NTNU
Norwegian University of Science and Technology
Department of Marine Technology

M.Sc.THESIS

Title: Design of a motor yacht with emphasize on hull design	**Delivered:** 14.06.2010 **Availability:** Open
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Abstract:

Todays shipping industry contribute significantly to the global anthropogenic emissions. By designing a ship hull which reduces its resistance through the water but maintain the intact stability of a conventional hull, the whole shipping industry can be affected, and reduce its total global emissions considerably.

By designing a slimmer hull than a conventional hull, but with a wider mid ship above and under the water line, this project tried to make a hull which will reduce its resistance through the water, but maintain some of the stability when inclinging. This will give a ship that will reduce its fuel consumption significantly in steady seas states, and still have the needed stability in rough weather. The new hull was designed to fulfill the needed arrangement of a general luxury yacht, and was tested for stability criteria for both intact and damaged situations. The resistance was predicted with the use of Holtrop—84 resistance prediction method.

This project resulted in a ship hull which fulfilled the needed arrangement with a ship size of 30 meters, beam length of 7 meters and a designed draught of 1.75 meters. The stability criteria from the IMO were all abided for four different loading conditions and three given damage scenarios. The stability for the new hull had an average loss of 30 percent for the maximum GZ value compared to a conventional hull. The resistance prediction resulted in a 24 percent reduced need in engine power.

Based on the results from this thesis the new hull has reduced the engine power and corresponding emissions with 24 percent. However, the intact stability was reduced even more, with an average 30 percent reduction in maximum GZ value. This implies that there has to be done some changes and further testing with the hull design before it can be adopted as a new way to design ship hulls. But hopefully has this project inspired both students and naval architects to find new alternatives for the conventional hull form.

Keyword:

Hull design
Luxury Yacht
Hull resistance
Stability

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Preface

This project was conducted as a master thesis in the 10th semester of my MSc. Degree at the Norwegian University of Science and technology.

With this master thesis I wanted to design and test a new type of ship hull, and find alternatives for the conventional hull design. “The design of a ship is just one big compromise” Stig Remøy, the president of Olympic shipping, once said during a presentation of the maritime cluster on Sunnmøre. This has also been the red thread through this thesis, where different needs and parameters have been continuously considered at the same time. This thesis has mainly focused on the calculations regarding the new hull. The design process for the arrangement has been kept at a low level, but detailed enough to confirm that the new hull is adequate for a general luxury yacht.

I also wanted to use the knowledge I’ve gained through 5 years at NTNU in this project, and this master thesis has therefore become a product consisting of several different subjects.

I would like to thank my supervisor professor Bjørn Oskar Sillerud who was very helpful with finding both useful challenges and solutions during the project. I would also like to thank Ulstein Design & Solutions AS who let me use the comprehensive computer program NAPA, and Radovan Gasparovic for the technical guidance.

I hope this master thesis will inspire both students and ship engineers to try new methods for the hull design. Technology combined with creativity is the way to a more sustainable future.

Trondheim, 14th June 2010

Martin Brandshaug

Master thesis assignment

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Master Thesis in Marine Systems Design spring 2010
for
Stud. techn. Martin Brandshaug

"Design of a motor yacht with emphasize on hull design"

Aim and focus

The aim and focus with this thesis is to design a motor yacht and try to make some improvements concerning the hull design.

Scope and main activities

The candidate should presumably cover the following main points:

1. Determine the needed size of the yacht.
2. Determine the dimensions and hull parameters.
3. Design and make drawings of the general arrangement (including the internal arrangement).
4. Make intact- and damage stability calculations.
5. Compare the hull design with a "conventional hull" design with respect to
    a. Stability
    b. Resistance (frictional and other components)
6. Discuss the results.

The advisor at NTNU will be the undersigned.
The candidate shall try to make well balanced evaluation/design, taking into account technical, economical and environmental considerations, national and international rules – if applicable.
The thesis shall be prepared in accordance with the guidelines of The Department of Marine Technology.
The candidate shall give precise references to literature, telephone conversations and other communications. Collected material should preferably follow the thesis.

The candidate shall be in regular contact with the undersigned, who, if necessary, can make alterations to this text.

To be delivered within the 14th of June.
MTS spring 2010
Bjørn Sillerud

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Summary

This thesis consists of two integrated parts. The main attempt is to design and test a new hull which will reduce the total water resistance and need for engine power, but maintains the stability of a conventional hull. To see if the hull is sufficient enough for a general luxury yacht, there will also be a need for an arrangement design process for the calculation of the needed volume and equipment.

Based on external conditions the main parameters for the yacht was set. This resulted in a 30 meter long yacht, with a draught of 1.75 meters and a beam length of 7 meters. The yacht has a fuel capacity of 18 tons and a fresh water capacity of 4000 liters. Regarding accommodation and facilities it has 5 bed rooms, 5 bath rooms, kitchen, restaurant and a room for a small boat. The yacht is equipped with watertight bulkheads to prevent flooding of the complete ship, and floating devices to prevent sinking if the ship should be completely flooded. The yacht will in total have a lightweight of 191 tons and a deadweight at departure of 26 tons.

The idea for the new hull is to have a more slender hull than a conventional hull, but maintain the volume in the midship under and over the water surface. This will, in theory, give reduced water resistance because of the reduced waterline beam length. However, when inclining the increase in waterline area will maintain some of the stability. To be able to compare the results it was also modeled a conventional hull for this thesis. This comparison hull has the same main parameters as the new hull, but designed with a conventional midship with long flat sides.

The two different hulls were given four loading conditions. The first loading condition had 100 % fuel, fresh water and food supply. The second one had 10 %, and the third one had 50 %. The last loading condition had 100 % fuel, fresh water and food supply and no use of the water ballast tanks. The intact stability was tested for each loading condition and checked up against the IMO criteria for passenger and cargo vessels of all sizes. The calculations showed that the general stability was weakened with 30 percent for the new type of hull, but the increased stability was noticed at 5-10° heeling angle because of the larger waterline area.

The new hull with an initial loading condition consisting of 100 % fuel, fresh water and food supply was then tested for three given damage scenarios. In scenario 1 the water entry started on the port side in the fore part of the ship, simulating a crash while coming along the quay. Scenario 2 simulated a front crash, resulting in flooding of the two front water ballast tanks and the chain room. The last scenario simulated a run aground of the ocean floor, resulting in flooding of three water ballast tanks and the fresh water tank. Damage scenario 1 resulted in a heel angle of 21° and the water level reaching 7 centimeters above the hull height. As a consequence of this there must be installed one or two more water tight walls, bulkheads, in the two corridors at this deck.

The resistance of the two hulls was predicted with the Holtrop-84 resistance prediction method. Holtrop has implemented statistical results from several model tests in a formula which calculates the ship resistance based on some of the main parameters of the hull form. Based on the results from this test the new hull required 24 % less engine power than the conventional hull. This can save fuel for over 72 000 US$ per year.

The new hull design has both its advantages and disadvantages, but much research remains before it can be either refused or accepted as a new way to design ship hulls. The stability and resistance can in general not be compared, but the calculations show a larger reduction of the stability than for the resistance, which implies that both changes and more testing must be executed before the new hull can be introduced to the yacht market.

1 Introduction

The shipping industry of today represents a significant contribution to the total global man made emissions. Recent numbers show that the shipping industry is responsible for 3% of the CO_2 emissions, 4-9% of the SO_2 emissions and 10-15% of the NO_X emissions created by the mankind[1]. A change in the hull design which will reduce the need for engine power but still maintain the stability would therefore be very useful in the development of a more sustainable shipping industry. The reduction of resistance based on the hull form will be beneficial for several kinds of different vessels, and would have a massive effect on the total emissions coming from ships.

The ship building industry has for many years tried to develop new structures and designs which in one way or the other are improved. In the last ten years most of the big ship design offices in Norway has introduced new ship hulls. They have discovered that development and creativity is very necessary in the Norwegian ship industry, if it ought to survive.

Most of the resistance a ship experiences when it's sliding through the water is because of the wet surface area, the form of the hull and the beam length of the waterline area. A change in one of these parameters will have an impact on the vessels stability as well, and the challenge will be to find the compromise between a hull with good stability and a hull with reduced resistance through the water.

In this thesis the ship hull will be more slender than a conventional hull, but have a wider midship above and under the waterline, still maintaining the slim waterline area of the ship. In theory this will reduce the water resistance through the water but maintain the stability when the ship is inclining.

This thesis consists of two integrated parts. The main purpose is to design and test a complete new hull for a yacht. To make sure the hull is both efficient and sufficient for a typically equipped and sized yacht, the hull will be installed with the rooms, tanks and equipment that are needed. The ship stability will then be tested for both intact and damaged loading conditions, and checked against IMOs criteria for intact stability. The resistance of the ship will be predicted for a given state. The intact stability and resistance calculations will be compared to a conventional hull, and some of the fundamental results will be pointed out and discussed.

2 Design

2.1 Brief history

The word yacht actually comes from the Dutch word *jacht,* which means *hunting* or *to hunt*. The earliest yachts were actually light and fast sailing vessels used by the Dutch Navy. Then after some years Dutch merchants started using private yachts to greet their returning ships. These private yachts was then slowly adopted into their spare time, and in the beginning of the 17th century the jachts-term was therefore divided into speel-jachts and oorlog-jachts, yachts for sport and naval duties. [2]

Today the yacht term is mostly in use for the leisure time vessels. The term is though still quite vague, so the term has been divided into more segments. For instance is the size of a yacht divided into three subcategories. The Luxury yachts which are no longer than 40 feet are more commonly called *cabin cruisers* or *cruisers*. The *mega yachts* usually refer to any yacht with sail and/or engine which is more than 100 feet or 34 meters. The largest yachts are called *super yachts*, and are longer than 200 feet or 70 meters.

In this thesis the design will be of an engine driven cruising yacht with all the equipment and facilities needed for a long weekend at the sea. The main purpose of this yacht is to see if the new type of hull will be suitable for a standard leisure time ship. The general arrangement and the needed rooms are therefore chosen to resemble other yachts on the market. However, some creativity and new ideas will be used also for this part of the project.

2.2 The general arrangement idea

Inspired by the platform supply vessels used by the offshore industry, this yacht will have a large and open aft deck. This will generate an open space for recreation where the people onboard can enjoy the sun and water. This open place will give the passengers a perfect view to the surrounding landscape and scenery, and let the people become closer to the environment.

The master bed room will be situated in the fore end of the ship. With windows in the front of the bed room the passengers can see were the ship is sailing, and have a perfect view every morning they wake up.

Regarding facilities the ship will have a room for a small boat or water jet at the complete aft of the ship, right above the waterline. With a winch system the boat or jet can be draged onboard easily straight from the water. This room will need a strong and secure door in the aft to prevent water from entering.

2.3 Specifications

To start the designing process some main criteria is needed as a starting platform. This is the external conditions which constrains some of the main parameters describing the vessel. Since the yacht of this project doesn't have any job description or any harbor restrictions to follow, the conditions will be chosen by own thoughts and ideas. The conditions will be as follow:

- Approximately 30 meters long
- Accommodation for 10 people
- Endurance of at least one weekend
- Ship velocity of 15 knots

The reason why the yacht should be approximately 30 meters long is a compromise between the market for luxury yachts and the needed length for the calculations of this project. When predicting the hull resistance a change in the conventional hull form will be easier to notice in the results if the hull is longer and therefore bigger. But then again shouldn't the yacht be too long, cause the bigger the yacht is the fewer people have the capacity and amount of money to buy one, and hence the market shrinks.

Accommodation for ten people is a criterion chosen by looking at the number of passengers which is typical for other yachts in the same size category. With room for ten people it's possible for the owner and his or hers family to bring some guests for their weekend at sea. It's also with this criterion possible to have room for a hired crew which can take care of all the work needed onboard the yacht.

The endurance of a complete weekend is set to prevent the volume for storage and fuel to become unduly large, but still make sure the ship won't be too dependent on often fuel and water supply. With an endurance of up to a complete weekend the owner of the yacht may plan their trip after where they would like to go, and not necessarily to the place where the closest filling station for fuel and fresh water is situated.

The hull length of 30 meters is limiting the maximum speed for the yacht; this is called the hull speed. As the hull slides through the water, the hull itself creates its own waves at the bow and stern of the vessel. These waves increase their wave length as a function of the ship velocity. At one point these waves will combine, making the ship float in the middle of the one big wave. The resistance in the water increases substantially at this point, and it requires a lot of engine power to increase the ship velocity.[3]

The hull speed can be predicted by a simple formula.

$$V = 2.55 \cdot \sqrt{LWL}$$

Formel 1 Hull speed prediction

Where V is the ship velocity in knots and LWL is the length of the waterline of the ship.

For the yacht of this thesis this will give a hull speed of 14 knots. This is a quite conservative prediction of the hull speed, and the yacht for this project will therefore have a top speed of 15 knots. With a speed of 15 knots 10 hours a day, the ship will have a range of about 450 nm, which is more than sufficient for its use.

2.4 Comparison ship

Figur 1 The Giant 100

When designing a new ship, it's much more efficient to look at what has already been done. A yacht that matches the criteria for this project is the Giant 100. [4] It has a length overall of 30 meters, and a beam length of 7 meters. It's made up of Glass-reinforced plastic, better known as fiberglass, and has a draught of 2.6 meters.
It has two main engines each with 2000 break horse power which equals 1470 kw. With this power installed it has a cruising speed of 22 knots, and a motoring top speed of 26 knots. It has a fuel capacity of 14 000 liters and a fresh water capacity of 2500 liters. For the preliminary stage of the designing process this projects yacht will have the same engine power installed.

2.5 Calculation of the Deadweight

With all the external conditions and main dimensions in place, the needed space for the tanks, rooms and the total deadweight can be calculated. The deadweight is the maximum cargo load a ship can have stored, and still be at its so called loading line. [3] The deadweight will for this yacht consist of fuel, freshwater, lubricant oil, food supplies, the weight of the people on board and their luggage.

2.5.1 Fuel

Fuel is essential for a ship since all of the ships systems depend on the power supply from the engines. For a leisure vessel of this size the fuel tanks will be quite directional for the final size of the ship. The specific fuel oil consumption for ships in general is normally a bit less than 200 g/kWh.[5] To calculate the need of fuel the endurance of the ship is needed. During the weekend at sea the yachts engines will be at full effect for about 10 hours a day. For a weekend the yacht will therefore need approximately 88 200 kWh and a corresponding fuel capacity of 18 ton fuel. With a fuel density of 940 kg/m^3 [6] the needed volume of the fuel tank is 20 cubic meters.

2.5.2 Lubricant oil

The need for lubricant oil is typically about 1.5 g/kWh [3]. For this vessel it will give an oil consumption of about 133 kg. The oil tank will with a density of 860 kg/m^3 [6] require a volume of 0.15 m3.

2.5.3 People

The weight and volume depending on the number of persons on board are the people's weight and their corresponding luggage, fresh water and food supply. In this project it's assumed a total weight per person including luggage to 150 kg. With ten people on board this equals 1500 kg.

2.5.4 Freshwater

Normally a human beings consumption of freshwater per 24 hours is about 100 liter. [3] This includes cooking, showering and other needs. This will be about 3000 kg of water, or 3 m^3. Since water is so essential for life on board the ship will have a capacity of 4000 liters of water, and the fresh water tank will therefore need a volume of 4 m^3.

2.5.5 Food

The need for food will be about 2 kilograms per person per day and therefore about 60 kilograms. Some of this food supply will on the other hand be dry and therefore perfectly fine to store over an amount of time, and therefore the stored food supply at all time will be about 100 kilograms.

2.5.6 Other necessaries

With other necessaries the storage needed for soap, maintenance equipment and so on is taken into account. By setting the total weight factor to 1000 kg for these objects the ship will have a slack for the calculation of deadweight.

2.5.7 Total deadweight

The ship will with these calculations and evaluations have a total deadweight of about 25 tons.

3 Arrangement

3.1 Tank arrangement

The need for fuel and freshwater tanks is as mentioned earlier quite essential for the size of the ship, and are the two tanks which must be placed first. The other tanks needed are oil tank, water ballast tanks, grey water tanks and black water tanks.

Greywater is wastewater from the domestic work like laundry, dishwashing and bathing. This water can be recycled and then used like normal water, but for this ship with its small size and short endurance it's simpler to store the water when close to shore. The yacht can then release the grey water in designated areas when in harbor, or release it out into the open sea when it's further from shore. Greywater is normally about 50- 80 % [7] of the total amount of freshwater used by a household. For this ship with a total amount of 4000 liters of freshwater this equals about 3000 liters and a needed volume of 3 m^3.

Blackwater, or sewage, is wastewater containing human matter and comes from the toilets. This water needs strict filtering and cleansing procedures and most countries has strict regulations for dumping of this water. Therefore, this projects vessel will have tanks for storing of the blackwater so that it can be taken care of when back in harbor. It's assumed that the black water tanks will consume the water which is not grey water, and therefore require a volume of 1 m^3.

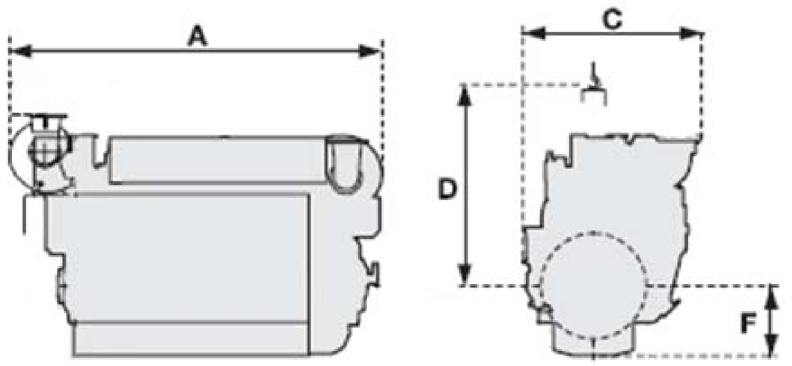
According to the Norwegian Maritime Directorate there are not any regulations concerning a double bottom for vessel under 50 meters of length [8]. However, for environmental considerations there is no reason why this yacht shouldn't have a double bottom. The regulations aren't the same for all countries and according to SOLAS 2009 all dry cargo and passenger ships should have a double bottom installed, which also will be the case for the yacht of this project.

3.2 Bed rooms

The number of bed rooms is set so that two persons share each room. Each room shall have their corresponding bathroom. The size of each room shall be large enough for the beds and the needed space for storage of the luggage. Three of the bed rooms shall have bunk beds to save place, but the master and guest bedroom shall have room for double beds for extra luxury. The bathrooms shall be sized so they have the room for toilet, shower and washbasin. This requires a minimum area of 8 m^2 for every bed room, and 4 m^2 for every bathroom.

3.3 Engine room

The engine room size is dependent on the space required by the two engines of 1470 kW each. From MAN Turbo & Diesel an engine of 1440 kW require a space as shown in figure 2. [5] This equals a minimum area of 15 m^2. The design of the vessel will have a slack for the engine size so that changes can be done after the resistance prediction. A potential buyer will then also have a choice of how a big engine he or she would like.



Where ,

A=4011 mm
C=1713 mm
D+F=1800 mm +624 mm =2424 mm

Figur 2 Engine size

Other rooms related to the engine room are the repair shop and control room. The repair shop needs space for tools and equipment for any potential repairs. The control room is a room where all the ship engines and systems can be monitored. Both these rooms will be sized as a function of the available space as they both are flexible regarding the space required.

3.4 Other rooms

The storage rooms and linen store will in general not require a massive amount of space, however to simplify the use of the rooms, they should be big enough for easy access.

The chain room will need the room for the anchor, chain and wire required for anchoring at depths around 20 meters. Guidelines for the length of anchors say that the length of chain should be at least equal to the ship length, which will for this case be at least 30 meters. [9] The total length of chain and wire combined should be 7 times the water depth. This is to prevent too much tension in the wire, as the extra length will work like a spring because of the change in geometry for the chain and wire. [10] In total this will give 35 meters chain, and about 100 meter of wire. The diameter of the wire should be at least 3 centimeters. [11] The needed volume can be calculated as a function of the length and diameter of the wire. [12]

Net wire volume to be contained:

$$\frac{\pi d^2}{4} \cdot L \quad m^3$$

Formel 2 Net wire volume

Where d is the wire diameter, and L is wire length.

Necessary volume to contain wire

$$1.3 \cdot \frac{\pi d^2}{4} \cdot L \quad m^3$$

Formel 3 Necessary wire volume

The total volume of the wire will be 0.09 m^3. With 35 meter chain, 0.175 m^3, and a needed drum winch, the total required space will be 2 m^3

The yacht will have a minimum of two stairs per deck, and with an opening of at least 1.5 m^2. This will be at least 12 m^2 of stairs.

The minimum required space for the different types of rooms will be as described in table 1.

Name	Min. area (m^2)
Bed rooms	40
Bath rooms	20
Engine room	15
Repair shop	2
Control room	2
Storage rooms	6
Linen store	3
Chain room	2
Ventilation room	4
Kitchen	10
Restaurant	40
Stairs	12
Corridors	As needed
Bridge	5
Total	**Min. 161 m^2**

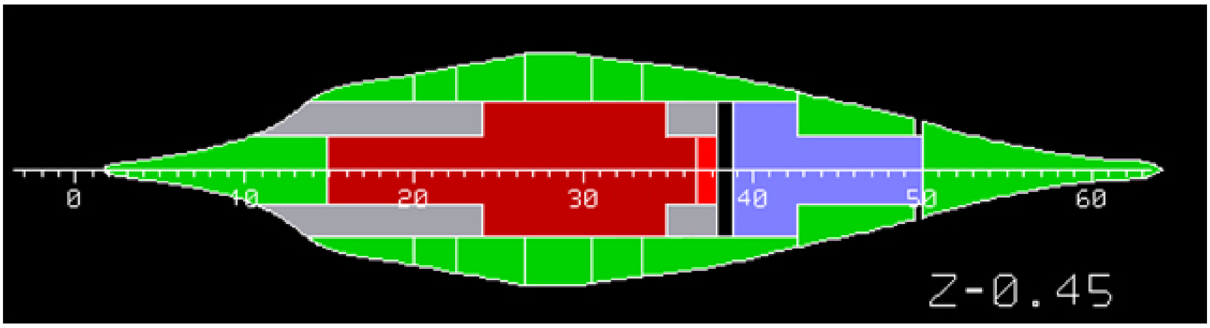
Tabell 1 Required room area

3.5 Placing of the rooms

With the requirements from the arrangement evaluation the different decks can be drawn. The different decks and their specifications are described in the following chapters.

3.5.1 Deck -1

Including the double bottom, deck -1 has a height from keel of 0.6 meters. This deck consists of most of the water ballast tanks, the HFO-tank, a small oil-tank, Grey- and black water tanks and fresh water tank. By having the freshwater, grey water and black water tanks installed at the same deck level there will be little or no change in center of gravity during the travel. The HFO-tank is made sure to have other tanks around to prevent leakage from this tank in case of any penetration of the hull. Because of the available space the HFO tank will be expanded to 21 cubic meters, or 21 000 liters of fuel, this will give a total deadweight of 26 tons. Most of the tanks are largest in the longitudinal direction to prevent transverse free surface effect. Deck -1 is drawn in figure 3.



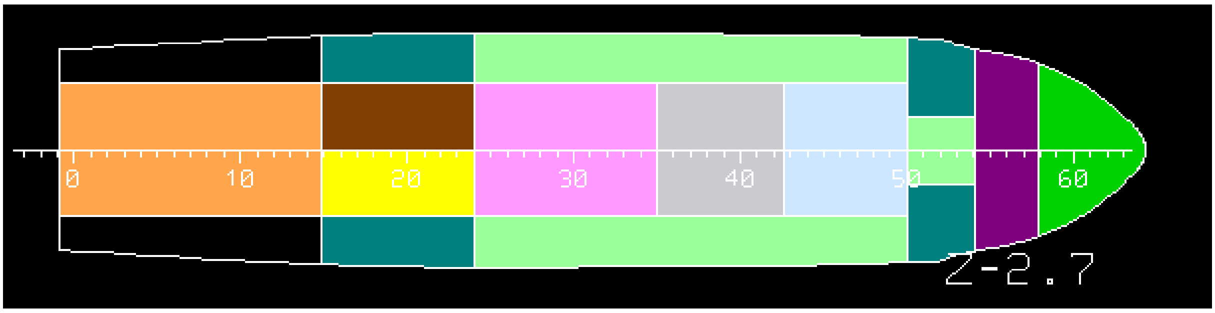
Figur 3 Deck -1

- 🟥 HFO tank
- ▨ Grey and black water tanks
- 🟥 Oil tank
- 🟦 Fresh water tank
- ⬛ Floating devices
- 🟩 Water ballast tanks

3.5.2 Deck 0

Deck 0 has a height of 3 meters to make room for the engines and for the pipes and cables which lay between the decks. In deck 0 the engine room, some floating devices, the engine repair shop, control room, storage, garbage, chain room and the fore peak water ballast tank are situated. The placement of the engine room is right underneath the boat room in the deck above. This simplifies the installation process of the engines, which can be lifted down through the boat room. The floor in the boat room can be removed so that access to the engine room becomes quite simple. The engine room is also close to the HFO tank to simplify the inlet of fuel.

Two of the largest floating devices are placed on each side of the engine room, since the engine room is the heaviest room onboard the yacht. The engine repair shop and control room is placed in front of the engine room for easy access. There are two stairs and to corridors for each side of this deck, for easy evacuation if needed. The storage is divided into two rooms, so that different temperature or other environmental factors can be changed for each room. The linen store is placed in front of the storage rooms. In the complete front of this deck are the chain room and fore peak water ballast tank. The chain room is quite heavy and can compensate for some of the trim created by the engine room. Deck 0 I drawn in figure 4.

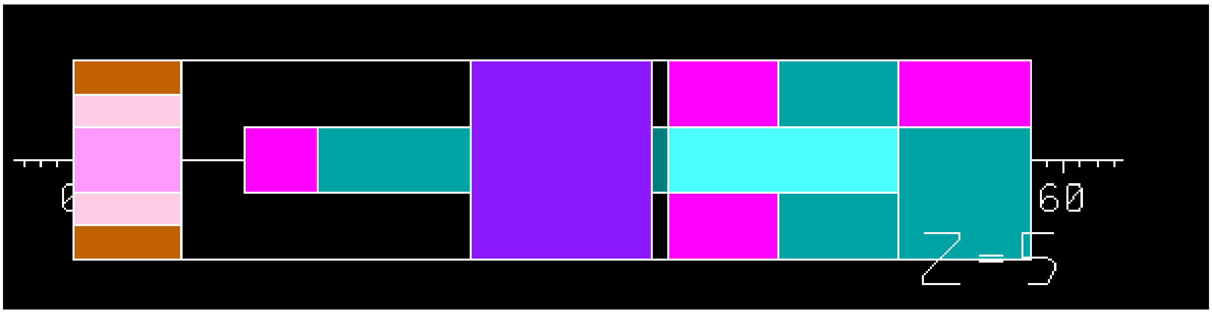


Figur 4 Deck 0

- ■ Engine room
- ■ Floating devices
- ■ Stairways
- ■ Machine repair shop
- ■ Machine control room
- ■ Corridor
- ■ Storage I
- ■ Storage II
- ■ Linen store
- ■ Chain room
- ■ Water ballast tank

3.5.3 Deck 1

In deck 1 most of the bed rooms with corresponding bath rooms are situated. The kitchen is placed right above the storage rooms so that it will be an easy access to food supply and other necessities. In this deck there is a room for a small boat in the complete aft of the ship. As mentioned earlier this room with its removable floor deck also works as a casing for an easy access to the engine room. Based on its need for connection to the open air and being close to engine room, the ventilation rooms are placed on each side of the aft part of this deck.

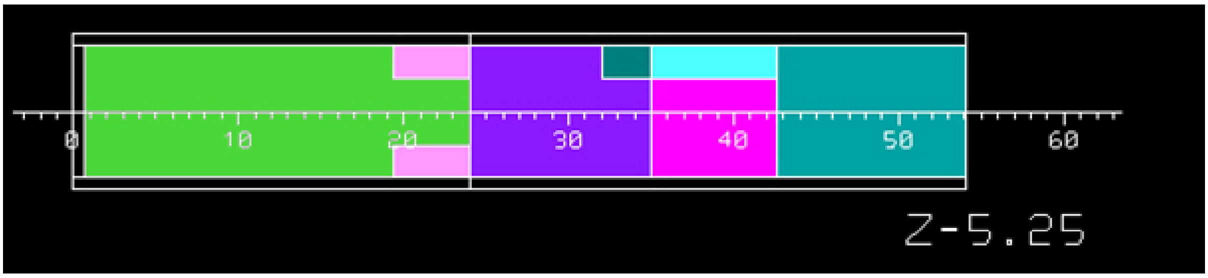


Figur 5 Deck 1

- ■ Boat room
- ■ Ventilation system
- ■ Ventilation system
- ■ Floating devices
- ■ Bath rooms
- ■ Bed rooms
- ■ Kitchen
- ■ Stairways
- ■ Corridor

3.5.4 Deck 2

Deck 2 is for most purposes the main deck of the ship. The master bed room is situated in the fore end of the ship to give the owners the perfect view every morning. This room has its own bathroom and a short way down a corridor to the restaurant and bar area, which is the place for all the meals and where the general leisure time will be spent. At the complete aft of this deck the major sun deck is situated, and two life rafts are placed on each side of the ship on this deck.

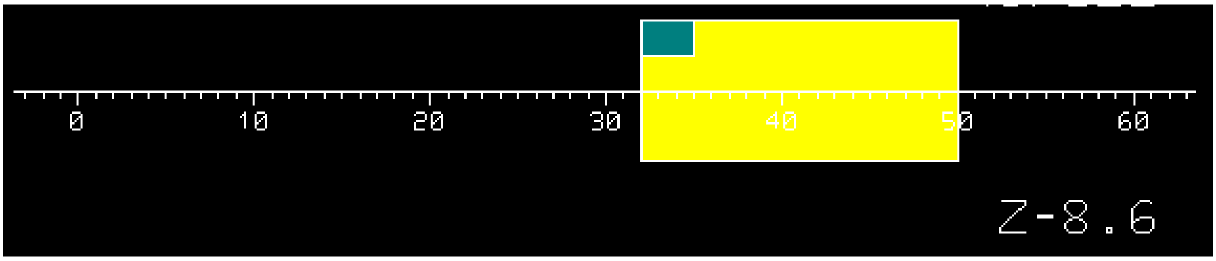


Figur 6 Deck 2

- ■ Aft deck
- ■ Life boats
- ■ Restaurant
- ■ Stairways
- ■ Bathroom
- ■ Corridor
- ■ Bedroom
- ■ Floating devices

3.5.5 Deck 3

In deck 3 there is no more than the control room. There is however an opening for designing this deck in another way, but for this project it will be sufficiently enough to keep this deck as a control deck.



Figur 7 Deck 3

- ■ Control room
- ■ Stairway

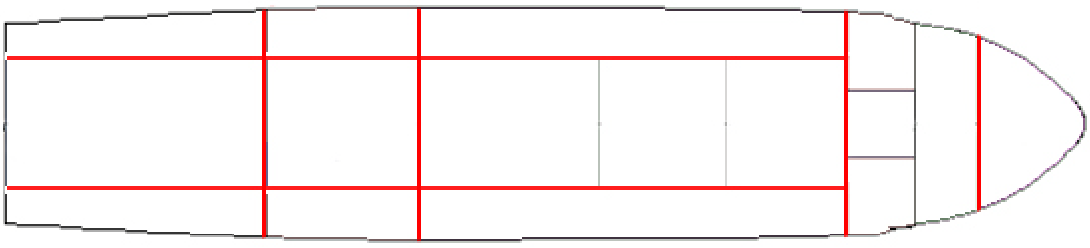
3.6 Watertight bulkheads

As seen from the pictures of the arrangement some of the rooms are much more vulnerable when it comes to water entry. The larger the room the larger the effect a potential water entry will have on the instability, especially for rooms placed further away from the center of gravity of the ship. Rooms with machinery and electronics such as the engine room and the control bridge are also very vulnerable because the equipment inside is crucial for the control of the vessel.

Bulkheads are transverse watertight walls starting from the ship hull to the main deck. These walls are designed to resist water from entering and fire from spreading. In addition they spread the hull stresses over larger areas. The strength of the bulkheads comes from the special corrugated shape of the walls as seen in figure 8.

Figur 8 Corrugated bulkhead

The foremost transverse watertight bulkhead is called the Collision Bulkhead. As its name implies this bulkhead is designed to protect the vessel in case of a collision. For the yacht the collision bulkhead is placed right after the fore peak water ballast tank. Then there are three more transverse bulk heads, one right in front of the linen store on deck 0, one right after the corridor, and one between the repair shop and engine room. Two longitudinal watertight bulkheads are placed on each side of the engine room to prevent water from entering. These two bulkheads are placed from the complete aft of the hull and all the way to the stairways in the front of deck 0. See figure 9.



Figur 9 The placement of bulkheads

3.7 Lightship weight

The lightship weight is the total weight of the hull construction, the machinery and ventilation system, the navigational equipment, interior and anchor handling equipment. As mentioned earlier the ship hull will be made of so called glass-reinforced plastic, or fiber glass, which has a density of 1.529 g/cm3. [13] The hull size and center of gravity is given by the computer program NAPA, where the ship model is drawn. By multiplying the volume of the hull with the density of fiber glass it results in a hull weight of 65 000 kg.

By making a list of all the rooms needed in excel, with a weight factor and center of gravity in each direction, X, Y and Z, the total light weight of the ship with corresponding center of gravity can easily be calculated. The tanks in the bottom of the ship and other vital constructions are assumed to be made out of steel and will therefore have a higher weight factor. This will help to increase the strength of the tanks. The engine room has a high weight factor because of the two engines which each has a weight of about 11 000 kg. These tanks and engine room contributes to a lower center of gravity which helps the ships stability.

With the weight factors and the placement of local center of gravities the total lightship weight is calculated to be 191 252.4 kg and the center of gravity is situated 13.77, 0.016 and 2.69 meters in the x, y and z direction respectively, measured from the complete aft of the ship, at the keel level. In appendix 1 the calculation of the lightweight and center of gravity can be found.

For the calculation of the loading conditions which are mentioned later in this thesis the distribution of the lightweight must be given. The computer program NAPA estimates this by an assumption made by Lloyd's. Lloyd's generates this distribution as a function of the ships block coefficient, C_B.

3.8 Floating devices

As the description of the arrangement mentioned, this yacht will have floating devices placed on several locations to prevent the ship from sinking if the whole ship will be flooded with water. If an accident would happen this will prevent the owner from losing the values in the ship and it can be transported to shore for repair. The disadvantage with these floating devices is that they take up space without being for any other use than to make the ship float if flooded. Therefore, to make the necessary room for these floating devices, all available space like void spaces need to be used.

The floating devices will have to compensate for the weight of the vessel when flooded which will quite simply equal to the lightweight of the ship, reduced by the buoyancy in the material the lightweight is made of. The yacht will consist of a mix of both steel and fiberglass which have a density of 7850 kg/m3 and 1529kg/m3 respectively. The steel won't help that much for the total buoyancy but the hull which is made of light fiberglass will contribute.

For the vessel to be floating this equilibrium must be maintained:

$$G = B_{tot} = B_{Lightship} + B_{Floatingdevices}$$

Formel 4 Equilibrium of floating

Where G is the total force of the ship weight in negative z-direction, and B is the buoyancies.

To find the volume needed for the floating devices the equilibrium formula is rearranged

$$B_{Floatingdevices} = G - B_{Lightship} = Lightshipweight \cdot g - \rho \cdot g \cdot Hullvolume$$

$$V_{Floatingdevices} = \frac{Lightshipweight \cdot g - \rho \cdot g \cdot Hullvolume}{\rho \cdot g} = \frac{191252kg - 1025\frac{kg}{m^3} \cdot 42.2m^3}{1025\frac{kg}{m^3}} = 144m^3$$

Formel 5 Volume of floating devices

The needed volume of floating devices will therefore be about 150 m^3. The total volume of floating devices for the yacht of this project will after the arrangement become 171.8 m^3, as seen in appendix 1, and is therefore more than sufficient. Extra floating capability will ease the rescue operation after flooding, because the ship will be more available in the surface.

4 The design of the hull

Based on the parameters from the arrangement the hull has a needed overall length of 30 meters and a beam length of 7 meters. The yacht will also be equipped with a bulbous bulb which will reduce the wave resistance.[3] Most engine driven displacement vessels longer than 15 meters uses a bulb to decrease the total resistance. To get the most correct results for the needed engine power in the resistance prediction, the hull for this project was equipped with a general bulbous bulb. The design of the bulb is created with the help from one of the templates in the NAPA program.

4.1 The idea

A slimmer hull shape requires less force through the water, but a slimmer hull also leads to decreased stability. Is it possible to both have a slim hull shape through the water, and combine this with the increased stability of a wider hull? In this thesis the hull is more slender than a conventional hull, but it also have a wider midship over and under the water surface. By maintaining the slim waterline area, the resistance through the water will in theory decrease while some of the stability is maintained when the yacht is inclining.

The ship stability is very much related to the ship GM value. The GM value can be calculated by this formula:

$$GM = BM + KB - KG$$

Formel 6 Initial metacentric height

Where KB is the length from keel to the centre of buoyancy of the ship and KG is the distance from keel to the centre of gravity of the ship. The BM value is calculated by

$$BM = \frac{I_x}{\nabla}$$

Formel 7 BM value

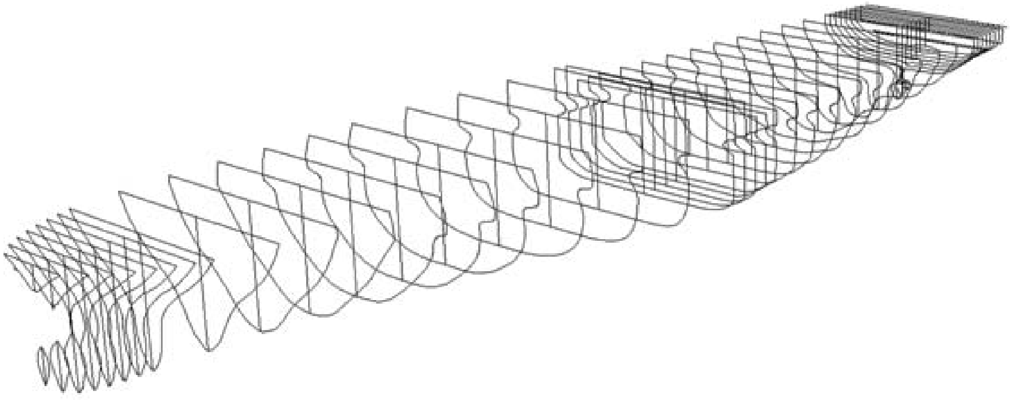
Where I is the second inertia moment of the water plane area.

$$I_x = \int_{Awl} y^2 dA_{wl}$$

Formel 8 Second inertia moment

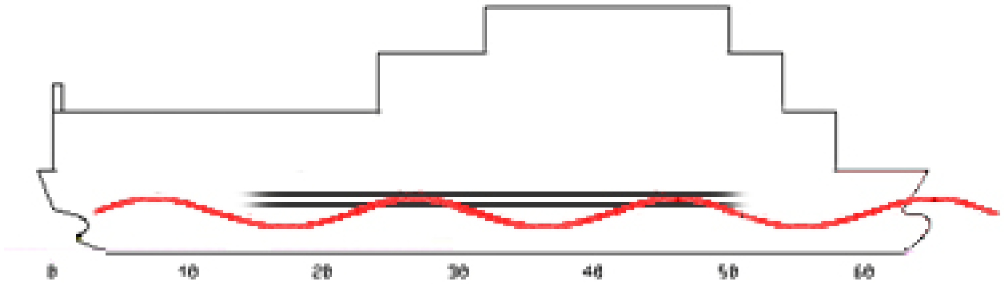
Where dA_{wl} is an element of the water line area, and y is the distance from the waterline area center to dA_{wl}

As this hull has a smaller waterline area than a conventional hull, the BM value will be smaller, and therefore result in a more unstable ship. However, by maintaining the volume both above and underneath the waterline at the midship, the vessel will when inclining increase the water plane area and therefore restore some of the stability. A picture of the hull idea can be seen in figure 10.



Figur 10 Sections of the hull

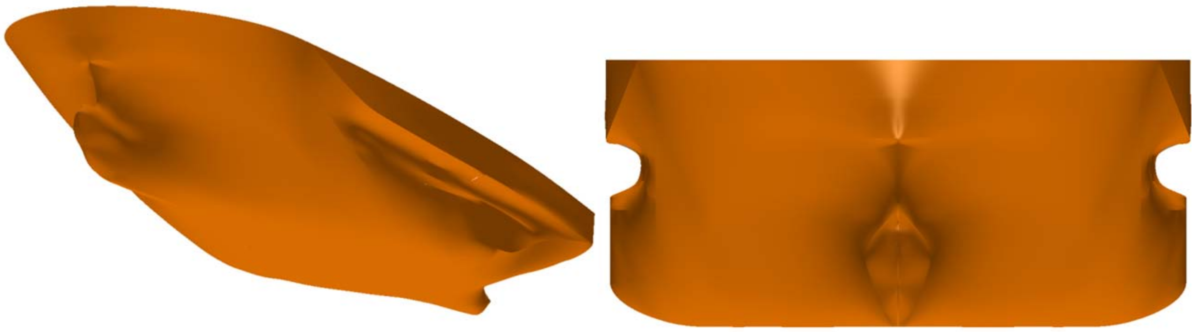
One of the big challenges with this hull will probably be discovered in head sea. The fore end of the ship should be as slim and smooth as possible to prevent the waves from slamming. If any angels should become close to orthogonal with the incoming waves, this could result in a major impact. This would not only create discomfort for the people onboard, but could also do severe damage to the hull. Therefore the curvature at the waterline should start a bit further back than the complete front of the yacht. By starting the curvature 10 meters behind the ship bow the wave force will be reduced when it enter the slender part of the hull. This is shown in figure 11.



Figur 11 Waves and the ship in profile

4.2 The slender hull

The ideas for the new type of hull resulted into the slender hull. The slender hull is as explained earlier in general just a slimmer version of any other conventional hull, but with a wider beam length under and above the waterline at the midship. This will hopefully decrease the water resistance and therefore the need for power, but still maintain some of the stability when the ship is inclining. In figure 12 two pictures show the model created in the computer program NAPA.



Figur 12 The slender hull

The hulls block coefficient is calculated by the computer program. By using the formula for this block coefficient the initial designed draught can be calculated. The combination of the designed draught and block coefficient is an iteration process which for this project resulted in an assumed designed draught of 1.68 meters and a block coefficient of 0.6

$$T=\frac{\nabla}{L\cdot B\cdot C_B}=\frac{\Delta}{\rho_W\cdot L\cdot B\cdot C_B}=\frac{217250kg}{1025\frac{kg}{m^3}\cdot 30m\cdot 7m\cdot 0.6}=1.68$$

Formel 9 Draught formula

Assuming there will be a need for the water ballast tanks, the designed draught is sat to be 1.75 meters. This is however a parameter which is likely to change as the design process continues.

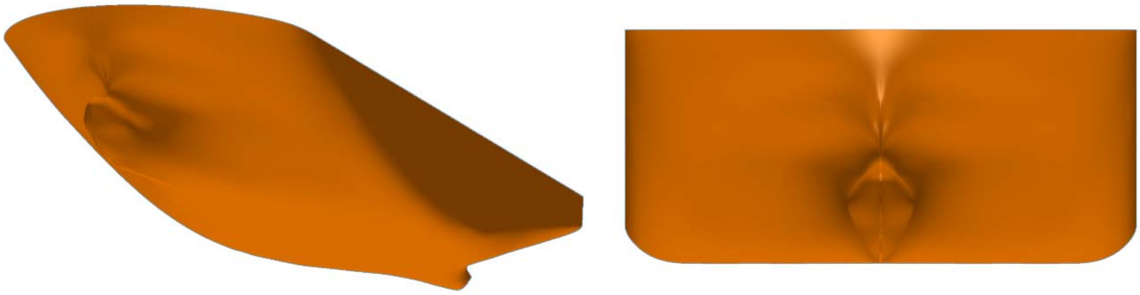
Based on the calculation of the designed draught the transient of the slender part of the hull takes place from 1.60 to 2.05 meters above the keel. This is to make sure the designed draught of 1.75 will notice the effect of the curvature, and the slack is to prevent slamming with the increase and decrease of water level because of the waves. At the water level the hull has a beam length of only 6.25 meters, which hopefully will decrease the hull resistance through the water quite substantially. As mentioned earlier the curvature of the slender part of the hull will start 10 meters behind the ship bow and it will have a length of 15 meters backwards. In table 2 some of the main geometry for this new type of hull with a designed draught of 1.75 meters is described.

Name	Value	Unit	Description
VOLM	236.3	M3	Volume molded
DISP	244.7	T	Total displacement
CB	0.6	-	Block coefficient
CP	0.7729	-	Prismatic coefficient
LCB	15.108	M	Longitudinal centre of buoyancy
VCB	0.977	M	Vertical center of buoyancy
KMT	3.029	M	Transverse metacentre height
LCA	14.43	M	Longitudinal centre of floatation
WLA	172.3	M2	Waterline area
WSA	246	M2	Wetted surface area
T	1.75	m	Draught, moulded

Tabell 2 Parameters for the new hull

4.3 Comparison hull

To be able to comment on the results for the new type of hull, there was a need for a hull to compare with. The hull for comparison is designed to be exact like the new hull, but with a conventional mid, front and aft part of the ship. This means that the hull has a length of 30 meters and a beam length of 7 meters. In figure 13 there is two pictures showing the model of the conventional hull for comparison made with the computer program NAPA.



Figur 13 The conventional hull

Because of the larger midship sections of this hull, the conventional hull has for the same draught a larger volume displacement, block coefficient and prismatic coefficient. As described in table 3, the largest difference between the two hulls is the water line area, which is about 14 percent smaller for the new hull.

Name	Value	Unit	Description
VOLM	265.7	M3	Volume molded
DISP	275.1	T	Total displacement
CB	0.6748	-	Block coefficient
CP	0.8408	-	Prismatic coefficient
LCB	15.084	M	Longitudinal centre of buoyancy
VCB	0.977	M	Vertical center of buoyancy
KMT	3.804	M	Transverse metacentre height
LCA	14.34	M	Longitudinal centre of floatation
WLA	199.9	M2	Waterline area
WSA	266	M2	Wetted surface area
T	1.75	m	Draught, moulded

Tabell 3 Parameters for the conventional hull

5 Stability calculations

5.1 Why NAPA?

There are a lot of software for calculating a ship's stability and maneuverability, and many of them are much easier in use than NAPA. However, NAPA is one of the most used computer software at all of the design departments at the ship design companies in Norway. NAPA also offers the complete package of resistance, intact stability and damage stability calculation, and works very well for small changes in the ship design. Therefore it's very suitable for the calculations needed for this thesis.

5.2 Intact stability

As put by the Norwegian Maritime Directorate the intact stability must be calculated in several different loading conditions[14]. The stability calculations need to be evaluated for both departure and arrival conditions. This correspond to 100 % fuel, fresh water and food supply at departure and 10 % fuel, fresh water and food supply at arrival. In addition to these two loading conditions the yacht will be checked for the state at the middle of the journey, for the condition in between of the two others. The yacht will also be evaluated for a condition which requires no use of the water ballast tanks.

These are the four different loading conditions:

LOAD CASE 1 – 100% FUEL AND STORAGE
LOAD CASE 2 – 10% FUEL AND STORAGE
LOAD CASE 3 – 50% FUEL AND STORAGE
LOAD CASE 4 – 100% FUEL AND STORAGE, AND NO USE OF WATER BALLAST TANKS.

5.2.1 Criteria

According to the IMO resolution A. 749(18) there are several criteria to abide for passenger and cargo ships of all sizes. This is to make sure the stability is sufficient for the different vessels in different states. The criteria for the intact state of the yacht of this thesis are described in table 4.

Criteria	Description	Required Value
Area 30	Area under GZ curve until 30° heeling angle	0.055
Area 40	Area under GZ curve until 40° heeling angle	0.09
Area 3040	Area under GZ curve from 30° to 40° heeling angle	0.03
GZ 0.2	Max GZ higher than 0.2 at an angle of heel equal to or larger than 30°	0.2
MAX GZ 25	Max GZ at an angle larger than 25°	25
GM 0.15	GM value higher than 0.15	0.15

Tabell 4 IMO intact stability criteria

5.2.2 Calculation of the GZ curve

The evaluation starts with the calculation of some of the parameters needed for the stability analysis. The GM value is measured as mentioned in chapter 4.1, and then corrected for the liquid free surface effect from the tanks. The GZ value is then calculated as the function of the changing GM value.

$$GZ = GM \cdot \sin \varphi$$

Formel 10 GZ calculation

Where ϕ is the angle of heel.

5.2.3 Dynamical stability

The dynamic stability is one of the stability characteristics for a vessel in motion, particularly in rolling movement, and is the needed energy to incline the vessel to a certain angle of heel in which the moment of statically stability is counteracted. [3] The dynamic stability is calculated by measuring the area underneath the righting lever curve, or the GZ curve, for any given angle of heel. The larger area underneath the GZ curve, the better is the dynamic stability. Waves and wind are two of the most common external forces on ships and platforms. Especially steep waves with short wavelengths can have a huge impact, and for smaller vessels these impacts can have severe consequences.

5.2.4 Stability for the new hull

5.2.4.1 Loading condition 1

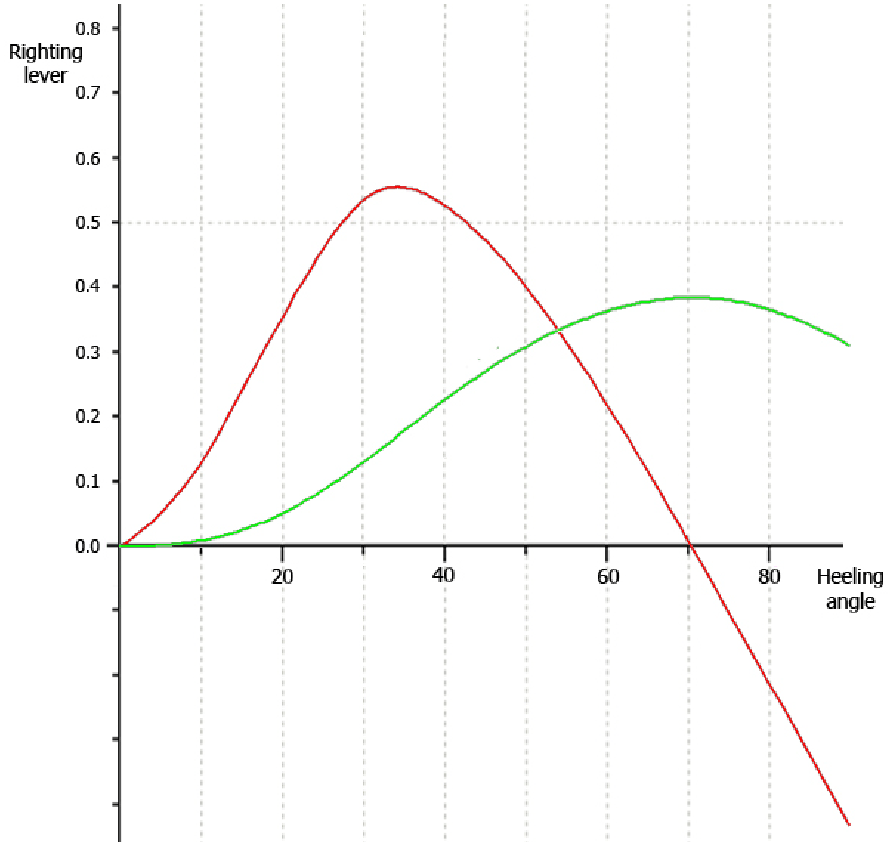
In loading case 1 the HFO, oil and fresh water –tanks are filled to their maximum capacity. The storage rooms for supply are filled with 10 % of their volume capacity, which is an estimate of the supplies needed at departure, and therefore the maximum needed capacity. The water ballast tanks are filled so that the ship floats at the designed waterline with 0° heel angle and a decent trim.

With these given loading conditions the ship will have the values presented in table 5. The total weight displacement will be 242.6 tons and the average draught is 1.74 meters. The trim value is -0.016 meters, which means that the fore end of the ship is slightly higher than the aft end. The ships initial metacentric height is well above 0 meters which is a good estimate for a decent stability.

Name	Value	Unit	Description
Disp	242.6	T	Total displacement
LCB	15.088	M	Longitudinal centre of buoyancy
T	1.738	M	Draught, moulded
TF	1.730	M	Draught fore, moulded
TA	1.746	M	Draught aft, moulded
TR	-0.016	M	Trim
HEEL	0.0	°	Heeling angle
GM	0.541	M	Metacentric height
GM0	0.795	M	Uncorrected GM
GMCORR	0.254	M	GM correction

Tabell 5 Parameters for loading condition 1, the new hull

Napa then generates a GZ curve for the initial loading case, and already the effect of the new hull design is noticeable in the calculations. In figure 14 of the GZ curve it's indicated that at approximately 5-10° of heeling angle the GZ value accelerates because of the increase in waterline area. In the same diagram it's also shown that the maximum GZ value is 0.56 m. The dynamical stability is at its highest at the point of vanishing stability at 75°, and is approximately 0.37 mrad.



Figur 14 GZ curve load 1, new hull

Based on the numbers from NAPA and the GZ curve the results can be compared with the criteria given by the IMO regulations. All the criteria and attained values is shown in table 6. As seen in the table are all of the criteria abided for loading condition 1.

Criteria	Description	Required Value	Attained Value	Status
Area 30	Area under GZ curve until 30° heeling angle	0.055	0.13163	OK
Area 40	Area under GZ curve until 40° heeling angle	0.09	0.22715	OK
Area 3040	Area under GZ curve from 30° to 40° heeling angle	0.03	0.095519	OK
GZ 0.2	Max GZ higher than 0.2	0.2	0.55574	OK
MAX GZ 25	Max GZ at an angle larger than 25°	25	34.1802	OK
GM 0.15	GM value higher than 0.15	0.15	0.54121	OK

Tabell 6 IMO criteria Load 1, new hull

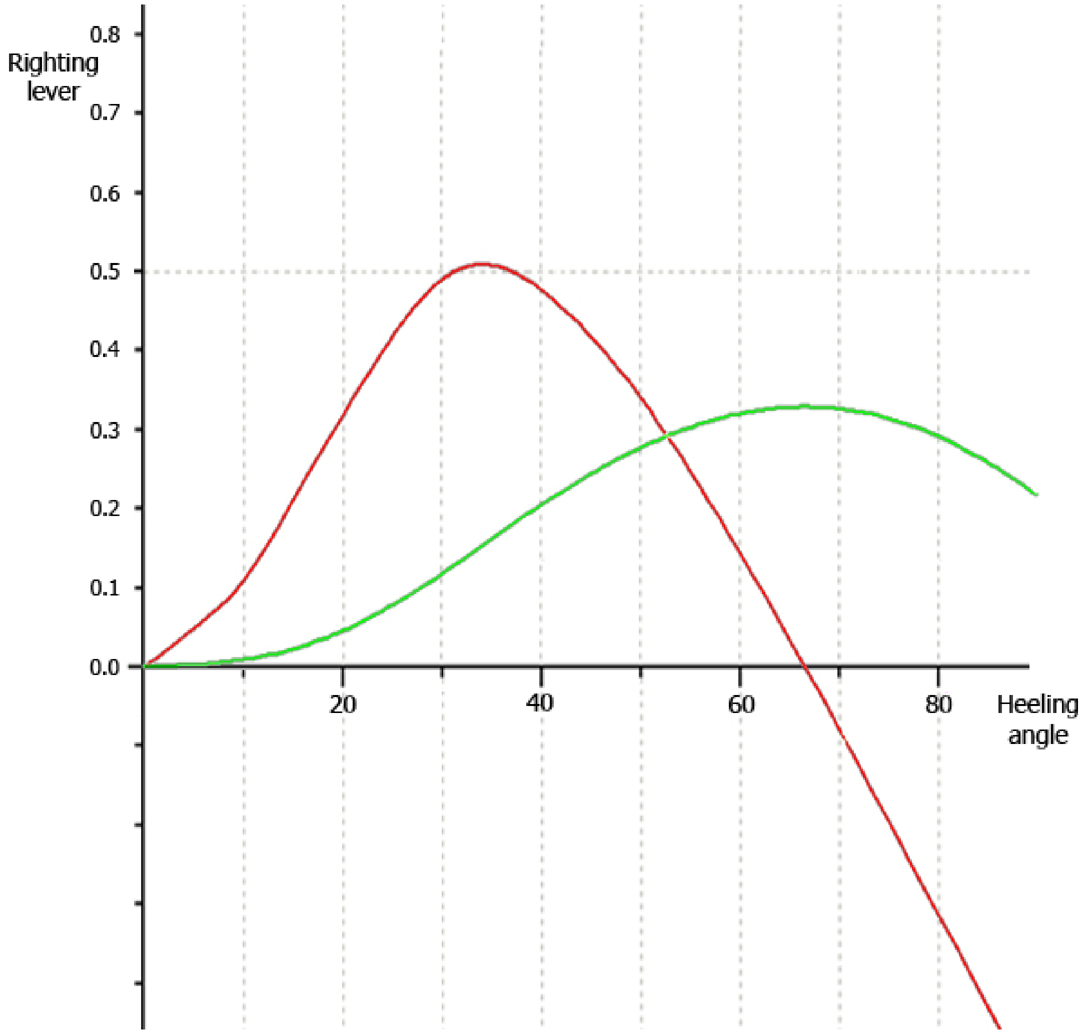
5.2.4.2 Loading condition 2

In loading condition 2 the HFO, oil and fresh water tanks are all filled with only 10 percent of their maximum capacity. The storage for supply is only filled with 1 percent of its capacity as an estimation of 10 percent of the food supply. The water ballast tanks are filled so that the ship will float with 0° heeling angle and a slight negative trim. The values resulting from the calculation of this loading condition can be seen in table 7. The total weight displacement will for this condition be 227.6 tons and the average draught is 1.65 meters. The trim value is -0.183 meters, which means that the fore end of the yacht is almost 20 cm higher than the aft end. The yachts initial metacentric height is well above 0 which is a good estimate for a decent stability.

Name	Value	Unit	Description
Disp	227.6	T	Total displacement
LCB	14.851	M	Longitudinal centre of buoyancy
T	1.649	M	Draught, moulded
TF	1.557	M	Draught fore, moulded
TA	1.741	M	Draught aft, moulded
TR	-0.183	M	Trim
HEEL	0.0	°	Heeling angle
GM	0.526	M	Metacentric height
GM0	0.801	M	Uncorrected GM
GMCORR	0.275	M	GM correction

Tabell 7 Parameters for loading condition 2, the new hull

Based on these values for the yacht, the GZ curve can be drawn. Because this loading condition has a slight decrease in GM value the ship gets a slightly lower GZ curve with its maximum at 0.51 m. The point of vanishing stability is at 67° and the maximum dynamical stability is 0.32 mrad.



Figur 15 GZ curve loading condition 2, the new hull

As for loading condition 1 the values from the GZ calculations is checked up against the IMO criteria. As seen in table 8 are all of the criteria abided also for this loading condition.

Criteria	Description	Required Value	Attained Value	Status
Area 30	Area under GZ curve until 30° heeling angle	0.055	0.11796	OK
Area 40	Area under GZ curve until 40° heeling angle	0.09	0.20539	OK
Area 3040	Area under GZ curve from 30° to 40° heeling angle	0.03	0.087429	OK
GZ 0.2	Max GZ higher than 0.2	0.2	0.51003	OK
MAX GZ 25	Max GZ at an angle larger than 25°	25	33.9849	OK
GM 0.15	GM value higher than 0.15	0.15	0.52601	OK

Tabell 8 IMO criteria Loading condition 2, the new hull

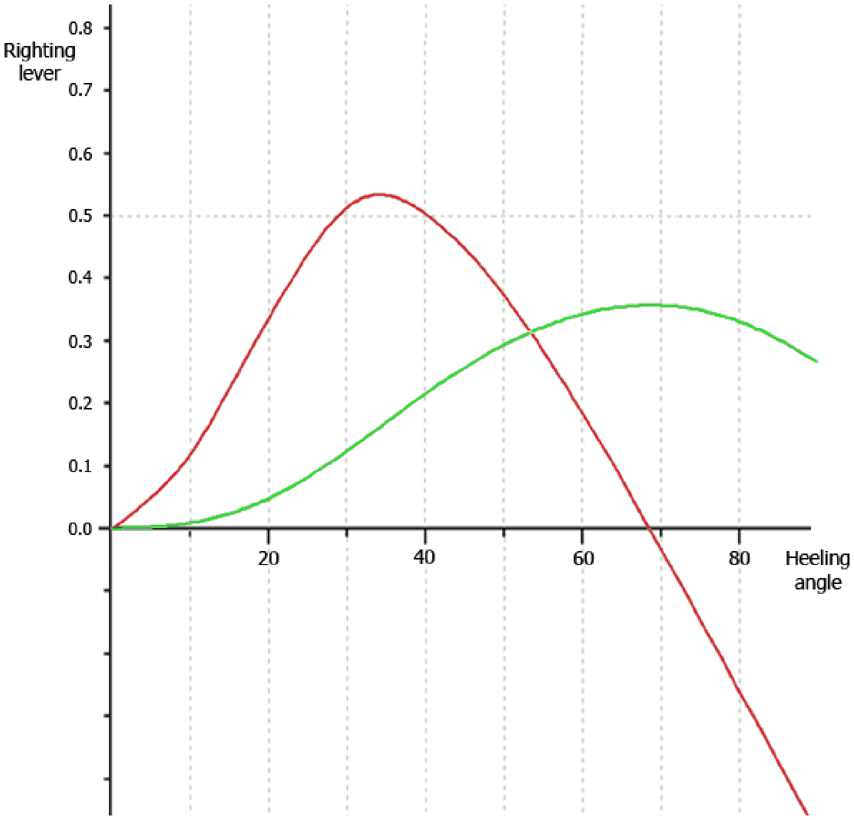
5.2.4.3 Loading condition 3

To see how the ship stability will be in the middle of the journey loading condition 3 evaluates the vessel with 50 percent of the fuel, fresh water and food supply. This is a situation where the free surface effect can give dangerous stability results. For this condition the ship get the values written in table 9.

Name	Value	Unit	Description
Disp	234.6	T	Total displacement
LCB	14.936	M	Longitudinal centre of buoyancy
T	1.690	M	Draught, moulded
TF	1.630	M	Draught fore, moulded
TA	1.751	M	Draught aft, moulded
TR	-0.121	M	Trim
HEEL	0.0	°	Heeling angle
GM	0.532	M	Metacentric height
GM0	0.799	M	Uncorrected GM
GMCORR	0.267	M	GM correction

Tabell 9 Parameters for loading condition 3, the new hull

As shown in table 9 does this loading condition give values in the between of loading condition 1 and 2. It’s obvious that the long tanks in the x-direction of the yacht has prevented some of the effects from the free surface effect. Based on the values from the stability calculation the GZ curve can be drawn as shown in figure 16.



Figur 16 GZ curve loading condition 3, the new hull

From the calculations of the stability it's shown that the maximum GZ value for the ship will be 0.53 meters for this loading condition. The point of vanishing stability is at 68° heeling angle, and the maximum dynamical GZ value is 0.35 mrad.

As seen in table 10 are all of IMOs criteria for the intact stability with loading condition 3 abided.

Criteria	Description	Required Value	Attained Value	Status
Area 30	Area under GZ curve until 30° heeling angle	0.055	0.12495	OK
Area 40	Area under GZ curve until 40° heeling angle	0.09	0.21668	OK
Area 3040	Area under GZ curve from 30° to 40° heeling angle	0.03	0.091728	OK
GZ 0.2	Max GZ higher than 0.2	0.2	0.53444	OK
MAX GZ 25	Max GZ at an angle larger than 25°	25	34.0881	OK
GM 0.15	GM value higher than 0.15	0.15	0.53213	OK

Tabell 10 IMO criteria Loading condition 3, the new hull

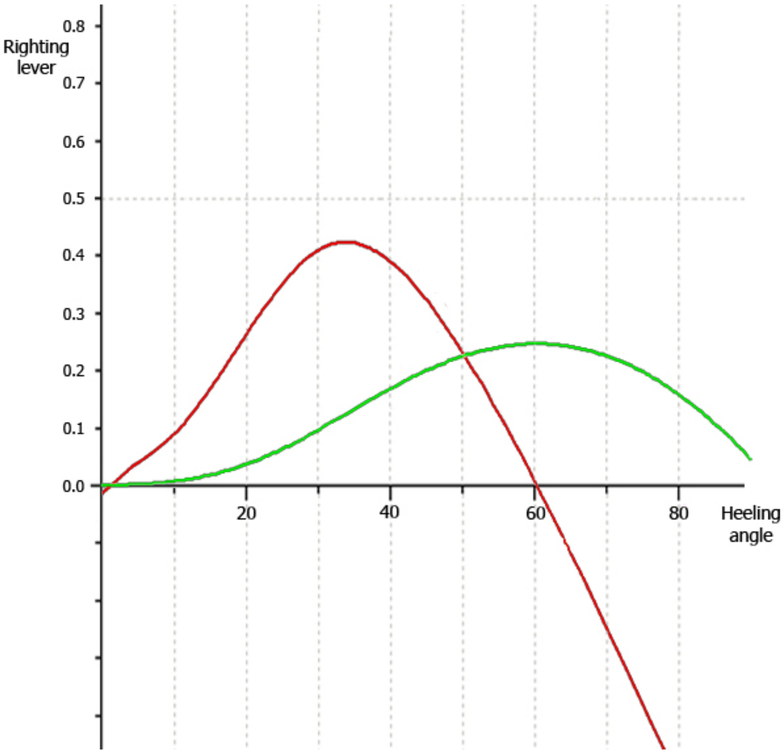
5.2.4.4 Loading condition 4

Loading condition 4 is a loading condition where the ship is fully loaded of fuel, fresh water and supplies but with no use of the water ballast tanks. This is to see whether or not the vessel is totally dependent on these tanks. The results from this loading condition can be seen in table 11.

Name	Value	Unit	Description
Disp	198.1	T	Total displacement
LCB	13.899	M	Longitudinal centre of buoyancy
T	1.463	M	Draught, moulded
TF	1.087	M	Draught fore, moulded
TA	1.840	M	Draught aft, moulded
TR	-0.753	M	Trim
HEEL	1.2	°	Heeling angle
GM	0.702	M	Metacentric height
GM0	0.958	M	Uncorrected GM
GMCORR	0.256	M	GM correction

Tabell 11 Parameters for loading condition 4, the new hull

As seen in table 11 will the draught without the water ballast tanks be at about 1.46 meters and therefore the curvature made for the designed waterline will have no use. The biggest disadvantage without the water ballast tanks is however the amount of trim, or the amount of heel in the longitudinal direction. This can be reduced by moving the engines further forth in the yacht, but water ballast tanks are for this use much more efficient and cheaper. The GZ curve for this loading condition can be seen in figure 17



Figur 17 GZ curve loading condition 4, the new hull

The maximum GZ value will for this load be 0.42 meter at an angle of 33.7°. The point of vanishing stability is at 60° of heel which is less than for all of the other loading conditions.

This loading condition was tested for the same IMO criteria as the other conditions. As table 12 shows are all of the criteria for the intact stability approved also for this loading condition. As a conclusion the ship will therefore have more than good enough stability even without the use of water ballast tanks. However, the use of water ballast tanks is needed to make the yacht float on an even keel in both longitudinal and transverse direction.

Criteria	Description	Required Value	Attained Value	Status
Area 30	Area under GZ curve until 30° heeling angle	0.055	0.097104	OK
Area 40	Area under GZ curve until 40° heeling angle	0.09	0.16934	OK
Area 3040	Area under GZ curve from 30° to 40° heeling angle	0.03	0.072235	OK
GZ 0.2	Max GZ higher than 0.2	0.2	0.42262	OK
MAX GZ 25	Max GZ at an angle larger than 25°	25	33.6926	OK
GM 0.15	GM value higher than 0.15	0.15	0.70182	OK

Tabell 12 IMO criteria Loading condition 4, the new hull

5.2.5 Stability for the conventional hull

The same loading conditions were tested for the conventional hull form to see if there was any difference in stability between the two hulls.

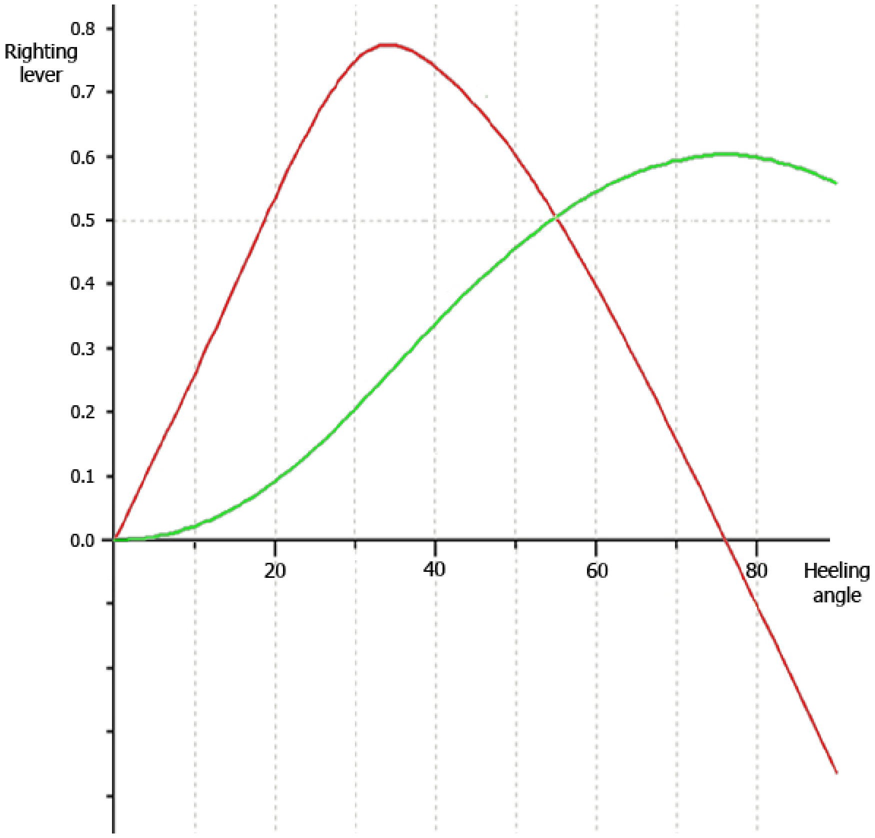
5.2.5.1 Loading condition 1

Loading condition 1 is defined as 100 % Fuel, fresh water and food supply. For the conventional hull loading condition 1 gives the geometric values as described in table 13. The volume displacement is around 10 tons more for the conventional hull even though the draught is decreased. The GM value is significantly improved with a whole meter in length. This is because of the much larger water plane area as mentioned earlier.

Name	Value	Unit	Description
Disp	251.7	T	Total displacement
LCB	14.940	M	Longitudinal centre of buoyancy
T	1.632	M	Draught, moulded
TF	1.572	M	Draught fore, moulded
TA	1.692	M	Draught aft, moulded
TR	-0.120	M	Trim
HEEL	0.0	°	Heeling angle
GM	1.502	M	Metacentric height
GM0	1.739	M	Uncorrected GM
GMCORR	0.237	M	GM correction

Tabell 13 Parameters for loading condition 1, the conventional hull

Given these values the GZ curve can be drawn as shown in figure 18. The maximum GZ value will for this loading condition be 0.78 meters, 0.2 meters more than for the new type of hull. The point of vanishing stability is at 76°, 6° more than for the new type of hull. The dynamical stability will for this point be 0.6 mrad, 0.23 mrad more than for the new type of hull. This means that the conventional hull has a higher ability to stand of external forces like waves and wind.



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Figur 18 GZ curve loading condition 1, the conventional hull

Since the conventional hull has improved stability compared to the new type of hull, all of IMOs criteria for the intact stability will be approved, as shown in table 14.

Criteria	Description	Required Value	Attained Value	Status
Area 30	Area under GZ curve until 30° heeling angle	0.055	0.20662	OK
Area 40	Area under GZ curve until 40° heeling angle	0.09	0.34009	OK
Area 3040	Area under GZ curve from 30° to 40° heeling angle	0.03	0.13347	OK
GZ 0.2	Max GZ higher than 0.2	0.2	0.77501	OK
MAX GZ 25	Max GZ at an angle larger than 25°	25	34.1469	OK
GM 0.15	GM value higher than 0.15	0.15	1.50184	OK

Tabell 14 IMO criteria Loading condition 1, the conventional hull

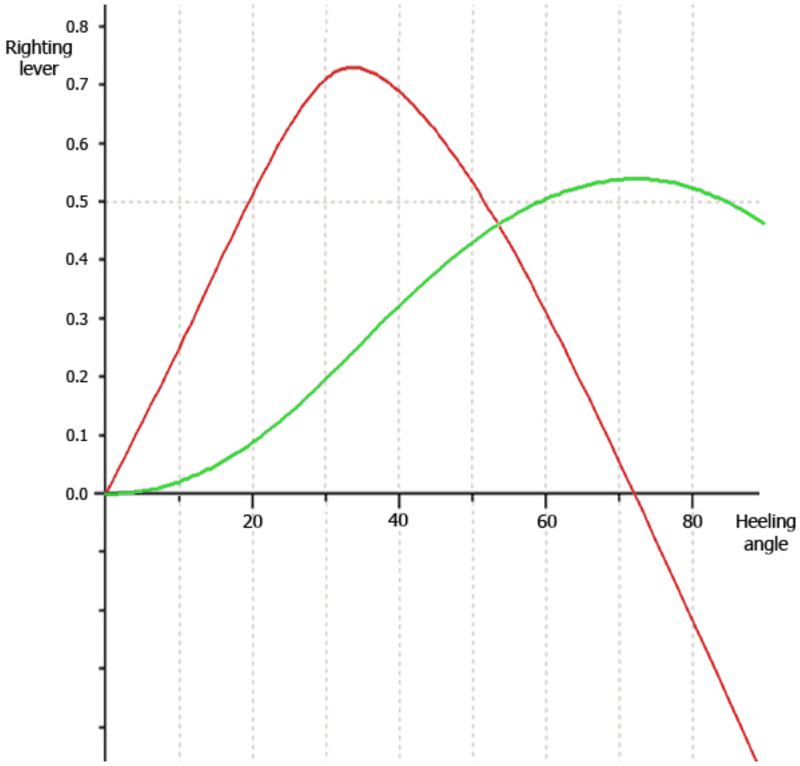
5.2.5.2 Loading condition 2

For the loading condition number 2 the yacht with the conventional hull is loaded with 10 % of the fuel, fresh water capacity and 1 percent of the food supply volume capacity. This loading condition gives the values as shown in table 15.

Name	Value	Unit	Description
Disp	240.9	T	Total displacement
LCB	14.987	M	Longitudinal centre of buoyancy
T	1.578	M	Draught, moulded
TF	1.522	M	Draught fore, moulded
TA	1.635	M	Draught aft, moulded
TR	-0.113	M	Trim
HEEL	0.0	°	Heeling angle
GM	1.435	M	Metacentric height
GM0	1.642	M	Uncorrected GM
GMCORR	0.207	M	GM correction

Tabell 15 Parameters for loading condition 2, the conventional hull

The GM value from loading condition 1 has decreased because the draught is lower and the water plane area becomes smaller. But as for loading condition 1 the general stability has improved compared to the new type of hull. For loading condition 2 the maximum GZ value is 0.73 meters, about 0.2 meters more than for the new type of hull. The point of vanishing stability is at 73° heeling angle. At this point the maximum dynamical GZ value is 0.54 mrad. See figure 19.



Figur 19 GZ curve loading condition 2, the conventional hull

From table 17 it's seen that all of the criteria from IMO for the intact stability are abided.

Criteria	Description	Required Value	Attained Value	Status
Area 30	Area under GZ curve until 30° heeling angle	0.055	0.19757	OK
Area 40	Area under GZ curve until 40° heeling angle	0.09	0.32332	OK
Area 3040	Area under GZ curve from 30° to 40° heeling angle	0.03	0.12576	OK
GZ 0.2	Max GZ higher than 0.2	0.2	0.73167	OK
MAX GZ 25	Max GZ at an angle larger than 25°	25	33.7018	OK
GM 0.15	GM value higher than 0.15	0.15	1.43492	OK

Tabell 16 IMO criteria Loading condition 2, the conventional hull

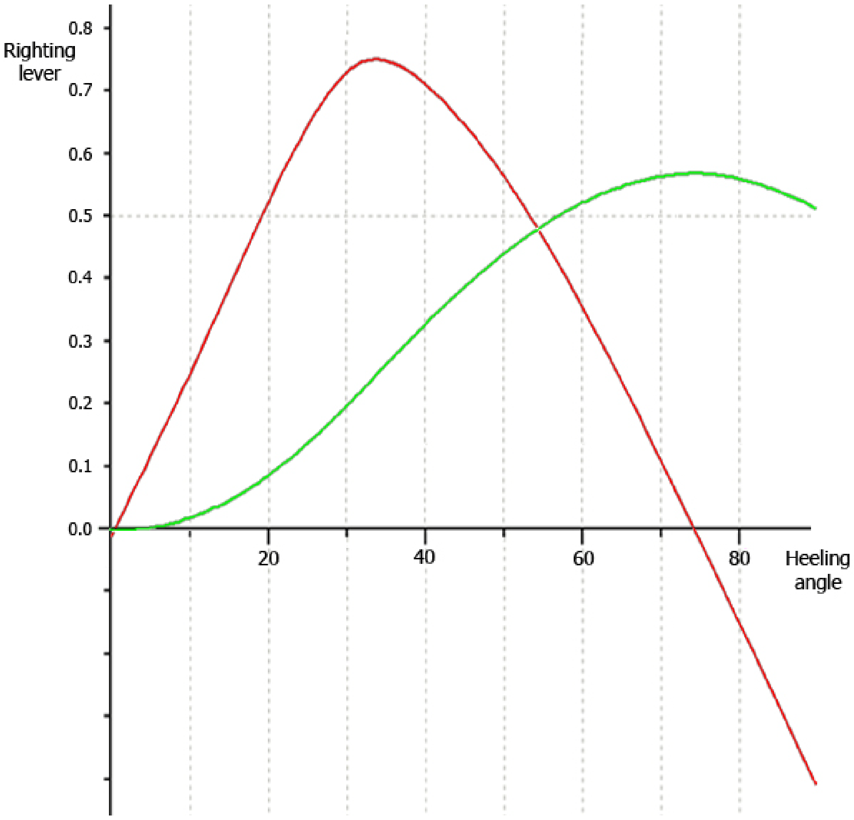
5.2.5.3 Loading condition 3

For the loading condition number 3 the yacht with the conventional hull is loaded with 50 % of the fuel and fresh water capacity. The storage room is filled with 5 percent of the food supply capacity as an estimation of 50 percent load. This loading condition resulted into the values given in table 17.

Name	Value	Unit	Description
Disp	252.5	T	Total displacement
LCB	15.136	M	Longitudinal centre of buoyancy
T	1.638	M	Draught, moulded
TF	1.634	M	Draught fore, moulded
TA	1.643	M	Draught aft, moulded
TR	-0.009	M	Trim
HEEL	0.5	°	Heeling angle
GM	1.476	M	Metacentric height
GM0	1.673	M	Uncorrected GM
GMCORR	0.197	M	GM correction

Tabell 17 Parameters for loading condition 3, the conventional hull

Based on these values the GZ curve can be drawn as shown in figure 20. For loading condition 3 with the use of the conventional hull the yacht attain a maximum GZ value of 0.75 meters. The point of vanishing stability occur at a heeling angle of 74°, and at this point the dynamical GZ value is at its maximum with 0.56 mrad.



Figur 20 GZ curve loading condition 3, the conventional hull

As for loading condition 1 and 2 all of the intact stability criteria given by IMO are abided. This is shown in table 18.

Criteria	Description	Required Value	Attained Value	Status
Area 30	Area under GZ curve until 30° heeling angle	0.055	0.19838	OK
Area 40	Area under GZ curve until 40° heeling angle	0.09	0.32732	OK
Area 3040	Area under GZ curve from 30° to 40° heeling angle	0.03	0.12894	OK
GZ 0.2	Max GZ higher than 0.2	0.2	0.74961	OK
MAX GZ 25	Max GZ at an angle larger than 25°	25	33.8316	OK
GM 0.15	GM value higher than 0.15	0.15	1.47583	OK

Tabell 18 IMO criteria Loading condition 3, the conventional hull

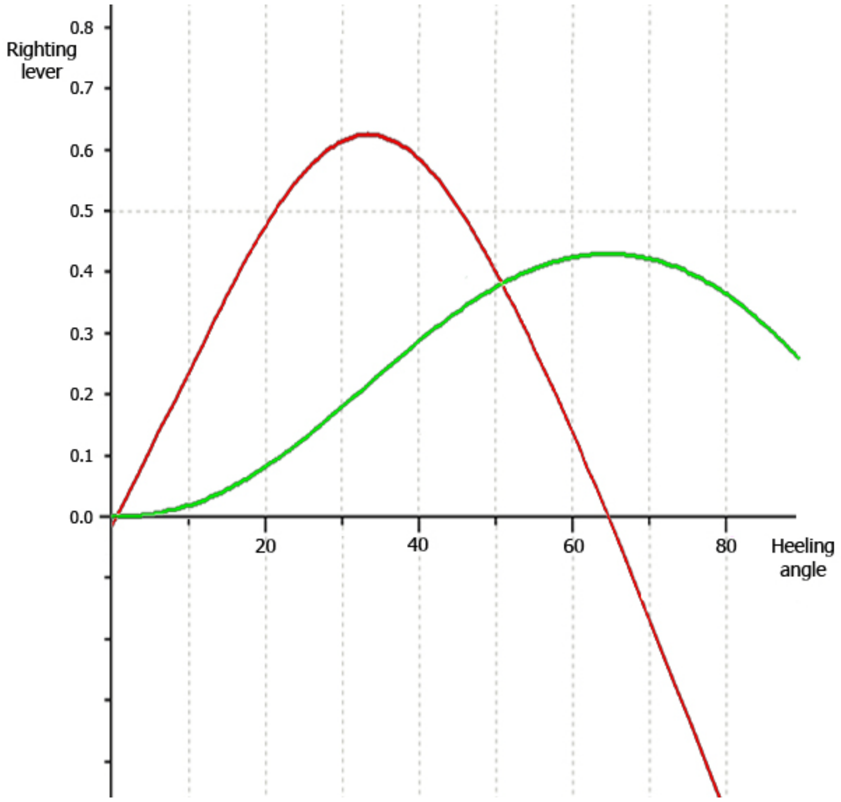
5.2.5.4 *Loading condition 4*

As for the new type of hull, the conventional hull was also tested to see if it made the yacht depended of the water ballast tanks. 100% fuel, freshwater, and food supply resulted in the values shown in table 19.

Name	Value	Unit	Description
Disp	198.1	T	Total displacement
LCB	13.9	M	Longitudinal centre of buoyancy
T	1.339	M	Draught, moulded
TF	0.980	M	Draught fore, moulded
TA	1.698	M	Draught aft, moulded
TR	-0.719	M	Trim
HEEL	0.6	°	Heeling angle
GM	1.452	M	Metacentric height
GM0	1.709	M	Uncorrected GM
GMCORR	0.257	M	GM correction

Tabell 19 Parameters for loading condition 4, the conventional hull

Also for the conventional hull the largest disadvantage is the major trim the vessel gets without the water ballast tanks. However, even without the water ballast tanks the stability is more than sufficient with a maximum GZ value of 0.62 meters. The point of vanishing stability occurs at 65° heel angle. At this point the vessel achieves a maximum dynamical GZ value of 0.42 mrad. See figure 21.



Figur 21 GZ curve loading condition 4, the conventional hull

As seen in table 20 are all of IMOs criteria for the intact stability abided, even without the use of water ballast tanks.

Criteria	Description	Required Value	Attained Value	Status
Area 30	Area under GZ curve until 30° heeling angle	0.055	0.1789	OK
Area 40	Area under GZ curve until 40° heeling angle	0.09	0.28614	OK
Area 3040	Area under GZ curve from 30° to 40° heeling angle	0.03	0.10724	OK
GZ 0.2	Max GZ higher than 0.2	0.2	0.62398	OK
MAX GZ 25	Max GZ at an angle larger than 25°	25	33.4369	OK
GM 0.15	GM value higher than 0.15	0.15	1.4518	OK

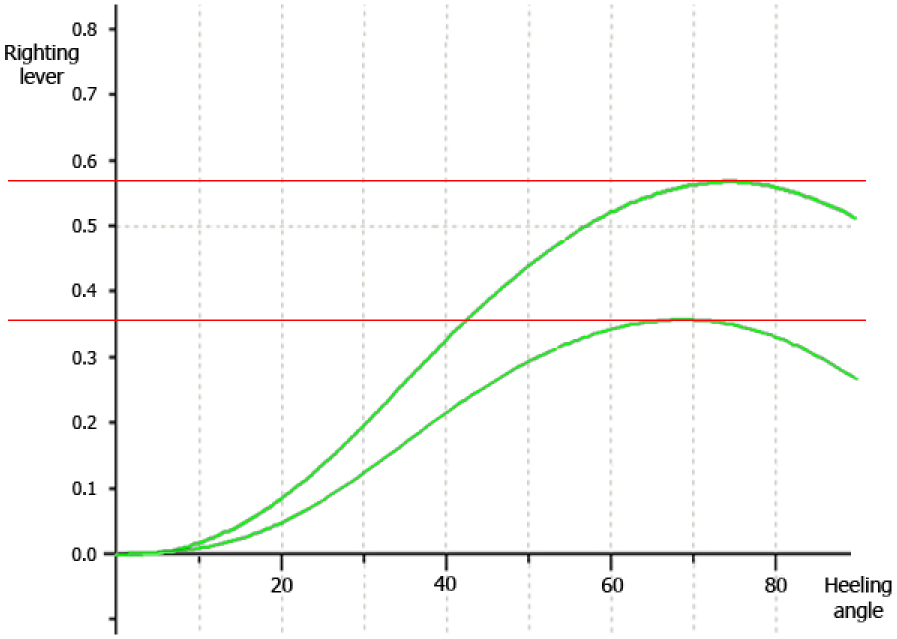
Tabell 20 IMO criteria Loading condition 4, the conventional hull

5.2.6 Discussion about the intact stability

For both hulls and for all of the different loading conditions the IMO criteria for the intact stability of a ship are abided. The margin is quite good for every condition, and there is therefore no reason why any changes in the design should be performed.

The stability tests show that the stability for the conventional hull was significantly better than for the new type of hull. This was expected since the initial stability is better because of the larger GM value as a function of the water line area. The discoveries from these calculations shows that even though the stability for the new hull was improved quite noticeable when inclining, the overall stability was weakened quite substantially. With loading condition 1 for the new type of hull the maximum GZ value was only 72 percent of the maximum GZ value for the conventional hull. For loading condition 2, 3 and 4, the percentage was 70, 71 and 68 percent, respectively. With loading condition 1 for the new hull and the conventional hull there was a dynamical GZ value of 0.37 mrad and 0.6 mrad, respectively. This is about 38 % less stability for the new hull. See figure 22.

The restoring moment is equal to the product of the weight displacement and the GZ value. Since both the displacement and the GZ value are larger for the conventional hull, the restoring moment will be much less for the new type of hull. This means that the yacht equipped with the new type of hull will have much less ability to stand off external forces like wind and waves. Since the new hull has about 96 percent of the volume displacement for loading condition 1, the total restoring moment for the new hull will only be 70 percent of the restoring moment for the conventional hull.



Figur 22 Dynamical stability loading condition 1

The test of loading condition 4 proved that both of the hull forms abided IMOs criteria for intact stability even without the use of water ballast tanks. This means that if any malfunction of the water ballast tanks would occur, and the yacht has no chance of filling them, the stability should still be sufficient. The trim was though quite large without the ballast tanks, and this can have an impact of the ability to maneuver the vessel.

5.3 Damage stability

Even though no damage stability requirements exists in Norwegian Maritime Directorates book of laws for vessels of this size the damage stability calculations will be done anyway. By doing this the hull can prove that the stability is good enough for situations that could occur and this would also help to discover the changes that needs to be done to make the yacht even more secure. The damage stability was calculated for loading conditions 1, 2 and 3 with scenarios which relate to situations which are more likely to occur during normal use of the vessel. The damage scenarios were as follow:

DAMAGE CASE 1 – TEAR UP ONE SIDE

DAMAGE CASE 2 – FRONT CRASH

DAMAGE CASE 3 – UNDERNEATH

The damage stability requirements of today are based on a probabilistic approach to the damage stability. This approach was originally developed in 1973, when a study of data from collisions was collected by the IMO. The data showed that damages mostly were sustained in the fore part of a vessel, and therefore the need of improving the design was greater in this region of the ship. The probabilistic approach is believed to be more realistic than the earlier deterministic method, which is based on theoretical principles. The probabilistic approach to damage stability was introduced for passenger ships in 1978, for cargo ships of 100 meters in length or more in 1990, and in 1996 it was also introduced for cargo ships from 80 to 100 meters of length. [15]

The probabilistic approach to the damage stability is very extensive, and requires both a large amount of data and advanced mathematical calculations. Therefore, for this project and for this yacht, the damage stability will only be checked as a general stability with corresponding GZ curve for different damage scenarios. The damage scenarios chosen relate as mentioned to situations which are likely to occur, and therefore the probability of the damages will still be taken into account.

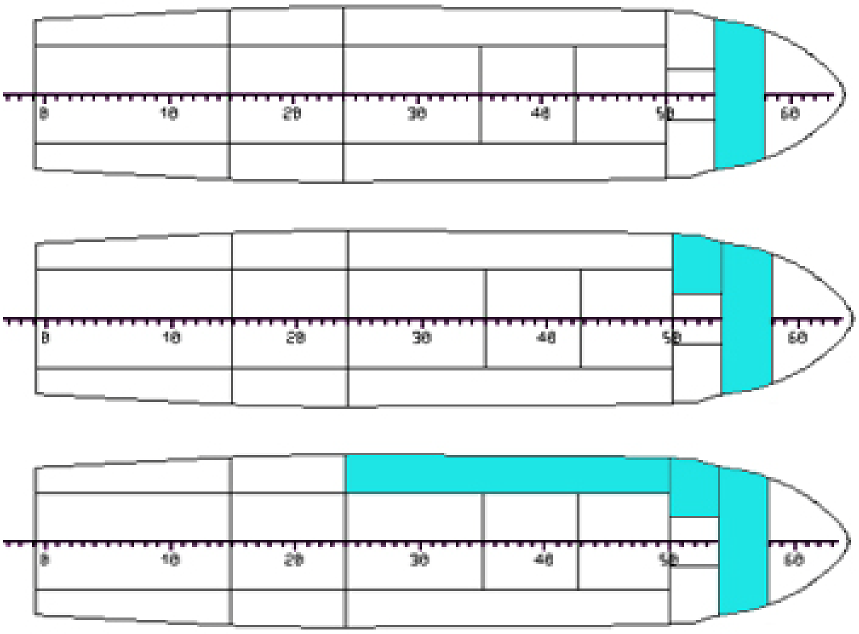
According to SOLAS 2009 [16] the damage stability calculations should be based on a trim value of ± 0.5 percent of the ship length. For the yacht of this project this will be a trim of no more than 0.15 meters. For larger trim levels than this the calculations need to be done for several different levels of trim. Even though loading condition 2 has a higher trim value than SOLAS requires, it will be sufficient for this project to do the calculations for only one level of trim.

Each of the damage cases has been divided into stages and phases for the measurements. A new stage is defined as when the water enters a new room, and the phases are calculation points in between of the stages. This is to see how the vessel responds to the water and how the water is moving.

All the values from the calculations can be seen in appendix 2. In appendix 3 there is a picture of the final floating position for each damage scenario.

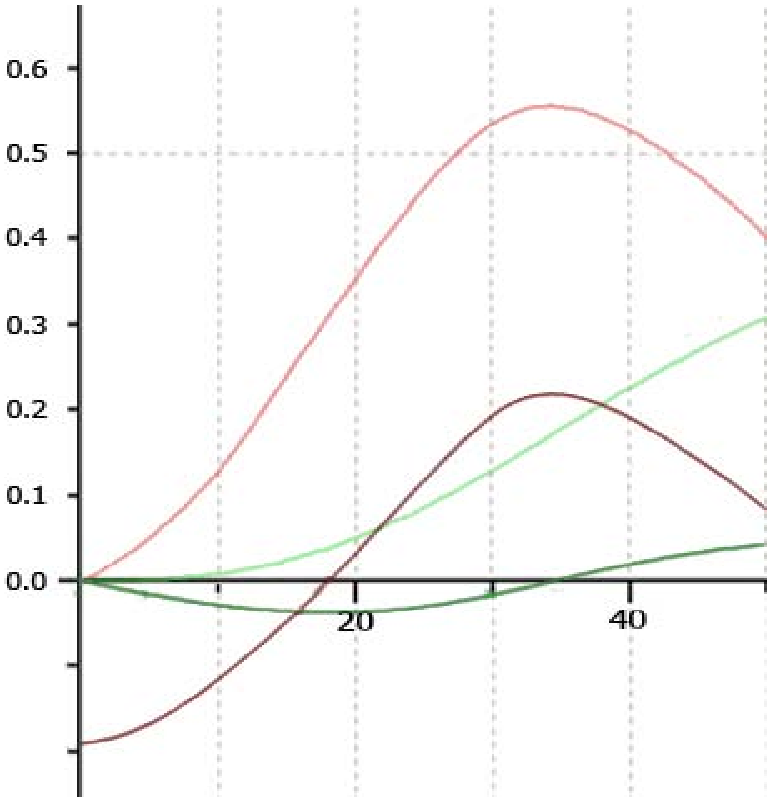
5.3.1 Damage case 1

In this case the ship has a water entry at sea level on the fore port side of the ship. This is a type of damage which could take place for instance when trying to come alongside the quay. The water entry is starting in the chain room at sea level. The simulation continues with a wider entry point which leads to water flooding into the port side stair at sea level. After this point the water continue into the long corridor on the port side. The three stages can be seen in figure 23.



Figur 23 Damage condition 1

The GZ curve for the final stage of the water flooding, when the water has completely filled the corridor on deck 0, is compared to the initial state in figure 24.

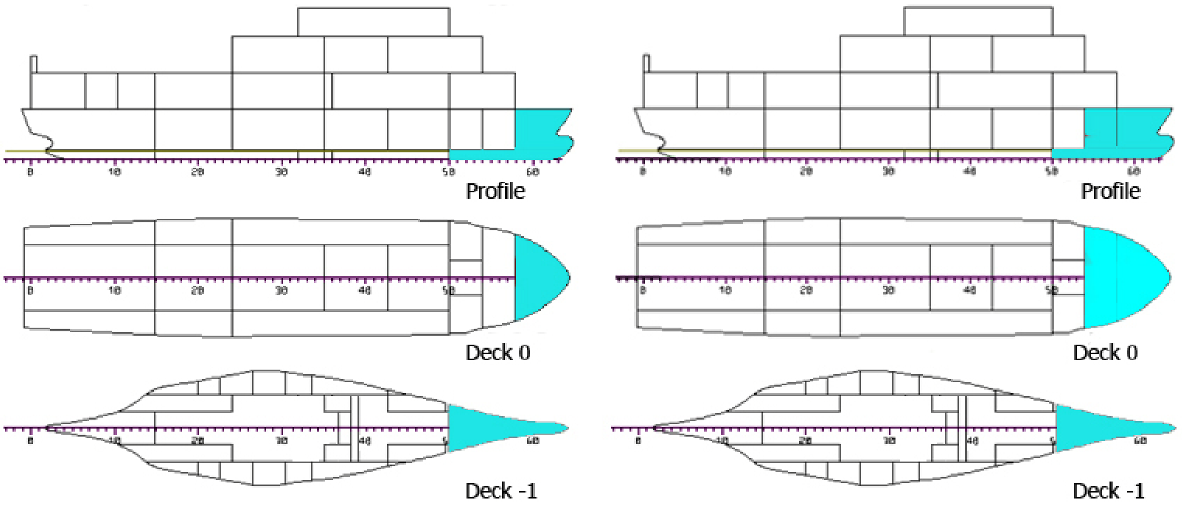


Figur 24 GZ curve, damage condition 1

The stability of the vessel is clearly weakened by the water flooding, and the maximum GZ value is now only 0.21 meters. The water flooding makes the vessel heel with an angle of 19° and the sea level reaches 0.07 meters above the hull. For loading conditions 2 and 3 the water which floods the corridor gives the vessel a heel angle of 21.2° and makes the sea level reach 0.08 meters above the hull. See appendix 2 for the calculation values for the simulation.

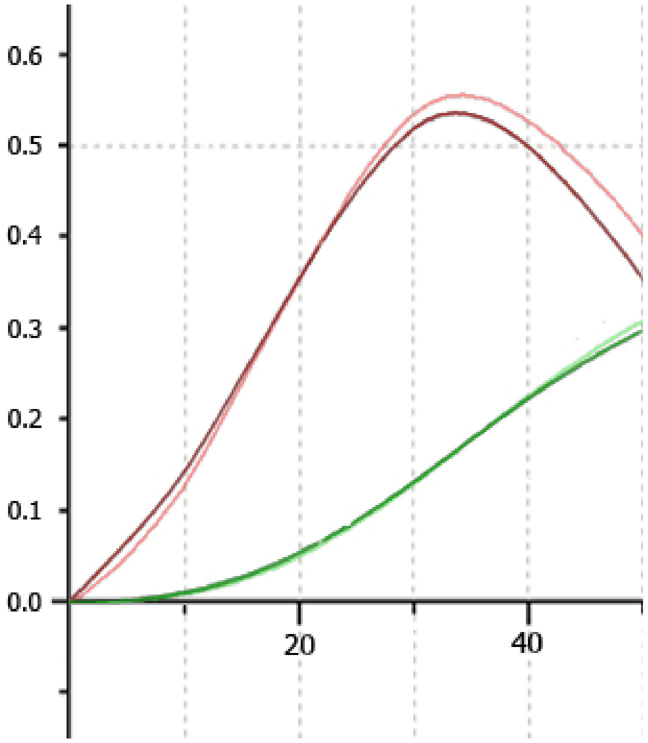
5.3.2 Damage case 2

Damage case 2 is made to simulate a crash situated in the front of the vessel. This is a type of damage which can occur when the yacht is heading into any other floating object or into the quay. The damage starts by water flooding of the two foremost water ballast tanks on deck -1 and 0. The water then continues in stage 2 to the chain room on deck 0. Figure 25 shows the water entry for different stages into the vessel.



Figur 25 Damage condition 2

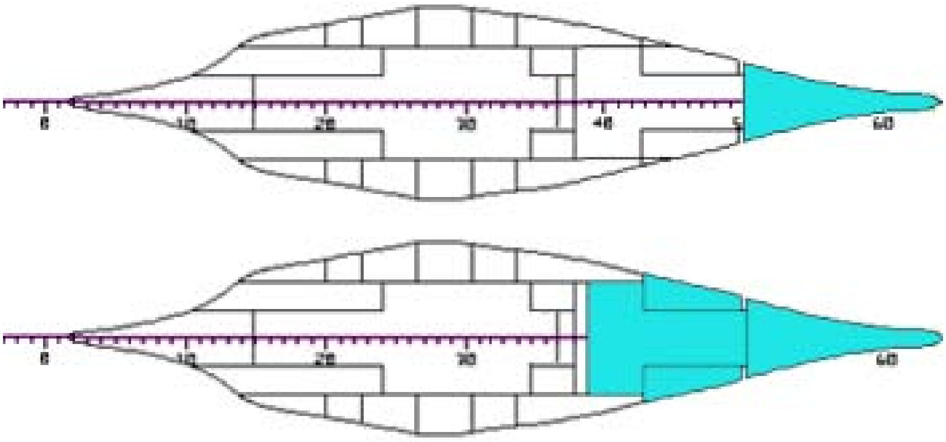
The water flooding the fore water ballast tanks only take the place of the water already there, so there is not so much change in the stability of the vessel. The little change in stability is because of the motion of the water. The rooms flooded are symmetrical over the X-axis and the flooding has therefore no effect on the heeling angle, but the freeboard decreases with 0.1 meters because of the change in trim value owing to the fact of water filling the chain room. All the values from the calculation are shown in appendix 2. The GZ curve after the final stage compared to the initial stage can be seen in figure 26.



Figur 26 GZ curve, damage condition 2

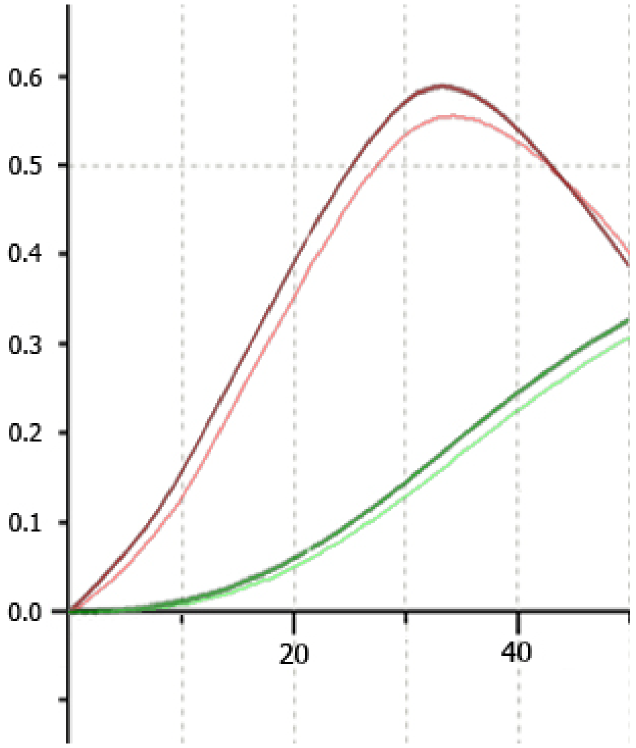
5.3.3 Damage case 3

In damage case 3 it's simulated that the vessel hits the sea floor. The water entry starts in the lowest fore part of the hull, enters the foremost water ballast tank at deck -1, and then continues in to the two next water ballast tanks and the fresh water tank. The different stages for damage scenario 3 can be seen in figure 27.



Figur 27 Damage condition 3

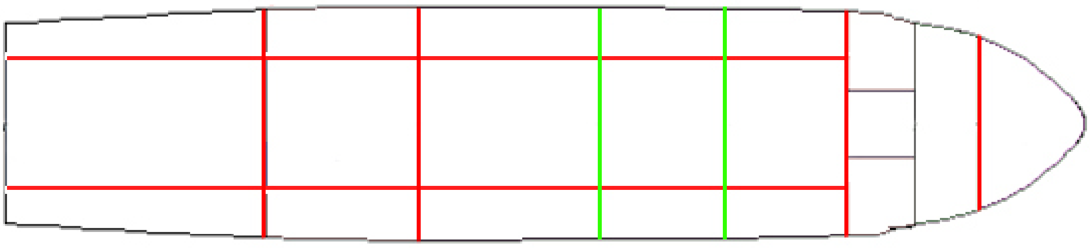
For this case as for damage case 2, the water flooding only changes place with the water already there, so there is a very little effect on the stability of the yacht. For loading condition number 1 the vessel doesn't even notice the flood, since the fresh water tank is already filled to the maximum capacity. For the two other conditions the freeboard decreases with 0.03 meters, because of the change in trim value. The GZ curve of the final stage compared to the initial stage can be seen in figure 28.



Figur 28 GZ curve, damage condition 3

5.3.4 Damage Conclusion

Based on the results from the damage stability calculation some changes in the design need to be done. For damage case number 1, when the water floods the corridor on the port side of the ship, the weakened stability made the sea level reach 3.28 meters up on the port side of the ship. This is 0.08 meters above the ship hull. Because of this it might be necessary to install one or two more transverse watertight bulkheads like shown in figure 29. The alternative would be to increase the hull height up to 3.4 meters or to increase the strength of the structure above the main deck. However, installing the needed bulkheads would be both cheaper and more effective to secure the ship from capsizing.



Figur 29 New bulkheads

6 Resistance prediction

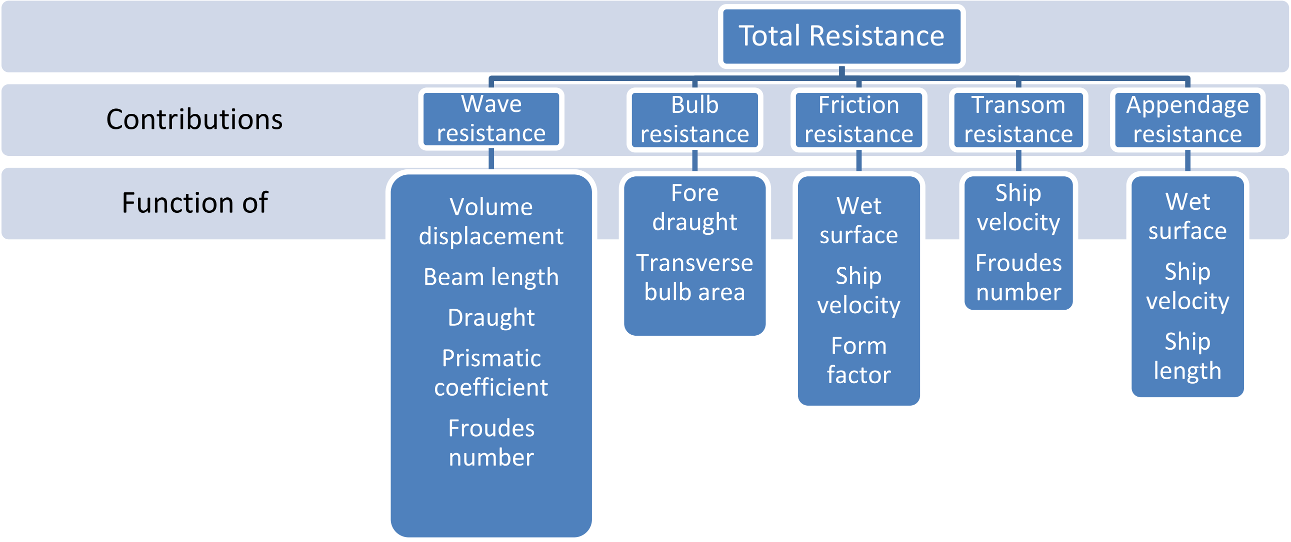
The total resistance of a ship consists of several segments, and is a result of the friction, shape, appendages, waves, wave breaking resistance and air resistance. When comparing the two hulls shapes in this project it’s the shape, wave resistance and wave breaking resistance that are the three factors who would make the largest difference between the hulls.

6.1 Holtrop -1984

There is many ways to calculate an assumption of the hull resistance to a ship, and each method has its positive and negative sides. For this project the Holtrop-84 prediction method will be used.

Holtrop's empirical method is based on a regression analysis of random models and full scale test data of several different hull forms[17]. Between 1978 and 1984 Holtrop published results from resistance tests from the towing tank in Wageningen. Together with these results he also published a series of formulas for calculating a prediction of a hulls resistance. One of the formulas was for calculating an assumption for the form factor of a ship.

The final resistance was according to Holtrop given as a sum of the wave resistance, bulb resistance, transom resistance, appendage resistance and friction resistance, as shown in figure 30.



Figur 30 The total resistance

Even though the Holtrop 84 method is the result of the most extensive statistic analyses of model tests ever made, the method has several weaknesses. The Holtrop Method was developed with a particular set of hull forms and data. Hulls which are outside of the box, like the one for this project, can get wrong results, and lead to predictions which are quite incorrect. In the calculations of the main parameters used in the calculations the estimation of the wet surface is for instance measured for a hull which lies still on the water. This wet surface will in real life change for different speeds because of the motion of the water and could give incorrect results.

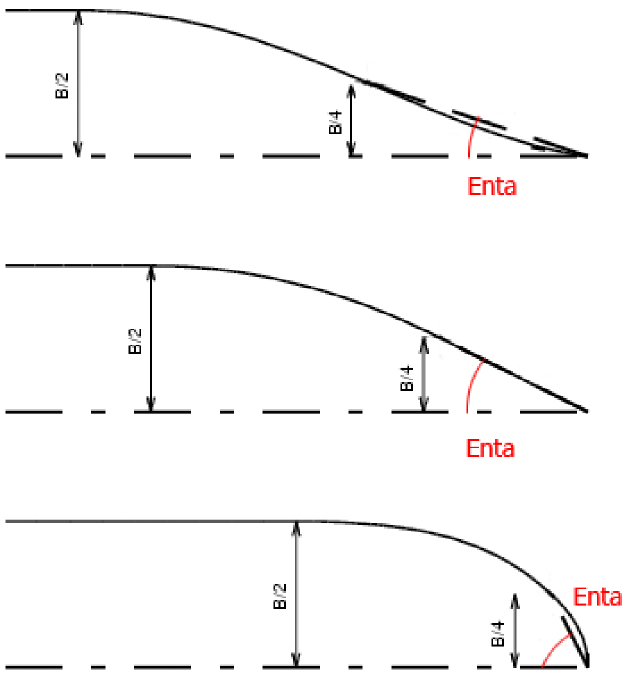
For this project two hull shapes will be tested against each other. The errors done will be the same for each hull, so for a comparison between two hulls the Holtrop resistance prediction method will be sufficient. For an accurate resistance prediction and corresponding need for engine power, model tests should be used.

6.1.1 Explanations to the factors mentioned

6.1.1.1 Main parameters

As mentioned earlier the Holtrop Method is based on several constants which are all a function of some of the main parameters of the hull shape. Here follows a quick explanation of some of the main parameters used for the resistance prediction.

The half angle of entrance, or enta, is measured as an angle made up of two points, the foremost point of the waterline and the foremost point of the waterline in which the beam length of the waterline is half the maximum beam length. See figure 31.



Figur 31 Half angle of entrance

Vetted surface area is the area of the hull which is under the water line, and is the biggest contributor to the friction resistance.

Moulded displacement volume is the displacement of a ship based on moulded dimensions, which equals the inner volume of a ship without the hull thickness. For the resistance prediction NAPA generates a massive model based on the arrangement and lightweight made for the loading conditions. The moulded displacement volume mentioned in the resistance prediction equals therefore to the moulded displacement volume and the hull thickness.

The Block coefficient is a coefficient which describes the ratio between the volume displacement and the box shape created by the length, beam and draught.

Midship section coefficient is a coefficient describing the ratio between the area of the midship section and the square made by the beam length and draught at the same place.

Appendages are additional parts on the hull, like rudders and sonar's.

6.1.1.2 Effective power

By predicting the resistance the need for engine power can be calculated. The effective power is a function of resistance: Effective power = Resistance * Speed. However, the effective power is not equal to the engine power. From the engine to the thrust given to push the ship there's a lot of losses in energy because of not optimized efficiency.

The total efficiency, or the overall propulsive coefficient, is a sum of the mechanical and propulsory efficiencies and is normally between 50 to 60 percent, dependent on the hull type, speed range, type of engine and propeller style.[3] On top of this the need of power will increase due to rough sea, wind and future fouling, therefore its normal to increase the engine power with a so called sea margin factor of 15 %.

6.2 Calculation

For the resistance prediction the draught was set to 1.75 meters for both of the hulls. As an estimate the diameter of the propeller was calculated to be 70 percent of the aft draught, T_A, which is normal for initial designing process. [3] This gives a propeller diameter of 1.225 meters. The wetted area of appendages is in NAPAs calculations defined as 2 percent of the total wetted surface multiplied with the number of propellers.

6.2.1 Resistance for the new hull

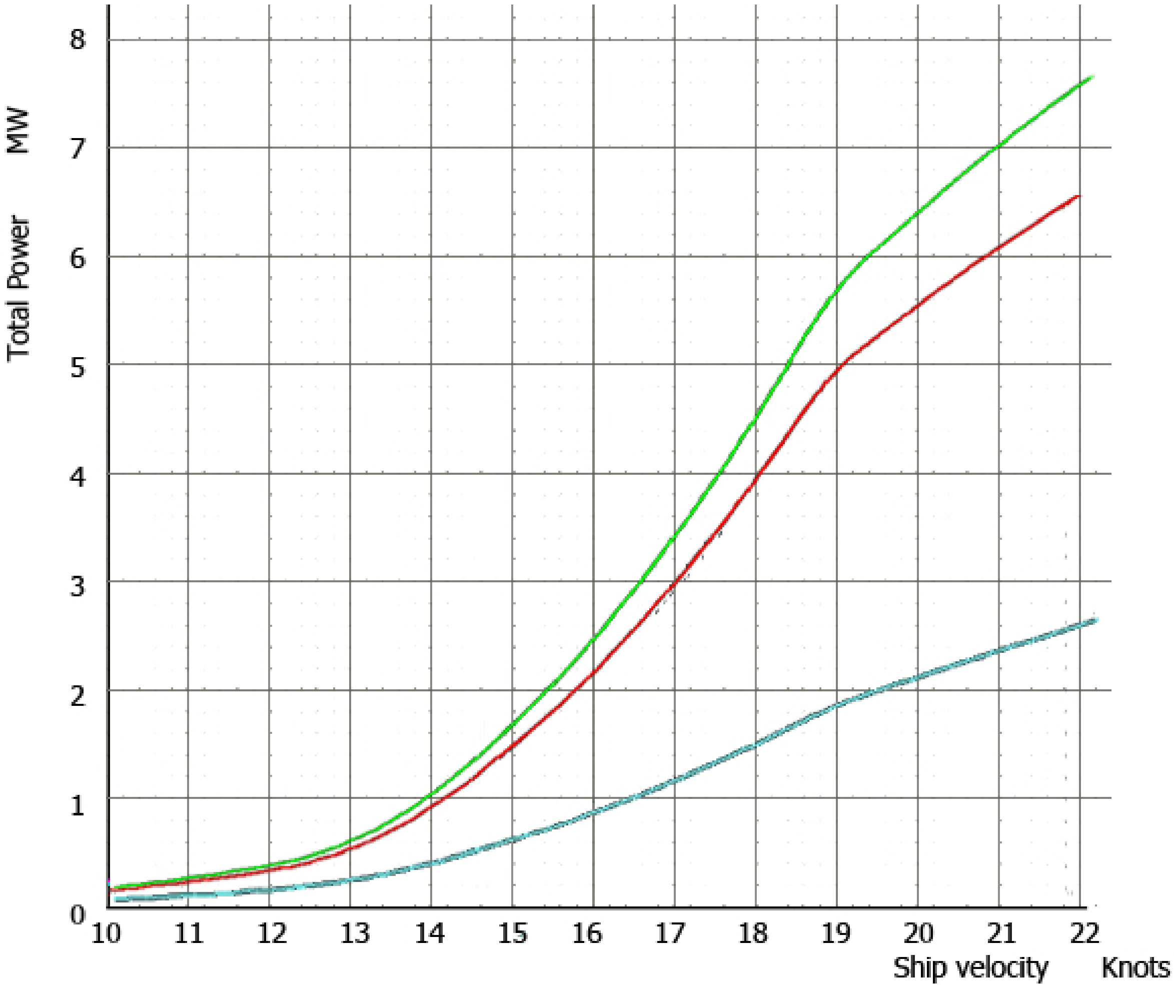
For the new hull with the slimmer waterline the numbers described in table 21 were calculated from the model.

Name	Unit		Description
Enta	°	27,79	Half angle of entrance
BWL	M	6,25	Breadth of waterline
LWL	M	31.90	Length of waterline
S	M2	246	Vetted surface area
DisV	M3	236	Moulded disp. Volume
C_B	-	0.720	Block coefficient
C_M	-	1.070	Midship section coefficient

Tabell 21 Parameters, resistance prediction new hull

It's noticed that the C_M value is larger than 1. This is because NAPA uses the breadth of the waterline in the calculation of the C_M value, and therefore the area of the midsection will be larger than the square made by the breadth of the waterline and draught. The BWL value could of course be corrected, but this would have made a larger error in the total resistance calculations.

Based on these parameters the Holtrop-84 resistance prediction method is used to calculate the resistance. The result is shown in figure 32.



Figur 32 Power requirement new hull

For the yacht with the new hull at a speed of 15 knots the total power needed from the engine will be 1.455 MW. With an additional sea margin of 15 % the needed engine power is 1.67 MW. P_E, or the thrust needed to push the boat, is calculated to 0.62 MW. At the point between 13 – 15 knots there is an acceleration in the required engine power. This shows the effect of the hull speed explained in chapter 2.3, and implies that the service speed of the yacht should be bellow 13 knots to save fuel.

The output for the resistance prediction can be seen in appendix 4.

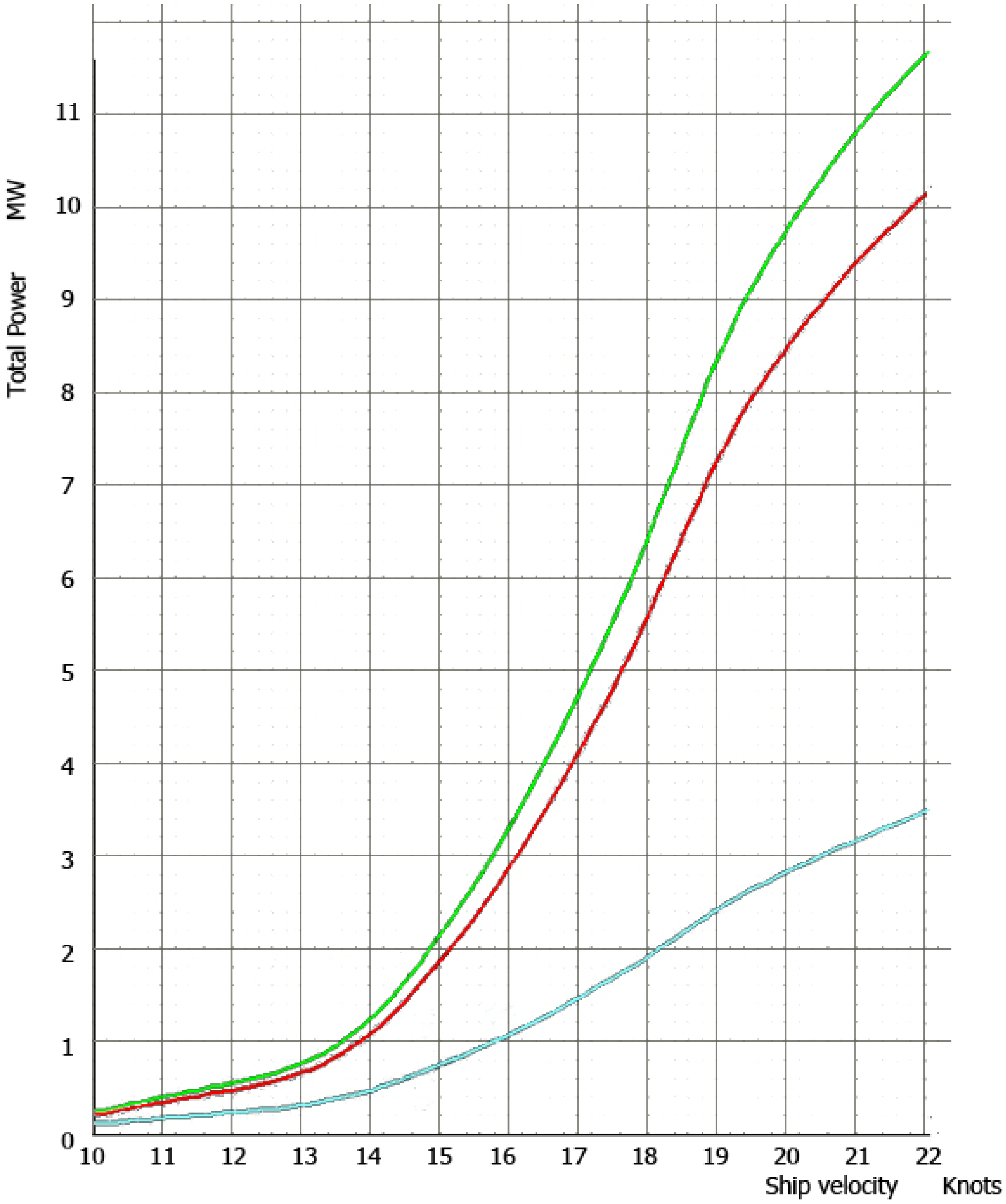
6.2.2 The comparison hull

For the comparison hull the parameters described in table 22 is got by analyzing the geometry of the model of the hull.

Name	Unit		Description
Enta	°	31,11	Half angle of entrance
BWL	M	7.00	Breadth of waterline
LWL	M	31.91	Length of waterline
S	M2	264	Vetted surface area
DisV	M3	266	Molded disp. Volume
C_B	-	0.723	Block coefficient
C_M	-	0.983	Midship section coefficient

Tabell 22 Parameters, resistance prediction conventional hull

The half angle of entrance has increased for this hull since the breadth of the waterline is larger. The surface area has also increased for the comparison hull because of the wider fore and aft part of the hull shape. Based on these parameters the Holtrop-84 resistance prediction method is used to calculate the resistance. The result is shown in figure 33.



Figur 33 Power requirement, conventional hull

For the comparison hull with a speed of 15 knots the total power required from the engine will be 1.9 MW. With an additional sea margin of 15 % the needed engine power is 2.185 MW. P_E is by NAPA calculated to be 0.78 MW for this hull.

The output for the resistance prediction can be seen in appendix 4.

6.2.3 Results

Based on Holtrop's resistance prediction method the required engine power will be reduced by 24% with the use of the new type of hull with a slimmer water line, as described in table 23.

	New hull (MW)	Conventional hull (MW)	Percentage
Power	1.455	1.9	77 %
Power + sea margin	1.67	2.185	76 %
P_E	0.62	0.78	79 %

Tabell 23 Resistance results

There are several reasons why this new hull shape will decrease the resistance. As mentioned earlier the Holtrop resistance prediction method uses some of the main dimensions for the calculation of the constants used for the total resistance calculation.

The bulb resistance, which is a function of the transverse bulb area and the fore draught, has in general a rather small contribution to the total resistance. The transverse bulb area is a bit smaller for the new hull, as the bulb shape is a function of the ships beam length, still are the difference quite vague and the transverse bulb resistance has a minimal impact on difference in total resistance. The transom resistance is also a function of the beam length, and becomes larger as the beam length increases, but also this resistance will give a small contribution to the total resistance.

According to Holtrop it's the wave and friction resistance who are the two largest contributors to the difference between the two hulls. The wave resistance is dependent on the volume displacement of the hull and the beam length, and will give the new hull form with its smaller waterline a reduced contribution to the total resistance force.

The largest contribution to the different resistance between the two hulls is the friction resistance. This resistance is based on the total wet surface area and the form factor, which both have the smallest values for the new type of hull. The curvature at the sides of the new type of hull would in general give the ship a larger wet surface area, but since both the fore and the aft part of hull also are slimmer, the total surface area becomes smaller.

7 Discussion

7.1 Resistance vs. stability

Based on the results from this thesis the new hull form has its big advantage in the decreased resistance in the water. The new hull has about 23 percent less need for engine power which is very beneficial for both the environment and for the operational cost of the vessel. However, the results from the stability tests show that there is a 30 % decrease in intact stability for all of the different loading conditions. For this projects yacht the stability was good enough, but for a conventional hull already being on the limit of the stability criteria, the use of this type of new hull would decrease the stability too much for the stability of the ship to be approved. Even though there is a larger decrease in intact stability than there is for the water resistance, these two parameters can't be measured up against each other. The stability criteria must be followed, no matter how good the ship slides through the water. But for the idea of this new type of hull to succeed it would probably require a larger decrease in the resistance than for the stability, which implies that there must be executed some changes in the new hull form before any new analyses should be done.

7.2 Motion

One of the biggest disadvantages with the slender hull will be its seakeeping ability in rough seas. The curvature on the sides of the hull can when facing head sea lead to some serious slamming problems. Even though the slimmer waterline of the hull in this project starts 10 meters behind the ship bow, the waves will still have some effect on the ships seakeeping ability.

All ships in waves encounter roll motions. For a yacht these roll motions can be of great discomfort to the crew and passengers, and can in some cases lead to severe damage on the hull and equipment onboard. Even though this project did not involve any dynamical analysis of the vessel in motion it's likely to think that because of the lack in initial stability the ship will probably experience a lot of roll motion in the first 5° – 10° of heeling. This will for instance for the bridge 6 meters above the waterline, give a transverse motion of 0.5-1 meters to each side.

The roll period of a ship has a direct relationship to the ships GM value, because the GM value is as mentioned earlier the proportional to the GZ value for small angles. If a ship has a large GM value the ship will also have a large righting arm and will therefore have a stiff and fast roll period. If the GM value is small the ship will have a small righting arm and will have a calmer and slower roll motion.

The period of roll can be estimated with this equation, taken from some notes which are found in appendix 5.

$$T = 0.44 \frac{B}{\sqrt{GM_T}}$$

Formel 11 Roll period

Where GM is the stability index mentioned earlier, and B is the beam length of the vessel.

This means that the conventional hull will have a roll period of 2.513 seconds, while the new type of hull will have a roll period of 3.74 seconds. Since it's the acceleration of motion which generates the most amount of discomfort on a vessel[18], the new hull will have an advantage here.

In one of the standards from IMO, ISO 2631, there is a restriction for the vertical acceleration of a vessel to reduce the risk of health injury and increase the comfort factor for both crew and passengers. The standards only take vertical acceleration into account because it does not exist sufficient data of the effects on the human body in the two other directions. Some other reports [18], as also mentioned by ISO 2631, implies that there is a larger effect of motion induced sickness when all three directions of motion are combined together. However, the vertical acceleration is the main contributor to the seasickness among crew and passenger, and this factor will actually be decreased for the new type of hull since the natural heave motion is a function of the water line area. [19]

$$T_{33} = 2\pi \left(\frac{M + A_{33}}{C_{33}} \right)^{\frac{1}{2}}$$

Where;

$$C_{33} = \rho g A_W$$

Formel 12 Heave period

As the waterline area is smaller for the new type of hull, the ships natural period will increase. For most cases, especially close to shore, the wave periods are relatively short. This implies that if the yacht with the new hull design has a longer natural period in heave, the yacht will have less motion and increased comfort onboard.

7.3 Design and construction process

A conventional hull design will have several advantages in the design and building process. In general there are three main factors contributing to the total cost of a vessel; design, material cost and production labour cost. A good estimation for the price of a new build passenger ferry or cruise ship is found by comparing the lightweight for several units of this kind of ships. In the book *System based ship design* by Kai Levander[20], there's a diagram showing the building cost per lightweight tons for different types of vessels. The yacht from this project will be somewhere between cruise ships and ferries, because of its luxury interior and small size. This will according to Levander give a building cost of 10 000 USD/LWT, and this equals for this project a building cost of 1 912 520 USD. However, by comparing other yachts of the same size[21], see table 25, it's shown that the price varies substantially between the different yachts. This shows that there is little relation between the size and price for luxury yachts, since the total price will be so dependent on the quality of the interior and equipment.

Name	Length (m)	Price (USD)
Cantieri Navali Lavagna Admiral 31	31,09	5 995 599,00
Falcon Yachts Falcon 102	31,09	6 954 780,00
Fipa Italiana Yachts Maiora 31 Dp	31,09	5 755 680,00
Leopard 32	31,09	13 789 650,00
Numarine 102	31,09	6 595 050,00
Heysea 101 luxury yacht	30,78	2 950 000,00
Argos 100	30,48	5 950 000,00
Poly Marine Luxury Yacht	30,48	7 199 995,00
Aquamarine	29,87	4 220 832,00

Tabell 24 Comparison Yachts

The construction of a conventional hull is much simpler because of the large flat parts and will require less man hours both for design and construction. The curvature on the sides of the new hull may cause some challenges in the building process, but since the hull consists of fiberglass the construction process doesn’t need to be that more difficult. Constructions made up of fiberglass are often molded in the same mold, and the extra building cost of the first model will therefore be reduced quite substantially the more units of the same hull you make. For other types of ships, consisting of steel plates, the extra cost for the construction of the hull will be very noticeable. The bending and installation of the curved steel plates require a lot of detailed work, which require many more man hours. The design process for the new hull will also require several more man hours especially in the beginning of the design process, because of the massive amount of testing and possible changes in the hull design. After a while this new hull design could become more standardized and in that way adapt to other sizes of ships more easily.

Because the new hull has a reduced need for engine power, the fuel consumption will be reduced. The designed yacht with a conventional hull will require an engine effect of 2.185 MW, which will for one weekend give a total fuel consumption of 13.1 tons fuel. The same yacht with this projects new type of hull will require an engine effect of 1.67 MW, which will correspond to 10 tons of fuel per weekend. With today’s fuel price of about 450 US$/ton [22] this will give a price reduction of 1 395 US$ per weekend. Assuming the yacht will be used every weekend this will give a fuel reduction of 72 540 US$ per year, and therefore compensate for some of the extra costs from the design and construction process of the new hull.

8 Conclusion

This master thesis resulted in a yacht with an overall length of 30 meters, a beam length at the waterline of 6.25 meters and a designed draught of 1.75 meters. The endurance of one weekend resulted in a fuel capacity of 18 ton fuel and a fresh water capacity of 4000 liter. With two engines of 1500 kW each, the yacht will do 15 knots and have a range of 450 nautical miles. The main parameters of the hull are given in table 26.

Name	Value	Unit
Deadweight	26	Tons
Lightship weight	191.25	Tons
Displacement	217.25	Tons
Service speed	15	Kn
Length	30	Meters
Breadth	7	Meters
Breadth WL	6.25	Meters
Draught	1.75	Meters
CB	0.6	-
CP	0.7729	-

Tabell 25 Main parameters of the new hull

The new hull has proved to be sufficient for a typical yacht with respect to the volume capacity and stability criteria for both intact and damage scenarios. The big advantage with the new design is a reduced water resistance because of the slimmer water line area. The disadvantage is the reduced stability compared to a conventional hull. Even though the stability and resistance of a vessel can’t be compared in general, the reduction in stability was about 5 percent larger than for the resistance. This is an indication on the fact that changes in the hull design need to be done before any further testing.

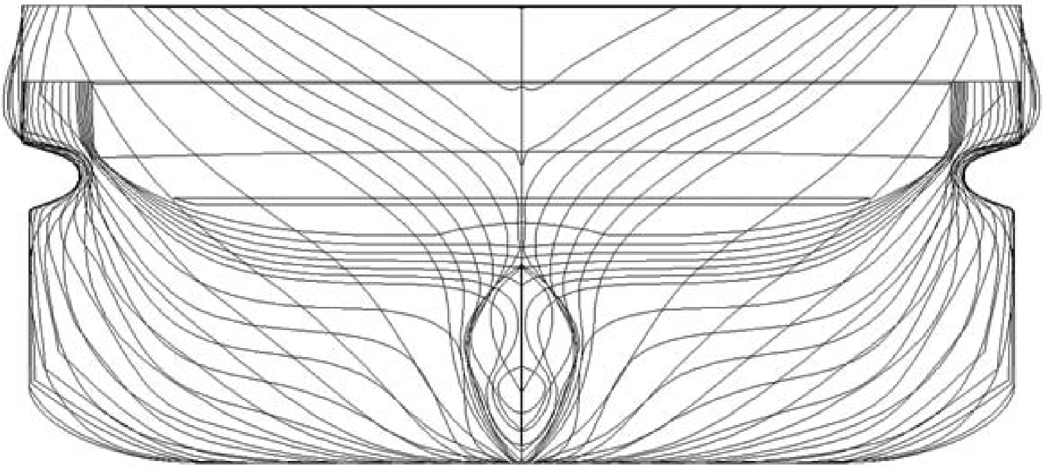
The feasibility of the new hull design depends on further testing with different kinds of shapes and angels of the slender water line. There should also be done dynamical analysis of the seakeeping capability to see how the new hull will for instance respond to incoming waves. Results from this thesis show that the new hull will respond with slow motions when facing waves; however the amount of motion has not been calculated in this thesis. If the new hull will experience too much motion it will not be suitable for yachts, but could be tested for other markets.

9 Further work

This thesis is a project which attempted to change the hull form of a conventional hull form to decrease the resistance in the water, and make a more efficient ship for a more sustainable future. Even though the results in this project show that the new type of hull has a larger amount of disadvantages than it has advantages, much research still remains before this new hull can be either refused or accepted as a new way of design ship hulls.

9.1 Perfection of the hull

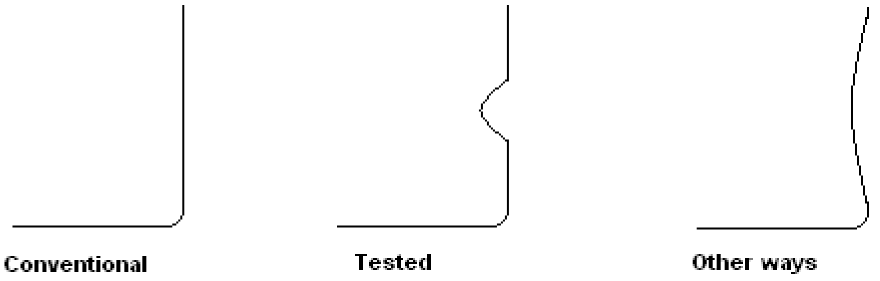
The hull is a very complex construction and many changes have been done during this project. The model of the hull consists of a grid made by very many curves and it’s therefore possible to make a lot of small and larger changes in the hull form. People who work with the computer program NAPA at a daily basis for fairing, or smoothing of the surface, usually spends more than a month to complete a smooth hull surface. This fairing of the surface will give more accurate results for each of the hull shapes.



Figur 34 The grids of the model

9.2 Angels and shape

The three main parameters which can be changed in the new attempts for the new hull form are the depth, height and length of the curvature. By drawing more models of the same hull with slightly different values for these parameters, as shown in figure 35, it could be possible to see what shape is most beneficial for reducing the resistance and still have an adequate stability. These different forms of the hull might as well have an impact on the motion of the vessel, and should be tested in a dynamical analysis.



Figur 35 Different shapes and angels

9.3 Further testing in different sea, loading and damage conditions

As mentioned in the thesis the main challenge with the new hull shape will probably be discovered when it's facing waves in head sea. Slamming, especially with breaking waves, can make sever damage on a ship hull, and a dynamical analysis of the hull in different sea states should be done to calculate the hulls seakeeping abilities. The seakeeping analysis should be done for different sea states and loading conditions to be able to find the hull shape which is best for all purposes. Then there should also be done more tests for different damage scenarios. The probabilistic approach to damage stability which was mentioned in chapter 5.3 should also be used for the calculation of these damage scenarios.

9.4 FEM-analysis of the stress in the hull.

Because the new hull form has a quite unconventional shape, it can respond differently to the forces made by the waves and the general pressure from the sea. Therefore the stress in the curvature of the slim waterline should be checked to be within the limits, to see if any strengthening actions need to be done with the hull.

9.5 Model testing

The resistance calculations in chapter 6 are as mentioned earlier based on empirical measurements from a group of conventional hull forms. These are therefore often not good enough for unconventional hull forms, like the one for this project. To confirm the results from this thesis a model test should be done. Model tests are as the name implies scaled down models of the hull which can be tested for both seakeeping ability and water resistance. These model tests are quite expensive because of its detailed handwork, and it's therefore recommended to do the changes in design, the calculations and the detailed work this chapter has mentioned before any investment in the model testing should be executed.

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11 Appendix

Appendix 1

Ship lightweight prediction

Name	Description	Area	Volume	Tykkelse	CGX	CGY	CGZ	Empty weight	kg*CGX	kg*CGY	kg*CGZ
Hull	The hull	424	42,4	0,1	14,55	0	2,13	64829,6	943270,7	0	138303,1
Deck -1											
WB aft	Water Ballast aft		4		5,14	0	0,31	1000	5140	0	310
WB Front	Water Ballast front		3,6		27,3	0	0,33	900	24570	0	297
WB1 BB	Water ballast tank 1 portside		0,5		8,91	2,28	0,4	125	1113,75	285	50
WB3 BB	Water ballast tank 2 portside		0,4		10,66	2,39	0,35	100	1066	239	35
WB5 BB	Water ballast tank 3 portside		1		12,32	2,51	0,33	250	3080	627,5	82,5
WB7 BB	Water ballast tank 4 portside		1,3		14,25	2,62	0,31	325	4631,25	851,5	100,75
WB2 SB	Water ballast tank 1 starboard		0,5		8,91	-2,28	-0,4	125	1113,75	-285	-50
WB4 SB	Water ballast tank 2 starboard		0,4		10,66	-2,39	0,35	100	1066	-239	35
WB6 SB	Water ballast tank 3 starboard		1		12,32	-2,51	0,33	250	3080	-627,5	82,5
WB8 SB	Water ballast tank 4 starboard		1,3		14,25	-2,62	0,31	325	4631,25	-851,5	100,75
HFO	HFO-tank		21		12,43	0	0,28	5250	65257,5	0	1470
GW BB	Grey water tank port side		2,7		9,43	1,47	0,31	675	6365,25	992,25	209,25
GW SB	Grey water tank starboard side		2,7		9,43	-1,47	0,31	675	6365,25	-992,25	209,25
BW BB	Black water tank port side		0,8		16,75	1,5	0,28	200	3350	300	56
BW SB	Black water tank starboard side		0,8		16,75	-1,5	0,28	200	3350	-300	56
FW	Fresh water tank		4		20,9	0	0,29	1000	20900	0	290
Deck 0											

FLO	Floating device 1 BB		14	4,11	2,52	2,15	100	411	252	215
FLO sb	Floating device 2 SB		14	4,11	-2,52	2,15	100	411	-252	215
ENG	Engine room		63,3	3,93	0	1,92	35660	140143,8	0	68467,2
STA0BB	Stairs bb		14,2	9,8	2,65	1,84	142	1391,6	376,3	261,28
STA0SB	Stairs sb		14,2	9,8	-2,65	1,84	142	1391,6	-376,3	261,28
MRE	Machine repair shop		22,3	9,7	1	1,76	4460	43262	4460	7849,6
CON	Control room		22,3	9,7	-1	1,76	4460	43262	-4460	7849,6
CCO0BB	Corridor BB		39	17,98	2,66	1,87	1950	35061	5187	3646,5
CCO0SB	Corridor SB		39	17,98	-2,66	1,87	1950	35061	-5187	3646,5
GST	Suplly storage		53,3	14,75	0	1,76	2665	39308,75	0	4690,4
LST	Linen store		37,2	19,42	0	1,76	1860	36121,2	0	3273,6
GAR	Garbage		35,4	23,17	0	1,76	1770	41010,9	0	3115,2
STA0BB2	Stair bb F		7,3	25,95	1,89	2,05	73	1894,35	137,97	149,65
STA0SB2	Stair SB F		7,3	25,95	-1,89	2,05	73	1894,35	-137,97	149,65
CCO	Corridor		9,7	26	0	1,76	485	12610	0	853,6
CHA	Chainroom		18,1	27,93	0	2,03	5620	156966,6	0	11408,6
WBF0	Water ballast front		12,4	30,09	0	2,18	3100	93279	0	6758
Deck 1										
MACBBA	Ventilation system		7,2	1,63	2,5	4,08	1440	2347,2	3600	5875,2
MACSB	Ventilation system		7,2	1,63	-2,5	4,08	1440	2347,2	-3600	5875,2
CA1BBA	Ventilation system		7,2	1,63	1,5	4,08	1440	2347,2	2160	5875,2
CA1SBA	Ventilation system		7,2	1,63	-1,5	4,08	1440	2347,2	-2160	5875,2
BOAT	Small boat/ water jet		14,4	1,63	0	4,08	500	815	0	2040
FLO5	Floating device BB		42,8	7,29	1,85	4,08	42,8	312,012	79,18	174,624
FLO6	Floating device SB		42,8	7,29	-1,85	4,08	42,8	312,012	-79,18	174,624
BAT5	Bathroom 5	5	10	6,28	0	4,08	2000	12560	0	8160

BED5	Bedroom 5	10,15	20,3	9,7	0	4,08	1015	9845,5	0	4141,2
MES	Kitchen	36,45	72,9	14,75	0	4,08	10935	161291,3	0	44614,8
FLO3	Floating device 3		2,2	17,75	2	4,08	2,2	39,05	4,4	8,976
FLO4	Floating device 4		2,2	17,75	-2	4,08	2,2	39,05	-4,4	8,976
FLO7	Floating device 7		10,8	14,37	3,18	4,08	10,8	155,196	34,344	44,064
FLO8	Floating device 8		10,8	14,37	-3,18	4,08	10,8	155,196	-34,344	44,064
FLO9	Floating device 9		11,3	19,5	2,17	6,26	11,3	220,35	24,521	70,738
FLO10	Floating device 10		11,3	19,5	-2,17	6,26	11,3	220,35	-24,521	70,738
FLO11	Floating device 11		4,1	6	2,17	5,67	4,1	24,6	8,897	23,247
FLOA	Floating device aft		1,4	0,17	0	5,67	1,4	0,238	0	7,938
FLO12	Floating device 12		4,1	6	-2,17	5,67	4,1	24,6	-8,897	23,247
STA1M	Stairs midship	1,1	2,2	17,75	0	4,08	22	390,5	0	89,76
PCO	Corridor	15,45	30,9	21,5	0	4,08	1545	33217,5	0	6303,6
BAT2	Bathroom 2	7,4	14,8	19,67	2	4,08	2960	58223,2	5920	12076,8
BAT3	Bathroom 3	7,4	14,8	19,67	-2	4,08	2960	58223,2	-5920	12076,8
BED2	Bed room 2	8,1	16,2	23,17	2	4,08	810	18767,7	1620	3304,8
BED3	Bed room 3	8,1	16,2	23,17	-2	4,08	810	18767,7	-1620	3304,8
BAT1	Bathroom 1	8,75	17,5	26,98	2	4,08	3500	94430	7000	14280
BED1	Bed room 1	17,5	35	26,98	-1	4,08	1750	47215	-1750	7140
Deck 2										
LFB1	Life boat BB		4,9	10,86	1,5	6,26	500	5430	750	3130
LFB2	Life boat SB		4,9	10,86	-1,5	6,26	500	5430	-750	3130
RES	Restaurant	22,05	44,1	14,6	-0,11	6,26	1000	14600	-110	6260
STA4	Stairs	2,85	5,7	16,75	1,5	7,09	57	954,75	85,5	404,13
PCO3	Corridor	4,15	8,3	19,42	1,5	6,26	415	8059,3	622,5	2597,9
BAT6	Bathroom 6	12,4	24,8	19,42	-0,5	6,26	4960	96323,2	-2480	31049,6

BED6	Bed room 6	24,4	48,8	24,17	0	6,26	2440	58974,8	0	15274,4
Deck 3										
BRIDGE	Control bridge	191,25	57,3	24	-0,07	8,17	5730	137520	-401,1	46814,1
	Total volume of floating devices						171,8			
								2633761	2966,9	514592,5
	Total weight and COG						**191252,4**	**13,77**	**0,0155**	**2,69**

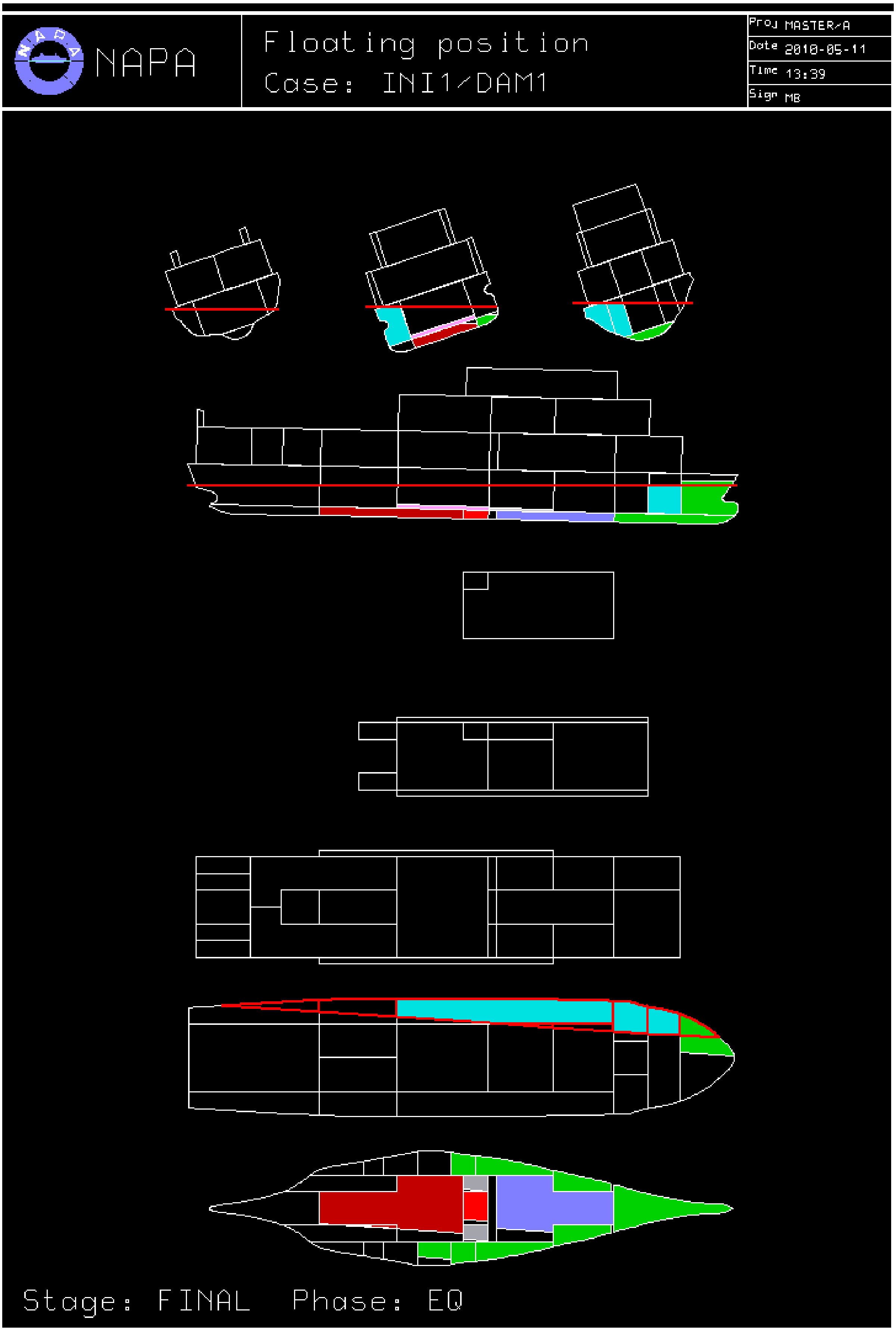
Appendix 2

INI1 = Loading condition 1
INI2 = Loading condition 2
INI3 = Loading condition 3

CASE	STAGE	PHASE	SIDE	T	TRIM	HEEL DEGREE		OPEN	RESMRG	COMMENT
				m	m de	degree			m	
INI1/DAM1	INTACT	EQ	-	1,738	-0,016	0,0	-	-	1,25	
INI1/DAM1	1	EQ	-	1,763	0,121	0,0	-	-	1,17	
INI1/DAM1	2	EQ	PS	1,78	0,212	1,8	-	-	1,03	
INI1/DAM1	FINAL	1	PS	1,803	0,265	5,6	-	-	0,77	
INI1/DAM1	FINAL	2	PS	1,822	0,338	8,9	-	-	0,51	
INI1/DAM1	FINAL	EQ	PS	1,839	0,629	18,7	-	-	-0,27	Marginlevel is sat as 3 meters
										Hull height is 3.2
INI1/DAM2	INTACT	EQ	-	1,738	-0,016	0,0	-	-	1,25	
INI1/DAM2	1	EQ	-	1,695	-0,284	0,0	-	-	1,16	
INI1/DAM2	FINAL	EQ	-	1,717	-0,162	0,0	-	-	1,2	
INI1/DAM3	INTACT	EQ	-	1,738	-0,016	0,0	-	-	1,25	
INI1/DAM3	1	1	-	1,737	-0,02	0,0	-	-	1,25	
INI1/DAM3	1	2	-	1,737	-0,02	0,0	-	-	1,25	
INI1/DAM3	1	EQ	-	1,737	-0,02	0,0	-	-	1,25	
INI1/DAM3	2	1	-	1,739	-0,017	0,0	-	-	1,25	
INI1/DAM3	2	2	-	1,739	-0,016	0,0	-	-	1,25	
INI1/DAM3	2	3	-	1,739	-0,015	0,0	-	-	1,25	
INI1/DAM3	2	4	-	1,74	-0,014	0,0	-	-	1,25	
INI1/DAM3	2	EQ	-	1,74	-0,013	0,0	-	-	1,25	
INI2/DAM1	INTACT	EQ	-	1,649	-0,188	0,0	-	-	1,25	
INI2/DAM1	1	EQ	-	1,669	-0,072	0,0	-	-	1,29	
INI2/DAM1	2	EQ	PS	1,684	0,004	1,6	-	-	1,22	
INI2/DAM1	FINAL	1	PS	1,707	0,07	6,3	-	-	0,88	
INI2/DAM1	FINAL	2	PS	1,721	0,149	9,8	-	-	0,62	
INI2/DAM1	FINAL	EQ	PS	1,716	0,502	21,2	-	-	-0,28	
INI2/DAM2	INTACT	EQ	-	1,649	-0,188	0,0	-	-	1,25	
INI2/DAM2	1	EQ	-	1,601	-0,488	0,0	-	-	1,15	
INI2/DAM2	FINAL	EQ	-	1,618	-0,392	0,0	-	-	1,18	

INI2/DAM3	INTACT	EQ	-	1,649	-0,188	0,0	-	-	1,25
INI2/DAM3	1	1	-	1,648	-0,192	0,0	-	-	1,25
INI2/DAM3	1	2	-	1,648	-0,192	0,0	-	-	1,25
INI2/DAM3	1	EQ	-	1,648	-0,192	0,0	-	-	1,25
INI2/DAM3	2	1	-	1,685	-0,084	0,0	-	-	1,27
INI2/DAM3	2	2	-	1,706	-0,022	0,0	-	-	1,28
INI2/DAM3	2	3	-	1,706	-0,021	0,0	-	-	1,28
INI2/DAM3	2	4	-	1,706	-0,021	0,0	-	-	1,28
INI2/DAM3	2	EQ	-	1,706	-0,021	0,0	-	-	1,28
INI3/DAM1	INTACT	EQ	-	1,649	-0,188	0,0	-	-	1,25
INI3/DAM1	1	EQ	-	1,669	-0,072	0,0	-	-	1,29
INI3/DAM1	2	EQ	PS	1,684	0,004	1,6	-	-	1,22
INI3/DAM1	FINAL	1	PS	1,707	0,07	6,3	-	-	0,88
INI3/DAM1	FINAL	2	PS	1,721	0,149	9,8	-	-	0,62
INI3/DAM1	FINAL	EQ	PS	1,716	0,502	21,2	-	-	-0,28
INI3/DAM2	INTACT	EQ	-	1,649	-0,188	0,0	-	-	1,25
INI3/DAM2	1	EQ	-	1,601	-0,488	0,0	-	-	1,15
INI3/DAM2	FINAL	EQ	-	1,618	-0,392	0,0	-	-	1,18
INI3/DAM3	INTACT	EQ	-	1,649	-0,188	0,0	-	-	1,25
INI3/DAM3	1	1	-	1,648	-0,192	0,0	-	-	1,25
INI3/DAM3	1	2	-	1,648	-0,192	0,0	-	-	1,25
INI3/DAM3	1	EQ	-	1,648	-0,192	0,0	-	-	1,25
INI3/DAM3	2	1	-	1,685	-0,084	0,0	-	-	1,27
INI3/DAM3	2	2	-	1,706	-0,022	0,0	-	-	1,28
INI3/DAM3	2	3	-	1,706	-0,021	0,0	-	-	1,28
INI3/DAM3	2	4	-	1,706	-0,021	0,0	-	-	1,28
INI3/DAM3	2	EQ	-	1,706	-0,021	0,0	-	-	1,28

Appendix 3



Floating position

Case: INI1/DAM1

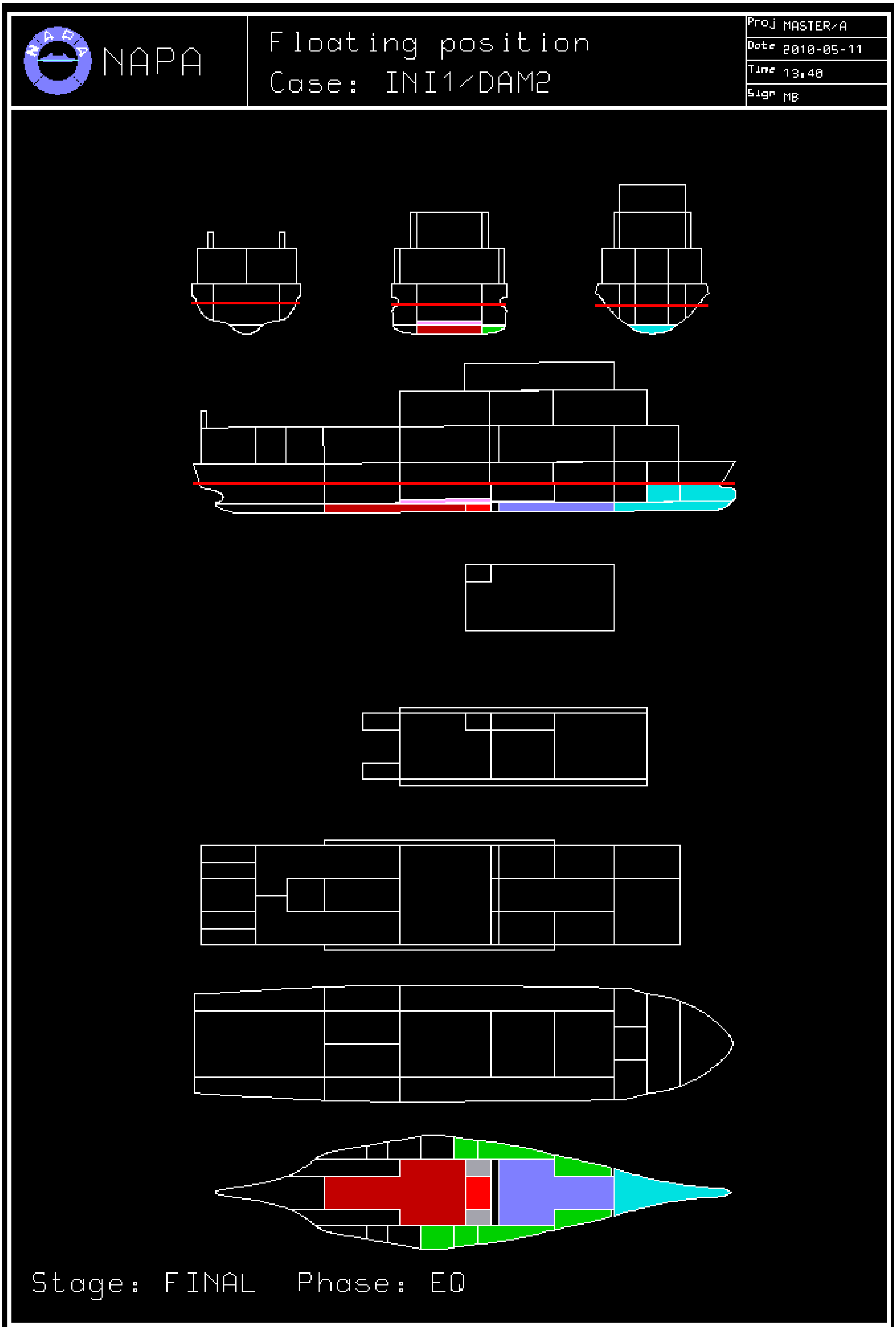
Proj MASTER-A

Date 2010-05-11

Time 13:39

Sign MB

Stage: FINAL Phase: EQ



NAPA

Floating position

Case: INI1/DAM2

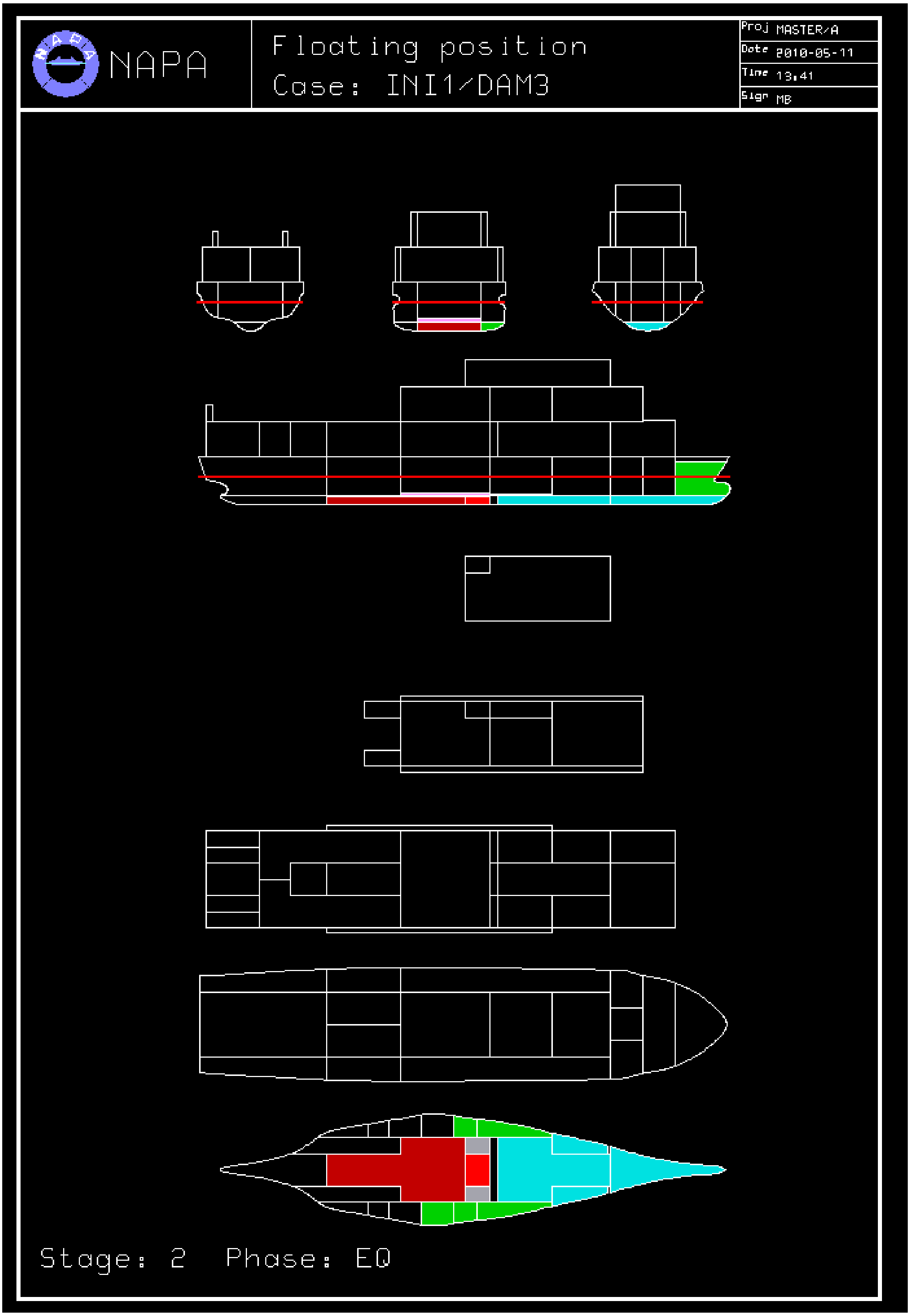
Proj MASTER/A

Date 2010-05-11

Time 13.40

Sign MB

Stage: FINAL Phase: EQ



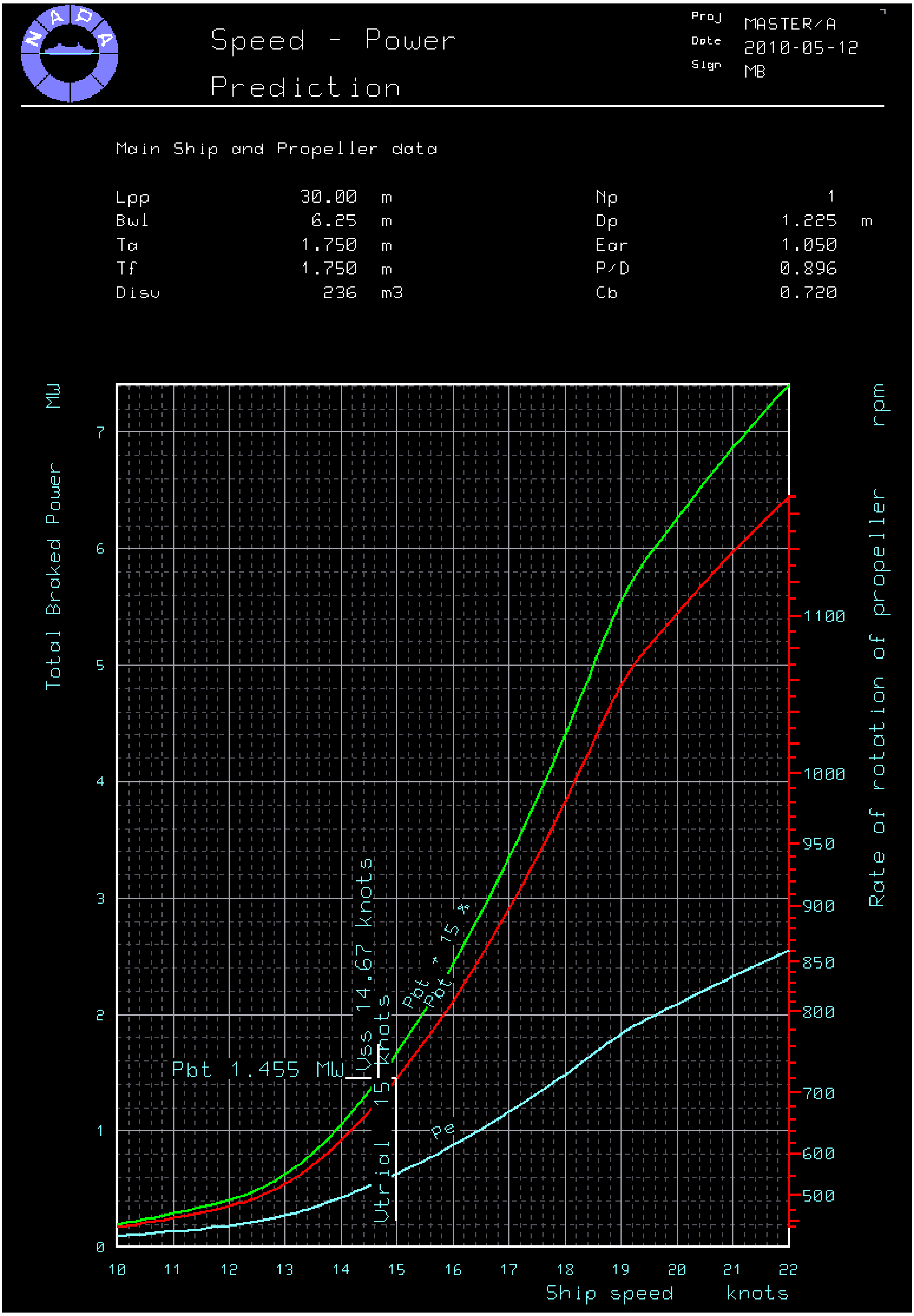
Floating position
Case: INI1/DAM3

Proj MASTER/A
Date 2010-05-11
Time 13:41
Sign MB

Stage: 2 Phase: EQ

Appendix 4

Resistance new hull



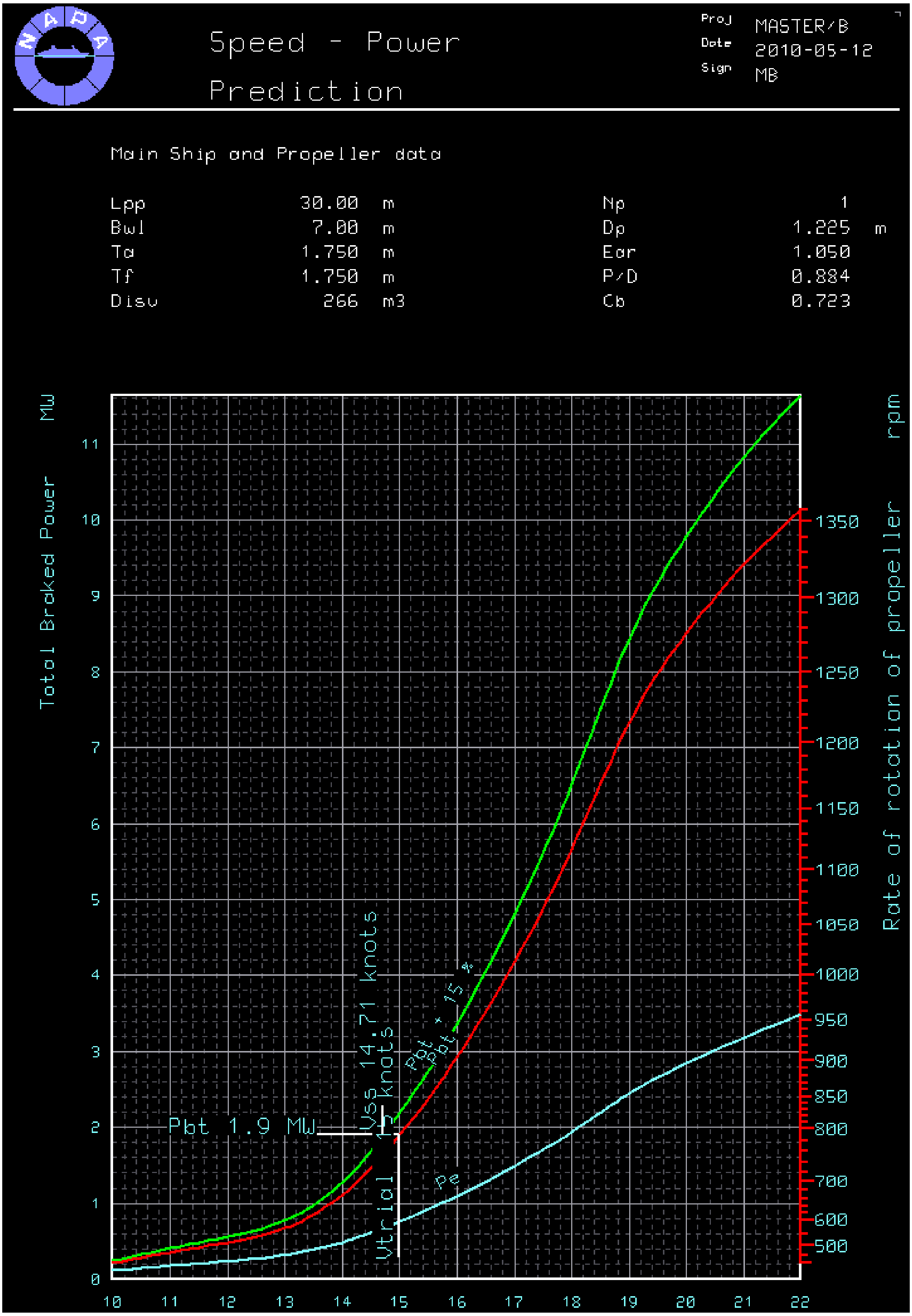
Speed - Power Prediction

Proj MASTER/A
Date 2010-05-12
Sign MB

Main Ship and Propeller data

Lpp	30.00	m	Np	1	
Bwl	6.25	m	Dp	1.225	m
Ta	1.750	m	Ear	1.050	
Tf	1.750	m	P/D	0.896	
Disv	236	m3	Cb	0.720	

Resistance conventional hull



Speed - Power

Prediction

Proj MASTER/B
Date 2010-05-12
Sign MB

Main Ship and Propeller data

Lpp	30.00	m	Np	1	
Bwl	7.00	m	Dp	1.225	m
Ta	1.750	m	Ear	1.050	
Tf	1.750	m	P/D	0.884	
Disv	266	m3	Cb	0.723	

Appendix 5

RULLE-/HIV-FORMEL

Den eksakte formelen for et fartøys egen-rulle-periode er:

$$T_R = 2\pi \sqrt{\frac{I_M + AM_R}{\Delta g GM_T}}\ [\mathrm{s}]\quad \text{(når alt settes inn i kg, m og s)}$$

Formelen forenkles:

$$T_R = 2\pi \cdot i \sqrt{\frac{1 + AM_R / I_M}{g \cdot GM_T}}\ [\mathrm{s}]$$

(Formel for stampe-perioden settes opp på tilsvarende vis med i_L, AM_S og GM_L).

Med $i \cdot \sqrt{1 + AM_R / I_M} \approx 0.44 \cdot B/2$ fås:

$$T_R \approx 0.44\ B / \sqrt{GM_T}$$

En ofte antatt verdi: $GM_T \approx \underline{0.05\ B}[\mathrm{m}]$

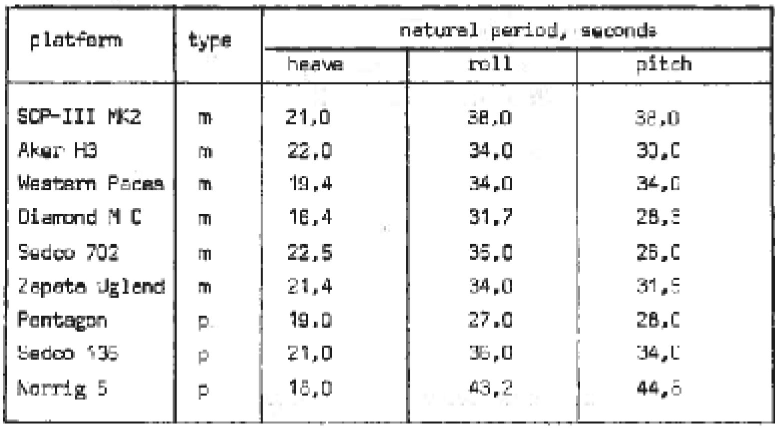
$$T_R \approx 2\sqrt{B}$$

På tilsvarende vis som over får vi for hivperioden:

$$T_H = 2\pi \sqrt{\frac{\nabla\rho + AM_H}{\rho g A_W}}\ [\mathrm{s}]$$

Formelen viser enkelt betydningen av lite vannlinjeareal, stort deplasement (dvs. ballast) og stor medsvingende vannmasse ⇒ semi submersibles.

Noen verdier for T_H , T_R og T_S (beregnet og/eller målt?) gitt på nstm-75:



platform	type	natural period, seconds		
		heave	roll	pitch
SCP-III MK2	m	21,0	38,0	38,0
Aker H3	m	22,0	34,0	30,0
Western Pacea	m	19,4	34,0	34,0
Diamond M C	m	16,4	31,7	28,9
Sedco 702	m	22,5	35,0	26,0
Zapata Ugland	m	21,4	34,0	31,5
Pentagon	p	19,0	27,0	28,0
Sedco 135	p	21,0	36,0	34,0
Norrig 5	p	16,0	43,2	44,6

RULLE-HIV-FORMEL bos 0409