Anders Torheim

Design of a gas carrier for transportation of NH_3 and CO_2

Bachelor's thesis in Ship Design
Supervisor: Håvard Vollset Lien
December 2021

Bachelor's thesis

NTNU
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Kunnskap for en bedre verden

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Preface

The following report is my bachelor's thesis for the bachelor's degree programme in ship design at the Department of Ocean Operations and Civil Engineering at the Norwegian University of Science and Technology (NTNU).

I would like to thank Horisont Energi, with a special notice to my contacts Ida Furru and Ola Ravndal, for providing me with this thesis. Their helpful guidance and supplement of information is appreciated.

A special thanks goes to Håvard Vollset Lien, my advisor at NTNU, for providing me with knowledge, and for excellent mentorship and guidance throughout the design process.

Abstract

This Bachelor’s Thesis is to design a carbon-emission free vessel for transportation of a given amount of liquid ammonia and liquid carbon dioxide per year. The mission requirements are given by Horisont Energi AS. From this specification, a transport logistics analysis is carried out. This analysis resulted in requirements to number of ships needed, speed and cargo capacity. The workflow in this project is based on the design spiral. The final ship design is cable of fulfilling the mission requirements. The work resulted in a general arrangement, lines plan, tank plan, stability calculations, and a specification. Also, an evaluation of the ships energy source and propulsion system is carried out.

Sammendrag

Denne bacheloroppgaven er å prosjektere et nullutslippskip av karbondioksid for transport av flytende ammoniakk og flytende karbondioksid. Kravspesifikasjonen til oppgaven er gitt av Horisont Energi AS. Fra denne spesifikasjonen er det gjort en analyse av transportlogistikken. Denne analysen resulterte i nødvendig antall skip, hastighet og lastekapasitet. Med designspiralen som utgangspunkt har arbeidet i denne oppgaven resultert i et skipsdesign som kan oppfylle kravspesifikasjonen. Generalarrangement, linjetegning, tankplan, stabilitetsberegninger og en kort spesifikasjon er blitt laget. En evaluering av forskjellige energibærere og løsninger for fremdriftssystem er også gjort.

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1 Introduction

1.1 Climate change motivation

The Paris Agreement entered into force on 4 November 2016. It is an agreement to reduce world-wide greenhouse gas, GHG, emissions. The main goal is to limit global warming to below 2 degrees Celsius, but preferably to below 1,5 degrees Celsius, compared to pre-industrial levels (UnitedNations 2021).

To achieve this goal, all types of industries around the world have do reduce their GHG emissions. This also includes the energy sector and the transportation sector. There has to come a transition in the world's energy supply to GHG emission free energy sources, and ultimately renewable energy sources. Also, the marine transportation sector has to switch from using fossil fuels such as heavy fuel oil, HFO, diesel, and LNG, over to other emissions free fuels. The International Maritime Organization, IMO, adopted in April 2018 the Initial Strategy on the reduction of GHG emissions from shipping. This states that GHG emissions from shipping shall be reduced to under half their level in 2008. The strategy also aims to phase out GHG emissions completely as soon as possible (IMO 2021).

1.2 Study Objective

Horisont Energi, HE, a Norwegian clean energy company, is planning on producing blue ammonia from natural gas. Through a production process of ammonia which includes carbon capture and storage, CCS, they will be able to deliver ammonia as a carbon neutral fuel. HE is also planning on offering carbon storage facilities to other businesses.

Horisont Energi is in the need for a vessel able to transport both carbon dioxide and ammonia. Because of their goal for a carbon neutral future the ships energy source is to be ammonia.

This Bachelor's Thesis is to design a carbon-emission free vessel for transportation of a given amount of CO2 and NH3 per year, based on the specifications given by HE. The project will result in a general arrangement, lines plan, tank arrangement, stability calculations and technical particulars. The vessels propulsion system is to be ammonia based.

1.3 Project specification

1.3.1 Project description

The work in this Bachelor's Thesis is to design one or several ships that transports ammonia from Hammerfest to Rotterdam, and carbon dioxide from Stockholm to Hammerfest. The ship design will therefore be a multi-cargo design, that being liquid ammonia and liquid carbon dioxide. The ship(s) is also to be zero-emissions of CO_2 vessels and comply with international regulations regarding NO_x and SO_x.

1.3.2 Specifications and constraints

The specifications given by Horisont Energi is listed in the following sub-chapters. It is sorted by the three port locations on the route. Here the required amount of cargo transported is listed. Other specifications that may be constraining are also shown.

1.3.2.1 Hammerfest

- Annual transportation of ammonia from Hammerfest is to be regular transportation of 400 000 tons per annum. If distributed evenly for each months follows 33 333 tons per month.
- Ice class is demanded if necessary.

1.3.2.2 Stockholm

- The CO_2 production in Stockholm is not constant and varies with three different seasons through the year. The CO_2 production is displayed in Table 1.1 below.

Table 1.1 CO2 production

CO_2 production			
High season		**Low season**	
140	t/h	84	t/h
6,5	months	2,5	months
4 680	h	1 800	h
655 200	T	151 200	T
100 800	T/months	60 480	T/months

High season is the months October-march. Low season is April, May and September. During the summer in June, July and August there is no CO_2 production.

- CO_2 intermediate storage in Stockholm is maximum 25 000 tons.
- Max draft is 11 meters.
- Max length overall is 162 meters.

1.3.2.3 Rotterdam

- No known constraints.
- Port fee is 10 000 € per arrival.

1.3.3 Additional information

- Horisont Energi has the ability to use a "rapid purge technology" which is under qualification. This will allow purging in 24 hours. The technology may be used if relevant.
- Loading and unloading rate set to is 1 200 m^3 per hour.
- The ship is to be a carbon emission free vessel.

1.3.4 Route

The route goes as follows. From Hammerfest to Rotterdam with ammonia as cargo. From Rotterdam to Stockholm with no cargo, but the purging process is running during transit. And from Stockholm back to Hammerfest with CO_2 as cargo. The route is displayed in Figure 1.1. In Table 1.2 information about cargo and distance for each leg is listed.

Table 1.2 Route information

Leg	Cargo	Distance
Hammerfest – Rotterdam	Ammonia (NH_3)	1400 nm
Rotterdam – Stockholm	Purging	1050 nm
Stockholm - Hammerfest	Carbon dioxide (CO_2)	2100 nm

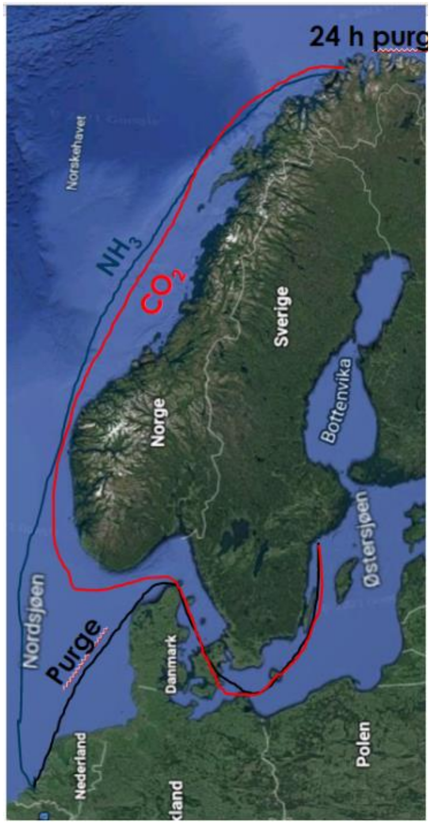

Figure 1.1 Route

1.3.5 Thermodynamic state of cargo

The thermodynamic state, including pressure, temperature, density and phase, of the two cargoes is listed in Table 1.3 below.

Table 1.3 Thermodynamic properties of cargo

Cargo	Pressure	Temperature	Density	Phase
NH_3	5 bar	-33 °C	0,682 ton/m^3	Fluid
CO_2	7 bar	-50 °C	1,155 ton/m^3	Fluid

2 Design Theory

2.1 Gas tankers

Transportation of gasses in their gaseous state is not physically practical onboard ships. When they are liquefied, the space they occupy is much less. Therefore, the gasses are brought to their liquid state either by being cooled down, pressurized or a combination of these. Gas carriers can be divided into the following categories.

1. Fully pressurized gas carriers
2. Fully refrigerated gas carriers
3. Semi-refrigerated gas carriers

Fully pressurized ships carry their cargo at ambient temperature, and at pressures normally up to 18 bar. No thermal insulation of the tanks, or a re-liquification plant is needed (Wärtsilä n.d b). Due to the high pressure, the tanks used are very small (Jørgen Amdahl 2017). The high design pressure also makes the tanks extremely heavy.

Fully refrigerated ships carry their cargo at atmospheric pressure, and at very low temperature. For LPG and LNG ships respectively, the cargo is kept at a temperature of -42 °C and -162 °C (Dokkum 2020). Large-scale cooling systems, and thermal insulation is needed because of the low temperature. Also, steel capable of withstanding the low temperatures is used in the tanks and the hull (Jørgen Amdahl 2017).

Semi-refrigerated ships carry their cargo at a combination of low temperature and high pressure. The pressure vessel tanks are designed for a vapour pressure of 4-8 bar. Low temperature steel is used to allow carriage of cargoes with temperature of -48 °C. In some cases, special alloy steel allows temperatures down to -104 °C. Semi-refrigerated ships is the most common for gas carriers in the size range of 1 500 to 30 000 m^3 (Wärtsilä n.d b).

The cargo tanks in gas carriers are divided into three types of independent freestanding tanks, and one type of dependent tank. The dependent tanks are bult into the hull of the ship. These tanks are commonly referred to as membrane tanks (Dokkum 2020).

The independent tanks are freely supported on foundations in the hull of the vessel. These tanks are not a part of the ship hull and does not contribute to strength of the hull girder. They are divided into the following three categories (Dokkum 2020):

- **Type A:** Fully cooled at atmospheric pressure with flat tank walls. Suitable for temperatures down to -42 °C.
- **Type B:** Fully cooled at atmospheric pressure. The tanks may be different-shaped, for example spherical steel tanks. Temperatures below -48 °C may be acceptable.
- **Type C:** Pressure vessel tanks. These are often designed as cylindrical horizontal tanks due to the high design pressure. The tanks may be insulated to prevent the pressure from rising. Pressures up to 18 bar is tolerated.

2.2 About the design process

2.2.1 Requirements to ships

Ship design is an iterative process. The goal is to come up with a final design that fulfils the specifications requirements given by the customer. In addition to these, there are three fundamental requirements for all types of ships (Jørgen Amdahl 2017):

- "The ship shall float with the correct side up and be stable".

  According to Archimedes' law, for a ship to stay afloat it needs to be able to displace a water-volume with the same weight as the mass of the ship. The ship also needs to comply with stability criteria.

- "The ship shall be sea-worthy"

  The ships need to be able to deliver cargo in good condition and on time. It follows that sufficient propulsion, steering, stability, freeboard, and ability to withstand forces from the surroundings needs to be in place.

- "Safety for passengers and cargo shall be maintained"

  Other than seaworthiness, sufficient safety equipment and crew training needs to be in place.

2.2.2 The design spiral

The iterative process of ship design is carried out through several stages. These stages form what often is referred to as the design spiral. To come up with the final ship design that fulfils all requirements, several rounds in the design spiral is needs to be done. The stages are listed successively in order as they should be completed. However, the most convenient workflow is not given explicitly, and depends on available information, specifications and constraints to the final design (Jørgen Amdahl 2017). Often the workflow follows a more web like path, rather than following the spiral successively. An illustration of the design spiral is shown in Figure 2.1 below.

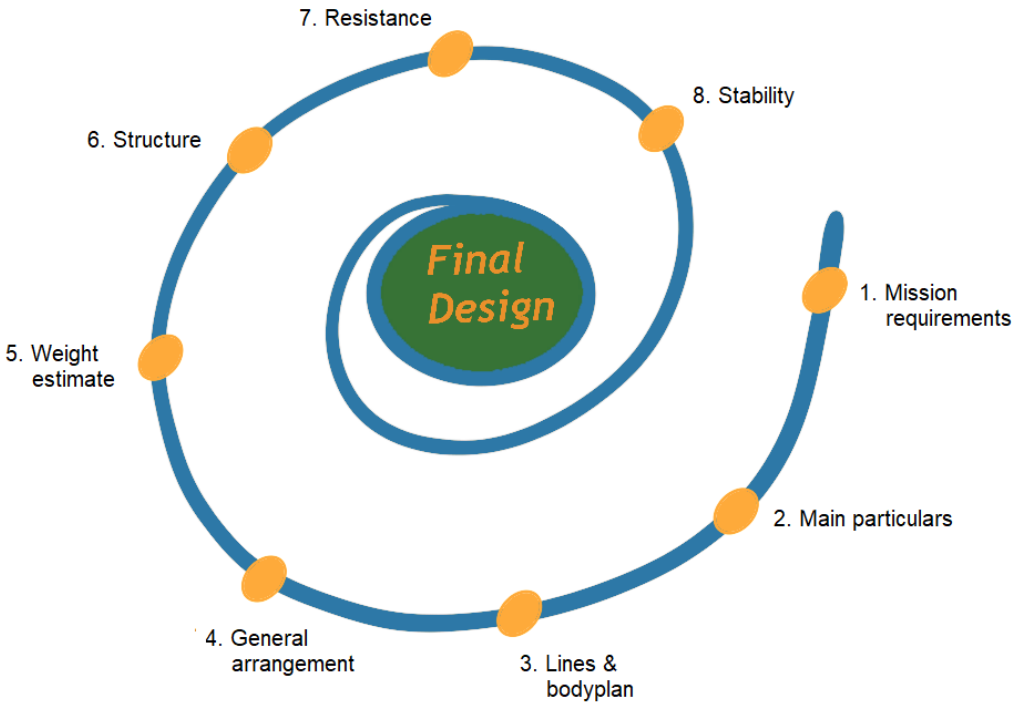

Figure 2.1 The design spiral

In the following, a description of each stage in the design spiral is given:

1. **Mission requirements**

   Specifications and customer requirements to the final ship design makes up the basis and starting point for the design process. Requirements like cargo capacity, speed, range, route, draft, and costings is specified.

2. **Main particulars**

   Needed displacement from deadweight (DWT) and lightship-weight (LWT) us found. Also dimensions for length (L), breath (B), depth (D), draft (T), and block coefficient (C_B) is set. These are related to each other as given in equation 2-1.

   $$C_B = \frac{DWT + LWT}{L * B * T} \quad (2\text{-}1)$$

   Starting values may be found from statistics.

3. **Lines and bodyplan**

   A hull shape is modelled based on the main particulars from stage 2. The displacement from the 2nd stage is obtained when the hull is shaped to the desired block coefficient. Also, the location of the longitudinal centre of buoyancy (LCB) is preferably located at the longitudinal centre of gravity (LCG), to minimize trim.

4. **General arrangement**
   The general arrangement is a key element in the design process. Here the design and layout of the ship is presented. It also contains all components of the hull and equipment on the ship. The general arrangement is continuously updated throughout the design process as changes and updates are made. It is therefore a valuable tool to keep track of the design process. It is also used as the foundation for the weight calculation in the next step in the design spiral.
5. **Weight estimate**
   The weight, LCG, and VCG of the hull and each component on board the ship is listed systematically. The total LWT is calculated together with its lateral- and vertical moment from the aft perpendicular and the baseline. Design margins are added.
6. **Structure**
   The hull is exposed to forces from the surroundings and weights from cargo and the ship itself. These forces result in stresses in hull girder. The hull needs to be strong enough do withstand these stresses. The structural design procedure (SDP) as described in the next section is carried out to dimension the hull plating, stiffeners, and girders. It should also be checked for buckling.
7. **Resistance**
   The required engine break power and fuel capacity is calculated using data from a resistance analysis. The resistance depends on the hull shape and wetted area.
8. **Stability**
   The final stage in the design spiral is a stability analysis. The ship must fulfil stability criteria given by IMO in all loading conditions.

When each round in the design spiral is completed, the resulting design is checked against the mission requirements. Eventual deviations are localised, and a new round in the design spiral is started. Finally, after several rounds, a final ship design that fulfils all specifications and requirements is obtained.

2.3 Structural design procedure

The structural strength of the hull girder is to be evaluated at stage 6 in the design spiral. Here the structural design procedure is used to calculate required plating and stiffener dimensions based on both global and local loads. The global loads come from still water bending moments and wave bending moments. The allowable local stress level from local loads is found in the DNV Rules for classification of ships.

The SDP is an iterative process and consists of eight stages. The stages are listed chronologically in the order as they should be completed. The procedure is described in the following. The iterative workflow is illustrated in figure Figure 2.2 below.

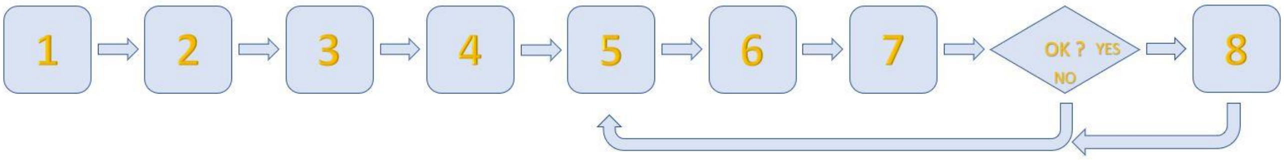

Figure 2.2 SDP workflow

Step 1 Input:

Gather input from the general arrangement to use in the further step.

Step 2 Stiffener topology:

Decide stiffener direction, distance *s* between stiffeners, and distance *l* between girders.

Step 3 Design bending moments:

The contributions to the total design bending moments come from still water bending moments, and wave bending moments. These are further divided into hogging and sagging moments. The critical still water moment is taken as the greatest of the moment calculated from the DNV Rules for classification of ships, or the moment from the actual loading condition. The wave bending moment is calculated from the DNV Rules for classification of ships.

Step 4 Critical cross section:

Identify the critical transverse cross section of the hull girder within 40 % of the midship section with regards to minimum section modulus.

Step 5 Plating and stiffener dimensions:

Calculate required dimensions of elements, i.e. plating and stiffeners, contributing to longitudinal strength based on local loads. Alternatively make an assumption of the values.

Step 6 Cross section properties:

From the critical cross section and established dimension, the values for neutral axis, moment of inertia, and section modulus for deck and bottom is calculated.

Step 7 Global longitudinal strength:

In this step, the global longitudinal strength is evaluated. The longitudinal stress level, σ_l, in the hull girder is calculated from maximum design bending moment and minimum section modulus for both deck and bottom. The stress level is calculated with the following formula.

$$\sigma_l = \frac{M_{SW} + M_W}{Z_{min}} \leq 175 * f_1 \qquad (2\text{-}2)$$

Here M_{SW} and M_W are the still water- and wave bending moment respectively. Z_{min} is the minimum section modulus. The value of the material factor f_1 is set to 1 for normal steel. For stell with higher strength, f_f may be higher.

If the calculated value stress level is higher than the allowed stress level 175*f_1, new values for the plating and stiffener dimensions need to be set in step 5. Consequently step 6 and 7 must be re-evaluated. When the global longitudinal stress level is below the allowed stress level, the process may be continued to step 8.

Step 8 Recalculate required plating and stiffener dimensions

In this step the local strength is evaluated. Based on acceptable global longitudinal strength a stress factor, f_2, is calculated for both deck and bottom using the following formula.

$$f_2 = \frac{5{,}7 * (M_{SW} + M_W)}{Z} \qquad (2\text{-}3)$$

Required dimensions for plating and stiffeners based on global strength is found from the rules in the DNV Rules for classification of ships. New dimensions are re-established. The updated values are applied in step 5 and the process is continued. This iterative workflow is continued until convergence is reached and both local and global strength requirements are fulfilled.

3 The design process

3.1 Design phase 1 Logistics and main particulars

3.1.1 Transport logistics

The final ship design, especially the main particulars, depends on the transport logistics. There are several combinations of payload capacity and transit speeds that fulfils the requirements to amount of cargo transported per month. Therefore, the transport logistics determines the needed payload capacity.

3.1.1.1 Logistics constraints

According to the project constraints, maximum CO_2 storage at the intermediate storage in Stockholm is 25 000 tons. As listed in Table 1.1, the CO_2 production is 140 tons/hour in High season, and 84 tons/hour in Low season. Because of this there are specific requirements to how often a ship must dock in Stockholm for CO_2 loading before the storage gets full. Table 1.1 is therefore updated to contain the maximum arrival period in Stockholm for both High season and Low season, as shown below in the orange row in Table 3.1.

Table 3.1 CO2 production with maximum arrival period

CO_2 production					
High season			**Low season**		
140	t/h		84	t/h	
6,5	months		2,5	months	
4 680	h		1 800	h	
655 200	T		151 200	T	
100 800	T/months		60 480	T/months	
Arrival period Stockholm	7,4	Days	Arrival period Stockholm	12,4	days

Another deciding factor for the logistics is the monthly required amount of transported CO_2. This is shown in the green row in Table 3.1 above. Also, the requirement of even transport of 400 000 tons of NH_3 per annum affect the logistics. Approximately 33 333 tons of NH3 has to be transported every month.

3.1.1.2 Logistics calculation

The logistics has been modelled in Excel. Screenshots from the spreadsheet is shown below in Table 3.2 and Table 3.3. Input parameters is marked with red, and important output data is marked with yellow.

Table 3.2 Example logistics model 1

			High Season - 3 ships							
Leg	**Cargo**	**Loading rate [m3/h]**	**Loading time [h]**	**Volume cargo [m3]**	**Weight cargo [ton]**	**Distance [nm]**	**Speed [kn]**	**Voyage time [h]**	**Accumulated voyage time [h]**	**Accumulated voyage time [days]**
Loading Hammerfest	NH3	1200	8	9600	6547,2				8,0	0,3
Hammerfest - Rotterdam	NH3				6547,2	1400	13	107,7	115,7	4,8
Unloadng Rotterdam	NH3	1200	8	-9600	-6547,2				123,7	5,2
Rotterdam - Stockholm	Purging				0	1050	13	81	204,5	8,5
Loading Stockholm	CO2	1200	14,1	16920	19542,6				218,6	9,1
Stockholm - Hammerfest	CO2				19542,6	2100	13	161,5	380,1	15,8
Unloading Hammerfest	CO2	1200	14,1	-16920	-19542,6				394,2	16,4
Purging Hammerfest	Purging		24		0				418,2	17,4

In this case, since it is modelled with three ships, the arrival period and cargo transported per month is as shown in Table 3.3.

Table 3.3 Example logistics model 2

Arrival period [days]	**CO2 in storage [ton]**	**Transported cargo**	**per month [ton]**	**per season [ton]**
5,81	19516	NH3	33816	219806
Roundtrips per ship	**Roundtrips for 3 ships**	CO2	100937	656093
11,2	33,6			

The input parameters, speed and loading time, has been varied and optimized so that the following output values are fulfilled:

- Frequent enough arrival period in Stockholm
- Requirement to amount of CO_2 transported per month
- Requirement to amount of NH_3 transported per month

Table 3.2 and Table 3.3 above shows the model for High season. An equivalent procedure has been carried out for Low season. For the period when there is no CO_2 production, in Off season, another model has been made. In Off season, only ammonia is transported from Hammerfest to Rotterdam. The logistics spreadsheet is shown in Appendix A.

The logistics calculation has also been done for a variated number of vessels. There are several combinations of number of vessels, speed and payload capacity that fulfils the logistics constraints. The goal for the logistics calculation is to find the best and most cost-effective combination for each of the three seasons.

3.1.2 Early cost estimation

The logistics plan which is decided upon at this early stage will influence the economy for the whole project. It is therefore important to decide on the logistics based on what is assumed to result in the lowest total cost, and the lowest cost per ton CO_2 and NH_3 transported.

Horisont Energi has provided a cost estimation model based on a reference ship. The model has a set of input values and applies these on the reference ship. Then different costing values is calculated and cost per unit cargo transported is given as output. Also, the total project cost is calculated. Reference ship data is listed in Table 3.4. The input parameters, calculations ant output parameters are listed below in Table 3.5.

Table 3.4 Cost model reference ship

Reference ship		
Reference	8000	cbm
Ref. cost	32	MUSD
at speed	4082	kW
SFC	**0,195**	kg/kWh
Consuption	796	kg/hr
Consuption	0,8	ton/hr
Consuption	19,1	ton/day
at rating	1,07	ton/hr

Table 3.5 Cost estimation model input, calculations, and output

Input	Distance [nm]	Size [m^3]	Contract speed [kts]	Logistics speed [kts]	Interest rate [%]	Loan period [yrs]
Calculations	Ship price [$]	Annual capex [$]	Fuel cost [$/yrs]	Crew & opex cost [$/yrs]	Annual cost [$/yrs]	
Output	Cost per unit NH_3 transported [$/ton]		Cost per unit CO_2 transported [$/ton]		Total project cost [$]	

3.1.3 Transport logistics results

The logistics results and cost estimation has been carried out for two, three, and four vessels and with different combinations of speed and payload capacity.

3.1.3.1 Two ships

With two ships, to load CO_2 in Stockholm frequent enough the minimum logistics speed is 17 knots. Then 25 000 tons of CO_2 is loaded at each arrival. The logistics speed is an average speed for the voyage between two ports. This speed is meant to account for lost time because of bad weather, manoeuvring time etc. Therefore approximately 2 knots is added to get the design speed. Hence the design speed for two vessels is 19 knots. A design speed of 19 knots is unrealistically high. The logistics model based on only two ships is then excluded.

It is worth mentioning in this report that it is the maximum CO_2 storage capacity in Stockholm that results in the excluding of the ability to use two ships. If the storage capacity was higher, the required speed would be lower. Then the ship size could be increased up to the maximum length and draft constraints. This might have been a cheaper solution, but is not further considered.

3.1.3.2 Three ships

The method described above in chapter 3.1.1.2 is used. A logistics plan has been made for the logistics speeds 10 – 19 knots. The maximum monthly cargo transported is CO_2 from Stockholm to Hammerfest during High season. Because of this, the payload capacity needed for this voyage is the deciding factor for the final payload capacity for the ships. For every speed the corresponding cargo transported per voyage is found. Since the loading and offloading rate is set to 1 200 m^3/hour the needed time for loading is calculated.

When setting up the logistics for Low season, the amount of CO_2 carried is set to the maximum payload capacity from High season. Then the speed is set to a minimum in order to fulfil the requirement to monthly cargo transported. The amount of ammonia transported per voyage is based on the speed and the requirement for monthly cargo transported. It is found to be viable with only two ships during Low season. Therefor two ships are used, and this is assumed to be cheaper than using three ships.

In Off season only ammonia is transported from Hammerfest to Rotterdam. The amount of ammonia transported per voyage is set to the maximum payload capacity. The speed is set thereafter. It is found to be viable with only one ship during Off season. Therefor one ship is used and is assumed to be cheaper than using two or three ships.

In Table 3.6 logistics speed, estimated cost per transported ton ammonia and CO_2, and estimated total project cost over 15 years for three ships is listed.

Table 3.6 Cost estimation three ships

Logistics speed [kts]	Cost per ton NH_3 transported [$/ton]	Cost per ton CO_2 transported [$/ton]	Total project cost 15 years [$]
10	$ 46,43	$ 46,08	$ 714 751 632
11	$ 45,00	$ 44,91	$ 694 698 761
12	$ 44,50	$ 44,08	$ 679 313 549
13	$ 43,43	$ 43,30	$ 664 241 268
14	$ 42,82	$ 42,67	$ 649 527 155
15	$ 41,99	$ 41,79	$ 638 803 576
16	$ 41,59	$ 41,34	$ 626 562 875
17	$ 40,86	$ 40,72	$ 616 923 669
18	$ 40,37	$ 40,04	$ 607 956 907
19	$ 39,88	$ 39,56	$ 598 988 859

The data in Table 3.6 is graphed in Figure 3.1 and Figure 3.2 below.

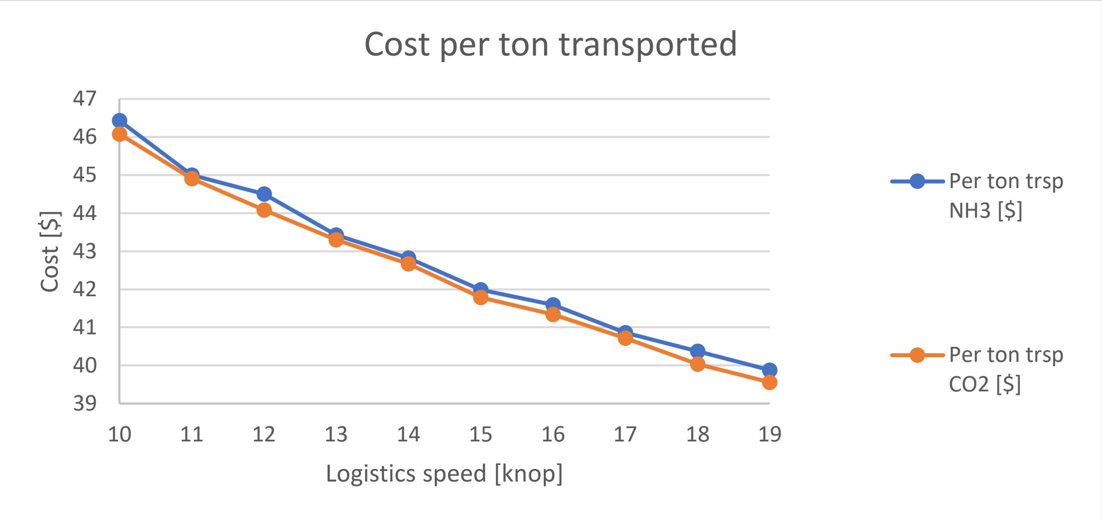

Figure 3.1 Cost per ton transported 3 ships

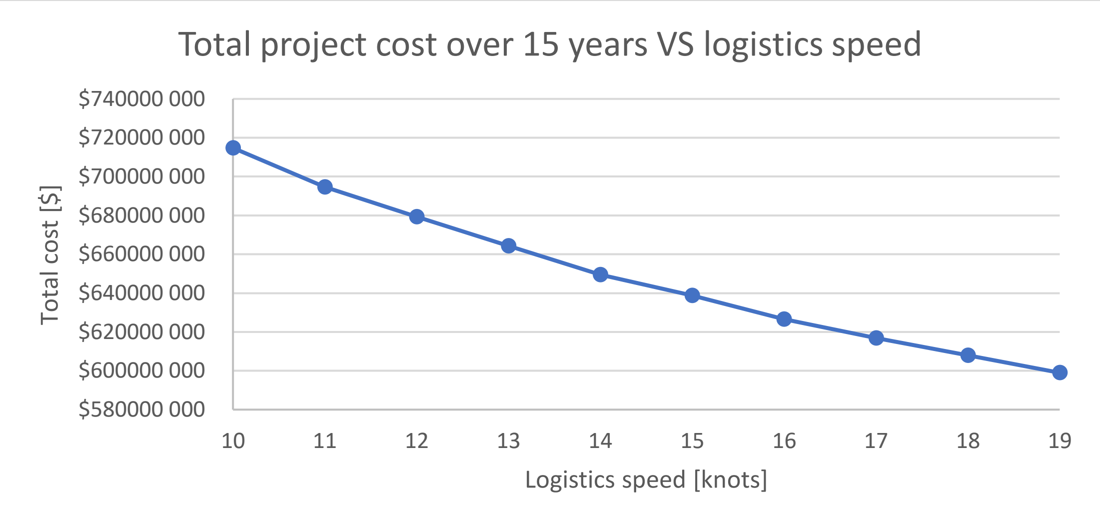

Figure 3.2 Total project cost 3 ships

It is clear from both Figure 3.1 and Figure 3.2 above that lowest cost is achieved with the highest speed. An explanation to that the cost model estimates lower cost with increasing speed may be that the because of that when the speed increases the size of the vessel decreases. The building cost and loan cost decreases with smaller ships. The eventual increased fuel cost because of higher speeds does not weigh out the decreased build and loan cost due to smaller ships.

3.1.3.3 Four ships

The same procedure as described for in section 3.1.3.2 for three ships is used for the case of four ships. During High season four ships is used.

It has been tested for using two ships during Low season with the payload capacity found in High season for four ships, however the logistics model in Excel shows that this is not feasible because the payload capacity is too low. It is therefore necessary to use three ships during Low season.

The same goes for Off season; it is not possible to use only one ship during Off season when the logistics in High season is optimized for four ships. The payload capacity is too low. It is therefore necessary to use two ships during Off season

In Table 3.7 logistics speed, estimated cost per transported ton ammonia and CO_2, and estimated total project cost over 15 years for four ships is listed.

Table 3.7 Cost estimation four ships

Logistics speed [kts]	Cost per ton NH_3 transported [$/ton]	Cost per ton CO_2 transported [$/ton]	Total project cost 15 years [$]
10	$ 54,35	$ 53,95	$ 835 704 293
12	$ 52,45	$ 51,90	$ 795 861 655
14	$ 50,50	$ 50,30	$ 763 669 180
16	$ 48,99	$ 48,87	$ 737 900 010
18	$ 47,65	$ 47,82	$ 715 632 922

The data in Table 3.7 is graphed in Figure 3.3 and Figure 3.4 below.

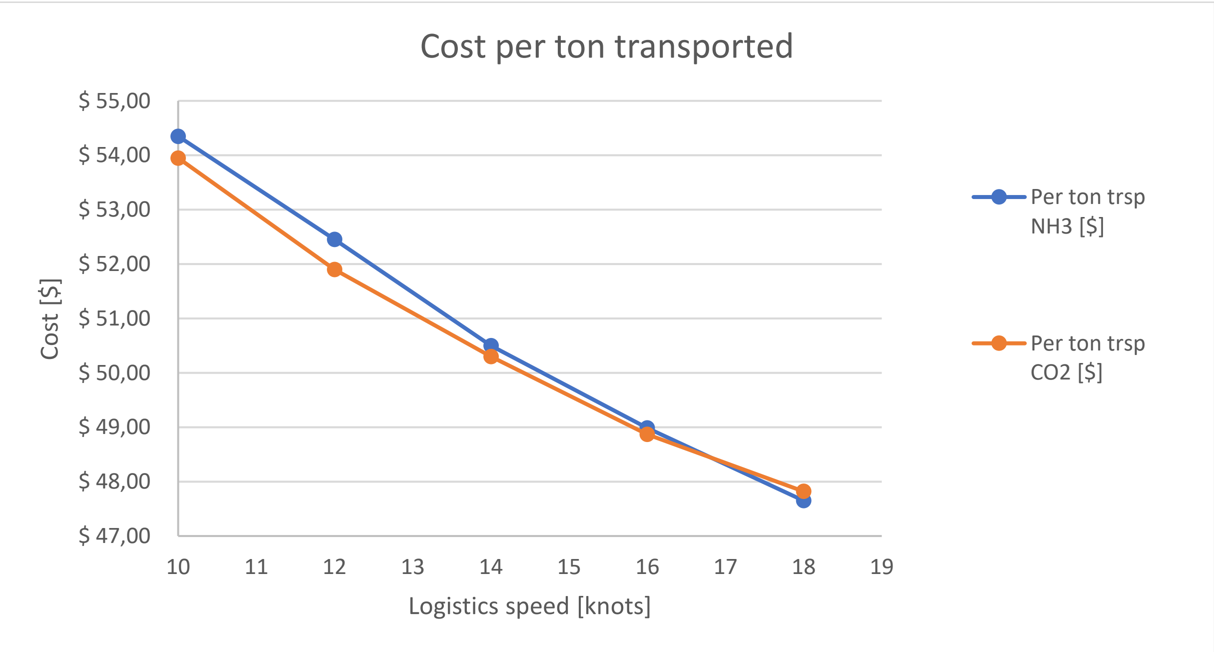

Figure 3.3 Cost per ton transported 4 ships

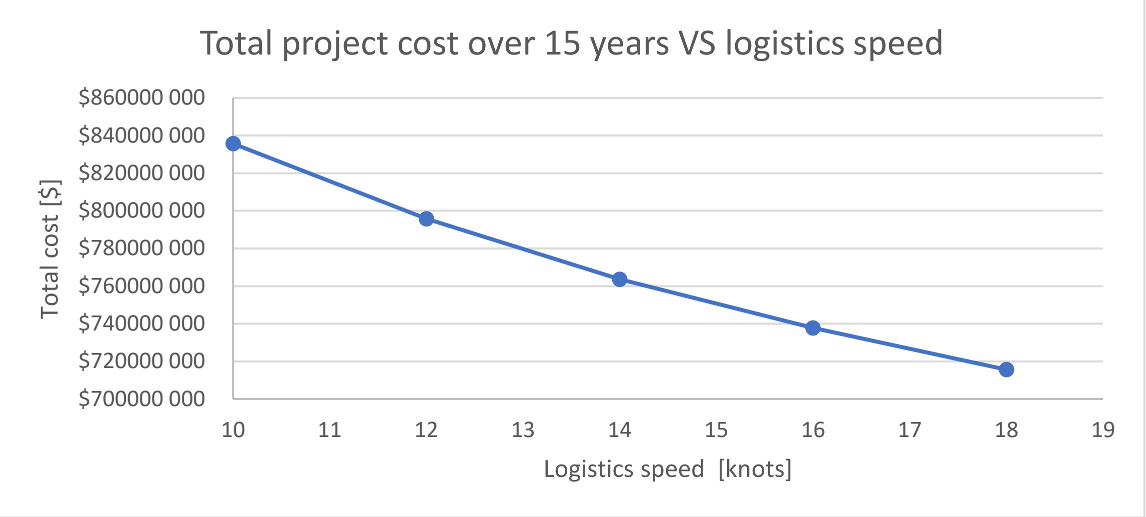

Figure 3.4 Total project cost 3 ships

When comparing the cost per transported ton of cargo, and the total project cost for three and four ships, it is clear that it is cheapest to use three ships. It is therefore decided to use three ships in the logistics, and the ships is designed thereafter.

3.1.3.4 Final decided logistics

The costing model shows that the cost decreases with increased speed. Hence it is beneficial to set the speed as high as possible. As mentioned earlier in chapter 3.1.3.1 a design speed of 19 knots is unrealistically high. Also design speeds up to 16-17 knots is considered not to be feasible. Figure 3.5 based on tanker statistics shows that 16 knots lie in the upper bound. Therefore, a design speed of 15 knots, and a logistics speed of 13 knots are decided upon.

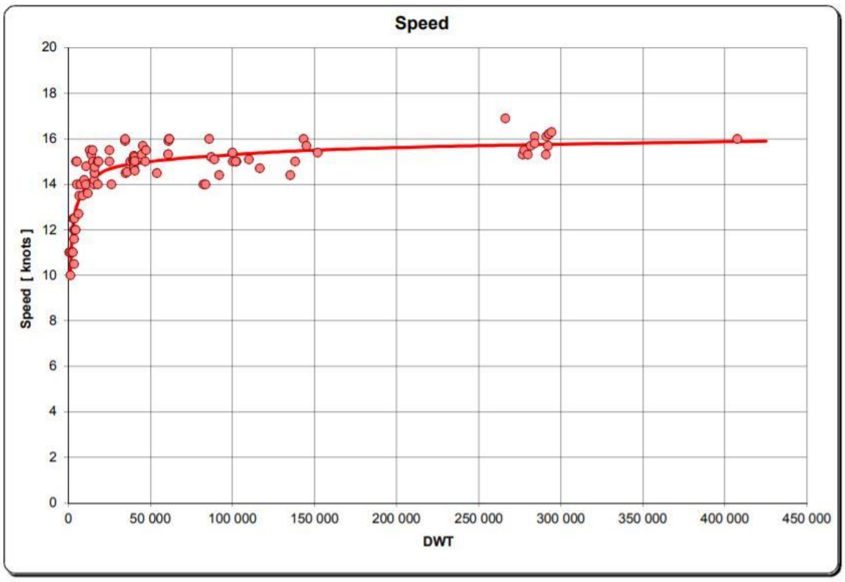

Figure 3.5 Tanker speed statistics, (Levander 2012)

Table 3.8 below shows the decided logistics and monthly and annually cargo transported. Also, the costings based on the cost estimation model is shown.

Table 3.8 Logistics, costings and total cargo transported for 3 ships

High Season - 3 ships

Leg	Cargo	Loading rate [m3/h]	Loading time [h]	Volume cargo [m3]	Weight cargo [ton]	Distance [nm]	Speed [kn]	Voyage time [h]	Accumulated voyage time [h]	Accumulated voyage time [days]
Loading Hammerfest	NH3	1200	8	**9600**	**6547,2**				8,0	0,3
Hammerfest - Rotterdam	NH3				6547,2	1400	**13**	107,7	115,7	4,8
Unloadng Rotterdam	NH3	1200	8	-9600	-6547,2				123,7	5,2
Rotterdam - Stockholm	Purging				0	1050	**13**	81	204,5	8,5
Loading Stockholm	CO2	1200	14,1	**16920**	**19542,6**				218,6	9,1
Stockholm - Hammerfest	CO2				19542,6	2100	**13**	161,5	380,1	15,8
Unloading Hammerfest	CO2	1200	14,1	-16920	-19542,6				394,2	16,4
Purging Hammerfest	Purging		24		0				418,2	**17,4**

Arrival period [days]	CO2 in storage [ton]	Roundtrips per ship	Roundtrips 3 ships	Transported cargo	per month [ton]	per season [ton]
5,81	19516	11,2	33,6	NH3	**33816**	219806
				CO2	**100937**	656093

Low Season - 2 ships

Leg	Cargo	Loading rate [m3/h]	Loading time [h]	Volume cargo [m3]	Weight cargo [ton]	Distance [nm]	Speed [kn]	Voyage time [h]	Accumulated voyage time [h]	Accumulated voyage time [days]
Loading Hammerfest	NH3	1200	13	**15600**	**10639,2**				13,0	0,5
Hammerfest - Rotterdam	NH3				10639,2	1400	**11,8**	118,6	131,6	5,5
Unloadng Rotterdam	NH3	1200	13	-15600	-10639,2				144,6	6,0
Rotterdam - Stockholm	Purging				0	1050	**11,8**	89,0	233,6	9,7
Loading Stockholm	CO2	1200	14,1	**16920**	**19542,6**				247,7	10,3
Stockholm - Hammerfest	CO2				19542,6	2100	**11,8**	178,0	425,7	17,7
Unloading Hammerfest	CO2	1200	14,1	-16920	-19542,6				439,8	18,3
Purging Hammerfest	Purging		24						463,8	**19,3**

Arrival period [days]	CO2 in storage [ton]	Roundtrips per ship	Roundtrips 2 ships	Transported cargo	per month [ton]	per season [ton]
9,66	19479	3,9	7,8	NH3	**33033**	82582
				CO2	**60676**	151691

Off Season - 1 ship

Leg	Cargo	Loading rate [m3/h]	Loading time [h]	Volume cargo [m3]	Weight cargo [ton]	Distance [nm]	Speed [kn]	Voyage time [h]	Accumulated voyage time [h]	Accumulated voyage time [days]
Loading Hammerfest	NH3	1200	14,1	**16920**	**11539,44**				14,1	0,6
Hammerfest - Rotterdam	NH3				11539,44	1400	**12,7**	110,2	124,3	5,2
Unloading Rotterdam	NH3	1200	14,1	-16920	-11539,44				138,4	5,8
Rotterdam - Hammerfest	No cargo				0	1400	**12,7**	110,2	248,7	**10,4**

Arrival period [days]	CO2 in storage [ton]	Roundtrips per ship	Roundtrips 1 ship	Transported cargo	per month [ton]	per season [ton]
10,4	0	8,7	8,7	NH3	**33411**	100233
				CO2	**0**	0

Costings

Cargo	Cost per ton trsp [$/ton]	Total project cost 15 years [$]
NH3	$ **43,43**	$ **664 241 268**
CO2	$ **43,30**	

Total cargo transported per year

Transported cargo	per year [ton]
NH3	**402621**
CO2	**807784**

The following bullet points are key points from the decided logistics in Table 3.8:

- Number of ships: 3 ships
- Design speed: 15 knots
- Cargo capacity, volume: Approx. 16 900 m^3
- Cargo capacity, mass: Approx. 19 600 ton

3.1.4 Main particulars

To find starting values for the main particulars, ship statistics provided by Kai Levander in "System Based Ship Design" (Levander 2012) is used. Based on the deadweight, values for lightweight, length overall, length between perpendiculars, breadth, draft, and depth is found.

The deadweight, DWT, is approximated to equal the cargo capacity. I.e., the DWT is set to 19 600 tons. The statistical dimensions based on this is listed below in Table 3.9.

Table 3.9 Main particulars from statistics

DWT [ton]	19 600 ton
LWT [ton]	5 400 ton
Displacement (DWT + LWT)	25 000 ton
Loa [m]	150 m
Lpp [m]	147 m
B [m]	24 m
T [m]	9 m
D [m]	13 m
C_B [-]	0,74

These particulars based on statistics is checked by using empirical formulas. Froude number is calculated from the speed and the length:

$$Fn = \frac{V}{\sqrt{g * L}} \quad (3\text{-}1)$$

Here *V* is the speed in m/s, *g* is the gravitational acceleration, and *L* is L_{pp} in meters.

Based on Froude number, the following formulas from Schneekluth is used to estimate C_B

$$C_B = 1{,}06 - 1{,}68 * Fn \quad (3\text{-}2)$$

$$C_B = \frac{0{,}145}{Fn} \quad (3\text{-}3)$$

The following formulae from Posdunine is used to estimate the length:

$$L = C\left(\frac{V}{V+2}\right)^2 \Delta^{\frac{1}{3}} \quad (3\text{-}4)$$

Here *L* is the length in meters, *V* is the speed in knots, and Δ is the displacement in tons. *C* is a constant set to 7,30. Recommended values for *C* is…

Also the following formula, Shneekluths formula, which is based on statistics, gives an estimation for the most economical length:

$$Lpp = \Delta^{0,3} * V^{0,3} * 3{,}2 * \frac{C_B + 0{,}5}{\left(\frac{0{,}145}{Fn}\right) + 0{,}5} \quad (3\text{-}5)$$

Here Δ is the displacement in tons and *V* is the speed in knots.

The results from these formulas are presented in Table 3.10 below.

Table 3.10 Main particulars based on empirical formulas

Formulae	Result	Comment
Froude number (3-6)	Fn = 0,20	
Schneekluth nr. 2 (3-7)	C_B = 0,72	Indicates lower C_B
Schneekluth nr. 2 (3-8)	C_B = 0,71	Indicates lower C_B
Posdunine (3-9)	Lpp = 166 m	Indicates increased length
Schneekluth (3-10)	Lpp = 151 m	Indicates increased length

From the results in Table 3.10 it is decided to increase L_{pp} to 151 meters and decrease C_B to 0,71.

To set a value for L_{oa}, three meters is added to L_{pp}.

With length, breadth, C_B, and displacement fixed, the required draft is 9,5 meters.

The resulting main particulars are presented in Table 3.11 below. Main particular ratios are listed in Table 3.12 below.

Table 3.11 Main particulars

DWT [ton]	19 600 ton
LWT [ton]	5 400 ton
Displacement [ton]	25 000 ton
L_{pp} [m]	151 m
L_{oa} [m]	154 m
B [m]	24 m
T [m]	9,5 m
D [m]	12 m
C_B [-]	0,71

Table 3.12 Main particulars ratios

L/B [-]	6,29
B/T [-]	2,53
[B/D] [-]	2,00
[L/D] [-]	12,58

3.2 Design phase 2 The design spiral round 1

3.2.1 Lines plan

From the main particulars established above, the hull shape is to be modelled. The computer programme *Maxsurf Modeler* is used for this task. This is done by forming a half cylinder with the desired dimensions. Length, breadth, depth, and design draft is fed as input to the programme. Thereafter, by moving control points, the half cylinder with these dimensions is shaped to comply with the following criteria.

The first criterion is to obtain the block coefficient of 0,71. This is to ensure that the ship floats on the decided waterline, provided that the weight assumption is correct.

A second criterion is to shape the foreship and the bow to the desired shape. The bow is shaped to have a typical shape for this type of vessel. A simple bulbous bow is also modelled. The ship will mainly be operated under the two loading conditions transit with CO2 as cargo, and transit with ammonia as cargo. A bulbous bow designed for these loading conditions would be beneficial, however, a more detailed bow design is not carried out.

A third criterion is to shape the aftship to the desired shape. The aftship is designed so that there is enough space for the propeller, and enough clearance between the propeller and the hull above. An early estimation of the propeller diameter is done based on the load on the propeller, which is not to be above 300 kW per m^2. This is to minimize cavitation and to enable the propeller to work efficiently. The propeller diameter is estimated from the following formulae.

$$L = \frac{P_B}{\pi * r^2} \qquad (3\text{-}6)$$

Here L is the allowed propeller load, P_B is the break power delivered from the engine, and r is the propeller radius. Based on installed engine power in a reference ship the break power is assumed to be 6500 kW. It then follows that the required propeller diameter is 5,3 m.

To achieve optimal water flow conditions around the propeller, and thereby maximizing the propeller efficiency, the propeller clearance is set to 25% of the propeller diameter. It then follows that the required vertical distance from baseline to the hull, at the longitudinal position where the propeller is located, is 6,6 m.

When designing the aftship it is also important to consider the need for buoyancy and also hull resistance due to submerged transom area. Since a weight calculation and an analysis of how the hull floats is not yet carried out this early in the design process, the aftship is not designed with the need for buoyancy in mind. However, to minimize hull resistance, the aftship is designed so that the transom plate extends down not further than to the design waterline.

The aftship is also meant to contain a skeg, but this is not modelled because it is not relevant this early in the design process, other than that it contributes to small amount of buoyancy. The resulting hull shape from the first round in the design spiral is shown below in Figure 3.6.

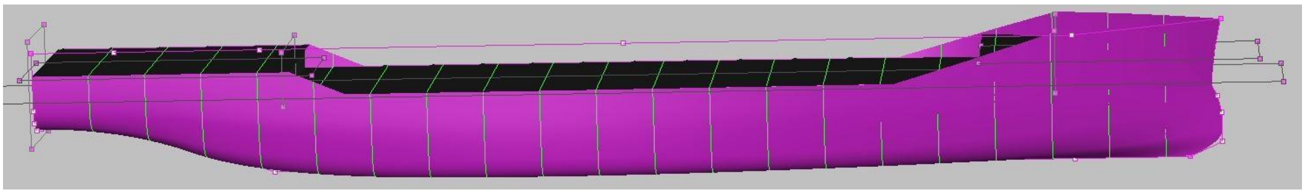

Figure 3.6 Hull shape from first round in the design spiral

3.2.2 General Arrangement

In the first round in the design spiral a detailed general arrangement is not necessary. The main goal at this stage is to include the hull shape and main equipment so that the most important weights are included. The lines forming the hull shape is exported from *Maxsurf Modeler* and imported to *Autocad*, where the general arrangement is drawn. The general arrangement for the first round in the design spiral is shown below in Figure 3.7.

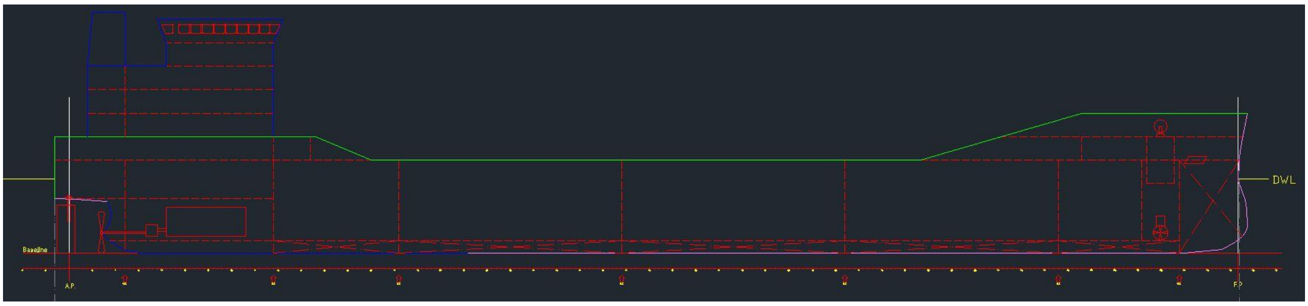

Figure 3.7 General arrangement from first round in the design spiral

3.2.2.1 General arrangement from ship classification rules.

An important dimension often referred to in IMO-rules and ship classification rules is the rule length, as defined by the International Convention of Load Lines. The rule length is either 96% of the length of the waterline at 85% of the least moulded depth, or as the length from the fore side of the stem to the axis of the rudderstock, if that be greater (DNV 2016).

From the first and the second part of this definition it follows that the rule length is 151 m or 146,7 m respectively. The rule length, L_F, then becomes 151 m.

The number of transverse watertight bulkheads required is derived from the rule length. Rule A302 in DNV Rules for classification of ships Pt. 3 Ch.1 Sec. 3 states that 7 watertight bulkheads is required for this length (DNV 2016).

The required placement of the collision bulkhead is found from rule 4.1.1 in DNV Rules for classification of Ships Pt. 3 Ch. 2 Sec. 2 (DNV 2021a). It is found that the collision bulkhead is to be in a position of 7,32 m to 11,85 m abaft the fore perpendicular, FP. A location of 7,6 m abaft FP is chosen.

An aft peak bulkhead shall also be provided according to DNV Rules for classification of Ships Pt. 3 Ch. 2 Sec. 2 rule 5.1.1. Its exact location is not further specified other than it shall enclose the stern tube and rudder trunk in a watertight compartment (DNV 2021a).

A double bottom is fitted in the first round in the design spiral. DNV Rules for classification of Ships rule 2.3 states the requirements to the height of the double bottom. The height h_{DB}, in mm, measured from the keel line needs to be h_{DB} = 1000*B/20, where B is the breadth measured in mm. In this case, it follows that h_{DB} = 1200 mm. However, the minimum height allowed is 760 mm, and it does not need to be higher than 2000 mm (DNV 2021a). To account for accessibility and production, the height of the double bottom is set to 1600 mm.

3.2.2.2 Other general arrangement design features

The extent of the cargo area and the placement of the engine room bulkhead are based on general arrangements from similar ships found in various publications of *Significant Ships* published by The Royal Institution of Naval Architects, RINA. The vertical distance between the double bottom and the main deck is divided by a tween deck at height of 7 m. A superstructure is also drawn, where the height of the bridge deck and the conning station is chosen based on the requirements to visibility from the bridge specified in SOLAS chapter V Regulation 22. The view of the ship surface from the conning station is not to be obscured by more than two ship lengths or 500 m, whichever is less.

3.2.2.3 Cargo tanks

Gas carriers are in the IGC code divided into three types according to the products they are intended to carry and the hazards the products represent. The types are type 1G ship, type 2G/2PG ship and type 3G ship. A type 1G ship is a gas carrier intended to carry products considered to present the greatest overall hazard and types 2G/2PG and type 3G for products of progressively lower hazards. Therefore, the rules regulating a type 1G ship will be the strictest regarding damage survivability and cargo tank location (DNV 2021b).

Section 19 rule 1.1 in DNV Rules for classification of Ships Pt. 5 Ch. 7 specifies the ship type that is required for the product it is intended to carry. For ammonia, type 2G is required. For carbon dioxide, type 3G is required. It then follows that the vessel is to be a type 2G ship because these rules are the strictest (DNV 2021b).

The location of the cargo tanks is regulated by the IGC code. When the rules in DNV Rules for classification of Ships Pt. 5 Ch. 7 is fulfilled, the rules in the IGC code are also fulfilled.

Section 2 rule 4.1.1.2 regulates the placement of cargo tanks for type 2G ships regarding minimum distances inboard. In this case the minimum distance from the keel is 1,6 m, and the minimum distance from the ship side is 1,03 m. The placement of the cargo tanks fulfils these requirements.

An evaluation of the cargo tanks is carried out. Since the liquid CO_2 is to be carried at -50 °C at a pressure of 7 bar, cylindrical horizontal type C tanks that can withstand this pressure is chosen as cargo tanks.

The cargo hold area is 105,6 m in length. When using three separate cargo tanks with horizontal distance of 1,8 m between them and a clearance of 1,8 m between the tanks and the fore and aft bulkhead forming the cargo hold area, the available length for the cargo tanks is 32,8 m per tank. The tanks are placed on top of the double bottom, and a radius of 7,5 m is set for the inner tank volume. The outer radius of the tanks is estimated to be 8 m.

3.2.3 Weight estimation

3.2.3.1 Weight calculation method

The weight estimation is done systematically in an Excel spreadsheet where each weight component is listed with its LCG, VCG and horizontal extent. The weights are grouped in the following different weight groups; steel hull, propulsion- and manoeuvring system, other main equipment, steel outfitting, systems, accommodation, miscellaneous and finally margins are added. The final weight estimation spreadsheet is shown in Appendix B.

In the first round of the design spiral the steel hull weights is calculated using areas measured from the general arrangement in *Autocad*, an estimated plate thickness and a structure factor to take care of stiffener dimensions. For equipment in the other weight categories, the weights are either assumed or found exact from data given by the manufacturer. Examples are engine dimensions and weight from an engine manufacturer, or cargo tank dimensions and weight from a tank manufacturer.

3.2.3.2 Fuel weight

An early estimation on required fuel capacity based on engine power from similar ships, and the range of the ship is carried out. The engine power is estimated to 7200 kW. The range is set to be the distance of one full round trip, which is 4550 nm. The total energy consumption is calculated. The ships fuel is to be ammonia. However, since the specific ammonia consumption for a suitable ammonia fuelled engine is not yet known, the fuel estimation is done for HFO, and a SFOC of 180 g/kWh. A safety margin of 10% is added. Then the ratio between the energy density, in MJ/L, for HFO and liquid ammonia at -33°C is used to convert the required volume for HFO to the required volume for liquid ammonia. This ratio is $\frac{35}{12,7} = 2,756$ (MAN 2019). The required volume of ammonia fuel is estimated to be 1417 m^3, which corresponds to 966 tons.

3.2.3.3 Cargo tank weight

The weight of the three cargo tanks needs to be estimated. From a list of MAN Cryo tank sizes the average weight per surface area is calculated to be 0,34 ton/m^2 (MAN 2016). This is used as a scaling factor to estimate the weight of the cargo tanks installed in the ship. The surface area per cargo tank is 824,4 m^2. It then follows that the weight of each cargo tank is estimated to 280 tons. This weight is used in the first round in the design spiral.

3.2.4 Hull structure

The hulls structural strength is evaluated at this stage in the design spiral. Based on both global design bending moments due to stillwater and wave bending moments, and local loads, the plating and stiffener dimensions in the hull is calculated. The structural design procedure described previously is used.

3.2.4.1 Stiffener topology

The ship is decided to be longitudinally stiffened. This is because it gives the hull a higher capacity against buckling due to longitudinal stresses. Further, the distance between stiffeners is set to $s = 600\ mm$ and the distance between girders is set to $l = 2400\ mm$, so that $\frac{s}{l} = 0,25$.

3.2.4.2 Design bending moments

The design bending moments consist of both stillwater moments and wave bending moments. The stillwater bending moments are taken as the bending moments calculated from the DNV rules, or as the bending moment taken from a critical loading condition, if that be greater. The stillwater bending moments calculated from the DNV Rules are the bending moments from the DNV Rules for classification of Ships Pt. 3 Ch.1 Sec. 5 rule B106 (DNV 2016). The bending moment from a critical loading condition is found from *Maxsurf Stability* where the ship is loaded so that the stillwater bending moment is maximized.

The wave bending moments are calculated from the DNV Rules for classification of Ships Pt. 3 Ch.1 Sec. 5 rule B201 (DNV 2016). Sagging and hogging moments are found for both stillwater bending moments and wave bending moments. The total design bending moments are summarised for both sagging and hogging moments separately below in Table 3.13.

Table 3.13 Design bending moments

	Sagging moments [kNm]	**Hogging moments [kNm]**
Stillwater from DNV rules	486 973 kNm	599 351 kNm
Stillwater from load case	938 817 kNm	998 619 kNm
Wave bending	824 108 kNm	711 729 kNm
Design bending moments	**1 762 925 kNm**	**1 710 348 kNm**

3.2.4.3 Critical cross section

The critical cross section is taken as the cross section amidships in the longitudinal direction. A simplification of this cross section used in the first round in the design spiral is illustrated in Figure 3.1.

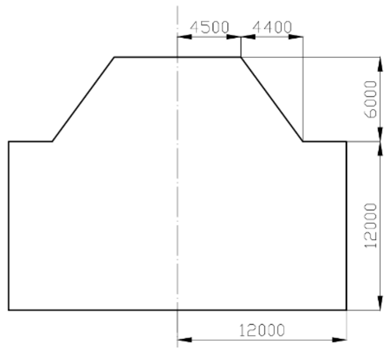

Figure 3.8 Critical cross section 1

3.2.4.4 Results

When the plating and stiffener dimension and cross section properties are calculated in an iterative process, the global longitudinal strength is evaluated. The requirement for the global longitudinal strength is satisfied when the maximum occurring stress level in the hull is below 175*f1, where f1 is the material factor. The normal steel quality NV-NS with material factor f1=1,00 is used. The plating and stiffener dimension also need to fulfil the local requirements in DNV Rules for classification of Ships Pt. 3 Ch. 1 of 2016. The resulting plating and stiffener dimensions in the first round in the design spiral is shown in

Table 3.14 Resulting structure dimensions 1st round.

Category	Component	Dimensions [mm]	Type
Bottom structure	Plating	12	Plate
	Stiffeners	340 x 12	Holland profile
	Side girder	1000 x 12, 400 x 12	Web, Flange
	Centre girder	1000 x 12, 400 x 12	Web, Flange
Side structure	Plating	12	Plate
	Stiffeners	320 x 14	Holland profile
Deck structure	Plating	10	Plate
	Stiffeners	160 x 8	Holland profile
Tank casing sides	Plating	14	Plate
	Stiffeners	370 x 18	Holland profile
Tank casing top	Plating	20	Plate
	Stiffeners	370 x 18	Holland profile

Table 3.14 Resulting structure dimensions 1st round

3.2.5 Status

The first round in the design spiral is now completed. However, a stability analysis is not carried out. This is because an analysis of the cargo capacity shows that the total volume in the cargo tanks is not sufficient.

3.2.5.1 Cargo capacity analysis

When using three identical cargo tanks the required volume in each tank is $\frac{17000\ m^3}{3} = 5667\ m^3$. The tanks with the dimensions considered in section 3.2.2.3 are cylindrical without rounded ends. These tanks have a maximum capacity of 5680 m^3, considering a permeability of 98 %. However, cylindrical type C tanks designed to withstand a pressure of 7 bar, needs to have rounded ends. Therefore, the volume capacity per tank is significantly lower than required.

Based on drawings of other cylindrical type C tanks, a cylindrical 32,8 meters long tank with rounded ends is modelled in *Maxsurf Modeler.* When this design is imported to *Maxsurf*

Stability, the volume capacity of this updated tank is calculated to be 5041 m^3, which is 626 m^3 less than required per tank.

Since the cargo capacity of the tanks is not sufficient, measures need to be taken. The cargo tanks need to be elongated. The extra length with a radius of 7,5 m needed for each tank is calculated by to be $\frac{5667\ m^3 - 5041\ m^3}{\pi * (7{,}5\ m)^2 * 0{,}98} = 3{,}6\ m$ per tank. For three tanks a total extra length of 10,8 m is needed. The resulting inner tank dimensions is showed in Figure 3.9.

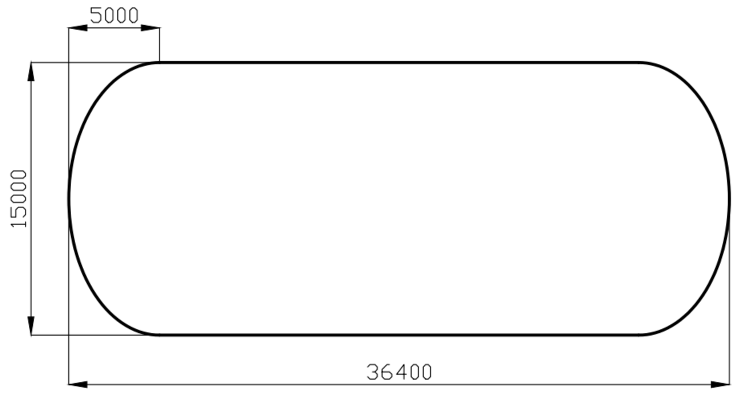

Figure 3.9 Inner cargo tank dimensions in millimetres

It is found form the general arrangement that there is not enough space in the cargo hold area for this increase in the cargo tank length. Consequently, the length of the ship is increased by 12 meters to an over all length of L_{OA} = 162 meters in order to fit three tanks with the new dimensions in the cargo hold area. The maximum length given in the project specifications in section 1.3.2.2 is 162 meters.

3.3 Design phase 3 The design spiral round 2 & 3

The workflow during the 2nd and 3rd round in the design spiral has not followed the design spiral chronologically step by step, but rather a more chaotic process has been used. As changes at one stage is made, the corresponding changes in the other stages in the design spiral is updated. An illustration of the process is shown in Figure 3.10.

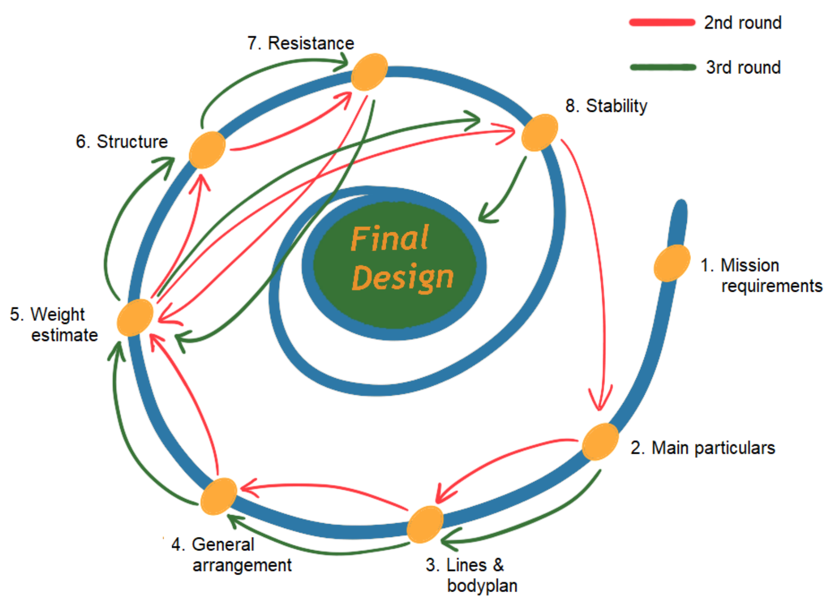

Figure 3.10 Design process phase 3

During this design phase, the major design changes are:

- A length increase to L_{OA} = 162 meters in order to fit the required cargo tanks.
- A freeboard increase to D = 15 meters in order to comply with stability criteria.

3.3.1 Main particulars

The main particulars used in the 2nd and 3rd round in the design spiral are listed in Table 3.15 below.

The change in the main particulars in the 2nd round is an increase in length to L_{OA} = 162 m, as discussed above. The length between the perpendiculars is increased accordingly to L_{PP} = 157,4 m. The breath, design waterline and depth are kept unchanged.

The stability analysis carried out in the 2nd round shows that some of the stability criteria is not fulfilled. Also, the ship floats on a deeper waterline than expected due to heavier lightship weight than expected. Therefore, the freeboard is increased to obtain better stability. The depth is increased to D = 15 m. The weight and stability in are discussed further in the following sections.

Table 3.15 Main particulars design phase 3

Dimension	**2nd round**	**3rd round**
Loa [m]	162,0 m	162,0 m
Lpp [m]	157,4 m	157,4 m
B [m]	24 m	24 m
T [m]	9,5 m	10,5 m
D [m]	12 m	15 m
C_B [-]	0,68	0,70

3.3.2 Lines plan

The hull modelled in *Maxsurf Modeler* is updated to the new length and block coefficient in the 2nd round in the design spiral. No further changes are made to the hull.

In the 3rd round in the design spiral, the depth of the modelled hull is increased to 15 meters. As discussed in the following sections, the ship floats on a deeper waterline than the design waterline in the 1st and 2nd round. Therefore, the design waterline in the 3rd round is set to T = 10,5 meters. Also, the aft ship section is updated due to an unacceptable high hull resistance. This is discussed later in section 3.3.6. The resulting block coefficient is 0,70.

3.3.3 General arrangement

Due to the length and depth increase, the general arrangement is updated accordingly. Other minor changes are also done. The rule length is now L_F = 157,4 meters. However, an increase in the amount of transverse watertight bulkheads is not needed, according to the DNV rules.

3.3.3.1 Double bottom

General arrangements from similar ships found in various publications of *Significant Ships* shows that these vessels are not fitted with a double bottom. A double bottom arrangement is normally required according to the SOLAS convention. However, “a double bottom need not to be fitted in way of watertight compartments used exclusively for the carriage of liquids, provided the safety of the ship in the event of a bottom damage is not thereby impaired” (DNV 2021a). Therefore, if it can be proven that the ship is capable of withstanding bottom damage, a double bottom need not to be fitted.

An analysis of the survivability of the ship when bottom damages is present is not carried out. However, it is assumed that in the case of bottom damages, the mounted cargo tanks will provide enough buoyancy so that the safety of the ship is not impaired. The double bottom is thereby removed from the general arrangement, which is updated accordingly. As a consequence, there is more available space for the cargo tanks.

3.3.3.2 Fuel tanks and the IGF Code

The fuel is earlier said to be liquid ammonia which is produced by Horisont Energi in Hammerfest. Information from Horisont Energi is that the ships can be fuelled at the ammonia loading port in Hammerfest. It is considered sufficient for the fuel capacity to be enough for one roundtrip with a 10 % margin added.

Since the ships fuel is ammonia, the regulations in the International Code of Safety for Ships Using Gases or Other Low-Flashpoint fuels i.e., the IGF-code, is applied. Part A-1 Regulation 5.3.3 in the IGF-Code states that the fuel tanks shall be protected from external damage caused by collision or grounding, and how the protective measures shall be taken (IMO-Vega n.d a). The minimum distance from the ship side, measured to the tank shell, is *B*/5 or 11,5 meters, whichever is less. Here *B* is the breath of the ship. The minimum distance from the ship side is therefore $B/5 = 24/5 = 4{,}8$ meters. Due to lack of available space for the fuel tanks inside the ship hull, the fuel tanks are placed on the weather deck, as shown in the general arrangement provided in the appendices.

3.3.4 Weight estimate

The weight estimate is updated continuously as the general arrangement is changed. The weight of the hull is updated to contain the weight of the plating and stiffeners with the dimensions derived from the structural analysis in the previous round in the design spiral. Also, the areas from the updated general arrangement are used.

3.3.4.1 Cargo tank weight

The estimation of the cargo tank weight in the 1st round in the design spiral is considered to be a bit low. In an e-mail from MAN-Cryo it is communicated that the weight of a cylindrical type C tank with the dimensions as shown in Figure 3.9 might be approximately 500 tons. However, this estimated weight is not certain. This is the weight of each cargo tank used in the final weight estimation. A major contribution to why the ship is significantly heavier than estimated from the statistic comes from the heavy cargo tanks.

3.3.4.2 Fuel weight

The weight estimation is updated after the resistance analysis is done in both the 2nd and 3rd round in the design spiral. This is because from the resistance analysis the required break power and thereby the required fuel capacity is calculated. The lowered hull resistance due to the updated hull lines in the aft ship results in a lowered fuel consumption, and a lesser fuel capacity is required. The results from the resistance analysis are presented in Table 3.19 in section 3.3.6 below.

With data from the resistance analysis, the required fuel capacity is calculated in the following way. The total energy consumption for one roundtrip is calculated from the hull resistance, speed, and distance. The specific ammonia consumption for the engine installed is also needed. In an email from MAN Energy Solutions, it is communicated that the specific ammonia consumption for MAN B&W 2-stroke engines is approximately 370-380 g/kWh. A mean value of 375 g/kWh is used in the calculation. Then a 10 % safety margin is added. The resulting ammonia fuel capacity is listed in Table 3.16 below.

Table 3.16 Fuel capacity 2nd & 3rd round

Round in the design spiral	Break power [kW]	Fuel capacity [tons]
2nd	10 253,97 kW	1 295,99 tons
3rd	6 520,46 kW	824,11 tons

3.3.4.3 Fuel tank weight

The fuel is contained in six identical tanks located on the weather deck. From the list of MAN Cryo tank sizes a suitable tank is chosen. The volume per tank needed is 201 m^3. One of the tanks in the list from MAN Cryo has a volume of 201 m^3. These tanks are chosen to be the fuel tanks. They weigh 80 tons per tank (MAN 2016).

3.3.5 Hull Structure

The hull strength analysis is updated in both the 2nd and the 3rd round in the design spiral. The moulded depth increase to 15 meters in the 3rd round lead to a change in the cross section used in the calculations. Also, the inner ship sides forming the ballast tanks in the ship side is modelled in the cross section. This cross section is showed in Figure 3.11.

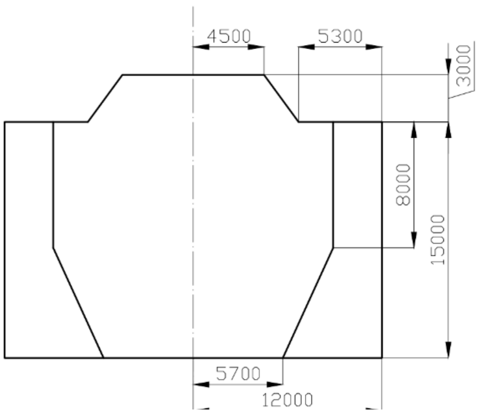

Figure 3.11 Critical cross section design spiral round 2 & 3

The design bending moments are kept unchanged. That is because the length used when calculating the bending moments from the DNV rules is the length between the perpendiculars after the length increase. Also, the bending moments from the critical loading conditions are kept unchanged because the bending moments are considered to be high enough.

Based on this new cross section, new dimensions in plate thickness and stiffeners are calculated. These are listed in Table 4.3 section 4.5.

3.3.6 Resistance analysis

The resistance analysis is carried out in *Maxsurf Resistance*. Here the modelled hull and the design waterline is imported. The input data to the calculation method for the 2nd and the 3rd round in the design spiral is listed in Table 3.17 and Table 3.18. The main difference here is the transom area and the transom waterline beam. The Holtrop resistance calculation methos is used. The resulting resistance curves for power vs speed for the 2nd and 3rd round is shown in Figure 3.12 and Figure 3.13.

Table 3.17 Input data for resistance calculation 2nd round

	Item	Value	Units
1	LWL	160,899	m
2	Beam	23,723	m
3	Draft	10,5	m
4	Displaced volume	28086,314	m^3
5	Wetted area	5557,652	m^2
6	Prismatic coeff. (Cp)	0,805	
7	Waterpl. area coeff. (Cwp)	0,908	
8	1/2 angle of entrance	23,7	deg.
9	LCG from midships(+ve for'	-2,652	m
10	Transom area	71,866	m^2
11	Transom wl beam	23,674	m
12	Transom draft	3,5	m
13	Max sectional area	216,906	m^2
14	Bulb transverse area	1,88	m^2
15	Bulb height from keel	9,5	m
16	Draft at FP	10,5	m
17	Deadrise at 50% LWL	7,6	deg.
18	Hard chine or Round bilge	Round bilge	
19			
20	Frontal Area	390	m^2
21	Headwind	0	kts
22	Drag Coefficient	1	
23	Air density	0,001	tonne/m
24	Appendage Area	288,56	m^2
25	Nominal App. length	32,55	m
26	Appendage Factor	2	
27			
28	Correlation allow.	0,0004	
29	Kinematic viscosity	0,000001188	m^2/s
30	Water Density	1,026	tonne/m

Table 3.18 Input data for resistance calculation 3rd round

	Item	Value	Units
1	LWL	160,899	m
2	Beam	23,671	m
3	Draft	10,5	m
4	Displaced volume	27978,638	m^3
5	Wetted area	5453,228	m^2
6	Prismatic coeff. (Cp)	0,803	
7	Waterpl. area coeff. (Cwp)	0,902	
8	1/2 angle of entrance	23,7	deg.
9	LCG from midships(+ve for'	-2,181	m
10	Transom area	2,769	m^2
11	Transom wl beam	14,747	m
12	Transom draft	0,288	m
13	Max sectional area	216,654	m^2
14	Bulb transverse area	1,88	m^2
15	Bulb height from keel	9,5	m
16	Draft at FP	10,5	m
17	Deadrise at 50% LWL	7,5	deg.
18	Hard chine or Round bilge	Round bilge	
19			
20	Frontal Area	390	m^2
21	Headwind	0	kts
22	Drag Coefficient	1	
23	Air density	0,001	tonne/m
24	Appendage Area	288,56	m^2
25	Nominal App. length	32,55	m
26	Appendage Factor	2	
27			
28	Correlation allow.	0,0004	
29	Kinematic viscosity	0,000001188	m^2/s
30	Water Density	1,026	tonne/m

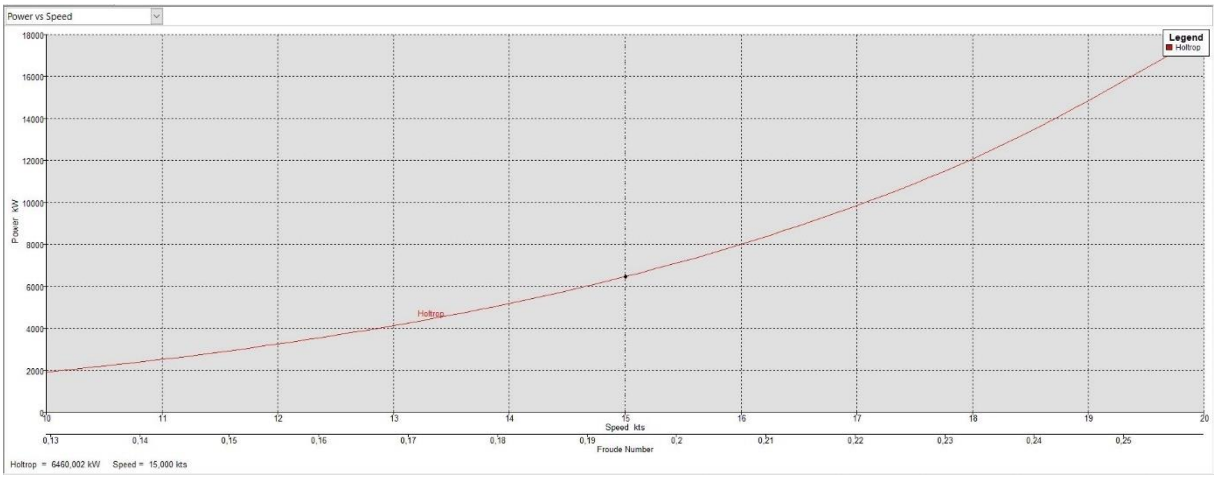

Figure 3.12 Resistance curve 2nd round

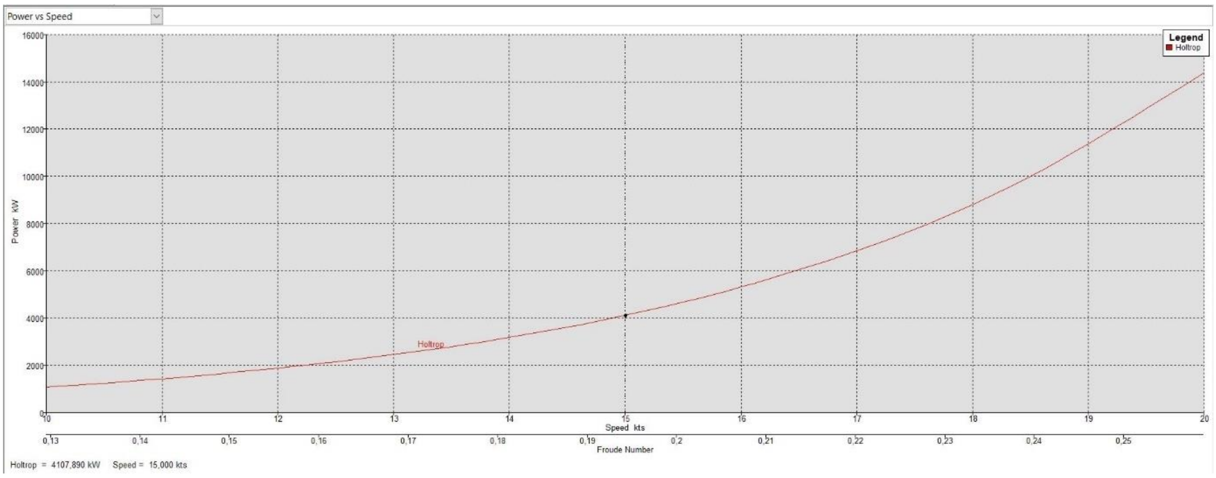

Figure 3.13 Resistance curve 3rd round

The reduced transom area as shown in Table 3.17 and Table 3.18 resulted in a significantly lowered resistance and consequently installed power, as shown in Figure 3.12 and Figure 3.13.

For the design speed at 15 knots, the results from the resistance analysis are shown in Table 3.19 below. The updated hull in the aft ship resulted in a reduction in the hull resistance by 36,4 %. To calculate the required break power delivered from the engine, the propulsion efficiency, η_D, of the propeller and mechanical efficiency, η_M, of the shaft and gearbox needs to be considered. The propeller efficiency is set to 66 %, and the mechanical efficiency is set to 96 %. A more detailed analysis of the efficiencies used in the resistance analysis is not carrier out. The total efficiency, η_T, then becomes $\eta_T = \eta_D * \eta_M = 0{,}66 * 0{,}96 = 0{,}63$. With a total efficiency of η_T = 0,63, to propel the ship forwards at 15 knots, the required installed break power is 6520,46 kW, as shown in Table 3.19 below.

Table 3.19 Resistance analysis results

Round in the design spiral	Holtrop resistance [kN]	Power [kW], 100 % efficiency	Power [kW], 63 % efficiency
2nd	837,10 kN	6 460,00 kW	10 253,97 kW
3rd	532,30 kN	4 107,89 kW	6 520,46 kW

3.3.7 Stability

The final stage in the design spiral is a stability analysis. In *Maxsurf Stability*, stability for each loading condition is checked. The trim and draft are also checked. The loading conditions with description is listed in Table 3.20 below.

3.3.7.1 Loading conditions

The loading conditions are made from the lightship weight the deadweight. The deadweight is calculated by setting the fill percent in each of the modelled cargo and ballast water tanks. The fuel weights are added manually as individual weights. As a consequence of the fuel tanks being located on top of the weather deck, they could not be modelled as tanks in the hull in *Maxsurf Stability.*

Table 3.20 Loading conditions

Loading condition	Cargo	Fuel	Ballast
Lightship	No	No	No
Departure port CO_2	CO_2, 100%	100%	1 530 tons
Departure port NH_3	NH_3, 100%	100%	No
Arrival port CO_2	CO_2, 100%	10%	1 682 tons
Arrival port NH_3	NH_3, 100%	10%	No
Departure port ballast	No	100%	5 415 tons
Arrival port ballast	No	10%	6 515 tons

3.3.7.2 Draft

The analysis in the 2nd round in the design spiral showed that the vessel floats on a deeper waterline than expected from the statistics in the 1st round. The final weight of the ship in the departure port with CO_2 loading condition is 30 392 tons, an increase of 5 400 tons compared to the statistics. Therefore, the draft of the design waterline is increased, by 1 meter, to T_{DWL} = 10,5 meters.

3.3.7.3 Stability

The ships stability is checked to fulfil the requirements found in the IMO MSC.267(85) Code on Intact Stability Ch2 - General Criteria. This contains requirements to the area under the GZ curve. The stability criteria is listed in Table 3.21 below.

Table 3.21 IMO stability criteria

Criteria number	Criteria	Minimum value
2.2.1.a	Area 0 to 30 deg	3,1513 m.deg
2.2.1.b	Area 0 to 40 deg	5,1566 m.deg
2.2.1.c	Area 30 to 30 deg	1,7189 m.deg
2.2.2	Max GZ at 30 deg or greater	0,200 m
2.2.3	Angle of maximum GZ	25,0 deg
2.2.4	Initial GM_t	0,150 m
2.3	Severe wind and rolling	
	Angle of steady heel	Max 16,0 deg
	Angle of steady heel / deck immersion angle	Max 80 %
	Area1 / Area2	Min 100 %

The stability analysis in the 2nd round in the design spiral showed that the stability criteria was not fulfilled for the departure port with CO_2 loading condition. The criteria number 2.2.3.c, 2.2.2, and 2.2.3 failed by -29,80%, -5,00%, and -12,73% respectively. The resulting GZ curve for the loading condition after the 2nd round in the design spiral is shown in Figure 3.14 below.

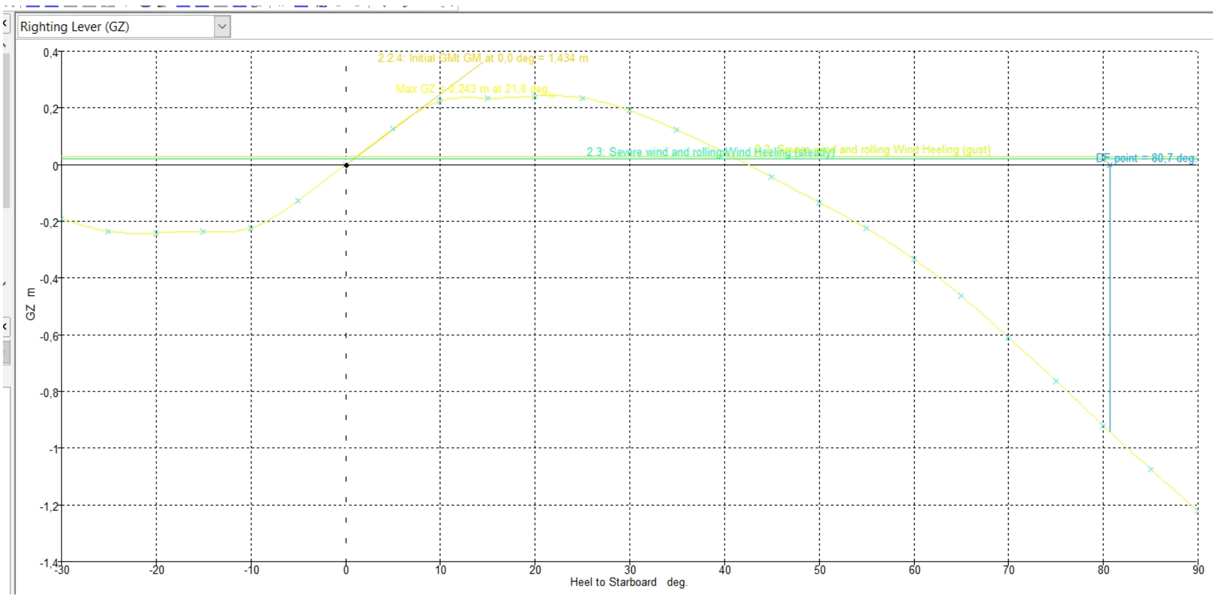

Figure 3.14 GZ curve for departure port CO2 2nd round

Since the stability criteria was not fulfilled, it was decided to increase the freeboard. The moulded depth was increased by 3 meters to D = 15 meters. This led to the stability criteria being fulfilled for all the loading conditions in the 3rd round in the design spiral.

3.3.7.4 Required freeboard

The required freeboard from the International Convention on Load Lines is calculated from regulation 28, 30, and 31 in Chapter 3 (IMO-Vega n.d b). The tabular freeboard for a type A ship with a length of 157 m is found to be 2 080 mm from regulation 28. A type A ship is a vessel designed to carry only liquid cargoes in bulk. A correction factor for the block coefficient is found using regulation 30. For a block coefficient of 0,7, the correction factor is 1,0147. Also, a correction for depth is found from regulation 31. With the rule length and depth of the ship as input, the correction becomes 1 127 mm. The resulting required freeboard then becomes

$$2\ 080\ mm * 1{,}0147 + 1\ 127\ mm = 3\ 238\ mm.$$

The freeboard when the ship is floating on the design waterline is

$$15\ 000\ mm - 10\ 500\ mm = 4\ 500\ mm.$$

The loading condition with the deepest waterline is the departure port with CO2 loading condition, with a waterline at 11 000 mm. At this loading condition, the resulting freeboard is $15\ 000\ mm - 11\ 000\ mm = 4\ 000\ mm$. The ship therefore fulfils the tabular freeboard requirements in the International Convention on Load Lines.

3.4 Design phase 4 Energy source and propulsion system

According to the specifications given by Horisont Energi, the ship is to be a carbon emission free vessel. Therefore, traditional fuels like HFO, MDO, MGO, and LNG cannot be used. A discussion of alternative fuels and the propulsion systems is presented below.

3.4.1 Energy source

The maritime industry is currently facing a fuel transition from fossil fuels to non-fossil fuels. In order to tackle climate change, it is certain that this transition is coming. However, it is not certain which fuel we are transitioning to (DNV 2021c). It is not only sufficient to introduce fuels that have a zero or next to none GHG emissions when burned. The total CO_2 and GHG emissions during the fuel's lifecycle needs to be taken into account. In the DNV Maritime Forecast to 2050 report, this is referred to as tank-to-propeller emissions and well-to-tank emissions (DNV 2021c).

The well-to-tank perspective for the fuel is important. That is because the fuel's potential to reduce GHG emissions depends on the energy source, the fuel processing, and the supply chain (DNV 2021c). If a non-fossil fuel requires much energy in the production process, and is produced using energy from fossil-fuels, the reduction in lifecycle-GHG emissions is likely to be none or even negative. If a long and energy consuming supply chain is present, the reduction in GHG emissions might be considerably lower than expected. This shows that the total lifecycle-GHG emissions needs to be considered.

The DNV Maritime Forecast to 2050 states that the fuels need to be produced by either renewable energy sources or zero carbon energy sources. These primary energy sources can be categorized as (DNV 2021c):

- **Biofuels** from sustainable bioenergy sources
- **Electrofuels** from renewable electricity
- **Blue fuels** from reformed natural gas using CCS

The non-fossil fuels for future use discussed in the DNV Maritime Forecast to 2050 are ammonia, hydrogen, and methanol. These fuels are discussed as potential fuels to use for the vessel in this project. In Table 3.22 below, the fuels are listed with energy content, energy density, technology readiness level (TRL) for internal combustion engines (ICEs), and challenges. MGO is also included. The data is found in the MAN B&W two-stroke engine operating on ammonia (MAN 2020), and the DNV Maritime Forecast to 2050 (DNV 2021c). A description of the TRL levels is provided in Appendix C.

Table 3.22 Non-fossil fuel candidates

Fuel	Energy content, LHV [MJ/kg]	Energy density [MJ/L]	TRL	Challenges
Ammonia (NH_3) (liquid, -33°C)	18,6	12,7	5-6	Toxicity, Combustion properties, N_2O emissions, Potential ammonia slip
Hydrogen (H_2) (liquid, -253°C)	120	8,5	6-7	No class rules developed, Potential explosion risk, Very low boiling temperature
Methanol (CH_3OH) (65°C)	19,9	14,9	9	Not a fully carbon free fuel
MGO	42,7	35,7	9	A fossil-fuel

3.4.1.1 Methanol

Methanol is a promising future fuel for the maritime industry and can be produced from renewable feedstocks like bioenergy. Of the three non-fossil fuel candidates, methanol has the highest energy density. Also, the TRL for methanol is 9. The technology is ready for commercial application. Two-stroke methanol engines are commercially available (DNV 2021c). Despite these positive sides, methanol is not chosen as the fuel to be used. Methanol contains carbon, and CO_2 is produced in the combustion process.

3.4.1.2 Hydrogen

Hydrogen can be an electrofuel produced from electrolysis of water. When the electricity used comes from renewable sources, it becomes a carbon-neutral fuel.

Liquid hydrogen has a high energy content of 120 MJ/kg, however, the volumetric energy density of 8,5 MJ/L is very low. Therefore, for deep sea transport, the use of hydrogen is challenging due to the amount of storage space required. The fuel tank size needed for liquid hydrogen relative to MGO is 4,2 times the size, when considering energy density.

Because of the low ignition energy and the wide flammability range of hydrogen, there exists a potential risk of explosion. Hydrogen is also challenging to store in its liquid form due to its very low boiling temperature (DNV 2021c). Hydrogen is stored in its liquid form either at a high pressure of 250-700 bar or at very low temperatures of -253 °C. This is expensive and volume intensive (DNV 2020), and makes it difficult to handle hydrogen both ashore and onboard. The TLR of hydrogen is 6-7.

The liquification process for hydrogen requires a lot of energy, because hydrogen is liquefied at -253 °C. The energy needed to liquefy hydrogen varies with the capacity of the liquefaction plant. For the largest liquefaction plants, with a capacity of 1000 kg/h, at least 30 % of the higher heating value (HHV) of hydrogen is needed. The energy needed increases with lowered liquefaction plant capacity. For small plants the energy used in the liquefaction process may even exceed the HHV of hydrogen (Ulf Bossel n.d). Hydrogen is not the chosen fuel for the ship in this project.

3.4.1.3 Ammonia

Safety and regulatory challenges, and challenges regarding storing large quantities of hydrogen onboard ships, have led to the exploration of alternative hydrogen based energy carriers such as ammonia (DNV 2021c).

There are some advantages to using ammonia compared to hydrogen. Ammonia has a volumetric energy density of 12,7 MJ/L, which is considerably higher than for hydrogen. When comparing the volumetric energy density of ammonia and MGO, it is found that a tank volume 2,8 times larger is needed to carry the same amount of energy in ammonia compared to MGO. The lower heating value of 18,6 MJ/kg is comparable to methanol (MAN 2020).

Ammonia can be stored at much higher temperatures than hydrogen. See Table 3.22. Therefore, it is less expensive and less complex to transport and store than hydrogen and other fuels in need of cryogenic temperatures (MAN 2020).

The lower explosion limit of ammonia at 15 % is higher than for hydrogen. The minimum ignition energy of ammonia is 8 mJ compared to 0,017 mJ for hydrogen (DNV 2020). Therefore, the lower risk of fire and explosion in ambient atmosphere for ammonia makes it safer to store in large quantities in terms of fire safety (MAN 2020).

Challenges related to ammonia as fuel include toxicity, combustion properties, nitrous oxide (N_2O) emissions, and potential ammonia slip (DNV 2021c). To manage the toxicity of ammonia, safety precautions need to be in place. It is vital to detect any leakages and direct these to a safe location. Double-walled design of fuel systems and piping is needed. Also, an ammonia capture system must be in place to prevent the release of ammonia to the surroundings (MAN 2020).

Ammonia has a low flame speed and narrow flammability range of 15-28 % (DNV 2020). Therefore, a low engine speed is needed to make time for the combustion to finish. Large dimensions lead to large volume-to-surface ratios, which are beneficial for a complete combustion (MAN 2020). Therefore, a large slow speed two-stroke combustion engine is suitable for burning ammonia.

The combustion of ammonia does not produce CO_2 because it does not contain carbon. However, there are other potential emission to air gasses. The NO_x levels produced in a two-stroke ammonia engine is expected to be in the range of a low-speed diesel engine. To reduce these emissions selective catalytic reduction (SCR) technology can be used. Ammonia, which is already carried as fuel, can be used as the catalytic agent (MAN 2020).

Other emissions to air that need to be minimized are ammonia slip and N_2O emissions. This is due to the toxicity of ammonia, and the high global warming potential of 265 (DNV 2020) for N_2O. These emissions can be minimized by ensuring a complete combustion of the ammonia fuel (MAN 2020). It is important that the introduction of a new non-fossil fuel to be used in the maritime sector does not arise new problematic emission problems for the shipping industry.

The TRL level for ammonia is estimated by DNV to be 5-6, which is a bit lower than for hydrogen and methanol. However, DNV has published the first-ever class rules for ammonia as fuel, in July 2021 (DNV 2021c).

The underlying reason for why this project is started, is because Horisont Energi is planning on producing ammonia from natural gas, using CCS, in Hammerfest. This makes the ammonia fuel a blue carbon-free fuel. It is also convenient to choose ammonia due to its availability at the production plant. As a consequence, the supply chain is super short and does not lead to any GHG-emissions, because transportation is not needed. This, combined with the facts discussed earlier in this chapter results in that ammonia, produced by Horisont Energi as a blue carbon-free fuel, is chosen as the fuel to be used in this project.

3.4.2 Propulsion system

The propulsion system on the ship is in this project is considered to contain the systems from the main engine to the propeller and rudder. Sufficient propulsion and manoeuvrability, maximized efficiency, and power generation for electricity consumers and auxiliary systems are deciding factors when choosing the propulsion system. Efficiency is especially emphasised to keep the volume needed for the ammonia fuel to a minimum.

3.4.2.1 Main energy converter

The main energy converter is converting the chemical energy in the fuel to either rotational energy in the case of an ICE, or to electricity in the case of a fuel cell. DNV estimates the TRL for these ammonia energy converters to be 6-7. However, the fuel cell technology is generally less mature than ICEs. Fuel cells have yet to be commercially applied in shipping (DNV 2021c).

Two-stroke internal combustion engines are considered as the best energy converter due to large combustion chambers and long time scales with low RPM. This enables ammonia, with a slow burn rate to fully combust. Other advantages with ICEs compared to fuel cells is cost, power density, load response and robustness (DNV 2020).

MAN Energy Solutions is currently in a process of developing a two-stroke ammonia engine. In the *MAN B&W two-stroke engine operating on ammonia*, they write that “We will finalise the development process of the ammonia engine in 2021 and the commercial design verification is scheduled for 2023” (MAN 2020). Based on this a two-stroke ammonia engine is chosen as the main energy converter for the ship.

3.4.2.2 Power transmission

The power transmission from the engine to the propeller can either be mechanical through a shaft, or electrical. The highest transmission efficiency is obtained with a mechanical drive. Also, the arrangement of the engine room and propeller makes a mechanical transmission suitable, and an electrical transmission is not necessary. Therefore, a mechanical transmission through a shaft is chosen. Also, using a two-stroke slow speed ICE as a generator is not convenient due to the large dimensions and low RPM.

3.4.2.3 Propeller

The ship in this project has a relatively simple operational profile which mainly consists of time in transit, with a constant propulsion power demand, and time in harbour. A fixed pitch propeller is therefore favourable, due to a higher efficiency compared to a variable pitch propeller. Also, the number of propellers is evaluated. The highest efficiency is obtained with only one propeller. Therefore, one fixed pitch propeller is chosen to propel the ship. The aftship is designed so that one large propeller can be fitted. A bow thruster is fitted in the bow to obtain sufficient manoeuvrability.

3.4.2.4 Electricity production

Electricity is needed to power auxiliary systems like cargo handling systems, fuel supply systems, steering gear, bow thruster, and accommodation loads. Since the ship is to be a carbon emission free vessel, axillary diesel generators cannot be used.

As earlier mentioned, using slow speed two-stroke ICEs as auxiliary engines is not convenient. Four-stroke ICEs with smaller dimensions and higher RPM is more suitable. Wärtsilä have started developing a four-stroke ICE able to run on ammonia. Together with shipowners and energy companies, Wärtsilä plans to begin its first full scale, four-stroke engine tests in 2021 (Wärtsilä 2020). The product platform W31 provide modularity for the potential future conversion for ammonia use (DNV 2020). The Wärtsilä 31 product platform can be used as an auxiliary engine (Wärtsilä 2021), which is an electric power generator.

Another option for power generation is to use a shaft generator. The onboard electricity consumers have to be supplied with electric power with constant voltage and frequency by the shaft generator whilst RPM of the main engine changes (Wärtsilä n.d a). Therefore, a frequency converter is needed in the arrangement. Then the shaft generator and frequency converter combined can supply three-phase current with constant voltage and frequency. This is a PTO (power take out) system. Electric power generation from a shaft generator is a preferred solution because the main engine powering the generator and the propeller can be run at optimal RPM and loads. In this way the fuel consumption is minimized.

In the case where an ammonia fuelled four-stroke generator is commercially available, it could be beneficial to include both a shaft generator and an auxiliary ammonia generator. The auxiliary generator could be used to power cargo handling systems and accommodation when in harbour. Also, a PTI/PTH (power take in / power take home) system could be included in the machinery arrangement. Then the propeller could also be powered by the auxiliary generator. With this configuration redundancy is obtained, and the propeller could be powered by PTI/PTH in the case of main engine failure. This arrangement gives freedom in the power generation and distribution (Wärtsilä n.d a).

The discussion of the machinery arrangement above leads to the following choices. A two-stroke ammonia ICE will be the main energy converter to power the fixed pitch propeller through a mechanical shaft. A shaft generator is installed on the shaft between the main engine and the propeller. For power generation in harbour, and for redundancy, one or multiple auxiliary ammonia powered generators is included in the arrangement. A main switchboard is also needed for power distribution. Between the shaft generator and the main switchboard, a frequency converter is installed so that electric power with constant voltage and frequency can be supplied to the main switchboard. The frequency converter is also used to power the PTI/PTO system in the shaft generator. Finally, the bow thruster is powered by electric current with the desired frequency from the frequency converter. The resulting machinery arrangement is illustrated below in Figure 3.15.

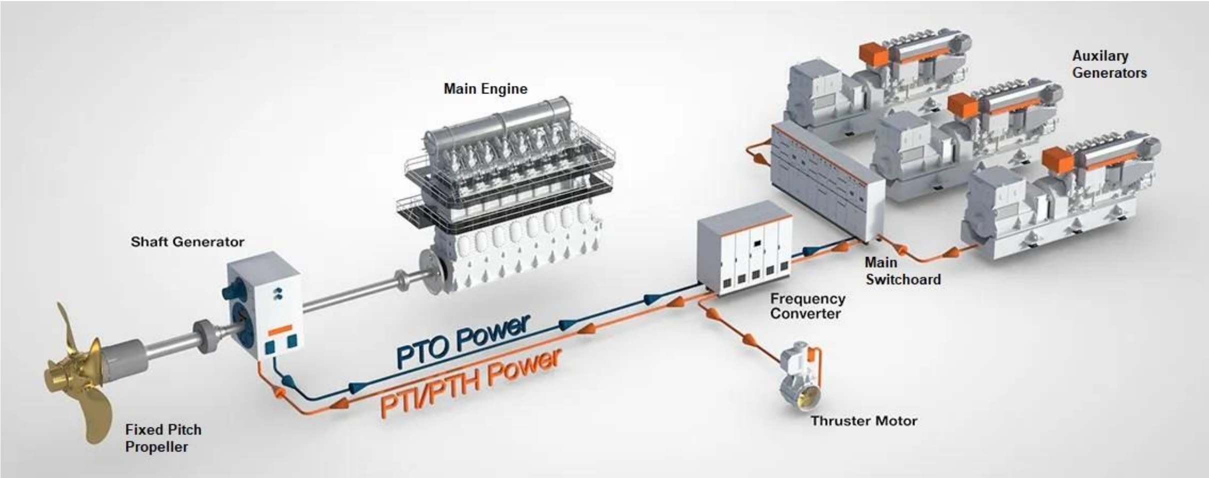

Figure 3.15 Machinery arrangement, (Wärtsilä n.d a)

The calculation of the required fuel capacity is done based on the power required to propel the ship at the design speed of 15 knots, and safety margin of 10% is added. The calculation does not consider the fuel consumption related to electric power generation. Therefore, the fuel capacity of the ship might not be sufficient. This problem could be solved by using boil of gas in the ammonia cargo tanks as fuel. Another option is to include ammonia bunkering in Rotterdam in the logistics. However, this problem is not further considered in this project.

4 Results

The final design in this Bachelor's thesis is a result from the mission requirements given by Horisont Energi after the completement of three rounds in the design spiral. The result is presented in the following sections.

4.1 Main Particulars

The final main particulars are listed below in Table 4.1. They are within the constraints given in the project specification.

Table 4.1 Final main particulars

DWT [ton]	20 018 ton
LWT [ton]	8 442 ton
Displacement [ton]	28 460 ton
L_{pp} [m]	157,4 m
L_{oa} [m]	162 m
B [m]	24 m
T [m]	10,5 m
D [m]	15 m
C_B [-]	0,70
L/B [-]	6,56
B/T [-]	2,29
B/D [-]	1,60
L/D [-]	10,49

4.2 Hull lines

A screenshot of the resulting hull shape is shown below in Figure 4.1 .The final lines plan is also supplied in the appendices.

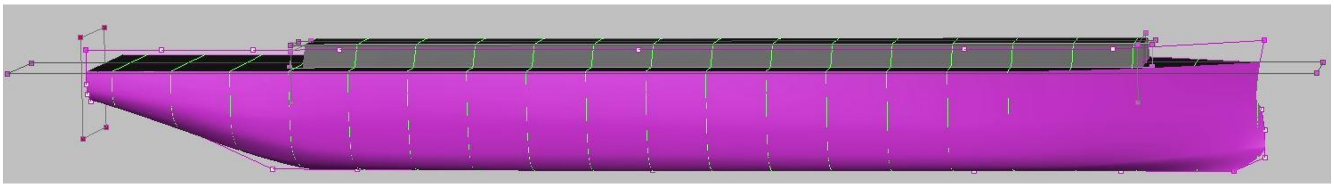

Figure 4.1 Final hull shape

A detailed modelling of a bulbous bow and a skeg is not done in this project due to lack of time and the fact that they are not considered to be of importance at this stage in the design process. However, if there was time to complete a fourth round in the design spiral, it would be natural include a more detailed design of these elements.

4.3 General arrangement

The resulting general arrangement is supplied in the appendices. A screenshot of the profile view is shown in Figure 4.2 below. Also, a tank plan can be found in the appendices

Horizontal cylindrical type C tanks is chosen due to the design pressure of 7 bar. Also, a cylindrical shape is preferred due to the rapid purge technology that is to be used. The thickness of the tanks is estimated to be 500 mm, without a further tank structure analysis. There is a clearance of 1 000 mm from the outer tank walls to the surroundings.

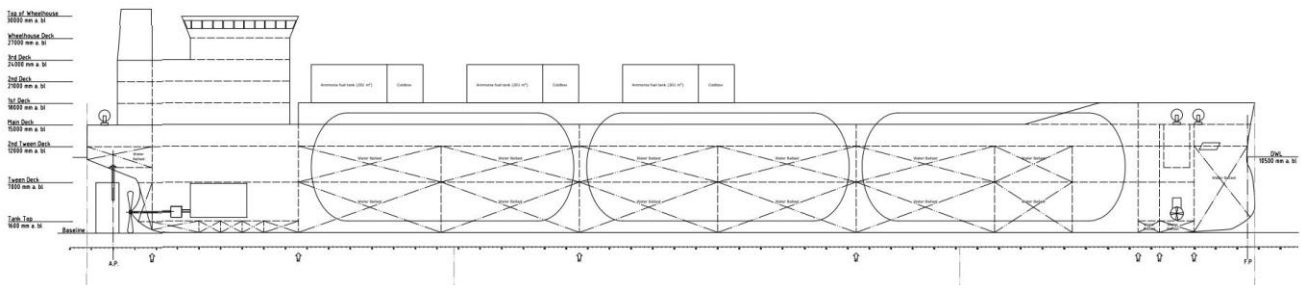

Figure 4.2 Profile view arrangement

4.4 Weight estimation

The final estimated LWT is 8 442 tons, which is 3 042 tons more than estimated from the statistics. As discussed earlier, a major contribution to this comes from the heavy cargo tanks. In Table 4.2 the weight of each weight group in the LWT is listed. Figure 4.3 shows the LWT distribution. The total weight of the cargo tanks is 1 500 tons. This is 75 % of the steel outfitting weight, and 18 % of the total LWT. The calculation spreadsheet in excel is supplied in the Appendix B.

Table 4.2 LWT weight groups

Weight group	Total weight
Steel hull	3 642,5 tons
Propulsion and manoeuvring system	236,5 tons
Other main equipment	126,0 tons
Steel outfitting	1 994,4 tons
Systems	747,0 tons
Accommodation	258,8 tons
Miscellaneous	30,0 tons
Margins	1 407,0 tons
Total LWT	**8 442,3 tons**

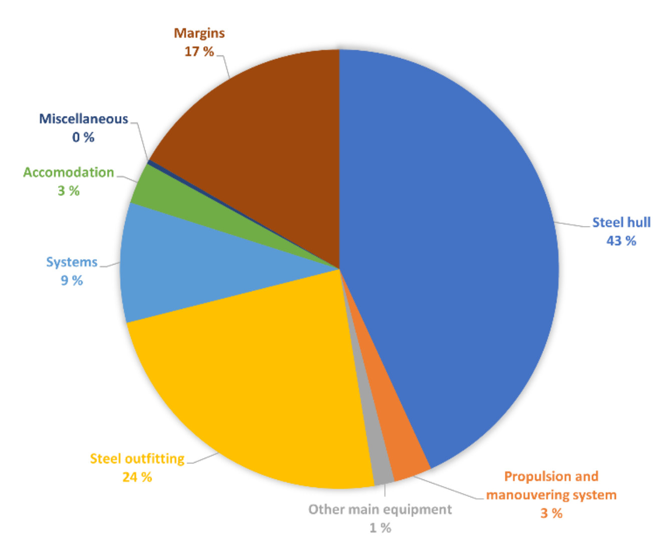

Figure 4.3 LWT distribution

4.5 Hull structure

The final hull structure is a result from the SDP method in round three in the design spiral, with input from the simplified critical cross section in Figure 3.11 and the design bending moments in Table 3.13. A screenshot of the cross-section frame with stiffeners is shown in Figure 4.4. The final structure dimensions are listed in Table 4.3.

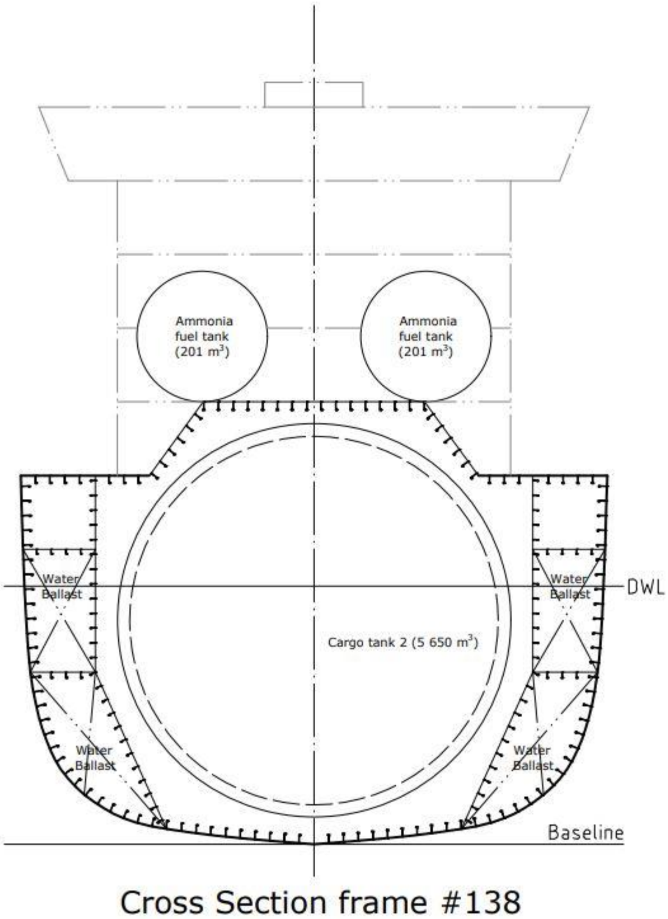

Figure 4.4 Resulting critical cross section

Table 4.3 Final structure dimensions

Category	Component	Dimensions [mm]	Type
Bottom structure	Plating	12	Plate
	Stiffeners	340 x 13	Holland profile
	Side girder	1000 x 12, 400 x 12	Web, Flange
	Centre girder	1000 x 12, 400 x 12	Web, Flange
Outer side structure	Plating	12	Plate
	Stiffeners	340 x 13	Holland profile
Inner side structure, lower	Plating	7	Plate
	Stiffeners	240 x 11	Holland profile
Inner side structure, upper	Plating	6	Plate
	Stiffeners	200 x 11	Holland profile
Deck structure	Plating	12	Plate
	Stiffeners	320 x 14	Holland profile
Tank casing sides	Plating	13	Plate
	Stiffeners	320 x 16	Holland profile
Tank casing top	Plating	17	Plate
	Stiffeners	340 x 16	Holland profile

4.6 Loading conditions

The seven loading conditions defined in *Maxsurf Stability* are presented in the following sections with displacement, draft, trim, still water moment, and a stability analysis. All the stability criteria in the IMO MSC.267(85) Code on Intact Stability Ch2 - General Criteria, listed in Table 3.21, are fulfilled for all the defined loading conditions. The defined weights, the resulting still water bending moments, stability report, and the GZ-curve for all loading conditions can be found in Appendix F. The amount of cargo, fuel and ballast are specified in Table 3.20.

4.6.1 LC Lightship

The main results from the hydrostatics, longitudinal strength and stability for the lightship loading condition are presented in Table 4.4 below.

Table 4.4 LC Lightship hydrostatics, longitudinal strength, and stability

Hydrostatics				
Displacement	Draft at AP	Draft Amidships	Draft at FP	Trim
8 442 tons	6,1 m	4,1 m	2,1 m	+3,9 m
Longitudinal Strength				
Stillwater bending moment		Type of bending moment		
413 517 kNm		Hogging moment		
Stability				
Initial GMt	Max GZ	Angle of max GZ		
3,30 m	1,05 m	28,2 deg		

The resulting waterline for the lightship loading condition is shown in Figure 4.5 below.

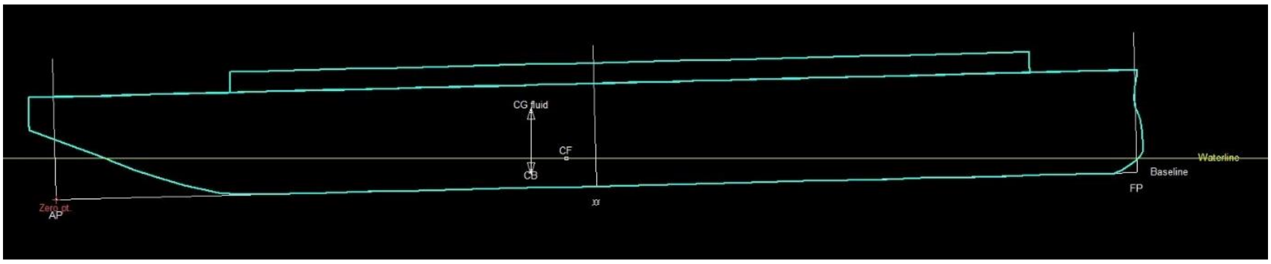

Figure 4.5 LC Lightship waterline

4.6.2 LC Departure Port CO_2

The main results from the hydrostatics, longitudinal strength and stability for the departure port with CO_2 loading condition are presented in Table 4.5 below.

Table 4.5 LC Departure Port CO2 hydrostatics, longitudinal strength, and stability

Hydrostatics				
Displacement	Draft at AP	Draft Amidships	Draft at FP	Trim
30 392 tons	11,0 m	11,0 m	11,0 m	+0,0 m
Longitudinal Strength				
Stillwater bending moment		Type of bending moment		
166 360 kNm		Sagging moment		
Stability				
Initial GMt	Max GZ	Angle of max GZ		
1,38 m	0,62 m	25,9 deg		

The resulting waterline for the departure port with CO_2 loading condition is shown in Figure 4.6 below.

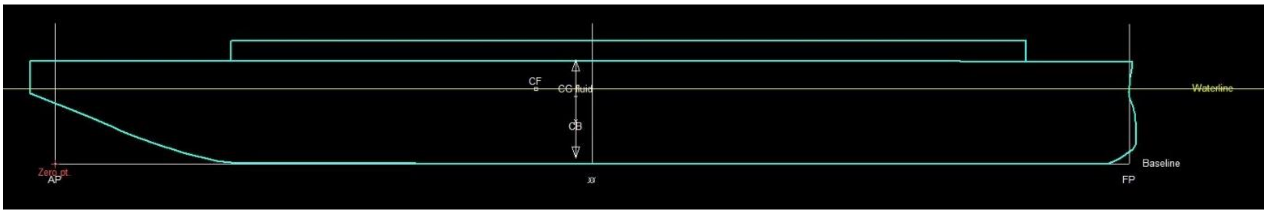

Figure 4.6 LC Departure Port CO2 waterline

4.6.3 LC Departure Port NH_3

The main results from the hydrostatics, longitudinal strength and stability for the departure port with NH_3 loading condition are presented in Table 4.6 below.

Table 4.6 LC Departure Port NH3 hydrostatics, longitudinal strength, and stability

<table>
<tr><th colspan="30">Hydrostatics</th></tr>
<tr><td colspan="6">Displacement</td><td colspan="6">Draft at AP</td><td colspan="6">Draft Amidships</td><td colspan="6">Draft at FP</td><td colspan="6">Trim</td></tr>
<tr><td colspan="6">20 845 tons</td><td colspan="6">8,5 m</td><td colspan="6">8,2 m</td><td colspan="6">7,9 m</td><td colspan="6">+0,6 m</td></tr>
<tr><th colspan="30">Longitudinal Strength</th></tr>
<tr><td colspan="15">Stillwater bending moment</td><td colspan="15">Type of bending moment</td></tr>
<tr><td colspan="15">92 379 kNm</td><td colspan="15">Hogging moment</td></tr>
<tr><th colspan="30">Stability</th></tr>
<tr><td colspan="10">Initial GMt</td><td colspan="10">Max GZ</td><td colspan="10">Angle of max GZ</td></tr>
<tr><td colspan="10">0,89 m</td><td colspan="10">0,87 m</td><td colspan="10">38,2 deg</td></tr>
</table>

The resulting waterline for the departure port with NH_3 loading condition is shown in Figure 4.7 below.

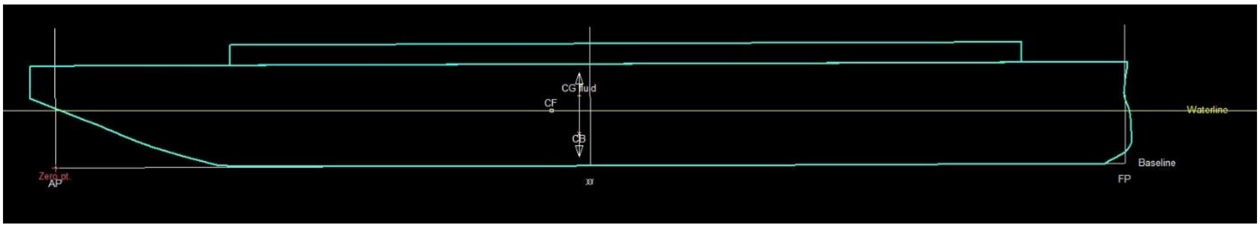

Figure 4.7 LC Departure Port NH3 waterline

4.6.4 LC Arrival Port CO_2

The main results from the hydrostatics, longitudinal strength and stability for the arrival port with CO_2 loading condition are presented in Table 4.7 below.

Table 4.7 LC Arrival Port CO2 hydrostatics, longitudinal strength, and stability

Hydrostatics				
Displacement	Draft at AP	Draft Amidships	Draft at FP	Trim
29 785 tons	10,7 m	10,8 m	10,9 m	-0,2 m
Longitudinal Strength				
Stillwater bending moment		Type of bending moment		
115 591 kNm		Sagging moment		
Stability				
Initial GMt	Max GZ	Angle of max GZ		
1,66 m	0,78 m	28,6 deg		

The resulting waterline for the arrival port with CO_2 loading condition is shown in Figure 4.8 below.

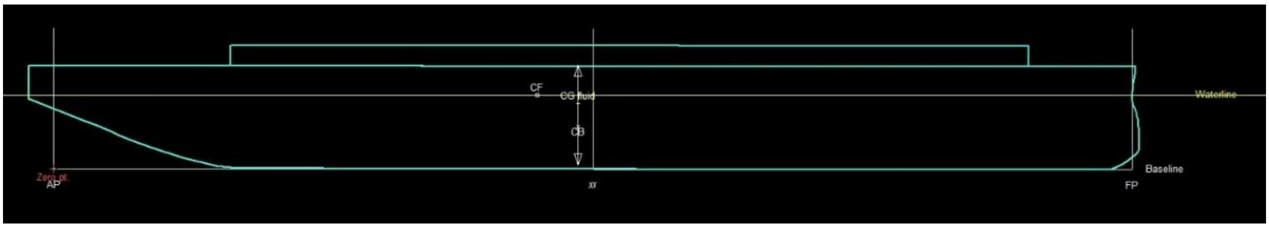

Figure 4.8 LC Arrival Port CO2 waterline

4.6.5 LC Arrival Port NH_3

The main results from the hydrostatics, longitudinal strength and stability for the arrival port with NH_3 loading condition are presented in Table 4.8 below.

Table 4.8 LC Arrival Port NH3 hydrostatics, longitudinal strength, and stability

Hydrostatics				
Displacement	Draft at AP	Draft Amidships	Draft at FP	Trim
20 086 tons	8,1 m	8,0 m	7,8 m	+0,3 m
Longitudinal Strength				
Stillwater bending moment		Type of bending moment		
123 564 kNm		Hogging moment		
Stability				
Initial GMt	Max GZ	Angle of max GZ		
1,29 m	1,15 m	40,0 deg		

The resulting waterline for the arrival port with NH_3 loading condition is shown in Figure 4.9 below.

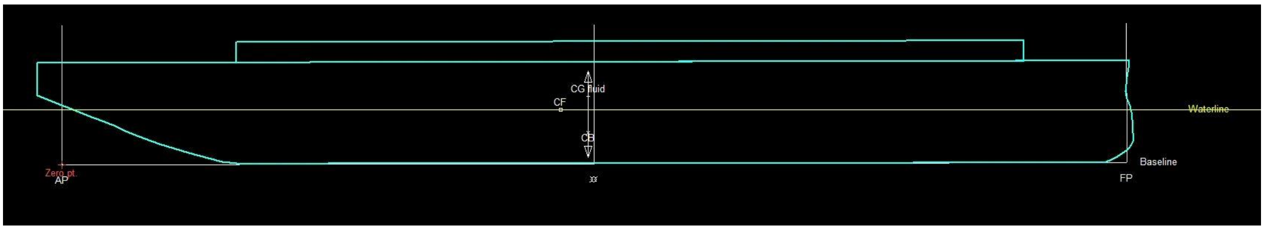

Figure 4.9 LC Arrival Port NH3 waterline

4.6.6 LC Departure Port Ballast

The main results from the hydrostatics, longitudinal strength and stability for the departure port with ballast loading condition are presented in Table 4.9 below.

Table 4.9 LC Departure Port Ballast hydrostatics, longitudinal strength, and stability

Hydrostatics				
Displacement	Draft at AP	Draft Amidships	Draft at FP	Trim
14 701 tons	7,2 m	6,2 m	5,3 m	+2,0 m
Longitudinal Strength				
Stillwater bending moment		Type of bending moment		
224 258 kNm		Hogging moment		
Stability				
Initial GMt	Max GZ	Angle of max GZ		
2,23 m	1,60 m	45,0 deg		

The resulting waterline for the departure port with ballast loading condition is shown in Figure 4.10 below.

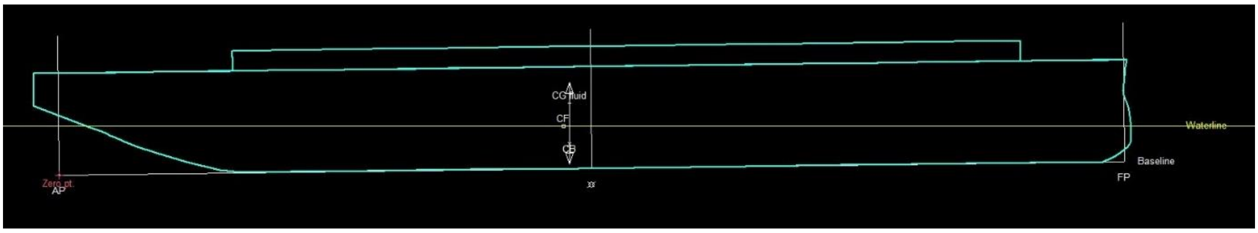

Figure 4.10 LC Departure Port Ballast waterline

4.6.7 LC Arrival Port Ballast

The main results from the hydrostatics, longitudinal strength and stability for the arrival port with ballast loading condition are presented in Table 4.10 below.

Table 4.10 LC Arrival Port Ballast hydrostatics, longitudinal strength, and stability

Hydrostatics				
Displacement	Draft at AP	Draft Amidships	Draft at FP	Trim
15 042 tons	7,7 m	6,3 m	5,0 m	+2,7 m
Longitudinal Strength				
Stillwater bending moment		Type of bending moment		
204 684 kNm		Hogging moment		
Stability				
Initial GMt	Max GZ	Angle of max GZ		
2,81 m	2,02 m	45,9 deg		

The resulting waterline for the arrival port with ballast loading condition is shown in Figure 4.11 below.

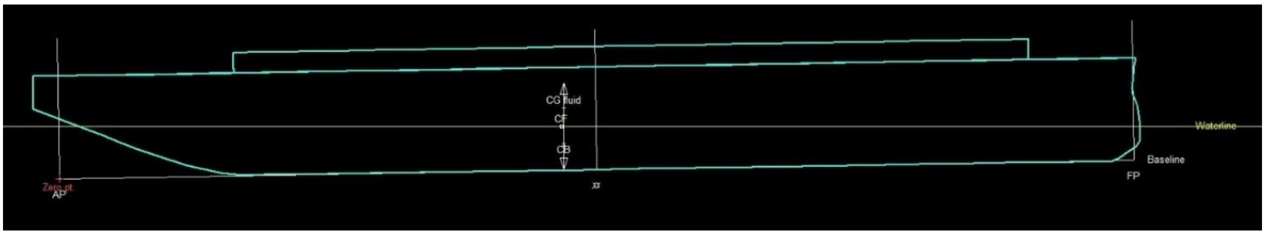

Figure 4.11 LC Arrival Port Ballast waterline

5 Conclusion

The result in this project is a ship design that fulfils the specifications and mission requirements given by Horisont Energi. The transport logistics analysis showed that three ships are needed to annually transport the amount of cargo as specified. The ships are designed for a design speed of 15 knots. However, the speed used in the logistics is 13 knots. After the completement of three rounds in the design spiral, the final ship design is a design that complies with IMO stability regulations. Also, the maximum cargo capacity is 16 950 m^3, which is 30 m^3 more than required from the logistics analysis. This makes the three ships and their final design capable of annually transporting the required amount of cargo.

Acronyms and Nomenclature

Acronyms

AP	Aft perpendicular
CCS	Carbon capture and storage
CO_2	Carbon dioxide
DWT	Deadweight
FP	Fore perpendicular
GHG	Greenhouse gas
HE	Horisont Energi
HFO	Heavy fuel oil
HFO	Heavy fuel oil
HHV	Higher heating value
ICE	Internal Combustion Engine
IMO	International Maritime Organization
LCB	Longitudinal centre of buoyancy
LCG	Longitudinal centre of gravity
LHV	Lower heating value
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LWT	Lightweight
MGO	Marine gas oil
N_2O	Nitrous Oxide
NH_3	Ammonia
PTH	Power take home

PTI	Power take in
PTO	Power take out
SCR	Selective Catalytic Reduction
SDP	Structural design procedure
SFOC	Specific fuel oil consumption
SOLAS	Safety of Life at Sea
VCG	Vertical centre of gravity

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Appendix A

High Season - 3 ships

Leg	Cargo	Loading rate [m3/h]	Loading time [h]	Volume cargo [m3]	Weight cargo [ton]	Distance [nm]	Speed [kn]	Voyage time [h]	Accumulated voyage time [h]	Accumulated voyage time [days]
Loading Hammerfest	NH3	1200	8	**9600**	**6547,2**				8,0	0,3
Hammerfest - Rotterdam	NH3				6547,2	1400	**13**	107,7	115,7	4,8
Unloadng Rotterdam	NH3	1200	8	-9600	-6547,2				123,7	5,2
Rotterdam - Stockholm	Purging				0	1050	**13**	81	204,5	8,5
Loading Stockholm	CO2	1200	14,1	**16920**	**19542,6**				218,6	9,1
Stockholm - Hammerfest	CO2				19542,6	2100	**13**	161,5	380,1	15,8
Unloading Hammerfest	CO2	1200	14,1	-16920	-19542,6				394,2	16,4
Purging Hammerfest	Purging		24		0				418,2	**17,4**

Arrival period [days]	CO2 in storage [ton]	Roundtrips per ship	Roundtrips 3 ships	Transported cargo	per month [ton]	per season [ton]
5,81	19516	11,2	33,6	NH3	**33816**	219806
				CO2	**100937**	656093

Low Season - 2 ships

Leg	Cargo	Loading rate [m3/h]	Loading time [h]	Volume cargo [m3]	Weight cargo [ton]	Distance [nm]	Speed [kn]	Voyage time [h]	Accumulated voyage time [h]	Accumulated voyage time [days]
Loading Hammerfest	NH3	1200	13	**15600**	**10639,2**				13,0	0,5
Hammerfest - Rotterdam	NH3				10639,2	1400	**11,8**	118,6	131,6	5,5
Unloadng Rotterdam	NH3	1200	13	-15600	-10639,2				144,6	6,0
Rotterdam - Stockholm	Purging				0	1050	**11,8**	89,0	233,6	9,7
Loading Stockholm	CO2	1200	14,1	**16920**	**19542,6**				247,7	10,3
Stockholm - Hammerfest	CO2				19542,6	2100	**11,8**	178,0	425,7	17,7
Unloading Hammerfest	CO2	1200	14,1	-16920	-19542,6				439,8	18,3
Purging Hammerfest	Purging		24						463,8	**19,3**

Arrival period [days]	CO2 in storage [ton]	Roundtrips per ship	Roundtrips 2 ships	Transported cargo	per month [ton]	per season [ton]
9,66	19479	3,9	7,8	NH3	**33033**	82582
				CO2	**60676**	151691

Off Season - 1 ship

Leg	Cargo	Loading rate [m3/h]	Loading time [h]	Volume cargo [m3]	Weight cargo [ton]	Distance [nm]	Speed [kn]	Voyage time [h]	Accumulated voyage time [h]	Accumulated voyage time [days]
Loading Hammerfest	NH3	1200	14,1	**16920**	**11539,44**				14,1	0,6
Hammerfest - Rotterdam	NH3				11539,44	1400	**12,7**	110,2	124,3	5,2
Unloading Rotterdam	NH3	1200	14,1	-16920	-11539,44				138,4	5,8
Rotterdam - Hammerfest	No cargo				0	1400	**12,7**	110,2	248,7	**10,4**

Arrival period [days]	CO2 in storage [ton]	Roundtrips per ship	Roundtrips 1 ship	Transported cargo	per month [ton]	per season [ton]
10,4	0	8,7	8,7	NH3	**33411**	100233
				CO2	**0**	0

Costings

Cargo	Cost per ton trsp [$/ton]	Total project cost 15 years [$]
NH3	$ **43,43**	$ **664 241 268**
CO2	$ **43,30**	

Total cargo transported per year

Transported cargo	per year [ton]
NH3	**402621**
CO2	**807784**

Appendix B

Lightship Weight Calculation Sheet

Project Bacheloroppgave NH_3/CO_2 combination carrier
Date: 17.11.2021
By: A.Torheim

* LCG's measured from AP
* VCG's measured from Baseline

Density steel: 8 t/m3

Item	Quantity	Unit weight [t]	Total weight [t]	LCG [m]	Aft limit [m]	Fwd limit [m]	VCG [m]	LMOM [tm]	VMOM [tm]	Comment
Steel hull										
Bottom plating	1	189	189	83,7	10	157,4	0,8	15819,3	151,2	1055 m2, 22,37 mm plating
Shell plating from tank top to tween	1	300	300	79,3	1,2	157,4	3,5	23790	1050	1675 m2, 22,37 mm plating
Shell plating from tween deck to main deck	1	460	460	76,9	-3,6	157,4	11,02	35374	5069,2	2568 m2, 22,37 mm plating
Inner side plating from bottom to tween deck	1	184	184	84	25,8	142,2	3,5	15456	644	1792 m2, 12,82 mm plating
Inner side plating from tween deck to main deck	1	158	158	84	25,8	142,2	11	13272	1738	1862 m2, 10,61 mm plating
Shell plating forecastle	1	28	28	145,7	134	157,4	16,4	4079,6	459,2	158 m2, 22,37 mm plating
Girders in hull	3	21	63	78,7	0	157,4	0,6	4958,1	37,8	157m x 1400mm x 12 mm
Aftship decks and bulkheads	-	-	332,5	17,00	-3,6	47,4	12,06	5652,9089	4009	See seperate worksheet in this file
Midship decks and bulkheads	-	-	249,19	82,38	47,4	117,6	11,49	20527,3986	2864	See seperate worksheet in this file
Foreship decks and bulkheads	-	-	120,1	139,31	117,6	158,4	11,50	16731,4166	1382	See seperate worksheet in this file
Superstructure	-	-	297,2	13,75	0,6	24,6	21,49	4087,25	6388	See seperate worksheet in this file
Tank casing sides	1	167,6	167,6	84,00	25,80	142,20	15,00	14078,4	2514	866,4 m2, 24,18 mm plating
Tank casing top	1	365,4	365,4	84,00	25,80	142,20	17,98	30693,6	6570	1047,6 m2, 29,07 mm plating
Additional 25 % structure	-	-	728	77,4	-3,6	158,4	8	56385,7065	5828	Expected increase due to method
Propulsion- and manouvering system										
Main engine	1	76,5	76,5	14,7	10,8	18,6	4,5	1124,55	344,25	Wartsila 12V31DF 7200 kW
Gearbox	1	40	40	12,45	11,7	13,2	2,9	498	116	Assumed
Shaft	1	15	15	5,3	2,5	8,1	2,5	79,5	37,5	Assumed
Propeller	1	16	16	2,4	2,2	2,6	2,5	38,4	40	Assumed
Auxiliary generator set	1	30	30	23,5	21	26	3	705	90	Assumed
Bow tunnel thruster incl. Motor	1	13	13	147,6	147	148,2	3,3	1918,8	42,9	Assumed
Rudder	1	14	14	-0,9	-2,4	0,6	3,1	-12,6	43,4	Assumed
Steering gear	1	2	2	0	-0,4	0,4	7,2	0	14,4	Assumed
Misc. Equipment in engine room	1	30	30	17,4	5,4	29,4	5,1	522	153	Assumed
Other main equipment										
Winch 1	1	10	10	150,6	150,1	151,1	16,3	1506	163	Assumed
Winch 2	1	10	10	150,6	150,1	151,1	16,3	1506	163	Assumed
Winch 3	1	10	10	0	-0,5	0,5	13,3	0	133	Assumed
Winch 4	1	10	10	0	-0,5	0,5	13,3	0	133	Assumed
Windlass	2	7	14	147,6	147,1	148,1	16,3	2066,4	228,2	Assumed
Anchors	2	6	12	152,2	151	153,4	12	1826,4	144	Assumed
Anchor chain	2	30	60	147,6	145,8	149,4	12	8856	720	Assumed
Steel outfitting										
Railings	1	8	8	77,4	-3,6	158,4	15	619,2	120	Assumed
Bollards fwd	6	0,4	2,4	142,3	126,6	158	15	341,52	36	Assumed
Bollards aft	4	0,4	1,6	0,9	-3,6	5,4	15	1,44	24	Assumed
External stairs	12	0,2	2,4	77,4	-3,6	158,4	18	185,76	43,2	Assumed
Tank 1	1	500	500	45,8075	27,6	64,015	9,1	22903,75	4550	Assumed
Tank 2	1	500	500	84,0225	65,815	102,23	9,1	42011,25	4550	Assumed
Tank 3	1	500	500	122,2425	104,03	140,455	9,1	61121,25	4550	Assumed
Fuel tank aft	2	80	160	35,35	27,6	43,1	20,65	5656	3304	Assumed
Fuel tank mid	2	80	160	56,95	49,2	64,7	20,65	9112	3304	Assumed
Fuel tank fore	2	80	160	78,55	70,8	86,3	20,65	12568	3304	Assumed
Systems										
Fuel oil system	1	225	225	77,7	5,4	150	1,6	17482,5	360	15 t per 1000 GT
Ballast system	1	120	120	77,7	5,4	150	1,6	9324	192	8 t per 1000 GT
Sanitary system (black and grey water)	1	45	45	14,8	0,6	29	10	666	450	3 t per 1000 GT
Fresh water system	1	45	45	14,8	0,6	29	10	666	450	3 t per 1000 GT
Bilge system	1	45	45	73,2	-3,6	150	1,6	3294	72	3 t per 1000 GT
Ventilation ducts	1	75	75	12,7	-3,6	29	15	952,5	1125	5 t per 1000 GT
Switchboards and converters	1	10	10	17,4	5,4	29,4	7	174	70	Assumed
Electric cables	1	165	165	77,4	-3,6	158,4	8	12771	1320	Typically 10-12 tonn per 1000 GT
Cargo handling system	1	17	17	82,2	29,4	135	8	1397,4	136	Assumed
Accommodation										
Main deck [m^2]	362,4	0,15	54,36	12,6	0,6	24,6	16,5	684,936	896,94	Assume 150 kg/m2
1st deck [m^2]	362,4	0,15	54,36	12,6	0,6	24,6	19,5	684,936	1060,02	Assume 150 kg/m2
2nd deck [m^2]	362,4	0,15	54,36	12,6	0,6	24,6	22,5	684,936	1223,1	Assume 150 kg/m2
3rd deck [m^2]	362,4	0,15	54,36	12,6	0,6	24,6	25,5	684,936	1386,18	Assume 150 kg/m2
Wheelhouse deck [m^2]	276	0,15	41,4	17,7	10,8	24,6	28,5	732,78	1179,9	Assume 150 kg/m2
Miscellanous										
Painting	1	25	25	77,4	-3,6	158,4	7	1935	175	Assumed
Sacrifical anodes	1	5	5	74,1	-1,8	150	2	370,5	10	Assumed
Sum without margins			7035,2	69,45			10,68	488566	75161	
Construction margin (5 %)			351,8	69,45	-3,6	158,4	12,68	24428,28623	4461,56385	2 m above VCG
Design margin (10 %)			703,5	69,45	-3,6	158,4	12,68	48856,57246	8923,1277	2 m above VCG
Future growth margin [5%]			351,8	69,45	-3,6	158,4	12,68	24428,28623	4461,56385	2 m above VCG
Lightship used in calculations			**8442,3**	**69,45**			**11,02**	586279	93007	

Log:

Date	Weight [t]	LCG [m]	VCG [m]	Comment
20.10.2021	4442,0	61,93	9,69	First estimate
29.10.2021	6425,6	68,68	10,02	Updated hull weights based on plating thickness. Implemented weights from tank casing. Updated to better weight estimate for cargo tanks
02.11.2021	6838,1	68,03	11,05	Included fuel tank weights. Set VCG for margins 2 m above VCG
04.11.2021	7288,1	67,83	11,66	Updated fuel tank weights (115t per) and length
10.11.2021	8477,8	68,47	11,55	Updated cargo tank weights (500t per) and various hull weights (area)
16.11.2021	8694,3	68,18	11,29	Updated hull weights; area, thickness, LCG, VCG. Reduced design margin to 10%. Included accomodation weights on main deck
17.11.2021	8442,3	68,53	11,01	Updated fuel tank weights and dimensions based on MAN Cryo 201 m3 tank. (80t per tank)

Steel weight calculation - aftship section

Project Bacheloroppgave NH3/CO2 combination carrier
Date: 17.11.2021
By: A.Torheim

* LCG's measured from AP
* VCG's measured from Baseline

Item	Quantity	Unit weight [t]	Total weight [t]	LCG [m]	VCG [m]	LMOM [tm]	VMOM [tm]	Comment
Tween deck	1	53,27	53,3	18,20	7,00	970	373	627,6 m², 10,61 mm
2nd tween deck	1	69,72	69,72	15,08	12,00	1051,3776	836,64	830 m2, 7 mm, faktor 1.5
Main deck	1	164,81	164,8	17,33	15,00	2856	2472	931,8 m², 22,11 mm
Aft peak bulkhead	1	18,50	18,5	5,40	8,50	100	157	206 m², 8 mm, faktor 1.4
Engine room bulkhead	1	26,20	26,2	25,80	6,50	676	170	292 m², 8 mm, faktor 1.4
			0,0			0	0	
			0,0			0	0	
Sum without margins			332,5	17,00	12,06	5653	4009	

Steel weight calculation - midship section

Project Bacheloroppgave NH3/CO2 combination carrier
Date: 17.11.2021
By: A.Torheim

* LCG's measured from AP
* VCG's measured from Baseline

Item	Quantity	Unit weight [t]	Total weight [t]	LCG [m]	VCG [m]	LMOM [tm]	VMOM [tm]	Comment
Tween deck	1	30,14	30,1	80,99	7,00	2441	211	355,2 m², 10,61 mm
2nd tween deck	1	33,70	33,70	81,50	12,00	2746,55	404,4	401,2 m2, 7 mm, faktor 1.5
Main deck	1	127,55	127,6	82,20	15,00	10485	1913	721,1 m², 22,11 mm
Bulkhead 1	1	28,90	28,9	64,80	5,80	1873	168	323 m², 8 mm, faktor 1.4
Bulkhead 2	1	28,90	28,9	103,20	5,80	2982	168	323 m², 8 mm, faktor 1.4
			0,0			0	0	
			0,0			0	0	
Sum without margins			249,2	82,38	11,49	20527	2864	

Steel weight calculation - foreship section

Project Bacheloroppgave NH3/CO2 combination carrier
Date: 17.11.2021
By: A.Torheim

* LCG's measured from AP
* VCG's measured from Baseline

Item	Quantity	Unit weight [t]	Total weight [t]	LCG [m]	VCG [m]	LMOM [tm]	VMOM [tm]	Comment
Tween deck	1	5,31	5,3	137,66	7,00	731	37	62,54 m², 10,61 mm
2nd tween deck	1	17,27	17,27	139	12	2400,53	207,24	205,6 m2, 7 mm, faktor 1.5
Main deck	1	57,52	57,5	135,60	15,00	7800	863	325,2 m², 22,11 mm
Bulkhead 3	1	17,00	17,0	142,20	6,70	2417	114	189,8 m², 8 mm, faktor 1.4
Bulkhead 4	1	14,00	14,0	145,20	6,90	2033	97	156,2 m², 8 mm, faktor 1.4
Collision bulkhead	1	9,00	9,0	150,00	7,10	1350	64	100,6 m², 8 mm, faktor 1.4
			0,0			0	0	
			0,0			0	0	
Sum without margins			120,1	139,31	11,50	16731	1382	

Steel weight calculation - superstructure

Project Bacheloroppgave NH3/CO2 combination carrier
Date: 17.11.2021
By: A.Torheim

* LCG's measured from AP
* VCG's measured from Baseline

Item	Quantity	Unit weight [t]	Total weight [t]	LCG [m]	VCG [m]	LMOM [tm]	VMOM [tm]	Comment
Deck 1	1	66,4	66,4	12,90	15,00	857	996	791 m², 7 mm, faktor 1.5
Deck 2	1	30,4	30,4	13,30	18,00	404	547	362 m², 7 mm, faktor 1.5
Deck 3	1	30,4	30,4	13,20	21,00	401	638	362 m², 7 mm, faktor 1.5
Deck 4	1	30,4	30,4	13,20	24,00	401	730	362 m², 7 mm, faktor 1.5
Wheelhouse deck	1	23,2	23,2	17,70	27,00	411	626	276 m², 7 mm, faktor 1.5
Wheehouse top	1	30,5	30,5	17,70	30,00	540	915	363 m², 7 mm, faktor 1.5
						0	0	
Front bulkhead	1	12,0	12,0	24,60	21,00	295	252	192m², 6 mm, faktor 1.3
Side bulkheads	1	32,1	32,1	13,40	20,50	430	658	515 m², 6 mm, faktor 1.3
Aft bulkheads lower	1	9,0	9,0	0,60	19,50	5	176	144 m², 6 mm, faktor 1.3
Aft bulkheads upper	1	3,0	3,00	10,80	25,50	32	77	48 m², 6 mm, faktor 1.3
Wheelhouse bulkheads	1	14,5	14,5	17,70	28,50	257	413	232 m², 6 mm, faktor 1.3
Funnel above superstructure	1	7,7	7,7	3,30	27,50	25	212	123 m², 6 mm, faktor 1.3
Funnel inner bulkheads	1	7,6	7,6	3,70	19,50	28	148	122 m², 6 mm, faktor 1.3
Sum without margins			297,2	13,75	21,49	4087	6388	

Appendix C

For technology readiness level (TRL), the following definitions apply (EU)

TRL 1 – basic principles observed
TRL 2 – technology concept formulated
TRL 3 – experimental proof of concept
TRL 4 – technology validated in lab
TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7 – system prototype demonstration in operational environment
TRL 8 – system complete and qualified
TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

Source: (DNV, 2021c)

Appendix D

Motstand og drivstoffkapasitet

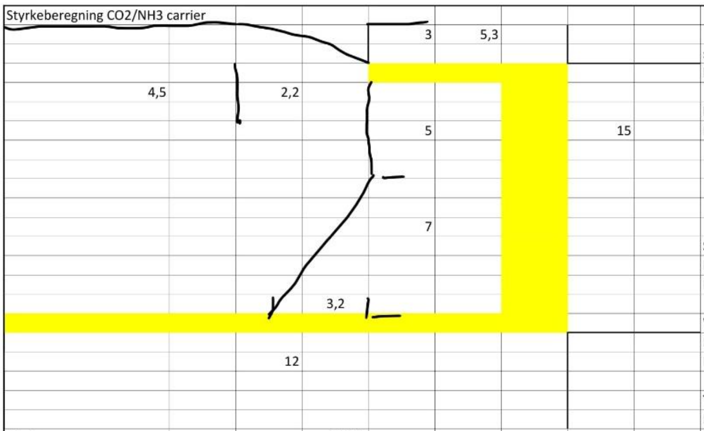
Motstand fra maxsurf

	Speed [knots]	Froude No. LWL	Froude No. Vol	Holtrop resist. [kN]	Power 100% eff [kW]	Power at efficiency [kW] 60 %	61 %	62 %	63 %	64 %	65 %	66 %	67 %	68 %
1	10	0,13	0,298	209,00	1075,19	1791,98	1762,60	1734,18	1706,65	1679,98	1654,14	1629,07	1604,76	1581,16
2	10,25	0,133	0,306	219,30	1156,58	1927,64	1896,04	1865,45	1835,84	1807,16	1779,36	1752,40	1726,24	1700,86
3	10,5	0,136	0,313	230,00	1242,53	2070,88	2036,93	2004,08	1972,27	1941,45	1911,58	1882,62	1854,52	1827,25
4	10,75	0,139	0,321	241,20	1333,65	2222,75	2186,31	2151,05	2116,91	2083,83	2051,77	2020,68	1990,52	1961,25
5	11	0,142	0,328	252,80	1430,80	2384,67	2345,58	2307,74	2271,11	2235,63	2201,23	2167,88	2135,52	2104,12
6	11,25	0,146	0,335	265,00	1533,60	2556,00	2514,10	2473,55	2434,29	2396,25	2359,38	2323,64	2288,96	2255,29
7	11,5	0,149	0,343	277,60	1642,43	2737,39	2692,51	2649,08	2607,03	2566,30	2526,82	2488,53	2451,39	2415,34
8	11,75	0,152	0,35	290,80	1757,71	2929,52	2881,50	2835,02	2790,02	2746,43	2704,18	2663,20	2623,45	2584,87
9	12	0,155	0,358	304,50	1879,91	3133,18	3081,82	3032,11	2983,98	2937,36	2892,17	2848,35	2805,83	2764,57
10	12,25	0,159	0,365	318,90	2009,51	3349,18	3294,28	3241,14	3189,70	3139,86	3091,55	3044,71	2999,27	2955,16
11	12,5	0,162	0,373	333,90	2147,05	3578,42	3519,76	3462,99	3408,02	3354,77	3303,16	3253,11	3204,55	3157,43
12	12,75	0,165	0,38	349,60	2293,12	3821,86	3759,21	3698,58	3639,87	3583,00	3527,87	3474,42	3422,56	3372,23
13	13	0,168	0,388	366,10	2448,33	4080,55	4013,65	3948,92	3886,23	3825,51	3766,66	3709,59	3654,22	3600,48
14	13,25	0,172	0,395	383,40	2613,35	4355,58	4284,17	4215,07	4148,17	4083,35	4020,53	3959,61	3900,51	3843,15
15	13,5	0,175	0,403	401,60	2788,88	4648,13	4571,93	4498,19	4426,79	4357,62	4290,58	4225,57	4162,50	4101,29
16	13,75	0,178	0,41	420,70	2975,68	4959,47	4878,16	4799,48	4723,30	4649,50	4577,97	4508,61	4441,31	4376,00
17	14	0,181	0,417	440,80	3174,57	5290,94	5204,20	5120,27	5038,99	4960,26	4883,95	4809,95	4738,16	4668,48
18	14,25	0,185	0,425	461,90	3386,37	5643,94	5551,42	5461,88	5375,18	5291,20	5209,79	5130,86	5054,28	4979,95
19	14,5	0,188	0,432	484,20	3611,92	6019,87	5921,18	5825,68	5733,21	5643,63	5556,80	5472,61	5390,93	5311,65
20	14,75	0,191	0,44	507,70	3852,10	6420,17	6314,92	6213,07	6114,45	6018,91	5926,31	5836,52	5749,41	5664,86
21	15	0,194	0,447	532,30	4107,89	6846,48	6734,25	6625,63	6520,46	6418,58	6319,83	6224,08	6131,18	6041,01
22	15,25	0,198	0,455	558,40	4380,45	7300,76	7181,07	7065,25	6953,10	6844,46	6739,16	6637,05	6537,99	6441,84
23	15,5	0,201	0,462	585,80	4671,13	7785,21	7657,58	7534,07	7414,48	7298,63	7186,35	7077,46	6971,83	6869,30
24	15,75	0,204	0,47	614,80	4981,20	8301,99	8165,89	8034,19	7906,66	7783,12	7663,38	7547,27	7434,62	7325,29
25	16	0,207	0,477	645,30	5311,64	8852,74	8707,61	8567,16	8431,18	8299,44	8171,76	8047,94	7927,82	7811,24
26	16,25	0,21	0,484	677,40	5662,96	9438,26	9283,53	9133,80	8988,82	8848,37	8712,24	8580,23	8452,17	8327,88
27	16,5	0,214	0,492	711,00	6035,29	10058,81	9893,91	9734,34	9579,82	9430,14	9285,06	9144,38	9007,89	8875,42
28	16,75	0,217	0,499	746,10	6428,94	10714,90	10539,24	10369,26	10204,67	10045,22	9890,68	9740,82	9595,43	9454,32
29	17	0,22	0,507	782,70	6845,03	11408,38	11221,36	11040,37	10865,12	10695,35	10530,81	10371,25	10216,46	10066,22
30	17,25	0,223	0,514	821,00	7286,03	12143,38	11944,30	11751,65	11565,12	11384,42	11209,27	11039,43	10874,67	10714,74
31	17,5	0,227	0,522	861,50	7755,84	12926,40	12714,49	12509,42	12310,85	12118,50	11932,06	11751,27	11575,88	11405,64
32	17,75	0,23	0,529	904,50	8259,29	13765,48	13539,82	13321,43	13109,98	12905,14	12706,60	12514,07	12327,30	12146,01
33	18	0,233	0,537	950,40	8801,13	14668,56	14428,09	14195,38	13970,05	13751,77	13540,20	13335,05	13136,02	12942,84
34	18,25	0,236	0,544	999,60	9384,80	15641,34	15384,92	15136,78	14896,51	14663,75	14438,16	14219,40	14007,17	13801,18
35	18,5	0,24	0,552	1051,90	10011,24	16685,40	16411,87	16147,16	15890,86	15642,57	15401,91	15168,55	14942,15	14722,41
36	18,75	0,243	0,559	1107,00	10678,16	17796,93	17505,18	17222,83	16949,46	16684,62	16427,93	16179,03	15937,55	15703,17
37	19	0,246	0,566	1164,30	11380,01	18966,68	18655,75	18354,85	18063,50	17781,26	17507,70	17242,44	16985,09	16735,31
38	19,25	0,249	0,574	1222,70	12108,92	20181,53	19850,68	19530,51	19220,50	18920,18	18629,10	18346,84	18073,01	17807,23
39	19,5	0,253	0,581	1281,60	12856,40	21427,34	21076,07	20736,13	20406,99	20088,13	19779,08	19479,40	19188,66	18906,47
40	19,75	0,256	0,589	1340,10	13615,60	22692,67	22320,65	21960,64	21612,06	21274,37	20947,08	20629,70	20321,79	20022,94
41	20	0,259	0,596	1397,90	14383,32	23972,20	23579,21	23198,90	22830,67	22473,94	22128,19	21792,91	21467,64	21151,94

Fuel estimat		
SFOC [g/kWh]	375	for MAN B&W 2 takt ammoniakk
Rekkevidde [nm]	4550	
Hastighet [knop]	15	
Tid [h]	303,3333333	
Virkningsgrad [-]	0,63	
Effekt aksling [kW]	6520,46	
Energi [kWh]	1977872,963	
Masse NH3 [tonn]	**824,11**	med 10% margin
Volum NH3 [m3]	**1208,38**	flytende, med 10% margin

Appendix E

Styrkeberegning CO2/NH3 carrier



L [m]			157,4					
B [m]			24					
T [m]			10,5					
D [m]			15					
Flytspenning [MPa]			235					
Sikkerhetsfaktor mot flyt			1,5					
Cb			0,7					
							Bredde dekk	
hdb	mm	1000	dobbelbunnshøyde				5300	m
f1	1,00							
Bunn								
t_0_bunn	mm	12						
stdim_bunn	mm2	6224	HP	340	x	13		
t_eqv_bunn	mm	22,37333						
Side bærer								
t_0_SidBær	mm	12						
Høyde	mm	1000						
Bredde flens	mm	400						
Senter bærer								
t_0_SentBær	mm	12						
Høyde	mm	1000						
Bredde flens	mm	400						
Skuteside ytre								
t_0_SkutSid_y	mm	12						
stdim_SkutSid_y	mm2	6224	HP	340	x	13		
t_eqv_SkutSid_y	mm	22,37333						
Skuteside indre nedre								
t_0_SkutSid_i_n	mm	7						
stdim_SkutSid_i_n	mm2	3489	HP	240	x	11		
t_eqv_SkutSid_i_n	mm	12,815						
Skuteside indre øvre								
t_0_SkutSid_i_o	mm	6						
stdim_SkutSid_i_o	mm2	2766	HP	200	x	11		
t_eqv_SkutSid_i_o	mm	10,61						
Dekk 15m								
t_0_Dekk	mm	12						
stdim_Dekk	mm2	6065	HP	320	x	14		
t_eqv_Dekk	mm	22,108						
Tank hus side								
t_0_Tk_hus_sid	mm	13						
stdim_Tk_hus_sid	mm2	6705	HP	320	x	16		
t_eqv_Tk hus_sid	mm	24,175						
Tank hus top								
t_0_Tk_hus_top	mm	17						
stdim_Tk_hus_top	mm2	7244	HP	340	x	16		
t_eqv_Tk hus_top	mm	29,07333						

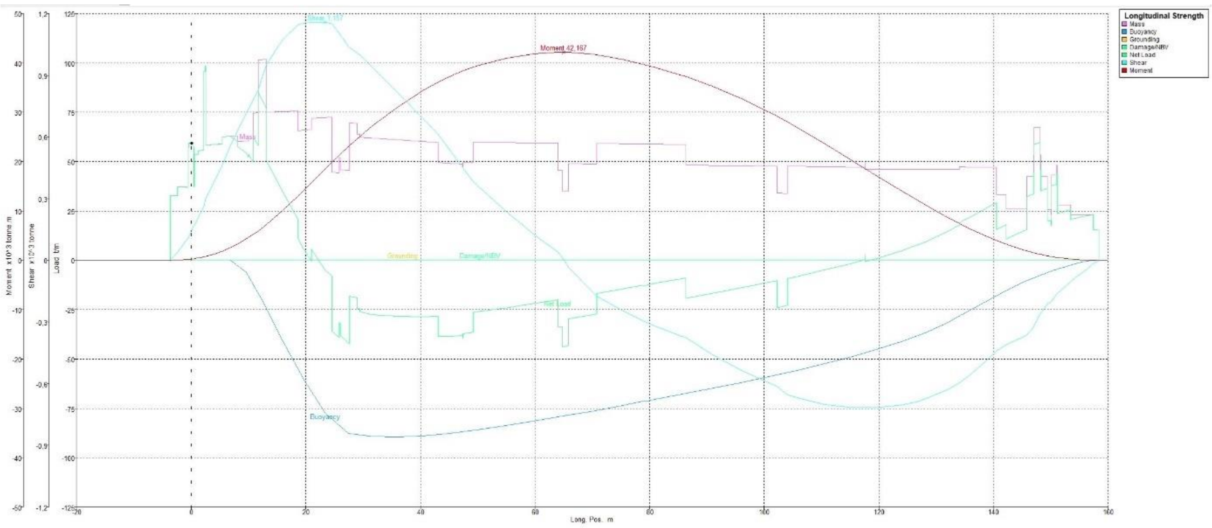
s [mm]	600		s/l	0,25
l [mm]	2400			
Design Bending moments				
Parametere	Cw	9		
	L	157,4		
	B	24		
	Cb	0,7		
	alpha	1		
Stillwater	Regelmoment	Moment fra kritisk lastkondisjon		
Ms sagging [kNm]	-486973	-938817		
Ms hogging [kNm]	599351	998619		
Wave loads				
Mw sagging [kNm]	-824108			
Mw hogging [kNm]	711729			
Total Design Bending moments				
M_design_sag	1762925			
M_design_hog	1710348			
Beregning NA				
Element	Areal [mm^2]	Lokal NA abbl [mm]	Treghetsmoment [mm4]	
Bunn	268480	11,19	1,70E+13	
TT	0	0	0	
Dekk	117174,1667	14988,95	5,77E+12	
Side ytre	335600	7500	4,17E+12	
Side indre nedre	98633,88408	3500	1,97E+12	
Side indre øvre	53050	9500	1,24E+11	
Sidebærer	16800	615	9,42E+11	
Senterbærer	16800	615	9,42E+11	
Tank hus side	89936,20	16500	6,60E+12	
Tank hus top	130830,00	17985,46	1,31E+13	
			5,07E+13	
NA	mm abbl	7969		
Treghetsmoment		Halve tv.snitt	Hele tv.snitt	
I	mm4	5,07E+13	1,01E+14	
Motstandsmoment				
Z_bunn	mm3	1,27E+10		
Z_dekk	mm3	1,44E+10		
Z_tank_hus_top	mm3	1,01E+10		
Sigma_max_bunn	MPa	138,68	Krav	
Sigma_max_dekk	MPa	122,37	175*f1	
Sigma_max_tank_hus_top	MPa	174,57		
Spenningsfaktor f2				
f2_bunn		0,79047008		
f2_dekk		0,697480568		
F2_tank_hus_top		0,995070697		

Lokale krav basert på f2																				
Bunn og dobbeltbunn				137,2542			Sider							Dekk						
C 701 Bottom longitudinals							C 101 Side plating							C 102 deck plating		Strength deck		C 104 not be less than		
p	kN/m2	126,9818					Sigma_bunn	N/mm2	120					p	kN/m2	22,8		t	8,6	OK
Sigma	N/mm2	1,22E+02		max 160*f	160		Sigma_dekk	N/mm2	120					Sigma	N/mm2	120				
Z	cm3	298,0	OK				Sigma_tkhutp	N/mm2	95,64		C 102 not be less than			t	mm	4,4				
							t_bunn	mm	10,5		t	11,3	OK							
C 302 Bottom plating				304 not be less than			t_dekk	mm	4,4		t	11,3	OK	C 301 Longitudinals						
p	kN/m2	126,9818		t	11,3	OK	t_tkhutp	mm	3,3		t	9,7	OK	p	kN/m2	22,8				
Sigma	N/mm2	120												Sigma	N/mm2	134,3275		max 160*f1	160	
ka		1,076406					C 301 Longitudinals							Z	cm3	48,7	OK	min	15	
t	mm	10,5					Sigma_bunn	N/mm2	122,24		max 160*f	160								
							Sigma_dekk	N/mm2	305,01		max 160*f	160								
							Sigma_tkhutp	N/mm2	387,84		max 160*f	160		Tank hus						
							Z_bunn	cm3	298,0	OK	min	15		C202 deck plating above strength deck, minumimskrav til t						
							Z_dekk	cm3	40,9	OK	min	15		t	mm	5,5	OK			
							Z_tkhutp	cm3	18,3	OK	min	15								
														C301 Longitudinals for tank hus						
														p	kN/m2	5				
														Sigma	N/mm2	95,64081		max 160*f1	160	
														Z	cm3	15,0		min	15	OK

Appendix F

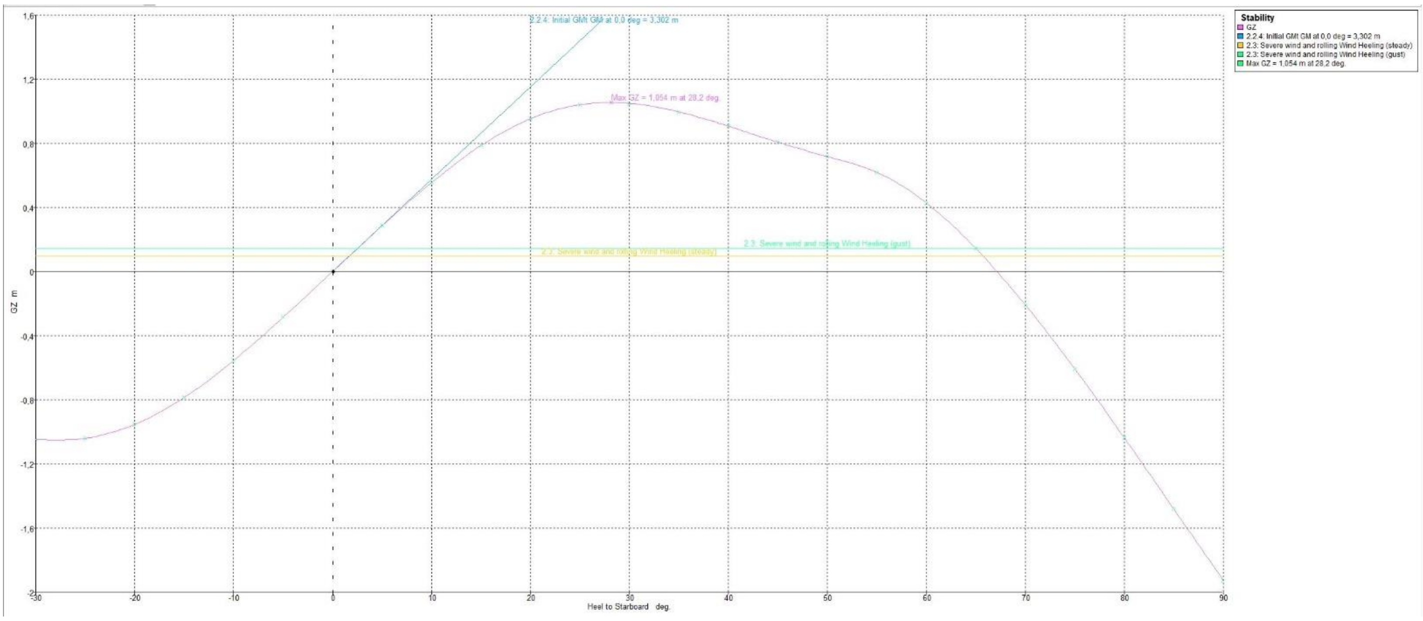
LC Lightship

	Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Long. Arm m	Aft. Limit m	Fwd. Limit m	Vert. Arm m
1	Lightship	1	8441,830	8441,830	69,446			11,016



Code	Criteria	Value	Units	Actual	Status	Margin %
267(85) Ch2 - General Criteria	2.3: IMO roll back angle					
	L, Stability calculated	150,545	m			
	B, Stability calculated	23,953	m			
	d, Stability calculated	4,11	m			
	GMf, Stability calculated	3,302	m			
	VCG, Stability calculated	11,016	m			
	CB, Stability calculated	0,466				
	Ak, keel area, user spec.	10,8	m^2			
	Method for k factor	Tabulated value for k				
	Evaluates to	22,9	deg			
	Intermediate values					
	B / d			5,828		
	100 Ak / L / B			0,3		
	C		IMO units	0,442		
	T		s	11,662		
	OG, Centre of gravity above WL		m	6,907		
	X1		IMO units	0,8		
	X2		IMO units	0,773		
	k tabulated		IMO units	0,994		
	r		IMO units	1,738		
	s		IMO units	0,067		
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 30				Pass	
	from the greater of					
	spec. heel angle	0	deg	0		
	to the lesser of					
	spec. heel angle	30	deg	30		
	angle of vanishing stability	67,1	deg			
	shall not be less than (>=)	3,1513	m.deg	20,8568	Pass	561,85
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 40				Pass	
	from the greater of					
	spec. heel angle	0	deg	0		
	to the lesser of					
	spec. heel angle	40	deg	40		
	first downflooding angle	n/a	deg			
	angle of vanishing stability	67,1	deg			
	shall not be less than (>=)	5,1566	m.deg	30,7512	Pass	496,35
267(85) Ch2 - General Criteria	2.2.1: Area 30 to 40				Pass	
	from the greater of					
	spec. heel angle	30	deg	30		
	to the lesser of					
	spec. heel angle	40	deg	40		
	first downflooding angle	n/a	deg			
	angle of vanishing stability	67,1	deg			
	shall not be less than (>=)	1,7189	m.deg	9,8943	Pass	475,62
267(85) Ch2 - General Criteria	2.2.2: Max GZ at 30 or greater				Pass	

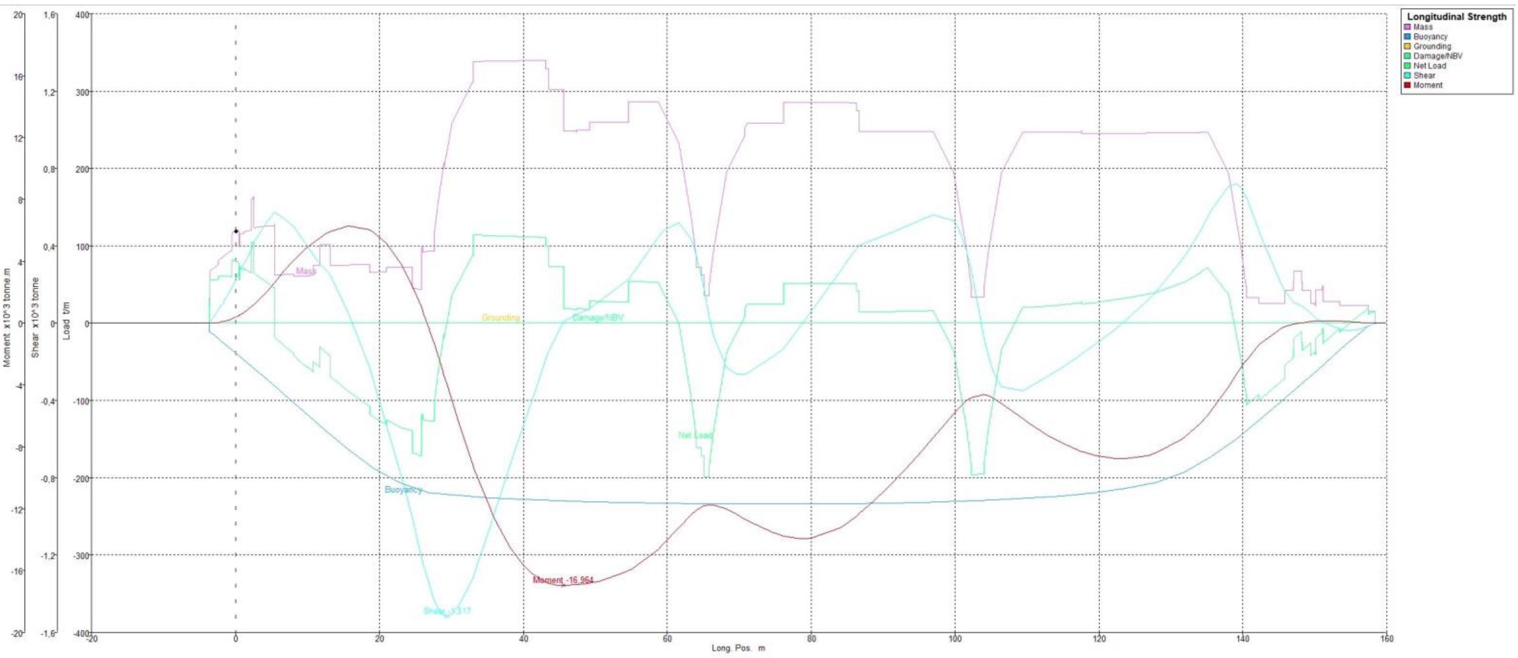
	in the range from the greater of					
	spec. heel angle	30	deg	30		
	to the lesser of					
	spec. heel angle	90	deg	90		
	angle of max. GZ	28,2	deg			
	shall not be less than (>=)	0,2	m	1,048	Pass	424
	Intermediate values					
	angle at which this GZ occurs		deg	30		
267(85) Ch2 - General Criteria	2.2.3: Angle of maximum GZ				Pass	
	shall not be less than (>=)	25	deg	28,2	Pass	12,73
267(85) Ch2 - General Criteria	2.2.4: Initial GMt				Pass	
	spec. heel angle	0	deg			
	shall not be less than (>=)	0,15	m	3,302	Pass	2101,33
267(85) Ch2 - General Criteria	2.3: Severe wind and rolling				Pass	
	Wind arm: a P A (h - H) / (g disp.) cos^n(phi)					
	constant: a =	0,99966				
	wind pressure: P =	504	Pa			
	area centroid height (from zero point): h =	15,8	m			
	total area: A =	1139,1	m^2			
	H = mean draft / 2	2,055	m			
	cosine power: n =	0				
	gust ratio	1,5				
	Area2 integrated to the lesser of					
	2.3: IMO roll back angle from equilibrium (with steady heel arm)	22,9 (-21,3)	deg	-21,3		
	Area 1 upper integration range, to the lesser of:					
	first downflooding angle	n/a	deg			
	angle of vanishing stability (with gust heel arm)	65	deg	65		
	Angle for GZ(max) in GZ ratio, the lesser of:					
	angle of max. GZ	28,2	deg	28,2		
	Select required angle for angle of steady heel ratio:	DeckEdgeImmersionAngle				
	Criteria:				Pass	
	Angle of steady heel shall not be greater than (<=)	16	deg	1,7	Pass	89,65
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80	%	3,49	Pass	95,64
	Area1 / Area2 shall not be less than (>=)	100	%	247,55	Pass	147,55
	Intermediate values					
	Heel arm amplitude		m	0,095		
	Equilibrium angle with gust heel arm		deg	2,5		
	Deck edge immersion angle		deg	47,4		
	Area1 (under GZ), from 2,5 to 65,0 deg.		m.deg	46,1198		
	Area1 (under HA), from 2,5 to 65,0 deg.		m.deg	8,9347		
	Area1, from 2,5 to 65,0 deg.		m.deg	37,1851		
	Area2 (under GZ), from -21,3 to 2,5 deg.		m.deg	-11,6269		
	Area2 (under HA), from -21,3 to 2,5 deg.		m.deg	3,3943		
	Area2, from -21,3 to 2,5 deg.		m.deg	15,0212		



1	Draft Amidships m	4,110
2	Displacement t	8442
3	Heel deg	0,0
4	Draft at FP m	2,142
5	Draft at AP m	6,077
6	Draft at LCF m	4,216
7	Trim (+ve by stern) m	3,935
8	WL Length m	150,54
9	Beam max extents on WL m	22,067
10	Wetted Area m^2	3156,6
11	Waterpl. Area m^2	2772,8
12	Prismatic coeff. (Cp)	0,626
13	Block coeff. (Cb)	0,466
14	Max Sect. area coeff. (Cm)	0,777
15	Waterpl. area coeff. (Cwp)	0,835
16	LCB from zero pt. (+ve fwd) m	69,235
17	LCF from zero pt. (+ve fwd) m	74,472
18	KB m	2,607
19	KG fluid m	11,016
20	BMt m	11,713
21	BML m	488,88
22	GMt corrected m	3,301
23	GML m	480,47
24	KMt m	14,317
25	KML m	491,33
26	Immersion (TPc) tonne/cm	28,422
27	MTc tonne.m	257,70
28	RM at 1deg = GMt.Disp.sin(1) tonne.	486,40
29	Max deck inclination deg	1,4321
30	Trim angle (+ve by stern) deg	1,4321

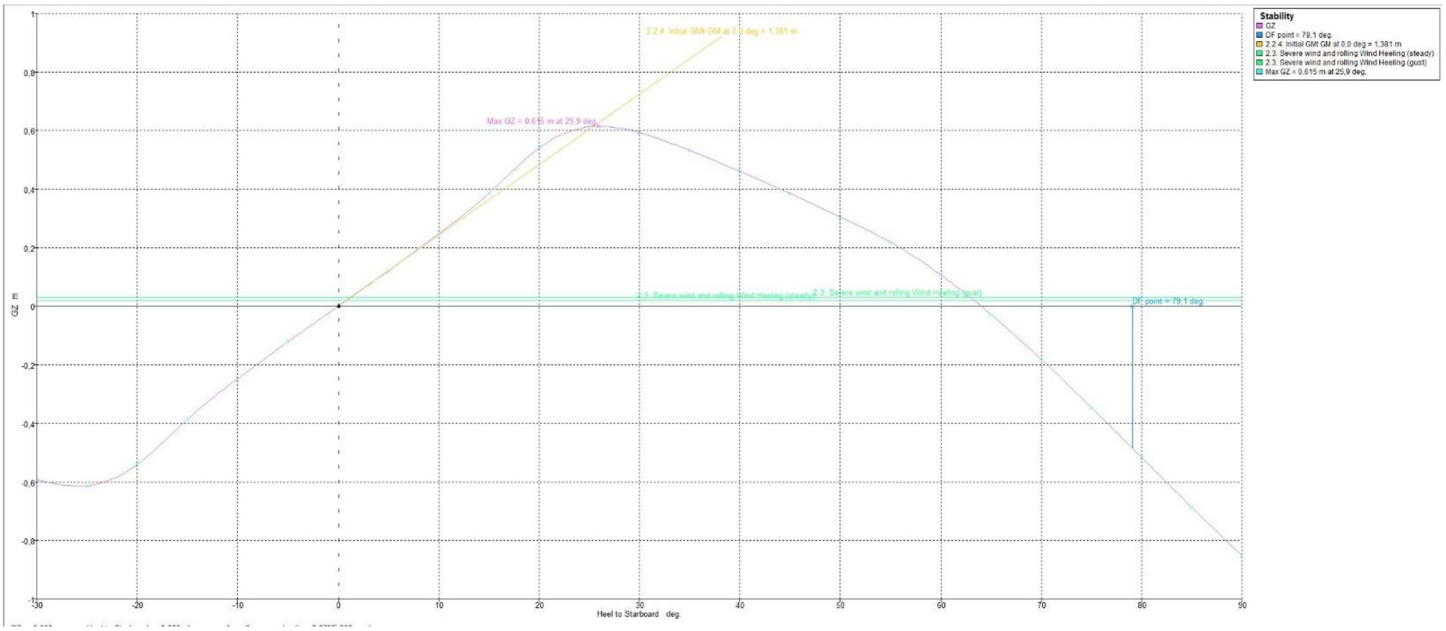
LC Departure Port CO2

	Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Long. Arm m	Aft. Limit m	Fwd. Limit m	Vert. Arm m
1	Lightship	1	8441,830	8441,830	69,446			11,016
2	Tk 1 Fore peak	0%	268,986	0,000	151,467			0,000
3	Tk 2 BW 1 Port	0%	9,009	0,000	147,280			0,000
4	Tk 3 BW 1 Stb	0%	9,009	0,000	147,280			0,000
5	Tk 4 BW 2 Port	0%	8,895	0,000	143,611			0,000
6	Tk 5 BW 2 Stb	0%	8,895	0,000	143,611			0,000
7	Cargo Tank 1 CO2	100%	6525,714	6525,714	122,237			9,100
8	Cargo Tank 2 CO2	100%	6525,714	6525,714	84,022			9,100
9	Cargo Tank 3 CO2	100%	6525,716	6525,716	45,807			9,100
10	Cargo Tank 1 NH3	0%	3853,280	0,000	122,237			1,600
11	Cargo Tank 2 NH3	0%	3853,280	0,000	84,022			1,600
12	Cargo Tank 3 NH3	0%	3853,280	0,000	45,807			1,600
13	Tk 6 BW 3 Port	0%	95,054	0,000	122,461			0,871
14	Tk 7 BW 3 STB	0%	95,054	0,000	122,461			0,871
15	Tk 8 BW 4 Port	0%	290,196	0,000	103,309			0,682
16	Tk 9 BW 4 STB	0%	290,196	0,000	103,309			0,682
17	Tk 10 BW 5 Port	0%	334,810	0,000	84,109			0,619
18	Tk 11 BW 5 STB	0%	334,810	0,000	84,109			0,619
19	Tk 12 BW 6 Port	0%	341,475	0,000	76,828			0,616
20	Tk 13 BW 6 STB	0%	341,475	0,000	76,828			0,616
21	Tk 14 BW 7 Port	0%	332,123	0,000	64,691			0,643
22	Tk 15 BW 7 STB	0%	332,123	0,000	64,691			0,643
23	Tk 16 BW 8 Port	75%	304,408	228,306	36,199			3,592
24	Tk 17 BW 8 STB	75%	304,408	228,306	36,199			3,592
25	Tk BW Aft Upper Port	100%	260,457	260,457	1,304			10,699
26	TK BW Aft Upper STB	100%	260,457	260,457	1,304			10,699
27	Fuel Aft STB	1	140,600	140,600	38,250	33,000	43,500	20,650
28	Fuel Aft Port	1	140,600	140,600	38,250	33,000	43,500	20,650
29	Fuel mid STB	1	140,600	140,600	59,850	54,600	65,100	20,650
30	Fuel mid Port	1	140,600	140,600	59,850	54,600	65,100	20,650
31	Fuel fore STB	1	140,600	140,600	81,450	76,200	86,700	20,650
32	Fuel fore Port	1	140,600	140,600	81,450	76,200	86,700	20,650
33	Tk 18 BW 3 Port Upper	0%	94,369	0,000	127,016			7,000
34	Tk 19 BW 3 STB Upper	0%	94,369	0,000	127,016			7,000
35	Tk 20 BW 4 Port Upper	0%	229,105	0,000	112,367			7,000
36	Tk 21 BW 4 STB Upper	0%	229,105	0,000	112,367			7,000
37	Tk 22 BW 5 Port Upper	0%	260,105	0,000	93,456			7,000
38	Tk 23 BW 5 STB Upper	0%	260,105	0,000	93,456			7,000
39	Tk 24 BW 6 Port Upper	0%	273,705	0,000	74,367			7,000
40	Tk 25 BW 6 STB Upper	0%	273,705	0,000	74,367			7,000
41	Tk 26 BW 7 Port Upper	0%	273,733	0,000	55,270			7,000
42	Tk 27 BW 7 STB Upper	0%	273,733	0,000	55,270			7,000
43	Tk 28 BW 8 Port Upper	100%	276,148	276,148	35,711			9,560
44	Tk 29 BW 8 STB Upper	100%	276,148	276,148	35,711			9,560
45	**Total Loadcase**			**30392,39**	**76,288**			**9,906**



Code	Criteria	Value	Units	Actual	Status	Margin %
267(85) Ch2 - General Criteria	2.3: IMO roll back angle					
	L, Stability calculated	160,929	m			
	B, Stability calculated	23,953	m			
	d, Stability calculated	10,995	m			
	GMf, Stability calculated	1,381	m			
	VCG, Stability calculated	9,909	m			
	CB, Stability calculated	0,704				
	Ak, keel area, user spec.	10,8	m^2			
	Method for k factor	Tabulated value for k				
	Evaluates to	20,1	deg			
	Intermediate values					
	B / d			2,178		
	100 Ak / L / B			0,28		
	C		IMO units	0,354		
	T		s	14,425		
	OG, Centre of gravity above WL		m	-1,086		
	X1		IMO units	1		
	X2		IMO units	1		
	k tabulated		IMO units	0,994		
	r		IMO units	0,671		
	s		IMO units	0,051		
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 30				Pass	
	from the greater of					
	spec. heel angle	0	deg	0		
	to the lesser of					
	spec. heel angle	30	deg	30		
	angle of vanishing stability	64	deg			
	shall not be less than (>=)	3,1513	m.deg	11,0839	Pass	251,72
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 40				Pass	
	from the greater of					
	spec. heel angle	0	deg	0		
	to the lesser of					
	spec. heel angle	40	deg	40		
	first downflooding angle	79,1	deg			
	angle of vanishing stability	64	deg			
	shall not be less than (>=)	5,1566	m.deg	16,3833	Pass	217,72
267(85) Ch2 - General Criteria	2.2.1: Area 30 to 40				Pass	
	from the greater of					
	spec. heel angle	30	deg	30		
	to the lesser of					
	spec. heel angle	40	deg	40		
	first downflooding angle	79,1	deg			
	angle of vanishing stability	64	deg			
	shall not be less than (>=)	1,7189	m.deg	5,2994	Pass	208,3
267(85) Ch2 - General Criteria	2.2.2: Max GZ at 30 or greater				Pass	

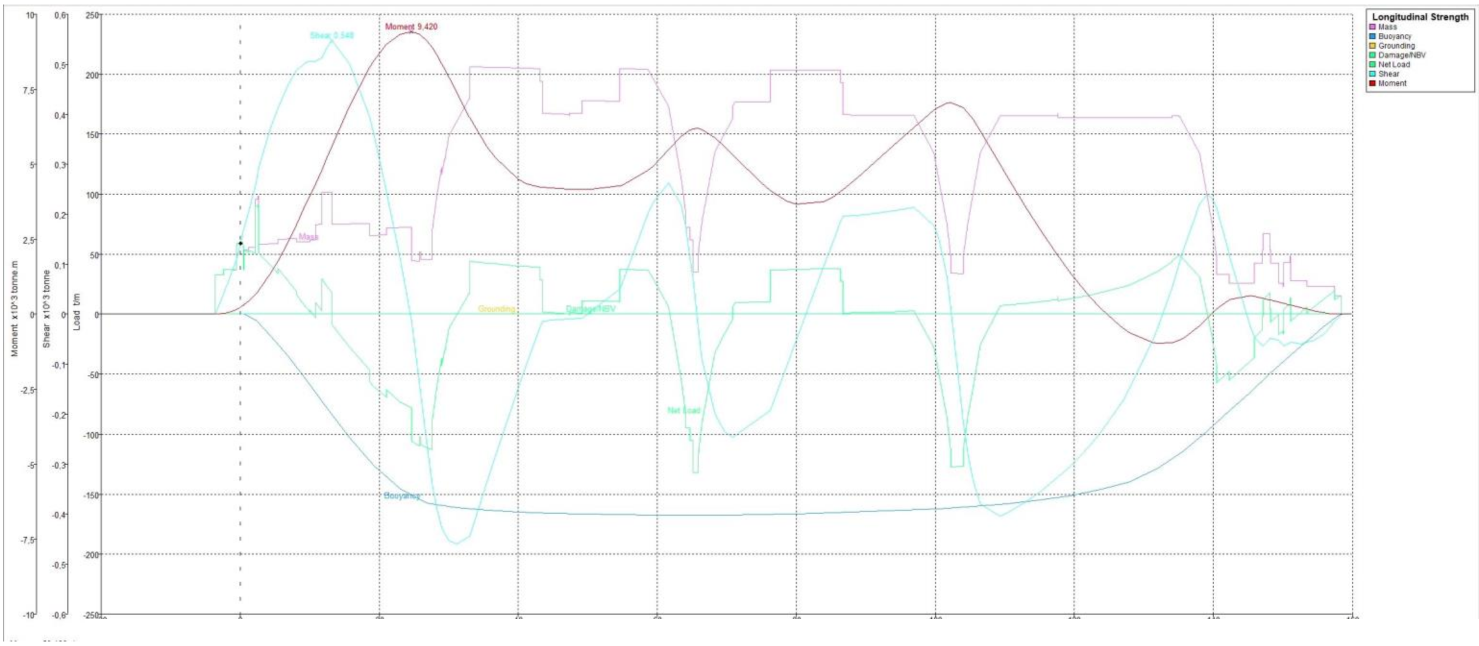
	in the range from the greater of					
	spec. heel angle	30	deg	30		
	to the lesser of					
	spec. heel angle	90	deg	90		
	angle of max. GZ	25,9	deg			
	shall not be less than (>=)	0,2	m	0,593	Pass	196,5
	Intermediate values					
	angle at which this GZ occurs		deg	30		
267(85) Ch2 - General Criteria	2.2.3: Angle of maximum GZ				Pass	
	shall not be less than (>=)	25	deg	25,9	Pass	3,64
267(85) Ch2 - General Criteria	2.2.4: Initial GMt				Pass	
	spec. heel angle	0	deg			
	shall not be less than (>=)	0,15	m	1,381	Pass	820,67
267(85) Ch2 - General Criteria	2.3: Severe wind and rolling				Pass	
	Wind arm: a P A (h - H) / (g disp.) cos^n(phi)					
	constant: a =	0,99966				
	wind pressure: P =	504	Pa			
	area centroid height (from zero point): h =	15,8	m			
	total area: A =	1139,1	m^2			
	H = mean draft / 2	5,498	m			
	cosine power: n =	0				
	gust ratio	1,5				
	Area2 integrated to the lesser of					
	2.3: IMO roll back angle from equilibrium (with steady heel arm)	20,1 (-19,2)	deg	-19,2		
	Area 1 upper integration range, to the lesser of:					
	first downflooding angle	79,1	deg			
	angle of vanishing stability (with gust heel arm)	62,9	deg	62,9		
	Angle for GZ(max) in GZ ratio, the lesser of:					
	angle of max. GZ	25,9	deg	25,9		
	Select required angle for angle of steady heel ratio:	DeckEdgeImmersionAngle				
	Criteria:				Pass	
	Angle of steady heel shall not be greater than (<=)	16	deg	0,8	Pass	94,84
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80	%	4,38	Pass	94,53
	Area1 / Area2 shall not be less than (>=)	100	%	390,53	Pass	290,53
	Intermediate values					
	Heel arm amplitude		m	0,02		
	Equilibrium angle with gust heel arm		deg	1,2		
	Deck edge immersion angle		deg	18,8		
	Area1 (under GZ), from 1,2 to 62,9 deg.		m.deg	22,5467		
	Area1 (under HA), from 1,2 to 62,9 deg.		m.deg	1,8363		
	Area1, from 1,2 to 62,9 deg.		m.deg	20,7104		
	Area2 (under GZ), from -19,2 to 1,2 deg.		m.deg	-4,6939		
	Area2 (under HA), from -19,2 to 1,2 deg.		m.deg	0,6093		
	Area2, from -19,2 to 1,2 deg.		m.deg	5,3032		



1	Draft Amidships m	10,995
2	Displacement t	30392
3	Heel deg	0,0
4	Draft at FP m	11,039
5	Draft at AP m	10,951
6	Draft at LCF m	10,990
7	Trim (+ve by stern) m	-0,088
8	WL Length m	160,92
9	Beam max extents on WL m	23,714
10	Wetted Area m^2	5628,7
11	Waterpl. Area m^2	3458,7
12	Prismatic coeff. (Cp)	0,807
13	Block coeff. (Cb)	0,704
14	Max Sect. area coeff. (Cm)	0,879
15	Waterpl. area coeff. (Cwp)	0,906
16	LCB from zero pt. (+ve fwd) m	76,292
17	LCF from zero pt. (+ve fwd) m	70,450
18	KB m	6,252
19	KG fluid m	9,909
20	BMt m	5,039
21	BML m	215,76
22	GMt corrected m	1,382
23	GML m	212,10
24	KMt m	11,291
25	KML m	222,01
26	Immersion (TPc) tonne/cm	35,452
27	MTc tonne.m	409,55
28	RM at 1deg = GMt.Disp.sin(1) tonne.m	732,85
29	Max deck inclination deg	0,0319
30	Trim angle (+ve by stern) deg	-0,031

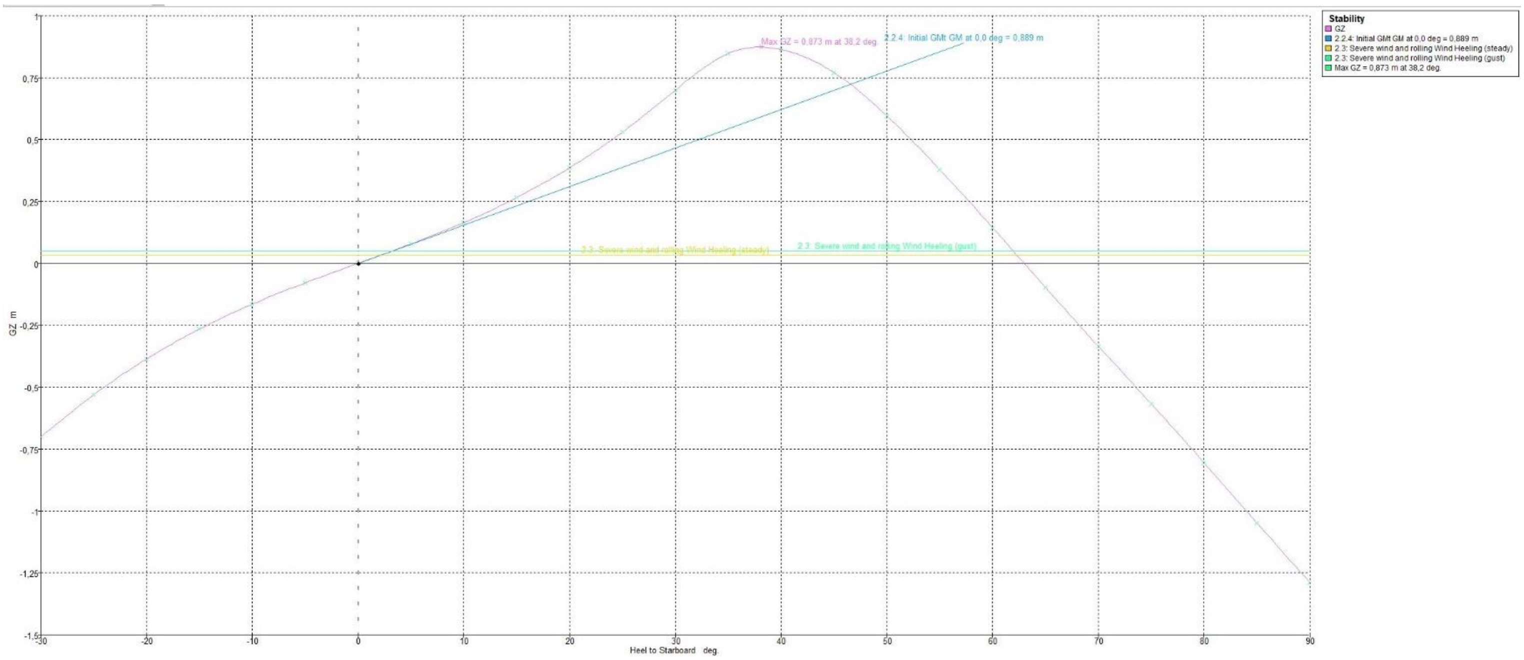
LC Departure Port NH3

	Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Long. Arm m	Aft. Limit m	Fwd. Limit m	Vert. Arm m
1	Lightship	1	8441,830	8441,830	69,446			11,016
2	Tk 1 Fore peak	0%	268,986	0,000	151,467			0,000
3	Tk 2 BW 1 Port	0%	9,009	0,000	147,280			0,000
4	Tk 3 BW 1 Stb	0%	9,009	0,000	147,280			0,000
5	Tk 4 BW 2 Port	0%	8,895	0,000	143,611			0,000
6	Tk 5 BW 2 Stb	0%	8,895	0,000	143,611			0,000
7	Cargo Tank 1 CO2	0%	6525,714	0,000	122,237			1,600
8	Cargo Tank 2 CO2	0%	6525,714	0,000	84,022			1,600
9	Cargo Tank 3 CO2	0%	6525,716	0,000	45,807			1,600
10	Cargo Tank 1 NH3	100%	3853,280	3853,280	122,237			9,100
11	Cargo Tank 2 NH3	100%	3853,280	3853,280	84,022			9,100
12	Cargo Tank 3 NH3	100%	3853,280	3853,280	45,807			9,100
13	Tk 6 BW 3 Port	0%	95,054	0,000	122,461			0,871
14	Tk 7 BW 3 STB	0%	95,054	0,000	122,461			0,871
15	Tk 8 BW 4 Port	0%	290,196	0,000	103,309			0,682
16	Tk 9 BW 4 STB	0%	290,196	0,000	103,309			0,682
17	Tk 10 BW 5 Port	0%	334,810	0,000	84,109			0,619
18	Tk 11 BW 5 STB	0%	334,810	0,000	84,109			0,619
19	Tk 12 BW 6 Port	0%	341,475	0,000	76,828			0,616
20	Tk 13 BW 6 STB	0%	341,475	0,000	76,828			0,616
21	Tk 14 BW 7 Port	0%	332,123	0,000	64,691			0,643
22	Tk 15 BW 7 STB	0%	332,123	0,000	64,691			0,643
23	Tk 16 BW 8 Port	0%	304,408	0,000	45,488			0,771
24	Tk 17 BW 8 STB	0%	304,408	0,000	45,488			0,771
25	Tk BW Aft Upper Port	0%	260,457	0,000	2,735			9,100
26	TK BW Aft Upper STB	0%	260,457	0,000	2,735			9,100
27	Fuel Aft STB	1	140,600	140,600	38,250	33,000	43,500	20,650
28	Fuel Aft Port	1	140,600	140,600	38,250	33,000	43,500	20,650
29	Fuel mid STB	1	140,600	140,600	59,850	54,600	65,100	20,650
30	Fuel mid Port	1	140,600	140,600	59,850	54,600	65,100	20,650
31	Fuel fore STB	1	140,600	140,600	81,450	76,200	86,700	20,650
32	Fuel fore Port	1	140,600	140,600	81,450	76,200	86,700	20,650
33	Tk 18 BW 3 Port Upper	0%	94,369	0,000	127,016			7,000
34	Tk 19 BW 3 STB Upper	0%	94,369	0,000	127,016			7,000
35	Tk 20 BW 4 Port Upper	0%	229,105	0,000	112,367			7,000
36	Tk 21 BW 4 STB Upper	0%	229,105	0,000	112,367			7,000
37	Tk 22 BW 5 Port Upper	0%	260,105	0,000	93,456			7,000
38	Tk 23 BW 5 STB Upper	0%	260,105	0,000	93,456			7,000
39	Tk 24 BW 6 Port Upper	0%	273,705	0,000	74,367			7,000
40	Tk 25 BW 6 STB Upper	0%	273,705	0,000	74,367			7,000
41	Tk 26 BW 7 Port Upper	0%	273,733	0,000	55,270			7,000
42	Tk 27 BW 7 STB Upper	0%	273,733	0,000	55,270			7,000
43	Tk 28 BW 8 Port Upper	0%	276,148	0,000	35,715			7,000
44	Tk 29 BW 8 STB Upper	0%	276,148	0,000	35,715			7,000
45	**Total Loadcase**			**20845,27**	**77,141**			**10,343**



Code	Criteria	Value	Units	Actual	Status	Margin %
267(85) Ch2 - General Criteria	2.3: IMO roll back angle					
	L, Stability calculated	157,335	m			
	B, Stability calculated	23,953	m			
	d, Stability calculated	8,191	m			
	GMf, Stability calculated	0,889	m			
	VCG, Stability calculated	10,343	m			
	CB, Stability calculated	0,665				
	Ak, keel area, user spec.	10,8	m^2			
	Method for k factor	Tabulated value for k				
	Evaluates to	17,4	deg			
	Intermediate values					
	B / d			2,924		
	100 Ak / L / B			0,287		
	C		IMO units	0,373		
	T		s	18,934		
	OG, Centre of gravity above WL		m	2,153		
	X1		IMO units	0,908		
	X2		IMO units	0,979		
	k tabulated		IMO units	0,994		
	r		IMO units	0,888		
	s		IMO units	0,037		
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 30				Pass	
	from the greater of					
	spec. heel angle	0	deg	0		
	to the lesser of					
	spec. heel angle	30	deg	30		
	angle of vanishing stability	63	deg			
	shall not be less than (>=)	3,1513	m.deg	8,8368	Pass	180,42
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 40				Pass	
	from the greater of					
	spec. heel angle	0	deg	0		
	to the lesser of					
	spec. heel angle	40	deg	40		
	first downflooding angle	n/a	deg			
	angle of vanishing stability	63	deg			
	shall not be less than (>=)	5,1566	m.deg	17,0792	Pass	231,21
267(85) Ch2 - General Criteria	2.2.1: Area 30 to 40				Pass	
	from the greater of					
	spec. heel angle	30	deg	30		
	to the lesser of					
	spec. heel angle	40	deg	40		
	first downflooding angle	n/a	deg			
	angle of vanishing stability	63	deg			
	shall not be less than (>=)	1,7189	m.deg	8,2423	Pass	379,51
267(85) Ch2 - General Criteria	2.2.2: Max GZ at 30 or greater				Pass	

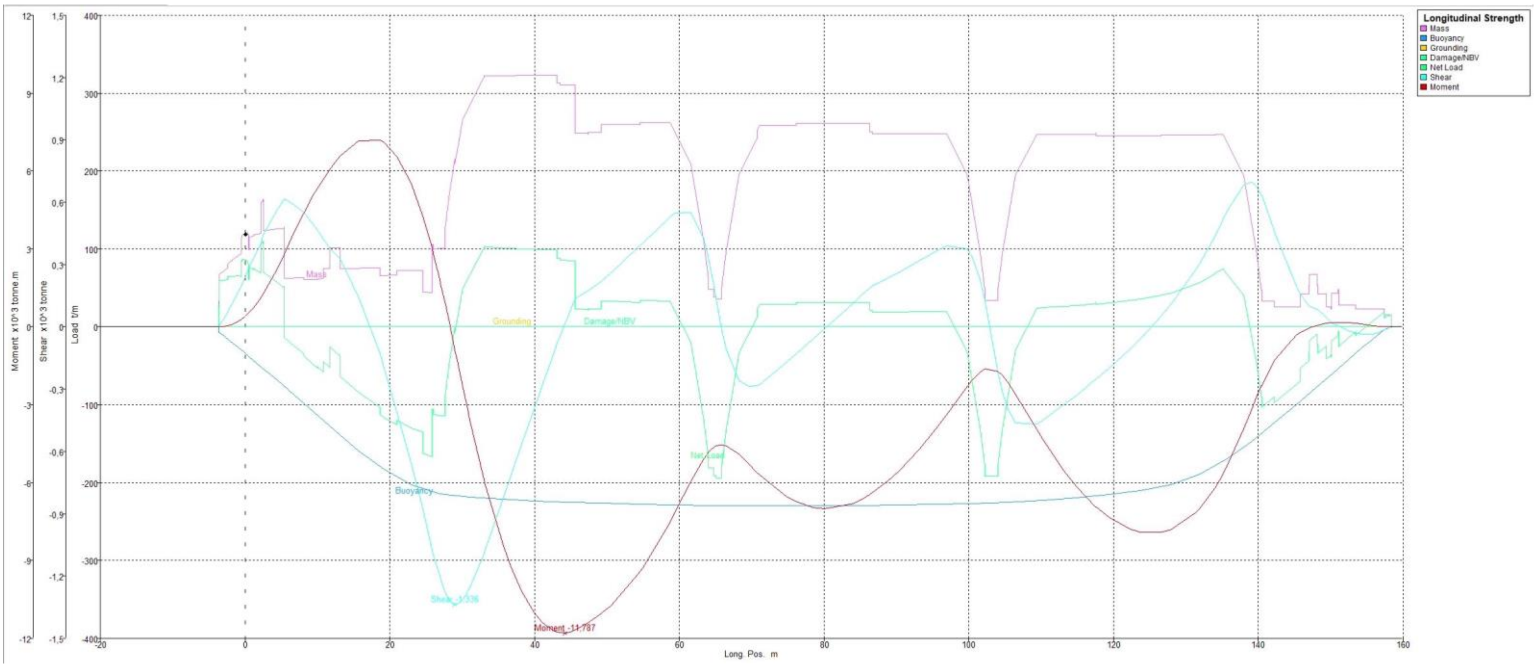
	in the range from the greater of					
	spec. heel angle	30	deg	30		
	to the lesser of					
	spec. heel angle	90	deg			
	angle of max. GZ	38,2	deg	38,2		
	shall not be less than (>=)	0,2	m	0,873	Pass	336,5
	Intermediate values					
	angle at which this GZ occurs		deg	38,2		
267(85) Ch2 - General Criteria	2.2.3: Angle of maximum GZ				Pass	
	shall not be less than (>=)	25	deg	38,2	Pass	52,73
267(85) Ch2 - General Criteria	2.2.4: Initial GMt				Pass	
	spec. heel angle	0	deg			
	shall not be less than (>=)	0,15	m	0,889	Pass	492,67
267(85) Ch2 - General Criteria	2.3: Severe wind and rolling				Pass	
	Wind arm: a P A (h - H) / (g disp.) cos^n(phi)					
	constant: a =	0,99966				
	wind pressure: P =	504	Pa			
	area centroid height (from zero point): h =	15,8	m			
	total area: A =	1139,1	m^2			
	H = mean draft / 2	4,095	m			
	cosine power: n =	0				
	gust ratio	1,5				
	Area2 integrated to the lesser of					
	2.3: IMO roll back angle from equilibrium (with steady heel arm)	17,4 (-15,2)	deg	-15,2		
	Area 1 upper integration range, to the lesser of:					
	first downflooding angle	n/a	deg			
	angle of vanishing stability (with gust heel arm)	62	deg	62		
	Angle for GZ(max) in GZ ratio, the lesser of:					
	angle of max. GZ	38,2	deg	38,2		
	Select required angle for angle of steady heel ratio:	DeckEdgeImmersionAngle				
	Criteria:				Pass	
	Angle of steady heel shall not be greater than (<=)	16	deg	2,1	Pass	86,78
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80	%	6,78	Pass	91,53
	Area1 / Area2 shall not be less than (>=)	100	%	928,88	Pass	828,88
	Intermediate values					
	Heel arm amplitude		m	0,033		
	Equilibrium angle with gust heel arm		deg	3,2		
	Deck edge immersion angle		deg	31,2		
	Area1 (under GZ), from 3,2 to 62,0 deg.		m.deg	28,5248		
	Area1 (under HA), from 3,2 to 62,0 deg.		m.deg	2,8987		
	Area1, from 3,2 to 62,0 deg.		m.deg	25,6261		
	Area2 (under GZ), from -15,2 to 3,2 deg.		m.deg	-1,8519		
	Area2 (under HA), from -15,2 to 3,2 deg.		m.deg	0,9069		
	Area2, from -15,2 to 3,2 deg.		m.deg	2,7588		



1	Draft Amidships m	8,191
2	Displacement t	20845
3	Heel deg	0,0
4	Draft at FP m	7,877
5	Draft at AP m	8,505
6	Draft at LCF m	8,213
7	Trim (+ve by stern) m	0,629
8	WL Length m	157,32
9	Beam max extents on WL m	23,392
10	Wetted Area m^2	4609,0
11	Waterpl. Area m^2	3243,0
12	Prismatic coeff. (Cp)	0,792
13	Block coeff. (Cb)	0,665
14	Max Sect. area coeff. (Cm)	0,849
15	Waterpl. area coeff. (Cwp)	0,881
16	LCB from zero pt. (+ve fwd) m	77,129
17	LCF from zero pt. (+ve fwd) m	73,104
18	KB m	4,712
19	KG fluid m	10,343
20	BMt m	6,520
21	BML m	270,10
22	GMt corrected m	0,888
23	GML m	264,47
24	KMt m	11,232
25	KML m	274,81
26	Immersion (TPc) tonne/cm	33,242
27	MTc tonne.m	350,26
28	RM at 1deg = GMt.Disp.sin(1) tonne.	323,16
29	Max deck inclination deg	0,2288
30	Trim angle (+ve by stern) deg	0,2288

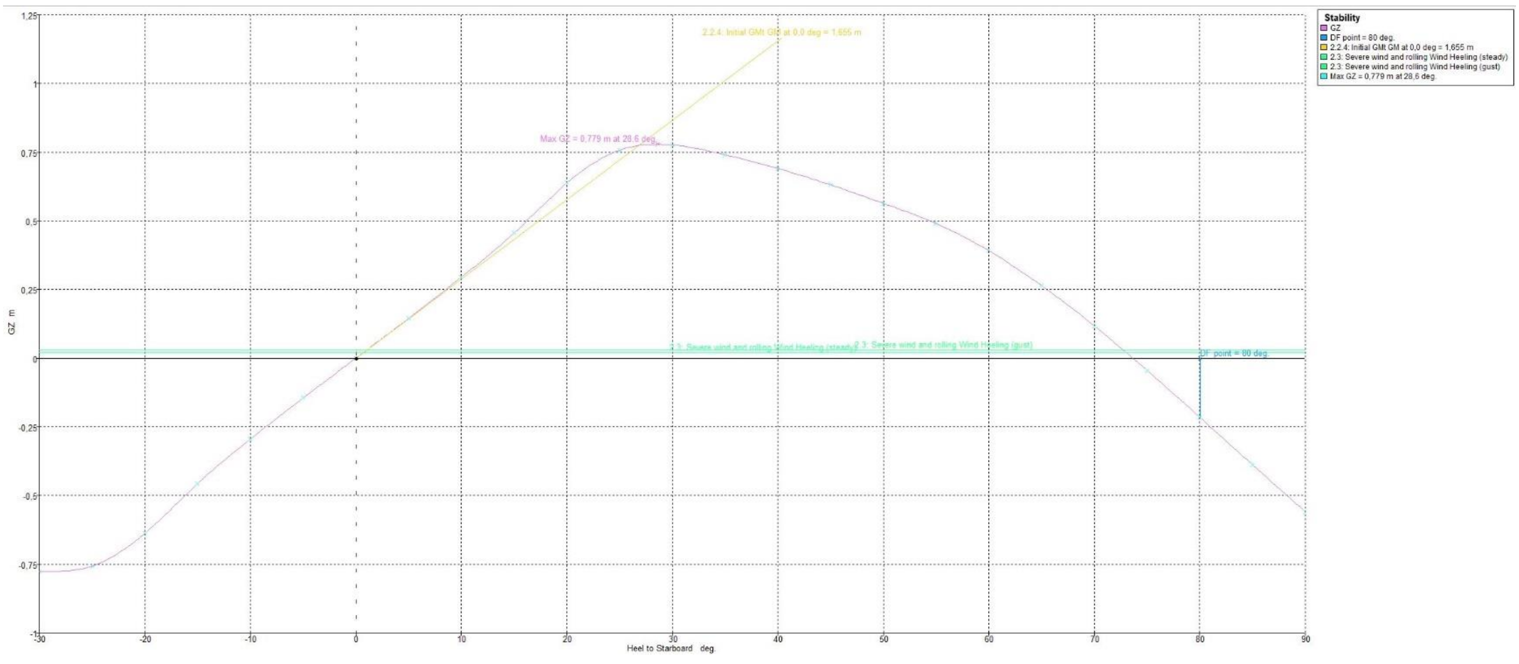
Arrival Port CO2

	Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Long. Arm m	Aft. Limit m	Fwd. Limit m	Vert. Arm m
1	**Lightship**	**1**	8441,830	8441,830	69,446			11,016
2	Tk 1 Fore peak	**0%**	268,986	0,000	151,467			0,000
3	Tk 2 BW 1 Port	**0%**	9,009	0,000	147,280			0,000
4	Tk 3 BW 1 Stb	**0%**	9,009	0,000	147,280			0,000
5	Tk 4 BW 2 Port	**0%**	8,895	0,000	143,611			0,000
6	Tk 5 BW 2 Stb	**0%**	8,895	0,000	143,611			0,000
7	Cargo Tank 1 CO2	**100%**	6525,714	6525,714	122,237			9,100
8	Cargo Tank 2 CO2	**100%**	6525,714	6525,714	84,022			9,100
9	Cargo Tank 3 CO2	**100%**	6525,716	6525,716	45,807			9,100
10	Cargo Tank 1 NH3	**0%**	3853,280	0,000	122,237			1,600
11	Cargo Tank 2 NH3	**0%**	3853,280	0,000	84,022			1,600
12	Cargo Tank 3 NH3	**0%**	3853,280	0,000	45,807			1,600
13	Tk 6 BW 3 Port	**0%**	95,054	0,000	122,461			0,871
14	Tk 7 BW 3 STB	**0%**	95,054	0,000	122,461			0,871
15	Tk 8 BW 4 Port	**0%**	290,196	0,000	103,309			0,682
16	Tk 9 BW 4 STB	**0%**	290,196	0,000	103,309			0,682
17	Tk 10 BW 5 Port	**0%**	334,810	0,000	84,109			0,619
18	Tk 11 BW 5 STB	**0%**	334,810	0,000	84,109			0,619
19	Tk 12 BW 6 Port	**0%**	341,475	0,000	76,828			0,616
20	Tk 13 BW 6 STB	**0%**	341,475	0,000	76,828			0,616
21	Tk 14 BW 7 Port	**0%**	332,123	0,000	64,691			0,643
22	Tk 15 BW 7 STB	**0%**	332,123	0,000	64,691			0,643
23	Tk 16 BW 8 Port	**100%**	304,408	304,408	36,080			4,262
24	Tk 17 BW 8 STB	**100%**	304,408	304,408	36,080			4,262
25	Tk BW Aft Upper Port	**100%**	260,457	260,457	1,304			10,699
26	TK BW Aft Upper STB	**100%**	260,457	260,457	1,304			10,699
27	Fuel Aft STB	0,1	140,600	14,060	38,250	33,000	43,500	20,650
28	Fuel Aft Port	0,1	140,600	14,060	38,250	33,000	43,500	20,650
29	Fuel mid STB	0,1	140,600	14,060	59,850	54,600	65,100	20,650
30	Fuel mid Port	0,1	140,600	14,060	59,850	54,600	65,100	20,650
31	Fuel fore STB	0,1	140,600	14,060	81,450	76,200	86,700	20,650
32	Fuel fore Port	0,1	140,600	14,060	81,450	76,200	86,700	20,650
33	Tk 18 BW 3 Port Upper	**0%**	94,369	0,000	127,016			7,000
34	Tk 19 BW 3 STB Upper	**0%**	94,369	0,000	127,016			7,000
35	Tk 20 BW 4 Port Upper	**0%**	229,105	0,000	112,367			7,000
36	Tk 21 BW 4 STB Upper	**0%**	229,105	0,000	112,367			7,000
37	Tk 22 BW 5 Port Upper	**0%**	260,105	0,000	93,456			7,000
38	Tk 23 BW 5 STB Upper	**0%**	260,105	0,000	93,456			7,000
39	Tk 24 BW 6 Port Upper	**0%**	273,705	0,000	74,367			7,000
40	Tk 25 BW 6 STB Upper	**0%**	273,705	0,000	74,367			7,000
41	Tk 26 BW 7 Port Upper	**0%**	273,733	0,000	55,270			7,000
42	Tk 27 BW 7 STB Upper	**0%**	273,733	0,000	55,270			7,000
43	Tk 28 BW 8 Port Upper	**100%**	276,148	276,148	35,711			9,560
44	Tk 29 BW 8 STB Upper	**100%**	276,148	276,148	35,711			9,560
45	**Total Loadcase**			**29785,36**	**76,500**			**9,613**



Code	Criteria	Value	Units	Actual	Status	Margin %
267(85) Ch2 - General Criteria	2.3: IMO roll back angle					
	L, Stability calculated	160,921	m			
	B, Stability calculated	23,953	m			
	d, Stability calculated	10,827	m			
	GMf, Stability calculated	1,655	m			
	VCG, Stability calculated	9,613	m			
	CB, Stability calculated	0,699				
	Ak, keel area, user spec.	10,8	m^2			
	Method for k factor	Tabulated value for k				
	Evaluates to	21,2	deg			
	Intermediate values					
	B / d			2,212		
	100 Ak / L / B			0,28		
	C		IMO units	0,355		
	T		s	13,206		
	OG, Centre of gravity above WL		m	-1,214		
	X1		IMO units	1		
	X2		IMO units	0,999		
	k tabulated		IMO units	0,994		
	r		IMO units	0,663		
	s		IMO units	0,058		
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 30				Pass	
	from the greater of					
	spec. heel angle	0	deg	0		
	to the lesser of					
	spec. heel angle	30	deg	30		
	angle of vanishing stability	73,6	deg			
	shall not be less than (>=)	3,1513	m.deg	13,4601	Pass	327,13
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 40				Pass	
	from the greater of					
	spec. heel angle	0	deg	0		
	to the lesser of					
	spec. heel angle	40	deg	40		
	first downflooding angle	80	deg			
	angle of vanishing stability	73,6	deg			
	shall not be less than (>=)	5,1566	m.deg	20,842	Pass	304,18
267(85) Ch2 - General Criteria	2.2.1: Area 30 to 40				Pass	
	from the greater of					
	spec. heel angle	30	deg	30		
	to the lesser of					
	spec. heel angle	40	deg	40		
	first downflooding angle	80	deg			
	angle of vanishing stability	73,6	deg			
	shall not be less than (>=)	1,7189	m.deg	7,3819	Pass	329,45
267(85) Ch2 - General Criteria	2.2.2: Max GZ at 30 or greater				Pass	

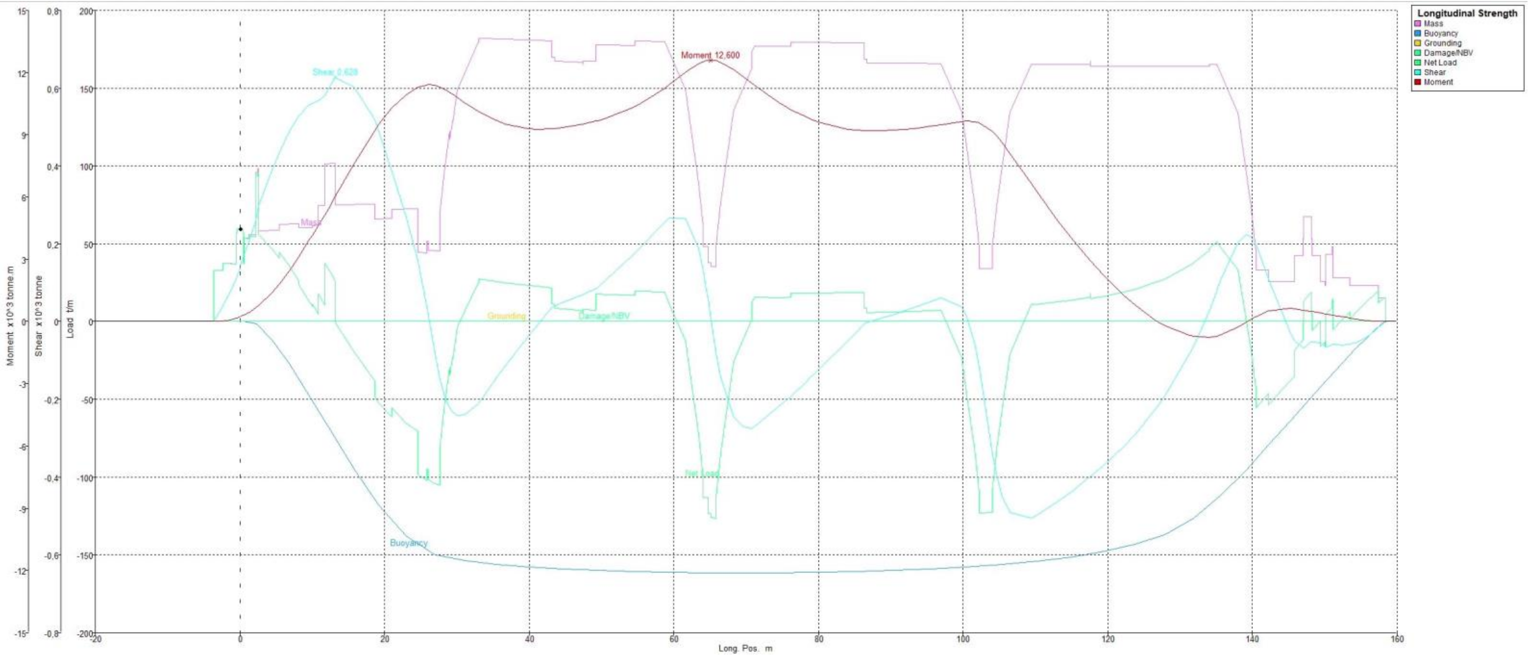
	in the range from the greater of					
	spec. heel angle	30	deg	30		
	to the lesser of					
	spec. heel angle	90	deg	90		
	angle of max. GZ	28,6	deg			
	shall not be less than (>=)	0,2	m	0,776	Pass	288
	Intermediate values					
	angle at which this GZ occurs		deg	30		
267(85) Ch2 - General Criteria	2.2.3: Angle of maximum GZ				Pass	
	shall not be less than (>=)	25	deg	28,6	Pass	14,54
267(85) Ch2 - General Criteria	2.2.4: Initial GMt				Pass	
	spec. heel angle	0	deg			
	shall not be less than (>=)	0,15	m	1,655	Pass	1003,33
267(85) Ch2 - General Criteria	2.3: Severe wind and rolling				Pass	
	Wind arm: a P A (h - H) / (g disp.) cos^n(phi)					
	constant: a =	0,99966				
	wind pressure: P =	504	Pa			
	area centroid height (from zero point): h =	15,8	m			
	total area: A =	1139,1	m^2			
	H = mean draft / 2	5,414	m			
	cosine power: n =	0				
	gust ratio	1,5				
	Area2 integrated to the lesser of					
	2.3: IMO roll back angle from equilibrium (with steady heel arm)	21,2 (-20,5)	deg	-20,5		
	Area 1 upper integration range, to the lesser of:					
	first downflooding angle	80	deg			
	angle of vanishing stability (with gust heel arm)	72,7	deg	72,7		
	Angle for GZ(max) in GZ ratio, the lesser of:					
	angle of max. GZ	28,6	deg	28,6		
	Select required angle for angle of steady heel ratio:	DeckEdgeImmersionAngle				
	Criteria:				Pass	
	Angle of steady heel shall not be greater than (<=)	16	deg	0,7	Pass	95,58
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80	%	3,62	Pass	95,48
	Area1 / Area2 shall not be less than (>=)	100	%	463,97	Pass	363,97
	Intermediate values					
	Heel arm amplitude		m	0,02		
	Equilibrium angle with gust heel arm		deg	1,1		
	Deck edge immersion angle		deg	19,5		
	Area1 (under GZ), from 1,1 to 72,7 deg.		m.deg	34,7802		
	Area1 (under HA), from 1,1 to 72,7 deg.		m.deg	2,1927		
	Area1, from 1,1 to 72,7 deg.		m.deg	32,5875		
	Area2 (under GZ), from -20,5 to 1,1 deg.		m.deg	-6,3641		
	Area2 (under HA), from -20,5 to 1,1 deg.		m.deg	0,6596		
	Area2, from -20,5 to 1,1 deg.		m.deg	7,0237		



1	Draft Amidships m	10,827
2	Displacement t	29785
3	Heel deg	0,0
4	Draft at FP m	10,904
5	Draft at AP m	10,749
6	Draft at LCF m	10,819
7	Trim (+ve by stern) m	-0,155
8	WL Length m	160,92
9	Beam max extents on WL m	23,697
10	Wetted Area m^2	5568,2
11	Waterpl. Area m^2	3451,1
12	Prismatic coeff. (Cp)	0,805
13	Block coeff. (Cb)	0,699
14	Max Sect. area coeff. (Cm)	0,877
15	Waterpl. area coeff. (Cwp)	0,905
16	LCB from zero pt. (+ve fwd) m	76,504
17	LCF from zero pt. (+ve fwd) m	70,511
18	KB m	6,157
19	KG fluid m	9,613
20	BMt m	5,112
21	BML m	219,12
22	GMt corrected m	1,655
23	GML m	215,66
24	KMt m	11,269
25	KML m	225,28
26	Immersion (TPc) tonne/cm	35,374
27	MTc tonne.m	408,11
28	RM at 1deg = GMt.Disp.sin(1) tonne.	860,48
29	Max deck inclination deg	0,0564
30	Trim angle (+ve by stern) deg	-0,056

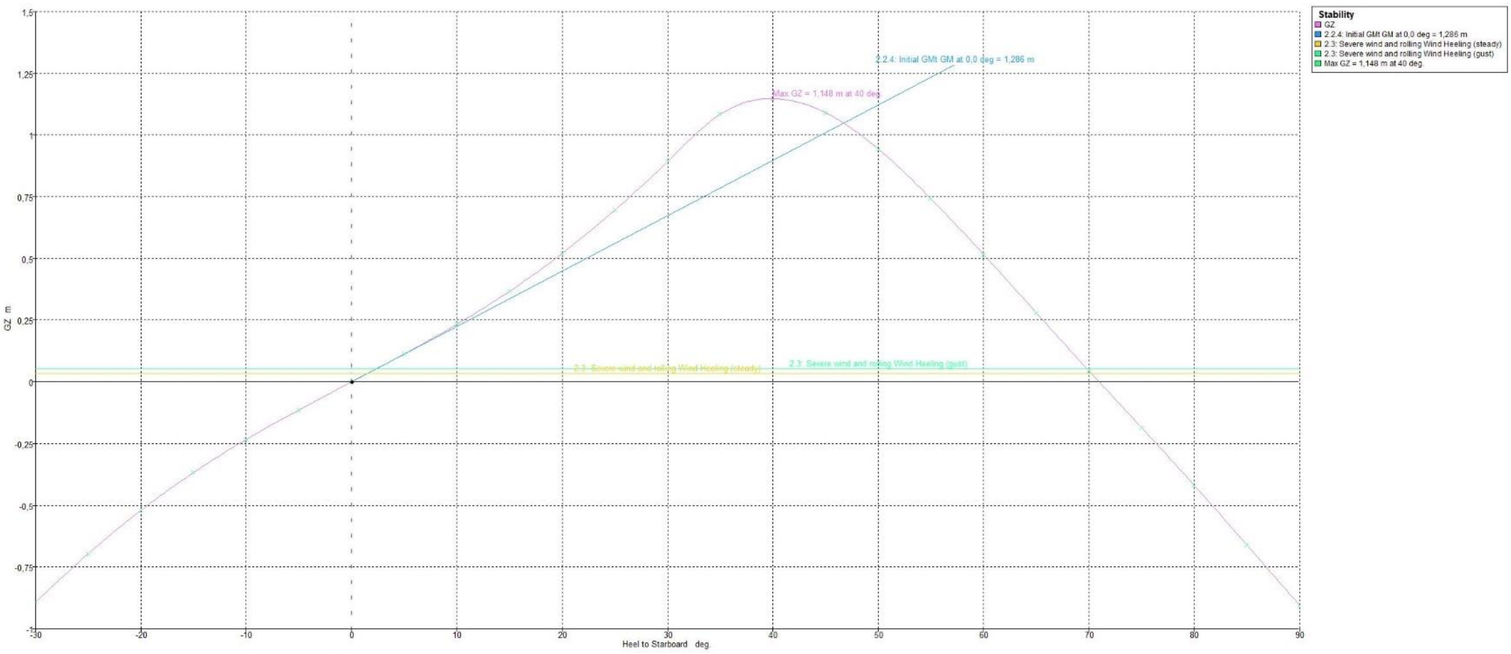
Arrival Port NH3

	Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Long. Arm m	Aft. Limit m	Fwd. Limit m	Vert. Arm m
1	Lightship	1	8441,830	8441,830	69,446			11,016
2	Tk 1 Fore peak	0%	268,986	0,000	151,467			0,000
3	Tk 2 BW 1 Port	0%	9,009	0,000	147,280			0,000
4	Tk 3 BW 1 Stb	0%	9,009	0,000	147,280			0,000
5	Tk 4 BW 2 Port	0%	8,895	0,000	143,611			0,000
6	Tk 5 BW 2 Stb	0%	8,895	0,000	143,611			0,000
7	Cargo Tank 1 CO2	0%	6525,714	0,000	122,237			1,600
8	Cargo Tank 2 CO2	0%	6525,714	0,000	84,022			1,600
9	Cargo Tank 3 CO2	0%	6525,716	0,000	45,807			1,600
10	Cargo Tank 1 NH3	100%	3853,280	3853,280	122,237			9,100
11	Cargo Tank 2 NH3	100%	3853,280	3853,280	84,022			9,100
12	Cargo Tank 3 NH3	100%	3853,280	3853,280	45,807			9,100
13	Tk 6 BW 3 Port	0%	95,054	0,000	122,461			0,871
14	Tk 7 BW 3 STB	0%	95,054	0,000	122,461			0,871
15	Tk 8 BW 4 Port	0%	290,196	0,000	103,309			0,682
16	Tk 9 BW 4 STB	0%	290,196	0,000	103,309			0,682
17	Tk 10 BW 5 Port	0%	334,810	0,000	84,109			0,619
18	Tk 11 BW 5 STB	0%	334,810	0,000	84,109			0,619
19	Tk 12 BW 6 Port	0%	341,475	0,000	76,828			0,616
20	Tk 13 BW 6 STB	0%	341,475	0,000	76,828			0,616
21	Tk 14 BW 7 Port	0%	332,123	0,000	64,691			0,643
22	Tk 15 BW 7 STB	0%	332,123	0,000	64,691			0,643
23	Tk 16 BW 8 Port	0%	304,408	0,000	45,488			0,771
24	Tk 17 BW 8 STB	0%	304,408	0,000	45,488			0,771
25	Tk BW Aft Upper Port	0%	260,457	0,000	2,735			9,100
26	TK BW Aft Upper STB	0%	260,457	0,000	2,735			9,100
27	Fuel Aft STB	0,1	140,600	14,060	38,250	33,000	43,500	20,650
28	Fuel Aft Port	0,1	140,600	14,060	38,250	33,000	43,500	20,650
29	Fuel mid STB	0,1	140,600	14,060	59,850	54,600	65,100	20,650
30	Fuel mid Port	0,1	140,600	14,060	59,850	54,600	65,100	20,650
31	Fuel fore STB	0,1	140,600	14,060	81,450	76,200	86,700	20,650
32	Fuel fore Port	0,1	140,600	14,060	81,450	76,200	86,700	20,650
33	Tk 18 BW 3 Port Upper	0%	94,369	0,000	127,016			7,000
34	Tk 19 BW 3 STB Upper	0%	94,369	0,000	127,016			7,000
35	Tk 20 BW 4 Port Upper	0%	229,105	0,000	112,367			7,000
36	Tk 21 BW 4 STB Upper	0%	229,105	0,000	112,367			7,000
37	Tk 22 BW 5 Port Upper	0%	260,105	0,000	93,456			7,000
38	Tk 23 BW 5 STB Upper	0%	260,105	0,000	93,456			7,000
39	Tk 24 BW 6 Port Upper	0%	273,705	0,000	74,367			7,000
40	Tk 25 BW 6 STB Upper	0%	273,705	0,000	74,367			7,000
41	Tk 26 BW 7 Port Upper	0%	273,733	0,000	55,270			7,000
42	Tk 27 BW 7 STB Upper	0%	273,733	0,000	55,270			7,000
43	Tk 28 BW 8 Port Upper	0%	276,148	0,000	35,715			7,000
44	Tk 29 BW 8 STB Upper	0%	276,148	0,000	35,715			7,000
45	Total Loadcase			20086,03	77,795			9,954



Code	Criteria	Value	Units	Actual	Status	Margin %
267(85) Ch2 - General Criteria	2.3: IMO roll back angle					
	L, Stability calculated	156,415	m			
	B, Stability calculated	23,953	m			
	d, Stability calculated	7,971	m			
	GMf, Stability calculated	1,286	m			
	VCG, Stability calculated	9,954	m			
	CB, Stability calculated	0,671				
	Ak, keel area, user spec.	10,8	m^2			
	Method for k factor	Tabulated value for k				
	Evaluates to	19	deg			
	Intermediate values					
	B / d			3,005		
	100 Ak / L / B			0,288		
	C		IMO units	0,375		
	T		s	15,838		
	OG, Centre of gravity above WL		m	1,983		
	X1		IMO units	0,899		
	X2		IMO units	0,983		
	k tabulated		IMO units	0,994		
	r		IMO units	0,879		
	s		IMO units	0,045		
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 30				Pass	
	from the greater of					
	spec. heel angle	0	deg	0		
	to the lesser of					
	spec. heel angle	30	deg	30		
	angle of vanishing stability	71	deg			
	shall not be less than (>=)	3,1513	m.deg	11,8484	Pass	275,99
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 40				Pass	
	from the greater of					
	spec. heel angle	0	deg	0		
	to the lesser of					
	spec. heel angle	40	deg	40		
	first downflooding angle	n/a	deg			
	angle of vanishing stability	71	deg			
	shall not be less than (>=)	5,1566	m.deg	22,4558	Pass	335,48
267(85) Ch2 - General Criteria	2.2.1: Area 30 to 40				Pass	
	from the greater of					
	spec. heel angle	30	deg	30		
	to the lesser of					
	spec. heel angle	40	deg	40		
	first downflooding angle	n/a	deg			
	angle of vanishing stability	71	deg			
	shall not be less than (>=)	1,7189	m.deg	10,6074	Pass	517,1
267(85) Ch2 - General Criteria	2.2.2: Max GZ at 30 or greater				Pass	

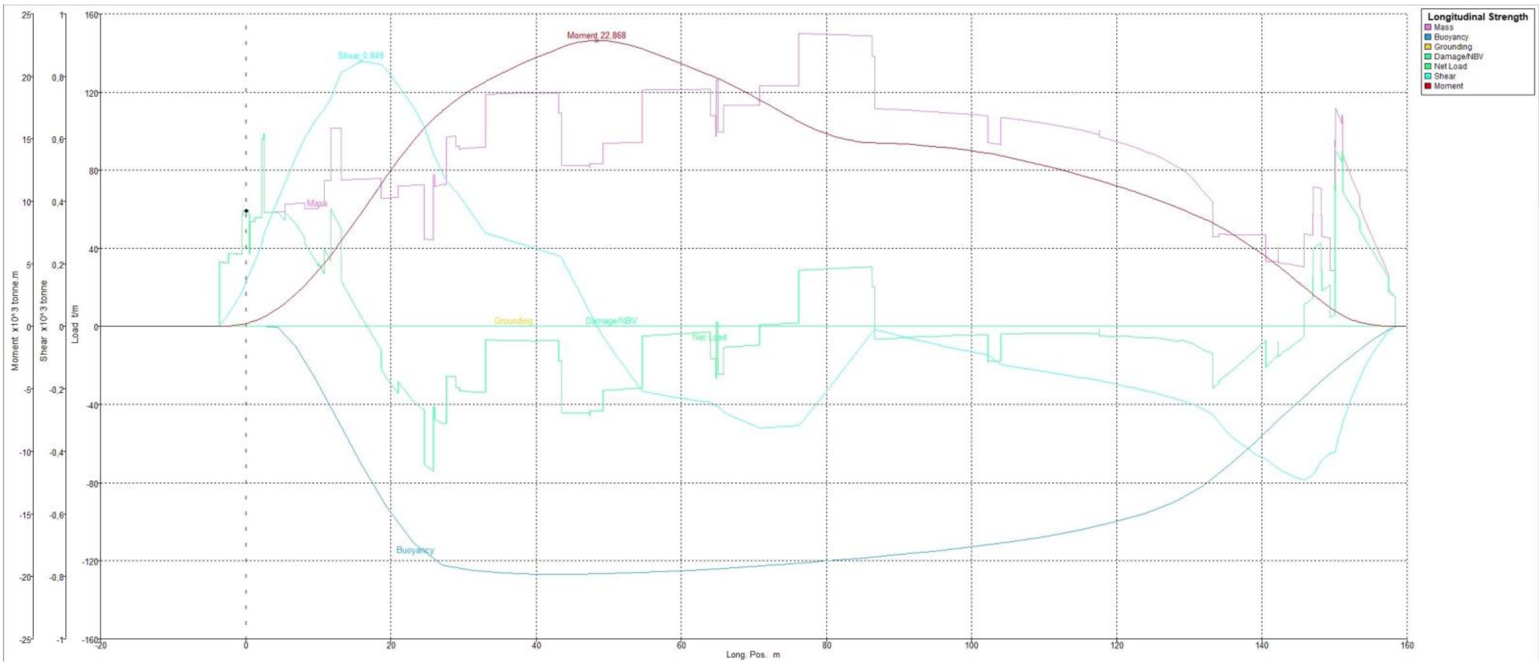
	in the range from the greater of					
	spec. heel angle	30	deg	30		
	to the lesser of					
	spec. heel angle	90	deg			
	angle of max. GZ	40	deg	40		
	shall not be less than (>=)	0,2	m	1,148	Pass	474
	Intermediate values					
	angle at which this GZ occurs		deg	40		
267(85) Ch2 - General Criteria	2.2.3: Angle of maximum GZ				Pass	
	shall not be less than (>=)	25	deg	40	Pass	60
267(85) Ch2 - General Criteria	2.2.4: Initial GMt				Pass	
	spec. heel angle	0	deg			
	shall not be less than (>=)	0,15	m	1,286	Pass	757,33
267(85) Ch2 - General Criteria	2.3: Severe wind and rolling				Pass	
	Wind arm: a P A (h - H) / (g disp.) cos^n(phi)					
	constant: a =	0,99966				
	wind pressure: P =	504	Pa			
	area centroid height (from zero point): h =	15,8	m			
	total area: A =	1139,1	m^2			
	H = mean draft / 2	3,986	m			
	cosine power: n =	0				
	gust ratio	1,5				
	Area2 integrated to the lesser of					
	2.3: IMO roll back angle from equilibrium (with steady heel arm)	19,0 (-17,5)	deg	-17,5		
	Area 1 upper integration range, to the lesser of:					
	first downflooding angle	n/a	deg			
	angle of vanishing stability (with gust heel arm)	69,8	deg	69,8		
	Angle for GZ(max) in GZ ratio, the lesser of:					
	angle of max. GZ	40	deg	40		
	Select required angle for angle of steady heel ratio:	DeckEdgeImmersionAngle				
	Criteria:				Pass	
	Angle of steady heel shall not be greater than (<=)	16	deg	1,5	Pass	90,43
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80	%	4,79	Pass	94,01
	Area1 / Area2 shall not be less than (>=)	100	%	868,26	Pass	768,26
	Intermediate values					
	Heel arm amplitude		m	0,034		
	Equilibrium angle with gust heel arm		deg	2,3		
	Deck edge immersion angle		deg	32		
	Area1 (under GZ), from 2,3 to 69,8 deg.		m.deg	43,3343		
	Area1 (under HA), from 2,3 to 69,8 deg.		m.deg	3,4881		
	Area1, from 2,3 to 69,8 deg.		m.deg	39,8462		
	Area2 (under GZ), from -17,5 to 2,3 deg.		m.deg	-3,5695		
	Area2 (under HA), from -17,5 to 2,3 deg.		m.deg	1,0197		
	Area2, from -17,5 to 2,3 deg.		m.deg	4,5892		



1	Draft Amidships m	7,971
2	Displacement t	20086
3	Heel deg	0,0
4	Draft at FP m	7,806
5	Draft at AP m	8,137
6	Draft at LCF m	7,982
7	Trim (+ve by stern) m	0,331
8	WL Length m	156,40
9	Beam max extents on WL m	23,344
10	Wetted Area m^2	4516,5
11	Waterpl. Area m^2	3206,5
12	Prismatic coeff. (Cp)	0,795
13	Block coeff. (Cb)	0,671
14	Max Sect. area coeff. (Cm)	0,847
15	Waterpl. area coeff. (Cwp)	0,878
16	LCB from zero pt. (+ve fwd) m	77,791
17	LCF from zero pt. (+ve fwd) m	73,759
18	KB m	4,583
19	KG fluid m	9,954
20	BMt m	6,657
21	BML m	272,28
22	GMt corrected m	1,285
23	GML m	266,91
24	KMt m	11,239
25	KML m	276,87
26	Immersion (TPc) tonne/cm	32,867
27	MTc tonne.m	340,62
28	RM at 1deg = GMt.Disp.sin(1) tonne.	450,51
29	Max deck inclination deg	0,1203
30	Trim angle (+ve by stern) deg	0,1203

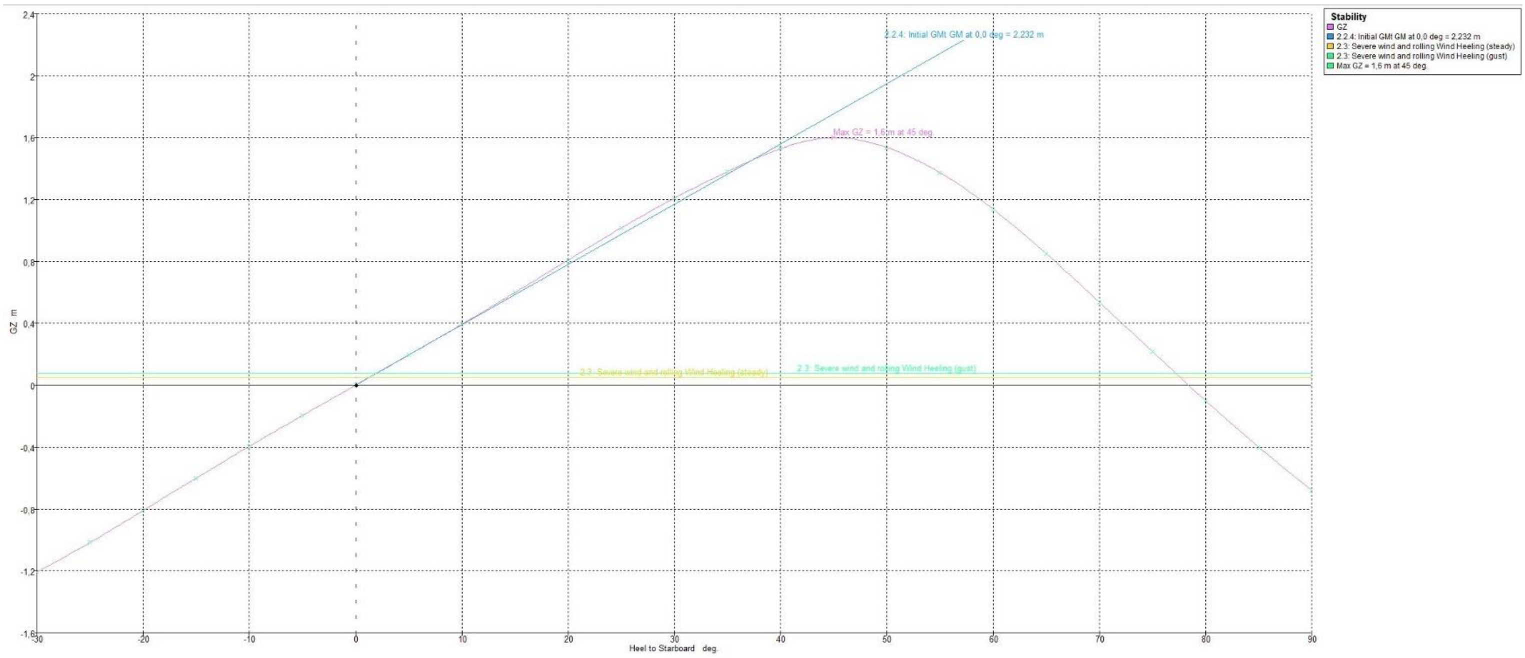
Departure Port Ballast

	Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Long. Arm m	Aft. Limit m	Fwd. Limit m	Vert. Arm m
1	Lightship	1	8441,830	8441,830	69,446			11,016
2	Tk 1 Fore peak	100%	268,986	268,986	152,599			7,061
3	Tk 2 BW 1 Port	100%	9,009	9,009	147,336			1,067
4	Tk 3 BW 1 Stb	100%	9,009	9,009	147,336			1,067
5	Tk 4 BW 2 Port	100%	8,895	8,895	143,627			1,051
6	Tk 5 BW 2 Stb	100%	8,895	8,895	143,627			1,051
7	Cargo Tank 1 CO2	0%	6525,714	0,000	122,237			1,600
8	Cargo Tank 2 CO2	0%	6525,714	0,000	84,022			1,600
9	Cargo Tank 3 CO2	0%	6525,716	0,000	45,807			1,600
10	Cargo Tank 1 NH3	0%	3853,280	0,000	122,237			1,600
11	Cargo Tank 2 NH3	0%	3853,280	0,000	84,022			1,600
12	Cargo Tank 3 NH3	0%	3853,280	0,000	45,807			1,600
13	Tk 6 BW 3 Port	100%	95,054	95,054	126,922			4,226
14	Tk 7 BW 3 STB	100%	95,054	95,054	126,922			4,226
15	Tk 8 BW 4 Port	100%	290,196	290,196	112,335			4,025
16	Tk 9 BW 4 STB	100%	290,196	290,196	112,335			4,025
17	Tk 10 BW 5 Port	100%	334,810	334,810	93,524			4,013
18	Tk 11 BW 5 STB	100%	334,810	334,810	93,524			4,013
19	Tk 12 BW 6 Port	100%	341,475	341,475	74,406			4,048
20	Tk 13 BW 6 STB	100%	341,475	341,475	74,406			4,048
21	Tk 14 BW 7 Port	100%	332,123	332,123	55,285			4,080
22	Tk 15 BW 7 STB	100%	332,123	332,123	55,285			4,080
23	Tk 16 BW 8 Port	100%	304,408	304,408	36,080			4,262
24	Tk 17 BW 8 STB	100%	304,408	304,408	36,080			4,262
25	Tk BW Aft Upper Port	0%	260,457	0,000	2,735			9,100
26	TK BW Aft Upper STB	0%	260,457	0,000	2,735			9,100
27	Fuel Aft STB	1	140,600	140,600	38,250	33,000	43,500	20,650
28	Fuel Aft Port	1	140,600	140,600	38,250	33,000	43,500	20,650
29	Fuel mid STB	1	140,600	140,600	59,850	54,600	65,100	20,650
30	Fuel mid Port	1	140,600	140,600	59,850	54,600	65,100	20,650
31	Fuel fore STB	1	140,600	140,600	81,450	76,200	86,700	20,650
32	Fuel fore Port	1	140,600	140,600	81,450	76,200	86,700	20,650
33	Tk 18 BW 3 Port Upper	100%	94,369	94,369	127,295			9,684
34	Tk 19 BW 3 STB Upper	100%	94,369	94,369	127,295			9,684
35	Tk 20 BW 4 Port Upper	100%	229,105	229,105	112,486			9,581
36	Tk 21 BW 4 STB Upper	100%	229,105	229,105	112,486			9,581
37	Tk 22 BW 5 Port Upper	100%	260,105	260,105	93,475			9,550
38	Tk 23 BW 5 STB Upper	100%	260,105	260,105	93,475			9,550
39	Tk 24 BW 6 Port Upper	100%	273,705	273,705	74,359			9,544
40	Tk 25 BW 6 STB Upper	100%	273,705	273,705	74,359			9,544
41	Tk 26 BW 7 Port Upper	0%	273,733	0,000	55,270			7,000
42	Tk 27 BW 7 STB Upper	0%	273,733	0,000	55,270			7,000
43	Tk 28 BW 8 Port Upper	0%	276,148	0,000	35,715			7,000
44	Tk 29 BW 8 STB Upper	0%	276,148	0,000	35,715			7,000
45	**Total Loadcase**			**14700,92**	**75,461**			**9,704**



Code	Criteria	Value	Units	Actual	Status	Margin %
267(85) Ch2 - General Criteria	2.3: IMO roll back angle					
	L, Stability calculated	154,331	m			
	B, Stability calculated	23,953	m			
	d, Stability calculated	6,248	m			
	GMf, Stability calculated	2,232	m			
	VCG, Stability calculated	9,704	m			
	CB, Stability calculated	0,595				
	Ak, keel area, user spec.	10,8	m^2			
	Method for k factor	Tabulated value for k				
	Evaluates to	20,8	deg			
	Intermediate values					
	B / d			3,834		
	100 Ak / L / B			0,292		
	C		IMO units	0,395		
	T		s	12,66		
	OG, Centre of gravity above WL		m	3,456		
	X1		IMO units	0,8		
	X2		IMO units	0,944		
	k tabulated		IMO units	0,994		
	r		IMO units	1,062		
	s		IMO units	0,061		
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 30				Pass	
	from the greater of					
	spec. heel angle	0	deg	0		
	to the lesser of					
	spec. heel angle	30	deg	30		
	angle of vanishing stability	78,4	deg			
	shall not be less than (>=)	3,1513	m.deg	18,0991	Pass	474,34
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 40				Pass	
	from the greater of					
	spec. heel angle	0	deg	0		
	to the lesser of					
	spec. heel angle	40	deg	40		
	first downflooding angle	n/a	deg			
	angle of vanishing stability	78,4	deg			
	shall not be less than (>=)	5,1566	m.deg	31,8679	Pass	518
267(85) Ch2 - General Criteria	2.2.1: Area 30 to 40				Pass	
	from the greater of					
	spec. heel angle	30	deg	30		
	to the lesser of					
	spec. heel angle	40	deg	40		
	first downflooding angle	n/a	deg			
	angle of vanishing stability	78,4	deg			
	shall not be less than (>=)	1,7189	m.deg	13,7688	Pass	701,02
267(85) Ch2 - General Criteria	2.2.2: Max GZ at 30 or greater				Pass	

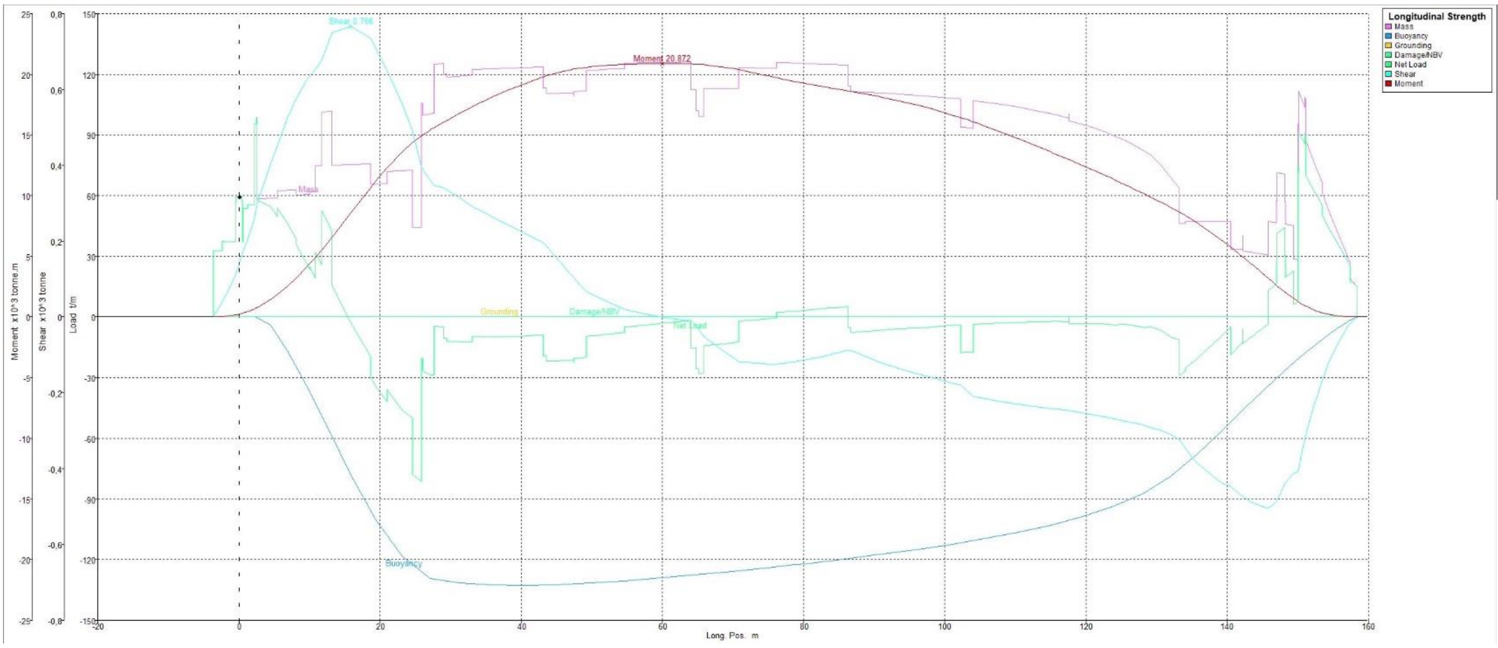
	in the range from the greater of					
	spec. heel angle	30	deg	30		
	to the lesser of					
	spec. heel angle	90	deg			
	angle of max. GZ	45	deg	45		
	shall not be less than (>=)	0,2	m	1,6	Pass	700
	Intermediate values					
	angle at which this GZ occurs		deg	45		
267(85) Ch2 - General Criteria	2.2.3: Angle of maximum GZ				Pass	
	shall not be less than (>=)	25	deg	45	Pass	80
267(85) Ch2 - General Criteria	2.2.4: Initial GMt				Pass	
	spec. heel angle	0	deg			
	shall not be less than (>=)	0,15	m	2,232	Pass	1388
267(85) Ch2 - General Criteria	2.3: Severe wind and rolling				Pass	
	Wind arm: a P A (h - H) / (g disp.) cos^n(phi)					
	constant: a =	0,99966				
	wind pressure: P =	504	Pa			
	area centroid height (from zero point): h =	15,8	m			
	total area: A =	1139,1	m^2			
	H = mean draft / 2	3,124	m			
	cosine power: n =	0				
	gust ratio	1,5				
	Area2 integrated to the lesser of					
	2.3: IMO roll back angle from equilibrium (with steady heel arm)	20,8 (-19,5)	deg	-19,5		
	Area 1 upper integration range, to the lesser of:					
	first downflooding angle	n/a	deg			
	angle of vanishing stability (with gust heel arm)	77,2	deg	77,2		
	Angle for GZ(max) in GZ ratio, the lesser of:					
	angle of max. GZ	45	deg	45		
	Select required angle for angle of steady heel ratio:	DeckEdgeImmersionAngle				
	Criteria:				Pass	
	Angle of steady heel shall not be greater than (<=)	16	deg	1,3	Pass	91,91
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80	%	3,29	Pass	95,89
	Area1 / Area2 shall not be less than (>=)	100	%	723,63	Pass	623,63
	Intermediate values					
	Heel arm amplitude		m	0,05		
	Equilibrium angle with gust heel arm		deg	1,9		
	Deck edge immersion angle		deg	39,4		
	Area1 (under GZ), from 1,9 to 77,2 deg.		m.deg	71,8335		
	Area1 (under HA), from 1,9 to 77,2 deg.		m.deg	5,697		
	Area1, from 1,9 to 77,2 deg.		m.deg	66,1365		
	Area2 (under GZ), from -19,5 to 1,9 deg.		m.deg	-7,5139		
	Area2 (under HA), from -19,5 to 1,9 deg.		m.deg	1,6256		
	Area2, from -19,5 to 1,9 deg.		m.deg	9,1395		



1	Draft Amidships m	6,248
2	Displacement t	14701
3	Heel deg	0,0
4	Draft at FP m	5,255
5	Draft at AP m	7,242
6	Draft at LCF m	6,300
7	Trim (+ve by stern) m	1,987
8	WL Length m	154,33
9	Beam max extents on WL m	22,920
10	Wetted Area m^2	3914,6
11	Waterpl. Area m^2	3052,5
12	Prismatic coeff. (Cp)	0,750
13	Block coeff. (Cb)	0,595
14	Max Sect. area coeff. (Cm)	0,822
15	Waterpl. area coeff. (Cwp)	0,863
16	LCB from zero pt. (+ve fwd) m	75,386
17	LCF from zero pt. (+ve fwd) m	74,571
18	KB m	3,670
19	KG fluid m	9,704
20	BMt m	8,267
21	BML m	335,73
22	GMt corrected m	2,232
23	GML m	329,70
24	KMt m	11,936
25	KML m	339,38
26	Immersion (TPc) tonne/cm	31,289
27	MTc tonne.m	307,94
28	RM at 1deg = GMt.Disp.sin(1) tonne.	572,59
29	Max deck inclination deg	0,7233
30	Trim angle (+ve by stern) deg	0,7233

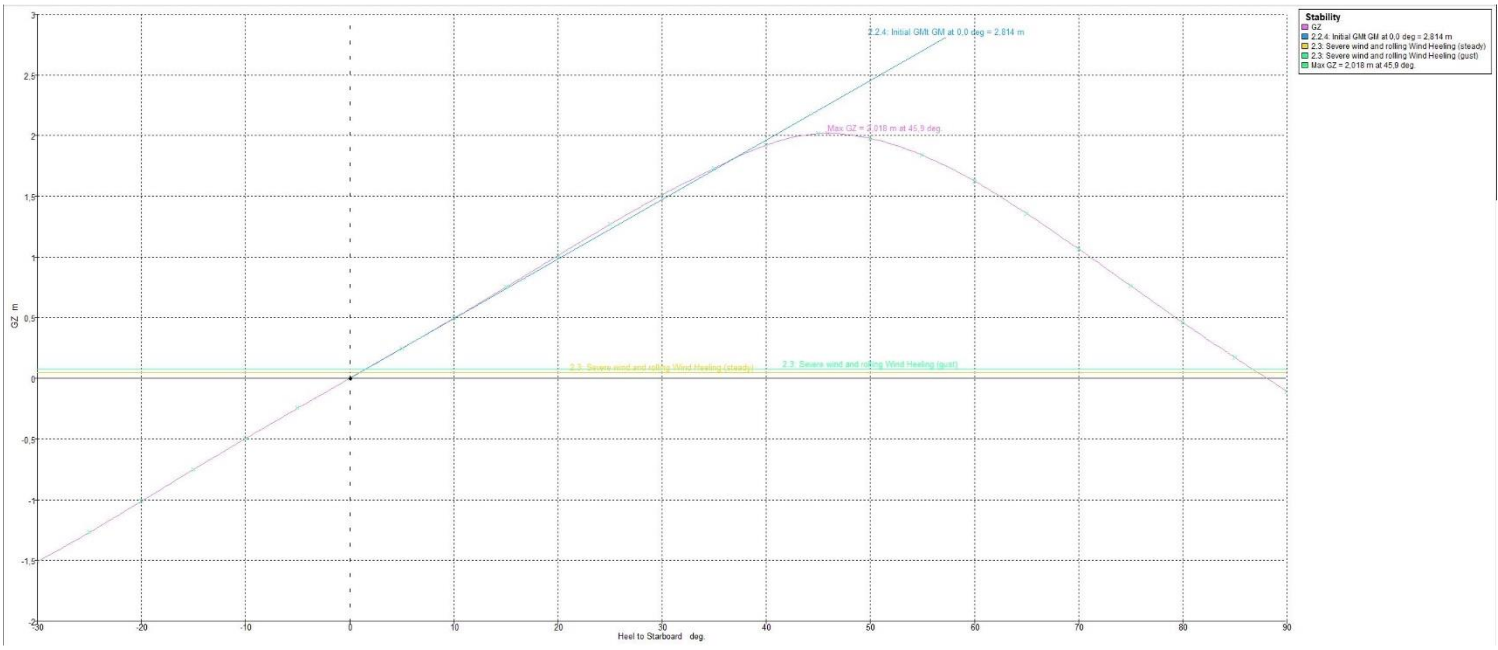
Arrival Port Ballast

	Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Long. Arm m	Aft. Limit m	Fwd. Limit m	Vert. Arm m
1	**Lightship**	1	8441,830	8441,830	69,446			11,016
2	Tk 1 Fore peak	**100%**	268,986	268,986	152,599			7,061
3	Tk 2 BW 1 Port	**100%**	9,009	9,009	147,336			1,067
4	Tk 3 BW 1 Stb	**100%**	9,009	9,009	147,336			1,067
5	Tk 4 BW 2 Port	**100%**	8,895	8,895	143,627			1,051
6	Tk 5 BW 2 Stb	**100%**	8,895	8,895	143,627			1,051
7	Cargo Tank 1 CO2	**0%**	6525,714	0,000	122,237			1,600
8	Cargo Tank 2 CO2	**0%**	6525,714	0,000	84,022			1,600
9	Cargo Tank 3 CO2	**0%**	6525,716	0,000	45,807			1,600
10	Cargo Tank 1 NH3	**0%**	3853,280	0,000	122,237			1,600
11	Cargo Tank 2 NH3	**0%**	3853,280	0,000	84,022			1,600
12	Cargo Tank 3 NH3	**0%**	3853,280	0,000	45,807			1,600
13	Tk 6 BW 3 Port	**100%**	95,054	95,054	126,922			4,226
14	Tk 7 BW 3 STB	**100%**	95,054	95,054	126,922			4,226
15	Tk 8 BW 4 Port	**100%**	290,196	290,196	112,335			4,025
16	Tk 9 BW 4 STB	**100%**	290,196	290,196	112,335			4,025
17	Tk 10 BW 5 Port	**100%**	334,810	334,810	93,524			4,013
18	Tk 11 BW 5 STB	**100%**	334,810	334,810	93,524			4,013
19	Tk 12 BW 6 Port	**100%**	341,475	341,475	74,406			4,048
20	Tk 13 BW 6 STB	**100%**	341,475	341,475	74,406			4,048
21	Tk 14 BW 7 Port	**100%**	332,123	332,123	55,285			4,080
22	Tk 15 BW 7 STB	**100%**	332,123	332,123	55,285			4,080
23	Tk 16 BW 8 Port	**100%**	304,408	304,408	36,080			4,262
24	Tk 17 BW 8 STB	**100%**	304,408	304,408	36,080			4,262
25	Tk BW Aft Upper Port	**0%**	260,457	0,000	2,735			9,100
26	TK BW Aft Upper STB	**0%**	260,457	0,000	2,735			9,100
27	Fuel Aft STB	0,1	140,600	14,060	38,250	33,000	43,500	20,650
28	Fuel Aft Port	0,1	140,600	14,060	38,250	33,000	43,500	20,650
29	Fuel mid STB	0,1	140,600	14,060	59,850	54,600	65,100	20,650
30	Fuel mid Port	0,1	140,600	14,060	59,850	54,600	65,100	20,650
31	Fuel fore STB	0,1	140,600	14,060	81,450	76,200	86,700	20,650
32	Fuel fore Port	0,1	140,600	14,060	81,450	76,200	86,700	20,650
33	Tk 18 BW 3 Port Upper	**100%**	94,369	94,369	127,295			9,684
34	Tk 19 BW 3 STB Upper	**100%**	94,369	94,369	127,295			9,684
35	Tk 20 BW 4 Port Upper	**100%**	229,105	229,105	112,486			9,581
36	Tk 21 BW 4 STB Upper	**100%**	229,105	229,105	112,486			9,581
37	Tk 22 BW 5 Port Upper	**100%**	260,105	260,105	93,475			9,550
38	Tk 23 BW 5 STB Upper	**100%**	260,105	260,105	93,475			9,550
39	Tk 24 BW 6 Port Upper	**100%**	273,705	273,705	74,359			9,544
40	Tk 25 BW 6 STB Upper	**100%**	273,705	273,705	74,359			9,544
41	Tk 26 BW 7 Port Upper	**100%**	273,733	273,733	55,238			9,550
42	Tk 27 BW 7 STB Upper	**100%**	273,733	273,733	55,238			9,550
43	Tk 28 BW 8 Port Upper	**100%**	276,148	276,148	35,711			9,560
44	Tk 29 BW 8 STB Upper	**100%**	276,148	276,148	35,711			9,560
45	**Total Loadcase**			**15041,44**	**74,054**			**9,141**



Code	Criteria	Value	Units	Actual	Status	Margin %
267(85) Ch2 - General Criteria	2.3: IMO roll back angle					
	L, Stability calculated	155,413	m			
	B, Stability calculated	23,953	m			
	d, Stability calculated	6,337	m			
	GMf, Stability calculated	2,814	m			
	VCG, Stability calculated	9,141	m			
	CB, Stability calculated	0,575				
	Ak, keel area, user spec.	10,8	m^2			
	Method for k factor	Tabulated value for k				
	Evaluates to	21,1	deg			
	Intermediate values					
	B / d			3,78		
	100 Ak / L / B			0,29		
	C		IMO units	0,393		
	T		s	11,225		
	OG, Centre of gravity above WL		m	2,804		
	X1		IMO units	0,8		
	X2		IMO units	0,92		
	k tabulated		IMO units	0,994		
	r		IMO units	0,995		
	s		IMO units	0,07		
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 30				Pass	
	from the greater of					
	spec. heel angle	0	deg	0		
	to the lesser of					
	spec. heel angle	30	deg	30		
	angle of vanishing stability	88,1	deg			
	shall not be less than (>=)	3,1513	m.deg	22,6499	Pass	618,75
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 40				Pass	
	from the greater of					
	spec. heel angle	0	deg	0		
	to the lesser of					
	spec. heel angle	40	deg	40		
	first downflooding angle	n/a	deg			
	angle of vanishing stability	88,1	deg			
	shall not be less than (>=)	5,1566	m.deg	39,9183	Pass	674,12
267(85) Ch2 - General Criteria	2.2.1: Area 30 to 40				Pass	
	from the greater of					
	spec. heel angle	30	deg	30		
	to the lesser of					
	spec. heel angle	40	deg	40		
	first downflooding angle	n/a	deg			
	angle of vanishing stability	88,1	deg			
	shall not be less than (>=)	1,7189	m.deg	17,2685	Pass	904,62
267(85) Ch2 - General Criteria	2.2.2: Max GZ at 30 or greater				Pass	

	in the range from the greater of					
	spec. heel angle	30	deg	30		
	to the lesser of					
	spec. heel angle	90	deg			
	angle of max. GZ	45,9	deg	45,9		
	shall not be less than (>=)	0,2	m	2,018	Pass	909
	Intermediate values					
	angle at which this GZ occurs		deg	45,9		
267(85) Ch2 - General Criteria	2.2.3: Angle of maximum GZ				Pass	
	shall not be less than (>=)	25	deg	45,9	Pass	83,64
267(85) Ch2 - General Criteria	2.2.4: Initial GMt				Pass	
	spec. heel angle	0	deg			
	shall not be less than (>=)	0,15	m	2,814	Pass	1776
267(85) Ch2 - General Criteria	2.3: Severe wind and rolling				Pass	
	Wind arm: a P A (h - H) / (g disp.) cos^n(phi)					
	constant: a =	0,99966				
	wind pressure: P =	504	Pa			
	area centroid height (from zero point): h =	15,8	m			
	total area: A =	1139,1	m^2			
	H = mean draft / 2	3,169	m			
	cosine power: n =	0				
	gust ratio	1,5				
	Area2 integrated to the lesser of					
	2.3: IMO roll back angle from equilibrium (with steady heel arm)	21,1 (-20,1)	deg	-20,1		
	Area 1 upper integration range, to the lesser of:					
	first downflooding angle	n/a	deg			
	angle of vanishing stability (with gust heel arm)	86,8	deg	86,8		
	Angle for GZ(max) in GZ ratio, the lesser of:					
	angle of max. GZ	45,9	deg	45,9		
	Select required angle for angle of steady heel ratio:	DeckEdgeImmersionAngle				
	Criteria:				Pass	
	Angle of steady heel shall not be greater than (<=)	16	deg	1	Pass	93,75
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80	%	2,71	Pass	96,61
	Area1 / Area2 shall not be less than (>=)	100	%	812,88	Pass	712,88
	Intermediate values					
	Heel arm amplitude		m	0,049		
	Equilibrium angle with gust heel arm		deg	1,5		
	Deck edge immersion angle		deg	36,9		
	Area1 (under GZ), from 1,5 to 86,8 deg.		m.deg	101,0139		
	Area1 (under HA), from 1,5 to 86,8 deg.		m.deg	6,2848		
	Area1, from 1,5 to 86,8 deg.		m.deg	94,7291		
	Area2 (under GZ), from -20,1 to 1,5 deg.		m.deg	-10,0592		
	Area2 (under HA), from -20,1 to 1,5 deg.		m.deg	1,5943		
	Area2, from -20,1 to 1,5 deg.		m.deg	11,6535		

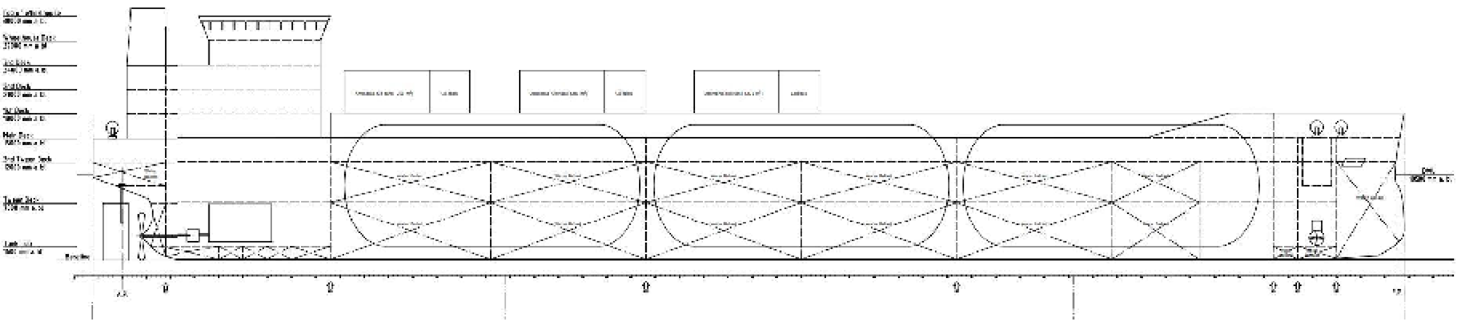


1	Draft Amidships m	6,337
2	Displacement t	15042
3	Heel deg	0,0
4	Draft at FP m	5,011
5	Draft at AP m	7,663
6	Draft at LCF m	6,421
7	Trim (+ve by stern) m	2,652
8	WL Length m	155,42
9	Beam max extents on WL m	23,041
10	Wetted Area m^2	3965,6
11	Waterpl. Area m^2	3088,0
12	Prismatic coeff. (Cp)	0,729
13	Block coeff. (Cb)	0,575
14	Max Sect. area coeff. (Cm)	0,820
15	Waterpl. area coeff. (Cwp)	0,862
16	LCB from zero pt. (+ve fwd) m	73,952
17	LCF from zero pt. (+ve fwd) m	73,698
18	KB m	3,751
19	KG fluid m	9,141
20	BMt m	8,205
21	BML m	338,24
22	GMt corrected m	2,815
23	GML m	332,85
24	KMt m	11,955
25	KML m	341,94
26	Immersion (TPc) tonne/cm	31,652
27	MTc tonne.m	318,08
28	RM at 1deg = GMt.Disp.sin(1) tonne.m	738,90
29	Max deck inclination deg	0,9654
30	Trim angle (+ve by stern) deg	0,9654

Appendix G

NH3 & CO2 Gas Carrier

Spesification



Main Particulars	
DWT [ton]	20 018 ton
LWT [ton]	8 442 ton
Displacement [ton]	28 460 ton
L_{pp} [m]	157,4 m
L_{oa} [m]	162 m
B [m]	24 m
T [m]	10,5 m
D [m]	15 m
C_B [-]	0,70
L/B [-]	6,56
B/T [-]	2,29
B/D [-]	1,60
L/D [-]	10,49

Machinery and Propulsion System	
Main Engine	MAN 2-stroke ammonia engine
Power Transmission	Mechanical shaft
Propeller	1 x Fixed Pith Propeller
Electricity Production	Shaft Generator (PTO/PTI/PTH) & Wärtsilä 4-stroke ammonia generator sets
Bow Thruster	Electric thruster motor

Loading Capacity	
Cargo	19 577 tons / 16 950 m3
Fuel	843 tons / 1 237 m3
Ballast	7 036 tons / 6 865 m3

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