and easy surveillance of the surrounding area and the helicopters will allow easy deployment of field parties.

Lastly the vessel will have several smaller manned vehicles equipped for various tasks. These include but are not limited to boats with diving facilities for research in coastal regions and a hovercraft for manoeuvring in varying types of terrain.

1.3 Design Constraints

When designing a vessel for conditions as harsh as the polar regions, there are naturally many constraints that affect the design. These are mainly the environmental, regulatory, and physical constraints.

1.3.1 Environmental Constraints

The ship needs to be able to operate in harsh weather conditions: in the polar regions there are thick ice sheets, strong icy winds and cold temperatures. In the arctic for instance the mean temperatures usually range between -13 °C and -32 °C but can go as low as -50 °C. A weather map of the arctic can be seen in Figure 1.

Some of the ice sheets the ship will encounter might be thicker than the ship has been designed to be able to break, and hence the vessel must be designed in such a way that severe damage does not occur if such a situation happens. The vessel must have water ballast tanks with water pumps for swinging the vessel from side to side to be detached from ice if it is stuck, because icebreaker assistance may not necessarily be available.

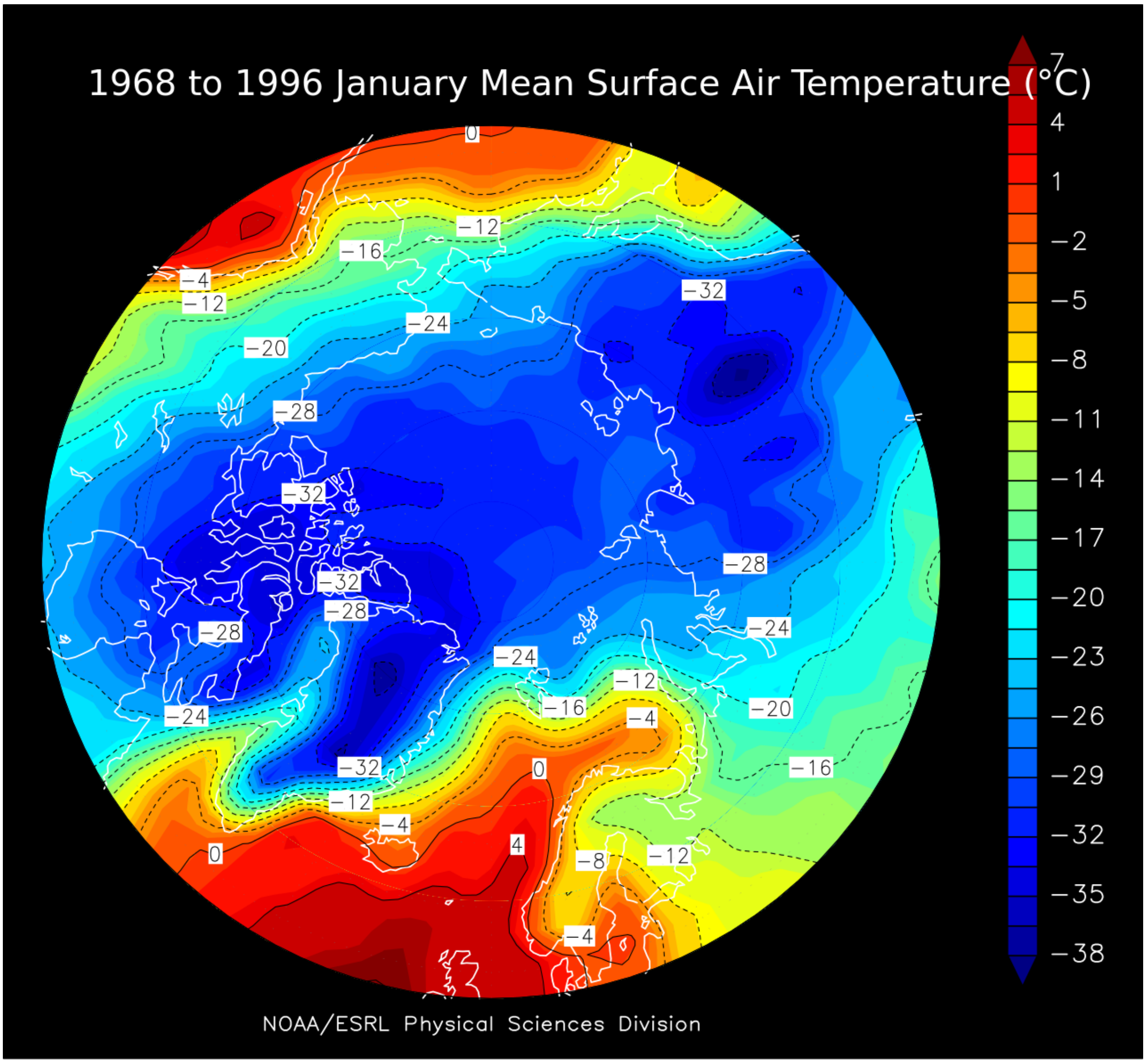


Figure 1: A weather map depicting the mean surface air temperature in the Arctic

Life-saving equipment plays a key role in such harsh conditions. Lifeboats needs to work in cold temperatures, have enough food inside and small heaters to keep water in a liquid state if the ship's crew needs to wait for rescue for a long time. Dismounting the lifeboats should be possible in all conditions and the system needs to be designed with cold temperatures and icing in mind.

Ice formation on a ship superstructure is severe in cold conditions and it may cause several problems including but not limited to significantly changing the vessel's centre of gravity and fouling exposed moving parts. Care must be taken to ensure the vessel can withstand such ice loads and still be stable. This will be achieved with a low centre of gravity, wide hull and large clearances.

The vessel needs to operate in ice and in open waters. As designing a bow that works in both conditions reasonably well is a compromise, the project will get the best out of both worlds by designing a double acting ship. In other words, a ship that is able to travel just as proficiently stern first as it is bow first. This way the ship's stern can be designed to break ice and the bow can be designed for maximum open water efficiency. Thus, the ship will brake heavy ice and simultaneously handle the resistance from waves in open water conditions. The vessel's Polar Class will be PC4, meaning it can operate all year around in severe ice conditions.

1.3.2 Regulatory Constraints

When traveling in the polar regions, all ships must comply with the IMO Polar Code. Research vessels are no exception to this, and so the ship must be designed with the restrictions set by the Polar Code in mind.

The structure of ships is regulated, most prominently by the IMO and the SOLAS convention. Regulations on the structure of ships includes the following aspects:

- construction and subdivision
- stability
- equipment
- storage
- navigation
- handling and nature of the cargo carried

In order to make sure that ships are complying with the regulations on ship structure and condition and that they can travel safely, there are several supervisory systems in the shipping industry:

- flag state control
- port state control - PARIS MOU and equivalents

1.3.2.1 Flag state control

Flag State Control is one of the basic premises of the IMO conventions. It means that the state where a ship is registered is responsible for supervising that the ship fulfils the requirements of those IMO Conventions that the state has ratified. The UNCLOS Convention gives the right for any state to register ships, in so far as there is a link between the ship and the state. In practice, the state can define the nature of this link, and so it can register any vessel it chooses. (Stopford, 2009) Countries without any maritime experience and expertise can also establish ship registers (Mitroussi, 2004).

1.3.2.2 Port state control

Port state control is a complementary instrument to flag state control, and it has been born due to the fact that flag states have different standards: some allow the operation of sub-standard ships (Karvonen et al. 2006). IMO has adopted a resolution on port state control inspections to identify deficiencies in ships, their equipment or crew. These procedures are not mandatory, but many countries have followed them (e.g. Paris MOU states). Ships with serious deficiencies can be detained and banned. The ships inspected are often selected using statistical methods to identify high-risk vessels, e.g. on the basis of ship age, flag and ship type. (Stopford 2009) Inspections are performed by national maritime authorities or other actors authorised by the national authority.

1.3.3 Physical constraints

The vessel will travel long distances and spend many hours at sea. Thus, medium to high fuel capacity will be required for the ship. Hydrogen will be used in the vessel to power the hotel load at times and this will naturally affect the choice of powerplant.

As the vessel will operate in extreme sea conditions, material choices have to be limited to those which can reliably endure these conditions.

Many scientific teams will travel on the vessel and each team would have its own scientific equipment. These teams include ice researchers, marine biologist, geologist etc. each with their own equipment. For this a large cargo hold and a separate smaller scientific cargo hold will be present. The ship will also be equipped with two 10 t cranes to handle all necessary cargo.

The ports that our ship will be using as its home ports are the port of Helsinki and the port of Cape Town. Therefore, it is important to consider the constraints set by these ports while defining our ship dimensions.

1.3.3.1 Helsinki port: size constraints

The Approach channel minimum width and minimum depth for the two harbours in Helsinki are as follows:

- West Harbour min. width 250m, depth 12,5m
- South Harbour min. width 100m, depth 12m

1.3.3.2 Cape Town port: size constraints

Victoria and Alfred Basins have a variety of berths available for ship and boat repair as well as berthing of smaller vessels, including research vessels and visiting naval ships

- Depth at entrance channel: 15.9 m
- Entrance depth at chart datum:
    - Victoria Basin: 11.6 m
    - Duncan Dock: 13.3 m
    - Ben Schoeman Dock: 13.0 m
- Permissible vessel dimensions:
    - Maximum length: 350 m
    - Maximum beam: 87 m
    - Maximum draft: 13 m

2 Vessel Categorization and Reference Ships

Once the main concept has been generated and all relevant constraints have been considered the design process moves on to categorize the vessel based on its main features and select reference material to be used in the design process. This process is outlined in the following section.

2.1 Categorization

A ship can be categorised based on many different factors. The most general factors are the ship mission, applied technologies, operational area and design limiting factors. In this section these factors will be discussed in detail.

The vessel is stationed at the Helsinki harbour and voyages to the Polar regions. The operational area of the FiPER is routed as follows:

- Helsinki Harbour – North Pole – Helsinki Harbour
- Helsinki Harbour – Cape Town Harbour – South Pole – Cape Town Harbour – Helsinki Harbour

The main ship building frame will be welded steel. There will be two big cargo handling cranes with a functional capability of 10 tonnes each and so the cargo handling will be based on vertical lifting, in other words the lift on lift off (Lo-Lo) principle.

Since the vessel is not going to be carrying any dense or physically large cargo, but instead personnel and research equipment, with transportable cargo being only a small part of the ships mission, the operational capabilities are unlikely to be restricted by weight or volume. Instead, the ship can be considered space limited.

The hull is a vital part of the ship and a lot of effort is required to design an efficient hull type. Since, FiPER will be designed for the Polar expeditions, the hull should be designed to withstand extreme ice loads. The vessel can be categorized as a double acting single hull ship.

As per market interests, the FiPER is a research-based vessel with primary objective to explore Polar regions to search for technical solutions and discoveries in different walks of life. Therefore, expeditions of FiPER will be funded by the government and It can be categorised as a vessel for technical solutions and explorations as per market interest.

2.2 Reference Ships

All design projects that aren't creating something truly unique need some form of previous project to serve as a reference, and this project is no exception. As the preliminary plan is to design a double acting polar research vessel similar ships were chosen as references. However, currently this is challenging as the double acting ship principal is still a new phenomenon in research vessels. The closest example found is the Viktor Chernomyrdin: a double acting icebreaker with some research facilities. This is not however a viable reference ship as it is still unfinished and has experienced issues with timetabling, budgeting and construction. Consequently, two reference ships were chosen, an existing polar research vessel and an existing double acting icebreaker.

The polar research vessel we chose was the RRS Sir David Attenborough and the double acting ship we chose was the Aleksandr Sannikov. Whilst the Viktor Chernomyrdin will undoubtedly be referenced during the design process, we have chosen the Aleksandr Sannikov as our reference ship because it is relatively new, uses contemporary technology, it has some of the features we intend to incorporate in our vessel, and compared with the Viktor Chernomyrdin it is operational at the moment.

2.2.1 RRS Sir David Attenborough

The list of main specifications of the RRS Sir David Attenborough can be seen in table below:

Table 1: The main specifications of the RRS Sir David Attenborough

Length	123,9 m
Beam	24 m
Draught	7 m
Depth	11 m
Displacement	12 790 tons
Installed Power	18 000 kW Diesel Engines
Propulsion Power	2 x 2 750 kW controllable pitch propellers
Speed (cruising/maximum)	13 knots / 17,5 knots
Range & Endurance	19 000 Nm or 60 days
Crew	28 crew & 60 scientists
Ice capability	PC 4, 1 m of ice at 3kn

In addition to the features listed in the table the RRS Sir David Attenborough is capable of launching and recovering aerial and ocean robotic systems and contains facilities to house one helicopter. The main difference is that project FiPER is going to be a double acting vessel and better equipped than the RRS Sir David Attenborough. For the double acting principal to be viable the vessel will need azimuth thrusters and potentially bow thrusters. The RRS Sir David Attenborough is shaft driven and she has both bow and stern thrusters.

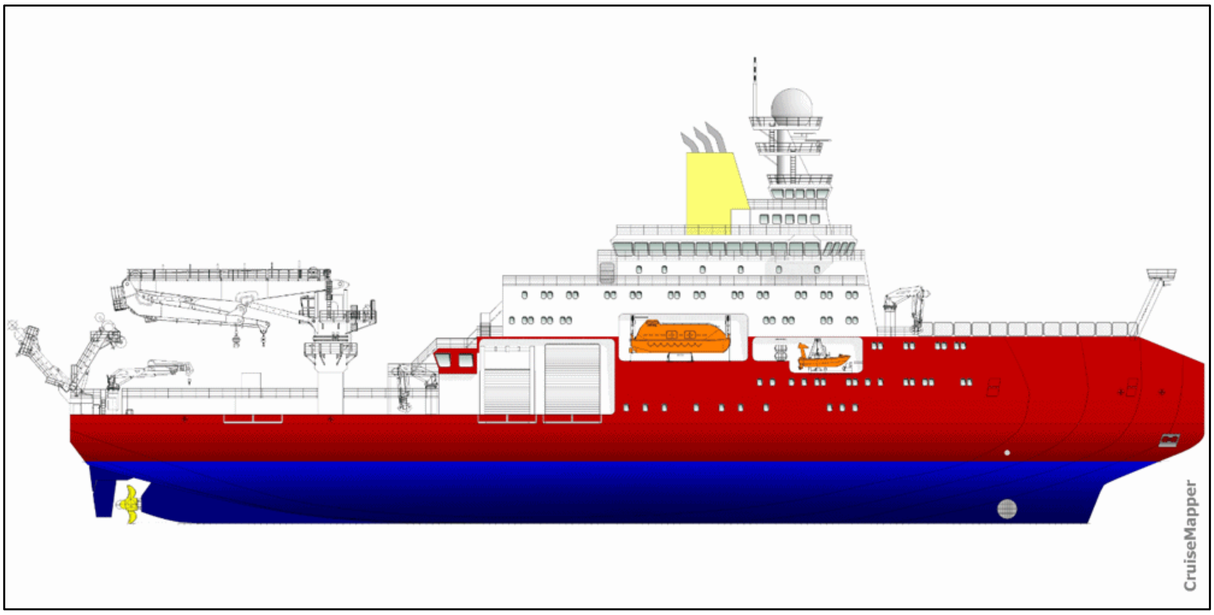


Figure 2: The RRS Sir David Attenborough

2.2.2 Aleksandr Sannikov

The main attributes of the Aleksandr Sannikov can be seen in following table:

Table 2: The main specifications of the Aleksandr Sannikov

Length	121,7 m
Beam	26 m
Draught	8 m
Propulsion Power	2 x 7 500 kW and 1 x 6 500 kW Azipods
Speed (cruising/maximum)	8 knots / 16 knots
Ice Capabilities	Icebreaker8, 2 m of ice at 2 kn

The Aleksandr Sannikov was built for Gazprom Neft by the Vyborg Shipyard and was completed in 2018. The vessel is based on the 'Aker ARC 130A' concept by Aker Arctic. It is classified as an Icebreaking Support Vessel. The vessel has a length of 121,7 m, a breadth of 26,0 m and a draught of 8,0 m. The ship is equipped with three azipod thrusters, two at the stern and one at the bow, with a total power of 21,5 MW. This is also fairly similar to the initial plan of this project for power rating. Lastly the ships icebreaking capabilities are similar to those that FiPER will require. The Aleksandr Sannikov is capable of crushing 2m of ice at a speed of 2 knots, both bow and stern first. FiPER will only need to crush thick ice stern first, and so its bow can be designed more in line with that of a oean going vessel, but these ice capabilities act as a good reference point. The cruising speed of the vessel in open waters is 8 knots, and its range is 30 days. This is something that FiPER will need to improve on.

Lastly this vessel is a good reference ship for this project because it has many of the facilities that FiPER will require. The ship is equipped with a large crane (25 t), a large cargo deck, a helicopter deck, various indoor facilities, multiple workboats, and is able to handle temperatures as low as -50 degrees Celsius. These are all functions that will be required to some degree from the FiPER project. In many ways the Viktor Chernomyrdin would have also been a valuable reference ship, as it includes within its design facilities accommodation for 90 additional personnel, 300 m2 of laboratories, a modular diving complex, an outboard lift and two helipads. It was decided however, that using a ship that is late from its construction timetable, over budget, and not in service at the moment as a main reference ship was not a wise idea.

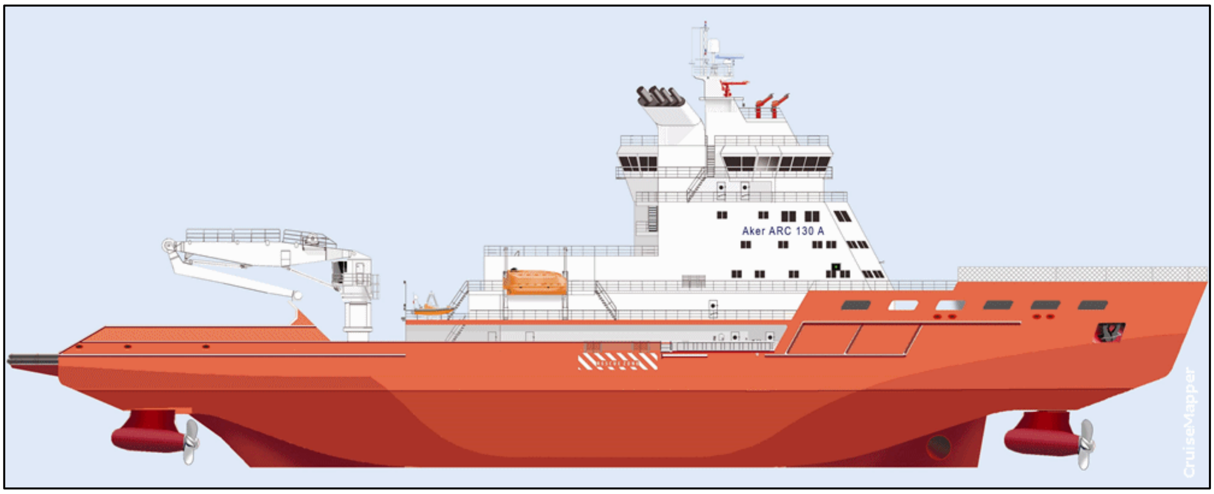


Figure 3: The Aleksandr Sannikov

3 Main Dimensions

Once the vessel has been categorized and the reference material has been selected the project can move on to defining the vessels main dimensions. This section explains that process. The main dimensions will be decided upon through the use of the statistical method and reference ships. Normand's number will also be discussed in the process.

3.1 Statistical Method

The statistical method began by collecting data from previously built polar research vessels and double acting ships. This data was collected so that trends in the main dimensions and in their ratios could be seen. This data was collected into the table that can be seen on the following page.

Table 3: The main specifications of the different reference ships used to determine the main dimensions of project FiPER

Name	Length (m)	Beam (m)	Draft (m)	Depth (m)	Freeboard (m)	L/B	B/T	Δ (t)	∇ (m³)
RRS Sir David Attenborough	128,90	24,00	7,00	11	4	5,37	3,43		
RRS James Cook	89,50	18,60	5,50	8,8	3,3	4,81	3,38		
RRS James Clark Ross	99,00	18,90	6,30			5,24	3,00	7767	7578
RRS Bransfield	99,00	18,00	6,70			5,50	2,69		
RV Polarstern	118,00	25,00	11,20			4,72	2,23	17300	16878
RV Kronprins Haakon	100,50	21,00	8,70	10,41	1,71	4,79	2,41		
RV Araon	110,00	19,00	9,90			5,79	1,92		
MV Xue Long	167,00	22,60	9,00	11,8	2,8	7,39	2,51		
MV Xue Long 2	122,50	22,30	7,90	11,8	3,9	5,49	2,82		
S. A. Agulhas II	134,00	21,70	7,7	10,6	3,1	6,18	2,05	13687	13353
Viktor Chernomyrdin	146,80	29,00	8,50			5,06	3,41		
Aleksandr Sannikov	121,70	25,00	8,00	11,5	3,5	4,87	3,13		
Mackinaw	73,00	17,80	4,90			4,10	3,63		
Average	**116**	**21,8**	**7,8**	**10,8**	**3,2**	**5,3**	**2,8**	**12918**	**12603**
FiPER	130,00	25,00	8,50	12,00	3,5	5,2	2,9		

Based on the average values generated by the table, the dimensions of FiPER were decided upon. It was decided that FiPER would be made approximately 10% larger in order to accommodate various facilities on board.

When the dimensions were decided, they were compared against generally acceptable guidelines. It turned out that FiPERs dimensions matched well with these guidelines:

- Length / beam: Should be between 4 and 10, Project FiPER has 5,2
- Beam / draught: Should be between 2,3 and 4,5, Project FiPER has 2,9
- Beam / depth: Should be between 1,75 and 3, Project FiPER has 2,9

These values were plotted for both project FiPER (seen in orange in the graphs) and the ships used in the statistical method (seen in blue in the graphs). They can be seen below:

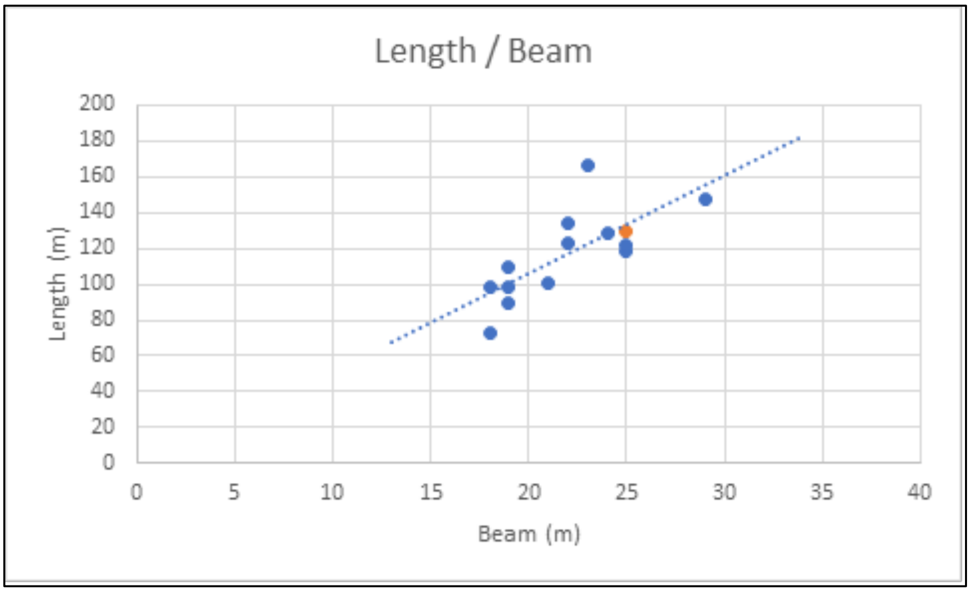


Figure 4: The length/beam ratio of reference ships in blue and project FiPER in orange

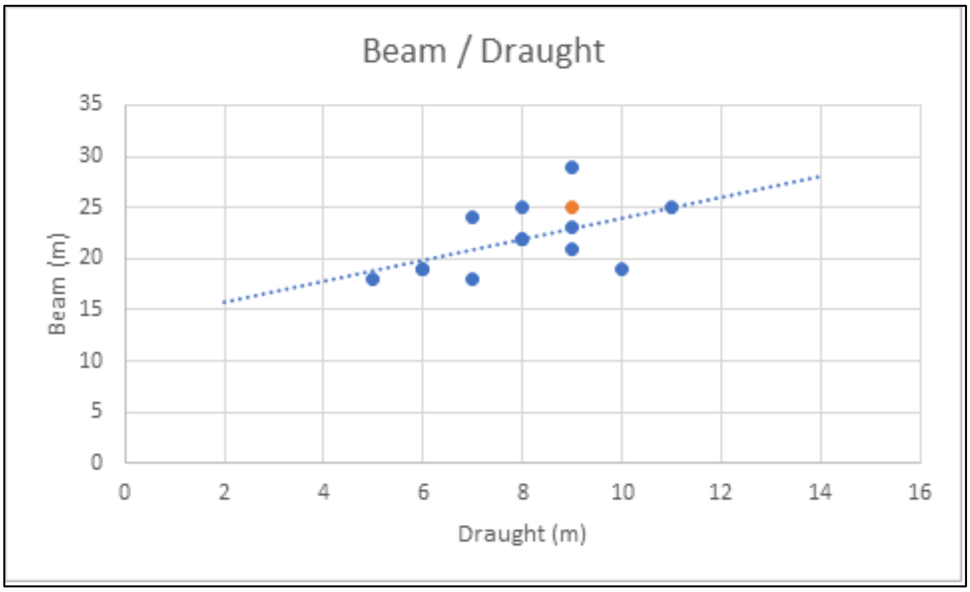


Figure 5: The beam/draught ratio of reference ships in blue and project FiPER in orange

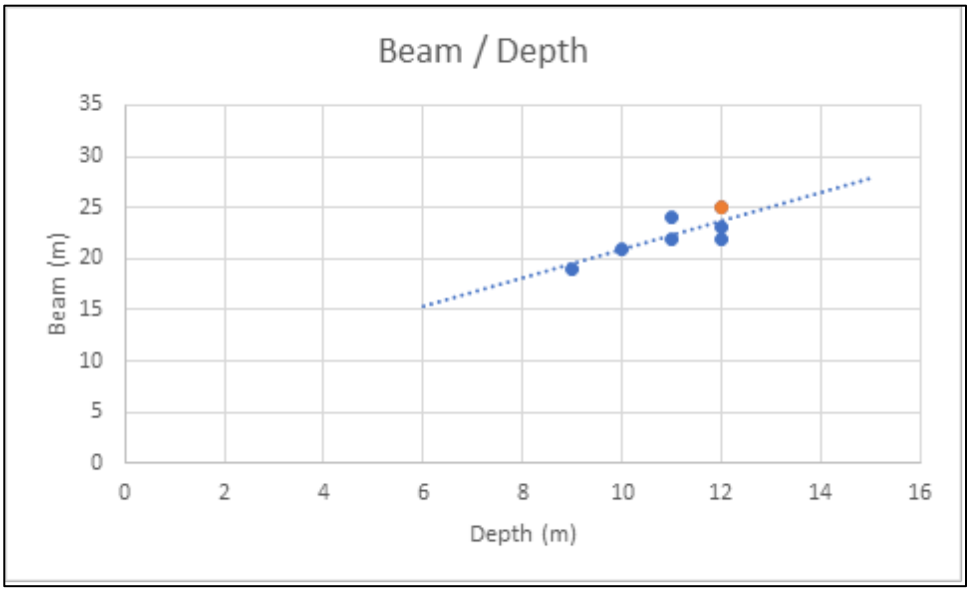


Figure 6: The beam/depth ratio of reference ships in blue and project FiPER in orange

As the tables show project FiPER fits well into the general trends in these types of vessels. This serves as important confirmation for the main dimensions chosen.

3.2 Normand's Number Method

Normand's number is a ratio that can be calculated for any given ship based on its weight and displacement. It can be used to determine the displacement of new ship designs given a (relatively small) change in deadweight and that the ratio of the dimensions stays constant. Normand's number can be mathematically determined to be the following:

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

Where,

$\Delta =$ The displacement of the ship

W_H =The hull weight of the ship

W_O =The outfitting weight of the ship

W_M =The machinery weight of the ship

W_F =The fuel weight of the ship

3.2.1 The Values

The problem with applying Normand's number to a design, is that it requires the estimation of several different weights of a ship. Now, in the case of a shipyard designing a ship, they have available to them the specifications of their previous builds. Thus, they are able to choose one of these vessels as their reference ship, and presumably have accurate estimates for the different weights required. However, in the case of this project, there is no previously built ships to use as a reference, and so the data available is very limited. This means that the different values required to calculate Normand's number will be rough estimates, and thus the results obtained will be only as accurate as the estimates.

The values required to calculate Normand's number were estimated using the following formulas:

$$\Delta = C_b \times L \times B \times T$$

$$W_H = \Delta - DWT$$

$$W_O = C_O \times V_{Gross}$$

$$W_M = C_M - \Delta^{\frac{2}{3}}$$

$$W_F = \frac{Energy\ Required}{Relative\ Energy\ Density\ of\ Fuel} = \frac{P_{requiered} \times t_{travelled}}{E_{Engine\&Powertrain} \times \rho_{Energy}}$$

Where,

L = The length in meters

B = The beam in meters

T = The draught in meters

Δ = The displacement of the ship in tons

DWT = The deadweight of the ship

C_O = The outfitting coefficient of the ship, equal to 0,012 ton/m^3

V_{Gross} = The gross volume of the ship

C_M = The machine weight coefficient, equal to 0,99 tons/m^3

$P_{Requiered}$ = The power required to travel at normal cruising speed in Watts

t_{travel} = The time required to travel the range at normal cruising speed in hours

$E_{Engine\&Powertrain}$ = The efficiency of the engine and powertrain

ρ_{Energy} = The energy density of the fuel used in Wh/kg

3.2.2 Calculating Normand's Number for SA Agulhas II

The SA Aguhlas II was not originally our reference ship. However, it is the ship that was used with the Normand's number method because it had the most data available, and therefore the least number of assumptions needed to be made. This meant that it was likely to give us the most accurate results. At first the following data was used to calculate Normand's number for the SA Aguhlas II:

- Length: 134,2 m
- Beam: 21,7 m
- Draught: 7,65 m
- C_B:0,66
- ρ_{water}: 1025 kg/m^3
- W_H:8907 t
- W_M:606 t
- W_O:267 t
- W_F:1070 t

This data yielded a result of 3,113. However, from this data the deadweight of the ship could be calculated to be 5381 tons, which is too high. The deadweight of the SA Aguhlas II is 4780 tons. Whilst maintaining the same proportions, the estimates were increased by 6% so that the calculated deadweight matched the actual deadweight:

- W_H 9441 t
- W_M 642 t
- W_O 283 t
- W_F 1134 t

With these values Normand's number was calculated to be 3.565 for the SA Agulhas II. Applying this Normand's number to our desired deadweight of 5275, required draft of 8,5 m and our initially estimated Block Coefficient of 0,62, we were able to calculate the following dimensions for our ship:

- Length 139 m
- Beam 22,5 m
- Δ 16870 tonnes

In some circumstances Normand's number can be used very successful, but unfortunately this is not one of them. The value that was calculated for Normand's number is a little higher than it should be, and this is most likely due to the estimates for the various weights not being very accurate. The other problem with Normand's number, is that it relies on the ratio of the main dimensions between the two ships being the same. In some cases, this does not pose a problem, but as the new design is a double acting polar research vessel, and a perfect reference ship for this does not exist, it leads to further inaccuracies in the Normand's number. Namely that the new vessel will be shorter and wider than predicted by Normand's number. However, despite these limitations Normand's number did provide dimensions for the ship that are very similar to those decided upon with the statistical method, and so this further validates the chosen dimensions.

4 Hull Form

Once project FiPER's main dimensions were defined, the hull form could be generated. Project FiPER's hull form was generated with the aid of two different software. First the lines plan was generated using excel. This lines plan included both a profile of the ship, and bow and stern forms. Once this lines plan was completed a 3D model of the ship's hull was generated using Delft Ship.

4.1 Bow and Stern Form

Because project FiPER is built around the double acting principal, care was taken when designing both the bow and stern form. These particulars will be discussed here

4.1.1 Bow

Even though project FiPER is a polar research vessel, it will spend a lot of its operational time in open waters, along with most of the other ice capable research vessels. It is important to design the vessel to be as economical as possible while traveling in open waters so operating costs would be smaller and there would be less pollution. This was one of the main reasons why FiPER was designed to be a double acting ship, so that it could have good open water characteristics while maintaining its ice breaking capability. This is why project FiPER's bow form is that of a ocean going vessel, sharp and with flaring bow shoulders. It is ultimately designed to take on waves as well as possible.

4.1.2 Stern

When ships encounter ice the ice breaking process can be divided into 2 different categories: bending and crushing. The ships bow (or in FiPER's case, stern) will apply a force to the ice, which can be divided into components facing straight down (Y) and straight ahead (X). This straight-ahead facing X-component of the force would cause ice crushing, resulting a significant resistance to the ship. Downwards facing y-force tries to bend the ice and resulting in fractures thus the ice being detached in big pieces and causing smaller resistance while going through an ice field.

Ice breaking ships usually have gently sloping bow. It is because ice breaking in bending manner is a more efficient way of going through ice than crushing. Gently sloping bows maximize the downwards heading Y-force making the icebreaking process as efficient as possible.

Our stern is designed in a similar way as an icebreakers bow would be: Gently sloping shape to provide maximum ice breaking capabilities and the "shoulders" of the stern and bottom of the stern are designed to push the ice under the ship and away from our Azipods. We don't want ice damaging our propellers or causing any more resistance while going through ice.

4.2 Excel Generated Lines Drawings

Defining the bow was easy because it could be modelled around virtually any slow-moving (Fn < 0,2) ship designed for open water. The stern however was more challenging and in the end was modelled around one of the reference ships, the Alexander Sannikov. The designed stern is capable of breaking 2m of ice at 2 knots, and consequently it was deemed suitable. Based on these references, the hull profile, a waterline drawing, and the bow and stern lines drawings were generated:

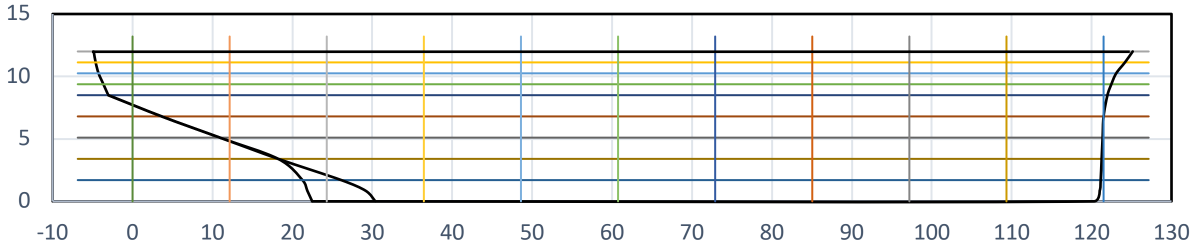


Figure 7: Profile view of the hull of project FiPER

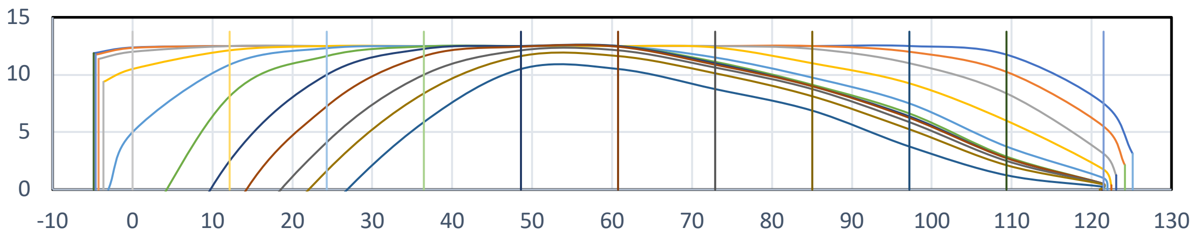


Figure 8: Waterline drawing of project FiPER

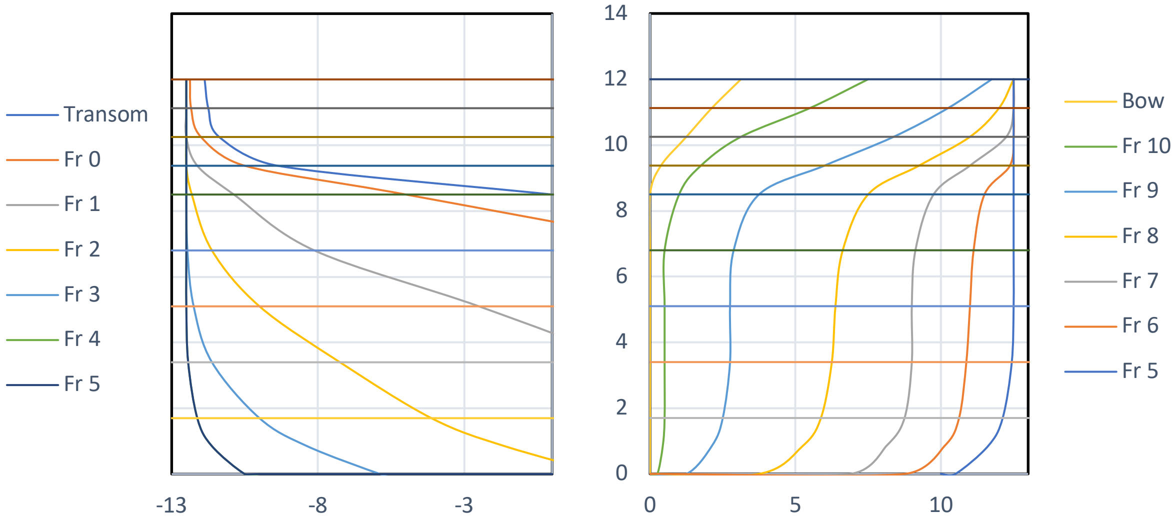


Figure 9: Stern (left) and bow (right) lines drawings

4.3 Delft Ship Generated Hull Model

The Delftship Model of FiPER's hull was generated based on the lines drawings generated in excel. From the model it can be clearly seen that the bow is shaped for optimum open water performance. The stern on the other hand is shaped to crush ice. Furthermore, the stern is the shape it is in order to fit two azimuth thrusters. The model was generated using the analytical method: plotting individual points to define the form of the hull.

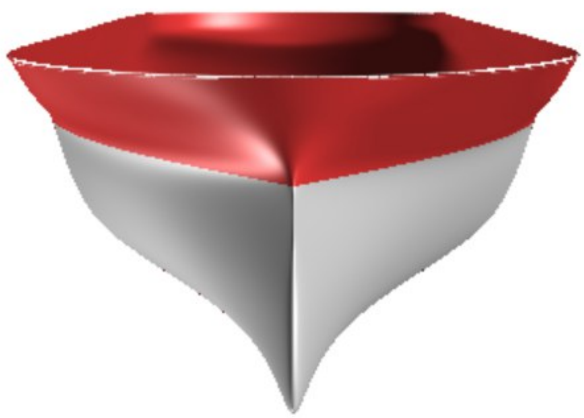


Figure 10: Delftship model bow view

Figure 11: Delftship model profile view

Figure 12: Delftship model stern view

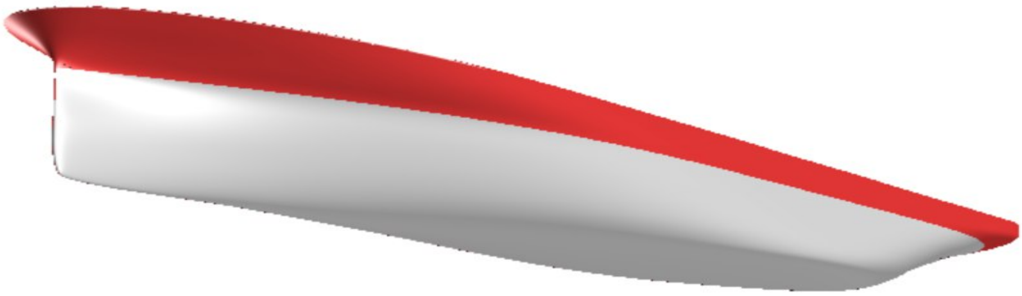


Figure 13: Delftship model bow view

5 Hydrostatics and Stability

Whilst designing the hull form for project FiPER it was important to bear in mind that the vessel would not only need to look like it had good open water characteristics, but that it would also need to deliver. Consequently, once the hull form was completed the project moved onto to analyse the hydrostatics and stability of the ship. This process is outlined in the following section.

5.1 Hydrostatics

The hydrostatics were delivered from Delftship, where the final hull form was modelled. The results are following:

Volume properties		Waterplane properties	
Moulded volume	15990,9 (m³)	Length on waterline	125,68 (m)
Total displaced volume	15990,9 (m³)	Beam on waterline	25,148 (m)
Displacement	16390,7 (tonnes)	Entrance angle	52,744 (Degr.)
Block coefficient	0,5951	Waterplane area	2594,4 (m²)
Prismatic coefficient	0,6362	Waterplane coefficient	0,8207
Vert. prismatic coefficient	0,7251	Waterplane center of floatation	57,941 (m)
Wetted surface area	3697,6 (m²)	Transverse moment of inertia	114582 (m⁴)
Longitudinal center of buoyancy	62,532 (m)	Longitudinal moment of inertia	2530517 (m⁴)
Longitudinal center of buoyancy	-1,964 %		
Vertical center of buoyancy	4,860 (m)		
Total length of submerged body	125,68 (m)		
Total beam of submerged body	25,152 (m)		

Figure 14: Hydrostatic parameters generated by Delftship for the 3D model of FiPER's hull

The displacement is close to what was decided earlier. The block coefficient and prismatic coefficients are small when considering that this vessel is an ice breaker. But as almost all polar research vessels operate most of the time in open waters, small coefficients reduce the water resistance in open waters providing smaller fuel consumption. Consequently, this was deemed a positive attribute.

We also used Simpson's integration method to verify the results Delftship gave us. Results of Simpson's integrations compared to Delftship's results are shown in table below:

Table 4: Comparison of different methods of calculating the vessels displacement and centre of buoyancy

Parameter	Delftship	Simpson's Integration
Displacement	15900 m^3	16000 m^3
Vertical center of buoyancy	4.86 m	4.88 m
Longitudinal center of buoyancy	62.5 m	62.3 m

As it can be seen, the results match with each other reasonably well.

5.2 Initial Stability

The metacentric height, GM, of this vessel has also been estimated. The GM is the measurement between the metacentre and centre of gravity. SOLAS regulations state that this should be above 0,15m. It cannot be too high either, otherwise the ship would be too stable and cause excessive accelerations when operating in waves resulting damage to cargo and in some cases people on board. Delftship gives following measurements to distance between metacentre and keel:

Table 5: Project FiPER's intial stability

Transvers metacentric height	12.026 m
Longitudinal metacentric height	163.11 m

It should be noticed that the measurement Delftship gives, is not truly accurate. Delftship does not know the effect on the height of the centre of gravity that the superstructure will cause or anything inside the hull. Furthermore, it can be seen in the options that this value really means the distance between metacentre and keel as in stability calculations known as KM.

The initial stability can be calculated with equation

$$GM = KM - KG$$

where KM is the distance between the keel and the metacentre and KG is the vertical centre of gravity. As is shown in section 9, lightship weight calculations, our estimation of KG would be 6,5m. The number can have a little variation as the structures might change when designing process advances, but for now it would give us a GM of 5,5 m. This shows that our research vessel has good initial stability characteristics and leaves room for structural changes.

6 General Arrangement

Once the hull form has been generated and deemed hydrostatically sound it is time to move on to the general arrangement of the vessel. The design of the superstructure began by looking at some reference ships' superstructures and then sketching something similar. It was decided that three decks would be needed in the superstructure, and 4 in the hull. The deck height was set to be approximately 3 meters, excluding the helicopter hangar which has to be higher because of the height of the helicopters.

6.1 Deck 7

Deck seven is going to be the bridge and is naturally the uppermost deck. There will be all the controls that this kind of modern research ship needs to have according to SOLAS regulations and IMO standards. They require things like integrated bridge- and navigation systems (IBS & INS), direction systems like magnetic compass and gyro compass, rate of turn indicators etc. They also require specific control systems, distance and position systems, detection systems like radars and recording systems. Only special feature of the bridge is that there are controls facing both directions because of FiPER is double acting. That also means that there will be good visibility to both stern and bow direction.

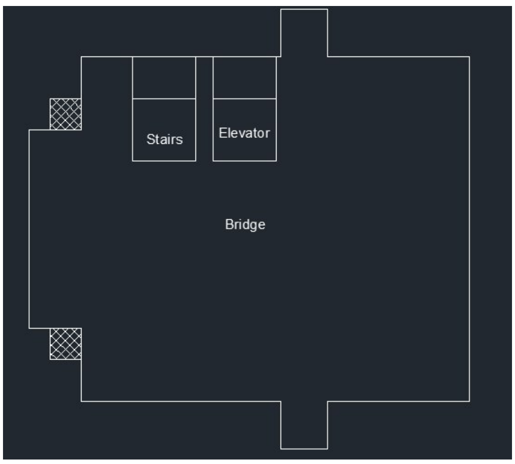


Figure 15: The general arrangement of the bridge (deck 7) of project FiPER

6.2 Deck 6

Deck 6 will have cabins for the crew and scientists. There is space for crew of 25 and for 60 scientists. For crew there is 20 cabins, so 15 crew members get their own cabin and 10 will live in shared, two person cabins. For scientists there are 30 cabins which means that every one of those are two person cabins. Crew cabins are 13 m2 and scientist cabins 12 m2. Total cabin area is 620 m2. Every cabin will have separate bathrooms with showers and some closets for clothes and personal belongings. In crew members private cabins there will be table for paperwork etc. In shared cabins the beds will be bunk beds.

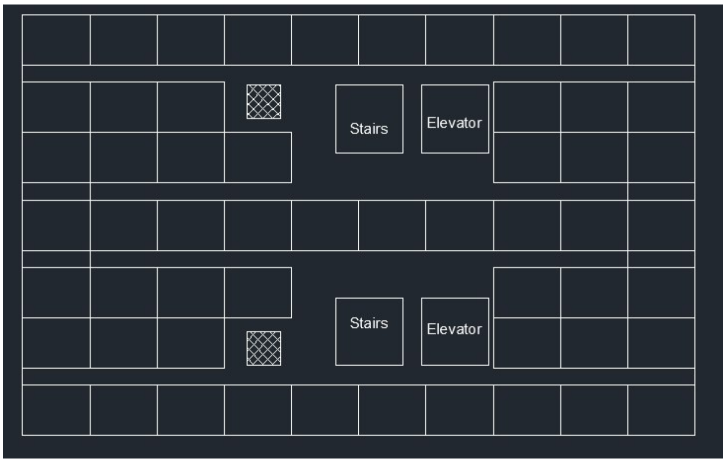


Figure 16: General arrangement of deck 6 of project FiPER

6.3 Deck 5

Deck 5 is the main deck. In front of the superstructure there will be one crane that is used to lift cargo and cargo/laboratory modules into the ship. There is also a large hatch from where those modules and other cargo are fitted inside the ship. In the superstructure deck 5 will have a general research hall and a helicopter hangar. Because of the helicopters this deck has to be 3,5 meters high. Behind the superstructure there will be helicopter platform with diameter of 21 meters. On both port and starboard side there will be one lifeboat with capacity for 150 persons. SOLAS requires that ships should have lifeboats to accommodate at least 125% of the number of crew and passengers, and every ship should carry at least two lifeboats with them. Behind the lifeboats there will be a hovercraft on the port side and a patrol boat at starboard. There will be crane at the stern of the ship as well. That is used to deploy the patrol boat and hover craft and to lift cargo.

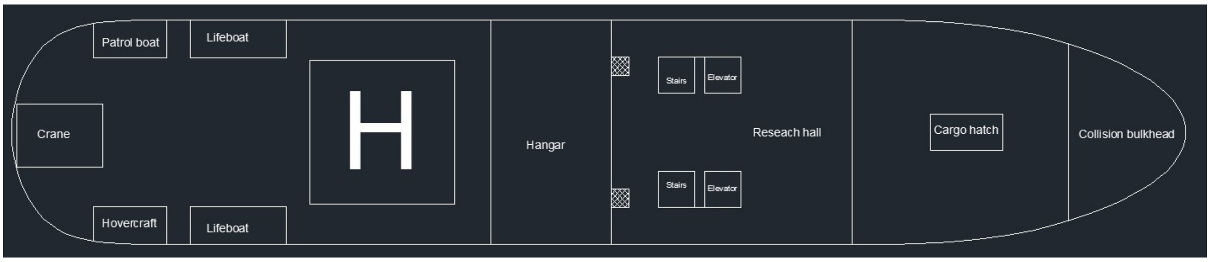


Figure 17: General arrangement of deck 5 (main deck) of project FiPER

6.4 Deck 4

The deck 4 has a height of 2,75 m. This area of the vessel has been majorly assigned for the leisure activities around the midship section and scientist accommodation at the stern. The total space for these sections of the ship is approximately 400 m2 each. During long journey of almost 3 months while working continuously, the research scientists and the crew members can always use a part of their daily routine as time for some relaxation and calming their nerves. For this purpose, we have decided to include some leisure facilities to our vessel. As an initial design approach, their will a library, fully equipped gym and sauna room and a coffee room with multimedia options. The space for each of these rooms is around 50 m2. There is going to be one messing halls having an area of 100 m2. As the working schedule for all of the crew members and the researching staff is not going to be the same, therefore, the messing area has enough space to accommodate the people with different schedules. The kitchen area will be approximately 50 m2 with all the necessary equipment for providing the healthy yet delicious food to the crew and scientists. The remaining space in this section can be assigned as storage space for food related stuff.

The other main space distribution in this deck 4 is allocated for the cargo hold. Now, this cargo space will be used for providing necessary supplies throughout the whole journey that FiPER will embark upon and also for the supply purposes for the research stations in the Polar regions as a part of the mission. There will be total of 5000 m3 of cargo hold. This area is connected with deck 3. The roof of deck 4 in this section consists partly of a removable hatch (hatch covers) to able the cranes to deal with the cargo supplies. The main cargo unit types will be pallets and containers. The cargo handling will be performed using vertical lift (lift on – lift off principle). Two cranes of capacity 10 tonnes each will be used to deal with this cargo.

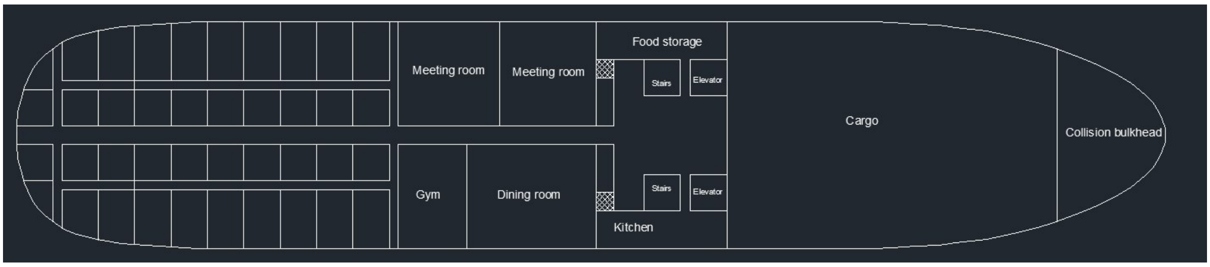


Figure 18: General arrangement of deck 4 of project FiPER

6.5 Deck 3

Next the general arrangement of deck 3 will be discussed. The main space has been allocated for research laboratories here. There is a total of 500m2 area dedicated for this purpose. There will be further small laboratories inside this space based on the diversity of research capabilities FiPER is going to be equipped with. In other words, this area is for multi-disciplinary usage. There will be minimum permanent installations to modify research options based on the mission. Data distribution will be performed with the aid of LAN network. The following are some of the options for space distribution:

- Observation room 20 m2 , 4 dry labs each 20 m2 and 2 wet labs each 40 m2
- 2 climate labs each 20 m2 and data centre 25 m2
- Electronics Lab 15 m2
- Cold room 30 m2
- Researchers meeting room 30 m2 and scientific storeroom 320 m2
- Deep freeze store 18 m2

Above are some of the options for the distribution but of course these can be modified according to the research criteria. Apart from this space, there will be modular type container hold space as well in the cargo hold to either utilize these modular containers as additional research operations or for the sake of cargo. The height of the main research space will be 2,75m. The height of the cargo area is not restricted by the deck as this area will be accessible by the crane for removing and adding of the cargo.

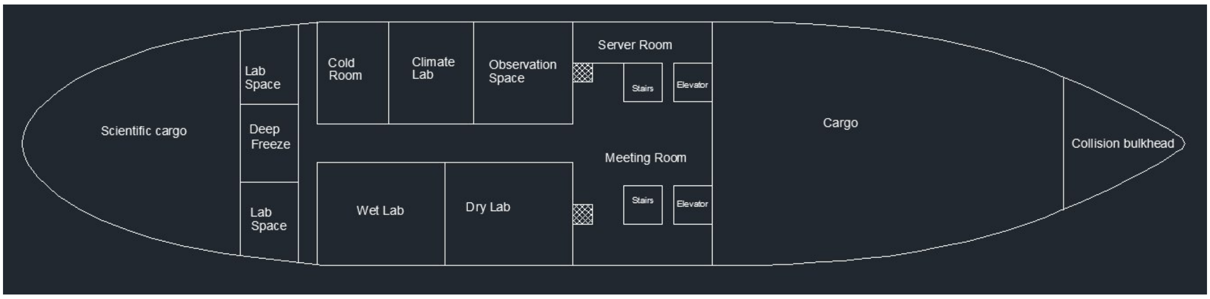


Figure 19: General arrangement of deck 3 of project FiPER

6.6 Deck1, Deck 2 and the Double Bottom

The bottom two decks of the ship will contain essential ship systems and the ships moonpool. Moonpools are installed into ships to allow access to the water regardless of the weather conditions and potential ice around the ship. They come in two main types, those that are located at the same height as the water and those that are equipped with an air lock and located at the bottom of the ship. Moonpools located at water level have several problems, the main one being that they require a long vertical corridor of water which takes up vast amounts of space and makes access to 'open water' cumbersome. This is why project FiPER has opted for a moonpool situated on the lowest deck of the ship. The moon pool will be of 2 meter diameter and be located in an airtight room of 36 m^2. The moon pool will have a door that can be opened and closed as needed, and the room will have fully controllable air exchange and an airlock, to allow complete control over the volume and quality of air present in the room. This is done in order to avoid flooding the room when the moonpool is opened.

These two decks will also contain the ships three engine rooms. Two engine rooms will be for the four diesel engines with a total power output of 38 400 kW. These rooms are estimated to require two decks in height and have a surface area of approximately 300 m^2 each. The third engine room will be for the hydrogen fuel cells and batteries. The hydrogen fuelcells will have a power rating of 10 300 kW. The fuelcells will require approximately 400 m^2 of deck space and will weigh about 30 tons. This will be distributed between decks 1 and 2.

Both the diesel engines and the fuelcells will naturally require fuel to operate. The diesel being dense will be located as low as possible, in conjunction with ballast tanks, whilst the hydrogen tanks will be located on deck two. The exact volumes of both fuels required remains to be calculated. At the moment the amount of diesel is estimated to be slightly over 2000 metric tons or about 3000 m^3. The amount of hydrogen will be significantly less, as the base hydrogen reserve of the ship is only intended for short periods during research. For longer periods of operating with hydrogen additional hydrogen tanks will be installed into the modular cargo hold on deck 3 and 4. All hydrogen storage facilities will be well ventilated spaces as required by regulations.

Decks 1 and 2 will also house the water tanks of the ship: the fresh water, grey water, black water, and ballast water. Due to water being heavy and dense, they are going to be located as low as possible, and in such a manner, that as water gets transferred from the fresh water tank to the grey and black water tanks the weight distribution doesn't change drastically. Because of regulations set in the polar code, all waste water must be transported away with the ship, and so the weight of the water supply should remain relatively constant, the only change is its location between the different tanks. The ballast water tanks will also be located in such a way that they can be used to compensate for the change in water and fuel levels. The general arrangement for deck 1, deck 2, and the double bottom can be seen in the following figures:

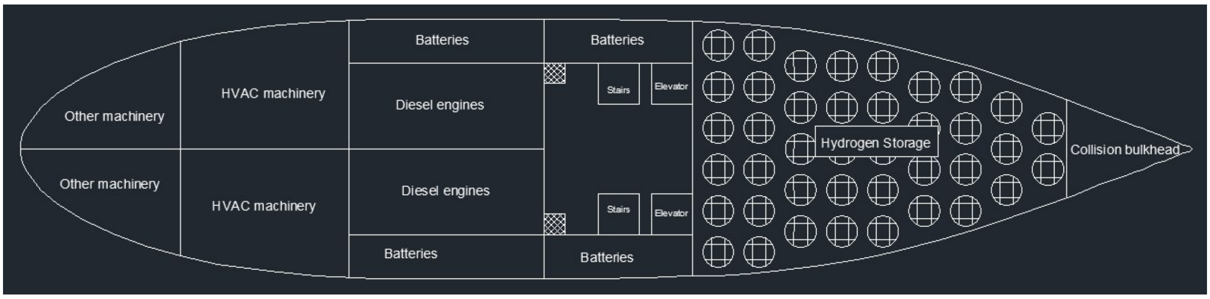


Figure 20: General arrangement of deck 2 of project FiPER

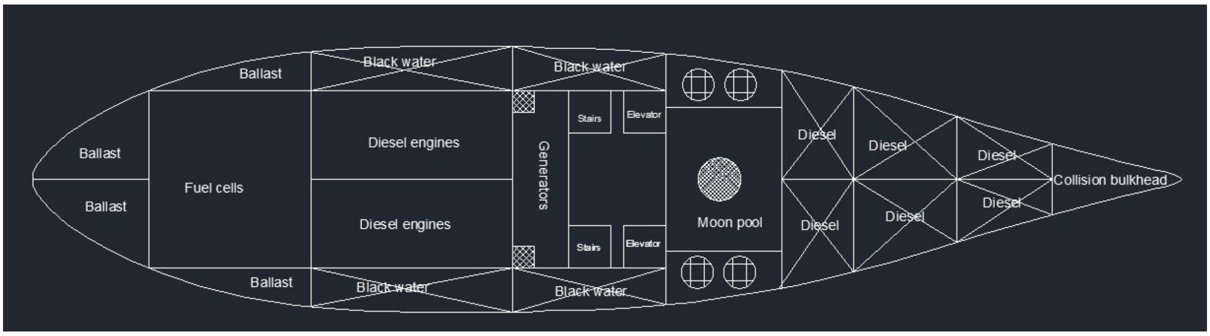


Figure 21: General arrangement of deck 1 of project FiPER

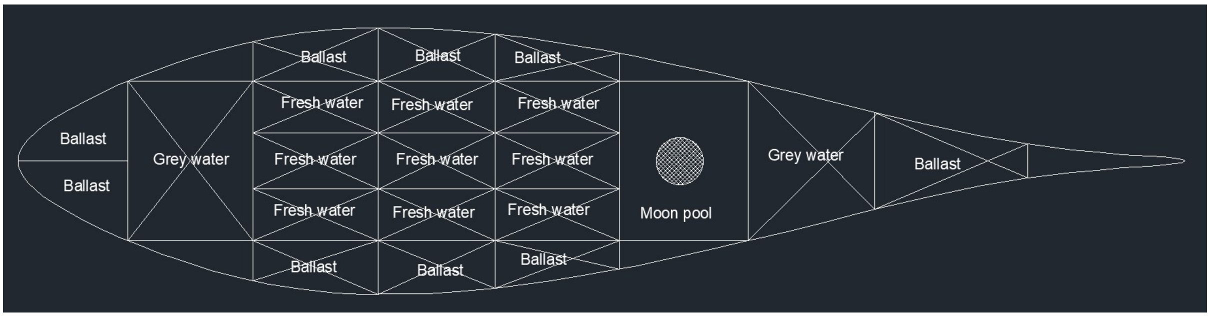


Figure 22: General arrangement of the double bottom of project FiPER

6.6 Profile and Cross-Sectional Drawings

Once the deck plans have been generated, the profile view of FiPER that represents different decks and can be drawn up. The red lines in the profile view represent the different fire zone distribution that has been defined according to the arrangements and guidelines provided by the regulations. After that the mid-ship and the engine room cross-sectional drawings will be presented.

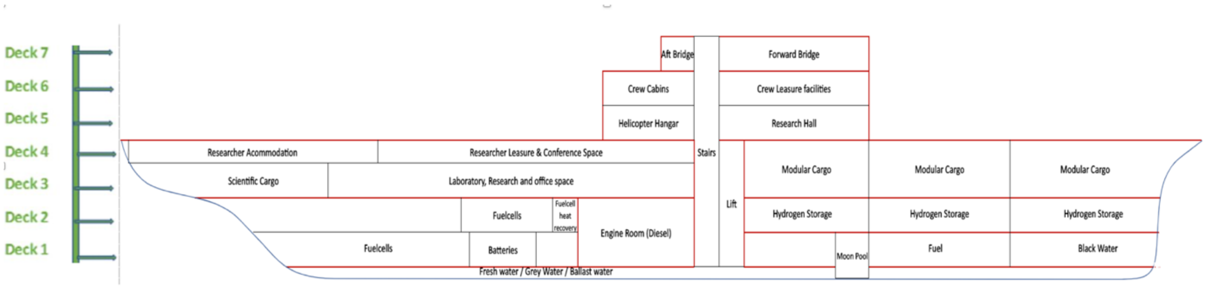


Figure 23: Profile view of project FiPER with 8 fire zones depicted in red

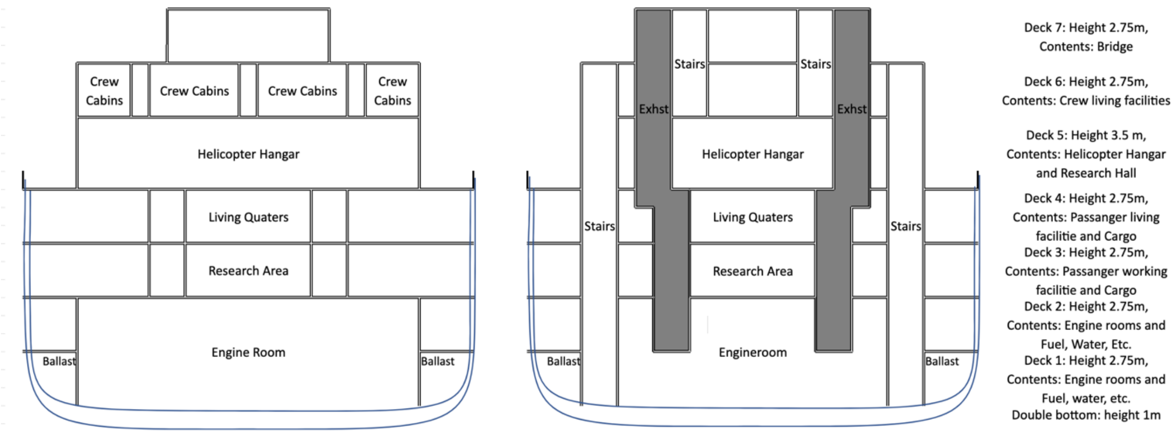


Figure 24: Cross-sectional drawings of the midship section (left) and engine room section (right)

7 Ship Structures

In this section we will discuss different structural requirements that the vessel has to possess and how these requirements are defined by the standards. The building material selection for the vessel will be discussed in detail and structural constraints set due to the general arrangement. And in the end, calculations for the ship's section modulus will be presented.

7.1 Structural Requirements

DNV GL's rules and standards will be followed for the ship's structural requirements. This classification society has written rules for different kind of vessels. From their rules the section covering vessels for special operations were chosen with a focus on icebreakers specifically. DNV GL's rules provide requirements for hull structure and stability. In addition to those there is also requirements for machinery.

7.1.1 Longitudinal bending strength and shear strength

In DNV GL's rules the design scenario for the evaluation of the longitudinal strength of the hull is a ramming impact on the bow. We did not find rules which deal with double acting icebreakers, but we thought that we shall consider our stern to be bow when going in ice and follow these rules.

There is a guide in DNV GL 2, 2020 that explains how to calculate longitudinal bending factors. Those are design vertical ice force, shear force and ice bending moment. DNV GL also specifies a table that points out longitudinal bending strength criteria that shall be satisfied. (Pt. 6 Ch. 6, Sec. 5, Table 10) DNV GL also specifies that design stress must be lower than the permissible stress. (DNV GL 2, 2020) DNV GL states that if the structure is analyzed using beam models,

bending and shear stress shall not be larger than $0.9 \times R_{eH}$ and $0.9 \times \tau_{eH}$,

where:

$$\tau_{eH} = \frac{R_{eH}}{\sqrt{3}}$$

7.1.2 Longitudinal hull girder strength

Design vertical shear force and bending moment along the hull girder should be calculated as Pt.6 Ch.6 Sec.6 [6.3] and Pt.6 Ch.6 Sec.6 [6.4] of DNV GL 2 require. FIB shall be calculated according to Pt. 5 Ch. 10 Sec. 10 [7.2] in DNV GL 1. Formulas and clear explanations can be found from DNV GL 1 and 2. There is said that all longitudinal strength criteria shall be satisfied with n=0,6. (DNV GL 1, 2020)

7.1.3 Structural continuity

About structural continuity there is not many rules from DNV GL. Structural continuity affects bending strength of the ship, so good continuity is required when designing ice breakers. If the ship had been designed without structural continuity, it is possible that it doesn't fulfil the requirements on strength.

Although no rules about structural continuity have been drawn up by the flag authorities either, we have designed our general arrangement and structures to be as continuous as possible. That can be seen from general arrangement drawings.

7.1.4 Conclusion of regulatory requirements

When designing the structure these previously presented requirements needs to be taken into count. The strength requirements that were followed are provided by DNV GL and they are made for icebreakers. There are not so many requirements about continuity, but it will affect a lot in strength if there are problems in continuity.

7.2 Material Selection

7.2.1 Hull Material

Requirement of hull material for efficient structure reliability is of utmost importance. In this regard, there are two main steel groups: normal steel and high strength steel. While selecting the right material, yield strength is an important feature. And in both steel groups, various grades are explored based on right chemical composition and mechanical properties.

While developing vessels to be operated in Polar regions, a critical factor that is associated with the steels properties is the its resistance to brittle fracture at low temperatures and high loading conditions especially in ice. Therefore, low temperature is an important factor for choosing the right materials considering brittle fracture. At low temperatures, the fracture toughness and ductility decrease, and steel can become more brittle, increasing the chances of catastrophic fracture especially below the waterline. Therefore, impact toughness is considered as an important criterion considering the range of temperatures the vessel is going to operate in.

The following are different steel grades used in construction of hull:

- Grade A steel is the impact force subjected to normal temperature (20 °C).

- Grade B steel impact force at 0 °C.

- Grade D steel impact force at -20 °C.

- Grade E steel impact force at -40 °C.

High-strength shipbuilding steel plate can be further divided into: AH32, DH32, EH32; AH36, DH36, EH36 and AH40, DH40, EH40. It is vital to control the carbon composition because increased carbon contents can reduce impact toughness at low temperatures. Here is a comparison for the chemical compositions of high-strength steels:

Table 6: Chemical composition of various steel grades

Elements	C	Mn	Al	Si	P	S
AH32	≤0.18	0.7-1.6	≥0.015	0.1-0.5	≤0.04	≤0.04
DH32	≤0.18	0.9-1.6	≥0.015	0.1-0.5	≤0.04	≤0.04
EH32	≤0.18	0.9-1.6	≥0.015	0.1-0.5	≤0.04	≤0.04
AH36	≤0.18	0.7-1.6	≥0.015	0.1-0.5	≤0.04	≤0.04
DH36	≤0.18	0.9–1.6	≥0.015	0.1-0.5	≤0.04	≤0.04
EH36	≤0.18	0.9-1.6	≥0.015	0.1-0.5	≤0.04	≤0.04

Below are the given mechanical properties between these steel grades:

Table 7: Mechanical properties of various steel grades

Steel Grade Thickness mm		Yield Point MPa	Tensile Strength MPa	Elongation %	V-type impact test		
					Temper a-ture °C	Average impact absorption work A_{kv}/J	
						Vertical	Horizontal
A	≤50	≥235	400-490	≥22	-	-	-
B	≤50	≥235	400-490	≥22	0	≥27	≥20
D	≤50	≥235	400-490	≥22	-10	≥27	≥20
E	≤50	≥235	400-490	≥22	-40	≥27	≥20
AH32	≤50	≥315	440-590	≥22	0	≥31	≥22
DH32	≤50	≥315	440-590	≥22	-20	≥31	≥22
EH32	≤50	≥315	440-590	≥22	-40	≥31	≥22
AH36	≤50	≥355	490-620	≥22	0	≥34	≥24
DH36	≤50	≥355	490-620	≥22	-20	≥34	≥24
EH36	≤50	≥355	490-620	≥22	-40	≥34	≥24

Based on high yield strength and impact toughness properties keeping in mind the low temperature set requirements, steel grade EH36 has been selected for the hull manufacturing.

7.2.2 Superstructure Material

The attempt to reduce the weight of different ships, improve the payload and reduce fuel consumption, has turned shipbuilders in the direction of aluminum alloys. They have the potential to reduce the weight of ship structures by up to 50%, compared to those made from low carbon steels. The view of steel as the most widely used material in the shipbuilding industry derives from its advanced mechanical properties and low manufacturing costs. However, the non-heat-treatable Al-Mg alloys have been considered favorable in respect to the costs and all the required properties for successful vessel service. The most popular aluminum alloys for use in corrosive environments are non-heat treatable 5000, and heat- treatable 6000 type alloys, because of stable strength parameters, weldability, and formability (the stress free zones can be defined more easily). The 6000 alloys are stronger but two to three times less corrosion resistant than the 5000 series. The requirement for maintenance of marine structure surfaces as they require less frequent painting or other coating refreshments is an important cost saving factor during the serving of the ship. Further, aluminum structures provide better strength to weight ratio. Apart from these, quality finish, corrosion resistance, and oxidation resistance are important parameters to define the age of the ship. Therefore, it is widely used nowadays in marine superstructures. For these reasons, we have opted the material of the superstructure manufacturing to be:

- Al-Mg alloy 5083 for platings
- Al-Mg alloy 6082 for extrusions

All the requirements for material selection have been understood from the DNV GL regulations. So, to conclude, the selected materials for vessel are:

- Hull – Steel EH36
- Superstructure – Al-Mg alloy 5083 & Al-Mg alloy 6082

7.2.3 Joining Aluminum Superstructure to Steel Hull

Many ships these days are combining aluminum superstructures to steel hulls. The standard for performing this task is the roll-bounded or explosively bounded bimetallic/trimetallic strip having a width of at least 4 times than the thickness of plate that it will be joining. For example, if aluminum plate is 10mm then bimetallic/trimetallic strip must be of 40mm wide which should be painted completely to avoid corrosion. Kimapong and Watanabe (2004) also proposed a simpler method to use stir friction stir welding to join 2mm 5083 plate to mild steel of same thickness. This is a more effective method and should be explored because it is much cheaper and provides cleaner joints between two metals of different chemistry.

7.3 Frame Spacings

Next a few frames spacing related topics as understood from the DNVGL regulations will be discussed. Ships of length more than 120 meters must include a longitudinal framing system. The system is designed in such a way as to withstand bending moments which can be more dominant in longer vessels. But there are special considerations to be taken into account while defining frame spacings for ice-breaking vessels. Usually, there is mixed frame spacing used for such kind keeping in mind the importance of good strength characteristics. Due to significant ice loads, transverse framing is done at the bottom and side platings to overcome huge stresses. Moreover, angles and t-stiffeners are to be included. Stiffeners are installed in such way that they are perpendicular to the ice loads. High strength steels will be opted for as a building material.

According to the DNV GL rules, the frame spacing for longer ships should not exceed 600 mm.

・For the transverse framing system, the frame spacing will be 600 mm with web frames on every third frame which will result into a total of 1800 mm web frame spacing. The reason for choosing this frame spacing is majorly dependent on the reason that, the vessel is going to experience high ice loads.

・For the longitudinal framing system: the space between longitudinal frames will be 600 mm between every sixth longitudinal girders and it adds up to 3600 mm in total.

The bracket attachments for frames will be done according to following figure:

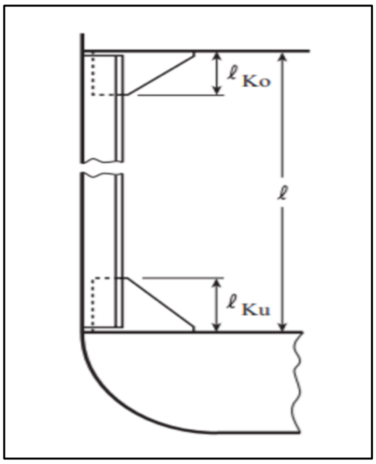


Figure 25: End attachment design

The end attachments for the tween deck and superstructure frames are to be connected to the main frames below or to the deck according to any of the following arrangement given by regulations:

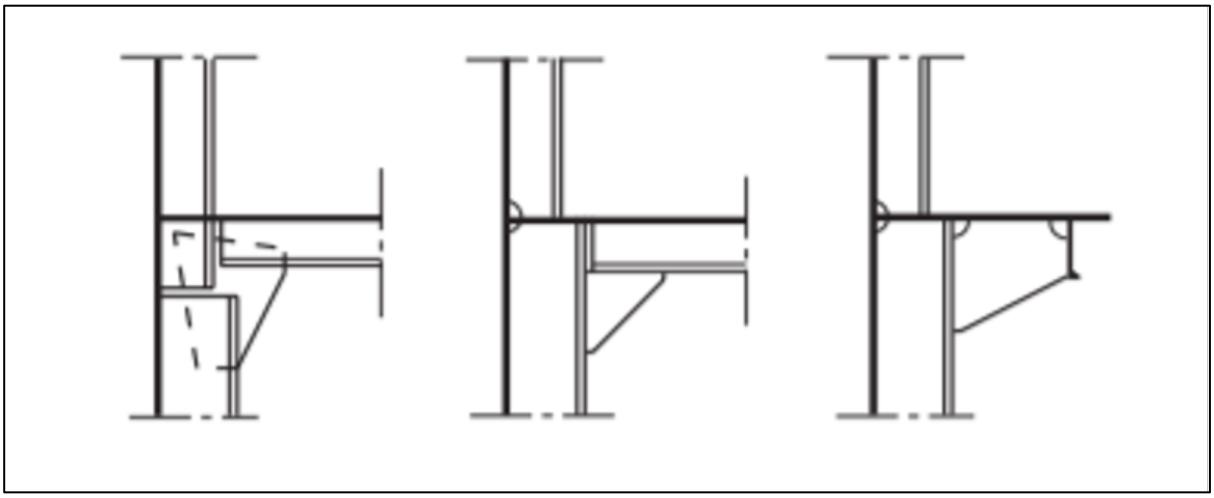


Figure 26: Tween deck and superstructure end attachment design

The peak frames will be connected to the stringer plates to ensure the sufficient transmission of shear forces. The frames in way of the cruiser stern arranged at changing angles to the transverse direction are to have a spacing not exceeding 600 mm and are to extend up to the deck above peak tank top maintaining the scantlings of the peak frames. Longitudinal frames will be preferably be continuous through floor plates and transverses. Attachments of their webs to the webs of floor plates and transverses are such that the support forces will be transmitted without exceeding a shear stress of 100/k [N/mm^2] where k is the material factor given in DNV GL rule book section 2,B.2. Where longitudinal are sniped at watertight floors and bulkheads, they will be attached to the floors by brackets of the thickness of plate floors, and with a length of weld at the longitudinal equal to 2 × depth of the bottom longitudinal. Since we will have a mixed frame system therefore, at the intersection of a longitudinal with a transverse support member (e.g., web), the shear connections and attached heel stiffener will be designed within the limit of the permissible stresses as per section 4.7. At intersections of longitudinal with transverse tank boundaries the local bending of tank plating will be prevented by effective stiffening. Following are typical intersections of longitudinal and transverse support members that will be implemented:

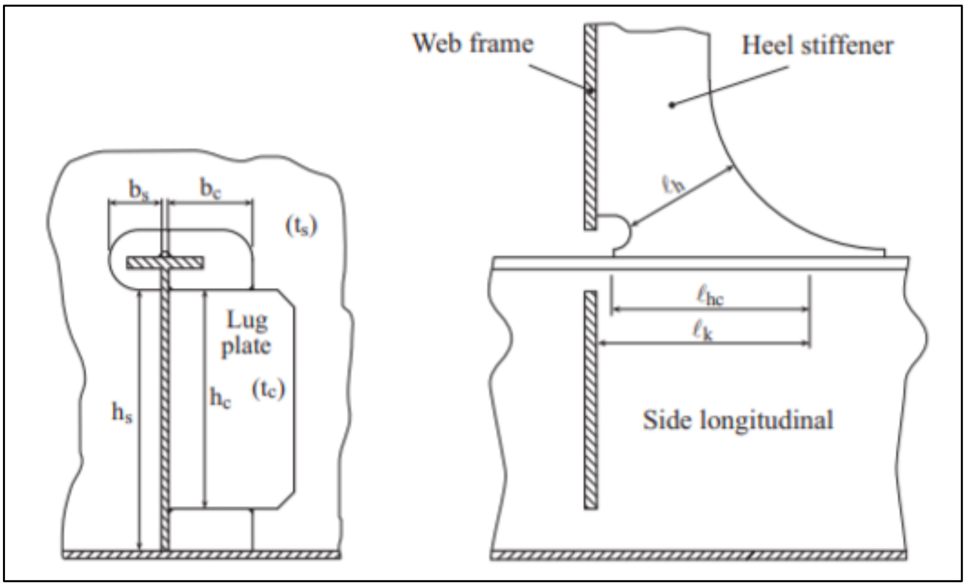


Figure 27: Mixed frame system strengthening

Looking at some of the reference data, the plate thicknesses has been initially proposed in the table given below. The reference data had much detailed calculations on the selection of this plan. Here are the proposed plate thickness values:

Table 8: Plate thickness values

Location	$T_{plate, rule}$[mm]	$T_{plate, selected}$[mm]
Hull Outer plate		25
Flat Bottom	18-20	25
Engine Room	8.9	9
Storage	7.38	8
Main Deck	7.88	8
Laboratory Section	6.88	7
Leisure Facilities	6.88	7
Cabins	6.88	7
Bridge	6.88	7

The hull outer plate has been chosen to be 25mm as a start but if required based on ice load reference data and load calculations, further re-enrolments can be implemented to induce better ice breaking capabilities.

7.4 Section Modulus

When calculating the section modulus of the different components of the ship an excel sheet generated by Spyros Hirdaris was used. We inputted data presented in Table 9 to the excel sheet and observed the results presented in Figure 28.

Table 9: Input dimensions

Unit	Breadth (m)	Depth (m)
Tank Bottom	21	0.025
Tank Top	22	0.01
Deck	25	0.01
Outer Shell	0.025	12
Inner Shell	0.01	11
Long. Bulkhead	0.01	12

The dimensions (Breath of tank top, bottom and deck and depth of Inner and outer shell and bulkheads) were chosen based on our delft ship model, and the thickness dimensions (Depth of tank top, bottom and deck and breath of Inner and outer shell and bulkheads) were based on an iterative process of calculating with different values until we attained a sufficient safety factor. This safety factor is 7,7 for the bottom of the ship and 4,4 for the deck of the ship.

Item [-]	Number of parts n [-]	Breadth b [m]	Depth d [m]	Height h_j [m]	Area A=n*b*d $[m^2]$	1. Moment $S=A*h_j$ $[m^3]$	2nd Moment @ centroid $i=n*b*d^3/12$ $[m^4]$	2nd moment @BL $I_S=A*h_j^2$ $[m^4]$
Tank Bottom	1	24,875	0,025	0,013	0,622	0,008	3,24E-05	9,72E-05
Tank top	1	24,875	0,01	0,995	0,249	0,248	2,07E-06	2,46E-01
Deck	1	24,875	0,01	11,995	0,249	2,984	2,07E-06	3,58E+01
Outer shell	2	0,025	12,000	6	0,600	3,600	7,20E+00	2,16E+01
Inner shell	2	0,01	11,000	5,5	0,220	1,210	2,22E+00	6,66E+00
Long. bulkhead	2	0,01	12,000	6	0,240	1,440	2,88E+00	8,64E+00
				Σ	2,179	9,489	12,298	72,932

Total cross-section		
Ship Depth D	12,00	m
Neutral axis	4,35	m from BL
Elements, $i_{,tot}$	12,30	m^4
Elements, $I_{S,tot}$	72,93	m^4
I_{BL}	85,23	m^4
I	43,91	m^4
Z_{deck}	5,743469211	m^3
Z_{bottom}	10,08596589	m^3

Load and response		
Moment	1,95E+08	Nm
σ_{deck}	33,95	MPa
σ_{bottom}	19,33	MPa

Tensile strength of AH36 =	500 MPa
Assume fatigue limit of 30% =	150 Mpa

Figure 28: Section modulus calculations

The fatigue limit of steel can be assumed as a rule of thumb to be 50% of the tensile strength. 30% was used to add to the safety factor of the vessel as a failure in the deck or the bottom could prove catastrophic.

The excel that was used for the calculations had the specifications of a model ship. The ship considered in this report is approximately 30% larger than the model ship, and so the force applied to the deck and the bottom was scaled by 30%, from 150’000’000 MPa to 200’000’000 MPa.

7.5 Structural Challenges

The laboratory space in deck 3 is near the diesel engine room, and there might be vibration sensitive research equipment and also researchers working hence structural vibration of the hull and noise levels must be handled in a way that they don't cause problems for scientific research. There exists the silent drive option with fuel cells and batteries powered by hydrogen, but the silent drive time is limited. Very effective floating floor system under the research spaces are needed and they can be costly. Also, the usage of the floating floor systems has to be taken account in the more detailed ship design, as in some cases they can amplify vibrations in other parts of the ship.

In the general arrangement the cargo hold has been designed to be a modular two decks high open space, where shipping containers can be loaded through a smaller hole and then they can be moved around the cargo space to their position. This requires a big open space, where structural continuity, stiffness and fatigues of the structure are problems that will be encountered. Parts of the space must be filled with longitudinal and transverse bulkheads but that will make it harder to move containers around to their position. Arranging the bulkheads and shipping container moving routers in an efficient way will be a challenge. Big holes will be needed in the main deck where the shipping containers can be lowered into cargo space, which will make the surrounding of the cargo space even weaker. Excessive strengthening of the main deck in this area must be done, but in a way that doesn't consume too much the available height of the cargo space. One of the cranes is located in the bow of the ship above the cargo space and it will cause a lot stress into structures below it. This means that the structures must be reinforced even more without sacrificing cargo space. All this taken into account, designing the area around the cargo space will be a challenge.

As the cargo space is modular (in our case meaning that it can also hold shipping container size rooms filled with research equipment and facilities) at least a part of the cargo shape would benefit from floating floor system, but it will encounter the same problems as said in the previous chapter. An easier way would be to make the vibration and noise insulation inside the "research container" but that would eat up already limited space inside the container.

Hydrogen storage area is not located in the main deck but under it in closed space. Any hydrogen leaking will cause a serious fire hazard hence the closed space must be well ventilated to remove any excess leaking hydrogen. Same is true for all spaces where hydrogen is handled.

This is an issue that must be taken into account in later stages of the design circle. Battery room in deck 1 must be well ventilated too, as almost all lead-acid type batteries will produce fumes such as hydrogen sulphide resulting excess corrosion and health hazard. Hydrogen fuel cells produce a lot of heat and those must be cooled down. This is not a big issue but building a cooling system that takes into account the requirements of both power sources is complicated.

The moon pool is below the water level so it must be pressurized so the whole space does not fill up. If the pressurizing system fails or there are any leaks it will cause unsafe situation and probably change the ship's stability. The Rooms and doors heading to the moon pool must be made watertight and able to withstand the failure of the moon pool system without causing any serious danger or risk of capsizing.

Helicopter storage space inside the superstructure will be a large open area where longitudinal or transverse support is limited. At the same time the structure needs to withstand loads coming from decks above and main deck below, so excessive strengthening of the surrounding area might be needed.

8 Operating Profile, Power, and Machinery

After the hull and superstructure have been designed it is time to move on and define the other specifications of the ship. This section begins by defining the operating profile, and then on the base of this the power and machinery required.

8.1 Operating Profile

The ship has two destinations, which are the north pole and the south pole. Here is an example of the operating profile for both of those destinations. The profile back to the home port (Helsinki) is same for each destination but simply in reverse order.

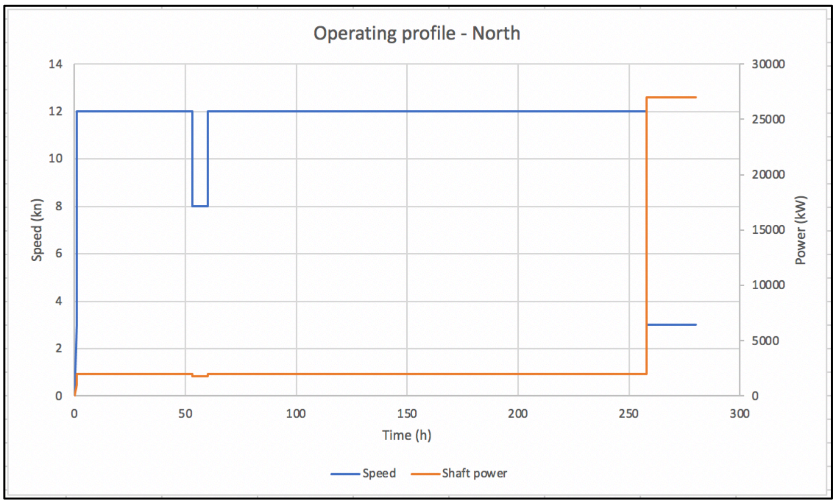


Figure 29: Operating profile – North Pole

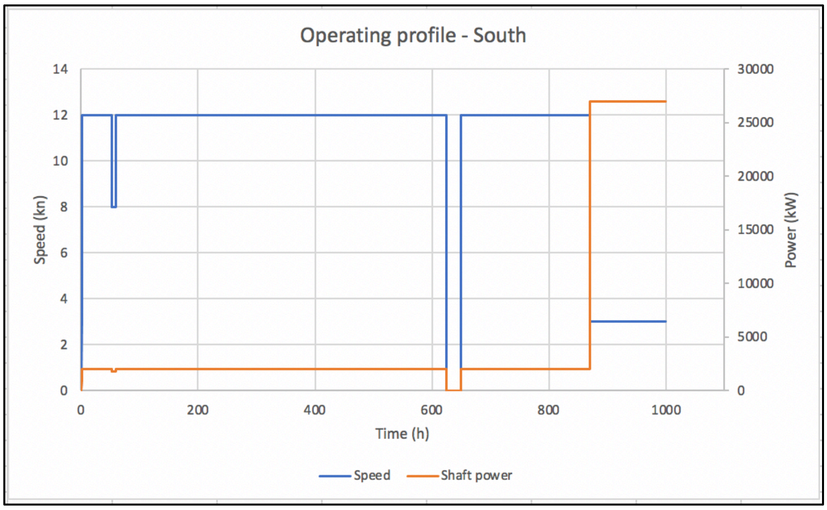


Figure 30: Operating profile – South Pole

In the x-axis the time in hours can be seen. In the left y-axis there is speed in knots, and in right y-axis there is needed shaft power for the speed. In real life the speed wouldn't be that constant, and neither would the power. For example, before increasing speed there should be peak in power.

In the previously shown operation profiles the cruising speed in open water is set to be 12 knots, and speed after reaching ice in Arctic and Antarctic is 3 knots. Starting port is Helsinki. First leg is from Helsinki to Kiel channel at 12 knots for 52 hours. We will go through Kiel channel at a limited speed of 8 knots and it takes 7 hours.

When going north, after the channel the ship will continue at 12 knots to its research destination in the arctic region. When it reaches ice after 258 hours, the speed will be reduced to 3 knots. In real life that speed wouldn't be constant, but it is hard to estimate the speed changes because ice thickness and strength changes a lot. The vessel will also drive in ice longer than 22 hours, but the time and research points change in every trip.

When going south, after the channel the vessel will continue at 12 knots towards Cape Town. It reaches it in 625 hours, and there it will have a 24-hour break for bunkering and resupplying. After the break it will again continue at 12 knots towards its research region. Like in Arctic, when it reach ice its speed will be reduced. It reaches ice after 870 hours.

8.2 Resistance and Power Calculations

The Ship's open water resistance and the necessity of propulsion power has been estimated with the power prediction method created by J. Holtrop and G.G.J. Mennen. The total resistance of the ship is divided into sub resistances.

$$R_{total} = R_F(1 + k_1) + R_{APP} + R_W + R_B + R_{TR} + R_A$$

An excel file where these calculations can be done with the help of Delftship and AUTOCAD where we can get values for the coefficients off the hull was used. Here are the calculating parameters we entered into the calculations:

Power Prediction Method - J. Holtrop and G.G.J. Mennen - 1982
Developed by: Gérson Beraldo Matter - 04.17.2000

PRINCIPAL PARTICULARS				
LBP =	125,680	m	-	Length Between Perpendiculars
B =	25,148	m	-	Beam
T =	8,500	m	-	Average Moulded Draught
lcb =	-1,900	%	-	Longitudinal Centre of Buoyancy as a percentage of LBP - + Foward of 0,5 LBP
Cp =	0,636		-	Prismatic Coefficient
Cb =	0,595		-	Block Coefficient
Cms =	0,936		-	Midship Section Coefficient
Cwp =	0,821		-	Waterplane Area Coefficient
Abt =	0,000	m2	-	Transverse Sectional Area of the Bulb at Fore Perpendicular (See the middle picture below)
Cstern =	0		-	Afterbody form: (see the left picture below)
Tf =	8,500	m	-	Foward draught of the ship
Ta =	8,500	m	-	Stern draught of the ship
hb =	0,000	m	-	Position of the centre of the transverse area Abt above the keel (See the middle picture below)
At =	0,000	m2	-	Immersed part of the transverse area of the transom (See the rigth picture below)
S =	0,000	m2	-	Wetted Surface - If you don't now, input zero and the program will estimate a value

Figure 31: Calculation of parameters

For the propulsion efficiency calculations, following parameters were obtained:

PROPULSION PARTICULARS				
Z =	5		-	Number of blades
P =	6,00	m	-	Pitch of the propeller
D =	8,00	m	-	Diameter of the propeller
Hp =	6,00	m	-	High of the shaft from keel line
K =	0,1		-	K = 0,2 for single-screw ships or 0,1 for twin-screw ships
eta0 =	0,7		-	Open water efficiency of the propeller
Speeds				
V0 =	1,00	knots	-	Initial Speed
Vf =	23,00	knots	-	Final Speed
WATER PARTICULARS				
Ni =	1,188E-06	m2/s	-	Kinematic Viscosity of Water
rho =	1025	kg/m3	-	Specific mass of water

Figure 32: Calculation of parameters for propulsion efficiency

The following results for the ships resistance and for the needed engine power were calculated:

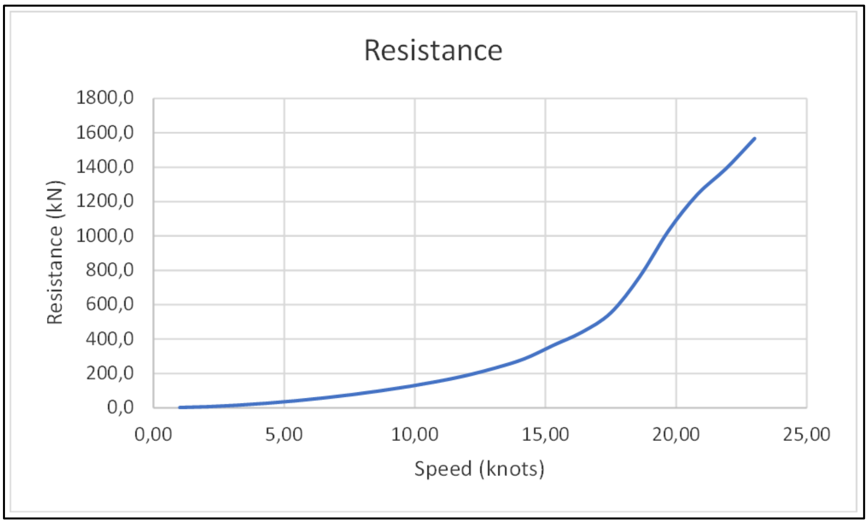


Figure 33: The ships resistance as a function of speed

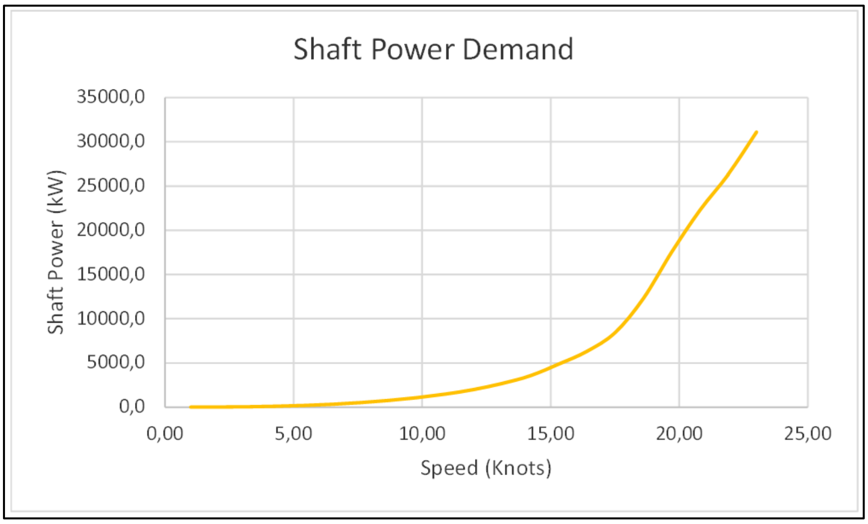


Figure 34: The ships power demand as a function of speed

Then the ship's wind resistance was calculated. The wind will have maximum resistance when its coming from opposite direction than where the ship is traveling. The ship's face area is roughly 260 square meters (87 for the hull and 173 for superstructure) and the equation how the wind resistance can be calculated is the following:

$$F_d = \frac{1}{2}\rho A v^2 C_d$$

For a rectangular box the drag coefficient is roughly 2. This describes the superstructure quite accurately. For the hull, drag coefficient of Long stream-lined body of 0,1 is used.

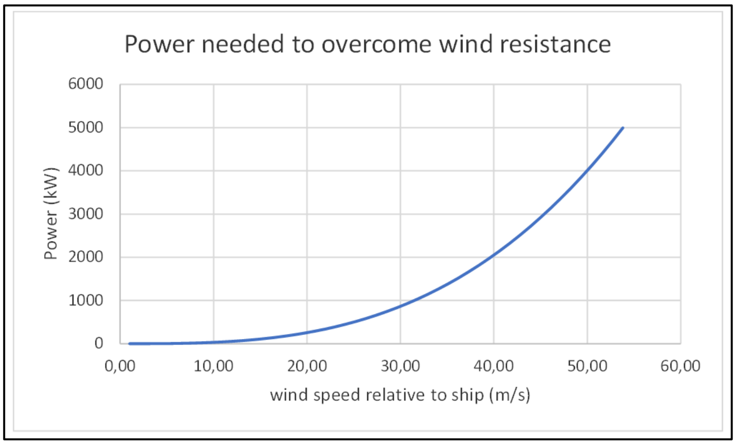


Figure 35: Power required to overcome wind resistance as a function of speed

For ice breaking resistance and power needed to break the ice Lindqvist method from 1989 was used and the following results for the shaft power were obtained:

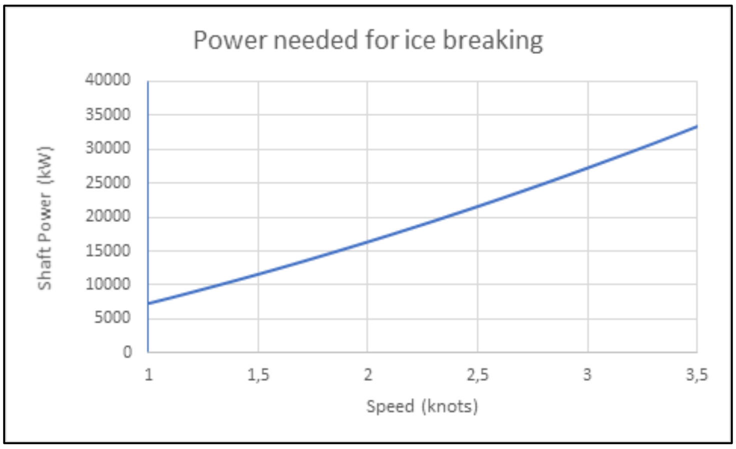


Figure 36: Power required to break 1,65 m of ice as a function of speed

8.3 Total Power Demand

The total power demand for a ship is a combination of the propulsion power required to move the ship, and the power required to make everything else possible on the ship. The power required to move the ship is possible to calculate once certain variables have been defined. These calculations can be seen in chapter resistance and power calculations. The power required to make everything else possible is however hard to calculate until most of the electrical consumers have been defined. In the preliminary design stage, defining all the electrical consumers cannot be done, and so a rough estimate has been made. This estimate, and the process of generating it, can be seen in chapter reserve power.

8.3.1 Total Power

The main propulsors will be two Azipods with fixed pitch propellers. This was chosen because it gives excellent manoeuvrability to the ship, which is important in ice and in ports.

The biggest shaft power that we need is 27MW. Azipods which have 13,5MW propulsion power each were chosen. The azipods are going to be VI series units. VI series is made for ice going vessels and power range is 6-17MW.

The ship is going to be fitted with two bow thrusters to increase manoeuvrability. They are used in the port areas. Our ship will have Wärtsilä Transverse Thrusters that are available in power range of 400-3550 kW. We chose FiPER’s to be 2MW.

8.3.2 Reserve Power

There are several ways to estimate the required reserve power for a ship. In this report statistical validation method has been employed. Other method would have been simple with better knowledge of electrical consumers: to go through different categories of power consumers and estimate the power consumption of each. Since at the moment the project is unable to perform these estimates accurately, the result will be validated by a second method: a statistical method based on reference ships. The estimates and the validation are explained in the section estimating different electrical consumers and section statistical validation.

8.3.3 Statistical Validation

This section will explain how the hotel load has be approximated using statistical data from similar ships. The problem with this method is that this data is hard to find, and only available for a few ships and so this method is used primarily to validate the estimate made in the previous section. Table below shows the data that was gathered.

Table 10: Total installed power capacities for selected polar research vessels

Name	TP (*MW*)	PP (*MW*)	RP (*MW*)	Δ
RSS Attenborough	18	11	7	12790
SA Agulhas II	12	9	3	13687
RV Kronprins	17	11	6	9145
Xue Long II	32.5	15	17	14300
HMS Protector	7	5	2	5000

From this data a graph can be drawn, lines of best fit can be applied and the hotel load for FiPER can be extrapolated. The graph can be seen in first figure below. From this data the values for Xue Long II have been excluded in order to get lines of best fit that make more sense.

This graph can be seen in second figure below. The line of best fit gives an equation for reserve power of RP= 0.0034×Δ0.7727. This estimates the required reserve power for project FiPER as a function of displacement to be equal to approximately 6 300 kW. Since the data is limited, and the line of best fit is only 36% accurate, the reserve power should account for this by having a safety factor of at least 64%, giving a required power to cover the hotel load of 10 300 kW.

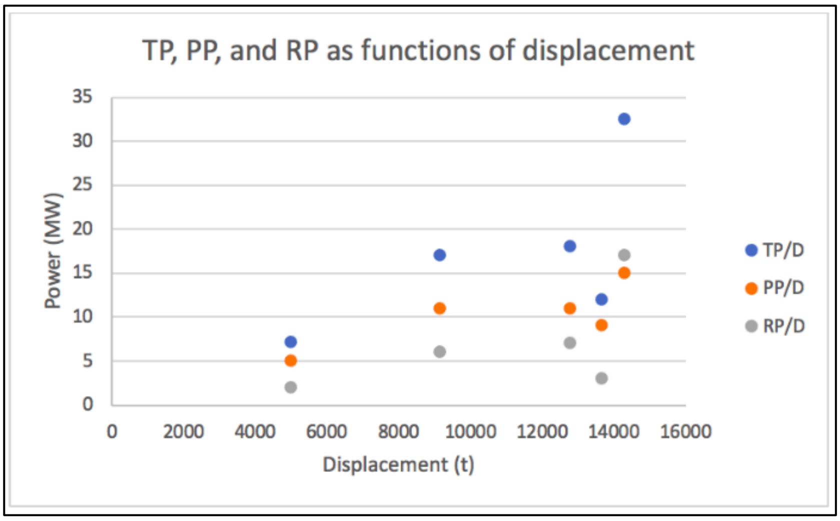


Figure 37: Total power (TP), propulsion power (PP), and reserve power (RP) as a function of displacement

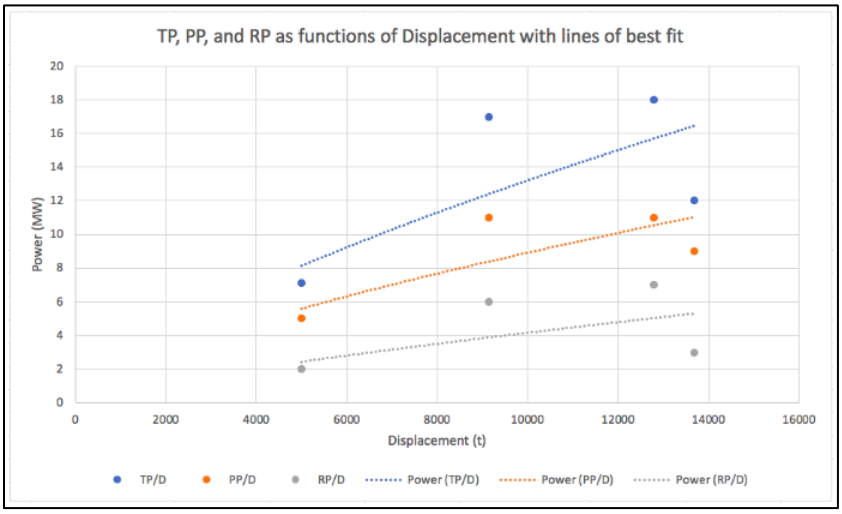


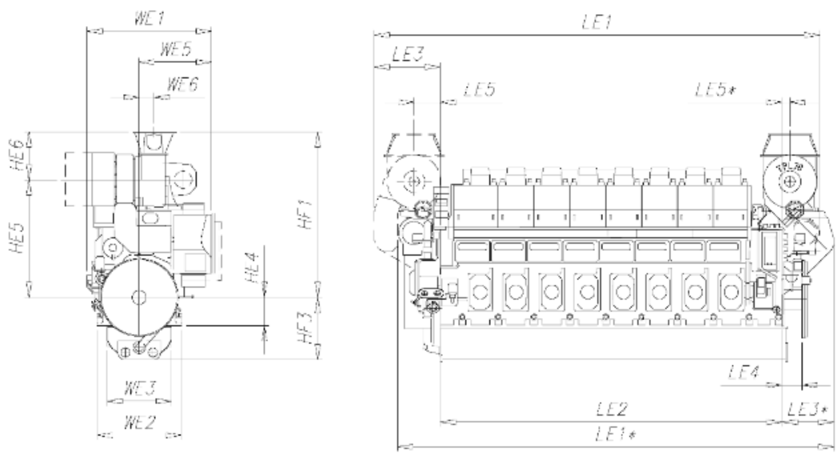
Figure 38: Total power, propulsion and reserve power as function of displacement with lines of best fit included

8.4 Engines

The vessel will have two energy sources that are diesel and hydrogen. Diesel is its main energy source when in transit, and hydrogen is for powering the ship in polar regions when standing still and doing research work.

8.4.1 Diesel Engines

Diesel engines were chosen from Wärtsilä. The highest shaft power is needed when breaking the ice. Breaking 1,65m ice at a speed of 3 knots requires 27 MW of shaft power. So, the required total power is approximately 35 MW. That means that the ship needs to be able to produce this amount of power with diesel engines. From Wärtsilä web pages a table of their engines with specifications can be seen. Four (4) 8L46F diesel engines in were selected to power the vessel. They are medium-speed 4-stroke diesel engines. They will be coupled to AMG model generators produced by ABB. The selected engines weigh 124 tons per unit, and their main dimensions can be seen in figure below. Total power is $4 \times 9\,600\ kW = 38\,400\ kW$. This is enough for breaking ice and producing electricity for accommodation. Those engines can be run on heavy fuel oil, marine diesel oil and light diesel.



LE1	LE1*	LE2	LE3	LE3*	LE4	LE5	LE5*	HE1
10260	10255	7810	1550	1465	460	800	180	3800
HE3	HE4	HE5	HE6	WE1	WE2	WE3	WE5	WE6
1430	650	2700	1100	3130	1940	1480	1760	340

Figure 39: Dimensions of Wärtsilä 8L46F

8.4.2 Fuel Cells

With the diesel engines the ship will have hydrogen fuel cells that can produce 10,3MW power. This is for accommodation and research activities when the ship is standing still in polar regions. It is environmentally friendly and there is a lot less vibrations hampering research work. There is no mass-produced product on the market yet, but fuel cells produced by ABB will be used.

8.5 Essential Ship Systems

The following section will explain the essential ship systems that will be aboard project FiPER.

8.5.1 Anchoring Equipment

Anchoring is a vital process on vessels. Shipping companies, port authorities and P&I Clubs value the safety of anchoring, which can be influenced by the incorrect anchoring operations and the increased traffic of ships as well as unfavourable weather conditions. An inappropriate anchoring can cause damage and loss to the vessel itself, other vessels, property, and the environment. The resultant losses of grounding and collision due to anchor dragging or loss can be considerable. So, the anchoring requirements are done keeping different elements like direction and strength of wind and currents, sea conditions, shallowness of water, underwater cables, and facilities etc in mind.

The distance to the nearest grounding line should be less than one nautical mile. The maximum depth of anchoring should not be beyond the capacity of windlass hauling. The under-keel clearance should be at least 20% of maximum vessel draft in loaded condition. The speed over the ground must be minimum when the vessel drops anchor. In general, it should be about 0.5 to 1 knot. The running out speed of anchor should be limited to 5-6 m/s and brake force can be implemented to control the speed. The anchor emergency disconnect system with anchor handling capability will be designed keeping in mind environmental conditions and provided with anti-icing protection. The anchor windlass and windlass controls will also be provided by anti-icing protection.

The crew would be able to easily access and operate the anchor windlass in an environment that protects them from wind, water spray, ice and slippery conditions, without the need to remove ice from equipment or decks. The material selection for anchor and chain will be made depending upon the design temperature ie. -50 degree Celsius. The DNVGL rules imply that chain type material would be K3 for temperatures < -20 degree Celsius. For anchor windlass components fabricated from plate material, Class III steel grades will be utilized. The anchor windlass shall have foundation bolts and shaft bearing holding bolts made from low temperature steel. The location of anchoring equipment will be represented in general arrangement as two bow anchors located on both sides of bow front and windlass connections.

8.5.2 Mooring Equipment

Mooring equipment is also chosen to suit the research ship's needs, and the location is mainly at the bow part with some options available at the mid-ship and stern sides as well. The winches will be installed of roller types controlled the same way as anchoring equipment. Crew would be able to remove snow and ice accumulation safely and efficiently from mooring winches and the surrounding work area to make operating them safe in a reasonable time prior to mooring. De-icing system is to be provided in the vicinity of the mooring winches. Mooring winches will be provided with covers to protect them from icing. Equipment material will be selected according to C1001 DNV GL rules, as per design temperatures described in previous section. Mooring winches will have foundation bolts and shaft bearing holding bolts made from low temperature steel. Mooring wires will be lubricated with low temperature wire rope dressing appropriate for the low design temperature. In details, mooring equipment will include bollards, chocks, fairleads, and roller pedestal. chain wheel, gear wheel, shaft, foundation bolt, drum, warping head on an anchor windlass and mooring wires.

8.5.3 Doors and Hatches

The vessel will be installed with weathertight doors and watertight doors in desired location. Weathertight doors are installed in following access openings:

- Bulkhead at ends of superstructure
- Bulkhead of deckhouse on freeboard deck openings
- Companionways on freeboard deck and superstructure deck

Except for pilot doors, which open inwards, weathertight doors will open outwards to provide additional security against the impact of sea. The material for them would generally be steel and are strongly attached to bulkheads, and framed, stiffened, and fitted so that the whole structure will have equivalent strength.

The areas which are highly prevented from flooding and most affected by it will have watertight doors. That means areas below the waterline. Such areas include engine room compartments and shaft tunnel etc. These doors will be sliding type watertight doors. The maintenance is highly important. These are going to powered by hydraulic cylinders. Drills for watertight doors operations will be done each week. The vessel will have both local and bridge control of these doors. The necessary instalment and operationality requirements will be according to SOLAS rules and regulations.

Small hatches will be designed to access spaces below the deck and will be capable of closing either watertight or weathertight as per requirement. These openings will be less than 2.5m. The hatch covers on the exposed decks will be weathertight. And hatch covers fitted in way of ballast tanks, fuel oil tanks will be watertight. Gross thickness of covers will not be less than 8mm and extra stiffening will be fitted where cover dimensions exceed 0.6m.

8.5.4 Evacuation System

Evacuation system designs are vital when we discuss the safe operations of the vessel. These should be reliable, accessible, and effective so that when the time comes, these can provide the most efficient safety measures. For this purpose, the vessel will have the following safety measuring equipment on board:

- Lifeboats and davits
- Life rafts
- Life jackets
- Life buoys
- Survival suits
- Evacuation slides and chutes

The drills for evacuation plans will be provided for the crew members within a designed schedule and the scientists on board will also be given safety and evacuation awareness seminars accordingly.

9 SFI Classification and Weigh Calculations

Once the operating profile has been generated and the major machinery selected, the vessel can undergo SFI classification and weight calculations. These are described in the following section.

9.1 SFI Classification

The SFI classification system is an international classification system used by ships and offshore structures. The SFI classification system divides the ship into ten main groups of which eight are commonly used. The eight main groups are then divided into different tiers based on subgroups. The main groups are as follows:

1. Ship General
2. Hull
3. Equipment for cargo
4. Ship equipment
5. Equipment for crew and passengers
6. Machinery main components
7. Systems for machinery main components 8. Ship common systems

The SFI classification system provides a clear, concise numbered list of the ships or structures main features and enables enhanced control of operations from the design of the structure to its daily operation. The following is the SFI classification of Project FiPER:

		Info (eg. Model)	Main Material	Main Dimensions	Weight	Cost
		SFI CLASSIFICATION				
Group 1:	General					
Group 2:	Hull and Superstructure					
	20: Hull Material	The hull shall be built of 'Grade A' steel	Steel			
	21: Hull Layout	210: Deck 5, Main deck	Steel	135 m * 25 m		
		211: Deck 4, Passenger acommodation, Cargo	Steel	135 m * 25 m * 2,75 m		
		212: Deck 3, Research area, Cargo	Steel	126 m * 25 m * 2,75 m		
		213: Deck 2, Ship systems and storage	Steel	115 m * 25 m * 2,75 m		
		214: Deck 1, Ship systems and storage	Steel	97 m * 25 m * 2,75 m		
		215: Double Bottom, water tanks	Steel	95 m * 25 m * 1 m		
	22: Engine Area	The main engine rooms will be located on decks 1 and 2		2 pcs, at aprox 300 m2/room		
	23: Cargo Area	The cargo area will be located in the bow of the ship on decks 3 and 4.		Aproximately 5000 m3		
	24: Superstructure Material	The superstructure will be built of aluminium	Aluminium			
	25: Superstructure Layout	250: Deck 7, Bridge	Aluminium	l:25 m * b:21 m * h:2,75 m		
		251: Deck 6, Crew Acommodation	Aluminium	l:35 m * b:21 m * h:2,75 m		
		252: Deck 5, Helicopter hangar and research hall	Aluminium	l:35 m * b:21 m		
	26: Material protection	The steel hull will be painted acording to regulations, the aluminium superstructure will be left untreated				
Group 3:	Cargo equiptment & machinery					
	30: Cranes	2 pcs, located at bow and stern	Steel	10 ton rating		
	31: Main Cargo Hatch	Main cargo hatch with cover	Steel	12 * 6		
	32: Container logistical system	System to manouver containers in decks 3 and 4.				

Figure 40: SFI classification for group 1-3

		Info (eg. Model)	Main Material	Main Dimensions	Weight	Cost
Group 4:	Ship specific equiptment & machinery					
	40: Anchoring System	Will be carried out according to DNVGL regulations				
	41: Mooring System	Will be carried out according to DNVGL regulations				
	42: Manouvering control stations	1 at forward wheel house, 1 at aft, and 1 in each wing				
	43: Tunnel Thrusters	2 pcs Wärtsilä with power 2 MW	Steel	2,4m*2,1m	13 tons/pcs	
	44: Ballast Tanks	Located in double bottom, exact number and volume to be specified				
	45: Navigation Equipment	inc. echo, speed, radar, magnet & gyro compass, AIS, strain sensors, cameras for taking photos for ice research, etc.				
	46: Communication equiptment	inc. Radio, LAN, VHF, UHF, etc.				
	47: Repair and Cleaning equiptment	Stocked as specified by machinery providers, such as Wärtsilä, ABB, etc.				
	48: Research Equiptment	Laboratory equiptment, research vehicles, Moon pool etc.				
Group 5:	Equiptment serving crew & passengers					
	50: Lifesaving equiptment	Lifeboats, 2 pcs		150 persons/lifeboat		
		Liferafts				
		First aid facilities acording to regulations				
		Firefighting facilities acording to regulations				
	51: Insulation, Panels, Bulkheads, etc.	Acommodation shall be aranged for 60 passangers and 25 crew as specfied in the GA		30 * 12 m2 for passangers, 25 * 12 m2 for crew		
	52: Stairs, Lift, Ladders, Steps and Railings	Two staircases lokated aproximately amidship running decks 1 - 7 and one cargo lift running decks 1-5				
	53: External Decks	Will have non skid coating, railings, etc. as specified by DNVGL				
	54: Furniture and Inventory	Cabins will be furnished with bed(s), desk, chair and cupboard,				
	55: Galley, Pantry and Laundry					
	56: Transport for crew	Gangway and platform for gangway on each side of vessel.	Steel	Gangway length: 10m		
	57: HVAC	Heating will harness excess heat from engines, and fuelcells where possible.				
	58: Sanitation					

Figure 41: SFI classification for group 4 & 5

		Info (eg. Model)	Main Material	Main Dimensions	Weight	Cost
Group 6:	Machinery main components					
	60: Engines	4 * Wärtsilä 8L46F, Total power 28,4 MW	Steel	10 * 5 * 2	124 tons/pcs	
	61: Azimuth Thrusters	2 pcs Wärtsilä VI series with 14 MW shaft power	Steel	Project specific	80 tons/pcs	
	62: Generators	2 pcs ABB AMG series generator, model 1600				
	63: Fuelcells	Manufactured by ABB, total power of aproximately 10 MW, PEM type		1000 m3	26 tons	19 000 €
	Equiptment serving main machinery					
Group 7	70: Fuel System	Diesel, stored in tanks in decks 1 and 2		Volume:	Volume*Density	
		Hydrogen, stored in pressurized tanks in deck 2		Volume: 240 m3	Volume*Density	
	71: Lubrication oil system					
	72: Cooling system	Each engine separate, with each engine having a HT and LT circuits.	Fresh water			
	73: Exhaust system	Exhausts shall be carried through central column of ship, which will house necesary components (SCR units, mufflers, urea injectors, etc.)				
	Ship common systems					
	80: Ballast, bildge and drain system	Bilge pumping system shall be completed according to Solas regulation 35-1				
		One oil water separator for engine room.				
Group 8:	81: Fire and lifeboat alarm systems	Smoke and heat detectors will be installed in all cabins and corridors, and further spaces that have high fire risk.				
		Ballast pumps will be arranges so that in the event of a fire, they can be used as fire pumps				
		A general allarm can be triggered manually or will automatically be triggered in the event of a fire				
	82: Electrical systems	Marine leadacid batteries will be the foundation of UPS system for essential ship systems (eg. navigation and emergency services)				

Figure 42: SFI classification for group 6-8

9.2 Weight Calculations

The weight of the ship is divided into two major categories. These include the lightship weight and the deadweight of the ship. These will be discussed in this section. The estimate of the lightship weight and the center of gravity based on this weight result will be performed using the provided excel spreadsheet. In the end the longitudinal center of gravity will also be estimated

9.2.1 Lightship Weight Estimation

The lightship weight of the ship is divided into three main sections. Machinery weight, outfitting weight, and the weight of the structure. All of these are going to be calculated based on the dimensions of the ship, weight coefficients and excel spreadsheet. First of all, the lightship weight is calculated based on the dimensions, block coefficients and longitudinal center of buoyancy. The resulting total lightship weight and height of the center of gravity measured from the keel are shown below:

Table 11: Lightship weight estimation for project FiPER

Length (m)	130
Beam (m)	25
Draught (m)	8,5
Depth (m)	12
Block Coefficient	0,64
Longitudinal Center of Buoyancy from aft (m)	62,3
Lightship Weight (tonnes)	7591
Distance of Center of gravity from keel (m)	6,56

Now the lightship weight based on its division among machinery, outfitting and structural weight will be calculated. First, the lightship weight of structures will be calculated. This includes the dimensions of the superstructure and a few coefficients like E which is the equipment number and K from the provided table for different vessels. The choice of selecting values used here for the calculations based on these coefficients in this section and in the coming sections where the outfitting and machinery weights are calculated will be discussed in the next part of the assignment since there is no direct way to choose these coefficients for the vessel type in question from the data provided. The machinery weight is calculated based on the power source maximum continuous rate MCR (kW), maximum rpm's N of the engine, machinery coefficient Cm and the total number of engines. And for the last part, to calculate the outfitting weight, one just has to input outfitting coefficient Co form the graph. Here are the results:

Table 12: Structural weight estimation for project FiPER

Length of superstructure (m)	35
Height of superstructure (m)	9
Equipment number E	5009.5
K	0.043
Structural weight WS (tonnes)	**4500**
Distance of Center of gravity of hull from keel (m)	**5.915**
Longitudinal center of gravity of hull (m)	**62.15**

Table 13: Machinery weight estimation for project FiPER

MCR (kW)	9600
N (rpm)	600
Number of engines	4
Cm	0.75
Height of engine room (m)	6
Height of double bottom (m)	1
Machinery weight MS (tonnes)	**1700**
Distance of center of gravity of machinery from keel (m)	**2.75**

Table 14: Outfitting weight estimation for project FiPER

Co	0.43
Outfitting weight Wo (tonnes)	**1400**
Distance of center of gravity of outfitting setup from keel (m)	**13.3**

So, based on all three categories of lightship weight, total weight can be calculated by summation of all of these. Hence, total lightship weight comes out to be:

$$W_{Lightship} = WS + MS + W_O = 4500 + 1700 + 1400 = 7600 \text{ tonnes}$$

9.2.2 Deadweight Estimation

The deadweight of the ship mainly includes the weight of fuel, ballast and fresh water, weight of the cargo etc. As per the mission to carry out research in the Antarctic, the ship has to travel a long distance from the Helsinki Port to South Africa and eventually to South pole. Due to this long journey complication, the ship has to carry a lot of fuel so that it can reach its destination with bunkering options in South Africa. Since the ship has two types of fuels on board ie. diesel and hydrogen, therefore the total quantity of fuel has been estimated to be 2700 tonnes. When the ship is heading towards the North pole, the distances are quite small as compared to the South pole, therefore, the fuel tonnage would reduce significantly, But the ships deadweight requirements have to be designed so that once the vessel is build, modifications to it won't be necessary. Therefore, fuel tonnage has been set to be approximately 2700 tonnes. Similarly based on the reference data and the size of the ship, the ballast and fresh-water tonnage has been decided to be 2200 tonnes roughly. And since the mission of FiPER is not to deliver cargo mainly but being a part of the goal to also supply cargo to research stations, the limit for cargo deadweight has been set to be roughly 3000 tonnes. Lastly, 10 tonnes of weight allocation have been given to the people on board with a rough average of each individual to be around 85 kg. So, based on all of these main factors, the following table presents the total deadweight design estimation of our ship:

Table 15: Deadweight estimatino for project FiPER

Fuel	2690
Cargo	3000
Fresh and ballast water	2200
People	10
Total deadweight (tonnes)	**7900**

In the end, one can calculate the total displacement in tonnes of the vessel based on both lightship weight and deadweight estimations that has been presented. This is just the sum of both of these weights. So here are the results:

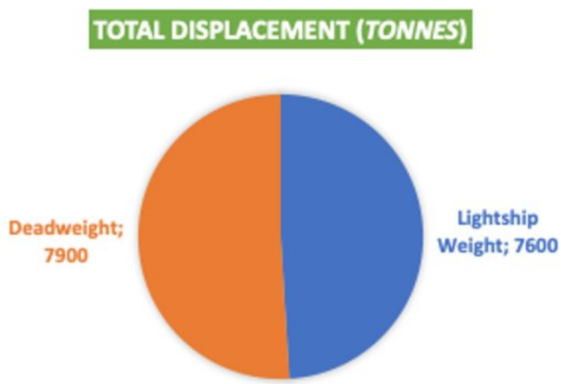


Figure 43: Distribution of total displacement for project FiPER

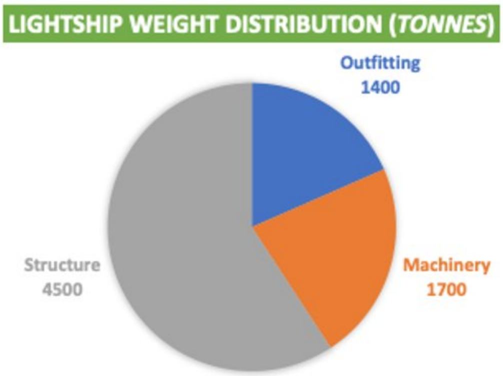


Figure 44: Distribution of lightship weight for project FiPER

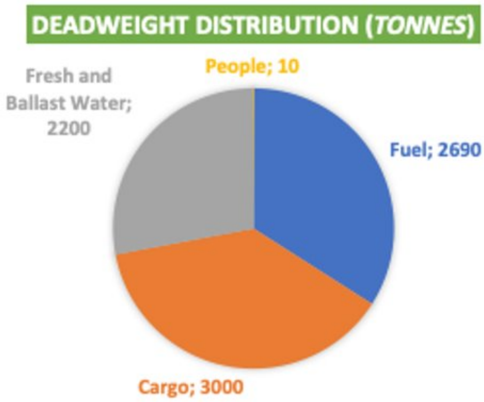


Figure 45: Distribution of deadweight for project FiPER

9.3 Level of Uncertainty in Weight Calculations

Estimating uncertainty in weight calculations began by looking at the uncertainty of the different coefficients in the lightship weight calculation excel. There was an exact value for the structural coefficient K of research ships in the data available. For machinery or outfitting coefficient, the values were not that exact. They required the estimation of both Co and Cm, because they were not defined for research ships. The were estimated minimum and maximum coefficients with the idea that FiPER's values will surely be between those. The Co value was estimated to be between 0,43-0,6. There is a big gap because it was estimated from Co database of cargo ships and passenger ships.

For machinery coefficient the value estimated is in the range of 0,75-0,83. Again situation was that there wasn't information about research ship's Cm. So, it had to be estimated with cargo ship and passenger ship values. The vessels Cm will be higher than in typical cargo ship because it has azimuth thrusters that are heavier implementation method of propulsion. Passenger ferries have also azipods usually, so that is why the vessels max Cm is the same as those.

The minimum and maximum values for WLS were calculated to be min 7591 tonnes and max 8690 tonnes. Difference between those values is 1099 tonnes, in other words 14,5%. Biggest uncertainty factor is outfitting weight, 553 ton, then structural weight, 417 ton and lastly machinery weight, 129 ton. Outfitting weight error is that big because of the difficulty to estimate Co.

9.4 Estimation of the Weight Reserve

The ship's predicted displacement is 16 565 tons. The Deadweight is estimated to be 7960 tonnes, so that would give a maximum value lightship weight of 8605 tons, assuming that the deadweight cant be made smaller because it would make the money-making potential of this ship lower and also the displacement can't be raised. The weight reserve at this point is affected largely by the calculation errors, but on average the weight reserve is roughly 460 tons, which is 5,4 %. However, because the error is so large, it can take all the weight reserve away leaving the project into a position, where the ship is overweight at this point. The calculations and estimations of coefficients need to be specified making the errors smaller. At the best-case scenario the ships lightship weight will be at 7591 tons leaving the project 1034 tons (or 12%) of weight reserve, which can be considered moderate at this point.

10 Cost, Key Performance Indexes, and SWAT analysis

The final step of the design process if the estimate the financial side of the project. This section will outline the estimated cost, the key performance indexes and finally a swat analysis of the project.

10.1 Cost Estimate

The building cost of a ship is estimated near the end of the first stage of the design spiral. There are many ways to complete this estimate, and usually several estimates are formed. These estimates can then be compared and used to validate (or dismiss) each other. In original assignment three different methods were used for estimating the cost, but two of them gave too small values, so we decided to follow only reference ship method.

10.1.1 Reference Ship Method

The problem with the other possible methods for estimating costs, is that polar research vessels have more sophisticated and expensive equipment on board than traditional passenger vessels for instance, and so those methods give too small values. Additionally, because polar research vessels are ice-class vessels and are thus expected to brake ice, this increases their cost significantly. Therefore, using reference ships to deduce the cost of project FiPER is a potentially promising method. The RRS Sir David Attenborough had a newbuild cost of 265.85 million dollars and a displacement of 12 790 tons. The S.A. Aghulas II had a newbuild cost of 84.18 million dollars and a displacement of 13687 tons. This gives the ships a cost of 20785 $/ton and 6 150 $/ton respectively, and 13220$/ton collectively. Project FiPERS displacement is approximately 16 000 tons, this means that using this method the newship cost would be 332.56 million dollars using RRS Sir David Attenborough as a reference, 98.40 million dollars using S.A. Aghulas II as a reference and 211.52 million dollars using the combined statistic as a reference. The problem with this method is the sparsity of the reference data. Two reference ships are not enough to provide an accurate estimate. Furthermore, the two reference ships have a significant difference in cost and so this leads to further uncertainty.

10.1.2 Conclusion

The problem with method used to estimate cost is twofold. The first problem is that this method doesn't take into account the new and innovative technologies that will be employed on the ship. This includes, but is not limited to, hydrogen fuel supply and fuel cells, azimuth thrusters for propulsion, and a hull designed according to the double acting principal. This means that in all likelihood the cost of building this ship will be higher than for example the reference ships used. However, the highest, and coincidentally the most realistic sounding, cost estimate received from this analysis is that extrapolated from the RRS Sir David Attenborough. As this was selected as one of the reference ships for this project and is the most contemporary example of a polar research vessel, for the remainder of this project the price based on this reference ship will be used as an estimate.

10.2 Defining the Key Performance Indexes

Key Perform Indexes (KPIs) can be used to evaluate the ship's performance in different areas and can be used to set targets of performance. The economic KPIs indicate the economic performance of the vessel. Economic KPIs relate to the building costs and/or operational costs of the ship. This vessel is a research vessel so the value it provides to its owner is not financial. Hence the choice of the investments Net Present Value (NPV) or the Internal Rate of Return (IRR) are choices which would be hard to justified. However, even if this investment is not going to offer money for the owner, it can offer value in terms of scientific research and new technology. The vessel will be at its best when the owner gets most of this value with minimum cost.

Part of the ship's defined mission is to transport cargo and people into Arctic or Antarctic research stations. The economic KPI of Required Freight Rate (RFR), which considers the amount of cargo transported per price would suit for this well. The other part of the mission is to do scientific research in Arctic or Antarctic waters. Its financial value it hard to measure but the cost of the trip can be measured. Therefore, the usage of Average Annual Costs (AAC) is preferred, and it is mainly used with vessels that do not create income (Guaoleni & Maggioncalda, 2018).

AAC is defined by following equation (Lamb, 2003):

$$AAC = P(CR-i-N) + Y$$

Where P is the initial investment, $CR-i-N$ is the Capital Recovery rate which is defined in table below and Y is the annual operating expenses.

N i = 1%		2%	3%	4%	5%	6%	7%	10%	12%	15%	20%
1	1.0100	1.0200	1.0300	1.0400	1.0500	1.0600	1.0700	1.1000	1.1200	1.1500	1.2000
2	.5076	.5155	.5226	.5305	.5376	.5455	.5529	.5760	.5917	.6150	.6545
3	.3401	.3466	.3534	.3604	.3671	.3741	.3811	.4021	.4164	.4380	.4747
4	.2564	.2625	.2691	.2755	.2820	.2886	.2952	.3155	.3292	.3503	.3863
5	.2062	.2121	.2183	.2246	.2309	.2374	.2439	.2638	.2774	.2983	.3344
10	.1056	.1113	.1172	.1233	.1295	.1359	.1424	.1627	.1770	.1993	.2385
15	.0721	.0778	.0838	.0899	.0963	.1030	.1098	.1315	.1468	.1710	.2139
20	.0554	.0612	.0672	.0736	.0802	.0872	.0944	.1175	.1339	.1598	.2054
25	.0454	.0512	.0574	.0640	.0710	.0782	.0858	.1102	.1275	.1547	.2021
50	.0255	.0318	.0389	.0465	.0548	.0634	.0725	.1009	.1204	.1501	.2000

Figure 46: Capital recovery factors

If the expense of the final disassembly or selling the vessel is desired to be evaluated within this calculation, then all of the expenses and initial investment should be discounted into zero and multiplied with the Capital Recovery factor suitable. This should be done too if the annual operating expenses vary significantly between operating years to provide more accurate figure (Lamb, 2013).

To estimate the amount of ACC one would need to define the annual operating expenses. A reference ship which is quite similar to FiPER was found. It was only a little bit bigger and more expensive and its being built currently in Australia. The building cost of that research vessel is $529 million and operating costs through its 30 years' operating life are $1,38 billion (Ship Technology 2020). So that would make the operational and maintenance costs for that vessel to be 46 million dollars per year.

Keeping mind that the building costs are roughly €330 million and if it is assumed that the operational costs will scale accordingly, we get that the yearly costs (Y) would be $38,7 million. The operational life would be 30 years (N=30) and with the current era of small interests, the interest of the projects capital is 2%. When plotting the CR -table the graphical estimation that the CR would be approximately 0,0455 was computed. Therefore;

$$AAC=330\ M\$ \times 0{,}0455+38{,}7M\$=53{,}715\ M\$$$

The average annual costs are *53,715 M$*.

10.3 Improving Key Performance Indexes

Since FiPER is going to be research ship that is not going to produce actual money to her owner, there is no such necessity to strive towards cheaper operating costs, bigger income, faster payback period etc. If it were, for example, a cruise ship, KPIs would be a completely different story.

The projects KPI is chosen to be Average Annual Costs (AAC). The variables that affect it are initial investment, capital recovery rate and annual operating expenses like presented above. If target would be to lower KPI, then there would be three ways to do it. If Initial investment or annual operating expenses are lowered, then AAC will lower also. If capital recovery rate can be made lower, then again AAC will be lower.

Annual operating expenses can be lowered with couple of ways. One way is to do less exploration, and another way is to drive slower. Breaking ice is very costly, so that needs to be reduced if operating expenses need to be lowered.

Initial investment can be lowered by trimming ships features. Capital recovery rate could be lowered by raising operational life or if we could get money with lower interest of capital.

10.4 SWOT Analysis

In the following section, we will present the SWOT analysis of our design phase of FiPER. SWOT analysis results are shown in the figure below:

SWOT Analysis of FiPER	
Strengths	**Weaknesses**
❖ Double acting vessel ❖ Ice-breaking capability of 1.65m at 3knots ❖ Hydrogen based secondary fuel source reducing pollution ❖ Voyage endurance up to 90 days ❖ State of the art research opportunities ❖ State of the art research equipment including moon pool, AUV's, laboratory vehicles etc ❖ Modular containers availability to expand research areas ❖ More cargo spaces for resupply ❖ Long life cycle of 30 years ❖ Hybrid propulsion for less noise	❖ Extreme weather ❖ Resource fluctuations ❖ High building cost including materials to withstand extreme weather conditions ❖ High propulsion power requirement ❖ Expensive passage ❖ Short navigation and research season ❖ One trip to Antarctic per year
Opportunities	**Threats**
❖ Increased research interest ❖ Oil and gas exploration possibilities using FiPER ❖ Exploration of new research areas ❖ Increased resources demand ❖ Increased climate change studies ❖ Decreasing polar ice coverage	❖ Impacts of climate change ❖ Impacts of competing products ❖ Impacts of IMO regulations ❖ Impacts of social and economic norms ❖ Higher insurance prices ❖ Loss of ice ❖ Geo-politics ❖ Availability of hydrogen fuel ❖ Decline stage of the product life cycle ❖ Funding issues due to global pandemics impacts (unpredictable trends and disruptions) ❖ Oil/energy costs ❖ Increased operating/technology prices

Figure 47: SWOT analysis of project FiPER

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