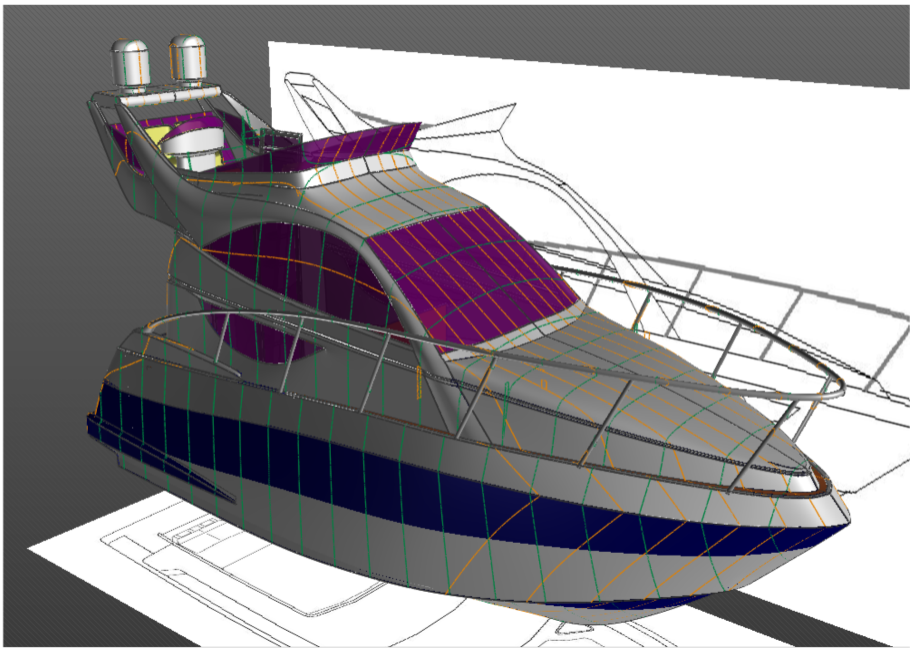
Instituto Superior Tecnico

NP - Small Craft Design

# 36-feet flybridge motor yacht

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June, 2022

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# 1 Introduction

In this project we are designing a motor boat, and showing all the steps we took to be able to design the boat. Our yacht is design for weekend trips and a relaxing experience. It will have the maximum capacity of 12 persons and can have four adults sleeping there. The autonomy is set for 8 hours of sailing at speed of 40 knots. So every aspect of this boat is designed with the purpose of a relaxing weekend trip. The objective is to carry out a preliminary design in reference of a boat that complies with international regulatory standards. In our case, the motor boat that was taken as a reference, more specifically a flybridge yacht with certain technical characteristics, which allowed us to develop a design that was in reference to an existing boat, with the aim of best performing the study following an existing physical reference. Following the aspects deriving from the nature of the type of boat, we can introduce by saying that this type of boat is suitable for planning long crossings, for transporting multiple people for recreational purposes, for achieving high performance through its planing hull type and its propulsion system, for the comfort of its passengers through the layout of its interior spaces, and finally for complying with the safety criteria imposed by international conventions.

## 1.1 Characterization of the vessel

As seen in the table below the characteristics of the vessel.

| | |
|---|---|
| Length overall | 11m |
| Breadth | 3.65m |
| Depth | 2.95m |
| Draught | 0,91m |
| Cb | 0,445 |
| Vs | 40 knots |
| Main Engine Power | 500kW |
| Autonomy | 8hours |
| Persons capacity | 12 persons |
| Sleeping capacity | 4 persons |
| Fresh water | 400 l |
| Light weight | 7011kg |
| Dead weight | 2010kg |
| Engine | Volvo Penta D6-340 Inboard engine |
| Propulsion | Hydrojets |
| Displacment | 12626 kg |
| Hull | Mono hull, Planning hull |
| Hull material | Composite of glass fiber and polyester |

## 1.2 Standards and Regulations

To make the ship as realistic as possible we have to follow the same regulations as the real ship manufacturing companies comply with. But since the ISO standards are quite hard to come by, we will use the regulation the professor introduced us to.[Prof Ventura 2022] Nordic Boat Standard from 1990 had most of the regulation that is still used to date and was free and open to everyone on the internet. So most of the regulation are taken from them. This supplemented with BV and DNV GL design regulations made it possible for us to see all the regulation needed in the design process. In addition, we can further consider conventions related to on-board safety, mainly prepared by SOLAS (safety of life at sea), an international body which consequently delegates, depending on the geometrical characteristics of the vessel in question, to secondary bodies, such as ISO standards, used to regulate the technical characteristics related to anchoring and mooring systems. In our case, we found it useful and effective to use the regulations prepared by the UK Small Craft Code relating to the mandatory safety equipment on board and the provision of safety functions. COLREG was also used to make the boat safe to sail. Convention on the International Regulations for Preventing Collisions at Sea give regulation for keeping the sea safe for collisions.

## 1.3 Similar ships

It is now very important to consider a study of this kind in the reference of existing yachts on the market, in order to better evaluate our choices on an objective and concrete basis. In our case, two yachts from the Cranchi manufacturer, the Z35 and T36, respectively, were taken as reference models, which best met the similarity with our design idea. The combination of the characteristics of these two yachts in terms of hull type, geometric features, layout with reference to the flybridge or open yacht concept and interior spaces. It allowed us to realise our design ideas and choice of materials, while respecting the regulations that bind them to the physical market. Thanks to this, we were able to break down physical, technical, technological and conventional limitations.

| Ship | Loa | B | T | Dead weigth | Sleep accomodation | People capacity | Fresh water [l] | Main engine kW | Fuel capacity [l] | Speed |
|---|---|---|---|---|---|---|---|---|---|---|
| Cranchi Z35 | 11,7 | 3,53 | 1 | 7250 | 5 | 12 | 190 | 398 | 600 | 35 |
| Cranchi T36 | 11,85 | 3,53 | 1 | 8500 | 4/6 | 12 | 190 | 398 | 600 | 29 |
| Windy W37 Shamal | 12,25 | 3,33 | 1,09 | 7500 | 4 | n/a | 200 | 648 | 650 | 46,7 |

Figure 1: Similar ships

# 2 Hull Form

This section will go into the methology of how we got our hull and its parameters. Using Delft Ship, Rhino, MaxSurf and the theory from class.

## 2.1 Hull form development

To first start the process we looked into similar ships that matched with our ideal ship. From that we saw that the hull form was a planing hull. So we decided to go for a planing hull as well as the similar ships.

With this in mind we went to Delft Ship to find an existing hull which we could use as a start for the hull form. This ship had a V-shape, hard chines and a dead rise at 50% of the length on waterline of about 22.3 degrees. These parameters all describe a planing hull, as well as the Froude number, which for our desired speed, it is greater than 1.2, typical Froude number of a planing hull. Nonetheless this model was for a ship that was a little too large for our purpose. So we needed to make some adjustments with the model to make it fit our needs. We changed the length, breadth, depth, and added some points to make the vessel slimmer then model we found.

This edited model was then exported to Rhino, where further adaptation was done, including the internal design and the general arrangement, with all machinery in the engine room, accommodation with beds, toilet, equipped kitchen and other necessary equipments for a proper functioning of the vessel and also to comply with regulations, especially Nordic Boat Standard (NBS). In Rhino we were also able to find information not presented on the design hydrostatics report generated by Delft Ship, like the precised deadrise angle. All the hull design information were needed as inputs for Maxsurf Resistance, the software used to find the hull resistance for the speed range from 10 to 40 knots, and with the estimated waterjet efficiency of 80%, we could find the necessary installed power in kilowatts.

## 2.2 Hydrostatic properties

A boat's weight, draught, trim, and freeboard all alter during its lifetime. The ship floats in varying densities of water. Its stability varies as well. If its condition is to be assessed under any given set of circumstances, its condition in a specific state must be understood so that the effect of changes from that state may be computed. The design condition is the precise condition. Changes in design and underwater form attributes are computed over a wide range of waterlines. This is known as hydrostatic data, and it is plotted versus draughts. Draughts are one metre apart. The displacement sheet is used to draw these curves. To produce hydrostatic curves, the following parameters are plotted against draught.

Volume of displacement

Displacement

Longitudinal centre of buoyancy from midship

Vertical centre of buoyancy above base line

Water plane area

Longitudinal centre of floatation from midship

Tonnes per centimeter immersion

Longitudinal moment of inertia about midship

Transverse moment of inertia about central line

Longitudinal moment of inertia about axis passing through LCF

Transverse meta-centric radius

Longitudinal meta-centric radius

Transverse meta-centre above base line

Longitudinal meta-centre above base line

Moment to change trim by 1 cm

Block coefficient

Midship section area coefficient

Water plane area coefficient

Longitudinal prismatic coefficient

Vertical prismatic coefficient

Wetted surface area of hull

| | |
|---|---|
| Draft Amidships m | 0.732 |
| Displacement t | 8.938 |
| Heel deg | -1.0 |
| Draft at FP m | 0.732 |
| Draft at AP m | 0.732 |
| Draft at LCF m | 0.754 |
| Trim (+ve by stern) m | 0.000 |
| WL Length m | 8.128 |
| Beam max extents on WL m | 3.474 |
| Wetted Area m^2 | 27.226 |
| Waterpl. Area m^2 | 23.618 |
| Prismatic coeff. (Cp) | 0.789 |
| Block coeff. (Cb) | 0.403 |
| Max Sect. area coeff. (Cm) | 0.520 |
| Waterpl. area coeff. (Cwp) | 0.836 |
| LCB from zero pt. (+ve fwd) m | 4.398 |
| LCF from zero pt. (+ve fwd) m | 4.355 |
| KB m | 0.510 |
| KG fluid m | 1.662 |
| BMt m | 2.189 |
| BML m | 12.434 |
| GMt corrected m | 1.037 |
| GML m | 11.282 |
| KMt m | 2.698 |
| KML m | 12.942 |
| Immersion (TPc) tonne/cm | 0.242 |
| MTc tonne.m | 0.000 |
| RM at 1deg = GMt.Disp.sin(1) tonne.m | 0.162 |
| Max deck inclination deg | 1.0221 |
| Trim angle (+ve by stern) deg | 0.0000 |

Figure 2: Hydrostatics for load case

# 3 Propulsion

## 3.1 Hull resistance and propulsive power estimate

The powering need for a boat is one of the most significant concerns for a naval architect. Once the hull form has been determined, the quantity of engine power required to satisfy the ship's operating needs must be determined. Knowing how much power is needed to move a ship allows the naval architect to choose a propulsion plant, calculate the quantity of fuel storage needed, and fine-tune the ship's centre of gravity calculation.

The propulsion system aboard a ship's goal is to transform fuel energy into useable push to drive the ship. The diagram below depicts a simplified view of a boat's propulsion train.

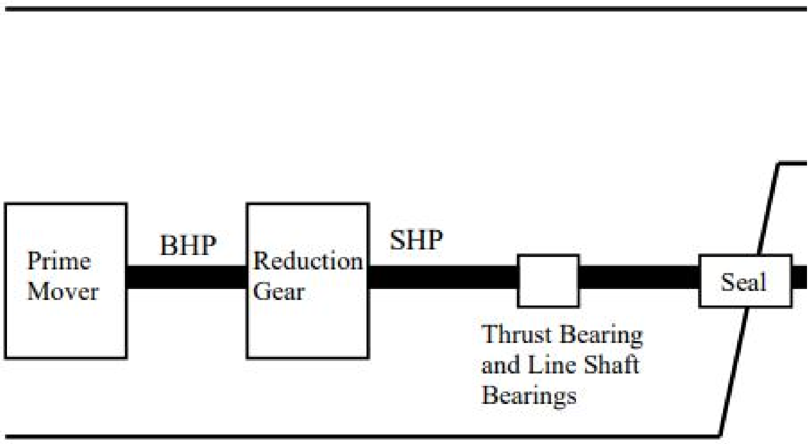


Figure 3: Boat Propulsion Line

The engine's power output is measured in BHP (Brake Horsepower). It is termed "brake" because engines are tested by applying a mechanical force to the shaft with a brake. The power of a rotating engine is the product of torque (ft-lb) and rotational speed (with suitable unit corrections). SHP - "Shaft Horsepower" is equal to Brake Horsepower less any mechanical losses in the reduction gear. The reduction gear decreases the engine's RPM (revolutions per minute) to an efficient propeller speed, such as dropping from a few thousand RPM for gas turbines to a few hundred RPM for a warship. Reduction gears are huge, heavy, and costly.

DHP - "Supplied Horsepower" is the power delivered to the propeller, which includes gearbox, bearing, and stern tube seal losses. Depending on the propulsion system, the supplied horsepower is generally 95-98 percent of the brake horsepower. The propeller is responsible for converting rotational power into useable thrust. THP - "Thrust Horsepower" is the power created by propeller thrust, which is equal to the product of advance speed and propeller thrust (with suitable unit conversions). This power includes gearbox, shafting, and propeller losses.

The power required to move the boat's hull at a given speed in the absence of propeller activity is referred to as "Effective Horsepower." It is calculated as the product of a ship's resistance and speed. This power is equal to the Brake Horsepower less losses due to the gearbox, shafting, and propeller, as well as propeller-hull contact.

In most cases, the Effective Horsepower is evaluated first, and then efficiency for each component of the drive train are assumed to estimate the needed Brake Horsepower to be fitted.

The graphic below depicts the energy losses in a typical marine propulsion system. The thermodynamic and mechanical losses in the engines are the most significant in the system, accounting for around 60 percent of the fuel energy lost before it becomes rotational power at the engine's output (Brake Horsepower). This massive loss is why engineers study thermodynamics and mechanical engineers seek for more fuel-efficient engines.

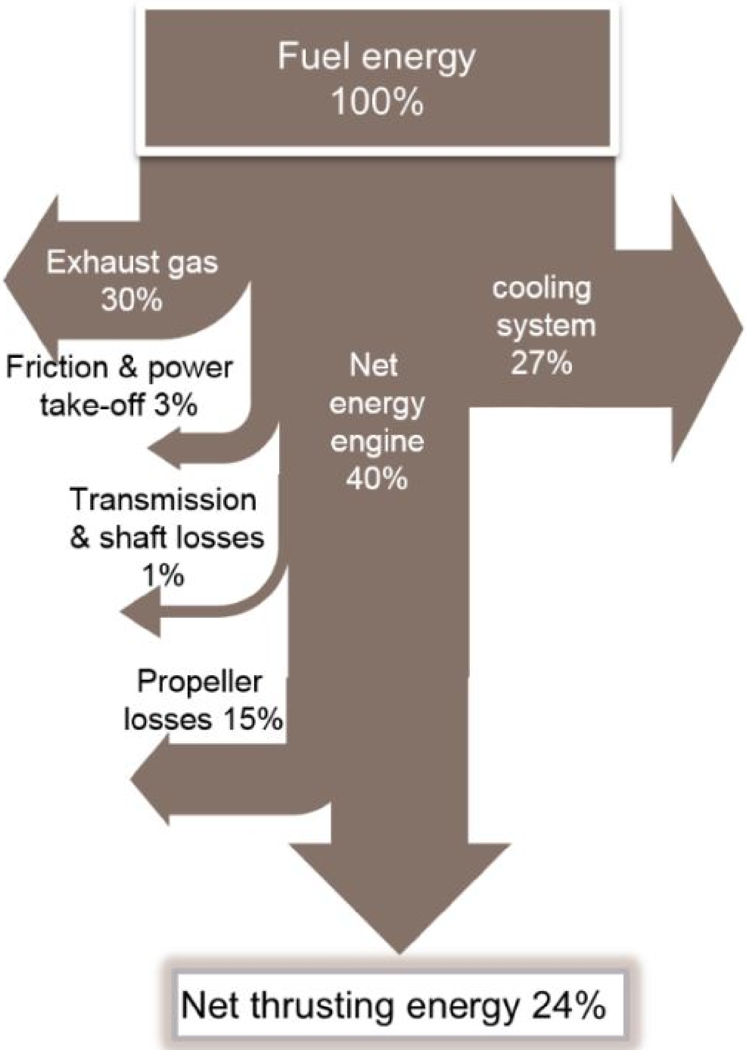


Figure 4: Losses in a Propulsion System

The losses in the gearbox, shafting, and propellers come next, resulting in just one-quarter of the initial fuel energy being converted to useable thrust energy to push the ship forward. The key areas under the supervision of the Naval Engineer are the hull shape to reduce the Effective Horsepower necessary to propel the ship and the propeller design to reduce propeller losses.

The Propulsive Efficiency is shown by a block diagram of a boat's drive system, beginning with the Brake Horsepower from the prime mover and finishing with the Effective Horsepower to drive the ship. In our case the sistem of propulsion is a waterjet and not a propeller, for this reason the efficiency it's going to be bigger.

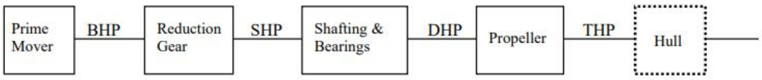


Figure 5: Block Diagram of Efficiency

The losses are mentioned below for each step of the drivetrain. Considering the following equations we can estimate that the range of efficiency working for a waterjet system it's around 0.85

$$\text{Gear Efficiency} \qquad \eta_{gear} = \frac{SHP}{BHP} \approx 0.95 - 0.99$$

$$\text{Shaft Efficiency} \qquad \eta_{shaft} = \frac{DHP}{SHP} \approx 0.97 - 0.99$$

$$\text{Propeller Efficiency} \qquad \eta_{propeller} = \frac{THP}{DHP} \approx 0.65 - 0.75$$

$$\text{Hull Efficiency} \qquad \eta_{hull} = \frac{EHP}{THP}$$

The efficiencies of the gear, shaft, and propeller are all mechanical or fluid losses. "Hull Efficiency" refers to the interaction between the hull and the propeller, which varies depending on the kind of ship. Instead than having to calculate the effect of each component's individual efficiencies, the efficiencies are sometimes merged into a single efficiency known as the propulsive efficiency ($\delta$P) or propulsive coefficient (PC)

$$\eta_P = PC = \frac{EHP}{SHP} = \eta_{gear}\eta_{shaft}\eta_{propeller}\eta_{hull}$$

The propulsive efficiency is the ratio of effective horsepower to shaft horsepower, allowing the designer to determine the amount of shaft horsepower necessary for the ship. Propulsive efficiency is commonly measured in the range of 55 percent to 75 percent.

"EHP" stands for "Effective Horsepower." Shaft horsepower and brake horsepower are acquired amounts from the engine manufacturer. Similarly, the quantity of thrust produced by a propeller is the result of analysis and computation. The naval architect must still decide how much power (BHP or SHP) is needed to push the ship across the water. The idea of Effective Horsepower is used to calculate the amount of power (EHP). The definition of effective horsepower is "the horsepower necessary to move the ship's hull at a given speed in the absence of propeller activity." Model data generated from towing tank research is frequently used to evaluate effective horsepower.

In these studies, a hull model is towed through water at a constant pace while the amount of force resisting the hull's movement is measured. The data from the model may then be scaled up to full-scale ship resistance. Knowing a ship's total hull resistance and speed through the water, the effective horsepower of the ship can be calculated using the following equation:

$$EHP = \frac{R_T V}{550 \frac{ft-lb}{\sec - HP}}$$

where: $EHP$ is the effective horsepower (HP)
$R_T$ is the total hull resistance (lb)
$V_S$ is the ship's speed (ft/sec)

The Total Hull Resistance (RT),as a boat travels over calm water, it encounters a force operating in the opposite direction of its motion. This force represents the water's resistance to the ship's motion, which is referred to as "total hull resistance" (RT). This resistance force is used to compute a ship's effective horsepower. The calm water resistance of a ship is determined by a variety of parameters, including ship speed, hull form (draught, beam, length, wetted surface area), and water temperature. The following figure depicts how total hull resistance grows with speed. It should be noted that the resistance curve is not linear, but rather steepens as speed rises. In following portions of this chapter, we shall look into why resistance grows so quickly at high speeds.

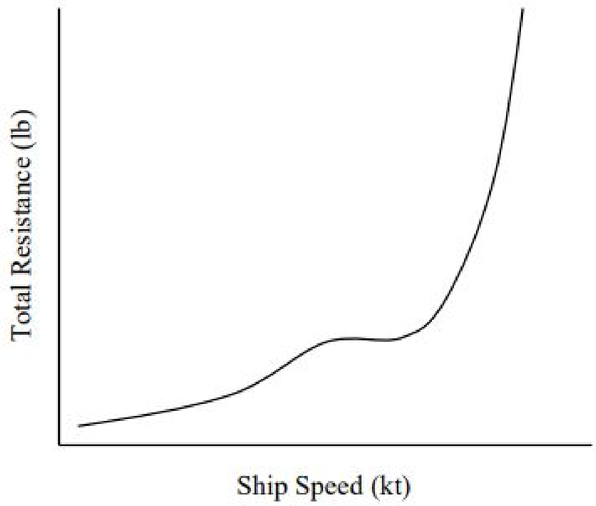


Figure 6: Example of Hull Resistance

The graph also depicts a "hump" in the total resistance curve. This hump is not an error, but rather a characteristic shared by virtually all ship resistance curves, as will be detailed later. As seen in earlier sections, the power required to drive a ship through the water is the product of total hull resistance and ship speed, therefore engine power grows faster than resistance. Ship power is often generally related to the cube of speed, therefore doubling (2x) a destroyer's speed from 15 knots to 30 knots will require 2 elevated of 3= 8 times as much power.

After all the consideration in the procdure we can now talk about the Total Hull Resistance Components, important elements that we will justy later thought our calculation. Many elements interact to generate the overall resistance force pressing on the hull when a ship passes through calm water. The friction and viscous effects of water acting on the hull, the energy required to produce and sustain the ship's distinctive bow and stern waves, and the resistance that air offers to ship motion are the primary variables impacting ship resistance. Total resistance may be expressed mathematically as RT = RV + RW + RAA. Where:

- RT denotes total hull resistance.
- RV stands for viscous (friction) resistance.
- RW = resistance to wave formation
- RAA is the amount of air resistance created by a ship travelling through calm air.

Other elements influencing overall hull resistance will be discussed as well. The graph depicts how the magnitude of each resistance component varies with ship speed. At low speeds, viscous resistance dominates, while at high speeds, the total resistance curve abruptly shifts higher as wave forming resistance takes over.USNA 2022

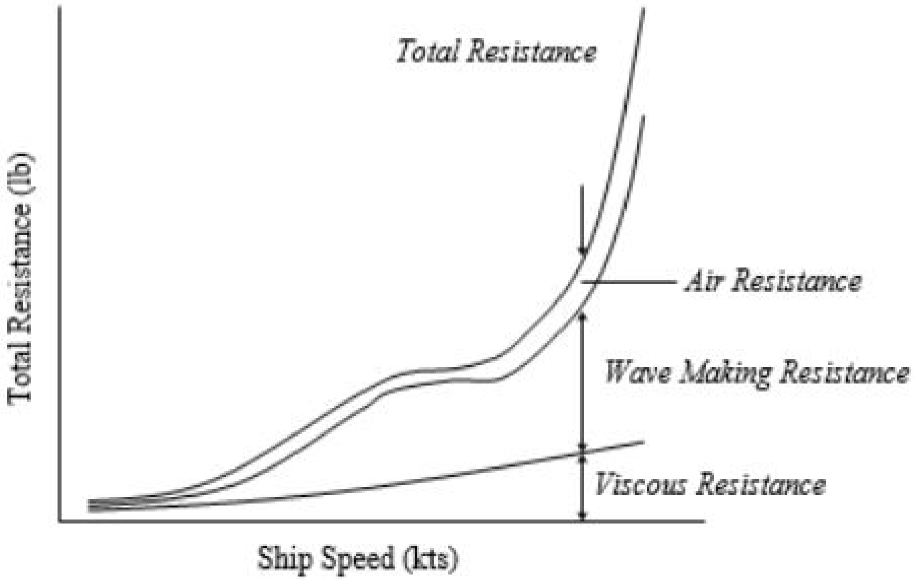


Figure 7: Resistance with all components

Applying all the concepts and evaluations made earlier, we can now deal more specifically with the choice we used in developing the study of hull strength and propulsion. Considering that our analysis was carried out using MAXSURF resistance commercial software, which automatically takes into account the principles and theories illustrated above, in order to optimise and increase the design process and study of resistance, with the aim of increasing the effectiveness of the choice inherent in the propulsion and engine system. Consequently, through the use of the software we were asked for some initial values of a geometric and impirical nature, obtained by processing the hull in the same software but inherent to the modelling part and through CAD drawing. Subsequently, one of the many methods available in the theory of planing hulls was selected to complete the strength analysis, in our case the Savitsky method, which was the most efficient and simple in reference to the type of vessel chosen.

The Savitsky method is commonly used to assess planing hull resistance. It is based on empirical prismatic equations and assumes that the part of the hull that comes into contact with the water when planing has a constant cross-section. When predicting resistance, the approach takes the running attitude of the hull into account by estimating the equilibrium trim angle through iteration. The entire hydrodynamic drag of a planing hull, according to Savitsky, may be expressed as:

$$D = \Delta tan(\tau) + \frac{\varphi U^2 C_f \Lambda B^2}{2cos(\beta)cos(\tau)}$$

Where $\Delta$ the displacement mass is,the trim angle is $\tau$, the hull speed is U, the beam is B, and the deadrise angle is $\beta$.

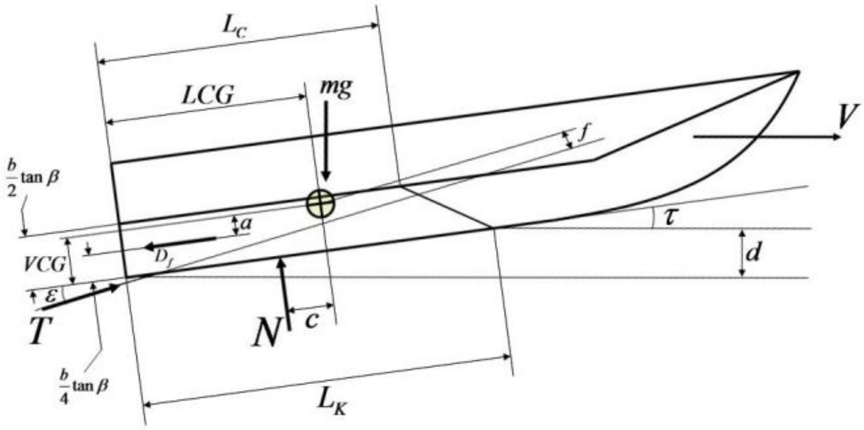


Figure 8: Example Planing Hull for Savitsky Method

Following the development of this method in the software, before starting the analysis relating to hull strength, we considered two transition phases of motion,pre-planing and planing, to enable us to subsequently compare the relationships of the curves in the merits of speed and power. According to the estimation and calculation made by the research of efficiency on board the boat, the reliable value is 80(DMS Marine Consultant 2019) Below we can find the initial implementation of the data used in the procedure for calculating the resistance of motion:

| Item | Value | Units | Savitsky Pre-planin g | Savitsky Planing |
|---|---|---|---|---|
| LWL | 8.336 | m | 8.336 | 8.336 |
| Beam | 3.651 | m | 3.651 | 3.651 |
| Draft | 0.91 | m | -- | -- |
| Displaced volume | 12.32 | m^3 | 12.32 | 12.32 |
| Wetted area | 31.79 | m^2 | 31.79 | -- |
| Prismatic coeff. (Cp) | 0.812 | | -- | -- |
| Waterpl. area coeff. (Cw | 0.838 | | -- | -- |
| 1/2 angle of entrance | 29.3 | deg. | 29.3 | -- |
| LCG from midships(+ve | -1.033 | m | -- | -1.033 |
| Transom area | 0 | m^2 | 0 | -- |
| Transom wl beam | 0 | m | -- | -- |
| Transom draft | 0 | m | -- | -- |
| Max sectional area | 1.82 | m^2 | 1.82 | -- |
| Bulb transverse area | 0 | m^2 | -- | -- |
| Bulb height from keel | 0 | m | -- | -- |
| Draft at FP | 0.91 | m | -- | -- |
| Deadrise at 50% LWL | 22.3 | deg. | -- | 22.3 |
| Hard chine or Round bil | Hard chine | | -- | -- |

Figure 9: Parameters of Resistance Computation

By iterating these parameters within the software operating with the defined method, it was possible to calculate the two fundamental curves for analysing the hull's resistance to motion. The two curves taken into analysis are respectively Resistance-Velocity and Power-Required-Velocity. In the following graphs, it is possible to observe the results obtained:

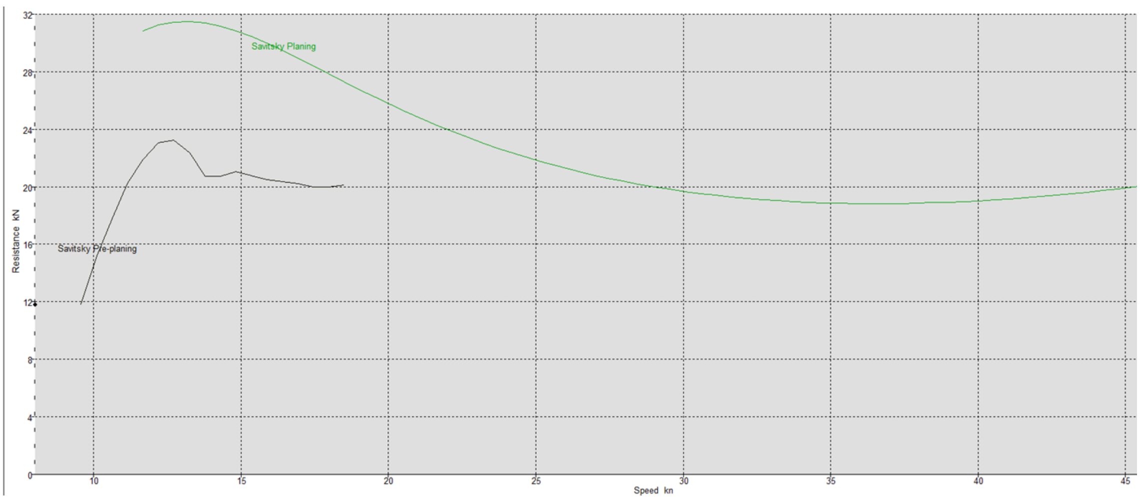


Figure 10: Results Resistance-Velocity

Beginning by analysing the results obtained for the Resistance-Speed curve, we can see that the two trends pre-planning and planning are different in behaviour. The former, as speed increases, shows a substantial increase in resistance, until reaching a peak where, due to causes and effects due to relative pressure drops, dimensionless coefficients such as Froude number, the displacement trend cannot continue to be disturbed in the same way by resistance, and a decrease in the latter follows as speed increases. Analysing the peak point of the displacement trend where the resistance is greatest, projecting the vertical through that point leads to the gliding trend, which, unlike the one before, exhibits decreasing behaviour as speed increases. This is because the submerged hull surface area and consequently the displacement decreases, bringing the boat to the planing course, resulting in a substantial increase in speed and thus in the high performance for which the boat is designed.

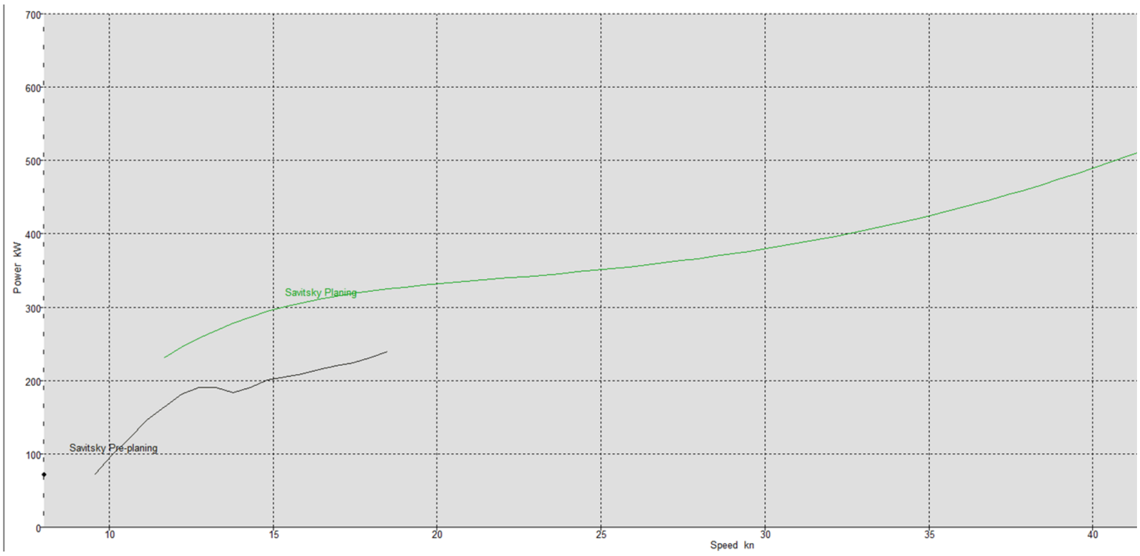


Figure 11: Results Power Required-Velocity

Moving on to the second graph in the comparison between different trends in pre-planing and planing in the reference between Required power and Speed, we obtain in this case curves that are more reflective for behavioural purposes. In the pre-planing curve, an increase in speed corresponds to an increase in power per displacement hull, until reaching a peak point at which mechanical and thermodynamic effects dampen the engine's performance, increasing energy losses as speed increases and consequently a decrease in required power. The situation regarding the planing regime is different in that as speed increases in a situation that is no longer a displacement hull, there is an increase in minimal power, which grows in a non-pronounced manner until it reaches a linear trend that will then resume its exponential trend once the speed has exceeded 30 knots. This is explained by the fact that in a planing hull the power required is not as incisive as in the case of a pre-planing hull, where the resistance to motion is greater and consequently the losses are greater. Less wetted surface precludes less power demand.

## 3.2 Water jet

A standard waterjet system consists of a flush-mounted input channel that directs water to the revolving pump impeller, a stationary guide vane package, an exit nozzle, and a steering/reversing mechanism. Waterjet propulsion works on the same basic principles as a screw propeller technology. Specifically, the propelling force is produced by adding momentum to the water by accelerating a specific flow of water in an astern direction.

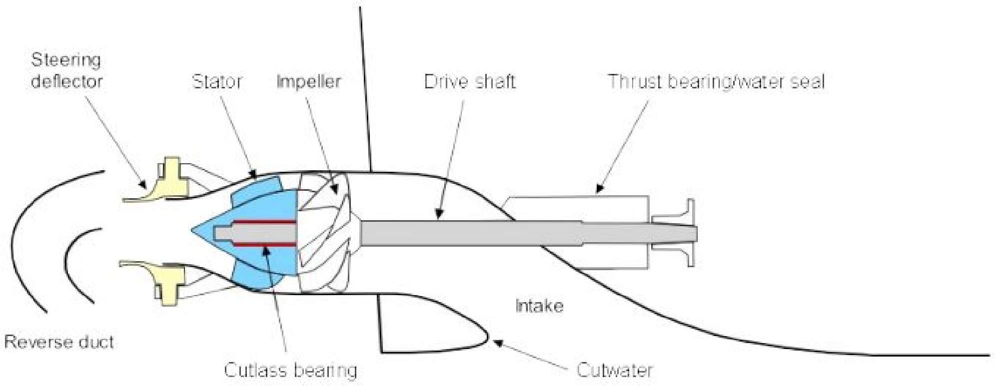


Figure 12: Hydro jets

Water from beneath the vessel is sent through an input duct to a precise inboard pump, which is often located near the transom and adds head to the water. When the water goes through an output nozzle into the ambient air pressure, this head is used to boost the velocity.

Waterjet propulsion provides several benefits over other types of maritime propulsion, including stern drives, outboard motors, shafted propellers, and surface drives. These benefits include:

-Excellent manoeuvrability, such as precise steering control at all boat speeds; "Zero Speed" steering effect provides 360° thrusting ability for docking and holding stationary; sideways movement is possible with multiple jet installations; and high efficiency astern thrust with "power-braking" ability at speed.

-High efficiency, such as propulsive coefficients that are as good as or higher than the best propeller systems achievable at medium to high planing speeds, flexibility when using multiple waterjets may allow operators to continue operating efficiently on fewer drives, low drag and shallow draught, and the absence of underwater appendages reduces hull resistance. In particular, the waterjet intake is flush with the hull bottom to facilitate access to shallow water locations and beach landings without risk of damage to the drive.

- Low Maintenance: No protruding propulsion gear means no impact damage or snags, as well as little downtime and simple maintenance routines.

-Smooth and quiet elements such as no hull vibration, torque effect, or high speed cavitation provide optimal comfort on board.

- A minimal underwater acoustic signature

- Total safety due to no propeller exposition for total safety near people in the water and marine creatures

- Maximum Engine Power because the design of the Jet unit impeller is carefully tuned to engine output, power absorption remains constant regardless of boat speed. There is no chance of engine overload under any circumstances.

- The single bundled module provides simplicity; no heavy and costly gearbox is required for multiple installations. Simple engine-to-jet coupling driveline

- Simple installation includes a complete factory tested package that was ready to bolt in with no tough engine alignment issues.

We choose to use water jets over traditional propellers as we found out it was more suited to our demands. The water jets are more efficient with speeds over 30 knots than propellers. Since our yacht will have a service speed of 40 knots it will benefit us. The water jets will give us more maneuverability and shallow water accessibility.

Our market catalogue selection is more targeted to the Hamilton waterjet since it has various benefits over other waterjet manufacturers. These are some examples:

- Excellent Cavitation Resistance Pump design provides up to 25 percent higher thrust than typical waterjets operating between 0 and 20 knots. Superior manoeuvrability at low speeds and acceleration to high speeds.

- Accurate Steering Control When steering, Hamilton Jet's unique JT steering nozzle reduces thrust loss. Because there is no centre deadband, course-keeping efficiency and overall boat speed are improved.

- Improved Performance Prediction Hamilton Jet's knowledge is backed up with reliable performance prediction software, which ensures that waterjets are a suitable propulsion choice for your vessel and recommends the best waterjet size and set up for each application.

The water jet we decided on using is the Hamilton HJ241[Hamilton 2022] with maximum power of 260 kW and maximum rpm between 3250-4000. We will attach two of these water jets on our yacht. As in this project we are not concerned with costs.

## 3.3 Engine

To supply our two water jets we have to inboard engines. Two Volvo Penta D6-340 engines with 250 kW and an rpm of 3400[Volvo 2022]. The reason why we went for an inboard engine is because of the following advantages.

- Good fuel efficiency
- Quite during operation
- Good longevity- usually beyond 6000 hours

There are some disadvantages regarding the inboard engines but they are mostly about the costs, as it more expensive to buy then a outboard engine, more expensive repairs. However it reduces interior space which is bad for a boat but we saw more advantages then disadvantages as cost was not looked at in this project.

## 3.4 Electricity

To determine the electricity usage we looked into the average current draw in amps for different appliances used in our ship. To find out how many hours per day the different appliances where used we took our personal life into account[LikaResort 2022]. All the three of us said how many hours per day we used things like the stove, tv and lights and then went for the average for that. Its hard to get a perfect estimation of power usage as its different for all kinds of people. But with our estimation, we added and error margin of 20%. To find the battery size we took a battery that could last for a whole weekend. Meaning we timed the need power per day with 3 days. Even though the battery would be charged every time the engine is running its good to have a lot electrical power ready as the boat often is used without the engine running.

| Applience | Average current draw amps | Avg usage time h/day | Average usage amps-hours/day |
|---|---|---|---|
| Fridge | 0,5 | 24 | 12 |
| Stove | 10 | 1 | 10 |
| Tv | 2 | 2 | 4 |
| Computer | 3 | 4 | 12 |
| Ligths 20 bulbs | 0,5 | 4 | 40 |
| Keetle | 6 | 0,2 | 1,2 |
| Fresh water pump | 6 | 0,3 | 1,8 |
| Instrument ligths | 0,25 | 12 | 3 |

| | |
|---|---|
| Needed amps-hours | 84 |
| Needed amps-hours with error margin of 20% | 100,8 |
| Needed kWh | 1,2096 |
| Needed battery capacity need 3 times daily usage | 302,4 |

Figure 13: Calculation of battery capacity

# 4 Lightweight

To calculate the Light weight of the boat we needed to look at the hull weight, superstructure, accommodation, equipment, engines and propulsion. We used the bottom up approach to find the light weight, meaning we used the 3d model and all the systems onboard to find the light weight and not using empirical formulae, as its very hard to find formulae that fit small motor boats.

To find the hull weight we used the 3D model for the boat. Using the model we were able to find the the surface area of the hull. With this surface area, we used NBS regulation for to find the required thickness of the hull. With the thickness we could find the density [kg/m2] of the composite material and therefore getting the hull weight.

| | | Area | t (mm) | kg/m2 | kg |
|---|---|---|---|---|---|
| Hull | keel | 36,38 | 22 | 37,627 | 1368,87 |
| | bottom | 15,46 | 15 | 25,48 | 393,93626 |
| | side | 14,35 | 15 | 25,48 | 365,65235 |
| | Total | | | | 2128,46 |

Figure 14: Hull weight

We used the Internet to look up different furnishes and equipment that we thought fit our boat. And took the weights from different specific products.

To account for error margins we added 5% of error to the total light weight. In the table below we how the light weight of the vessel. Here are all the links for the different kitchen furniture:[Fisherpanda 2022,Miele 2022b,Miele 2022a,Miele 2022c].

| Item | Weight [kg] | Lcg [m] | Tcg [m] | Vcg {m] | Ml [kg.m] | Mt [kg.m] | Mv [kh.m] |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| **Structures** | | | | | | | |
| Bottom | 1762.807 | 4.84 | 0 | 0.607 | 8531.99 | 0 | 1070.02 |
| Sides | 365.652 | 4.84 | 0 | 0.607 | 1769.76 | 0 | 221.951 |
| Decks | 529.82 | 3.719 | -0.027 | 1.12 | 1970.4 | -14.3051 | 593.398 |
| Superstructure | 1129.81 | 6.0384 | 0 | 3.817 | 6822.24 | 0 | 4312.48 |
| | | | | | | | |
| **Machinery** | | | | | | | |
| Engine 1 | 690 | 2.967 | 0.47 | 0.954 | 2047.23 | 324.3 | 658.26 |
| Engine 2 | 690 | 2.967 | -0.47 | 0.954 | 2047.23 | -324.3 | 658.26 |
| Water jet 1 | 130 | 0.96 | 0.387 | 0.646 | 124.8 | 50.31 | 83.98 |
| Water jet 2 | 130 | 0.96 | -0.387 | 0.646 | 124.8 | -50.31 | 83.98 |
| Generator | 90 | 3.444 | 0 | 0.324 | 309.96 | 0 | 29.16 |
| Inverter/Converter | 3.4 | 2.9 | 0 | 0.467 | 9.86 | 0 | 1.5878 |
| Batteries | 24.39 | 4.534 | -0.922 | 0.548 | 110.584 | -22.4876 | 13.3657 |
| Bilge system | 0.95 | 5.52 | 0 | 0.145 | 5.244 | 0 | 0.13775 |
| FW system | 1.6 | 5.804 | 0 | 0.45 | 9.2864 | 0 | 0.72 |
| FW tank | 39.07 | 6.729 | 0 | 0.52 | 262.902 | 0 | 20.3164 |
| Fuel tank | 39.43 | 4.047 | -0.329 | 0.841 | 159.573 | -12.9725 | 33.1606 |
| Sanitary discharge system | 39.07 | 4.91 | 0 | 0.52 | 191.834 | 0 | 20.3164 |
| | | | | | | | |
| **Equipment and outfitting** | | | | | | | |
| Furniture, appliances, etc (Kitchen) | 200 | 3 | 0.863 | 2.442 | 600 | 172.6 | 488.4 |
| Single bed 1 | 40 | 5.546 | -1.16 | 0.902 | 221.84 | -46.4 | 36.08 |
| Single bed 2 | 40 | 6.354 | 1.023 | 0.902 | 254.16 | -46.4 | 36.08 |
| Double bed | 70 | 7.954 | -0.279 | 1.051 | 556.78 | -19.53 | 73.57 |
| Table | 20 | 3.382 | -0.576 | 1.797 | 67.64 | | 35.94 |
| Galley equipment | | | | | 0 | 0 | 0 |
| Toilets | 10 | 4.53 | 0.981 | 1.229 | 45.3 | 9.81 | 12.29 |
| Anchoring equipment | 406.94 | 10.71 | 0 | 2.775 | 4358.33 | 0 | 1129.26 |
| | | | | | | | |
| Fire fighting equipment 1 | 54.9 | 1.95 | 0.845 | 0.956 | 107.055 | 46.3905 | 52.4844 |
| Fire fighting equipment 2 | 54.9 | 1.95 | -0.845 | 0.956 | 107.055 | -46.3905 | 52.4844 |
| Seat + Life jackets and safety equipment | 20 | 3.522 | -1.186 | 1.672 | 70.44 | -23.72 | 33.44 |
| | | | | | | | |
| Flybridge + Nav and com equipment | 100 | 3.424 | 0 | 5 | 342.4 | 0 | 500 |
| | | | | | | | |
| **Margin** | | | | | | | |
| Design margin (5%) | 329.13695 | | | | | | |
| | | | | | | | |
| Totals | 7011.87595 | | | | 31228.7 | -3.40519 | 10251.1 |
| | | | | | | | |
| **Lightweight** | 7011.87595 | 4.45369 | -0.000486 | 1.46196679 | | | |

Figure 15: Light weigth estimation

## 4.1 General arrangement

To find the general arrangement we have used pictures from the similar ship to find what is common to have onboard similar motorboats. To find the sizes of said furniture and equipment, we have looked at real products that's sold online. It is referenced in the excel sheet.

Here is a picture of one of the similar boats we used as inspiration for the internal layout of our boat.

Figure 16: Internal layout of similar boat

The ergonomics of this boat is set for a man a bit bigger then the average as its an luxury motorboat.

| | |
|---|---|
| Weigth | 90kg |
| Height | 190cm |
| Height of a person sitting upright | 97,2 |
| Height of a person sitting normal | 92,7 |
| Distance between elbows | 57 |
| Hips wide | 40 |
| Thight | 16 |
| Knee height | 57 |
| Calf height | 57 |
| Distance between calf and glutes | 52 |
| Distance between glutes and knee | 63 |

Table 1: Ergonomics

# 5 Systems

## 5.1 Fresh Water

The fresh water tank we have gone for is a 400 liter tank. From [sailing 2022] we found the daily usage of fresh water per person to be 150 l but that included laundry and the laundry takes so much water. So we found out that 100l per day should be plenty for one person. Since the vessel is capable to house four people for a trip we needed a tank of 400l. But this will only last for a day and not a weekend trip. that's why we have a fresh water production system. So we are able to supply the vessel with fresh water so the tank does not get empty.

The regulation from NBS says that:

- Fresh water tanks shall be readily accessible for cleaning
- Tanks shall have an inspection hatch with a diameter of at least 150mm
- Fresh water tanks shall be capable of being drained through a valve at the lowest point of the tank or through a suction line. The suction line shall end in a well in the bottom of the tank

## 5.2 Bilge system

Every boat need some kind of bilge system to be able to remove fluid from places it shouldn't be, especial in the engine room its important to maintain a dry environment. So a bilge system from Attwood - Heavy-Duty Bilge Pump 2000 / 12 V was installed. This system has a max flow rate of 126 l/min as its just over the criteria from NBS that states the minimum flow rate for a vessel of 11m should be 120 l/min.

## 5.3 Fuel system

To be able to substain our design speed with our design resistance we used the volva penta engines. From their catalogue we got their fuel usage of 70L/hour and with our goal of running the engines at design speed for 8 hours, we´ll need a 560 l fuel tank. From NBS we got the regulation regarding the fuel tanks. The fuel lines from tank to engine is made out of steel and has a valve on deck that can shut the flow of fuel at any time. The fuel tank is made of GRP (with polyester of grade 1), 5 mm thickness, internally coated with gelcoat or topcoat, as described in (NBS 2022).

## 5.4 Steering system

As previously described the maneuverability of the water jet is very good, but it can be maneuvered without a steering system. There i plenty of choice when choosing the system but we ended up with a hydraulic steering system system, As it is a highly reliable system. In a hydraulic steering system the wheel sends pressured oil down to the nozzel of the water jet and it can either turn it one way or the other. It will operate with an oil pressure of 5MPa.

The picture below shows how the steering wheel is connected to the water jet

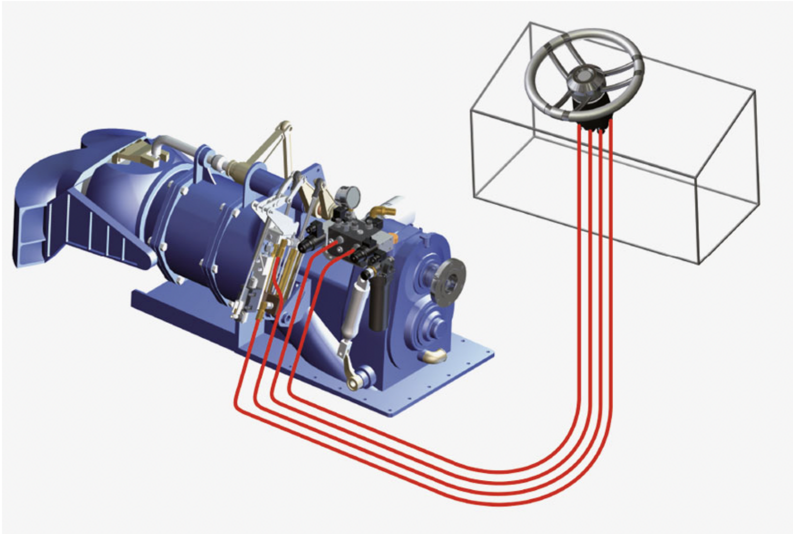

Figure 17: Steering system

The helm wheel hydraulic pump is directly connected to the water jet hydraulic steering actuator through hoses, but the oil feed is taken from the water jet integrated gearbox. It is possible to switch the oil feed from one water jet to another by means of a dedicated steering feed panel. An tie rod is required to mechanically synchronize the water jet steering nozzle.

%import./Sections/3Dmodel

# 6 Vessel Equipment

## 6.1 Anchoring and mooring equipment

Most marinas and ports provide three types of boat storage, ranging from ”dry dock” storage (where the boat is kept on land) to on-the-water storage at a dockside ”wet slip” or a mooring. The dry dock is normally the least expensive, followed by the mooring, and the slip is usually the most expensive. A slip is a designated area adjacent to a dock where people may easily access the boat on foot. A mooring is a semi-permanent anchoring system in the water that needs the use of a tender (or dinghy) to get to the boat from the pier. Moorings, as opposed to traditional anchors, which are stored onboard a boat and tossed overboard as needed, are secured to the ground and indicated by a floating buoy. Moorings, as opposed to traditional anchors, which are stowed onboard a boat and tossed overboard as needed, are anchored to the ground and indicated with a floating buoy to which the boat is subsequently tethered. It’s critical to understand the distinctions between mooring, anchoring, and docking, as well as when each is appropriate.

There are as many mooring possibilities as there are possible water and weather conditions. A little concrete block, for example, would be adequate for a short mooring in calm waters, but it would not withstand a storm. It is critical to understand the many alternatives for anchoring your boat in various scenarios. Fortunately, if you take the time to learn the distinctions, it’s not that difficult. While it is vital to spend hours understanding all of the many sorts of mooring scenarios and the names of the equipment involved, it all comes down to one thing: strength.

To be able to keep the boat secured when its engines is turned of we need an anchor. There is some regulation regulating what type of anchor, the weight, length of the chain and anchor points. ISO 15084 state ”crafts between 6 and 12 metres: at least 1 mooring point aft”. So our boat has a mooring point aft. From NBS we found that the weight of the anchor for a vessel with 11 metres is 5.9kg. The type of anchor we decided on is Guardian Anchors as they are made from the same high tensile, corrosion resistant aluminium magnesium alloy and manufacturing precision as Fortress.

The minimum chain cable length: 11.25 m (calculated with the formula $30\times\ln P - 42$). But to be a bit more flexible we decided that the chain length should be 25m so we can take anchorage at more places.

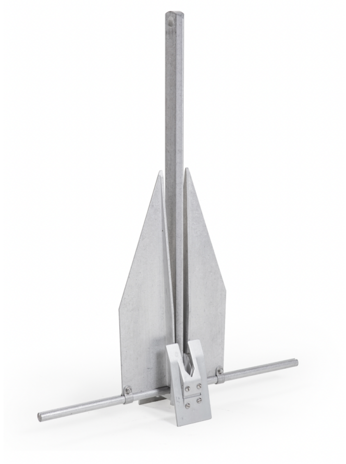

Figure 18: Guardian anchor

Next, it is important to analyse the instruments, compliant and suitable with regulations, useful for mooring a boat. The ISO15627 standard provides for the arrangement of relevant instruments essential to the safety of the boat in certain condition, subject to the weather conditions encountered and the geometric dimensions of the boat.

### 6.1.1 Shackles for Mooring

Mooring shackles are intended to firmly attach ropes and chains to other fittings while effectively and safely sustaining the weight of the cargo. Screw pin shackles (for non-permanent applications), safety bolt shackles (for long-term uses), and more derivatives and variants are available. They are available in a variety of materials, including untreated steel or iron and coated, finished, or galvanised steel surfaces.

### 6.1.2 Buoys for Mooring

A buoy is not required when anchoring your yacht, although it is a good idea for safety. This will absorb wind and wave action, bringing your chain to the surface and making it easier to discover. Choose a buoy that is the proper size for the boat and has the necessary protection characteristics. Buoys come in a variety of forms and sizes, and some are included in pre-packaged mooring packages.

### 6.1.3 Pennants for Moorings

There are mooring pennant laws almost anywhere boats are permitted. This "pennant" is actually a nylon rope connecting the buoy to the boat hitch. For applications requiring more endurance, they can be constructed from various materials. The most important aspect here is to select a line with a chafe-resistant coating to protect the mooring and the hull of the boat. Check that the pennant is just long enough to attach to the buoy. If it is overly long, it may cause damage to the outboard propulsion or a less secure position in the water during bad weather.

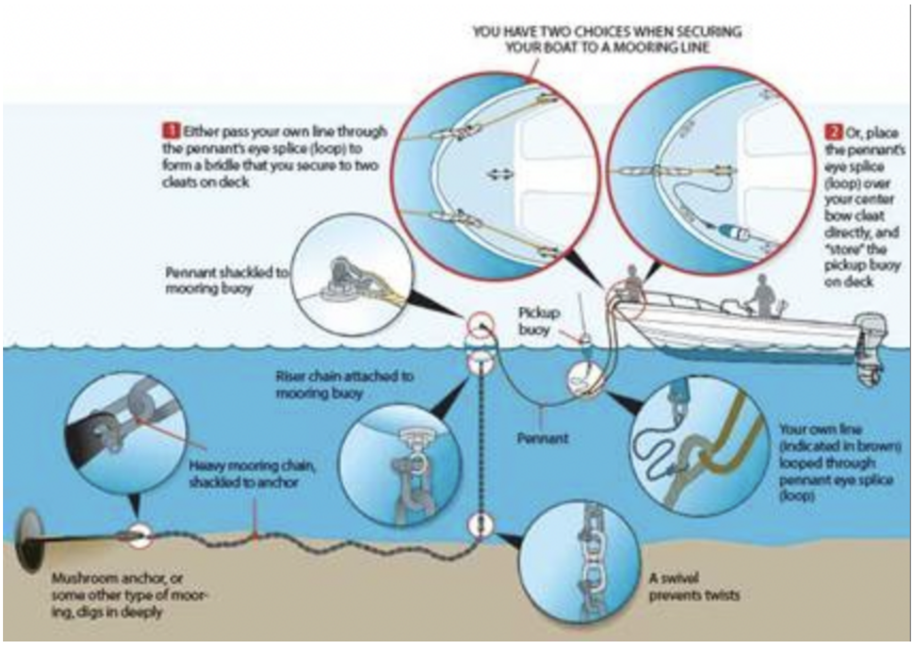


Figure 19: Mooring Equipments

## 6.2 Safety equipment

The UK Small Craft Codes connected to Harmonised Code (MGN 280 (M)) states that various safety equipment must be carried on board depending on the size of the boat. It may also be determined by where the boat will be utilised. Small Craft Codes in the United Kingdom differentiate between distance from the shore and four interior waterway categories: A - small rivers and canals with water depths of less than 1.5 metres B - larger rivers and canals with a depth of 1.5 metres or more and a substantial wave height of less than 0.6 metres at all times. C - tidal rivers, estuaries, and big, deep lakes and lochs where the significant wave height does not exceed 1.2 metres at any time. D - tidal rivers and estuaries where the major wave height never exceeds 2 metres.

Lifejackets, liferafts, flares, and fire extinguishers are all required for boats 13.7 metres or longer (Class XII). A leisure yacht under 13.7 metres in length is not obliged by law to have firefighting or lifesaving equipment (though it is still a good idea to do so). If there are employees on board, however, the owner is liable for their safety.

One of the most important aspects of boating safety is having the proper equipment on board and having it maintained on a regular basis. For this reason the safety equipment on board must be the follow:

### 6.2.1 Extinguishers and blankets

It is important to hire a surveyor to determine if the boat satisfies fire fighting criteria. Fires on board can be exceedingly dangerous, especially on vessels with fuel tanks and gas bottles. To be useful, each fire extinguisher must be large enough to handle the space in which it is to be used and must be maintained annually at a professional centre. It is also a good idea to carry fire blankets on board so that you have a variety of alternatives available. These should also be inspected annually for any holes or rips. When it comes to safety equipment, cutting shortcuts may be dangerous, so be sure you service everything.

The following are the fire safety criteria for UK boats based on boat length and weight: -2 multifunctional extinguishers (fire rating 13A/113B) for boats of 13.7 metres or less -2 firefighting buckets made of metal, plastic, or canvas with lanyards -1 fire blancket at every galley or cooking area where the risk is higher - 1 hand or power powered fire pump - Fire extinguishing methods must be adequate for the capacity of the engine compartment on boats equipped with inboard engines.

All life-saving equipment on sea-going ships must be retro-reflective in order to offer enhanced visibility during bad weather or at night.

### 6.2.2 Lifejackets

Lifejackets are compulsory on all boats except those which are intended for use in category A and B waters. Despite this, it's always a good idea to carry life jackets for everyone on board-particularly if some members on board are unable to swim. You should make sure the life jackets cater to all sizes and ages. It is strongly recommended that everyone on board wears a life jacket at all times.

In case someone falls overboard, the life jackets should be equipped with a floatation device such as a lifebuoy, a regular buoy or an inflatable lilo. It also should be fitted with a light, whistle, crotch straps to stop the life jacket riding up over your head and, if possible, a spray hood. Life jackets should also be regularly maintained and serviced to make sure they work properly.

### 6.2.3 Lifebuoy

In addition to life jackets, have several lifebuoys about the boat since they are easy to toss out if someone falls overboard. The number of lifebuoys on boats under 16.8 metres in length belonging to classes VIII(1), VIII(A)(T), IX, IX(A), IX(A)(T), XI and XII shall be equal to the number of people on board, with a minimum of two on board at any given moment. There must be self-igniting lights, 18-metre buoyant lifelines, and self-activating smoke signals among the lifebuoys on board. The lifebuoys should be placed on either side of the vessel and be capable of being quickly released from the navigating bridge.

### 6.2.4 Kill Cord

A kill cord should be worn by the driver at all times, in addition to a life jacket. The majority of death cords are coiled lanyards that may be worn around the thigh and will terminate the engine if the driver is flung off the helm. Nowadays, wireless kill cords are available, allowing the driver additional mobility. However, before purchasing, always ensure that it is compatible with the engine. When a person falls overboard, a wireless kill cord will stop the engine using wearable transmitters.

### 6.2.5 Kit for First Aid

A first-aid kit is usually a smart idea, especially when the nearest shop is across a large body of water. While it may not be as important as a kill switch or other items on the list, it might be incredibly beneficial if a passenger becomes unwell on board. Pain relievers, motion sickness medication, a thermometer, tweezers, scissors, alcohol, iodine tincture, gauze and bandages, plasters, sunscreen, after-sun lotion, and compresses should all be included in a basic first aid kit. If anyone on board requires special medication, make sure to note it.

### 6.2.6 Liferafts and oars

Considering a smaller vessel, might be considered carrying oars or paddles on board in case of engine failure. On a boat that's 13.7 metres or longer, you must carry a liferaft. It's important to have enough life rafts to safely accommodate everyone on board. In case someone falls overboard, it is also wise to have line throwing apparatus handy or an oar or paddle to use this to help guide the person back to the boat.

The UK regulations have started phasing out ORC liferafts since January 1, 2019. No new ORC liferafts may be installed on Class XII boats after this date, and they will be altogether prohibited by 2024. Instead, a SOLAS/MED liferaft or one designed to the ISO 9650-1- Small Craft Inflatable Liferafts Part 1 Type 1 Group A standard is required.

In terms of Liferaft Requirements, there are varied requirements based on the vessel and how far away from the shore you intend to travel: A SOLAS 'A' PACK is required if you are more than 150 miles from the shore. An ISO (¿24 hour) PACK, a SOLAS 'B' PACK, or a SOLAS 'A' PACK is required between 20 and 150 miles from the shore. A separate issue for Liferaft Storage, because every liferaft must be carried either: Stowed in certified FRP containers on the weather deck or in an open area. They should also have float free arrangements so that they may float freely and automatically inflate. Liferafts should be housed in FRP containers or in a valise in a conveniently accessible and dedicated weathertight locker opening directly to the weather deck on ships between 10.7 and 24 metres in length. Every inflatable liferaft on Class XII ships should be maintained at the manufacturer's suggested intervals by an authorised agent. If the liferaft is stored in a valise, it should be maintained at least once a year.

### 6.2.7 VHF radio on the go

In the case of an electrical breakdown or the need to escape ship, a portable VHF radio might save a lot the condition of hardship. With this in mind, purchasing a waterproof radio with GPS and digital selective calling is also a smart option (DSC). A DSC capability allows you to send an automatically prepared distress signal to the Coastguard and can repeat the warning if there is no response. The Icom IC-M94DE maritime VHF radio is one of the most recent handhelds on the market. It not only has DSC and GPS, but it is also the world's first maritime VHF hand portable radio with an integrated AIS receiver.

### 6.2.8 Equipment for Dredging

If the vessel lacks a bilge pump, having buckets on board is essential; even if the pump works well, having buckets on board is a good idea. Buckets are inexpensive and simple to use.

### 6.2.9 Appliances that throw lines

On vessels that go more than 150 miles from the shore, line-throwing equipment are necessary. A line-throwing machine can fling lines across large distances in order to reach somebody who has fallen overboard.

### 6.2.10 Ladder

Depending on the size of the boat, it may be required to construct a ladder to provide access from the side deck to the waterline. This is not necessary if the boat is made with a design that allows for simple access to the water, such as a RIB.

### 6.2.11 Navigation Lights on Motor Boats

Navigation lights ensure the safety of everyone at sea. The Convention on the International Regulations for Preventing Collisions at Sea (IMO COLREG 72) precisely sets out the guidelines for navigation lights, i.e., displaying lights, their range (distance from which the light is visible), as well as how they should be constructed and assembled.Svb24 2022

According to COLREGs part C, rule 20), navigation lights must always be used on board from sunset to sunrise or during the day if visibility is poor.Astrolabesailing 2022

EU approval can be identified via the wheel mark symbol and the notified body number. BSH approved navigation lights (previously DHI) are marked with a model number (e.g., BSH/00/01/90).

Despite the BSH's revisions, older lights with DHI clearance that have already been placed retain their approval.

Other nations, such as RINA (Registro Italiano Navale), MCA (Maritime and Coastguard Agency), and the USCG, have approved certain lights in addition to the wheel mark sign and German BSH certification (United States Coast Guard). These are now recognised, as long as the permission comes from a recognised national approval authority in the country of origin.

The International Maritime Organization (IMO) defines navigation lights in detail in sections C and D of the Definitions based on the 1972 International Regulations for the Prevention of Collisions at Sea (COL REG 72)

### 6.2.12 Side lights for starboard and port

A green light on the starboard side and a red light on the port side, which shine from dead ahead in an arc of 112.5° aft to a point 22.5° abaft the beam (behind the beam) on either side of the vessel.

On ships of less than 20 metres in length, the two individual sidelights may be replaced by a dual-colour combined light. This must be centrally located on the bow and stern axis.

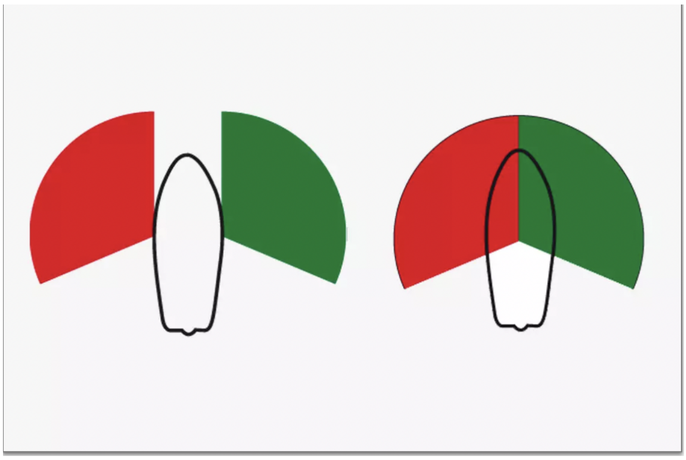

Figure 20: Side lights

### 6.2.13 Stern light

A white light mounted as close to the stern as possible and shines dead ahead in an arc of 135° (67.5° to each side). The mounting height should be aligned to the height of the side lights and should never be higher.

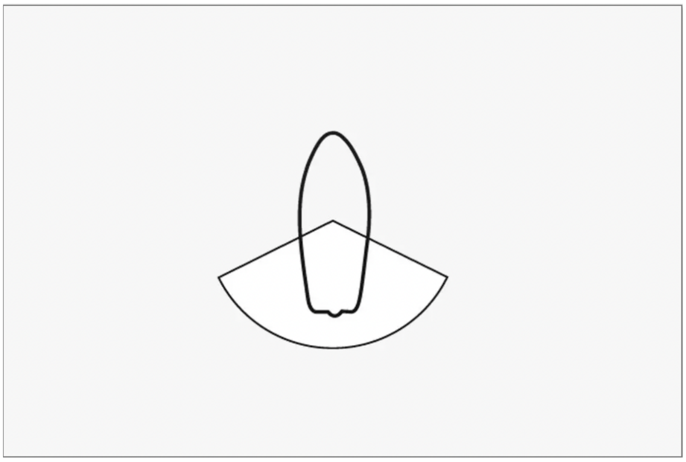

Figure 21: Stern light

#### 6.2.14 Mast-head light

A white light placed over the centre line of the vessel and shines dead ahead in an arc of 225° (from straight ahead up to 22.5° more aft than crosswise to each side). The mounting height should be at least 1 m higher than the side lights. In the past, the mast-head light was also referred to as a steam boat light or steamer light, as it is only seen on ships that operate under engine power.

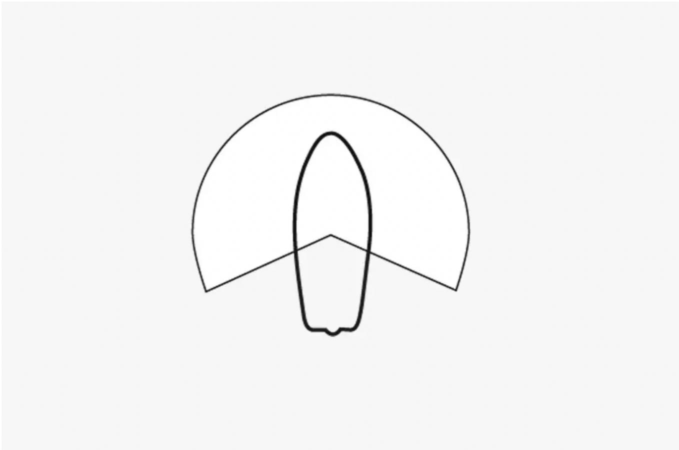

Figure 22: Masthead Light

#### 6.2.15 Signal light or all-round light

A light that shines in a complete circle of 360°. It may emit white, red or green light, depending on use. Examples of use: All sailboats and motorboats at anchor must exhibit a white anchor light. Ships over 12m in length must, if necessary, display vessel-in-distress lights (two red signal lights) placed at a vertical distance of at least 12 m. The distance between such lights must not exceed 1 m.

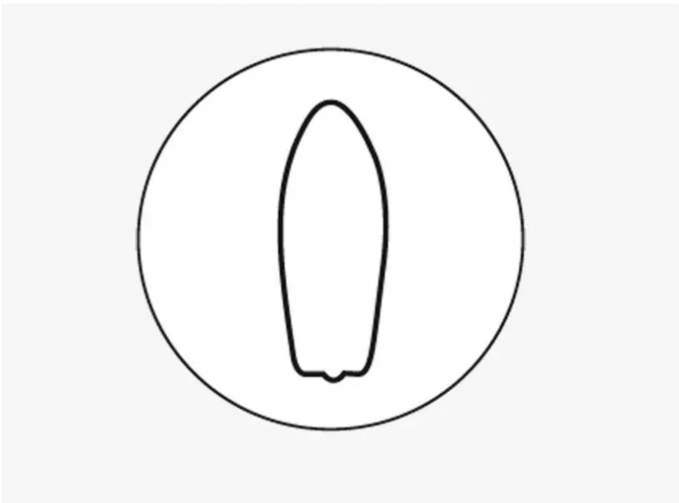

Figure 23: Signal light 360degree

Ships up to 12m in overall length Range in nautical miles (NM) Mast-head light 2 NM Side light (starboard /port) 1 NM Stern light 2 NM Three-colour light (sail boat when at sail) 2 NM All-round light (white, red, green all-round light) 2 NM

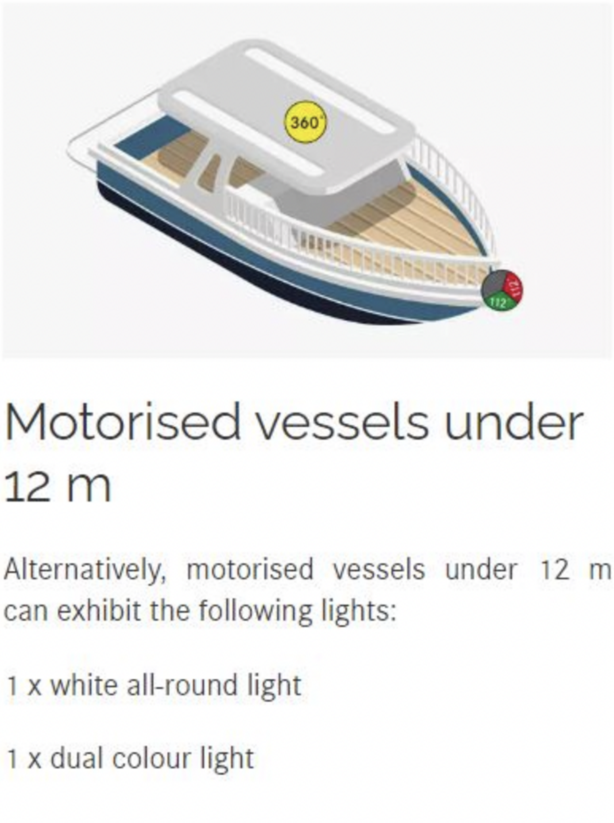


Figure 24: COLREG navigation light example

# 7 Stability

After doing the general arrangement, defining the weight and position of every structural part, system and equipment, we used Maxsurf Stability to compute hydrostatics, equilibrium, and check how stable the boat is in different conditions, like large angles. First, we did a table with all the parts that make up the lightweight: hull structure, nondetachable systems and equipments and accommodation furniture.

| Item | Weight [kg] | Lcg [m] | Tcg [m] | Vcg [m] | Ml [kg.m] | Mt [kg.m] | Mv [kh.m] |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| **Structures** | | | | | | | |
| Bottom | 1762.807 | 4.84 | 0 | 0.607 | 8531.99 | 0 | 1070.02 |
| Sides | 365.652 | 4.84 | 0 | 0.607 | 1769.76 | 0 | 221.951 |
| Decks | 529.82 | 3.719 | -0.027 | 1.12 | 1970.4 | -14.3051 | 593.398 |
| Superstructure | 1129.81 | 6.0384 | 0 | 3.817 | 6822.24 | 0 | 4312.48 |
| | | | | | | | |
| **Machinery** | | | | | | | |
| Engine 1 | 690 | 2.967 | 0.47 | 0.954 | 2047.23 | 324.3 | 658.26 |
| Engine 2 | 690 | 2.967 | -0.47 | 0.954 | 2047.23 | -324.3 | 658.26 |
| Water jet 1 | 130 | 0.96 | 0.387 | 0.646 | 124.8 | 50.31 | 83.98 |
| Water jet 2 | 130 | 0.96 | -0.387 | 0.646 | 124.8 | -50.31 | 83.98 |
| Generator | 90 | 3.444 | 0 | 0.324 | 309.96 | 0 | 29.16 |
| Inverter/Converter | 3.4 | 2.9 | 0 | 0.467 | 9.86 | 0 | 1.5878 |
| Batteries | 24.39 | 4.534 | -0.922 | 0.548 | 110.584 | -22.4876 | 13.3657 |
| Bilge system | 0.95 | 5.52 | 0 | 0.145 | 5.244 | 0 | 0.13775 |
| FW system | 1.6 | 5.804 | 0 | 0.45 | 9.2864 | 0 | 0.72 |
| FW tank | 39.07 | 6.729 | 0 | 0.52 | 262.902 | 0 | 20.3164 |
| Fuel tank | 39.43 | 4.047 | -0.329 | 0.841 | 159.573 | -12.9725 | 33.1606 |
| Sanitary discharge system | 39.07 | 4.91 | 0 | 0.52 | 191.834 | 0 | 20.3164 |
| | | | | | | | |
| **Equipment and outfitting** | | | | | | | |
| Furniture, appliances, etc (Kitchen) | 200 | 3 | 0.863 | 2.442 | 600 | 172.6 | 488.4 |
| Single bed 1 | 40 | 5.546 | -1.16 | 0.902 | 221.84 | -46.4 | 36.08 |
| Single bed 2 | 40 | 6.354 | 1.023 | 0.902 | 254.16 | -46.4 | 36.08 |
| Double bed | 70 | 7.954 | -0.279 | 1.051 | 556.78 | -19.53 | 73.57 |
| Table | 20 | 3.382 | -0.576 | 1.797 | 67.64 | | 35.94 |
| Galley equipment | | | | | 0 | 0 | 0 |
| Toilets | 10 | 4.53 | 0.981 | 1.229 | 45.3 | 9.81 | 12.29 |
| Anchoring equipment | 406.94 | 10.71 | 0 | 2.775 | 4358.33 | 0 | 1129.26 |
| | | | | | | | |
| Fire fighting equipment 1 | 54.9 | 1.95 | 0.845 | 0.956 | 107.055 | 46.3905 | 52.4844 |
| Fire fighting equipment 2 | 54.9 | 1.95 | -0.845 | 0.956 | 107.055 | -46.3905 | 52.4844 |
| Seat + Life jackets and safety equipment | 20 | 3.522 | -1.186 | 1.672 | 70.44 | -23.72 | 33.44 |
| | | | | | | | |
| Flybridge + Nav and com equipment | 100 | 3.424 | 0 | 5 | 342.4 | 0 | 500 |
| | | | | | | | |
| **Margin** | | | | | | | |
| Design margin (5%) | 329.13695 | | | | | | |
| | | | | | | | |
| Totals | 7011.87595 | | | | 31228.7 | -3.40519 | 10251.1 |
| | | | | | | | |
| **Lightweight** | 7011.87595 | 4.45369 | -0.000486 | 1.46196679 | | | |

Figure 25: Stability booklet

Having the total lightweight with a 5% margin, and also the longitudinal centre of gravity (LCG), the vertical centre of gravity (VCG) and the transverse centre of gravity (TCG), the first stability check is the hydrostatics table for that lightweight distribution, here called "Specific conditions"

| | |
|---|---|
| Draft Amidships m | 0.642 |
| Displacement t | 7.012 |
| Heel deg | 0.0 |
| Draft at FP m | 0.642 |
| Draft at AP m | 0.642 |
| Draft at LCF m | 0.672 |
| Trim (+ve by stern) m | 0.000 |
| WL Length m | 7.999 |
| Beam max extents on WL m | 3.085 |
| Wetted Area m^2 | 23.659 |
| Waterpl. Area m^2 | 20.648 |
| Prismatic coeff. (Cp) | 0.786 |
| Block coeff. (Cb) | 0.403 |
| Max Sect. area coeff. (Cm) | 0.526 |
| Waterpl. area coeff. (Cwp) | 0.837 |
| LCB from zero pt. (+ve fwd) m | 4.461 |
| LCF from zero pt. (+ve fwd) m | 4.398 |
| KB m | 0.454 |
| KG m | 1.462 |
| BMt m | 1.926 |
| BML m | 13.341 |
| GMt m | 0.919 |
| GML m | 12.333 |
| KMt m | 2.381 |
| KML m | 13.795 |
| Immersion (TPc) tonne/cm | 0.212 |
| MTc tonne.m | 0.000 |
| RM at 1deg = GMt.Disp.sin(1) tonne.m | 0.112 |
| Max deck inclination deg | 0.3896 |
| Trim angle (+ve by stern) deg | 0.0000 |

Figure 26: Specific conditions

We can see that the weight is well distributed as the heel and trim are zero, that is, the LCG and TCG coincide or are very close (with no significant difference) to Longitudinal Centre of Buoyancy (LCB) and Transverse Centre of Buoyancy (TCB). The draught is much less than the design draught, as well as other details like the length of waterline for this draught, as this is just the lightweight. Maxsurf stability also computes the freeboard for the weight condition, as it can be seen on the table below.

| Key point | Type | Freeboard m |
|---|---|---|
| Margin Line (freeboard pos = 0.001 m) | | 0.327 |
| Deck Edge (freeboard pos = 0.001 m) | | 0.403 |

Figure 27: Key point table

Next we checked the stability for a real loadcase, that is, including the deadweight (fuel, fresh water, people and personal belongings). Maxsurf Stability asks for the weight and position of each part for computing the new hydrostatics. For this loadcase, it was considered a full fresh water tank and an empty sewage tank, simulating the initial condition of the boat just starting a trip. For people and some belongings, we have to keep in mind that they move all the time. For this analysis, it was considered an average position for people in the middle of the upper deck, and for their belongings, distributed between the main and the lower deck.

| Item Name | Quantity | Unit Mass tonne | Total Mass tonne | Long. Arm m | Trans. Arm m | Vert. Arm m | Total FSM tonne.m |
|---|---|---|---|---|---|---|---|
| Lightship | 1 | 7.012 | 7.012 | 4.459 | 0.001 | 1.466 | 0.000 |
| Fuel tank | 1 | 0.476 | 0.476 | 4.047 | -0.329 | 0.841 | 0.000 |
| Fresh Water | 1 | 0.400 | 0.400 | 6.729 | 0.000 | 0.520 | 0.000 |
| Sewage | 0 | 0.400 | 0.000 | 4.910 | 0.000 | 0.520 | 0.000 |
| People | 10 | 0.075 | 0.750 | 2.770 | 0.000 | 4.858 | 0.000 |
| Personal belongings | 5 | 0.030 | 0.150 | 6.015 | 0.000 | 0.702 | 0.000 |
| Personal | 5 | 0.030 | 0.150 | 2.623 | 0.000 | 1.440 | 0.000 |
| Total Loadcase | | | 8.938 | 4.392 | -0.017 | 1.662 | 0.000 |
| FS correction | | | | | | 0.000 | |
| VCG fluid | | | | | | 1.662 | |

Figure 28: load case 1

As we can see on the next table, the draught changed, as the total displacement increased, being closer to the design draught, however still smaller, meaning there is margin to carry more weight, and also that the design draught was a little overestimated. This can be also seen on the table after, as if we increased the draught to the design one, the freeboard would be too small. The boat is still stable and balanced in the longitudinal direction, as the trim remains zero. In the transverse direction, now there is a 1 degree heel caused by the deadweight, especially the fuel, as the tank is not exactly centred. Some equipments part of the lightweight are positioned on the opposite board to balance. Nonetheless, the fuel weight is more significant, at least with the tank 100% full. The diesel density was considered as 850 kg/m3.

| | |
|---|---|
| Draft Amidships m | 0.732 |
| Displacement t | 8.938 |
| Heel deg | -1.0 |
| Draft at FP m | 0.732 |
| Draft at AP m | 0.732 |
| Draft at LCF m | 0.754 |
| Trim (+ve by stern) m | 0.000 |
| WL Length m | 8.128 |
| Beam max extents on WL m | 3.474 |
| Wetted Area m^2 | 27.226 |
| Waterpl. Area m^2 | 23.618 |
| Prismatic coeff. (Cp) | 0.789 |
| Block coeff. (Cb) | 0.403 |
| Max Sect. area coeff. (Cm) | 0.520 |
| Waterpl. area coeff. (Cwp) | 0.836 |
| LCB from zero pt. (+ve fwd) m | 4.398 |
| LCF from zero pt. (+ve fwd) m | 4.355 |
| KB m | 0.510 |
| KG fluid m | 1.662 |
| BMt m | 2.189 |
| BML m | 12.434 |
| GMt corrected m | 1.037 |
| GML m | 11.282 |
| KMt m | 2.698 |
| KML m | 12.942 |
| Immersion (TPc) tonne/cm | 0.242 |
| MTc tonne.m | 0.000 |
| RM at 1deg = GMt.Disp.sin(1) tonne.m | 0.162 |
| Max deck inclination deg | 1.0221 |
| Trim angle (+ve by stern) deg | 0.0000 |

Figure 29: Hydrostatics for load case

(Key point for loadcase)

| Key point | Type | Freeboard m |
|---|---|---|
| Margin Line (freeboard pos = 0.001 m) | | 0.237 |
| Deck Edge (freeboard pos = 0.001 m) | | 0.313 |

Figure 30: Keypoint for load case

We also compared the hydrostatics for different draughts, as seen below.

| Draft Amidships m | 0.610 | 0.710 | 0.810 | 0.910 |
|---|---|---|---|---|
| Displacement t | 5.745 | 7.880 | 10.38 | 13.15 |
| Heel deg | 0.0 | 0.0 | 0.0 | 0.0 |
| Draft at FP m | 0.610 | 0.710 | 0.810 | 0.910 |
| Draft at AP m | 0.610 | 0.710 | 0.810 | 0.910 |
| Draft at LCF m | 0.610 | 0.710 | 0.810 | 0.910 |
| Trim (+ve by stern) m | 0.000 | 0.000 | 0.000 | 0.000 |
| WL Length m | 7.858 | 8.023 | 8.181 | 8.336 |
| Beam max extents on WL m | 2.843 | 3.241 | 3.648 | 3.648 |
| Wetted Area m^2 | 21.421 | 25.164 | 29.587 | 32.504 |
| Waterpl. Area m^2 | 18.792 | 21.864 | 25.259 | 26.598 |
| Prismatic coeff. (Cp) | 0.785 | 0.790 | 0.793 | 0.799 |
| Block coeff. (Cb) | 0.411 | 0.416 | 0.419 | 0.464 |
| Max Sect. area coeff. (Cm) | 0.524 | 0.527 | 0.529 | 0.581 |
| Waterpl. area coeff. (Cwp) | 0.841 | 0.841 | 0.846 | 0.875 |
| LCB from zero pt. (+ve fwd) m | 4.384 | 4.352 | 4.319 | 4.302 |
| LCF from zero pt. (+ve fwd) m | 4.352 | 4.334 | 4.321 | 4.405 |
| KB m | 0.413 | 0.480 | 0.547 | 0.611 |
| KG m | 1.462 | 1.462 | 1.462 | 1.462 |
| BMt m | 1.831 | 2.021 | 2.263 | 1.938 |
| BML m | 14.427 | 12.757 | 11.740 | 10.414 |
| GMt m | 0.782 | 1.039 | 1.348 | 1.088 |
| GML m | 13.378 | 11.774 | 10.825 | 9.564 |
| KMt m | 2.244 | 2.501 | 2.810 | 2.550 |
| KML m | 14.840 | 13.236 | 12.287 | 11.026 |
| Immersion (TPc) tonne/cm | 0.193 | 0.224 | 0.259 | 0.273 |
| MTc tonne.m | 0.000 | 0.000 | 0.000 | 0.000 |
| RM at 1deg = GMt.Disp.sin(1) tonne.m | 0.078 | 0.143 | 0.244 | 0.250 |
| Max deck inclination deg | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Trim angle (+ve by stern) deg | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Figure 31: Draughts and hydrostatics

(Graph of different parameters as a function of draught)

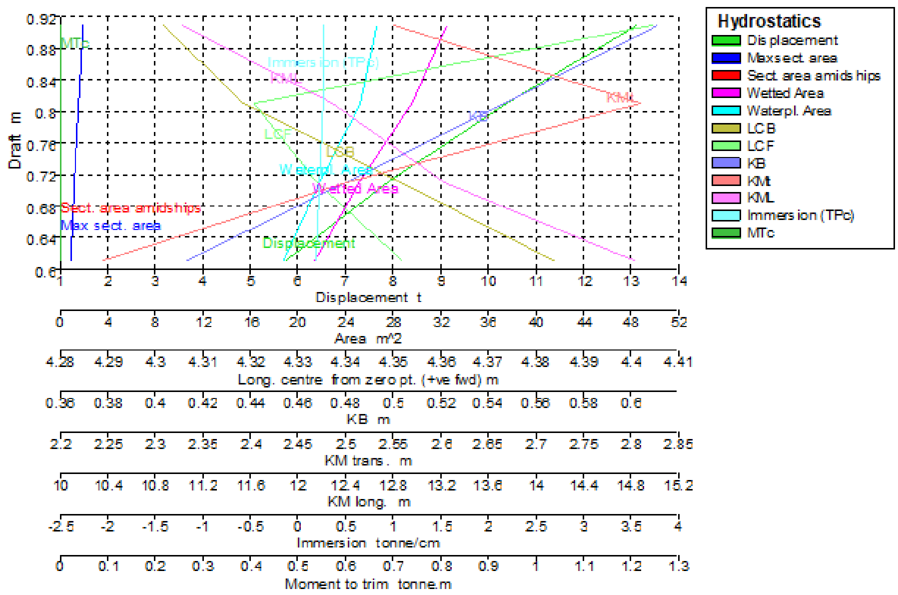


Figure 32: Graph of different parameters

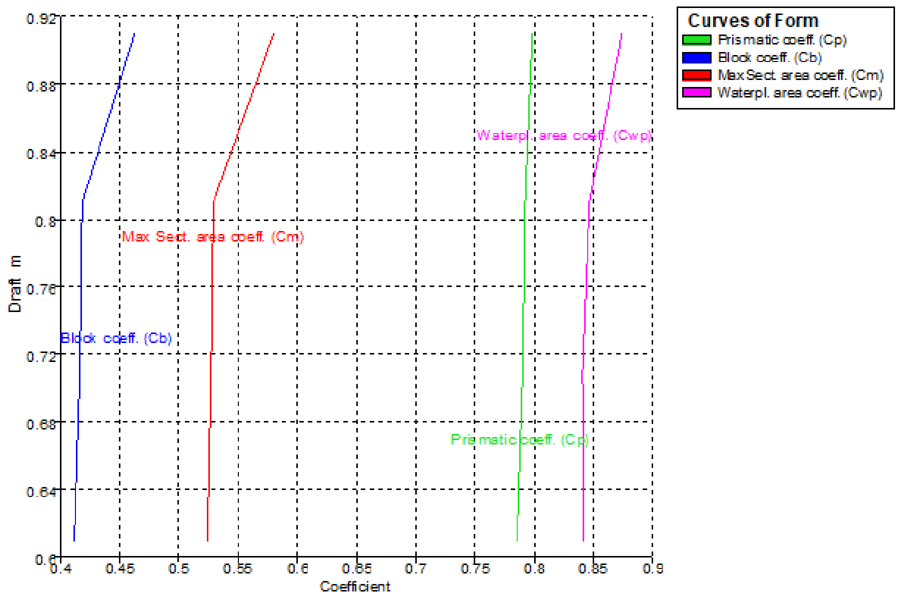


Figure 33: Coefficients

Now the most important part: the stability at large angles. We ask Maxsurf Stability to compute for a range of heel angles. The transverse stability is more important to check than the longitudinal one, as the moment of inertia is smaller, thus more critical. We analysed a range from 0 to 120 degrees.

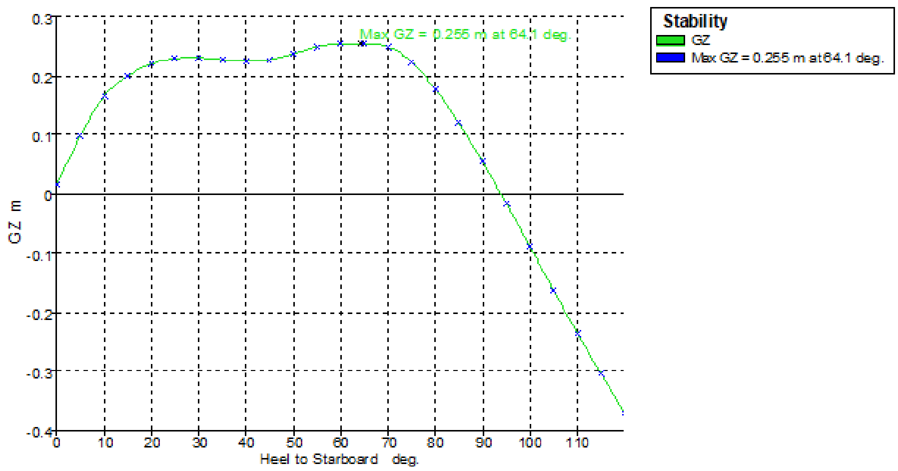


Figure 34: Gz curve

Besides the GZ curve, the software also provides a table showing how other parameters vary with the heel angle and GZ values, and one for the freeboard.

| Heel to Starboard deg | 0.0 | 10.0 | 20.0 | 40.0 | 60.0 | 70.0 | 80.0 | 90.0 |
|---|---|---|---|---|---|---|---|---|
| GZ m | 0.017 | 0.165 | 0.221 | 0.225 | 0.254 | 0.249 | 0.178 | 0.055 |
| Area under GZ curve from zero heel m.deg | 0.0000 | 0.9591 | 2.9356 | 7.4918 | 12.2533 | 14.7941 | 16.9974 | 18.1857 |
| Displacement t | 8.938 | 8.938 | 8.938 | 8.938 | 8.938 | 8.938 | 8.938 | 8.938 |
| Draft at FP m | 0.735 | 0.707 | 0.621 | 0.263 | -0.597 | -1.693 | -4.792 | n/a |
| Draft at AP m | 0.735 | 0.707 | 0.621 | 0.263 | -0.597 | -1.693 | -4.792 | n/a |
| WL Length m | 8.121 | 8.936 | 8.907 | 8.837 | 8.927 | 8.794 | 9.071 | 9.268 |
| Beam max extents on WL m | 3.416 | 3.087 | 2.842 | 2.751 | 2.921 | 2.786 | 2.430 | 2.274 |
| Wetted Area m^2 | 26.871 | 25.569 | 25.107 | 25.374 | 26.017 | 27.616 | 28.406 | 28.257 |
| Waterpl. Area m^2 | 23.286 | 21.765 | 20.649 | 20.454 | 20.527 | 19.750 | 17.378 | 16.349 |
| Prismatic coeff. (Cp) | 0.790 | 0.711 | 0.713 | 0.714 | 0.701 | 0.715 | 0.703 | 0.696 |
| Block coeff. (Cb) | 0.410 | 0.436 | 0.549 | 0.421 | 0.347 | 0.394 | 0.493 | 0.615 |
| LCB from zero pt. (+ve fwd) m | 4.397 | 4.397 | 4.400 | 4.411 | 4.412 | 4.402 | 4.382 | 4.355 |
| LCF from zero pt. (+ve fwd) m | 4.371 | 4.468 | 4.479 | 4.666 | 4.766 | 4.750 | 4.842 | 4.828 |
| Max deck inclination deg | 0.2578 | 10.0028 | 20.0033 | 40.0073 | 60.0035 | 70.0005 | 80.0002 | 90.0000 |
| Trim angle (+ve by stern) deg | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | n/a |

Figure 35: Large angle stability

| Key point | Immersion angle deg | Emergence angle deg | Freeboard at 0.0 deg m | Freeboard at 20.0 deg m | Freeboard at 40.0 deg m | Freeboard at 50.0 deg m |
|---|---|---|---|---|---|---|
| Margin Line (immersion pos = 0.524 m) | 40.9 | n/a | 0.234 | 0.327 | 0.016 | -0.152 |
| Deck Edge (immersion pos = 0.524 m) | 44.4 | n/a | 0.310 | 0.398 | 0.079 | -0.097 |

Figure 36: Freeboard at large angles

There are a few points to observe from the GZ curve. One is that at zero degrees GZ is not exactly zero, because of the small heel angle of 1 degree that we observed previously with the weight distribution. The most important point to observe is how stable the boat is. As the GZ curve presents positive values for positive angles up to 93.8 degrees, we can say the boat has stability up to that angle, that is, if she heels to that angle, she will still be able to come back to her original stable position, while when negative values for positive angles are reached (or positive values for negative angles), the boat capsizes. Another point is the maximum GZ value, which is 0.255 at 64.1 degrees. This is the angle with the most tendency for the boat to return to her upright position. Besides our interpretation of the GZ curve, we need to comply with regulations. NBS states the GZ value for an angle of 30 degrees should be at least 0.200 m, which is true for our case. It states that the maximum GZ value should be at an angle greater than 25 degrees, and this happens at 64.1 degrees. It also requires the GZ curve to be positive up to heeling angle of 40 degrees, and our boat can get up to 93.8 degrees with positive values. Last point in the regulation is that the GZ curve shall terminate where a filling opening will come below water. On the table showing freeboard at large angles, we can see the values are positive up to 40 degrees, so the requirement is fulfilled. NBS also requires a minimum freeboard of 200 mm, and both for the lightweight hydrostatics as well as for the loadcase, the freeboard is greater than 200 mm.

Concerning that people can move on the boat, we computed hydrostatics considering the average TCG for the 10 people on board to be 0.9 metres from centreline. The result was a heeling angle of 3.5 degrees. As we have freeboard up to 40 degrees, this is not a huge concern.

| | |
|---|---|
| Draft Amidships m | 0.719 |
| Displacement t | 8.938 |
| Heel deg | 3.5 |
| Draft at FP m | 0.719 |
| Draft at AP m | 0.719 |
| Draft at LCF m | 0.748 |
| Trim (+ve by stern) m | 0.000 |
| WL Length m | 8.143 |
| Beam max extents on WL m | 3.342 |
| Wetted Area m^2 | 27.151 |
| Waterpl. Area m^2 | 23.351 |
| Prismatic coeff. (Cp) | 0.790 |
| Block coeff. (Cb) | 0.420 |
| Max Sect. area coeff. (Cm) | 0.545 |
| Waterpl. area coeff. (Cwp) | 0.858 |
| LCB from zero pt. (+ve fwd) m | 4.400 |
| LCF from zero pt. (+ve fwd) m | 4.367 |
| KB m | 0.513 |
| KG fluid m | 1.662 |
| BMt m | 2.067 |
| BML m | 12.572 |
| GMt corrected m | 0.916 |
| GML m | 11.421 |
| KMt m | 2.576 |
| KML m | 13.061 |
| Immersion (TPc) tonne/cm | 0.239 |
| MTc tonne.m | 0.000 |
| RM at 1deg = GMt.Disp.sin(1) tonne.m | 0.143 |
| Max deck inclination deg | 3.4758 |
| Trim angle (+ve by stern) deg | 0.0000 |

Figure 37: Hydrostatics considering people movement on board

# 8 Conclusion

The main objective of our study project was achieved with excellent results. The preliminary design against similar boats taken as reference and the values given by the DelftShip functionalities were recalculated and studied, obtaining results that were highly reliable to the design reality. The design criteria governed by standards and conventions were verified and certified by the register taken as reference during the design process. The study and development of the shape of the hull according to the initial selection criteria was carried out successfully, allowing the geometric characteristics of the hull and its uniqueness in the representation of the lines in the longitudinal, ordinate and water line planes to be calculated using the commercial software MaxSurf modeler. Subsequently, the hydrostatic properties in the reference of the different draughts were verified and accepted in the reference of the initial thought information. With regard to the study of propulsion, through the use of commercial software such as MaxSurf Resistance, it was possible to iterate the theory of hull resistance and estimate the propulsive power required to move forward. The aim was to develop a line of thought with reference to Savitsky's method, which allowed us to obtain reliable results in the reference curves of the study. Subsequently, it was possible to dimension the choice of propulsion means with reference to availability in the market. In our case, our analysis did not take into account the procurement costs of the Hamilton waterjet system, allowing us only to analyse aspects relating to the final efficiency and performance of our planing hull. In this regard, the sizing of the chosen engines was correlated, taking as a reference target the values and systems on board the boats analysed. Once the design and sizing of the engine apparatus had taken place, a functional electrical system allowed us to achieve efficiency and safety standards in any possible scenario of our boat. The regulations allowed us to study everything in a workmanlike manner, following operating standards and classification registers attesting to international conventions. This aspect of the analysis allowed us to correctly design the equipment supply in order to improve one of the most important concepts in design, the safety of the boat and especially of the people on board. We searched for real equipments and checked the dimensions, weights and electrical requirements. It is also very important the 3D drawing, to make sure everything can fit on the boat in all 3 physical dimensions, and the stability booklet related to the chosen positions to guarantee that the weights are well distributed and the boat will be in equilibrium, that is, no trim and no heel. Designing a boat is an iterative process, and when we design in practice, after a preliminar design with estimates, we see differences that if we iterate the process doing a spiral of work, we can optimise the final result. One that showed a significant difference was the final draught, which was smaller than expected, but in our case it is a positive difference, as this allows us to have a little margin for weight carrying as well as more freeboard to meet the requirements from regulations. Even with a smaller draught, our boat is very stable with a great GZ curve going up to 40 degrees for freeboard and up to 93.8 for positive GZ values.

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# Appendix

There will be added all the models and excel sheet in the zip file

## A Vessel data sheet

| | |
|---|---|
| Length overall | 11m |
| Breadth | 3.65m |
| Depth | 2.95m |
| Draught | 0,91m |
| Cb | 0,445 |
| Vs | 40 knots |
| Main Engine Power | 500kW |
| Autonomy | 8hours |
| Persons capacity | 12 persons |
| Sleeping capacity | 4 persons |
| Fresh water | 400 l |
| Light weight | 7011kg |
| Dead weight | 2010kg |
| Engine | Volvo Penta D6-340 Inboard engine |
| Propulsion | Hydrojets |
| Displacment | 12626 kg |
| Hull | Mono hull, Planning hull |
| Hull material | Composite of glass fiber and polyester |

## B Lines plane

The lines plane modell is added to the zip file

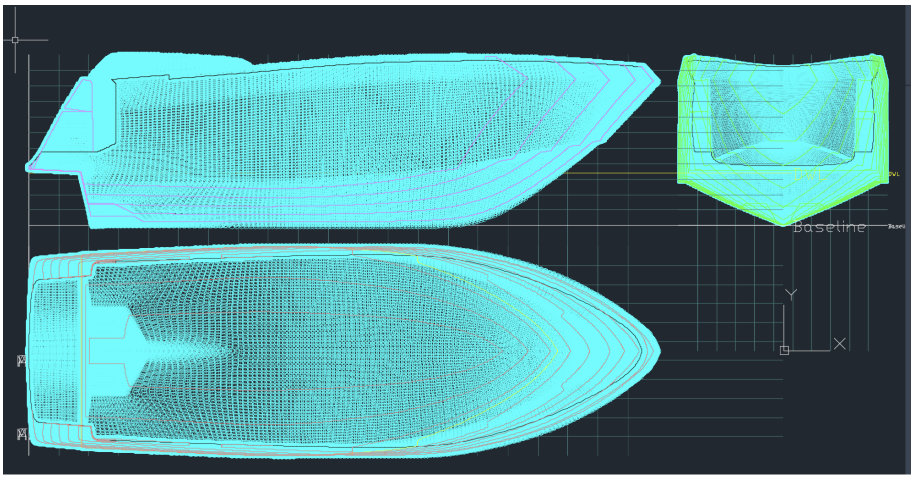


Figure 38: Lines Plane

# C General arrangement

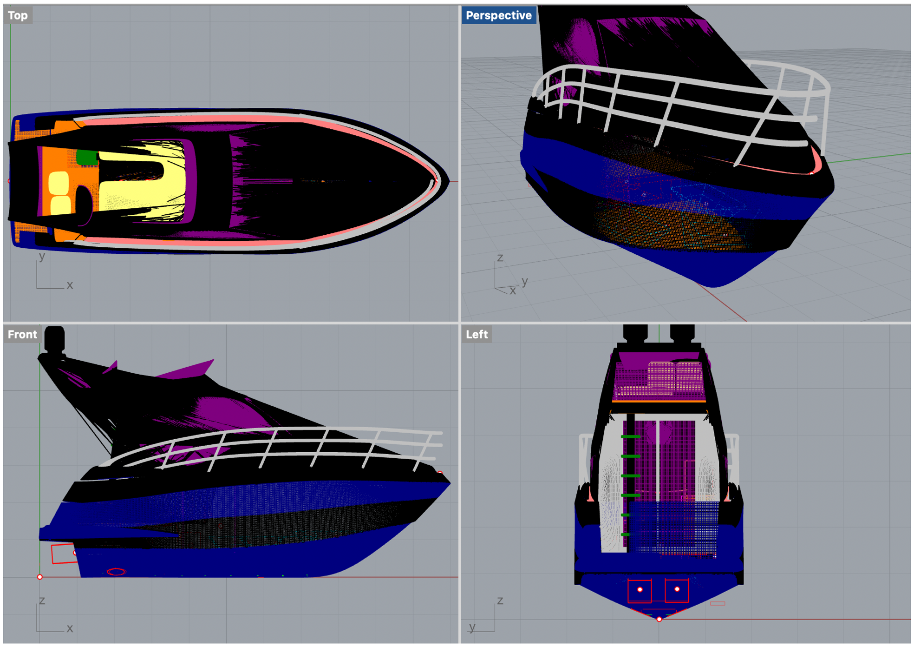


Figure 39: 3d modell

# D Hydrostatic properties

| | |
|---|---|
| Draft Amidships m | 0.732 |
| Displacement t | 8.938 |
| Heel deg | -1.0 |
| Draft at FP m | 0.732 |
| Draft at AP m | 0.732 |
| Draft at LCF m | 0.754 |
| Trim (+ve by stern) m | 0.000 |
| WL Length m | 8.128 |
| Beam max extents on WL m | 3.474 |
| Wetted Area m^2 | 27.226 |
| Waterpl. Area m^2 | 23.618 |
| Prismatic coeff. (Cp) | 0.789 |
| Block coeff. (Cb) | 0.403 |
| Max Sect. area coeff. (Cm) | 0.520 |
| Waterpl. area coeff. (Cwp) | 0.836 |
| LCB from zero pt. (+ve fwd) m | 4.398 |
| LCF from zero pt. (+ve fwd) m | 4.355 |
| KB m | 0.510 |
| KG fluid m | 1.662 |
| BMt m | 2.189 |
| BML m | 12.434 |
| GMt corrected m | 1.037 |
| GML m | 11.282 |
| KMt m | 2.698 |
| KML m | 12.942 |
| Immersion (TPc) tonne/cm | 0.242 |
| MTc tonne.m | 0.000 |
| RM at 1deg = GMt.Disp.sin(1) tonne.m | 0.162 |
| Max deck inclination deg | 1.0221 |
| Trim angle (+ve by stern) deg | 0.0000 |

Figure 40: Hydrostatics for load case

# E Light weight estimate

| Item | Weight [kg] | Lcg [m] | Tcg [m] | Vcg [m] | Ml [kg.m] | Mt [kg.m] | Mv [kh.m] |
|---|---|---|---|---|---|---|---|
| **Structures** | | | | | | | |
| Bottom | 1762.807 | 4.84 | 0 | 0.607 | 8531.99 | 0 | 1070.02 |
| Sides | 365.652 | 4.84 | 0 | 0.607 | 1769.76 | 0 | 221.951 |
| Decks | 529.82 | 3.719 | -0.027 | 1.12 | 1970.4 | -14.3051 | 593.398 |
| Superstructure | 1129.81 | 6.0384 | 0 | 3.817 | 6822.24 | 0 | 4312.48 |
| **Machinery** | | | | | | | |
| Engine 1 | 690 | 2.967 | 0.47 | 0.954 | 2047.23 | 324.3 | 658.26 |
| Engine 2 | 690 | 2.967 | -0.47 | 0.954 | 2047.23 | -324.3 | 658.26 |
| Water jet 1 | 130 | 0.96 | 0.387 | 0.646 | 124.8 | 50.31 | 83.98 |
| Water jet 2 | 130 | 0.96 | -0.387 | 0.646 | 124.8 | -50.31 | 83.98 |
| Generator | 90 | 3.444 | 0 | 0.324 | 309.96 | 0 | 29.16 |
| Inverter/Converter | 3.4 | 2.9 | 0 | 0.467 | 9.86 | 0 | 1.5878 |
| Batteries | 24.39 | 4.534 | -0.922 | 0.548 | 110.584 | -22.4876 | 13.3657 |
| Bilge system | 0.95 | 5.52 | 0 | 0.145 | 5.244 | 0 | 0.13775 |
| FW system | 1.6 | 5.804 | 0 | 0.45 | 9.2864 | 0 | 0.72 |
| FW tank | 39.07 | 6.729 | 0 | 0.52 | 262.902 | 0 | 20.3164 |
| Fuel tank | 39.43 | 4.047 | -0.329 | 0.841 | 159.573 | -12.9725 | 33.1606 |
| Sanitary discharge system | 39.07 | 4.91 | 0 | 0.52 | 191.834 | 0 | 20.3164 |
| **Equipment and outfitting** | | | | | | | |
| Furniture, appliances, etc (Kitchen) | 200 | 3 | 0.863 | 2.442 | 600 | 172.6 | 488.4 |
| Single bed 1 | 40 | 5.546 | -1.16 | 0.902 | 221.84 | -46.4 | 36.08 |
| Single bed 2 | 40 | 6.354 | 1.023 | 0.902 | 254.16 | -46.4 | 36.08 |
| Double bed | 70 | 7.954 | -0.279 | 1.051 | 556.78 | -19.53 | 73.57 |
| Table | 20 | 3.382 | -0.576 | 1.797 | 67.64 | | 35.94 |
| Galley equipment | | | | | 0 | 0 | 0 |
| Toilets | 10 | 4.53 | 0.981 | 1.229 | 45.3 | 9.81 | 12.29 |
| Anchoring equipment | 406.94 | 10.71 | 0 | 2.775 | 4358.33 | 0 | 1129.26 |
| Fire fighting equipment 1 | 54.9 | 1.95 | 0.845 | 0.956 | 107.055 | 46.3905 | 52.4844 |
| Fire fighting equipment 2 | 54.9 | 1.95 | -0.845 | 0.956 | 107.055 | -46.3905 | 52.4844 |
| Seat + Life jackets and safety equipment | 20 | 3.522 | -1.186 | 1.672 | 70.44 | -23.72 | 33.44 |
| Flybridge + Nav and com equipment | 100 | 3.424 | 0 | 5 | 342.4 | 0 | 500 |
| **Margin** | | | | | | | |
| Design margin (5%) | 329.13695 | | | | | | |
| Totals | 7011.87595 | | | | 31228.7 | -3.40519 | 10251.1 |
| **Lightweight** | 7011.87595 | 4.45369 | -0.000486 | 1.46196679 | | | |

Figure 41: Light weight estimation

# F Loading conditions

| Item Name | Quantity | Unit Mass tonne | Total Mass tonne | Long. Arm m | Trans. Arm m | Vert. Arm m | Total FSM tonne.m |
|---|---|---|---|---|---|---|---|
| Lightship | 1 | 7.012 | 7.012 | 4.459 | 0.001 | 1.466 | 0.000 |
| Fuel tank | 1 | 0.476 | 0.476 | 4.047 | -0.329 | 0.841 | 0.000 |
| Fresh Water | 1 | 0.400 | 0.400 | 6.729 | 0.000 | 0.520 | 0.000 |
| Sewage | 0 | 0.400 | 0.000 | 4.910 | 0.000 | 0.520 | 0.000 |
| People | 10 | 0.075 | 0.750 | 2.770 | 0.000 | 4.858 | 0.000 |
| Personal belongings | 5 | 0.030 | 0.150 | 6.015 | 0.000 | 0.702 | 0.000 |
| Personal | 5 | 0.030 | 0.150 | 2.623 | 0.000 | 1.440 | 0.000 |
| Total Loadcase | | | 8.938 | 4.392 | -0.017 | 1.662 | 0.000 |
| FS correction | | | | | | 0.000 | |
| VCG fluid | | | | | | 1.662 | |

Figure 42: Load condition