Aalto University School of Engineering

Department of Mechanical Engineering

Marine Technology

MEC-E1004 - Principles of Naval Architecture

The dual-class polar re-supply and research vessel Ondo

Final report

Team:

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Introduction

This is a final report considering the ship that this team designed as a part of the course MEC-E1004 Principles of Naval Architecture. The point of the project was to introduce students to some aspects of shipbuilding process and enhance their teamworking skills.

The vessel that team Ondo (from the Esperanto word "Wave" as in Aalto in Finnish) designed was an arctic dual-purpose research and passenger vessel. The idea was to design a low emission ship that would be capable of breaking relatively thin ice (under 1m thickness), carry researchers and allow them to do their research and carry some civilian passengers just for leisure purposes. This dual class defined some of the features of the ship because it has to comply for regulations regarding, not only research vessel with only professionals on board, but also for passenger vessel for civilians.

Some of the unique features of this vessel were: low emissions, which were tried to achieve with dual fuel technology using Liquified Natural Gas (LNG) and diesel fuel; Dynamic Positioning, which helps researchers do their jobs effectively; a moonpool from where an Unmanned Research Vehicle (URV) could be launched; its ice breaking capability which makes it self-sufficient in ice conditions, to name a few.

A weekly assignment was carried for 10 weeks total, each one having its own theme. This final report concludes the whole design process and wraps the weekly assignments in one package.

Project team

- *Iiro Littu*

I have completed a Bachelor of Engineering degree in Metropolia UAS as a Mechanical Engineer with Machine Design as my professional major. Therefore, I tend to think about assigns like these like an engineer. My strengths definitely are in the technical field and the engineering part of the project.

Before UAS I studied Metalwork and Machinery in the vocational school of Omnia and graduated as a Plater-Welder. So, my technical skills are not only from a book. My interest in the marine studies also descend from there, because after (and during) vocational school I worked at Arctech Helsinki Shipyard as a plater-welder (I was building the IB Polaris which quite often shows up in the promotional material for marine studies) so I might have some insight for those kinds of part of the project from the workers point of view.

I am interested and planning to take the study path of Arctic Marine Engineering. Because of my background, but also because I believe the know-how for that field is top notch in Aalto University and in Finland. I expect this course and this degree to be challenging but also interesting.

- *Julia Kokko*

I am a Mechanical Engineer, Machine Design as my major. I graduated from Metropolia UAS on May 2019. Before engineering studies, I completed high school in Hämeenlinna. Currently I am working full time and studying master’s degree in Marine Engineering on the side.

I do not have background in marine industry, but I got interested about the field about the time of my graduation from Metropolia. Now, I have been working with ships and ship related matters for little over a year. I work as a project engineer in a ship building project. Therefore, I have gained some knowledge on shipyard processes and ship building process in general. Although there is still a lot to learn. PNA course interests me because the subject is more or less my everyday working life at the moment. After this course I hope I have gained knowledge on this matter but also to be able to perform better at my job with overall understanding.

I have planned my study path to be something close to Ship Project Engineer. I have not yet decided what exact courses I am going to take, but I am aiming my studies to that direction now. I have also thought of taking Arctic and Production Engineering courses to combine all objects of my interest.

- *Janne Lahtinen*

Bachelors’ degree in maritime with sea captain unlimited license. My sailing career consists of various types of subsea construction vessels in oil and gas industry globally. Remotely operated vehicles, subsea robotics and saturation diving works have become familiar along the years at sea. Worksites have varied from polar ice region north of Alaska to Cook Strait in New Zealand onboard dynamically positioned vessels. I am Nautical institute accredited senior trainer and DP training center lead.

I have masters' degree in maritime management and currently I am studying in Aalto Department of Mechanical Engineering towards my PhD. In science, focusing to remote pilotage in intelligent fairway infrastructures.

In R&D field I am project manager of development of remote pilotage in Finnpilot Pilotage Ltd for the project Sea4Value-Fairway, and a member of steering committee of RAAS (Research Alliance for Autonomous Systems). I hold maritime advisory and project researcher capacity in numerous other on-going multinational and domestic research projects. Currently my main task is senior lecturers' position in SAMK (Satakunta University of Applied Sciences) in Rauma, Finland.

My PhD studies consist of research and related reporting, accompanied by 40 credits of studies that support achievement of professional goals. PNA was not a mandatory choice in the pool of studies. However extensive my sea going career may be, it would seem advantageous to gain deeper understanding of ship design and construction. After all, as a PhD student I am a member of Maritime Technology Research Group in Aalto.

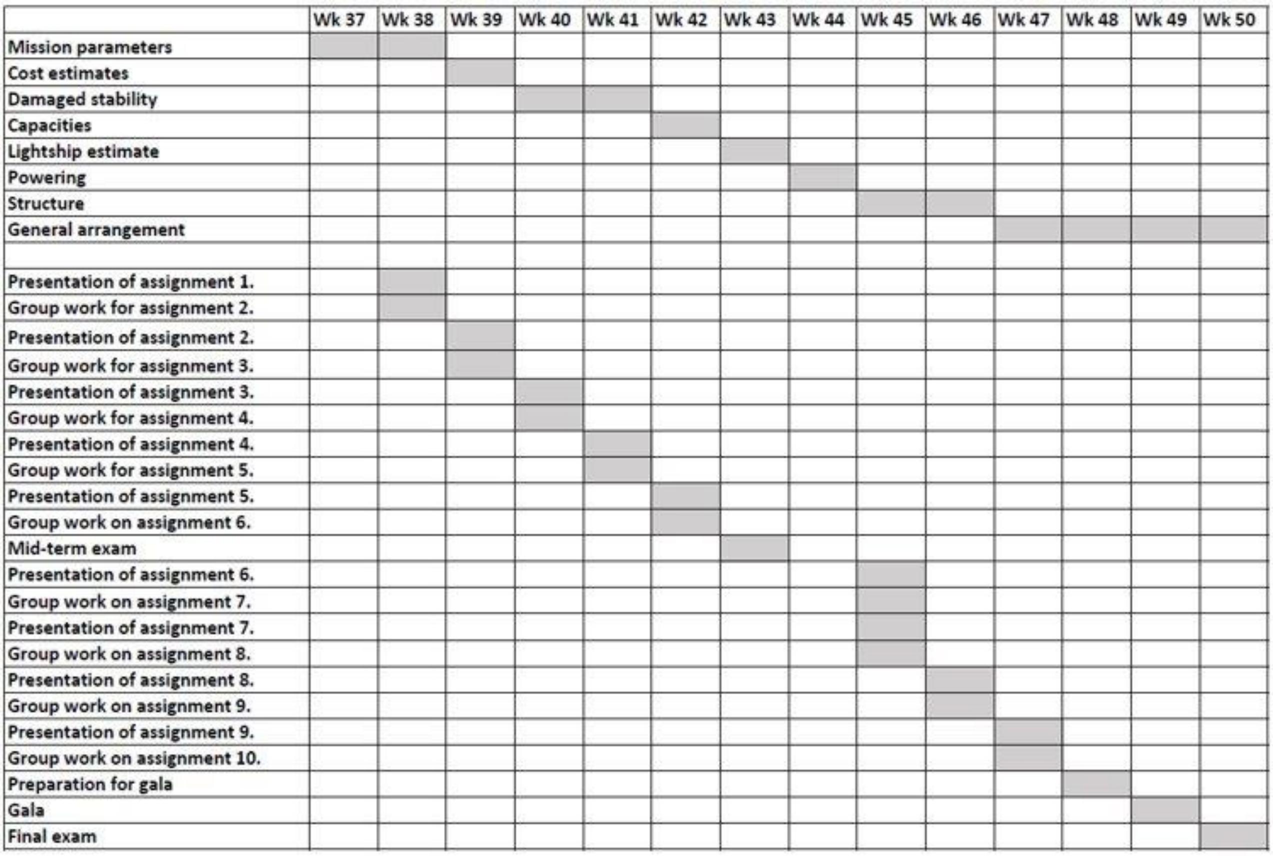
My PhD studies are widely wrapped around the research conducted as part of project "Intelligent Shipping Technology Laboratory (ISTLAB)", in which I am acting as operational director.

- *Tomás Sanches*

I earned my bachelor's degree in Mechanical Engineering this summer 2020 from the Technical University of Lisbon, Instituto Superior Técnico. Here, I was taught about the theory behind mathematics, classic mechanics, thermodynamics, materials science, electromagnetism and started to dig into the automation world. These last three years focused mainly in the theory component rather than putting them into practice. Therefore, during the first couple of weeks I might be more comfortable in knowing what to do beforehand (e.g. following bindingly the leader's defined strategy). Important to note is that this does not mean that I will not contribute with some original ideas. With time, I certainly believe I will develop my skills during this semester so that in the end I might be one good strategist and objectives setter.

I have actively looked for summer positions that would help me develop my practical side. For instance, during summer 2019, I stayed for a couple of months in Turku working for ILS Oy that specializes in marine technology. There, I had the opportunity to take part in some assisting tasks in Naval Architecture. Some of these included, conducting ship classification evaluation, damage control plans, ship quay trial programs and a general conceptual design work of one of the company's icebreaker projects. This said, I am not completely an outsider to this ship designing world. These experiences have led me to venture myself in taking a study path at Aalto University that merges Marine and Arctic Technology.

Project schedule



	Wk 37	Wk 38	Wk 39	Wk 40	Wk 41	Wk 42	Wk 43	Wk 44	Wk 45	Wk 46	Wk 47	Wk 48	Wk 49	Wk 50
Mission parameters	▨	▨												
Cost estimates			▨											
Damaged stability				▨	▨									
Capacities						▨								
Lightship estimate							▨							
Powering								▨						
Structure									▨	▨				
General arrangement											▨	▨	▨	▨
Presentation of assignment 1.		▨												
Group work for assignment 2.		▨												
Presentation of assignment 2.			▨											
Group work for assignment 3.			▨											
Presentation of assignment 3.				▨										
Group work for assignment 4.				▨										
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Presentation of assignment 9.											▨			
Group work on assignment 10.											▨			
Preparation for gala												▨		
Gala													▨	
Final exam														▨

Contents

Ondo

Abbreviations and symbols

PNA	Principles of Naval Architecture
PSSA	Particularly Sensitive Sea Area
LNG	Liquified Natural Gas
URV	Unmanned Research Vehicle
DP	Dynamic Positioning
WPA	Water Plane Area
CSA	Cross Sectional Area
SAC	Sectional Area Curve
Δ	Displacement in tonnes
ρ	Density
C_B	Block Coefficient
C_P	Prismatic Coefficient
WLA	Waterline Area
SOLAS	International Convention for the Safety of Life at Sea
GA	General Arrangement
WL	Waterline
LCB	Longitudinal Centre of Buoyancy
LCF	Longitudinal Centre of Floatation
KB	Vertical Centre of Buoyancy
DWT	Ship Deadweight
L	Ship’s Length
B	Ship’s Beam
T	Ship’s Draft
N	Normand’s Number

Ondo

L_p	Length of Parallel Midbody
IB	Ice Breaker
GA	General Arrangement

1 Design context

In this design project, Group 3 aim is to create a vision of a feasible ship design that incorporates modern technical solutions while being economically and financially sustainable and agile. This report outlines the technical and operational guidelines and restraints for the facilitation of the set project objectives. We are talking about a multi-use research vessel under the working name "Ondo", that aims to mitigate the environmental impact. Research vessel Ondo will navigate in PSSA (Particularly Sensitive Sea Area) waters protected setting requirements for the emissions and waste management. Therefore, green technology is widely utilized during this design. As this vessel is meant for polar region exploration, particular attention to safety and comfort needs to be taken. In this design project, the ship's operational area is handled as a use case route illustrated in Figure 1. Homeport for Ondo will be in West harbour in the Port of Helsinki, Finland. Use case route includes the following steps:

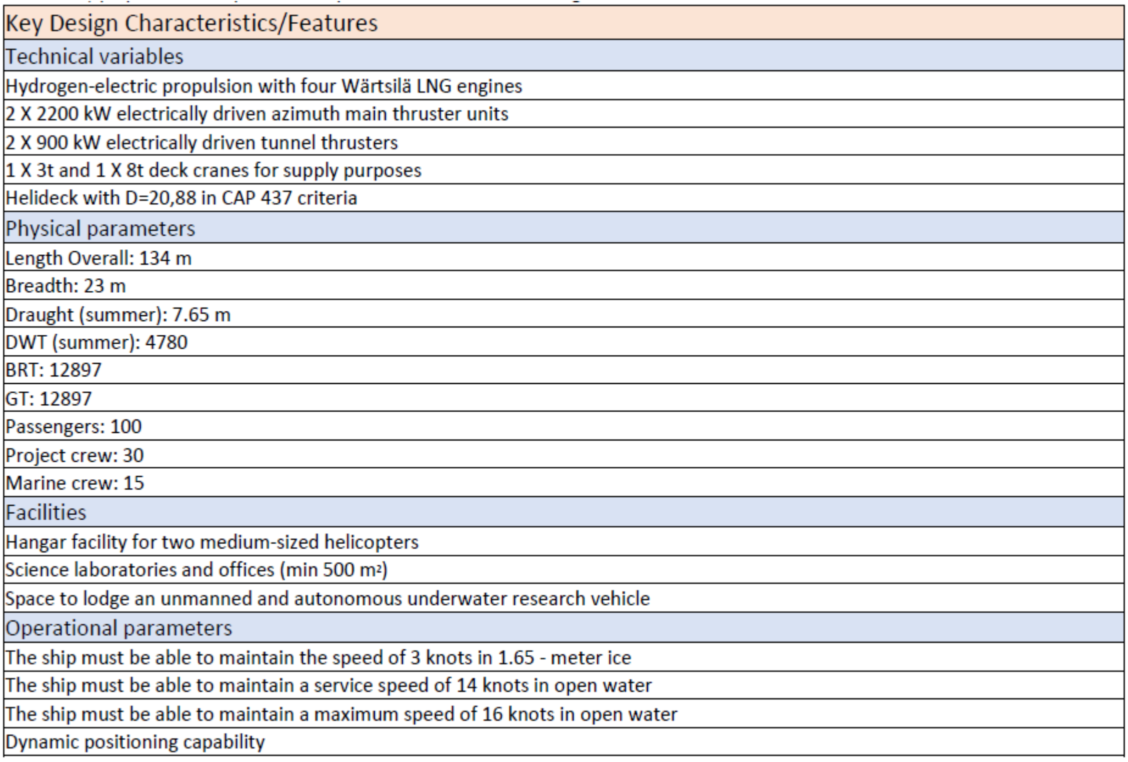
- Departure from West Harbour, in Helsinki, Finland.
- Enroute in the Baltic Sea for the Kiel canal entry in Holtenau, Germany.
- Enroute through Kiel canal for the exit in Brunsbuttel, Germany.
- Enroute to Strait of Kirkenes in the northern coast of Norway.
- Dynamically positioned subsea operations in Strait of Kirkenes.

Figure 1.Example of route for vessel Ondo.

The distribution between fresh water and seawater is necessary, as the vessel will gain more draft in freshwater, thus having different wave resistance in various bodies of water, pending on the salinity of the water. The onboard population is limited to 140. People on board are distributed between project crew, marine crew and passengers. Project crew consists of deck riggers, scientists, client representatives, marine warranty surveyors, ROV pilots and technical crew and another miscellaneous project workforce. During the voyage and subsea operation, passengers have, with appropriate safety restraints, the opportunity for a unique experience side to side with the operative crew. Therefore, laboratory and office facilities will have to be spacious to the level of facilitating efficient and safe data collection and assessment. In addition, pleasant hotel services will be a demand for prolonged offshore periods.

1.1 Design variables

In the table below can be found the original design features that we defined as a team in the beginning of the course. These include technical variables, physical and operational parameters that our design must meet.



Key Design Characteristics/Features
Technical variables
Hydrogen-electric propulsion with four Wärtsilä LNG engines
2 X 2200 kW electrically driven azimuth main thruster units
2 X 900 kW electrically driven tunnel thrusters
1 X 3t and 1 X 8t deck cranes for supply purposes
Helideck with D=20,88 in CAP 437 criteria
Physical parameters
Length Overall: 134 m
Breadth: 23 m
Draught (summer): 7.65 m
DWT (summer): 4780
BRT: 12897
GT: 12897
Passengers: 100
Project crew: 30
Marine crew: 15
Facilities
Hangar facility for two medium-sized helicopters
Science laboratories and offices (min 500 m^2)
Space to lodge an unmanned and autonomous underwater research vehicle
Operational parameters
The ship must be able to maintain the speed of 3 knots in 1.65 - meter ice
The ship must be able to maintain a service speed of 14 knots in open water
The ship must be able to maintain a maximum speed of 16 knots in open water
Dynamic positioning capability

1.2 Design boundaries

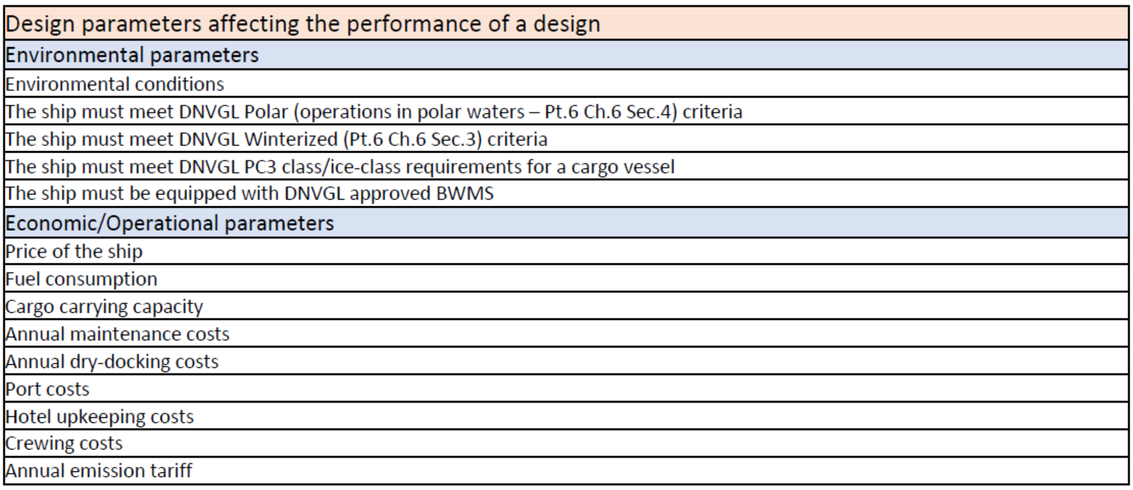
Following the design innovations come the design boundaries. Here we define what will not be part of this design task. In the following table, these boundaries can be consulted and are divided into two levels: system and ship level.

Design boundaries
System-level: The revenue for a vessel of this nature consists of the ability to maintain the ship in the charter, and for a client to be able to make a profit with the ship. From the design perspective, the ability to meet the demands of the research, passengers and icebreaking is a challenging combination. *Ship-level*: Bridging documentation defines the responsibilities between charterer and vessel owner. In ship level this defines the responsibilities in maintaining ship sea worthiness and compliance with applicable regulations and thus ability to maintain within a chartering contract. Ship level design

boundaries consist of ice-breaking capability, ROV facilitation and related moonpool, structural demands for the passenger facilitation, and finally, the solutions enabling mitigation of environmental impact.

1.3 Design parameters

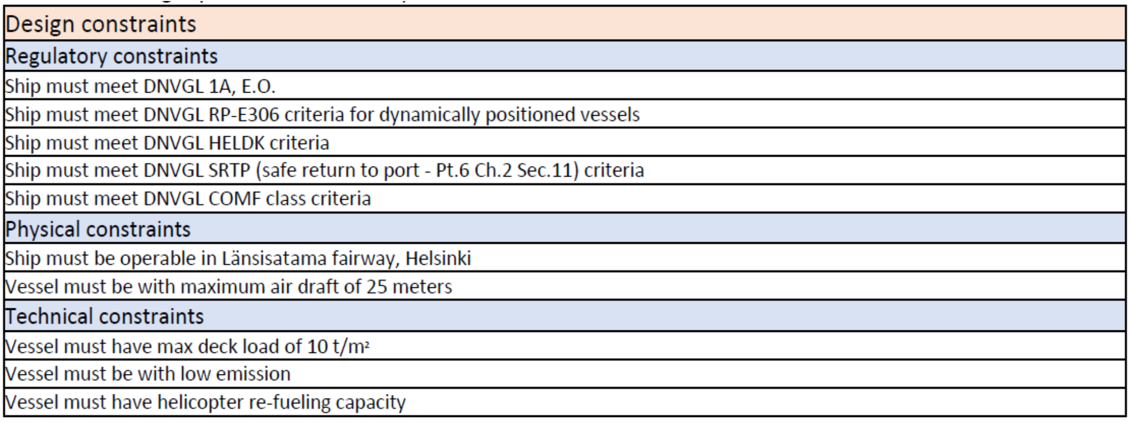
In this section there are presented factors that affect the performance of the design that we must consider but are beyond our control. These are shown in the table below:



Design parameters affecting the performance of a design
Environmental parameters
Environmental conditions
The ship must meet DNVGL Polar (operations in polar waters – Pt.6 Ch.6 Sec.4) criteria
The ship must meet DNVGL Winterized (Pt.6 Ch.6 Sec.3) criteria
The ship must meet DNVGL PC3 class/ice-class requirements for a cargo vessel
The ship must be equipped with DNVGL approved BWMS
Economic/Operational parameters
Price of the ship
Fuel consumption
Cargo carrying capacity
Annual maintenance costs
Annual dry-docking costs
Port costs
Hotel upkeeping costs
Crewing costs
Annual emission tariff

1.4 Design constraints

Our feasible design space will be limited by numerous factors. These can be found in the table below:



Design constraints
Regulatory constraints
Ship must meet DNVGL 1A, E.O.
Ship must meet DNVGL RP-E306 criteria for dynamically positioned vessels
Ship must meet DNVGL HELDK criteria
Ship must meet DNVGL SRTP (safe return to port - Pt.6 Ch.2 Sec.11) criteria
Ship must meet DNVGL COMF class criteria
Physical constraints
Ship must be operable in Länsisatama fairway, Helsinki
Vessel must be with maximum air draft of 25 meters
Technical constraints
Vessel must have max deck load of 10 t/m^2
Vessel must be with low emission
Vessel must have helicopter re-fueling capacity

1.5 Innovations and ideas

Some design innovations will take place. These are listed below:

- Modern laboratory facilities and equipment will be installed onboard. Laboratories will have incorporated artificial intelligence algorithms that will manage, filter, organize and treat the big flux of data that will be obtained during explorations. To withstand this amount of data processing as well as be able to be always connected to the rest of the world, wi-fi onboard and 5G technology installed. 5G technology will allow us to have all systems onboard connected to each other and a faster transfer of data to offices around the world.
- The latest dual redundant class 2 dynamic positioning system with user interfacing in bridge, will be installed. Algorithms will help to calculate optimal routes for the explorations taking into consideration data collected from all kinds of sensors onboard and meteorological info from outside sources. This will contribute to fuel savings mainly. Advanced decision-making systems support a dynamic positioning system in evaluating environmental conditions and optimal vessel response to them.
- Latest hydroacoustic technology will be implemented onboard to be able to analyse the seafloor and marine wildlife. To reduce the amount of noise affecting the data collected, intelligent noise absorbers are installed. Hydroacoustic system requires a retractable pole that extends four meters below the keel creating necessity to a hull penetration for the pole facilitation.
- Following the current covid-19 pandemic outbreak, special attention needs to be taken into passenger and crew health and safety. To avoid dissemination of plagues, a special disinfection system is installed onboard.
- For passenger comfortability and comfort class compliance, a resonance avoidance mechanism will be installed between deck house and deck plating to minimize vibration and sound in the accommodation and living quarters.
- Wave and/or wind extra power generation. This will enable us to take advantage of the rough and windy conditions in the Arctic and Antarctic Oceans to produce energy for propulsion and use onboard. This will allow us to reduce emissions and lead to greener research work.
- Ondo will take onboard an unmanned and autonomous underwater research vehicle. This will be semi-controlled from a special location in the command bridge. Due to the advanced telecommunication technology installed, the vehicle will be able to respond to any directive coming from the controller with very low latency.

2 Reference ship and data

2.1 Reference ship

Vessel name: S. A. AGULHAS II
DNV GL id: 30528
IMO number: 9577135
Draft summer: 7,65m
LOA: 134,2m
Beam: 21,7m
G.T.: 12897
NT: 3840
DWT: 4780
Class relation: In DNV GL Class
Signal letters: ZSNO
Flag: South Africa
Port: CAPE TOWN
Type: 401 - Passenger ship
Structural design type: Mono-hull ship
Regulatory regime: Ships
Main purpose: Passenger (researchers and recreational passengers) carriage
Additional purpose(s): Low flashpoint liquid supply

2.2 Requirements

2.2.1 Dual class

The vessel must meet classification society DNVGL requirements for icebreaking and arctic research. Simultaneously, the ship must meet the DNVGL requirements of a passenger ship.

2.2.2 Finance

Vessel passenger capability provides financial sustainability and diversity for the periods outside the arctic research chartering and during offshore operations. The vessel can be used for passenger service simultaneously when engaged in research work on charterers' approval. While this brings an extra income for the operator, it also increases, e.g., the hoteling costs and services related to the wellbeing of passengers, because the ship must have relatively large accommodation spaces and services. Along with the passengers comes larger laundry, larger dining areas, wider corridors and access/egress routes, additional lifesaving appliances and firefighting equipment, hotel staff, passenger vessel-related classification costs, increased fuel consumption, demand for the SRTP (Safe Return To Port) facility, and so forth.

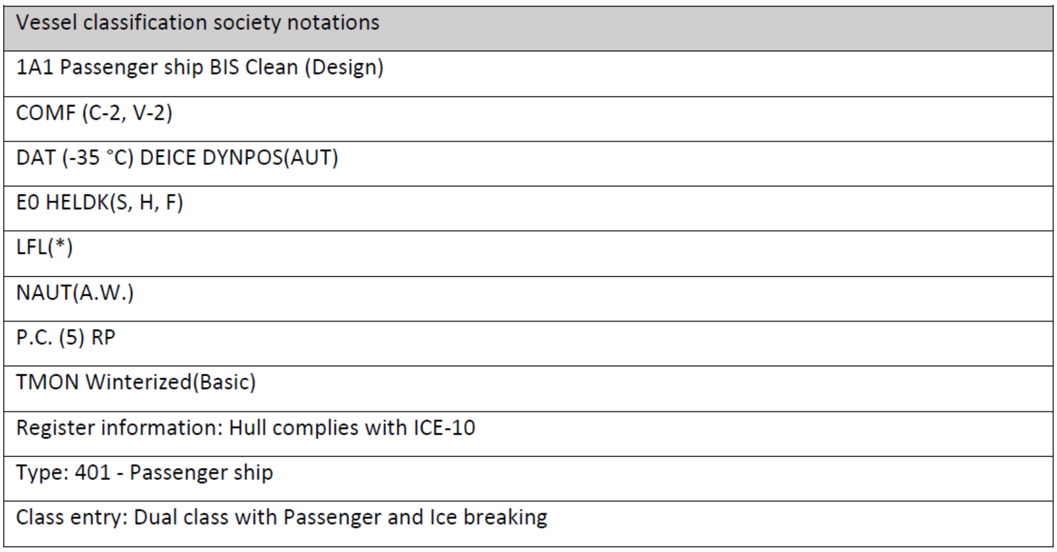
Chartering of Ondo is a voyage charter contract between the owner of the Ondo, and the company or an institution conducting the research work. Any passenger vessel use is with the sole responsibility of the vessel owner and can only happen with permission from the charterer. Therefore, the vessel has dual class, but only one charterer. In the sense of maritime law, an individual passenger is a charterer of a ship as he/she has purchased the services of the vessel with the agreed sum of money. However, in this design context, a passenger is not deemed a charterer.

2.2.3 Standards and regulations

A ship must meet SOLAS (Safety of Life at Sea) requirements, that reflect national and international regulations. It is noteworthy that IMO (International Maritime Organization) regulations are not directly law before ratified to federal legislation. Dual-class ship operating in the inhospitable waters must ensure safety and habitable environment (temperature, air quality, vibration, noise levels, lighting levels, fatigue decrease). The following regulations apply to our ship:

- IMO Polar Code operational requirements
- IMO Guidelines for Ships Operating in Polar Waters (Polar Code)
- Guidelines on voyage planning for passenger ships operating in remote areas
- Rules for Qualification/Ships, part 6 Additional class notations, Chapter 8
- Regulations for the Baltic Sea including PSSA and ice-class notations
- Applicable national regulations

2.3 Class notations



Vessel classification society notations
1A1 Passenger ship BIS Clean (Design)
COMF (C-2, V-2)
DAT (-35 °C) DEICE DYNPOS(AUT)
E0 HELDK(S, H, F)
LFL(*)
NAUT(A.W.)
P.C. (5) RP
TMON Winterized(Basic)
Register information: Hull complies with ICE-10
Type: 401 - Passenger ship
Class entry: Dual class with Passenger and Ice breaking

3 Main dimensions

This section of the final report of our design refers to main dimensions. Here we go through the process involved in the definition of this. Everything started by defining our constraints (discussed in section 1 of the report) which then enabled us to get some estimations for the main dimension. These estimations were made using two different approaches: Normand's Number and Statistical Method approaches.

3.1 Main dimensions calculations

As shown in the section 2.1 of the report, our South African reference ship S. A. Agulhas II has a draft (T) of 7.65m. By analyzing the physical constraints that our designed ship will face during voyage and when staying in ports, a maximum draft of 6.3 meters has come up in Jätkäsaari, Helsinki, Finland. Therefore, use of statistics and Normand's number will be used to get an estimation of main dimensions of a ship that might be applied to our designed vessel.

- *Normand's Number solutions*

First will be used the Normand's Number approach and the deduction of the parameters will be showed in detail. Our only restriction is to lower the draft relative to the reference ship. Our aim is to get a draft of 6.3 m. For reasons explained before, the deadweight of the new ship will be reduced by 1363 tons. This value was obtained as final while iterating these dimensions a couple of times in order to get a pleasant value. The L/B ratio will remain unchanged. The starting point values of our reference ship are shown in table below:

Table 1.Reference ship data (1).

Item	Reference Ship data
L (m)	134,2
B (m)	21,7
T (m)	7,65
Density of water (t/m^3)	1,025
Δ (tonne)	**13687**

From these parameters we can derive the Block Coefficient (C_B) of S. A. Agulhas II:

$$\Delta = \rho . L . B . T . C_B \leftrightarrow C_B = \frac{\Delta}{\rho . L . B . T} \approx 0.60$$

Next, we found possible values for the specified weights of the reference ship (estimation):

Table 2.Reference ship data (2).

Item	Reference Ship data
Hull weight W_H (tonne)	4000
Machinery Weight W_M (tonne)	1553
Outfitting weight W_O (tonne)	1801
Fuel weight W_F (tonne)	1553
Deadweight (tonne)	**6333**
L/B	**6,184**

Then the Normand's Number is obtained by applying its formula:

$$N = \frac{d\Delta}{dW} = \frac{\Delta}{\Delta - (W_H + W_O) - \frac{2}{3}(W_M + W_F)} \approx 2.354$$

We can now easily compute the new displacement (tonnes):

$$\Delta_{new} = \Delta + N.dW = 13687 - 2.354 \times 1363 \approx 10478 ton$$

In the new designed ship (L/B = 6.184, T = 6.3m and C_B =0.65):

$$\Delta = \rho.L.B.T.C_B \leftrightarrow L = \frac{\Delta}{\rho.B.T.C_B} = \frac{10478}{1.025 \times \frac{L}{6.184} \times 6.3 \times 0.60} \approx 129.4m$$

$$\frac{L}{B} = 6.184 \leftrightarrow B = 20.9m$$

As a result, the main dimensions obtained with the Normand's Number approach are shown in the following table:

Table 3.Ondo ship data (1).

Item	Ondo Ship data
L (m)	129,4
B (m)	20,9
T (m)	6,3
Density of water (t/m^3)	1,025
Δ (tonne)	**10478**

Ondo

- *Statistical Method Solutions*

Here a statistical method will be used to estimate the main dimensions of the new designed ship. For this, an important figure is the deadweight to displacement ratio. In order to have an idea of the values it might take we will calculate this ratio for our reference ship Agulhas II:

$$\frac{DWT}{\Delta} = \frac{6333}{13687} \approx 0.46$$

We then have the starting data that is presented in the following table:

Table 4.Ondo ship data (2).

Item	Ondo Ship data
Deadweight (ton)	4970
DWT/Δ	0,46
V (Knots)	14
Density of water (t/m3)	1,025
Hull Section type	V-section

This leads to the value of the displacement:

$$\frac{DWT}{\Delta} = 0.46 \leftrightarrow \Delta = \frac{4970}{0.46} \approx 10804\, ton$$

The length between perpendiculars of the ship is calculated the Schneekluth formula (V in knots):

$$L_{PP} = \Delta^{0.3}.V^{0.3}.C = \ 10804^{0.3} \times 14^{0.3} \times 3{,}4 = 121.7\, m$$

$$C = 3.4 - \frac{\Delta - 10^3}{10^6} \approx 3.4\,, \Delta \leq 201000\, t$$

After that, the Froude Number is obtained (V in m/s):

$$F_n = \frac{V}{\sqrt{g.L}} = 0.514.\frac{14}{\sqrt{9{,}81 \times 121{,}7}} \approx 0.21$$

And with Watson & Gilfillan we get the Block Coefficient (C_B):

$$C_B = 0.7 + 0.125 \tan^{-1}[\frac{23 - 100 \times F_n}{4}] = 0.7 + 0.125 \tan^{-1}[\frac{23 - 100 \times 0{,}21}{4}] \approx 0.76$$

We have all the conditions to find the dimension of the Beam of our ship (T = 6.3m):

$$\Delta = \rho . L . B . T . C_B \leftrightarrow B = \frac{\Delta}{\rho . L . T . C_B} = \frac{10804}{1{,}025 \times 121{,}7 \times 6{,}3 \times 0{,}76} \approx 18.1\ m$$

Using this statistical method, we were able to diminish the length of our ship in relation to the reference. But, to compensate this achievement, there was a big increase in the value of the Block Coefficient (C_B) that compromises the effectiveness and purpose of the planned vessel. In fact, there was an increase in this figure from 0.60 to 0.76. This situation was discussed with the mentor of our project, Pentti Kujala, who established with us a maximum allowable block coefficient of 0.7 in the limit. In addition, a reduction of almost 4 meters was verified in the beam which might compromise in terms of transport capacity and functionality in general. Therefore, we excluded these calculations from being plausible. In fact, the designed continued with the main dimensions calculated using the Normand's Number approach which looked much more reliable. In fact, the values obtained there for the length between perpendiculars (L_{pp}), beam (B), draft (T) and block coefficient (C_B) were the ones used in the process of the following sections. The displacement calculated was only used as a reference value as this suffered slight changes while working on the hull form. This process is explained in the following section of this report, section 4- Hull Form.

4 Hull form

Ship's hull and its form are crucial to be suitable for the vessel purpose and be suitable for the operating area. When defining Ondo hull form, the group needed to have in mind that the vessel is dual-class vessel. This means that when defining the hull form, both mission capabilities and passenger comfort needed to be considered. Also, regulations and technical requirements needed to be followed.

To define the ship's rough hull form, the Excel spreadsheet provided in the course, was used. This Excel spreadsheet determined: a profile plan, waterlines plan and body plans for the vessel. Vessel's cross sections are presented further in this report, in chapter 7. In this project phase, the group interviewed and discussed with two professionals: the group mentor Professor Pentti Kujala and IB Polaris' Captain Pasi Järvelin, to make sure that right kind of decisions were made.

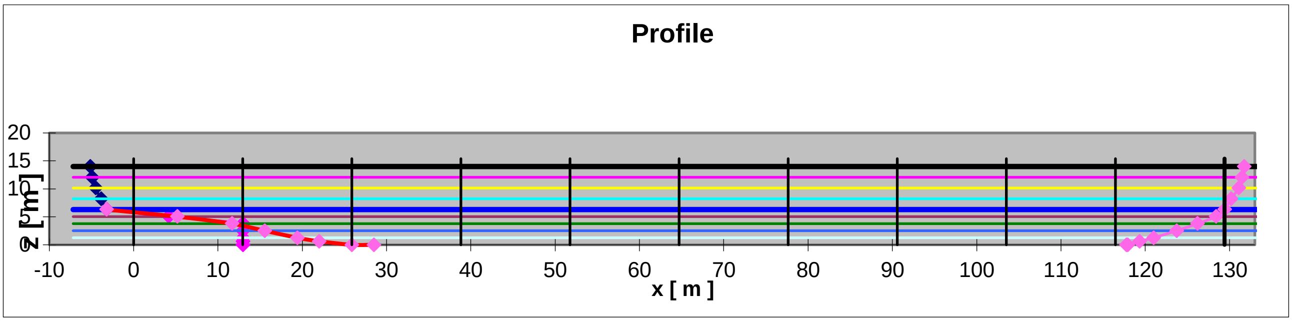


Figure 2. Profile plan of Ondo

4.1 Bow

Bow shape and design selection is one of the most important things when defining the hull form. The bow form affects greatly for e.g. to resistance and vessel buoyancy. Bow is the first part of the hull that gets in contact with the surrounding mass of water. Therefore, the bow type selection effects the hull speed in the entire length of the ship.

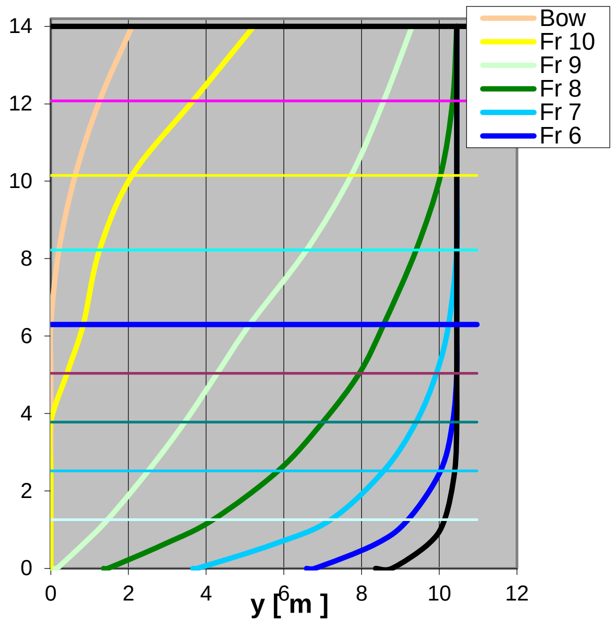


Figure 3. Body plan, fore

Convex bow shape is pre-conditional for the ice breaking capability. Because of this, it is imminent, that the resistance of water increases and the spoon shape bow (Figure 3) does not offer as much buoyancy as the bulbous bow type. Because of this, the vessel is more likely to have increased bow movement in high seas, resulting possibly a poor passenger experience in a pitching and heaving vessel. This is a choice that had to be made in between the ice breaking and passenger facilitation.

The group mentor Pentti Kujala confirmed that the group should select the spoon shape bow. Opinions of Professor Kujala on the suitable bow shape were supported by the interview of Captain Järvelin. As per Järvelin, moon shape bow is ideal for making progress in ice going conditions for two reasons. First, moon shape allows vessel bow to climb on ice to penetrate it, using the mass of the bow. Second, moon shape bow has lesser buoyancy due to not having a bulbous bow. This allows bow to sink to displacement draft easier, through the ice.

It is noteworthy, that ice breaker breaks the ice by penetrating it vertically. Horizontal movement through the ice is seldom a realistic choice in ice breaking. As the ice has no escape route from the front of the vessel's bow, it results a chunk of ice in front of the bow. Spoon shape bow pushes the ice under the vessel's hull in the reach of suction of the main propulsion.

4.2 Midship

Ondo design has no parallel body, as in there is no continuous midship section, as also Figure 4 below presents. Limited vessel length does not allow midship hull shape to provide extensive buoyancy. Therefore, alternative means were considered to provide increased stability being suitable for passenger vessel purposes.

There were two alternatives considered to increase passenger comfort: an extensive bilge keel in measurements of length and depth or additionally a pair of hydraulically controlled retractable stabilizing fins. Both options provide stability only in dynamic situation. More the hull speed, the higher increased stability these options provide.

However, for static stability, optional means for the prevention of vessel listing and rolling movement must be sourced. For static vessel status, an active and/or passive anti-roll ballast system would possibly provide a solution. Limited opportunities for the midship design reflect to considerations with non-lines drawing related factors, as above. Midship section must be obstacle free for the flow of ice pass the bottom plate. This may lead to restrictions in moon pool arrangement, in the event of such found necessary for the ROV-operations.

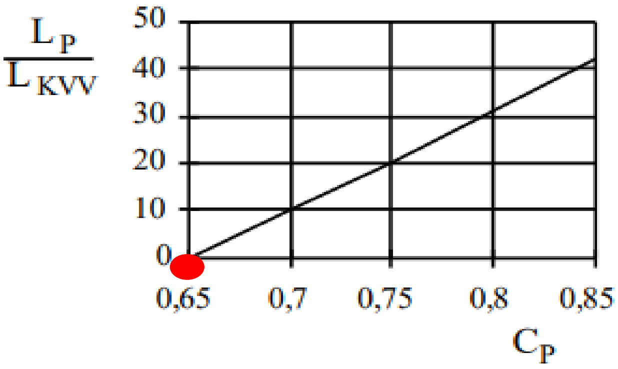


Figure 4. Length of parallel midbody (L_p) vs. Prismatic coefficient (C_p)

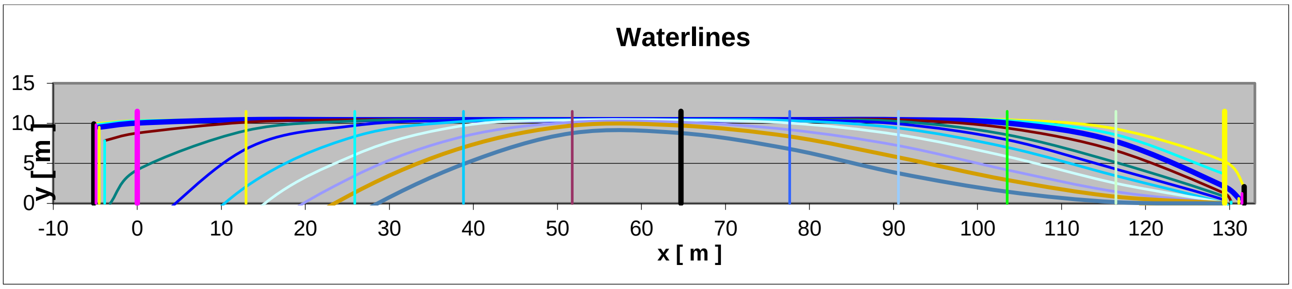


Figure 5. Waterlines plan

4.3 Stern

Ships stern shape is strongly affected with the propulsion configuration. Therefore, hull shape should not be discussed separately from the thruster options. Vessel is equipped with Azipod-type azimuth- thrusters at the stern. The group selected to use ABB provided Azipod- thrusters. Thrusters have ability to provide propulsion in 360° direction.

Ondo body plan from aft of the ship is presented in Figure 6, below. Some changes had to be done to the skeg offered by Excel spreadsheet, which led to reducing its length towards the stern. This way, the group was able to have free space between the two Azipods, in order to allow free rotation and good working capability. This was inspired by Polaris Icebreaker. More specifically, the skeg was extended only up to frame 1 as can be seen in the figure in the right presented below.

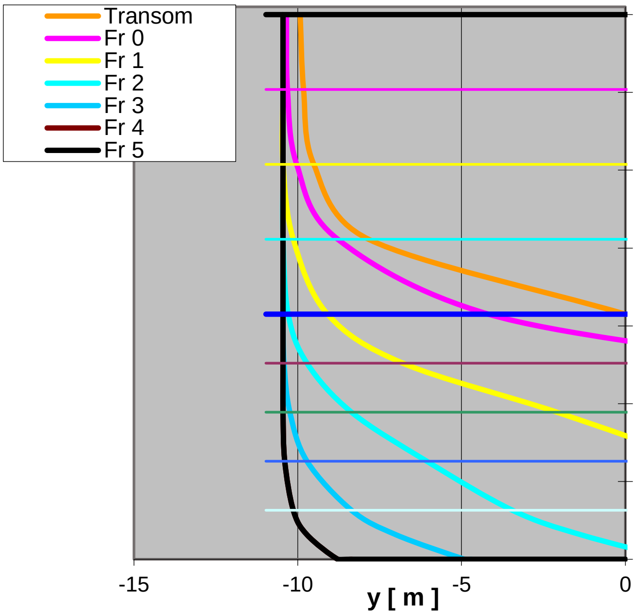


Figure 6. Body plan, aft

5 Hydrostatics

Hydrostatics in this project were assessed using two different methods. First, calculations with a provided Excel spreadsheet, which utilised the Simpson's integration method to estimate the ships hydrostatic characteristics. The other approach was to get the values from a free ship designing software named Delftship. The former one was deemed more reliable and thus the project continued based on them.

5.1 Simpsons integration method

In order to assess the hydrostatics and introduce issues related to stability of our current design, we used as a tool the Excel spreadsheet handed out in class for this purpose. To this process, the data obtained in the spreadsheet related to the Hull Form was used.

5.1.1 Water plane area (WPA)

The first thing that was done was to assess some properties regarding the Water Plane Area (WPA) of the ship. Here we had to input the length of our ship (L_{pp}) and the number of frames we were going to use. We chose 10 frames so that it would be in an agreement with the results obtained defining the hull form. In this part, we inserted the half-breath coordinates in order to define one side of the water plane area. This was easily done by using the output we got from the hull form definition.

Table 5.Length and spacing of frames.

Length	129,4	m
Intervals:	10	-
Spacing, s:	**12,94**	**m**

Table 6.Half-breaths of WPA.

		1/2 ordinates	SM	Product for area	Lever @ Frame 0	moment of area
Frame [-]	x-coordinate	y_n [m]	k_n [-]	$y_n * k_n$ [m^2]	R_n [m]	$y_n * k_n * R_n$ [m^3]
0	**0**	4,2	1	**4,2**	0	**0,0**
1	**12,94**	9,1	4	**36,4**	1	**36,4**
2	**25,88**	10,3	2	**20,6**	2	**41,2**
3	**38,82**	10,5	4	**41,8**	3	**125,4**
4	**51,76**	10,5	2	**20,9**	4	**83,6**
5	**64,7**	10,5	4	**41,8**	5	**209,0**
6	**77,64**	10,5	2	**20,9**	6	**125,4**
7	**90,58**	10,2	4	**41,0**	7	**286,7**
8	**103,52**	8,6	2	**17,1**	8	**137,1**

9	116,46	5,1	4	20,5	9	184,3	
10	129,4	0,8	1	0,8	10	8,4	
			Σ	266	m^2	1237	m^3

Table 7.Results: WPA and LCF.

WPA	**2294**	**m2**
LCF From fr0	**60,210**	**m**

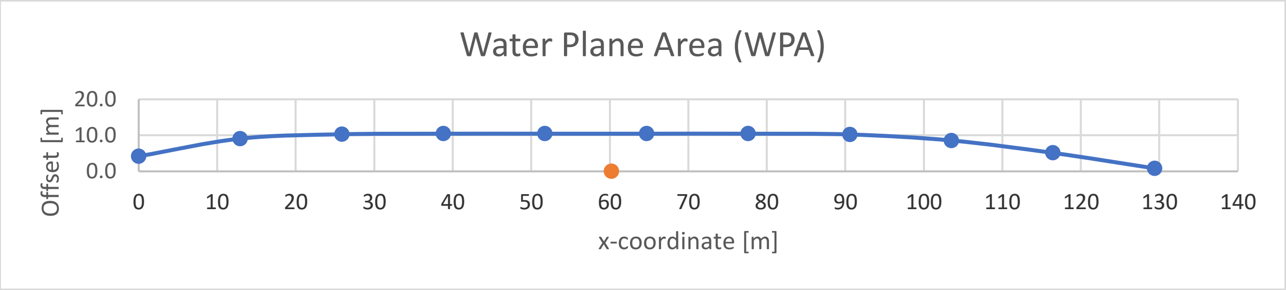


Figure 7.Plot of half WPA.

Having inserted all the data needed, we got values for both the Water Plane Area (WPA) in m^2 as well as the location in meters from frame zero of the Longitudinal Centre of Floatation (LCF). The LCF was found to be located between frames four and five, meaning that it is quite near midships (see orange point in the plot above). In addition to these results, a sketch of half of the WPA was obtained and is shown in the previous plot.

5.1.2 Cross-sectional area (CSA)

Afterwards, the Cross-Sectional Areas (CSA) were assessed for each frame. Here, only the results for frame five are shown. In addition to inputting the maximum draft allowed and the spacing between waterlines (here, once again, selected to be ten), the half-breath of frame five as a function of the waterlines defined had to be inserted. This was done using previous results that were got when defining the hull form.

Table 8.Maximum draft and spacing (1).

Maximum draft	6,3	m
Intervals:	10	-
Spacing, s:	**0,63**	**m**

Table 9.Half-breath on waterlines. Frame 5.

		1/2 ordinates	SM	Product for area	Lever @ Frame 0	moment of area	
WL [-]	Z-coordinate	y_n [m]	k_n [-]	$y_n * k_n$ [m^2]	R_n [m]	$y_n * k_n * R_n$ [m^3]	
0	0	8,4	1	8,4	0	0,0	
1	0,63	9,3	4	37,0	1	37,0	
2	1,26	10,1	2	20,2	2	40,4	
3	1,89	10,3	4	41,0	3	123,0	
4	2,52	10,4	2	20,8	4	83,2	
5	3,15	10,5	4	41,8	5	209,0	
6	3,78	10,5	2	20,9	6	125,4	
7	4,41	10,5	4	41,8	7	292,6	
8	5,04	10,5	2	20,9	8	167,2	
9	5,67	10,5	4	41,8	9	376,2	
10	6,3	10,5	1	10,5	10	104,5	
			Σ	305,0	m^2	1558,5	m^3

Table 10.Results: CSA and centre of CSA.

Cross sectional area	**128,1**	**m2**
Centre of CSA	**3,2**	**m**

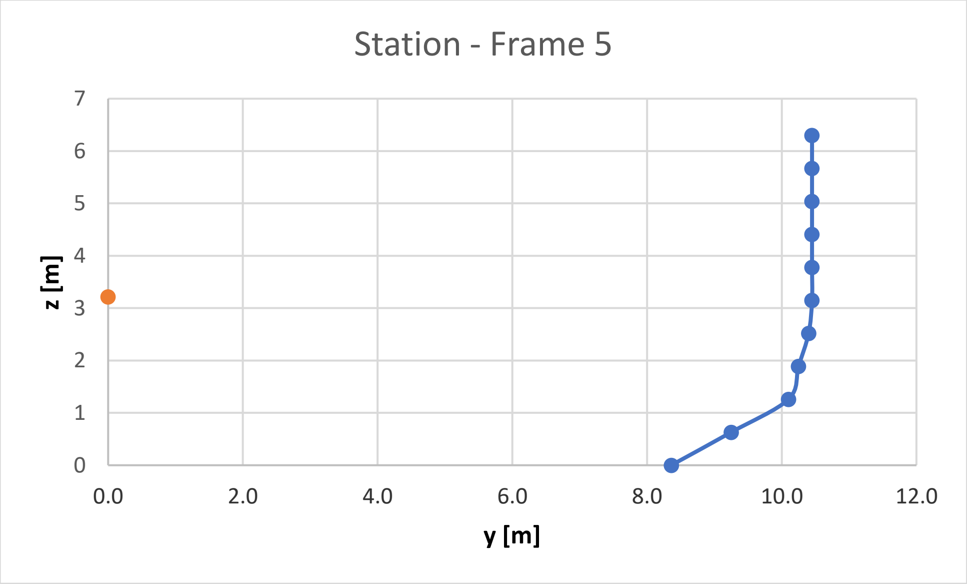


Figure 8.CSA of frame 5.

Using Simpson's Integration method, we were able to assess the values of the Cross-Sectional Area (CSA) for the station in frame five as well as the vertical location of the centre of the CSA. The half-breadth from frame five is shown in the previous plot. In this plot, it can be seen that there is some weird behaviour from the polynomial function that is interpolating the points in each waterline, more specifically between waterlines two to four. Therefore, it is important to have in mind that this might compromise somehow the results of this numerical integration.

5.1.3 Volume calculation – using cross-sectional areas (CSA)

This is the first way we took to assess the volume of displacement. Here this was calculated using Simpson's integration rule and by using the values of the cross-sectional areas (CSA) in each frame defined previously. In the calculations, only the value of the areas of each cross-section (depending on frame) had to be inputted. We got these values from applying the process described in 5.1.2 to each of the eleven sections defined.

Table 11.Length and frame spacing.

Length	129,4	m
Intervals:	10	-
Spacing, s:	**12,94**	**m**

Table 12.CSA for different frames.

		Cross-sectional area	SM	Product for volume	Lever @ Frame 0	Moment of volume	
Frame [-]	x-coordinate	A_n [m^2]	k_n [-]	$A_n * k_n$ [m^3]	R_n [m]	$A_n * k_n * R_n$ [m^4]	
0	**0**	4	1	**4**	0	**0**	
1	**12,94**	34	4	**136**	1	**136**	
2	**25,88**	82	2	**164**	2	**328**	
3	**38,82**	118	4	**472**	3	**1416**	
4	**51,76**	129	2	**258**	4	**1032**	
5	**64,7**	129	4	**516**	5	**2580**	
6	**77,64**	123	2	**246**	6	**1476**	
7	**90,58**	107	4	**428**	7	**2996**	
8	**103,52**	76	2	**152**	8	**1216**	
9	**116,46**	36	4	**144**	9	**1296**	
10	**129,4**	2	1	**2**	10	**20**	
			Σ	**2522**	m^3	**12496**	m^4

Table 13.Results: volume, displacement and LCB.

Volume	**10878**	**m3**
Density of water	1,025	t/m3
Displacement	**11150**	**t**
LCB from fr0	**64,1**	**m**

In the end, we got as results, values for the volume of displacement in cubic meters [m^3], displacement [ton] and the location of the longitudinal centre of buoyancy (LCB) taking as reference frame zero. By looking at the location of LCB, we can see that this point is located very close to frame five, which corresponds to midships.

5.1.4 Volume calculation – waterplane areas (WPA)

The second way how we assessed the volume of displacement and important related values, was by taking into consideration the different waterplane areas. In order to have enough values to insert in each waterline, we used linear interpolation in order to get the correspondent waterplane areas to waterlines that lay between the ones that are represented in the hull form (section 4). Therefore, we have to keep in mind that here was done an approximation and for that reason these results might differ slightly from the ones in the previous section 5.1.3. As input was inserted the maximum draft of the designed ship, the correspondent number of waterlines to be accounted for and the area of the several water plane areas (WPA) to be considered in the calculations.

Table 14.Maximum draft and spacing (2).

Maximum draft	6,3	m
Intervals:	10	-
Spacing, s:	**0,63**	**m**

Table 15.WPA for different waterlines.

		WPA	SM	Product for volume	Lever @ keel	moment of volume	
WL [-]	Z-coordinate	y_n [m^2]	k_n [-]	$y_n * k_n$ [m^3]	R_n [m]	$y_n * k_n * R_n$ [m^4]	
0	**0**	450,8	1	**450,8**	0	**0,0**	
1	**0,63**	576,1	4	**2304,4**	1	**2304,4**	
2	**1,26**	701,4	2	**1402,8**	2	**2805,6**	
3	**1,89**	759,2	4	**3036,8**	3	**9110,4**	
4	**2,52**	817,2	2	**1634,4**	4	**6537,6**	
5	**3,15**	872,0	4	**3488,0**	5	**17440,0**	
6	**3,78**	926,8	2	**1853,6**	6	**11121,6**	
7	**4,41**	991,8	4	**3967,0**	7	**27769,0**	
8	**5,04**	1056,7	2	**2113,4**	8	**16907,2**	
9	**5,67**	1105,3	4	**4421,2**	9	**39790,8**	
10	**6,3**	1153,9	1	**1153,9**	10	**11539,0**	
			Σ	**25826,3**	m^3	**145325,6**	m^4

Table 16.Results: volume and KB.

Volume	**10847**	**m3**
KB	**3,55**	**m**

Using Simpson's integration method, using the WPA, we were able to assess the values of the displaced volume in cubic meters and of the vertical location of the centre of buoyancy from the keel (KB) in meters. These results are shown in the previous table.

By comparing the two methods used for calculating the volume of displacement [m^3] – sections 5.1.3 and 5.1.4 -, it is seen that this last one gives a slight smaller value. This happens most likely because of the approximation we did using the linear interpolation with the aim of getting the areas of the intermediate waterplanes. In addition, imprecisions in rounding values might also contribute to this difference in results obtained. Still, this gives only a slight difference of less than 0.3% which can most likely be neglected or ignored.

5.1.5 Sectional area curve (SAC)

By using the Simpson's integration Excel spreadsheet, we also got as a result the section area curve (SAC) for our design (shown below). Here we can find the location of the longitudinal centre of buoyancy (LCB), which is located approximately 64.1 metres ahead towards the bow from frame zero (reference). This means that the LCB is located very close to frame five (x = 64.7m), between frames four and five. This means that this important point regarding stability is very close to midships. By comparing this result with the LCB calculated

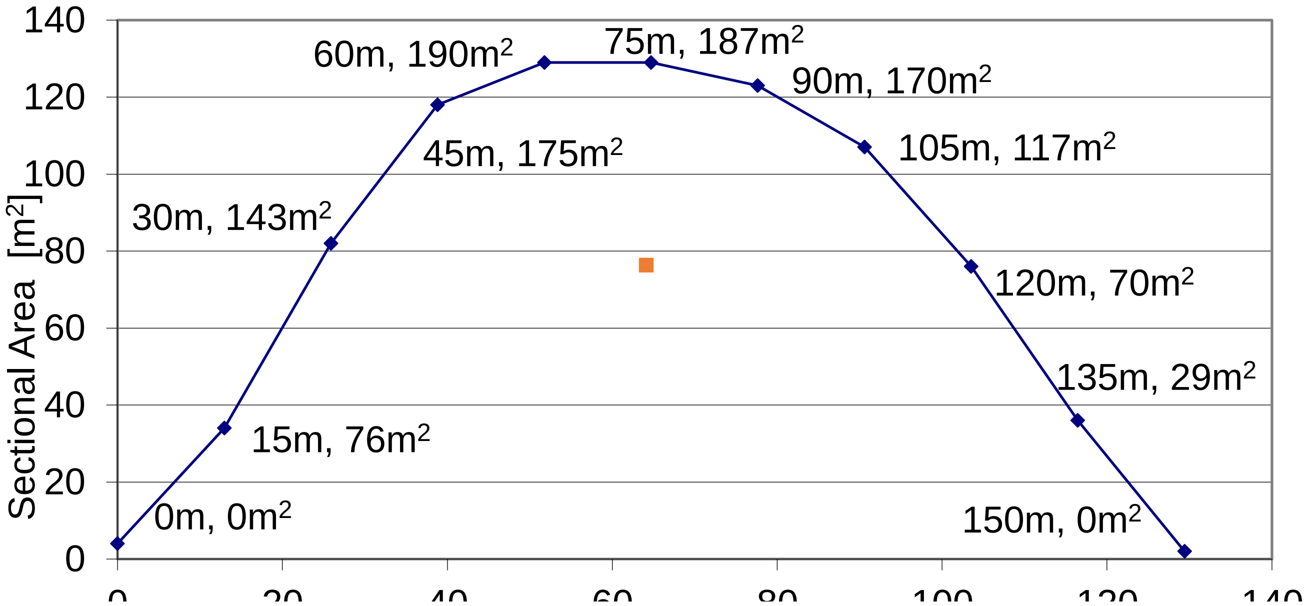


Figure 9.SAC obtained with Simpson's integration method.

while defining the hull form, it can be seen that they coincide quite well. Another important feature that can be observed here is that this SAC shows that our design presents somehow parallel mid-body (constant sectional area). This happens because between each frame the interpolation is linear. As in frame four and five the section areas are similar, this will result in a closely constant section area between them. This situation shows the importance of choosing a correct/adequate function to interpolate depending on the needs.

5.2 Delftship

A model render of the hull of the ship was made using a free software named Delftship. In Delftship there were two possible ways to determine the hull form of the ship. Either by visually placing reference points in the space with the help of so-called background images, which are the hull lines in this case, or by importing the reference points from a text file. In both of these approaches one must have the lines drawings available. In the latter approach, the points on which the lines drawings are based on must also be available. In this project both of these approaches were tried with several iterations. Finally, the importing method was found to yield better results. An Excel spreadsheet was provided to the students to help with the forming of the lines drawing, based on the main dimensions of the ship that were calculated earlier. From this spreadsheet, the reference points to form the 3D hull model were acquired. The coordinates were typed to Notepad to form a text file that could be imported to Delftship.

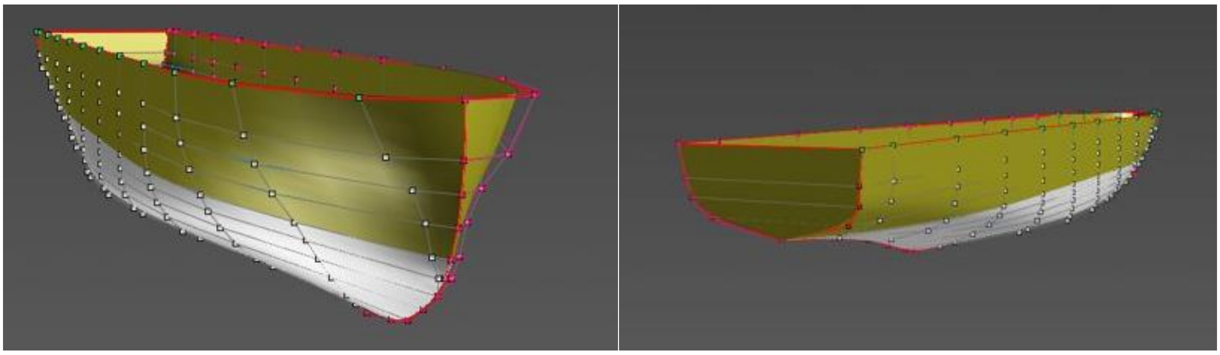


Figure 10 3D render from Delftship.

After the model was created in Delftship, several reports showcasing different statistics could be printed out. These reports include at least: ship design hydrostatics report, ship hydrostatics with various drafts and two different ship resistance reports. The hydrostatics reports provided pretty similar results to what the team acquired with different methods, so they are shown in this report. The resistance calculations of Delftship were not very plausible when compared to the results from the team’s calculations and the estimations of the team’s mentor Pentti Kujala. For this reason, the hydrostatics reports are shown in this report, but the resistance reports are neglected. The reports can be found in attachments 1 and 2.

6 General arrangement

S.A. Agulhas II general arrangement (GA) was used as a reference for the Ondo GA. The GA was done with AutoCAD software. All relevant machinery and equipment were fitted in the GA of the vessel. Some of the space reservations for the equipment are approximate since some dimensions were not specifically known.

6.1 Concepts

Since Ondo is a specific, dual-class vessel, there is not much spare space. All equipment, machinery-, hotel-, research- and cargo spaces must fit in relatively tight space. Also, there are regulatory equipment to fit onboard, such as lifesaving equipment.

Fire zones, watertight compartments and lifesaving equipment were selected based on set rules and regulations. Due the lack of space, a goal was to achieve a good people flow in the vessel. Also, laboratory spaces for research purposes and having enough cargo logistic and handling space had to be achieved, being able to fulfil all the intended missions.

6.2 Plans

Side view of the vessel (Figure 11) gives the overall idea of size relations of the vessel. All major equipment is seen in this view. The hull shown in this view is in accordance what was established during the previous the beginning of the project: a moon shaped bow due to icebreaking properties and a shape of stern that allows the implementation of Azipods.

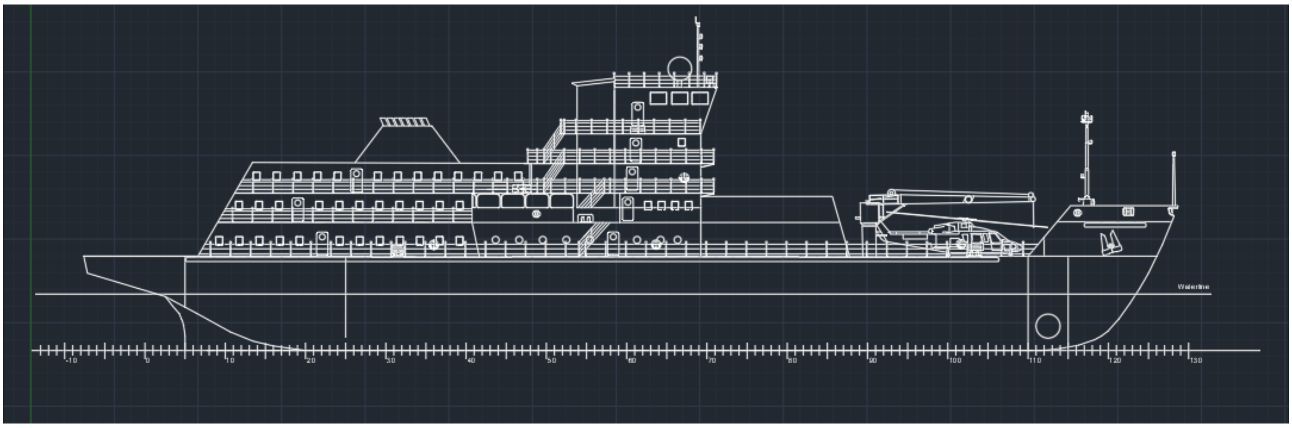


Figure 11. Side view

Fire zones (Figure 12) are presented with a general overview of the location of different spaces around the decks.

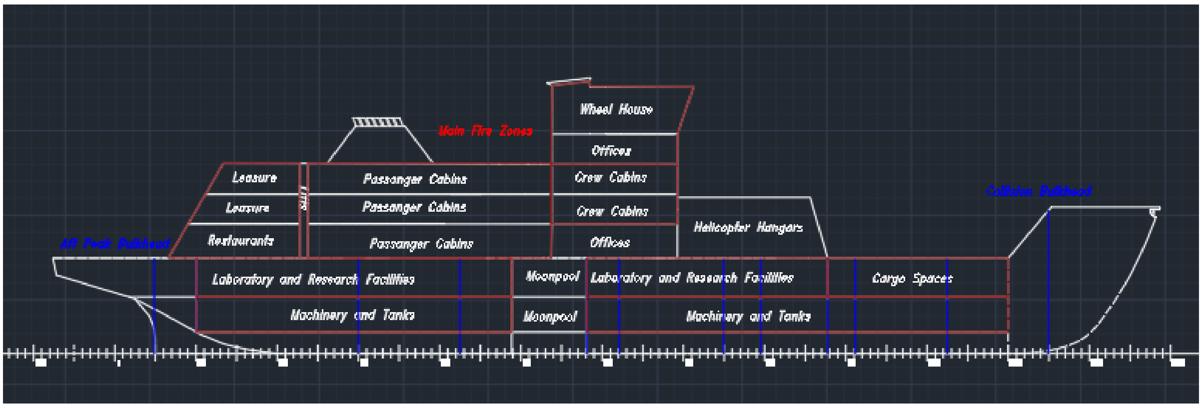


Figure 12. Location of spaces and fire zones

The second deck of Ondo (Figure 13) was designed more towards accommodation of both passengers and crew. Some leisure facilities were located at the aft end of the deck.

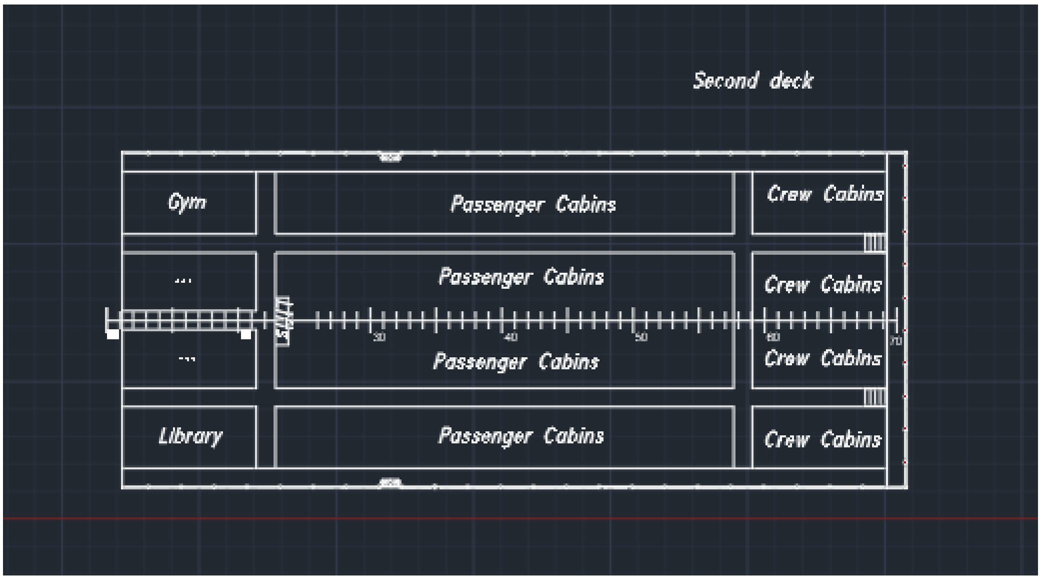


Figure 13. Second deck

The first deck of Ondo (Figure 14) is similar to the second deck. Therefore, here were located also accommodation of both passengers and crew. Some leisure facilities were located at the aft end of this deck. In addition, the helicopter hangar was located at the fore end of first deck.

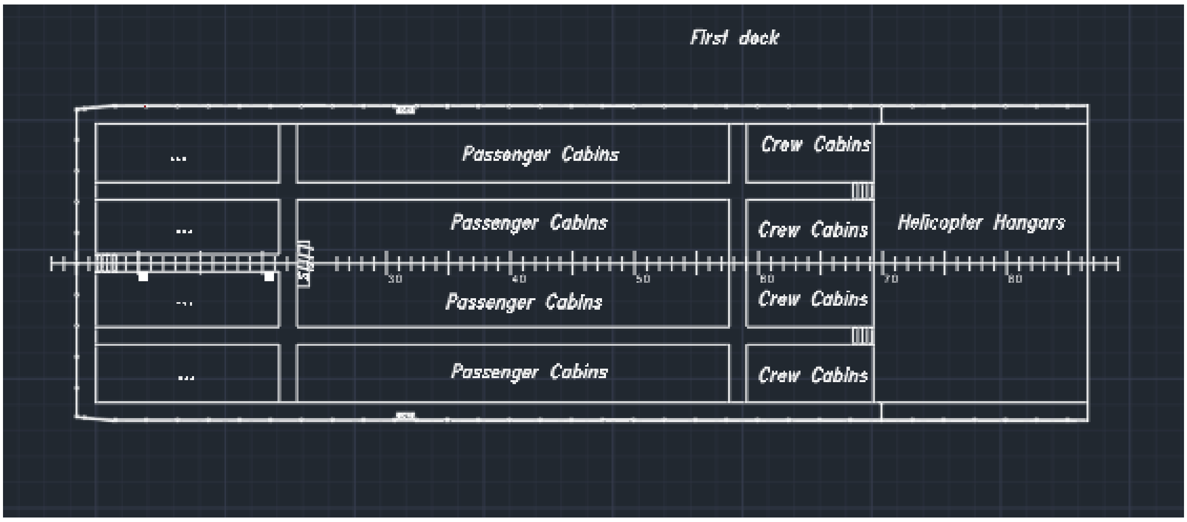


Figure 14. First deck

The main deck of Ondo (Figure 15) contains the helicopter deck and a cargo handling space at the fore part. Two deck cranes allow to handle containers and store them in a compartment located in the lower deck. This compartment is accessible from the main deck through a cargo hatch. Main deck also includes helicopter hangars and some passenger cabins. Additionally, offices for the research personnel and dining facilities are located here. Two lifeboats are found at the aft of the deck.

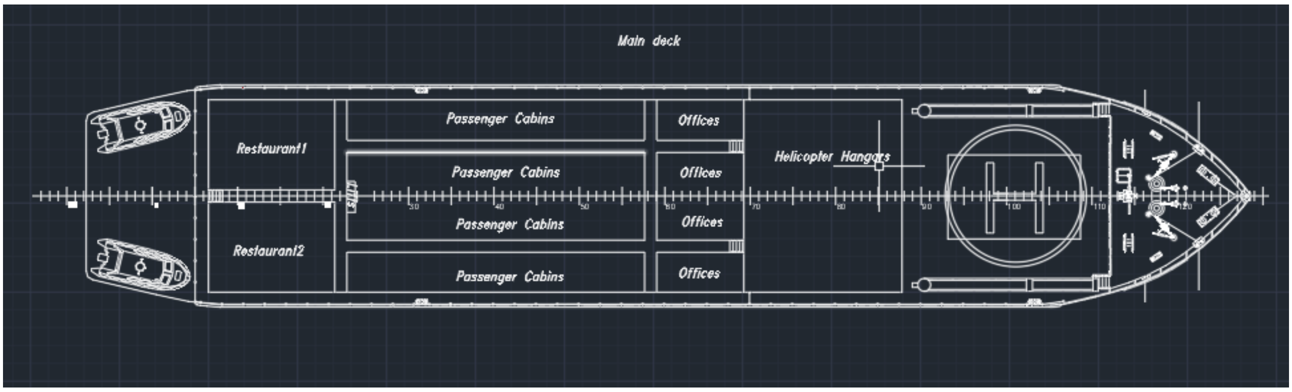


Figure 15. Main deck

The lower deck (Figure 16) is to serve research personnel and crew only. At the fore end, are located cargo spaces for storage of containers and other types cargo. Besides this, laboratory and research facilities fulfil rest of the space on this deck. An important feature to note is the moonpool located roughly in the middle of the deck.

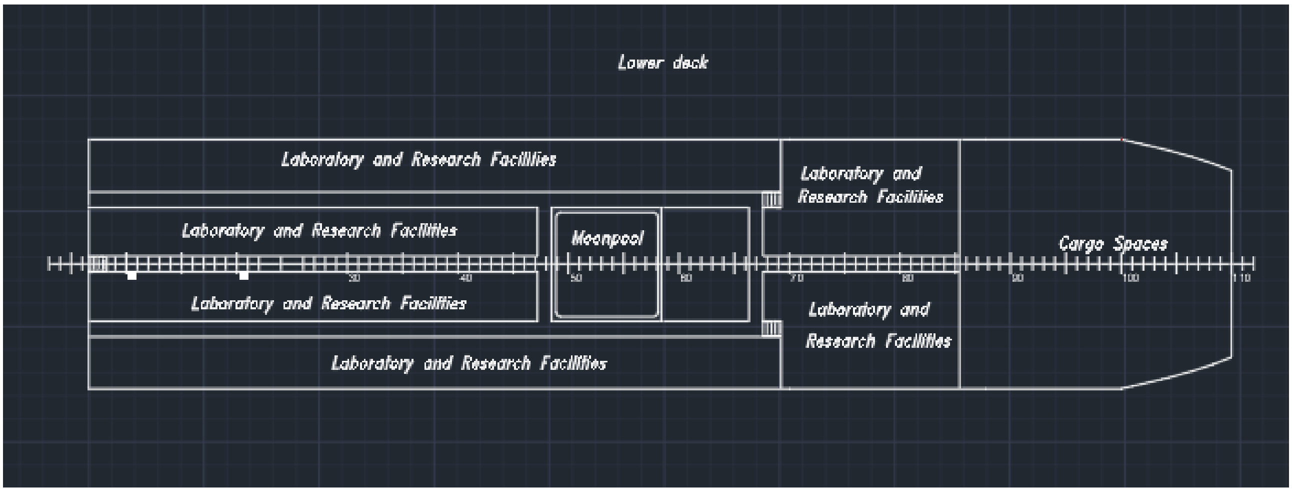


Figure 16 Lower deck

In the tween deck (Figure 17) are located tanks, storage- and machinery systems. Important feature is the moonpool, which is located right behind the main engine room. Also, the LNG gas storage, waste treatment systems, ROV lars, diesel generators, ballast water tanks, lubrification oil tank are located here.

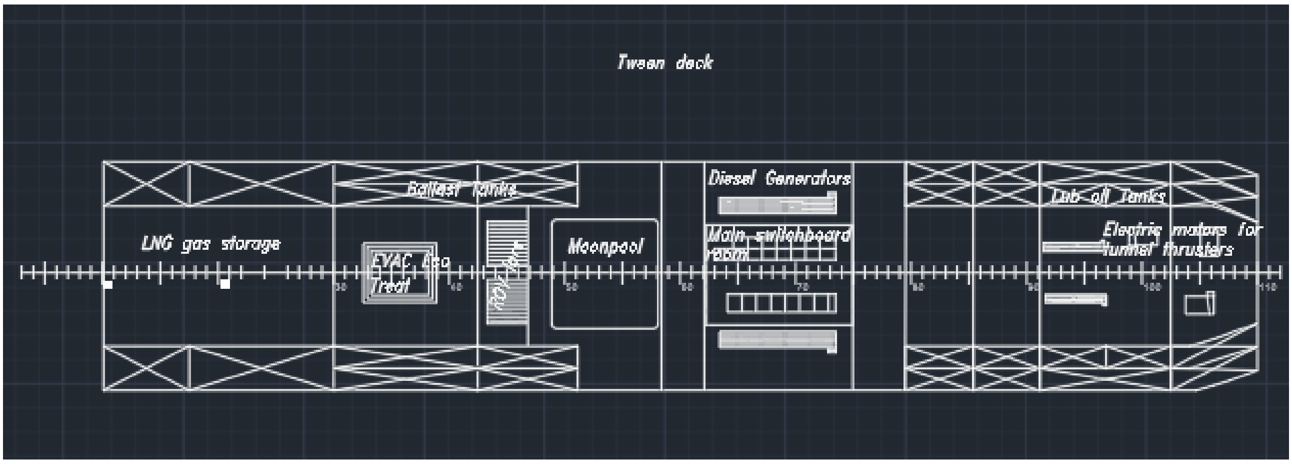


Figure 17 Tween deck

Watertight compartments can be seen in Figure 18, below. Ondo is a ship that locates in the interval of 125 < L < 145. Therefore, six bulkheads are required aft of the engine room and elsewhere seven is the minimum value. Having these situations in mind, the following distribution of bulkheads has come up (marked with blue). The aft and fore most bulkhead are the aft peak and collision bulkheads, respectively.

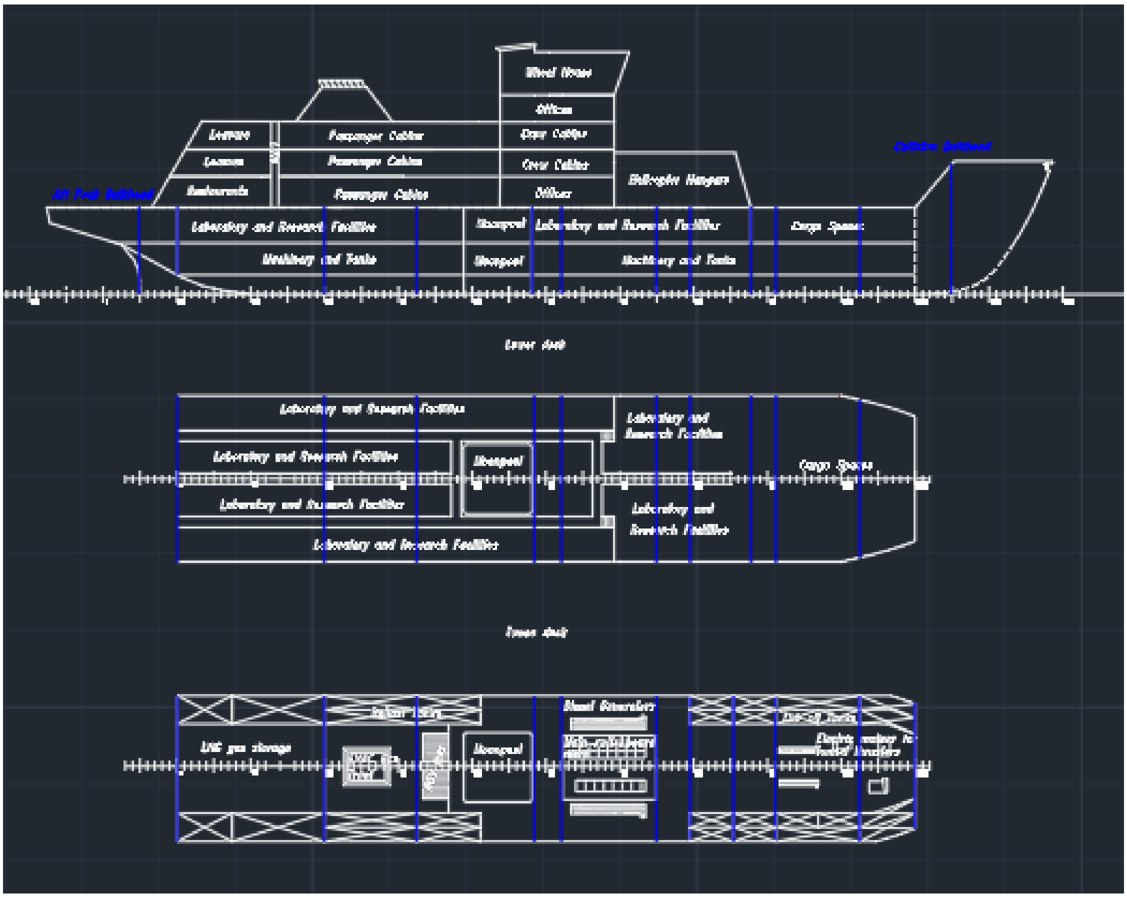


Figure 18. Watertight compartments

7 Ship structures

Ship structures and their design in this project were dominated mainly by a few factors that had to be considered. These were: Ondo is an ice breaking vessel, so in addition to the extra attention on the bow shape and performance, the hull must be able to withstand the additional forces that breaking the ice causes as well as the forces that ships must withstand always. Ondo also has a moonpool in the amidships, which makes an additional concern to the hull strength.

7.1 Regulations

Because of the moonpool Ondo has, the DNV GL section of ships with large openings was considered. (DNV GL Rules)

For ships with large deck openings, as defined in Ch.1 Sec.4 Table 7 (DNV GL Rules), the additional **longitudinal stresses** induced by acting still water and wave torsional moments shall be considered. Hence, for the seagoing condition, the hull girder longitudinal stress σ_{hg}, in N/mm^2, for a dynamic load case at the transverse section being considered is obtained from the following formula:

$$\sigma_{hg} = \sigma_{hg-sw} + \sigma_{hg-dyn}$$

where

$$\sigma_{hg-sw} = \begin{cases} \sigma_{sw-h} + |\sigma_{st}| \\ \sigma_{sw-h} - |\sigma_{st}| \\ \sigma_{sw-s} + |\sigma_{st}| \\ \sigma_{sw-s} - |\sigma_{st}| \end{cases}$$

$$\sigma_{hg-dyn} = \sigma_{wv-LC} + C_{ht}\sigma_{wh-LC} + \sigma_{wt-LC}$$

C_{ht} = reduction coefficient due combination with warping stress = 0.85

Along the length L, the hull girder longitudinal stress σ_{hg}, in N/mm^2, at any point being considered shall comply with the following formula:

$$|\sigma_{hg}| \leq \sigma_{hg-perm}$$

where:

$\sigma_{hg-perm}$ = permissible longitudinal stress, in N/mm^2

For ships with large deck openings, as defined in Ch.1 Sec.4 Table 7 (DNV GL Rules), the additional **shear stress** induced by acting still water and wave torsional moments shall be considered. Hence, for the seagoing condition, the hull girder shear stress τ_{hg}, in N/mm^2, for a dynamic load case at the transverse section being considered is obtained from the following formula:

$$\tau_{hg} = \tau_{hg-sw} + \tau_{hg-dyn}$$

Where

$$\tau_{hg-sw} = \begin{cases} \tau_{sw-pos} + |\tau_{st}| \\ \tau_{sw-pos} - |\tau_{st}| \\ \tau_{sw-neg} + |\tau_{st}| \\ \tau_{sw-neg} - |\tau_{st}| \end{cases}$$

$$\tau_{hg-dyn} = \tau_{wv-LC} + \tau_{wt-LC}$$

The **equivalent stress**, in N/mm^2, related to the hull girder longitudinal and shear stresses, σ_{hg} and τ_{hg} as defined in [3.1.1] and [3.2.1], respectively, at any point being considered is obtained from the following formula:

$$\sigma_v = \sqrt{\sigma_{hg}^2 + 3\tau_{hg}^2}$$

Along the length L, the **equivalent stress**, in N/mm2, at any point being considered shall comply with the following formula:

$$\sigma_v \leq \sigma_{v-perm}$$

where:

$\sigma_{v\text{-perm}}$ = permissible equivalent stress, in N/mm^2, to be taken as:

$$\sigma_{v-perm} = \frac{220}{k}$$

In DNVGL rules, hull girder ultimate strength check is not mandatory for vessel with length less or equal to 150m in LOA. (DNV GL Rules)

7.2 Cross-sections

Two cross section drawings were made, depicting the midship section, where the moonpool is located, and another one showing the engine room. These two parts were considered to be the most crucial parts of the ship structure. The midship section with the moonpool can be seen in Figure 19 and the engine room and main switchboard are shown in Figure 20.

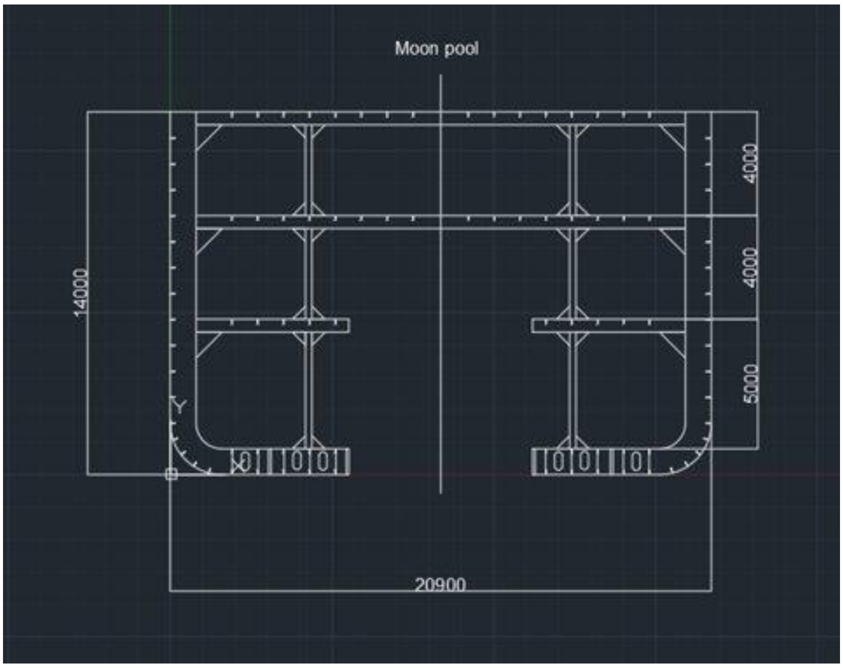


Figure 19 Midship section of Ondo with the moonpool

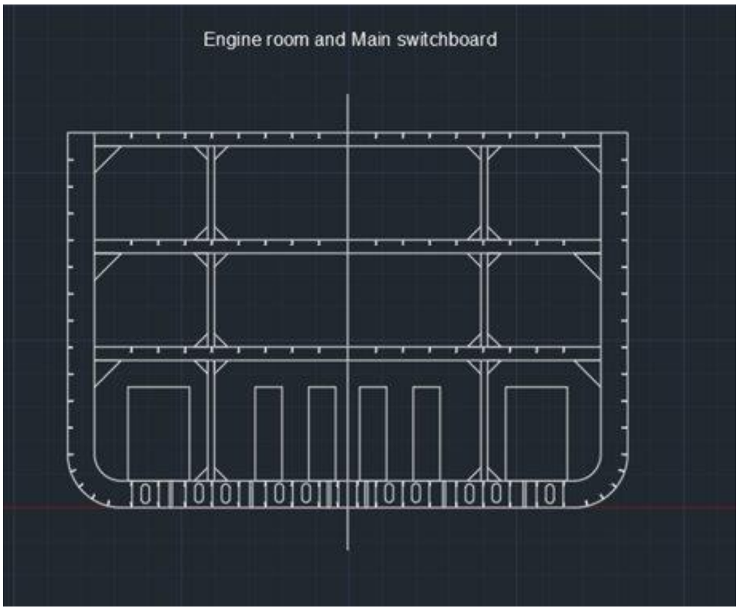
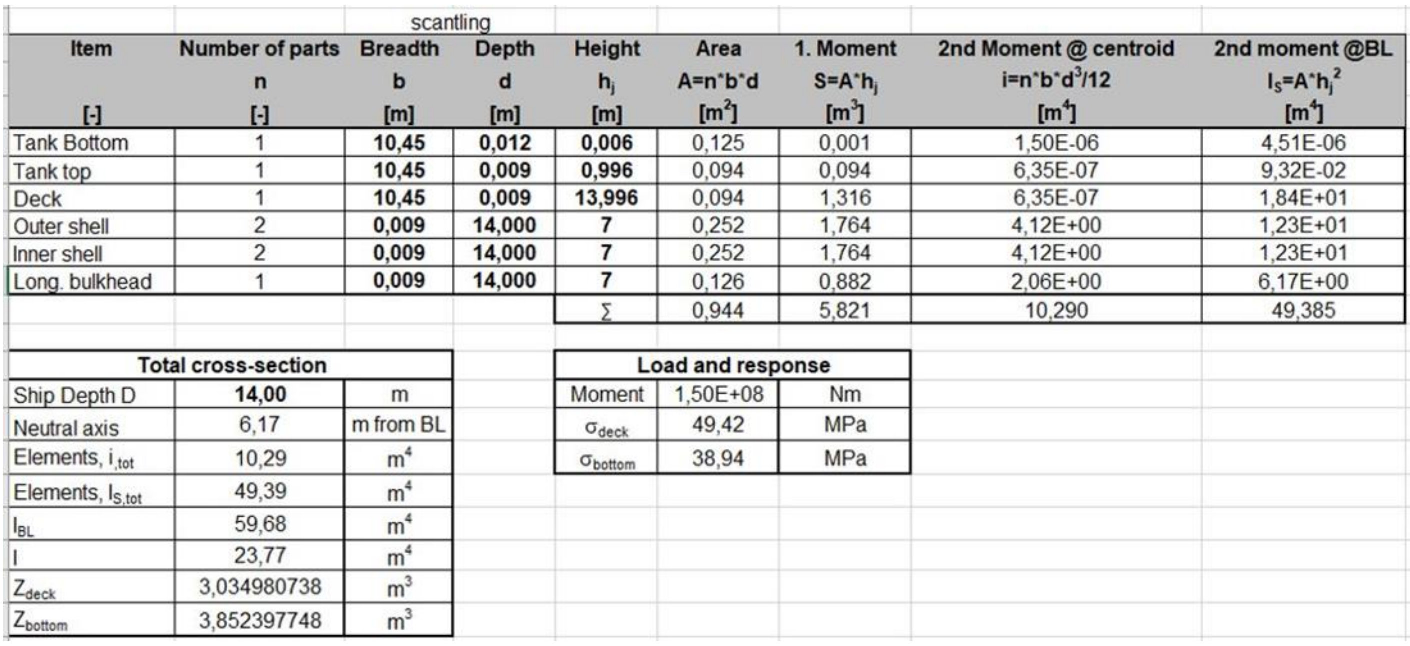


Figure 20 Engine room cross section of Ondo

7.3 Calculations

On the basis of the aforementioned cross-ship sections, sectional modulus calculations were made with an Excel spreadsheet that was provided to the students.

The calculations considered the dimensions, height above centroid of the ship and the area moment of inertia of each of the contributing component of the cross-section. Next, a bending moment of the ship section and the height of the deck above baseline were added. In this case, the readily provided value for the moment was used. Finally, the results were acquired, which included: the location of the neutral axis, the sectional modulus at the deck and the bottom, stresses at the deck and the bottom and the area moment of inertia of the ship section considered. A capture of the spreadsheet and the calculations is shown in Figure 21.



		scantling						
Item	**Number of parts**	**Breadth**	**Depth**	**Height**	**Area**	**1. Moment**	**2nd Moment @ centroid**	**2nd moment @BL**
	n	**b**	**d**	**h_j**	**A=n*b*d**	**$S=A*h_j$**	**$i=n*b*d^3/12$**	**$I_S=A*h_j^2$**
[-]	**[-]**	**[m]**	**[m]**	**[m]**	**[m^2]**	**[m^3]**	**[m^4]**	**[m^4]**
Tank Bottom	1	**10,45**	**0,012**	**0,006**	0,125	0,001	1,50E-06	4,51E-06
Tank top	1	**10,45**	**0,009**	**0,996**	0,094	0,094	6,35E-07	9,32E-02
Deck	1	**10,45**	**0,009**	**13,996**	0,094	1,316	6,35E-07	1,84E+01
Outer shell	2	**0,009**	**14,000**	**7**	0,252	1,764	4,12E+00	1,23E+01
Inner shell	2	**0,009**	**14,000**	**7**	0,252	1,764	4,12E+00	1,23E+01
Long. bulkhead	1	**0,009**	**14,000**	**7**	0,126	0,882	2,06E+00	6,17E+00
				∑	0,944	5,821	10,290	49,385

Total cross-section		
Ship Depth D	**14,00**	m
Neutral axis	6,17	m from BL
Elements, $i_{,tot}$	10,29	m^4
Elements, $I_{S,tot}$	49,39	m^4
I_{BL}	59,68	m^4
I	23,77	m^4
Z_{deck}	3,034980738	m^3
Z_{bottom}	3,852397748	m^3

Load and response		
Moment	1,50E+08	Nm
σ_{deck}	49,42	MPa
σ_{bottom}	38,94	MPa

Figure 21 Section modulus calculations of the midship cross-section of Ondo

8 Power and machinery

8.1 Ship mission

To make a reasonable estimation of the requirement of power onboard Ondo, a ship operational profile is needed as it helps determine a ship's speed and power demand over a specific period of time. Therefore, it takes a crucial role in the determination of a ship's total power demand, as it shows the maximum peak load that a ship will encounter throughout its operation.

This has been assessed already when introducing the design context of the project (section 1). However, here is presented once again an image showing a round trip to Kirkenes and in addition an operational profile (one way only) of Ondo during this journey, that shows the different speeds throughout the journey. This is the most important data when then doing calculations in terms of power requirements. Both these features can be found below in Figure 22 and Figure 23.

Figure 22.Intended Ondo route Helsinki – Kirkenes – Helsinki.

Figure 23.Speed profile for the Helsinki-Kirkenes voyage of 2378' overall distance.

8.2 Power requirements

An estimation of the resistance of Ondo has been done using the spreadsheet entitled ‘T8_Resistance and Power Calculation’ given during lecture 8 of the Principles of Naval Architecture course 2020.

A ship’s total resistance on calm water can be divided into three main components: frictional, residual (due to waves) and air resistance. In our case, Ondo is a ship with ice breaking capabilities and for this reason, ice resistance will be the dominating type of resistance. However, as in the PNA course there was not given much focus into ice resistance calculations, these will be excluded from this report and, instead, consulting our project mentor Pentti Kujala will be used as an estimation to these figures. This situation will then be taken into more consideration during our next iteration in the design spiral, as all members of Ondo who are continuing their studies in marine engineering, will be attending the course on winter navigation, starting in January.

In the calculations made using the Excel spreadsheet, only the frictional resistance is taken into account. Therefore, this estimation of total resistance is somehow lacking and might be much smaller than the actual resistance that Ondo will encounter throughout its journeys from Helsinki to polar regions. This leads to the necessity of awareness during this process and to keep in mind reasonable values, the data of the reference ship S. A. Agulhas II will be constantly compared to the results obtained here.

The Power Prediction Method used is the J. Holtrop and G.G.J. Mennen presented in 1982 and developed further by Gérson Beraldo Matter in 2000. We started by entering Ondo’s particulars such as main dimensions, dimensional coefficients and figures related to areas of features that have an important contribution to resistance in a ship, such as the area of the immersed part of the transverse area of the transom, which is tightly related to the flow separation that takes place. These values were mainly taken from previous work done with the hull lines as well as some estimations that were made regarding figures that were not directly available. The values entered can be found in the table below:

Table 17.Principle particulars of Ondo.

PRINCIPAL PARTICULARS		
LBP =	129,400	**m**
B =	20,900	**m**
T =	6,300	**m**
LCB =	-0,600	**%**
C_p =	0,628	
C_B =	0,616	
C_{ms} =	0,981	
C_{wp} =	0,853	
Abt =	0,000	**m^2**
Cstern =	0	
Tf =	6,300	**m**
Ta =	6,300	**m**
hb =	3,000	**m**
At =	40,000	**m^2**
S =	0,000	**m^2**

As seen from the values inputted, the transverse sectional area of the bulb at the fore perpendicular (Abt) was considered as being 0,000 m^2 since there is no bulbous bow in Ondo. The wetted surface area was inserted as 0 m^2 for getting an automatic estimation of this value (the wetted surface was not assessed using a CAD programme). The afterbody form was taken as having a normal section shape.

Having these values figured out, we then moved to the appendage's particulars. At this point we had to brainstorm about the features that are effectively present in Ondo. We concluded that from the features listed in the Excel spreadsheet, only a Skeg and a Bow Thruster should be considered (marked with 1 in the table below).

Table 18.Appendage's particulars of Ondo.

APPENDAGE'S PARTICULARS			
	1 + K2	**Sapp (m^2)**	**Presence**
Rudder Behind Skeg	1,70	0,00	0
Rudder Behind Stern	1,40	0,00	0
Twin-screw balance rudders	2,80	0,00	0
Shaft Brackets	3,00	0,00	0
Skeg	1,80	48,00	1

Strut Bossings	3,00	0,00	0		
Hull Bossings	2,00	0,00	0		
Shafts	3,00	0,00	0		
Stabilizer Fins	2,80	0,00	0		
Dome	2,70	0,00	0		
Bilge Keels	1,40	0,00	0	**Diameter**	
Bow Thruster	-	-	1	1,50	**m**
Stern Thruster	-	-	0	1,00	**m**

In the table above, in the column regarding presence, the value zero means that type of appendage is not considered in our design and a value of one refers to its presence. The wetted area of the skeg (Saap) was estimated by assuming our skeg (developed during the work on the hull form) to be of triangular shape. Taking its rough dimensions from the drawings we could then estimate its wetted area. When dealing with the bow thruster, a diameter of 1.50 metres was picked. The values marked in red have been taken as constants for the different appendage's particulars (not changed by us).

We moved then to the propulsion particulars. Important to note is that Ondo uses Azipods as propulsion units and this will be discussed further in the report. We are dealing with a twin-screw ship and for that reason K = 0,1. All the values inserted for the propulsion particulars are shown in the table below taken from the Excel file:

Table 19.Propulsion particulars of Ondo.

PROPULSION PARTICULARS		
Z =	4	
P =	2,17	**m**
D =	3,00	**m**
Hp =	2,50	**m**
K =	0,1	
η_0=	0,63	

The operation speeds of Ondo range from 0 to 16.5 knots. The typical cruising speed for the ship being designed is of 14 knots but an extra range of 2.5 knots is allowed above this speed to be able to perform at even greater speeds in case of necessity and mainly to give already some margin when choosing afterwards the machinery used for powering the propulsion system. On the other hand, water properties are also important when estimating the frictional component of the resistance of the ship. In fact, the kinematic viscosity of water is taken as N_i = 1,188E-06 m^2/s. In addition, the density of water is also an important figure when talking about resistance of a ship. Ondo will navigate in the Baltic sea as well as in the Atlantic, Northern and Southern Oceans. In the Baltic and specifically in the port of Helsinki, the density of the water can be approximated to fresh water, meaning that ρ = 1003 Kg/m^3. In the other extreme of density values is the Atlantic Ocean. Here the water is taken as having a density of 1025 Kg/m^3. As water friction resistance is affected by the density of the fluid (water) and this increases with the increase of the density, we take into consideration in this stage of the design the resistance calculated purely with a water density of ρ = 1025 Kg/m^3 as this leads to more conservative results (higher results in terms of total resistance).

With all these figures inserted in the Excel spreadsheet, we get then as a result the resistance of Ondo (in kN) as a function of speed (in Knots). In the plot presented below can be seen the values of the total resistance of the ship (RT) and the propeller thrust (T) as a function of the speed.

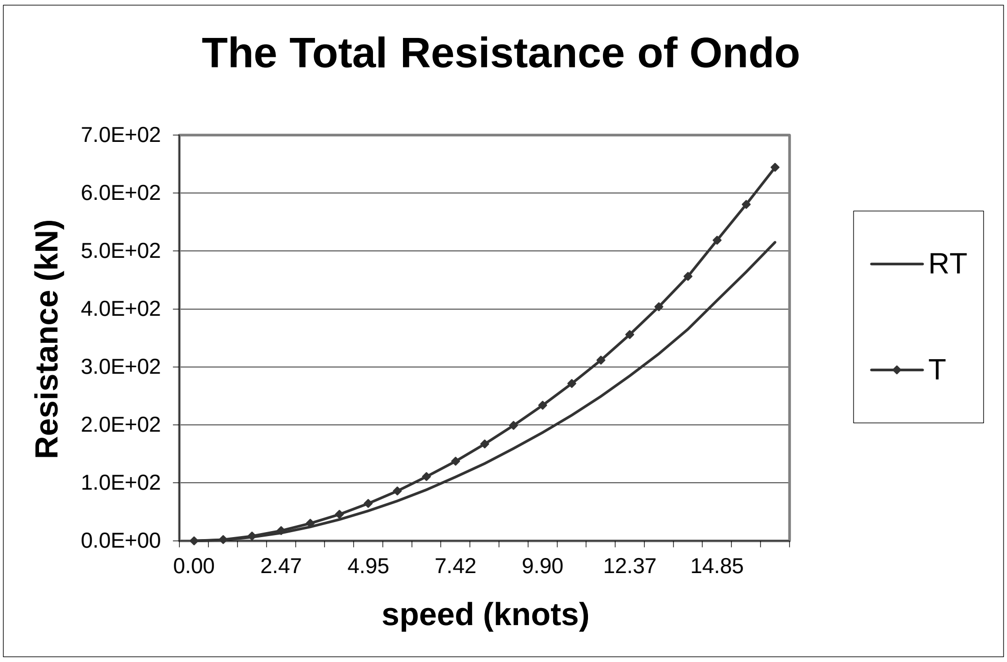


Figure 24. Resistance [kN] vs. speed [knots].

From the results above, can be concluded that at the cruising speed of Ondo (14 kn), the propeller thrust required is about 450 kN and the total resistance estimated is around 350 kN. On the other hand, as explained earlier, a maximum speed of 16.5 knots is considered to Ondo in these calculations. At this speed, these figures increase exponentially to a propeller thrust of 650 kN (orange in the graph) and total resistance of 500 kN (blue in the graph).

As referred before, Ondo will not be subjected solely to frictional resistance. In addition, residual (due to waves), air and ice loads resistance will also contribute to the total resistance.

Ice loads are not estimated in this report but regulation regarding the propulsion systems can be found from the Finnish-Swedish ice class rules. These give important reference data that can help choosing the correct machinery for ice going ships. We were able to get access to this kind of information through the Finnish Transport Safety Agency, by the publication entitled “Ice Class Regulation and the Application Thereof”. This data was kept in mind when later on choosing the propulsion machinery.

The results of the Excel calculations also include the power required for propulsion. This result is given as power (kW) as a function of speed (knots). Two functions are shown simultaneously: shaft power (Ps) and effective power (Pe). The graph obtained can be seen below:

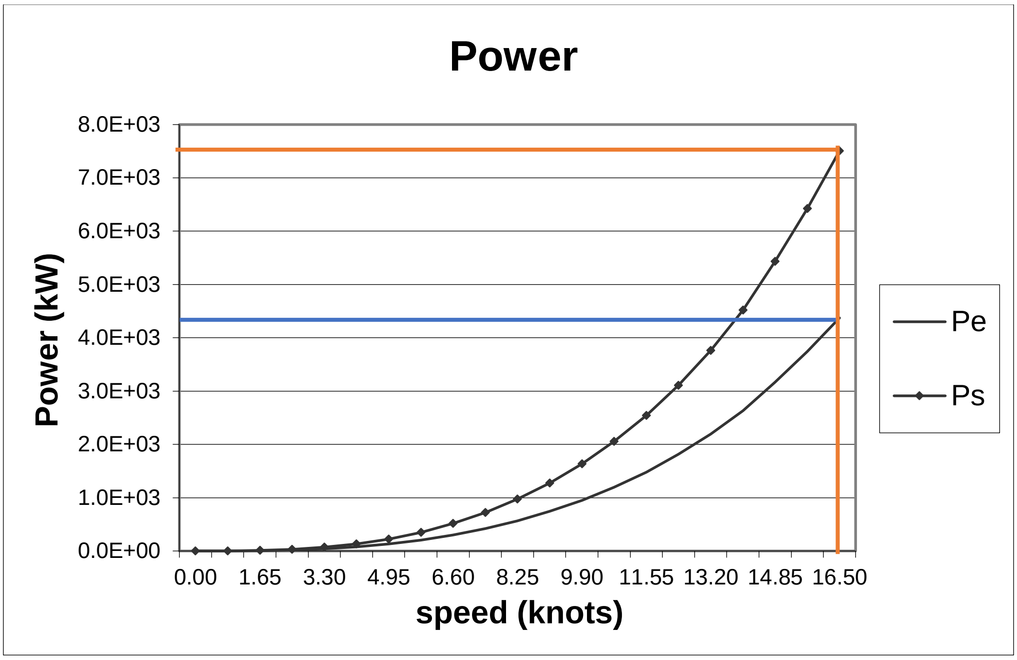


Figure 25. Power [kW] vs. speed [knots].

From the results above, can be concluded that at the cruising speed of Ondo (14 kn), the shaft power required is about 4.5 MW and the effective power estimated is around 2.5 MW. On the other hand, as explained earlier, a maximum speed of 16.5 knots is considered for Ondo in the calculations. At this speed, these figures increase exponentially to a shaft power of 7.5 MW and effective power of 4.25 MW.

By comparing these results with the propulsion power onboard our reference ship S.A. Agulhas II, we can conclude that our values are somewhat reliable. In fact, aboard S.A. Agulhas II, there is a Diesel-Electric propulsion system, with two shafts giving 2 x 4.500 kW. This means that the propulsion power onboard our reference ship is equal to 9 MW. In our case, the maximum power needed is around 7.5MW. This slight difference in the power requirements can be explained due to the different ice-breaking capacities of both ships. Agulhas can break 1m thick ice at a speed of 5 knots while our Ondo vessel is capable of navigating only on ice with thickness up to 0.6m without extra help from icebreakers. Therefore, this extra power capacity onboard the reference ship is due important extra resistance that comes from the ice loads.

From the calculations shown previously, we were able to assess the power needed to the propulsion of Ondo for navigation. However, onboard Ondo, there are several other features that require big amounts of power. These include hotel/accommodation demands, laboratory, deck cranes, bow thrusters used in manoeuvring, etc… Therefore, these extra demands need to be taken into consideration so that an informed choice of generators can be done as these need to account for the energy demand onboard. Once again, we look at our reference ship S.A. Agulhas II. This gets its power from four Wärtsilä 6L32 generators, giving each one a power of 3 MW. In conclusion, the total installed power onboard Agulhas is then 12 MW. The reference ship has higher demands for propulsion but, on the other hand, in our case, we are dealing with a dual-class ship that aims at meeting requirements from both passenger and research vessels. This is a notable feature, and this brings then higher energy demands when considering the passenger/hotel spaces. Therefore, an aim to an installed power onboard Ondo of also 12MW is also something we are looking at. This choice was discussed with our mentor Pentti Kujala who assertedly agreed with our proposal.

8.3 Ship machinery

Ondo has a power requirement of approximately 12 MW as stated earlier. This power is achieved through four Wärtsilä W6L32 generating sets, shown in Figure 26, which produce engine power of 3360 kW and generator power of 3230 kW each. The original idea was to make use of LNG as a source of power, because Ondo is supposed to be a low emission vessel. However, this is an area that has only been used quite recently and, in a few vessels only. Therefore, a diesel electric propulsion was much easier to design as information is readily available. There was an idea that the main propulsion power of circa 8 MW would be generated with a diesel genset and the auxiliary power could maybe then be generated with LNG. Due to the limited time of the course however, these problems couldn't be solved completely. Also, in diesel electric powered ships it is not very common to have the main engine and auxiliary engine separately. Some sort of dual fuel engine could maybe be a solution to this.

Figure 26 Wärtsilä W6L32 Diesel generating set

8.4 Propulsion

The propulsion for Ondo was decided to be azimuthing thrusters and more specifically two pieces of ABB Azipod ICE thrusters, seen in Figure 27. ABB Azipod ICE thrusters provide 2-5 MW of power each, so they are a good fit to Ondo, which requires approximately 8 MW of propulsion power.

Figure 27 ABB Azipod ICE thruster unit

Azipods have a lot of strengths on vessel types such as Ondo. To name a few, azipods or at least azimuthing thrusters complement and are somewhat required for the Dynamic Positioning of the vessel which is one of the things that makes Ondo a good vessel for conducting research. Azipods also perform well in ice breaking vessels because there is not a cone around the propeller and ice does not get stuck there. Azipods provide an accurate way of navigating without the use of a rudder. They allow a wide range of manoeuvres, which is a good thing with a self-sufficient vessel such as Ondo that operates in a remote location in harsh conditions.

Some other features of azipods that do not necessarily relate to the operating are that they omit the need to a main shaft as the power is conducted to the pod and the propeller electrically as the motor is placed inside the pod itself where the electric power is transformed to a rotating motion. As for when it comes to passenger comfort, azipods also reduce the noise and vibrations conducted to the hull as the motor is underwater and separate from the hull. This is favoured in Ondo, because the vessel is intended to carry civilian passengers as well.

8.5 Equipment

Ondo is equipped with different kinds of sensors and other equipment that helps the vessel to maintain its operability, passenger comfort, safety, achieve as low emission level as possible and to have a lowest possible fuel consumption. This mentioned equipment is not further specified or explained in this project, but they are essential part of the vessel. Passenger comfort and entertainment equipment and spaces also play a remarkable role.

9 Weight and stability

9.1 SFI standard definitions

The SFI Group System is the most used classification system for the maritime industry asset control and maintenance supervision globally. It is an internationally recognized standard providing subdivisions for technical and financial vessel management.

SFI system, later on referred to as "SFS- code", consists of a technical account structure covering all aspects of ship specification, and it can be used as a basic standard for all systems in the shipping/offshore industry. SFI- codes are presented in a tree structure with eight main groups, as follows:

- Primary Group 1 – Ship General.
- Primary Group 2 – Hull.
- Primary Group 3 - Equipment for Cargo.
- Primary Group 4 - Ship Equipment.
- Primary Group 5 - Equipment for Crew and Passengers.
- Primary Group 6 - Machinery Main Components.
- Primary Group 7 - Systems for Machinery Main Components.
- Primary Group 8 – Ship Common Systems.

For the vessel Ondo subdivisions are illustrated to the levels of primary- and secondary groups. These subdivisions can be found in the table below:

Table 20.SFI system for Ondo.

Primary Group	Secondary Group	SFI - Code
1. Ship General	1. General arrangement	11
	2. Docking plan	12
	3. Periodical maintenance	13
2. Hull	1. Hull materials	21
	2. Engine area	22
	3. Midship/Cargo area	23
	4. Superstructure and deckhouse	24

3. Equipment for Cargo	1. Cargo hatches	31
	2. Deck cranes	32
	3. Equipment for cargo	33
4. Ship Equipment	1. Navigation systems	41
	2. Communication equipment	42
	3. Manoeuvring machinery and equipment	43
	4. Anchoring and mooring equipment	44
5. Equipment for Crew and Passengers	1. Lifesaving equipment	51
	2. Firefighting appliances	52
	3. Watertight doors	53
6. Machinery Main Components	1. Main engines	61
	2. Propulsion systems	62
	3. Steering system	63
7. Systems for Machinery Main Components	1. Diesel system	71
	2. LNG system	72
	3. Cooling systems	73
8. Ship Common systems	1. Ballast water system	81
	2. Air and sounding system	82
	3. Electrical systems	83

This SFI system defined in this section will later on be used to estimate the building costs of Ondo. This is done in section 10.1.1.

9.2 Weight calculations

9.2.1 Lightship weight

The estimation of the lightship weight of Ondo was done using the EXCEL spreadsheet given in lecture 9 of Principles of Naval Architecture course. The calculations behind the spreadsheet and the final results are shown in this section.

There are three main divisions of the lightship weight: structural weight, machinery weight and the outfitting weight. These contributions will be calculated independently and them summed up in the end, to get the final lightship weight of Ondo.

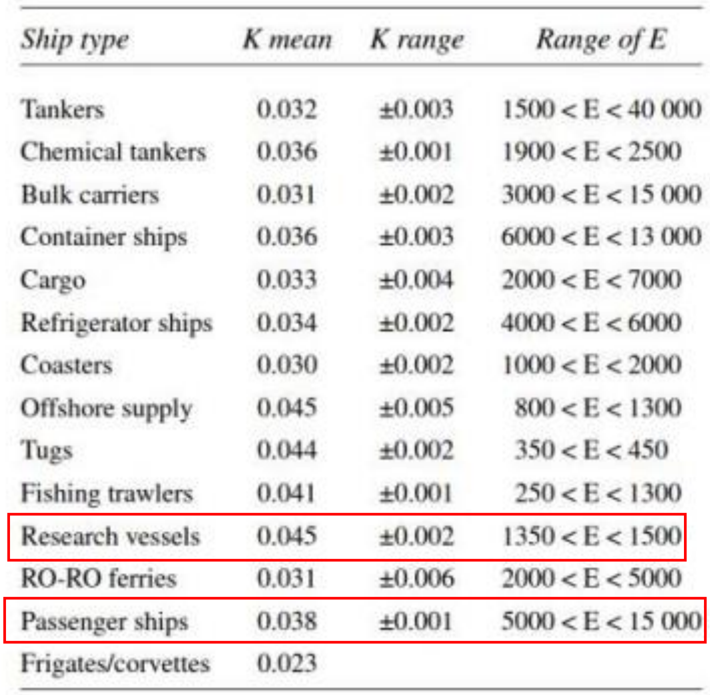
- *Structural weight*

Firstly, the structural weight is estimated using a formula based on Watson and Gilfillan approach:

$$W_s = KE^{1.36}[1+0.5(C_B-0.7)]$$

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

where C_B is the block coefficient. The factor K varies with the ship type and is shown in the following table. E is the equipment number, the third and the fourth terms are related to the superstructure and the deckhouse dimensions respectively.



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

Figure 28.Factor K according to ship type.

The data from Ondo needed to this part of the calculations can be obtained from previous reports and therefore, these are shown in tabular format below.

Ship's main characteristics	
L(m)	129,4
B(m)	20,9
T(m)	6,3
D(m)	14
CB	0,62
LCB(m) @AP (m)	64,31

Table 21. Ondo main characteristics.

Structural weight	
Length of superstructure (m)	80
Height of superstructure (m)	13,5
Length of deckhouse (m)	80
Height of deckhouse (m)	2,7

Table 22.Structural weight.

Based on the main dimensions, the superstructure dimensions and the deckhouse dimensions, the equipment number is given as follows:

$$E = 129.4(20.9 + 6.3) + 0.85 \times 129.4(14 - 6.3) + 0.85(80 \times 13.5) + 0.75(80 \times 2.7) = 5446.6$$

For the value of K, a value of 0.043 was considered. This because, Ondo is a dual class vessel (both research and passenger vessel) and for that reason we are considering a value of K that lays in both ranges. Them the steel weight of Ondo can be obtained:

$$W_s = 0.043 \times 5446.6^{1.36}[1 + 0.5(0.62 - 0.7)] = 4975.9ton$$

- *Machinery weight*

Then, the machinery weight is considered. This component of the total lightship weight is divided into main machinery weight and remainder weight. Following Watson and Gilfillan approach, the main machinery weight is estimated based on the following formula:

$$W_{ME} = \sum_i 12(MCR_i / N_{ei})^{0.84}$$

Where i is the index of multiple engines each of a maximum continuous rate MCR_i and rpm N_{ei}.

The data for the machinery of our design is shown in tabular format below. These values were derived from the selection of machinery done during last assignment.

Machinery weight	
MCR (KW)	3360
N (rpm)	720
type of plant	other
No of engines	4

Table 23.Machinery weight.

Therefore, the main machinery weight can be obtained:

$$W_{ME} = 4 \times [12(3360/720)^{0.84}] = 175.1ton$$

The remainder weight varies with the total plant maximum continuous rate:

$$W_{rem} = c_m (MCR)^{0.7}$$

A value of coefficient c_m =0.83 is here used as an approximation to passenger ships. The remainder weight can then be obtained easily:

$$W_{rem} = 0.83(4 \times 3360)^{0.7} = 644.1ton$$

As referred before, the machinery weight is the sum of both these components:

$$W_M = W_{ME} + W_{rem} = 175.1 + 644.1 = 819.2ton$$

- *Outfitting weight*

The outfitting weight is estimated using the following formula:

Ondo

$$W_o = C_o LB$$

where C_o is the outfitting weight coefficient and is a function of the ship type and length and its values can be obtained via the following graph (approximation to passenger ship with L/B=129.4/20.9=6.2):

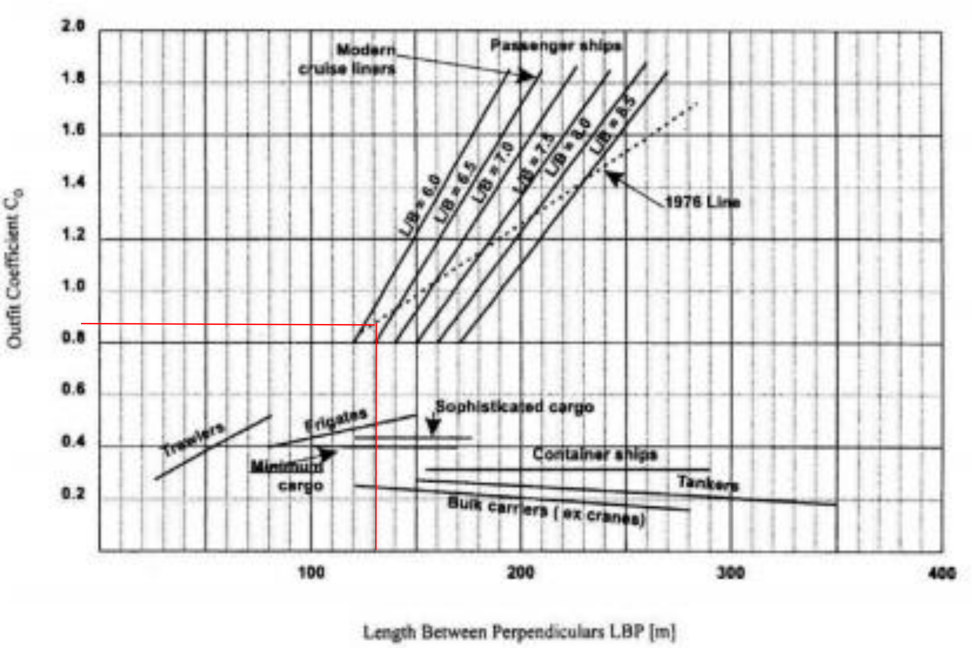


Figure 29.Outfit coefficient Co according to ship type and length.

By analysing the statistics graph above, a value for C_o of approximately 0.82 is obtained. Let us then determine the outfitting weight:

$$W_o = 0.82 \times 129.4 \times 20.9 = 2217.7 ton$$

Finally, the lightship weight of Ondo is the sum of all these components calculated previously:

$$W_{lightship.weight} = W_S + W_M + W_o = 4975.9 + 819.2 + 2217.7 = 8012.8 ton$$

9.2.2 Deadweight and displacement

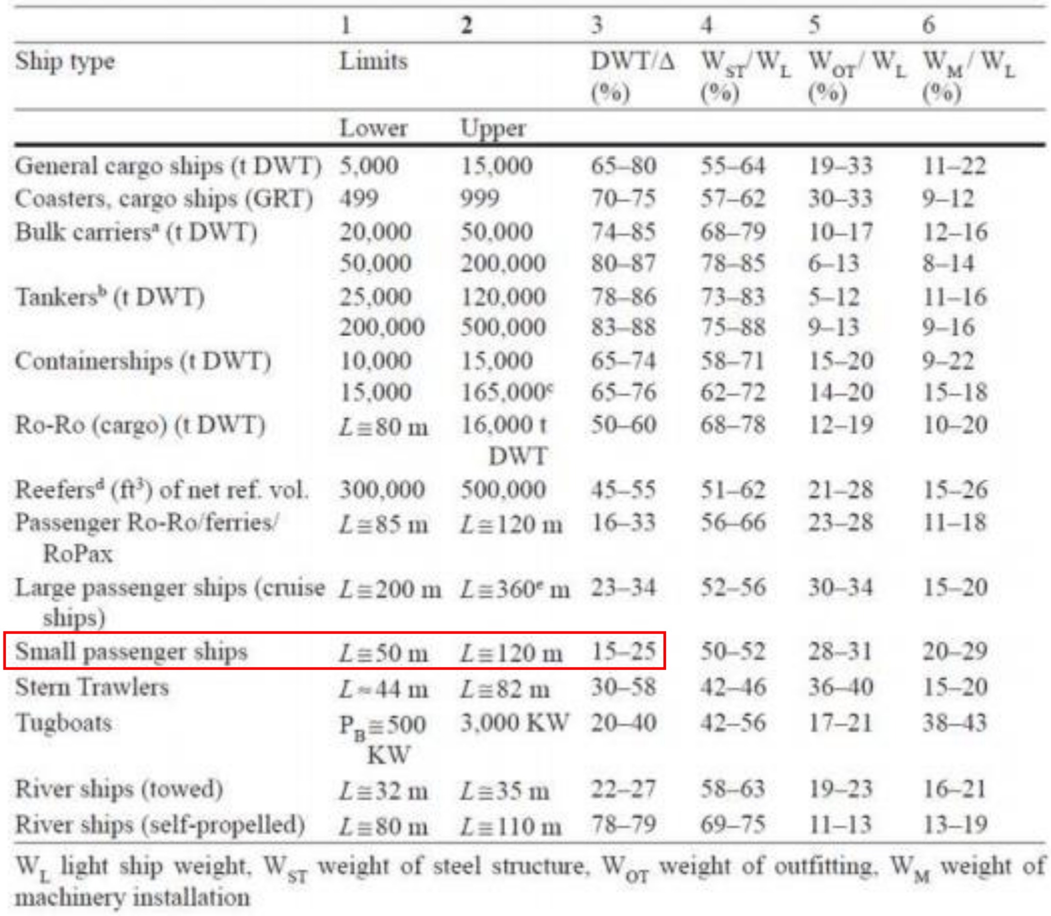
According to SOLAS, “Deadweight is the difference in tonnes between the displacement of a ship in water of a specific gravity of 1.025 at the load waterline corresponding to the assigned summer freeboard and the lightweight of the ship.” In an easier way, it just refers to the difference between an actual displacement and lightship weight.

From the previous section, we got an estimation of the lightship weight of Ondo. A value of $W_{lightship.weight} = 8012.8 ton$ was obtained.

From the definition of deadweight, we have:

$$DWT = \Delta - W_{lightship.weight}$$

We are able to get reference values for the ratio of DWT / Δ for different types of ships (e.g. bulk carriers, passenger vessels, container ships, etc…). Let us use this information, as a starting point:



	1	2	3	4	5	6
Ship type	Limits		DWT/Δ (%)	W_{ST}/W_L (%)	W_{OT}/W_L (%)	W_M/W_L (%)
	Lower	Upper				
General cargo ships (t DWT)	5,000	15,000	65–80	55–64	19–33	11–22
Coasters, cargo ships (GRT)	499	999	70–75	57–62	30–33	9–12
Bulk carriers[a] (t DWT)	20,000	50,000	74–85	68–79	10–17	12–16
	50,000	200,000	80–87	78–85	6–13	8–14
Tankers[b] (t DWT)	25,000	120,000	78–86	73–83	5–12	11–16
	200,000	500,000	83–88	75–88	9–13	9–16
Containerships (t DWT)	10,000	15,000	65–74	58–71	15–20	9–22
	15,000	165,000[c]	65–76	62–72	14–20	15–18
Ro-Ro (cargo) (t DWT)	$L \equiv 80$ m	16,000 t DWT	50–60	68–78	12–19	10–20
Reefers[d] (ft³) of net ref. vol.	300,000	500,000	45–55	51–62	21–28	15–26
Passenger Ro-Ro/ferries/ RoPax	$L \equiv 85$ m	$L \equiv 120$ m	16–33	56–66	23–28	11–18
Large passenger ships (cruise ships)	$L \equiv 200$ m	$L \equiv 360^e$ m	23–34	52–56	30–34	15–20
Small passenger ships	$L \equiv 50$ m	$L \equiv 120$ m	15–25	50–52	28–31	20–29
Stern Trawlers	$L \approx 44$ m	$L \equiv 82$ m	30–58	42–46	36–40	15–20
Tugboats	$P_B \equiv 500$ KW	3,000 KW	20–40	42–56	17–21	38–43
River ships (towed)	$L \equiv 32$ m	$L \equiv 35$ m	22–27	58–63	19–23	16–21
River ships (self-propelled)	$L \equiv 80$ m	$L \equiv 110$ m	78–79	69–75	11–13	13–19

W_L light ship weight, W_{ST} weight of steel structure, W_{OT} weight of outfitting, W_M weight of machinery installation

Figure 30. Reference values for deadweight/displacement ratio according to ship type.

In the table shown above, there is no reference to research vessels. However, Ondo is a dual-class vessel that tries to meet necessities of both passenger and research vessels. Therefore, for purposes of estimating these missing important figures (deadweight and displacement), let us consider the upper extreme value of the small passenger ships, added by a few percentages, trying to account for some heavier research material that is taken during journeys. These are for example, ROV's, heavy laboratory equipment, and cargo for offshore supply. Therefore, we will consider a ratio of DWT / Δ = 28%.

We are now in condition to determine a preliminary value for the deadweight of Ondo, using the relations referred before:

$$DWT / \Delta = 28\% \Leftrightarrow DWT = 0.28\Delta$$
$$\Delta - DWT = W_{lightship.weight} = 8012.8ton$$

- *Displacement:*

$$\Delta - 0.28\Delta = 8012.8ton \Leftrightarrow 0.72\Delta = 8012.8 \Rightarrow \Delta = 11128.9ton$$

- *Deadweight:*

$$DWT = 0.28\Delta = 0.28 \times 11128.9 = 3116.1ton$$

9.2.3 Uncertainty in calculations and weight reserve

The calculations made to determine the lightship weight of Ondo are only a rough estimation as they do not consider particular features that are onboard our design. Examples of these features are the moonpool, number and type of cranes, etc. Related to this situation, there might be critical situations that are a consequence of these weight calculation errors. In fact, we are dealing with a design which presents a small deadweight and displacement ratio (DWT / Δ) which then makes this even more concerning.

The risk of these calculation errors can be minimized by several forms:

- Order of magnitude assessments.
- Use of statistics, comparisons.
- Performing separate calculations using different methods.
- By adding weight reserves.
    - The lightweight and the height of the centre of gravity often increase during the building process.
    - Need to allow for possible design modifications as requested by the owner.
    - The lightweight reserve can vary depending on the ship type, the shipyard experience, and ship owner.
- By adding “scantling reserves”.

In this report, two of these points will be analysed in order to assess the uncertainty in the calculations and also to limit eventual impact of errors in the calculations made. Therefore, comparison and use of statistics will be carried out using a reference ship as well as adding weight reserves to Ondo.

- *Comparing displacement results with previous calculations/assessments and reference ship*

From the calculations made here to assess the displacement of Ondo, we obtained a value of approximately 11 129 tonnes. This value is extremely close to the one we calculated during the assignment regarding the hull form. Here, a value of 11 197 tonnes was determined by shaping the hull of our design. Therefore, this is one important verification that gives us some positiveness towards these calculations.

Furthermore, let us compare the results obtained here in terms of deadweight, lightship weight and displacement in comparison to the reference ship used throughout these weeks: S. A. Agulhas II.

By searching for the weight characteristics of our reference ship, we were able to come up with some reference values for the terms referred above. S. A. Agulhas II has a total displacement of 13 687 tonnes and a deadweight of 4 780 tonnes. This consequently gives a lightship weight of 8907 tonnes. We can see here some slight differences, but these can be explained due to heavier equipment onboard the reference ship, which is completely focused on research, rather than being a mix of passenger and research vessel like in Ondo. In fact, in the reference ship, the ratio given by DWT / Δ is about 35% contrasting with the value of 28% in Ondo. Furthermore, looking back at the use of Normand's Number to come up with our main dimensions, we aimed at a reduction of draft taking as starting point S. A. Agulhas and a significant reduction in the total displacement.

To sum up, we are quite confident with the results we got in this section.

- *Weight reserves*

Weight reserves are expressed as a percentage of the ship's total lightship weight. This is made in order to, at the delivery time of the ship, the reserve weight is 0%. This reserve amount of weight is determined considering the deadweight/displacement – ratio (DWT / Δ). As used several times before, the deadweight/displacement – ratio of Ondo is 28%. Therefore, let us use as reference the weight reserve to a prototype ship with a DWT / Δ ratio of 0.2 – 0.3 (lecture slides L09). These weight reserves for the different stages of Ondo design/production are then shown below:

- Preliminary weight calculations: 15% weight reserve. We are actually at this point right now. Therefore, a weight reserve (W_{res}) of $W_{res} = 0.15W_{lightship.weight} = 0.15 \times 8012.8 = 1201.9ton$ shall be used. This means that at the current stage of preliminary weight calculations, the value of lightship weight to be considered is $W^{'}_{lightship.weight} = W_{lightship.weight} + W_{res} = 8012.8 + 1201.9 = 9214.7ton$.
- Fixing of lines drawings: 10% weight reserve.

  $W^{'}_{lightship.weight} = W_{lightship.weight}(1+0.1) = 8012.8 \times 1.1 = 8814.1ton$.
- 6 months prior to ship delivery: 3% weight reserve.

  $W^{'}_{lightship.weight} = W_{lightship.weight}(1+0.03) = 8012.8 \times 1.03 = 8253.2ton$.

9.3 Ship vertical centre of gravity

Ondo's vertical centre of gravity (only considering the lightship weight) can be estimated using the procedure presented in this section. Here the vertical centre of gravity of three independent components, similar to what was done when estimating the three components that contribute to the lightship weight.

- *Vertical centre of gravity of the basic hull*

The vertical centre of gravity of the basic hull can be estimated using an equation proposed by Kupras:

$$VCG_{hull} = 0.01D[46.6 + 0.135(0.81 - C_B)(L/D)^2] \text{ for L > 120m}$$

$$VCG_{hull} = 0.01 \times 14[46.6 + 0.135(0.81 - 0.62)(129.4/14)^2] = 6.83m$$

- *Vertical centre of gravity of machinery*

The vertical centre of gravity of machinery is given as a function of the inner bottom height h_{db} and the height of the over-head of the engine room $D^{'}$ by Kupras:

$$VCG_M = h_{db} + 0.35(D^{'} - h_{db})$$

Both the inner bottom height h_{db} and the height of the over-head of the engine room $D^{'}$ were obtained from the cross-section drawings in section 7.2.

Height of engine room (m)	4,5
Height of double bottom (m)	1

Table 24.Height of engine room and double bottom.

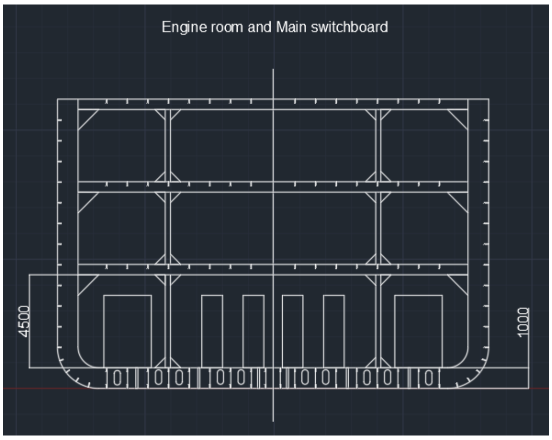


Figure 31.Cross-section: engine room and main switchboard.

$$VCG_M = 1 + 0.35 \times (4.5 - 1) = 2.23m$$

- *Vertical centre of gravity of outfitting*

The outfitting vertical centre of gravity is proposed by Kupras:

$$VCG_o = D + 1.25 + 0.01(L - 125) \text{ for } 125m \leq L \leq 250m$$

$$VCG_o = 14 + 1.25 + 0.01(129.4 - 125) = 15.29m$$

Finally, having the vertical centre of gravity of the three components that make up the lightship weight, we can calculate the vertical centre of gravity of Ondo (only considering lightship weight):

$$VCG_{light} = \frac{W_S \times VCG_S + W_M \times VCG_M + W_o \times VCG_o}{W_{light}}$$

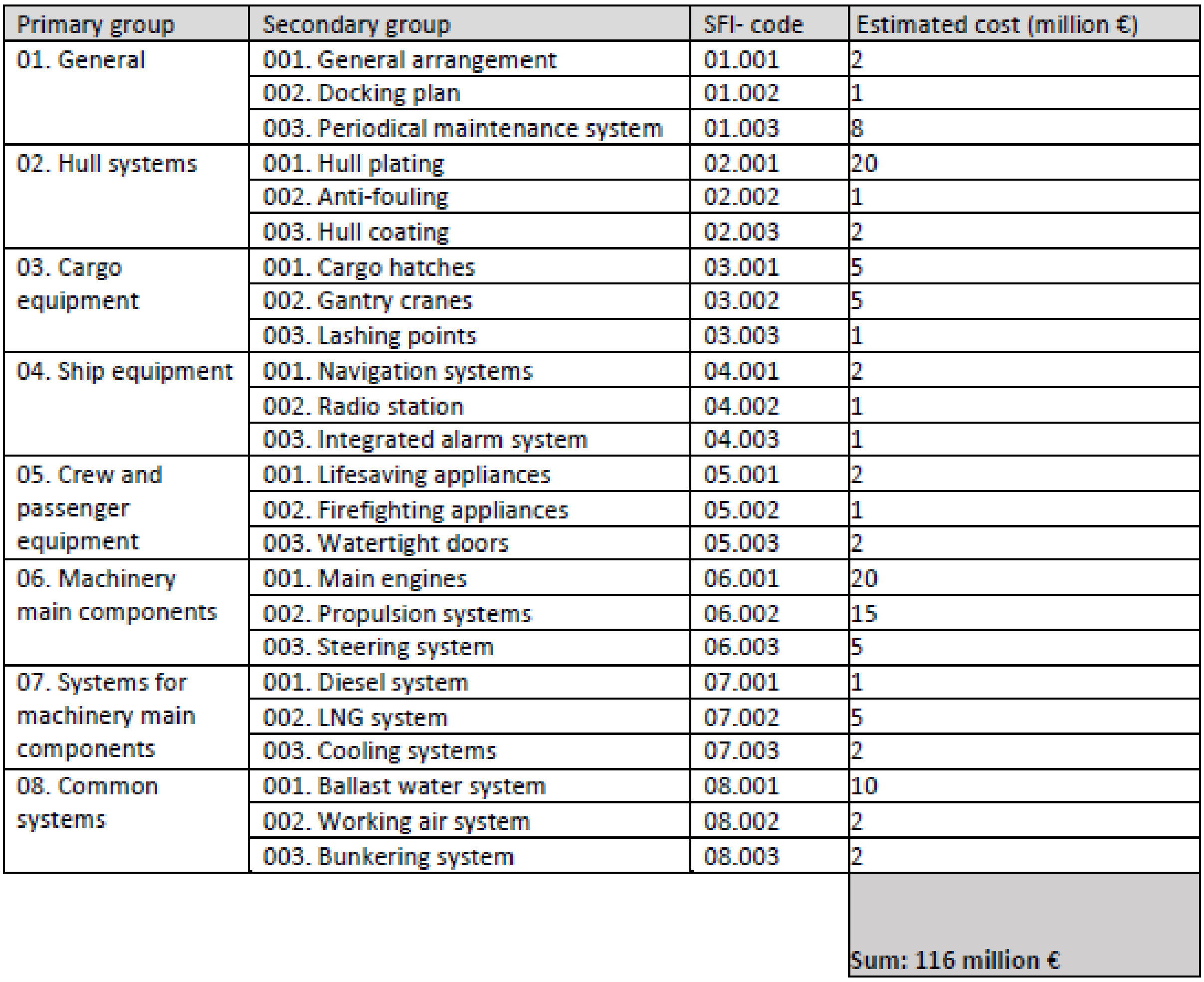
$$VCG_{light} = \frac{4975.9 \times 6.83 + 819.2 \times 2.23 + 2217.7 \times 15.29}{8012.8} = 8.70m$$

10 Economic assessment

10.1 Cost of ship systems and spaces

In this section, an estimation of the building costs is done using as a tool the SFI system defined previously in section 9.1. The estimated cost for each of the secondary group is presented in million euros.

Table 25.Estimation of building costs using the SFI system for Ondo.



Primary group	Secondary group	SFI- code	Estimated cost (million €)
01. General	001. General arrangement	01.001	2
	002. Docking plan	01.002	1
	003. Periodical maintenance system	01.003	8
02. Hull systems	001. Hull plating	02.001	20
	002. Anti-fouling	02.002	1
	003. Hull coating	02.003	2
03. Cargo equipment	001. Cargo hatches	03.001	5
	002. Gantry cranes	03.002	5
	003. Lashing points	03.003	1
04. Ship equipment	001. Navigation systems	04.001	2
	002. Radio station	04.002	1
	003. Integrated alarm system	04.003	1
05. Crew and passenger equipment	001. Lifesaving appliances	05.001	2
	002. Firefighting appliances	05.002	1
	003. Watertight doors	05.003	2
06. Machinery main components	001. Main engines	06.001	20
	002. Propulsion systems	06.002	15
	003. Steering system	06.003	5
07. Systems for machinery main components	001. Diesel system	07.001	1
	002. LNG system	07.002	5
	003. Cooling systems	07.003	2
08. Common systems	001. Ballast water system	08.001	10
	002. Working air system	08.002	2
	003. Bunkering system	08.003	2
			Sum: 116 million €

As a final result, we can see that the total building costs related to Ondo are about 116 million euros.

10.2 Cost comparison

Cost comparison was made against the known cost structure of the research vessel S.A. Agulhas II. Division of costs followed the structure of the SFI- groups. When ship building's main costs are evaluated, the main activities considered are building materials, workforce, energy, and consumables.

The workforce includes, but is not limited to, work preparers, cutting machine operators, crane operators, welders, platers, engineers, and transportation staff.

Main energy source in naval shipyards is electricity. Electricity feeds all large consumers in shipyards, such as cranes, mooring winches, and sea water pumps.

Consumables in the shipyard are restricted to acetylene and oxygen gases, welding gases, welding wires and electrodes, cutting and grinding equipment, sand- and grid blasting bulk, and finally paint and painting equipment.

After Leal and Gordo (2017) hull production costs are divided to:

- Contract signing
- Basic project
- Detail production project
- Ship hull construction
- Outfitting (piping, electricity, machinery, and systems)
- Sea trials and certification
- Ship owner delivery

Consequently, within the construction phase of the hull the following steps are acknowledged:

- Parts, plates, and stiffeners cut
- Plate union (bulkheads, floors, and shell)
- Assembly and welding of frames and stiffeners to form panels and subsets
- Union of subsets to form ship blocks
- Union of blocks to form the whole ship

After Leal and Gordo (2017), “a cost structure can be considered as the set of expenses that a given company has to consider in the manufacture of a product or in providing services. Each expense is associated with a cost centre that in turn is associated with a type of activity.” Along the lines of Leal and Gordo, we can connect SFI to the concept of the cost centre.

It is common knowledge in ship building, that cost of manpower is half of the construction cost of the vessel’s hull. Generally, it can be said, that the more complexed vessel, the higher are manpower costs in relation to the overall costs. In cruise vessels hull building costs are generated 60% of the manpower costs. It is then noteworthy, that the manpower costs are distributed evenly to the SFI codes that are associated with steel work. This is mostly in the SFI 02.001 Hull plating.

Focusing merely on the technical details of shipbuilding results in a biased understanding of overall costs for shipbuilding. There are significant costs implications related to the selected design solution, for example. It is the basic skill of a marine engineer and naval architect to keep an eye on the economic implications throughout the scope of the design of the ship. In evaluation of the overall costs, technical details are only a partial answer. As such, economic implications are largely in the shoulders of the experience of the individuals, as well based on known best practices (Lean and Gordo, 2017).

10.3 Ondo KPI (s)

A Key Performance Indicator measures the performance on critical aspects where cost, time and quality are three primary indicators. Key Performance Indicators (KPIs) should be considered with respect to the operation profile of the project or organization and should help to understand the state of their desired performances. In shipping, there are many KPIs used to determine their performance index. Payback Period, Net Present Costs (NPC), Internal Rate of Return (IRR), Net Present Value (NPV), Required Freight Rate (RFR), Life Cycle Costs (LCC) and Average Annual Costs (AAC) are some KPIs utilized in shipping industry.

- *Average Annual Costs (AAC)*

In our case due to the nature of our operation, and its mission and objectives, the Average Annual Costs (AAC) will be evaluated as KPI. This is because this KPI is usually related to ships that do not generate income such as research, naval and coast guard vessels and yachts. (Benford, 1963).

The values for AAC are related to the running of a specific service at a minimum average annual cost. (Benford, 1963). In other words, AAC can be found by converting the initial investment (P) to an equivalent uniform annual amount, which would be added to the annual operating costs (Y) and is given by:

$$ACC = P \times (CRF) + Y$$

Where the term (CRF) is the Capital Recovery Factor and is dependent on the annual interest rate and is selected based on the number of operating years. The dependence of this factor for different amount of operating years as a function of the annual interest rate can be found in the figure below.

Ondo

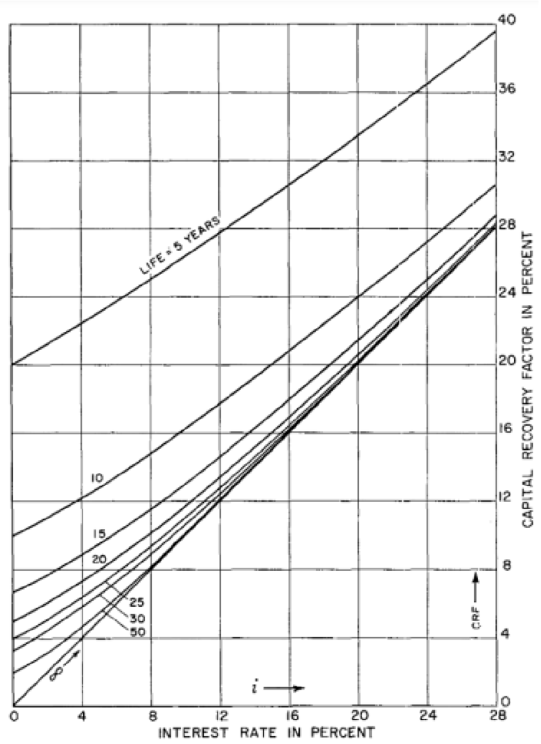


Figure 32. CRF factor as a function of interest rate.

In the case of Ondo, the vessel price was set as €140 million (P = €140 million in the previous equation) assuming that there is a profit margin of around 20% in addition to the building costs estimated previously. It is set that Ondo research vessel will be operating for twenty years, with an annual interest rate of 8%. Therefore, the value for the Capital Recovery Factor can be estimated from the graph presented previously. Let us then take CRF = 10%.

To continue the calculations of the KPI being considered, there is still missing the parameter Y which refers to the annual operating costs. For this purpose, we will do a rough estimate for this parameter.

Ondo has a crew of 45 people and we will consider that the vessel is under service yearly for about 100 full days just to simplify the estimation. The University of Connecticut gives some rates for the operation costs of small research vessels. Here, a rate of approximately €180 (2x €90/hour) for basic operating costs is taken as Ondo cannot be defined as a small research vessel and this value does not account crew charges. For crew charges, €42/hr for each crew staff will be considered. Assuming more that at each moment only half of the crew is effectively on working duties, we can then roughly estimate the yearly running costs from:

$$Y = 2 \times 90 \times 24 \times 100 + 42 \times 22.5 \times 24 \times 100 = €2.7 million$$

Finally, the value for the AAC of Ondo can be defined:

$$AAC = 140 \times 0.1 + 2.7 = €16.7 million$$

The importance of defining the Average Annual Costs (AAC) for Ondo as an important KPI is because it can be used in doing comparisons between similar vessel designs in order to find the lowest value of AAC. In fact, the most profitable and desirable ship will be the one that can produce the required service at the lowest average annual cost.

- *Net Present Value (NPV)*

However, as assessed in previous reports of this design process, besides the research occupancy of Ondo, it also includes luxury accommodation for about 100 passengers. Therefore, let us have a look as well at the Net Present Value (NPV) as an indicator of cash-flows throughout the service time of Ondo. The NPV can be calculated using the following mathematical equation:

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

Where -C_0 is the initial investment (ship price), C_i is the cash-flow (revenues – costs) during year, i is the interest rate and n is the number of years in service.

Using the results previously assessed in this section, we can then calculate the NPV value for the 20 years in service of Ondo. By checking reference daily prices for passengers travelling in high class ships to Antarctic regions, we came up with a value of €1,500 per person per day for entry level accommodations. This will be used in the calculations, and the results are shown below:

Initial investment	140 000 000	EUR
Carrying capacity	10 000	passengers/year
Freight rate	1 500,00	EUR/passenger
Annual revenues	15 000 000	EUR
Annual costs	2 700 000	EUR
Annual cash flow	12 300 000	
Interest rate	8,0 %	

Year	**NPV, annual cash flow**	**NPV**
0	-140 000 000 €	-140 000 000 €
1	11 388 889 €	-128 611 111 €
2	10 545 267 €	-118 065 844 €
6	7 751 086 €	-110 314 757 €
7	7 176 932 €	-103 137 825 €
8	6 645 307 €	-96 492 518 €
9	6 153 062 €	-90 339 456 €
10	5 697 280 €	-84 642 176 €
11	5 275 259 €	-79 366 917 €
12	4 884 499 €	-74 482 417 €
13	4 522 684 €	-69 959 733 €
14	4 187 671 €	-65 772 062 €
15	3 877 473 €	-61 894 589 €
16	3 590 253 €	-58 304 336 €
17	3 324 308 €	-54 980 028 €
18	3 078 063 €	-51 901 965 €
19	2 850 058 €	-49 051 907 €
20	2 638 943 €	-46 412 964 €

Figure 33. Net Present Value calculation over the operation years

From the results obtained, we can see that the final Net Present Value is -46 412 964 EUR. This means that our final NPV for Ondo is negative. However, the aim of passenger transportation, as referred before, is not the main mission of the designed vessel, but only a means of reducing costs of the voyages. In fact, when thinking about this factor, it can be seen that in the 20 years of operation, there is an increase of around 95 million euros in the NPV, meaning that a big part of the initial investment is paid with the contribution of passenger voyages.

10.3.1 Possible improvements to Ondo KPI (s)

After defining different KPI's for the Ondo vessel, we can then think about ways to improve these figures. When talking about the Average Annual Costs (AAC), we are looking at reducing them the maximum possible, in order to our vessel to be competitive against other similar ones. On the other hand, for an investment to be worth it, the Net Present Value (NPV) should become positive along the service time of the vessel. In fact, in the special case of Ondo, this has not been obtained yet.

- *Improvement of Average Annual Costs (AAC)*

As shown before in section 2, the mathematical formula used to calculate the AAC is:

$$AAC = P \times (CRI) + Y$$

This means that the initial investment (P), the Capital Recovery Factor (CRI) and the annual costs (Y) are the three contributors to this KPI. As the aim is to reduce the AAC, reducing even only one of the figures (P, CRI and Y) will contribute in lowering the AAC.

Therefore, the initial investment can be changed by negotiating the price, for instance, with the shipyard in terms of profit margin they are looking at. Also reducing building costs would have an influence in this figure. In addition, the Capital Recovery Factor is dependent both on the service time of the ship being considered and the annual interest rate. From Figure 32, we can see these dependences. By increasing the number of years in service and/or decreasing the interest rate, we manage to lower this multiplicative factor of the initial investment in the vessel. Finally, reducing the annual costs of operation of Ondo is possible by better fuel usage, route efficiency and better managing of voyages looking at the lowest cost possible.

- *Improvement of Net Present Value (NPV)*

As shown before in section 2, the mathematical formula used to calculate the NPV is:

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

This shows that the Net Present Value (NPV) is dependent on the initial cost of the ship, the cash-flow during the years of operation and the interest rate. The aim of this KPI is to show if an investment is worth it or no, giving reasoning for investing if the NPV for a particular project is positive. Therefore, we are looking at maximizing the value of NPV.

From the formula, we can conclude that this can be done by lowering the initial investment in the vessel, its purchase price (C_0) and the interest rate, or by increasing the positive cash-flows each year. How these figures can be changed have been discussed when discussing the improvement of the Average Annual Costs (AAC). Cash-flow during each year, is given by the difference between annual revenues and costs. Therefore, these can be manipulated by adjusting the freight rate for passenger transportation and reducing annual costs.

In the calculation of the NPV for Ondo in this section, we only took into consideration passenger transportation, but a more precise calculation of this Key Performance Indicator (KPI) could be done, and certainly more satisfying results would be obtained, if considering the freight rate of cargo transportation (which Ondo is also capable of up to some limitations).

10.4 SWOT analysis

SWOT-analysis is an abbreviation from words Strengths, Weaknesses, Opportunities and Threats. Normally a SWOT -analysis table is divided into 4 sections. This is used to identify, and target possibilities and possible threats directed to the item or process. To SWOT table, one lists internal strengths & weaknesses and external opportunities & threats as shown in Figure 34.

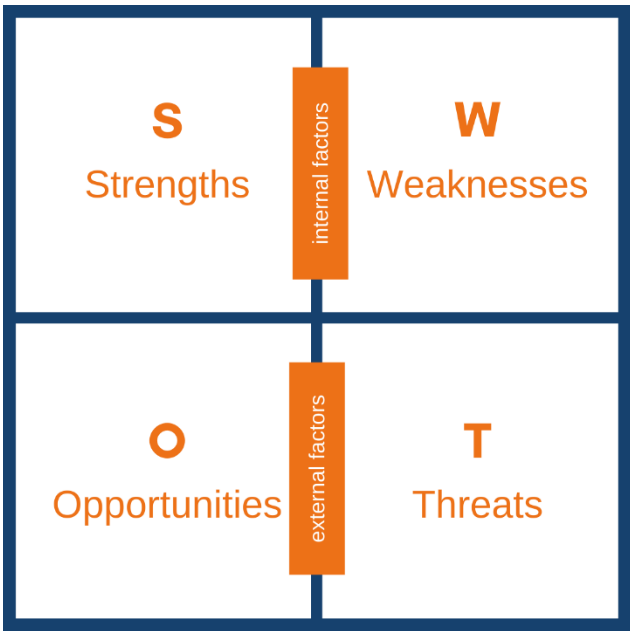


Figure 34. SWOT analysis table

Ondo

Ondo SWOT -analysis is presented in Table 26 below. Since Ondo missions are icebreaking, research, in some scale also cargo carriage and passenger travelling, there are possible threats and possibilities present. This kind of dual-class, multipurpose vessel is one of a kind, which also creates possible scenarios.

SWOT table does not only list good and bad things, but also internal and external factors. Internal factors are matters that are possible to affect by the owner or builder, e.g. size of the vessel or accommodation decisions. By external factors are meant the matters that are somewhat not in hand of the owner, e.g. customer behaviour or the World's economic situation. These external factors are more unpredictable which could also make them risks. Risks are crucial to identify as early in the process as possible and as thoroughly as possible. Should also be remembered that, not all risks mean that project is not worth doing it or it could not be a success. By identifying as much negative factors such, as threats, it is more likely to make the project a success.

Voyages are relatively long and performed sometimes even in the hardest weather conditions and in harsh sea areas, which increases vessel's operating- and hotel costs, as well as building costs and requirements for structures. On the other hand, vessel's multipurpose aspect creates more possible sources of income. While profiting from passenger income and possible research income. There is also a possibility to make profit by carrying and handling cargo. Ondo's cargo carrying capacity is not anywhere near a cargo vessel, but it still makes a possibility for income.

Beforementioned operation area makes this kind of travelling a unique experience for its passengers, which is most likely the reason they purchased tickets to such trip. Also, passengers are most likely to make this kind of travel only once or twice in their lifetime which makes them more willing to invest for this unique kind of experience.

KPIs determined in section 10.3 make great impact on SWOT -analysis. By those figures it is easier to predict and identify the factors that need more attention while making decisions regarding the vessel design and construction, while changes in the construction are easier and cheaper to implement. As mentioned earlier, KPIs could be improved by improving one or more factors affecting to KPIs. More factors improved, more impact it makes also to AAC.

Ondo

Table 26 Ondo SWOT analysis

Strengths (internal) - Vessel has more than one source of income (passenger- and cargo handling. Also, in some scale research activities). - Unique type of experience for a passenger, business opportunity. - Emissions taken considered (IMO 2050 goals).	**Weaknesses (internal)** - AAC not in the wanted level. - More passenger income needed. - More construction/ operating costs should be degreased. - KPI calculations does not consider income from other than passenger sources. - NPV negative.
Opportunities (external) - Multipurpose and dual-class business possibilities on market. - Research factor may interest other scientific societies. - People’s raised awareness of climate matters -> grown interest toward arctic areas.	**Threats (external)** - There is not enough interest (=paying customers) towards this kind of concept. - Climate change may change mission area conditions so that the vessel is not fit to it anymore. - Not enough income to make Ondo missions and operations profitable. - Maintenance costs increase too high due the dual-class requirements.

11 Marine Technology Gala – Feedback (04.12.2020)

The work developed during ten weeks of the Principles of Naval Architecture (PNA) course was presented to industry representatives and to staff of Aalto University on Friday, 4th December 2020.

After our presentation, our mentor Pentti Kujala congratulated us for the final result of the project and recognized our effort in delivering the final presentation. He also emphasized our dedication to the project, which was shown during the agreed meetings. Some details regarding the particulars of an ice-going ship were assessed and discussed but no great concerns rose, as this will be later on improved after taking the winter navigation course starting in January, just as an example of a course that will give us more understanding of these specific issues in ship design. These courses will then give us some inputs that will be extremely useful for a later iteration to this ship design.

In addition, Tuomas Romu also gave us some additional feedback in relation to the location and space around the azipods, taking into consideration the hull form we designed. From his perspective, there is not enough space to include two azipods in our design in order to take advantage of its effectiveness. In fact, a very long skeg is considered and therefore, the flow of water around the propulsion system does not allow to take the most out of it. For this reason, this situation will be further looked at in the future when more information is available and a more detailed loop in the designed spiral will be made.

After our presentation in the Marine Technology Gala, a representative of SYKE Merikeskus contacted us directly wishing to know more about the laboratory features we have thought about including onboard Ondo. No real specifications in terms of the laboratory facilities have been set during this round on the design spiral. The only requirement that has been set right from the beginning was the need to have an area occupied by offices and laboratory facilities of around 400 m^2. This was taken into consideration when defining the general arrangement (GA) for Ondo. In fact, there are a couple of decks that are fully dedicated to research purposes which are meant to meet this objective that was set. However, it would be interesting to contact with SYKE Merikeskus in a future iteration in order to be able to define and develop more this question of the research facilities.

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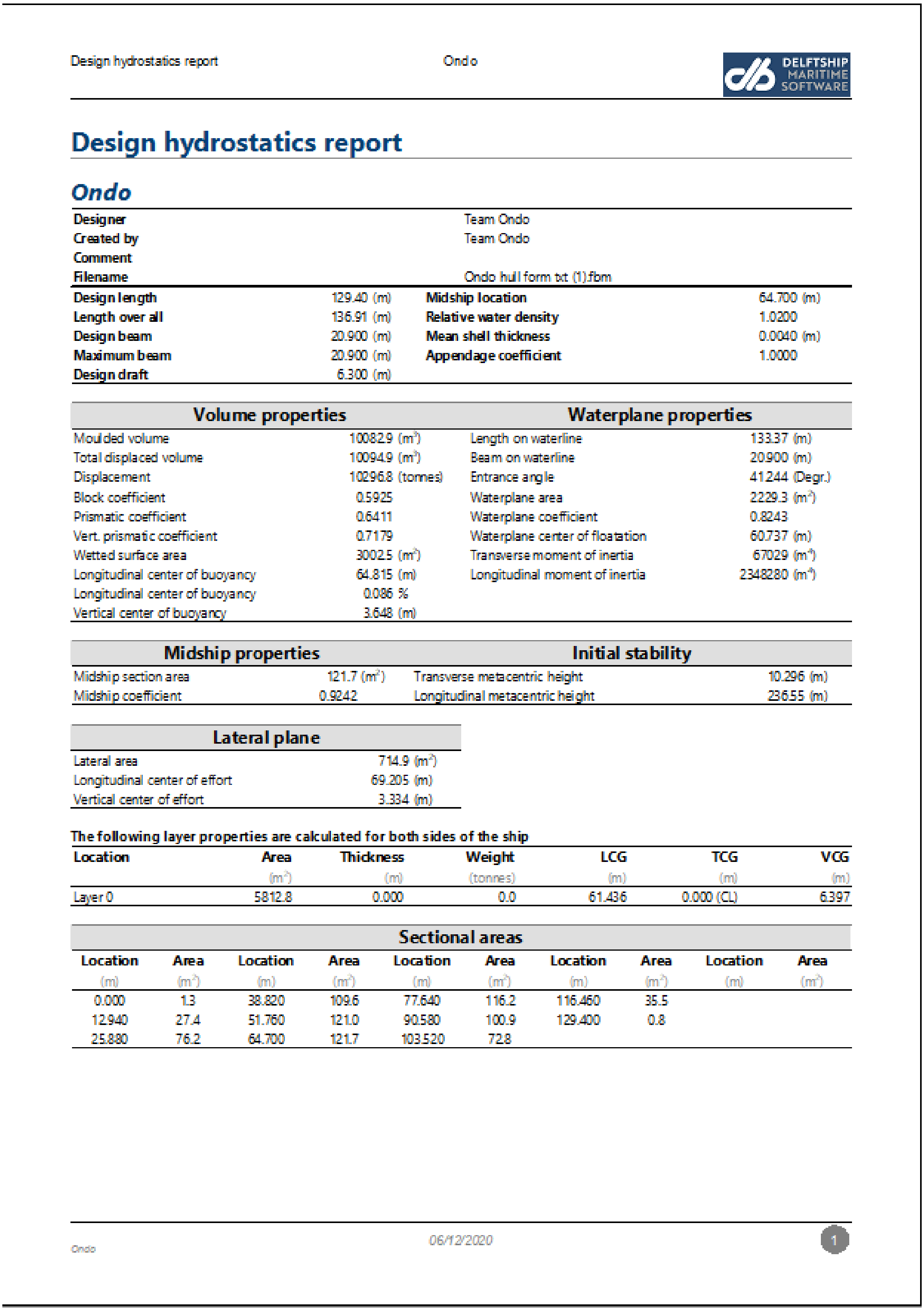
Attachments

Attachment 1 Design hydrostatics report from Delftship



Design hydrostatics report Ondo

Design hydrostatics report

Ondo

Designer	Team Ondo
Created by	Team Ondo
Comment	
Filename	Ondo hull form txt (1).fbm

Design length	129.40 (m)	**Midship location**	64.700 (m)
Length over all	136.91 (m)	**Relative water density**	1.0200
Design beam	20.900 (m)	**Mean shell thickness**	0.0040 (m)
Maximum beam	20.900 (m)	**Appendage coefficient**	1.0000
Design draft	6.300 (m)		

Volume properties		Waterplane properties	
Moulded volume	10082.9 (m^3)	Length on waterline	133.37 (m)
Total displaced volume	10094.9 (m^3)	Beam on waterline	20.900 (m)
Displacement	10296.8 (tonnes)	Entrance angle	41.244 (Degr.)
Block coefficient	0.5925	Waterplane area	2229.3 (m^2)
Prismatic coefficient	0.6411	Waterplane coefficient	0.8243
Vert. prismatic coefficient	0.7179	Waterplane center of floatation	60.737 (m)
Wetted surface area	3002.5 (m^2)	Transverse moment of inertia	67029 (m^4)
Longitudinal center of buoyancy	64.815 (m)	Longitudinal moment of inertia	2348280 (m^4)
Longitudinal center of buoyancy	0.086 %		
Vertical center of buoyancy	3.648 (m)		

Midship properties		Initial stability	
Midship section area	121.7 (m^2)	Transverse metacentric height	10.296 (m)
Midship coefficient	0.9242	Longitudinal metacentric height	236.55 (m)

Lateral plane	
Lateral area	714.9 (m^2)
Longitudinal center of effort	69.205 (m)
Vertical center of effort	3.334 (m)

The following layer properties are calculated for both sides of the ship

Location	Area (m^2)	Thickness (m)	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)
Layer 0	5812.8	0.000	0.0	61.436	0.000 (CL)	6.397

Sectional areas

Location (m)	Area (m^2)	Location (m)	Area (m^2)	Location (m)	Area (m^2)	Location (m)	Area (m^2)	Location (m)	Area (m^2)
0.000	1.3	38.820	109.6	77.640	116.2	116.460	35.5		
12.940	27.4	51.760	121.0	90.580	100.9	129.400	0.8		
25.880	76.2	64.700	121.7	103.520	72.8				

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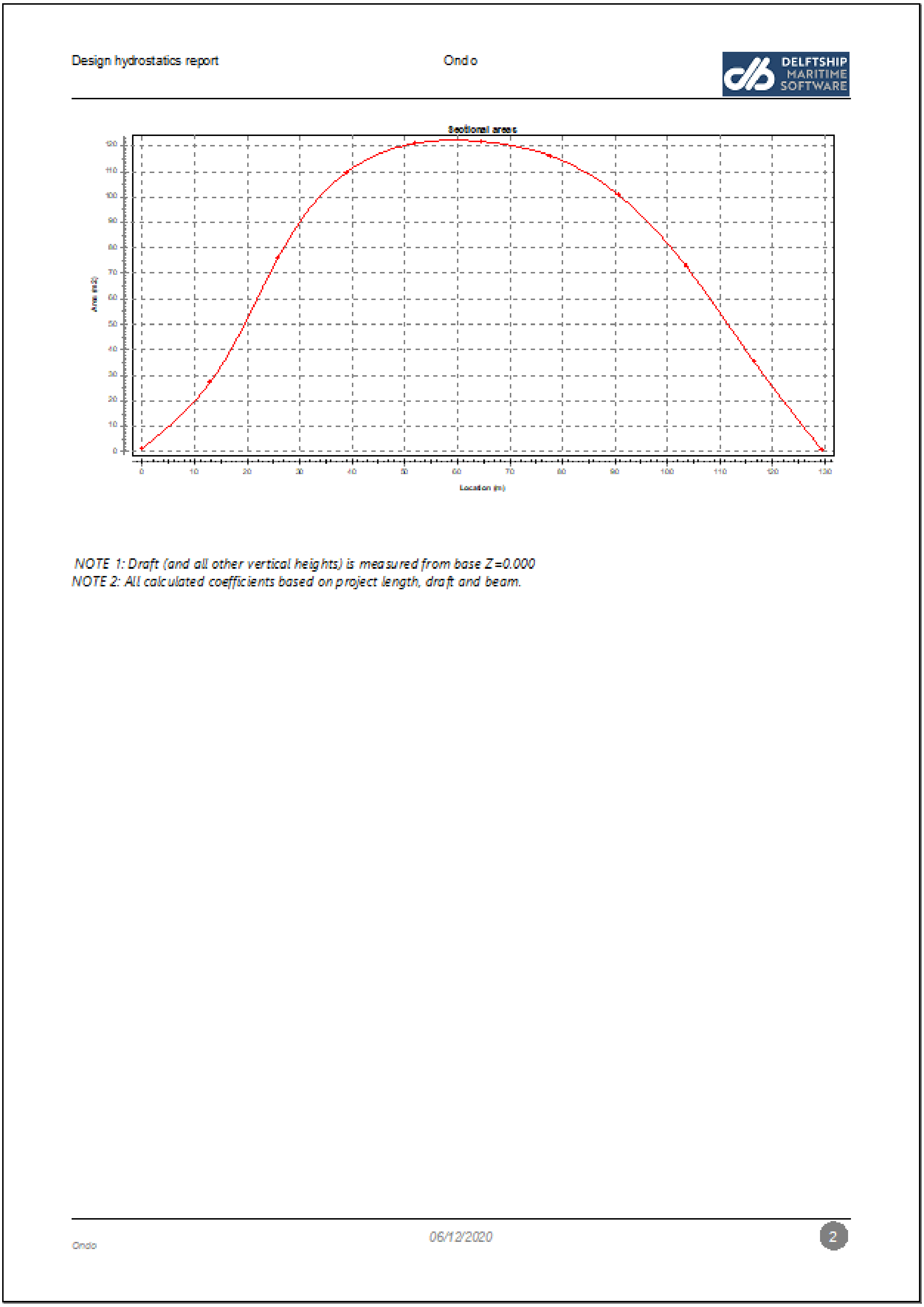

Design hydrostatics report Ondo

NOTE 1: Draft (and all other vertical heights) is measured from base Z=0.000
NOTE 2: All calculated coefficients based on project length, draft and beam.

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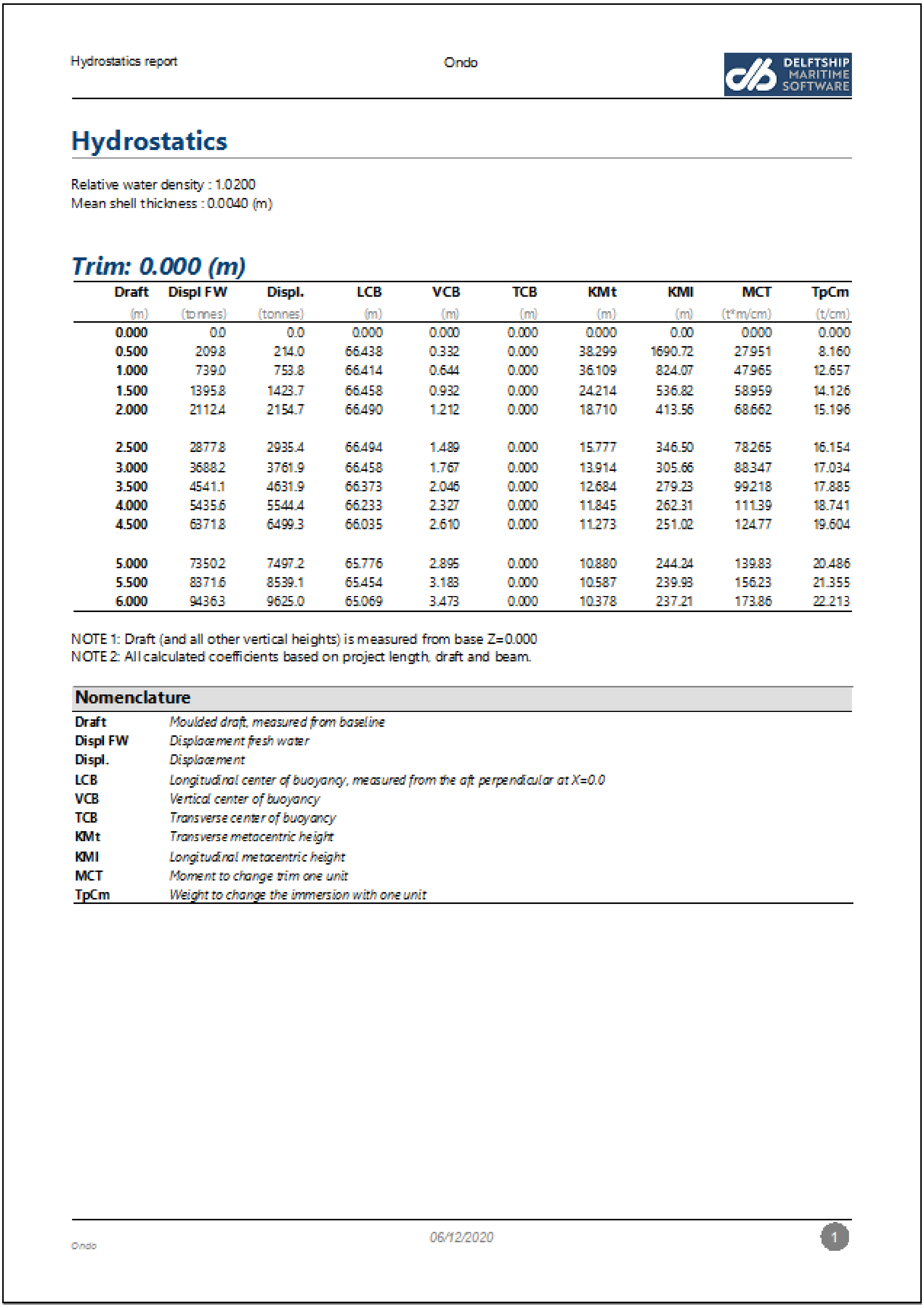
Attachment 2 Hydrostatics report from Delftship with various drafts



Hydrostatics report Ondo DELFTSHIP MARITIME SOFTWARE

Hydrostatics

Relative water density : 1.0200
Mean shell thickness : 0.0040 (m)

Trim: 0.000 (m)

Draft (m)	Displ FW (tonnes)	Displ. (tonnes)	LCB (m)	VCB (m)	TCB (m)	KMt (m)	KMl (m)	MCT (t*m/cm)	TpCm (t/cm)
0.000	0.0	0.0	0.000	0.000	0.000	0.000	0.00	0.000	0.000
0.500	209.8	214.0	66.438	0.332	0.000	38.299	1690.72	27.951	8.160
1.000	739.0	753.8	66.414	0.644	0.000	36.109	824.07	47.965	12.657
1.500	1395.8	1423.7	66.458	0.932	0.000	24.214	536.82	58.959	14.126
2.000	2112.4	2154.7	66.490	1.212	0.000	18.710	413.56	68.662	15.196
2.500	2877.8	2935.4	66.494	1.489	0.000	15.777	346.50	78.265	16.154
3.000	3688.2	3761.9	66.458	1.767	0.000	13.914	305.66	88.347	17.034
3.500	4541.1	4631.9	66.373	2.046	0.000	12.684	279.23	99.218	17.885
4.000	5435.6	5544.4	66.233	2.327	0.000	11.845	262.31	111.39	18.741
4.500	6371.8	6499.3	66.035	2.610	0.000	11.273	251.02	124.77	19.604
5.000	7350.2	7497.2	65.776	2.895	0.000	10.880	244.24	139.83	20.486
5.500	8371.6	8539.1	65.454	3.183	0.000	10.587	239.93	156.23	21.355
6.000	9436.3	9625.0	65.069	3.473	0.000	10.378	237.21	173.86	22.213

NOTE 1: Draft (and all other vertical heights) is measured from base Z=0.000
NOTE 2: All calculated coefficients based on project length, draft and beam.

Nomenclature

Draft	*Moulded draft, measured from baseline*
Displ FW	*Displacement fresh water*
Displ.	*Displacement*
LCB	*Longitudinal center of buoyancy, measured from the aft perpendicular at X=0.0*
VCB	*Vertical center of buoyancy*
TCB	*Transverse center of buoyancy*
KMt	*Transverse metacentric height*
KMl	*Longitudinal metacentric height*
MCT	*Moment to change trim one unit*
TpCm	*Weight to change the immersion with one unit*

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