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TESI DI LAUREA MAGISTRALE IN YACHT DESIGN

Preliminary design of a 60-foot cruiser sailboat

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1 Introduction

The subject of this thesis is a preliminary design of a 60 feet cruising sailboat. The study addresses the fundamental aspects that define the yacht's performance, safety, comfort and functionality, while considering the constraints and requirements typical of long-range cruising yachts.

The process followed corresponds to the ship design spiral, developed by Evans and explained in section 3.1. Furthermore, some influence matrixes were made to give an overview of the relation between the subjects that compose the design of the yacht and the importance of each one in this specific project.

2 Objective

The goal is to design a 60 feet yacht, called ARPEX, that at the same time provides comfort, performance and safety for the crew in unlimited ocean passages. To achieve this compromise, solutions have been adopted and will be explained along the report.

The main characteristics of the hull are defined by market research, and based on those, the design of the yacht was developed.

3 Methodology

3.1 Evans Spiral

The issue of ship design has long been addressed in academic circles, however, the first widely disseminated method in the naval field occurred only in 1959 with the publication of "Basic Design Concepts", reference [1], by J.H. Evans. In his article, Evans proposed a "Design Spiral" in which, through a predefined sequence, the design would evolve in a cyclical manner, refining with each complete turn of the spiral. Its major limitation lies in the verification of steps, as only after a complete turn in the spiral would it be possible to verify the previous step.

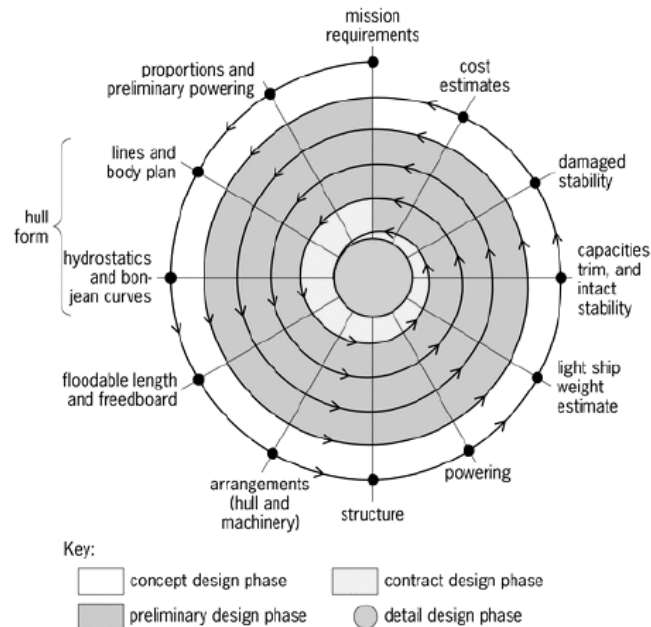


Figure 1: Evans Spiral.

3.2 Synthesis, Analysis and Evaluation

The spiral presented in the previous chapter is a general rule to be used for any ship design. For the sailboat specified in this thesis, a specific spiral was created.

To understand the main topics and analysis to be done, the concept of Synthesis, Analysis and Evaluation is introduced. It constitutes the three main steps to be followed at each stage of the project.

Synthesis is characterized as an "initial guess" and is the stage where creativity emerges. It involves the transcription of the object, defining the functional and physical elements.

Analysis is the subsequent stage. At this point, with the physical concepts in hand, the proposed ideas in the synthesis will be verified.

In the evaluation stage, the analysis will be judged based on the results obtained. Evaluation serves as a step to assess whether the project's expectations have been met. In the case of a negative response during evaluation, the process should be revisited starting from the synthesis. In the case of an affirmative response, the synthesis of the next functional element of the project follows.

3.2.1 Synthesis

The syntheses are the physical-functional characteristics of the yacht. To initiate the project, the syntheses take in account are the ones that are necessary for the design of the yacht, which are fundamental for it. The syntheses of our project consist of:

- Hull & Deck
- Keel & Rudder
- Sail Arrangement
- Rigging
- Arrangement (compartmentation)
- Structure Scantling
- Propulsion System

Once each synthesis is defined, it is possible to assemble the influence matrix Synthesis X Synthesis. This initial matrix relates the dependency of each synthesis to the others. It is a very common way to quantify, through a scoring table or here called "level of influence," the interdependence of each project synthesis.

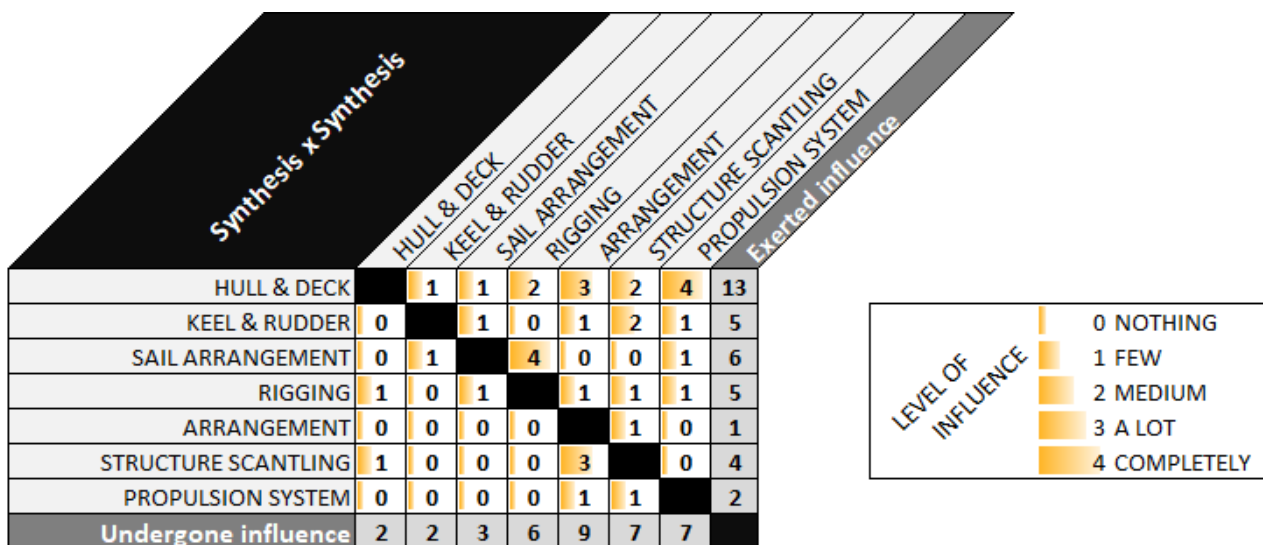


Figure 2: Influence Matrix.

From this table it is possible to observe that the hull is the most influencing subject and it is important to have a solid design on it, because it will affect the most subjects in the whole project. On the other hand, the arrangement is the most influenced subject.

3.2.2 Analysis

The analyses are checks and verifications that will validate the yacht, the object of design. Analysis is a moment of realization of the synthesis. It has a relationship of interdependence with synthesis because analyses can only be performed on something that already exists, i.e., the synthesis. The analysis tools can be software or a simple mathematical formula, and the result of the analysis is not always a verification number. The Analysis made for this design are:

- Keel & Rudder check
- Rigging check
- Yacht resistance
- Weight
- Propulsion Efficiency
- Structural Resistance (Global analysis)
- Equilibrium (Global analysis)
- Stability (Global analysis)
- Velocity prediction – VPP (Global analysis)

Figure 3 shows the Analysis versus Analysis Matrix. It presents the interdependency between the analysis meaning if the row analysis requires the column analysis done.

	GLOBAL ANALYSIS								
ANALYSIS X ANALYSIS	KEEL & RUDDERS CHECK	RIGGING CHECK	YACHT RESISTANCE	WEIGHT	PROPULSION EFFICIENCY	STRUCTURAL RESISTANCE	EQUILIBRIUM	STABILITY	VELOCITY PREDICTION (VPP)
KEEL & RUDDERS CHECK									
RIGGING CHECK						X	X		
YACHT RESISTANCE	X					X			
WEIGHT				X					
PROPULSION EFFICIENCY			X						
STRUCTURAL RESISTANCE	X	X				X			
EQUILIBRIUM				X					
STABILITY				X		X			
VELOCITY PREDICTION (VPP)		X		X		X	X		

Figure 3: Analysis vs Analysis.

3.2.3 Cross-matrix

The cross-matrix is composed of syntheses and the analyses. It represents how much the synthesis influence in the analysis. Each column is quantified by a percentage of influence, with the sum at the end of each column, with a total of 100%.

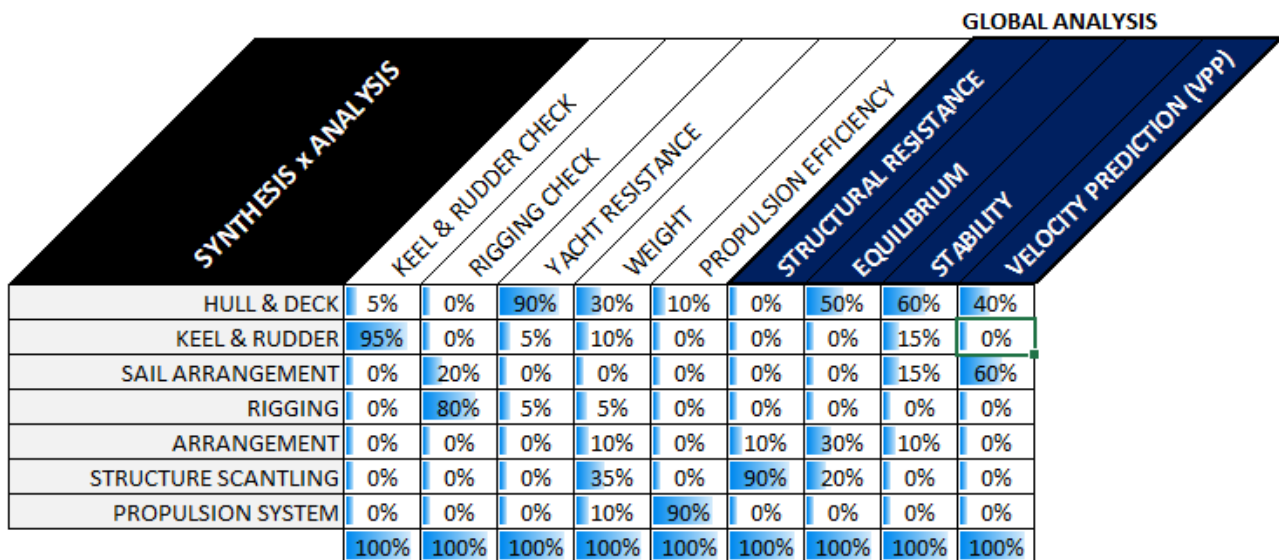


Figure 4: Cross-matrix.

These matrices give an understanding of the dependence of the systems and how they interact with each other. They are also very useful to see which subjects are needed for each analysis and that is important to relate the sequence of design.

4 Market Research

The market research is the first step to understand the usual dimensions used by competitors. It provides valuable insights for the design and first dimensions to be considered in the design.

The competitors chosen were sail boats from reliable shipyards fully equip for unlimited ocean passage-making.

Table 1: Competitors.

Yacht	LOA [m]	B [m]	D [m]	Δ [t]	Sail Area [m ²]	Lead ballast [t]	Cabins	Water capacity [L]	Shipyard	Material	Engine			
											number	brand	Pot [HP]	Diesel tank [L]
Exploration 60'	18,3	5,4	3,7	35	168,4	9,65	2-4	800	Garcia Yachts	Aluminium	1	-	180	2500
Oyster 595SII	18,1	5,4	2,7	30,8	167	-	3	1000	Oyster Yachts	GRP	1	Yanmar	150	1345
Solaris 60'	18,3	5,3	3,2	25,8	201	7,9	3	650	Solaris Yachts	GRP	1	Yanmar	110	450
Oceanis 60'	18,7	5,3	2,7	21,7	183	5	3	860	Beneteau	GRP	1	-	150	500
Hallberg-Rassy 57'	18,4	5,1	2,4	28	163	9,9	5	1030	Hallberg-Rassy	GRP	1	Volvo	175	1050
Jeanneau 60'	18,3	5,2	2,6	20,17	131	5	4	760	Jeanneau	GRP	1	Yanmar	150	318

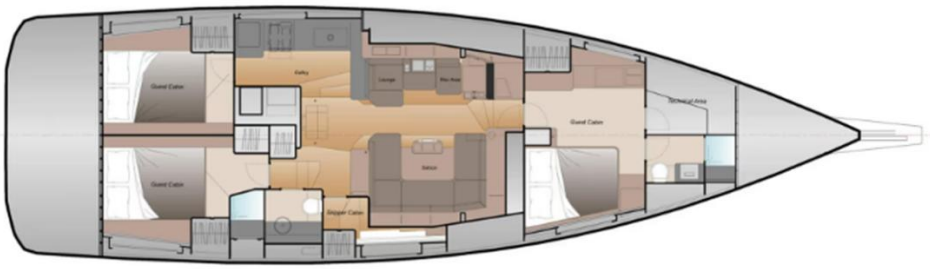


Figure 5: Exploration 60'.

Exploration 60'

LOA [m]	18,3
B [m]	5,4
T [m]	3,7
Δ [t]	35



Figure 6: Oyster 595SII.

Oyster 595SII

LOA [m]	18,1
B [m]	5,4
T [m]	2,7
Δ [t]	30,8

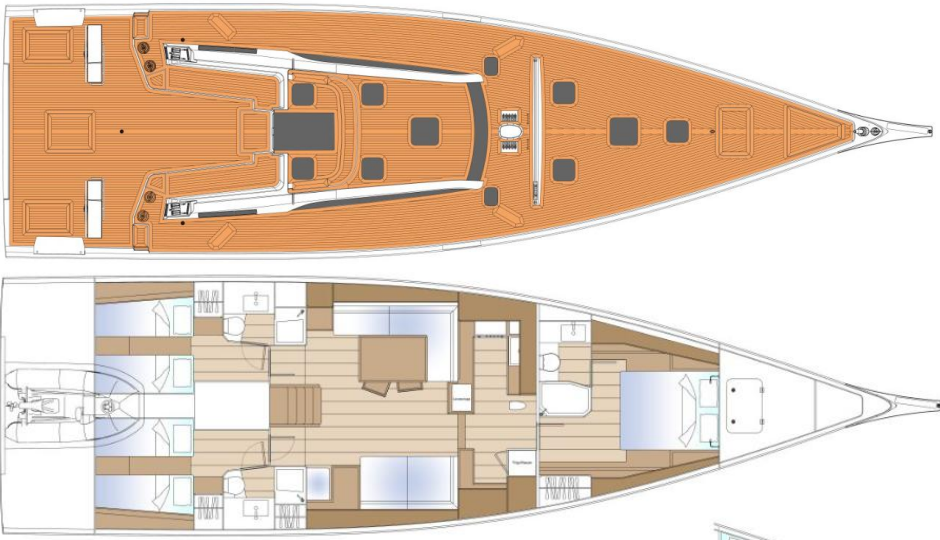


Figure 7: Solaris 60'.

Solaris 60'

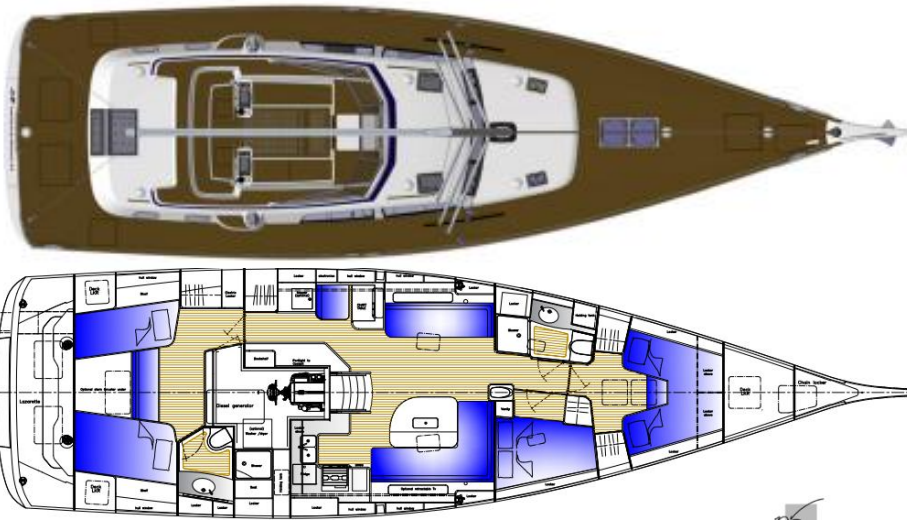
LOA [m]	18,3
B [m]	5,3
T [m]	3,2
Δ [t]	25,8



Oceanis 60'

LOA [m]	18,7
B [m]	5,3
T [m]	2,7
Δ [t]	21,7

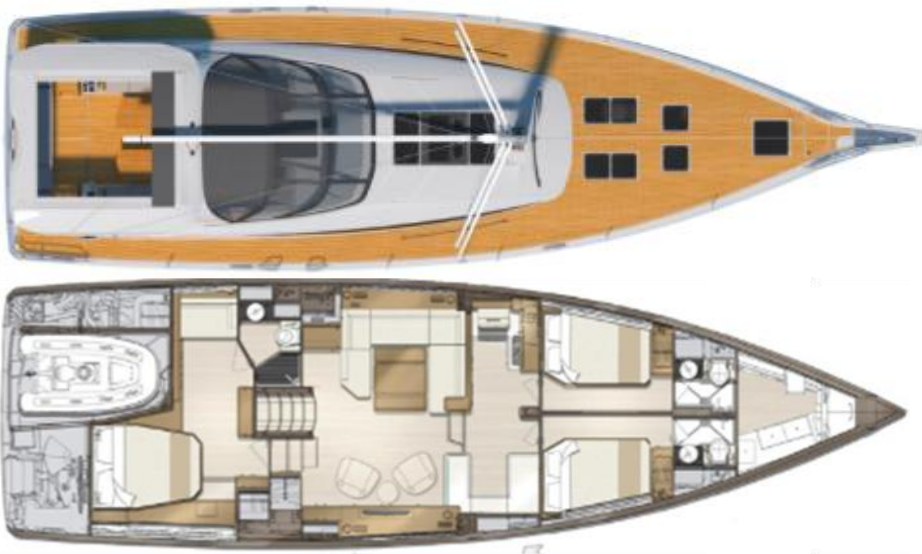
Figure 8: Oceanis 60'.



Hallberg-Rassy 57'

LOA [m]	18,4
B [m]	5,1
T [m]	2,4
Δ [t]	28

Figure 9: Hallberg-Rassy 57'.



Jeanneau 60'

LOA [m]	18,3
B [m]	5,2
T [m]	2,6
Δ [t]	20,17

Figure 10: Jeanneau 60'.

From this analysis of the competitors, some linear extrapolation and approximations were made and the main dimensions of Arpex are achieved. The interior was thought considering the Oyster 595II approach and the deck layout was considering the Hallberg-Rassy 57' with a central cockpit.

Table 2: First dimensions.

	LOA [m]	B [m]	H [m]	T [m]	Δ [t]	Sail Area [m ²]	Lead ballast [t]
Arpex	18,5	5,20	1,75	2,46	22	173,7	7

Hence, the first model if the hull initial dimensions can be achieved.

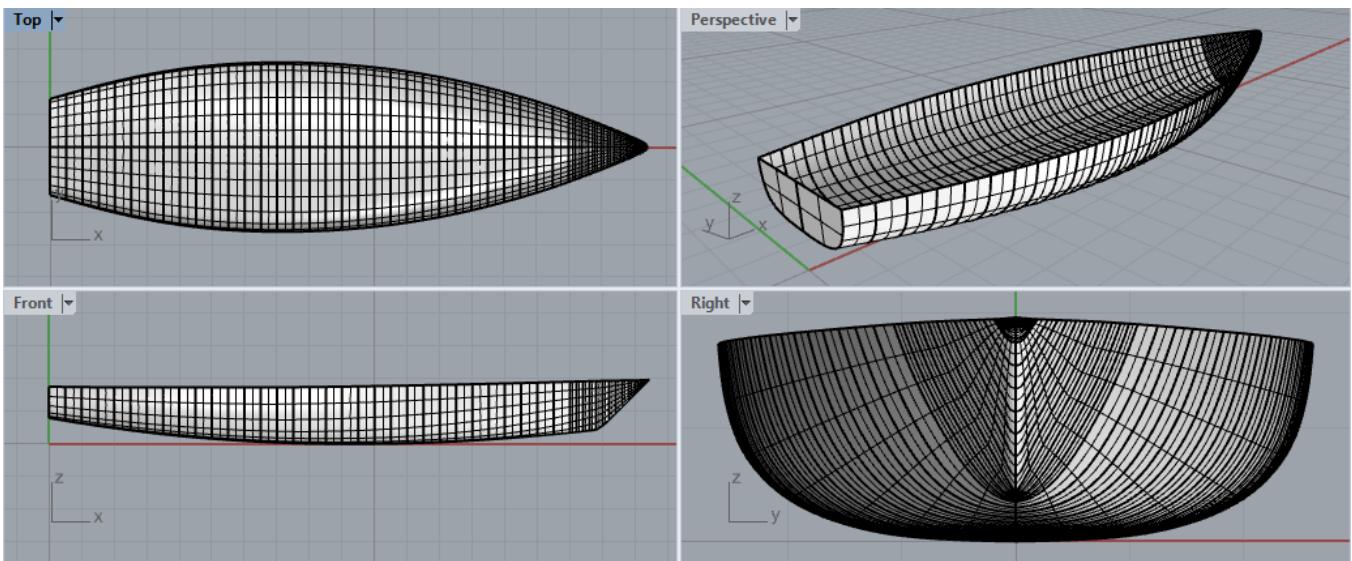


Figure 11: Preliminary hull.

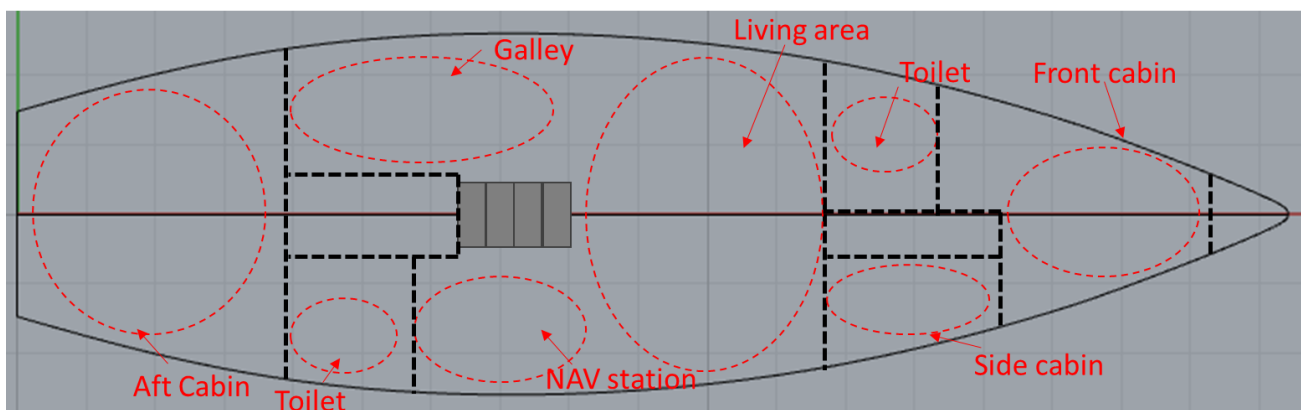


Figure 12: Preliminary layout.

5 Keel and Rudder design

Keel and rudder design play a fundamental role in the performance, stability, and handling of a sailboat.

The keel provides both ballast and hydrodynamic lift, helping the vessel resist sideways motion and maintain balance under sail (through the low CoG of the lead ballast). The purpose of the design is comfort and safety and the design of the keel also plays an important role in this matter. Since the sailboat is designed for long journeys, the objective is not performance but comfort.

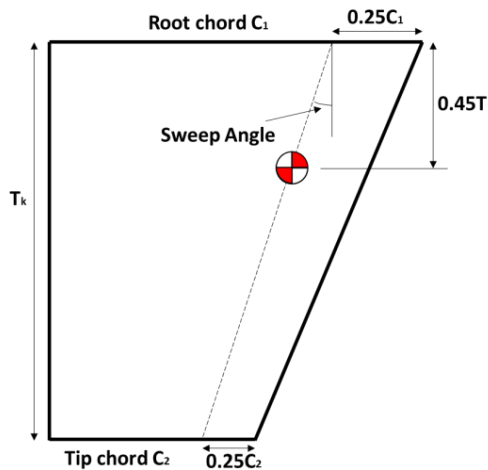
The rudder, on the other hand, is the primary control. Its design determines how effectively the sailboat can maintain course and manoeuvre in varying wind and sea conditions.

5.1 Keel

5.1.1 Keel Planform

The dimensions of the trapezoidal keel were achieved following chapter 6 of reference [2] and notes from classes of yacht dynamics.

The sweep angle was defined as 25% of the chord. Since the boat is designed from cruising conditions, it is important to consider the depth of the keel in order to allow access to shallow water close to the coast.



C_1 [m]	2
C_2 [m]	1,2
\bar{C} (mean chord)	1,6
T_k [m]	1,2
Area [m ²]	1,92
AR (aspect Ratio)	0,75

Figure 13: Keel definitions.

5.1.2 Profile

Some comparison between NACA profiles can be seen in Figure 14. It shows how the relation between thickness and chord (t/c) impacts the lift coefficient.

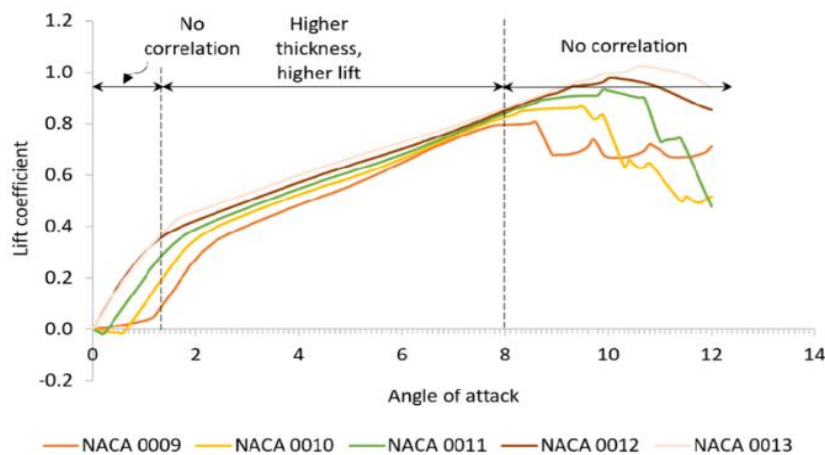


Figure 14: Relation between Lift and angle of attack for several NACA profiles.

The profile NACA 0012 was chosen for its robustness and predictability in stall.

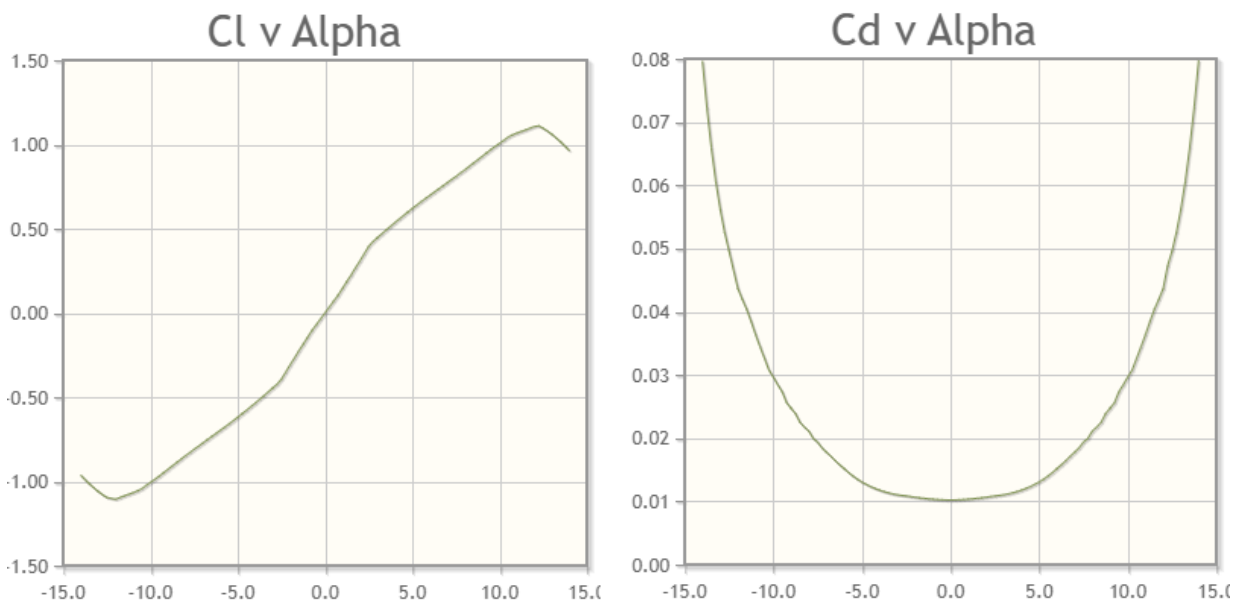
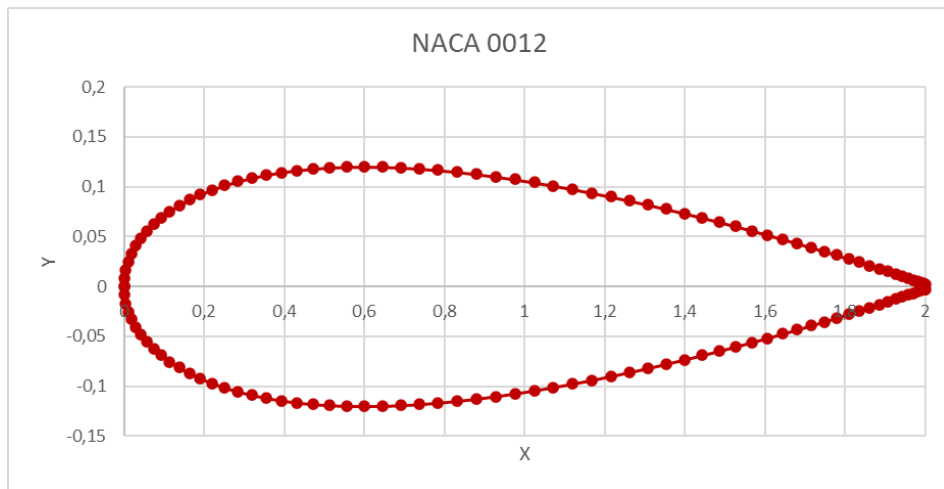


Figure 15: NACA 0012 profile. Lift and drag coefficients for approximate 10 knots speed.

5.1.3 Lead Ballast

The lead ballast considered in the competitors presented in chapter 4 are shown hereafter. The average corresponds to 28% of the sailboat's displacement. On modern cruiser ships this value lies between 30% and 40% of the displacement.

Table 3: Ballast ratio.

Yacht	LoA [m]	B [m]	D [m]	Δ [t]	Sail Area [m ²]	Lead ballast [t]	Ballast ratio [%]
Exploration 60'	18,3	5,4	3,7	35	168,4	9,65	28%
Oyster 595SII	18,1	5,4	2,7	30,8	167	-	-
Solaris 60'	18,3	5,3	3,2	25,8	201	7,9	31%
Oceanis 60'	18,7	5,3	2,7	21,7	183	5	23%
Hallberg-Rassy 57'	18,4	5,1	2,4	28	163	9,9	35%
Jeanneau 60'	18,3	5,2	2,6	20,17	131	5	25%

Lead ballast was set as 35% of the displacement, 7.8 tons. It will be fixed in the tip of the keel as a bulbous geometry.

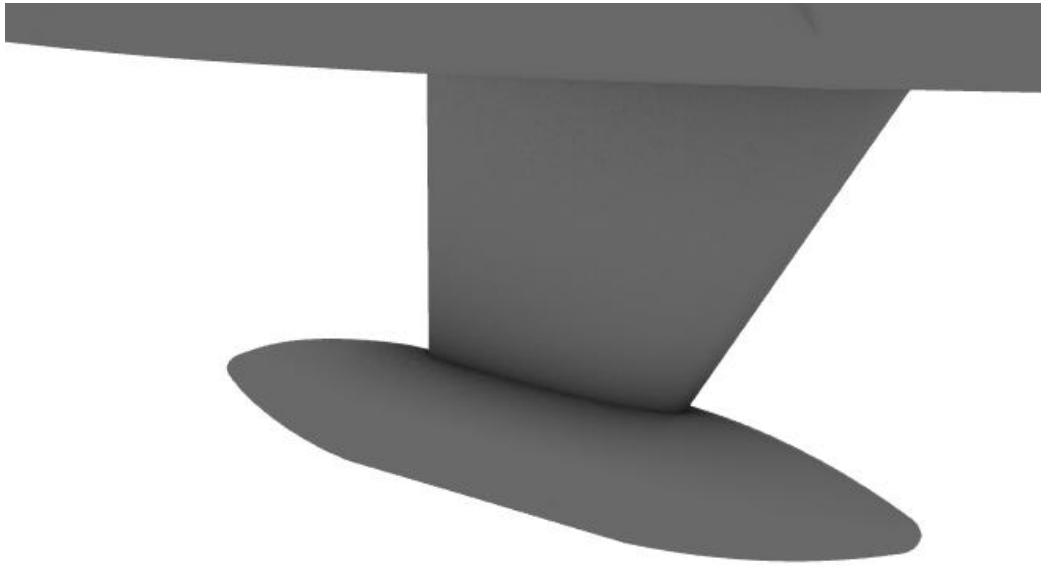


Figure 16: Keel with lead ballast attached.

5.2 Rudder

The rudder's design determines how effectively the sailboat can maintain course and manoeuvre in varying wind and sea conditions, as mentioned before.

For the Arpex, it was chosen the twin rudders configuration. It allows a better manoeuvrability of the sailboat since it is possible to guarantee a full submerged rudder when heeled. This provides an easily controlled boat during all sailing conditions, especially in rough weather.

Because of the reduced rudder surface, compared to a single rudder solution, the rudder loads will also decrease which will increase the safety factor.

The aspect ratio (AR) plays an important role in the definition of the planform. Lower AR is better for manoeuvre, since stall occurs in higher angles of attack, as shown in Figure 17. On the other hand, the lift force is much smaller. Hence, a compromise should be made in order to have balanced values.

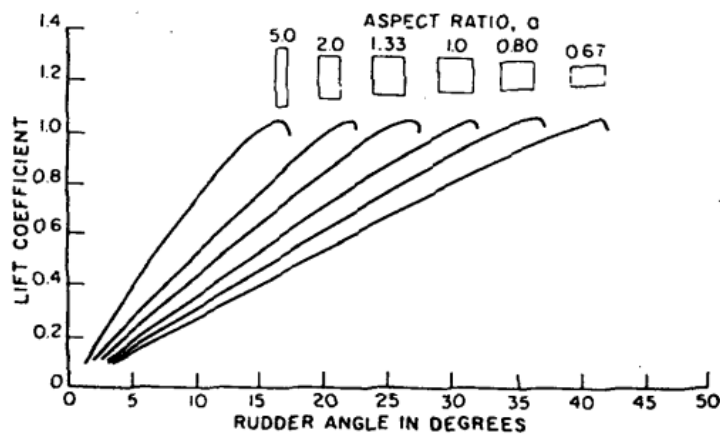
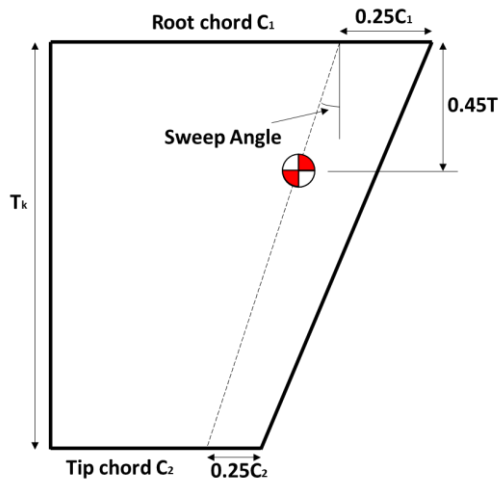


Figure 17: Relation between Lift and angle of attack for different Aspect Ratio (AR).

The same profile NACA 0012 was used for the rudders.



C_1 [m]	0,6
C_2 [m]	0,4
\bar{C} (mean chord)	0,5
T_k [m]	1,8
Area [m ²]	0,9
AR (aspect Ratio)	3,6

Figure 18: Rudder definitions.

To be aligned with the hull, the rudders were rotated in 8deg transversally and in 15deg longitudinally.

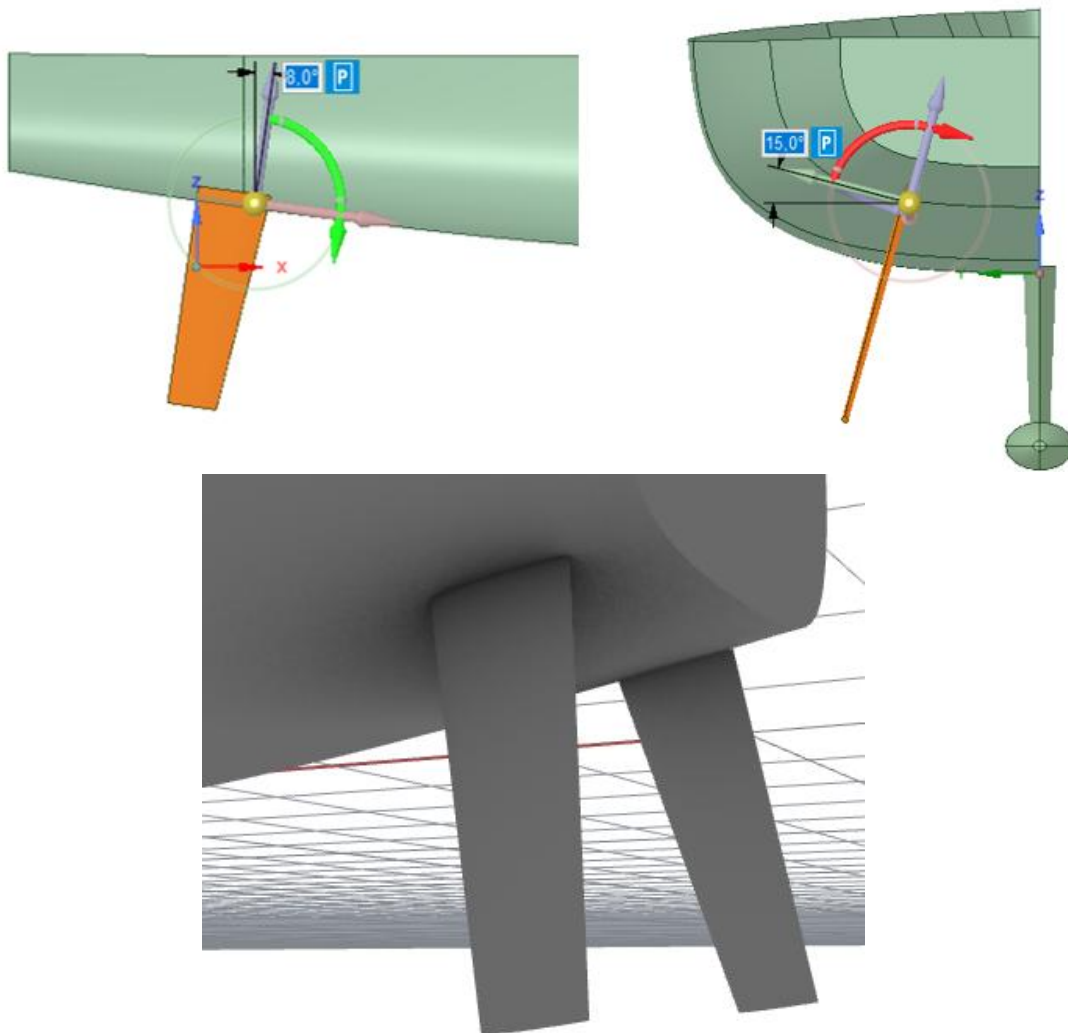


Figure 19: Rudder 3D.

6 Sail plan

The configuration of the sail plan has been defined according to the design objectives of the vessel. An overly generous sail area may enhance speed, but can adversely affect controllability, while an undersized sail plan leads to reduced performance. Main goal is to keep a good performance without compromising the ease handle.

The sail plans from competitors, shown in chapter 4, were also used in order to dimension the Arpex sail configuration.

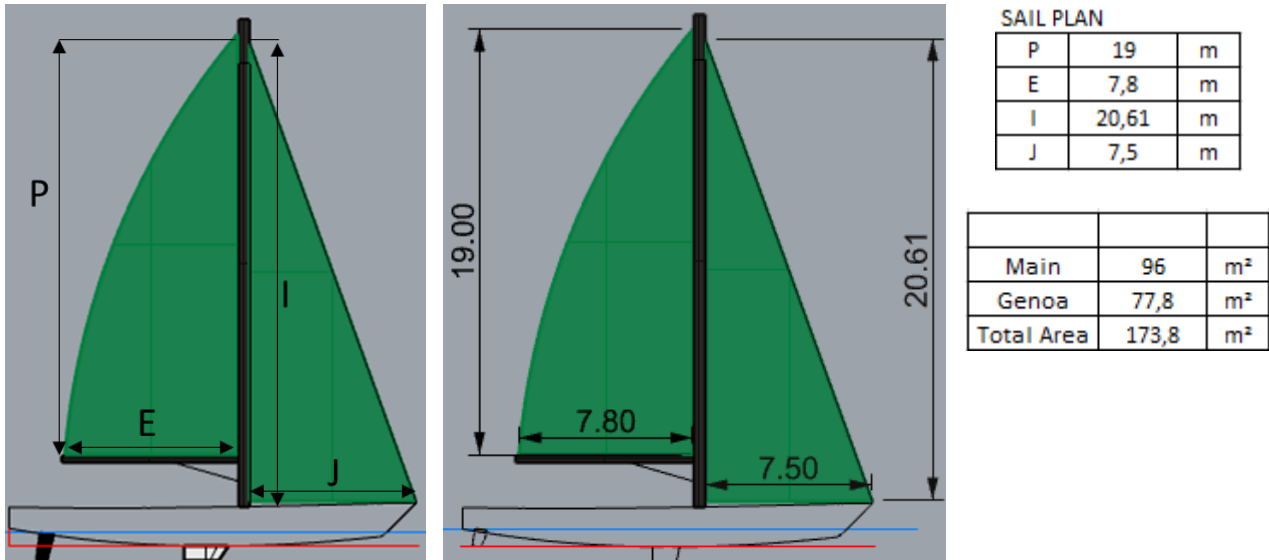
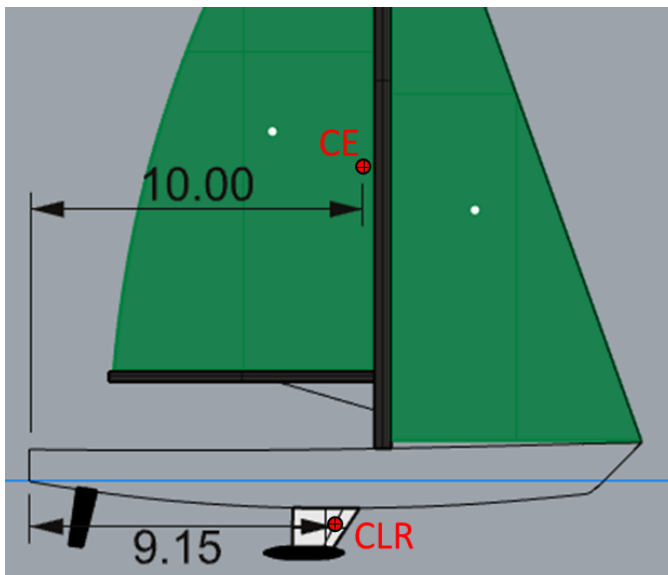


Figure 20: Sail Plan.

According to reference [2], is important to have a good balance between the center of effort on the sails (CE) and the hydrodynamic (CLR). According to experience, to have a well-balanced yacht the CE should be always in front of CLR, and the horizontal distance between them, called lead, is recommended to be 2%-6% of L_{WL} (for Arpex configuration).



$$L_{WL}=16,276\text{m}$$

$$\text{Lead} = \text{CLR} - \text{CR} = 10-9,15 = 0,85\text{m}$$

$$\text{Lead}/L_{WL} = 0,85/16,276=5,2\%$$

Figure 21: Lead check.

7 Rigging

For the dimensioning of rigging, chapter 11 of reference [2] was used. It refers to the Nordic Boat Standard (NBS).

The limits of using this approach are:

- Only valid for masthead and fractional rigs
- Considering 1 or 2 pairs of spreaders
- $\frac{I \times J}{E \times P} < 1,6$
- $Sail\ area > \frac{RM}{128 \times HA}$

Where RM is the righting moment, in [N.m], and HA is the heeling arm in [m].

RM is obtained from the formulas given in reference [2].

$$RM = 27 \times RM_{1^\circ} \times \frac{\Delta}{G} + \delta_{RM}$$

$$\delta_{RM} = 75 \times n \times (3,45 \times B - 4,9 \times F_S)$$

Where:

RM_{1° is the righting moment at 1 degree [Nm].

Δ is full load weight of boat [t]

G is the lightship weight of boat [t]

δ_{RM} is Additional moment from crew to windward [Nm]

n is number of people onboard

B is maximum beam [m]

F_S is freeboard at mast [m]

RM _{1°}	5351	Nm
n	8	-
F _S	1,12	m
δRM	7315	Nm
HA	9,54	m
RM	178460	Nm

SA	RM/(128HA)	CHECK
173,8	146,1	OK!

(I×J)/(E×P)	CHECK
1,04	OK!

The configuration decided is a fractional rig with two spreaders.

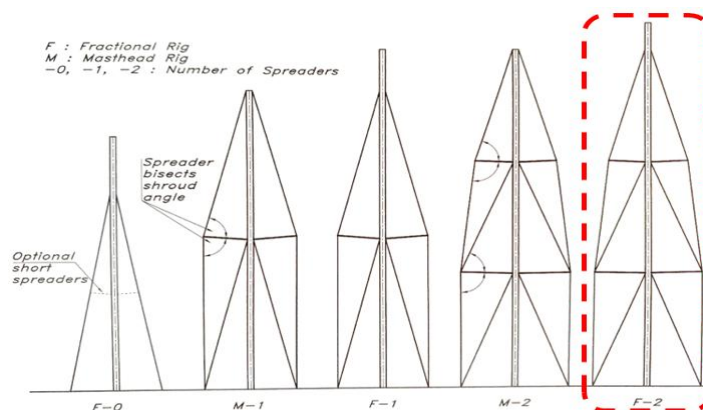


Figure 22: Types of rig configuration (reference [2]).

7.1 Forces on Shrouds

To dimension the shrouds, the forces acting on them need to be checked, following reference [2] and notes from yacht rigging classes. The forces come from the wind pressure on the sails and dynamic additions from wind and sea.

The data used for the calculations are presented in Table 4.

Table 4: Data used for calculation.

Data	Value	Unit	Data	Value	Unit
RM	178460	[Nm]	BD	2	[m]
a_1	22,5	[m]	β_1	16,76	deg
a_2	10,6	[m]	β_2	15,95	deg
l_1	7	[m]	β_3	12,53	deg
l_2	7	[m]	γ_1	1,25	deg
l_3	7,2	[m]	γ_2	3,27	deg
d_1	6,584	[m]			
d_2	0,413	[m]			

Two load cases are considered:

1. Case 1: Rig loaded by only foresail.
2. Case 2: Rig loaded by deep reefed mainsail.

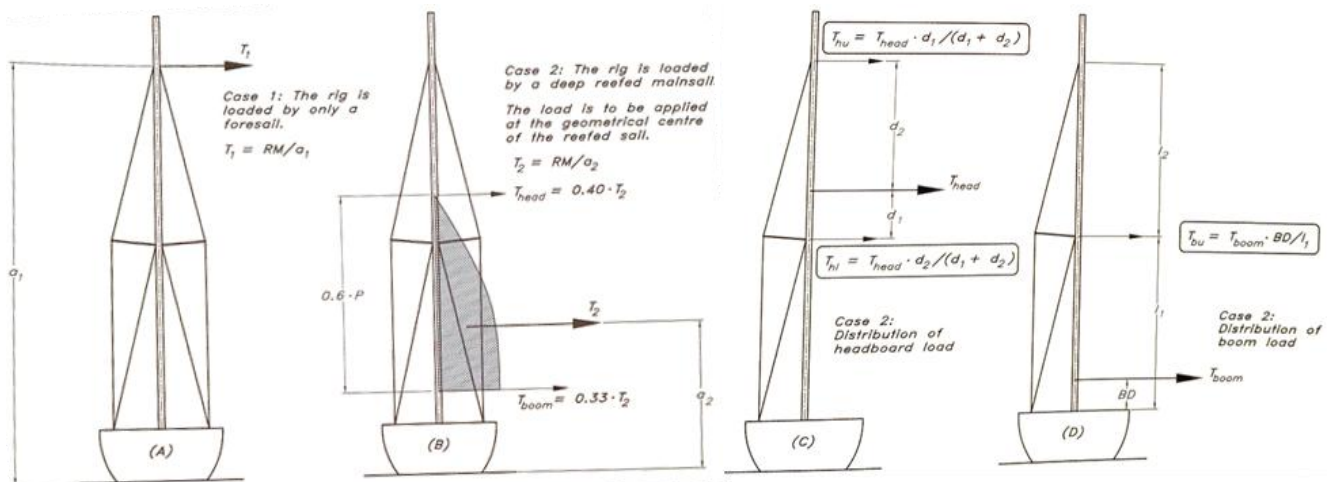


Figure 23: Transverse forces for cases 1 and 2. Reference [2].

Table 5: Transverse forces calculation.

T Forces	T_1	T_2	T_{head}	T_{boom}	T_{hl}	T_{hu}	T_{bu}
Equation	$\frac{RM}{a_1}$	$\frac{RM}{a_2}$	$0,4 \times T_2$	$0,33 \times T_2$	$T_{head} \times \frac{d_2}{d_1 + d_2}$	$T_{head} \times \frac{d_1}{d_1 + d_2}$	$T_{boom} \times \frac{BD}{l_1}$
Case 1 [N]	7932	-	-	-	-	-	-
Case 2 [N]	-	16836	6734	5556	397	6337	1587

After obtaining the transverse forces (T), the dimensioning forces (F) can be calculated, according to Figure 24.

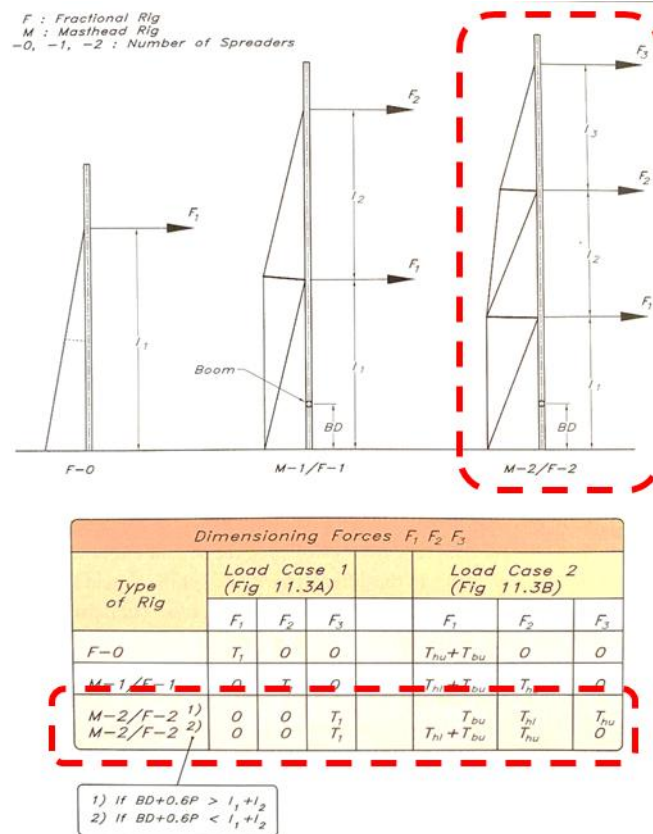


Figure 24: Dimensioning Forces, reference [2].

Table 6: Dimension forces.

F Forces	F_1	F_2	F_3
Case 1	0	0	T_1
Case 2	$T_{h1} + T_{bu}$	T_{hu}	0

Then, the final dimension loads can be calculated, applying some safety factors, as shown in Figure 25. Table 7 presents the calculated values following equations from Figure 25.

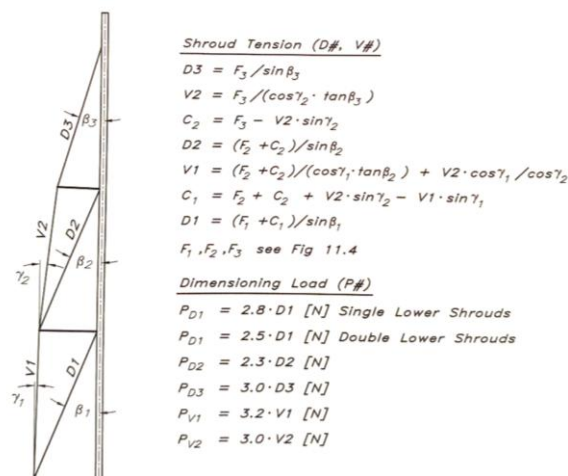


Figure 25: Dimensioning loads, reference [2].

Table 7: Dimensioning Loads calculation.

Shroud Tension	D ₃	V ₂	C ₂	D ₂	V ₁	C ₁	D ₁
Case 1 [N]	36559	35747	5891	21436	56412	6701	23235
Case 2 [N]	0	0	0	23057	22174	5853	27178
Dimensioning Load		P _{D1}	P _{D2}	P _{D3}	P _{V1}	P _{V2}	
	[N]	76098	53032	109678	180518	109678	
	[t]	7760	5408	11184	18408	11184	

The material selected for the rigging is stainless steel, with a 1x19 wire configuration. Besides being heavier than other materials, such as Kevlar, it compensates on the costs. The technical table of thickness and ultimate strength were taken from reference [3].

Table 8: Chosen wires for shrouds.

Shroud	Length [m]	Load [t]	1x19 wire type	Breaking load [t]	Weight [kg]
D ₁	7,46	7760	D10	7870	3,70
D ₂	7,28	5408	D10	7870	3,60
D ₃	7,38	11184	D12.7	11650	5,48
V ₁	7,15	18408	D18	18600	9,44
V ₂	7	11184	D12.7	11650	5,20

7.2 Forces on stays

Following reference [2], the longitudinal forces on stays can be calculated according to the following equation.

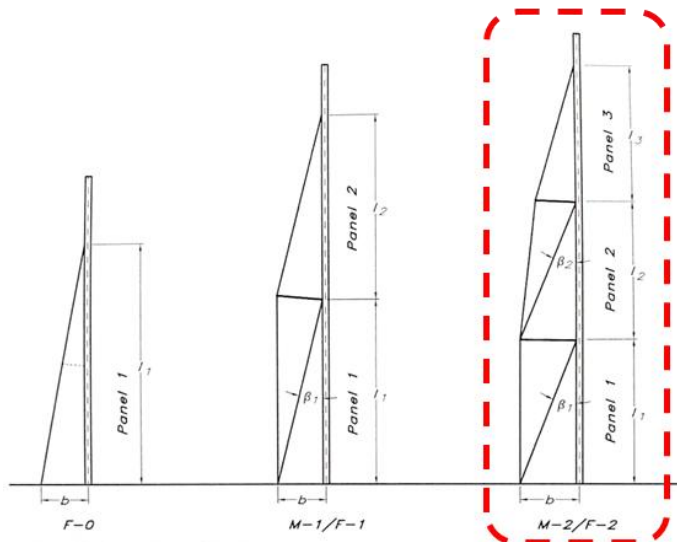
$$\text{Forestay : } P_{fo} = 15 \times \frac{RM}{l + F_s} \quad \text{Aftstay : } P_a = 2,8 \times \frac{RM}{l_a \times \sin \alpha_a}$$

Table 9: Chosen wires for stays.

Shroud	Length [m]	Load [t]	1x19 wire type	Breaking load [t]	Weight [kg]
Fore stay	22,07	12494	D14	13400	21,43
Aft stay	23,76	5185	D10	7870	11,77

7.3 Mast

The tensions calculated for shrouds and stays generate compression in the mast. To avoid buckling phenomena, it should have enough stiffness. The required transverse (I_x) and longitudinal (I_y) moments of inertia are presented hereafter, according to reference [2].



Required transverse moment of inertia, I_x , for the mast :

$$I_x = k_1 \cdot m \cdot PT \cdot l(n)^2 \text{ [mm}^4\text{]}$$

$PT = 1.5 \cdot RM/b$ [N]
 $k_1 =$ panel factor (see table below)
 $m = 1$ for aluminium
 7.25 for wood (Spruce)
 $70500/E$ for other materials
 $l(n) =$ actual panel length
 $k_3 = 1.35$ for deck stepped masts
 1.00 for keel stepped masts

When calculating I_x for panel 2
 PT is decreased by:

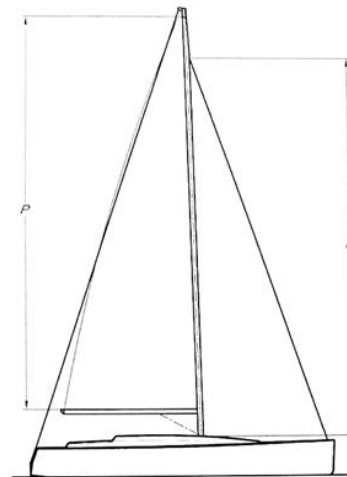
$$D1 \cdot \cos \beta_1$$

When calculating I_x for panel 3
 PT is decreased by:

$$D1 \cdot \cos \beta_1 + D2 \cdot \cos \beta_2$$

$D1$ is taken from Fig 11.6 for a single spreader rig.
 $D1$ and $D2$ are taken from Fig 11.7 for a double spreader rig.

Type of Rig	Panel Factor k_1	
	Panel 1	Panel 2 & 3
F-0	$2.4 \cdot k_3$	-
F-0 short spr.	$1.6 \cdot k_3$	-
M-1	$2.5 \cdot k_3$	3.50
F-1	$2.4 \cdot k_3$	3.35
M-2	$2.7 \cdot k_3$	3.80
F-2	$2.6 \cdot k_3$	3.60



Required Longitudinal Moment of Inertia for the Mast (I_y):

$$I_y = k_2 \cdot k_3 \cdot m \cdot PT \cdot h^2 \text{ [mm}^4\text{]}$$

$PT = 1.5 \cdot RM/b$ [N]

$k_2 =$ staying factor (see table below)

$m = 1$ for aluminium

7.25 for wood (spruce)

$70500/E$ for other materials

$k_3 = 1.35$ for deck stepped masts

1.00 for keel stepped masts

$h =$ height above deck or superstructure to the highest sail carrying forestay

Type of Staying	Staying Factor k_2				
	F-0	M-1	F-1	M-2	F-2
1) Double Lowers	-	0.85	0.80	0.90	0.85
2) Single Lowers	-	0.80	0.75	0.85	0.80
3) Runners & i.f.	-	-	0.85	-	0.80
4) Runners & c.s.	-	1.00	0.95	0.95	0.90
5) Swept spreaders	-	-	1.00	-	0.95
6a) Short spreaders	1.05	-	-	-	-
6b) No spreaders	2.00	-	-	-	-

Figure 26: Mast required inertias.

The data used for the calculation of inertias are presented in the following table.

Table 10: Data used for mast dimensioning.

Data	Value	Unit	Data	Value	Unit
RM	178230	[Nm]	l_1	7	[m]
b	2,15	[m]	l_2	7	[m]
k_3	1	-	l_3	7	[m]
k_2	0,95	-	h	20,61	[m]
m	1	-	Length	23,775	[m]
PT	124173	[N]			

Table 11: Required moments of inertia.

	Panel1	Panel2	Panel3	Unit
I_x Equations	$I_x = k_1 \cdot m \cdot PT \cdot l_1^2$	$I_x = k_1 \cdot m \cdot (PT - D_1 \cos \beta_1) \cdot l_2^2$	$I_x = k_1 \cdot m \cdot (PT - D_1 \cos \beta_1 - D_2 \cos \beta_2) \cdot l_3^2$	[mm ⁴]
I_y Equations	$I_y = k_2 \cdot k_3 \cdot m \cdot PT \cdot h^2$			[mm ⁴]
k_1	2,6	3,6	3,6	-
I_x	1582	1732	1341	[cm ⁴]
I_y	5011	5011	5011	[cm ⁴]

The dimensioning panel is the Panel 2. Mast was chosen based on the required inertias calculated. Catalogue from reference [4] was used.

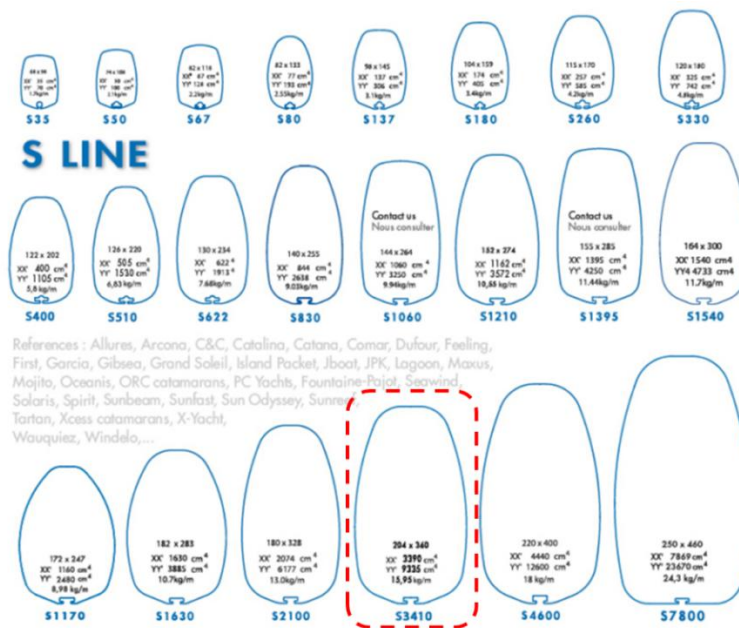
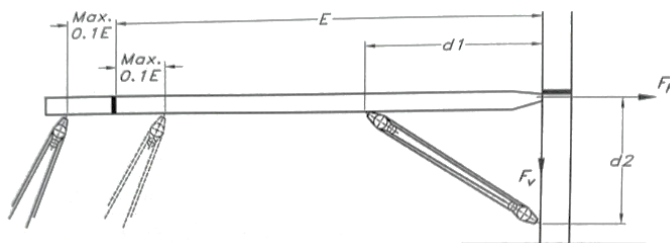


Figure 27: Mast section chosen.

7.4 Boom

For the boom dimension, the gooseneck shall resist some forces and the boom shall comply with a required section modulus, based on the righting moment, as shown in Figure 28.



The gooseneck shall be able to withstand a vertical and horizontal force of:

$$F_v = 0.5 \cdot RM \cdot E / (HA \cdot d1) \quad [N]$$

$$F_h = 0.5 \cdot RM \cdot E / (HA \cdot d2) \quad [N]$$

HA = distance from waterline to centre of effort of sails (see Fig 11.1)

Required vertical section modulus for the boom is:

$$SM = 600 \cdot RM \cdot (E - d1) / (\sigma_{0.2} \cdot HA) \quad [mm^3]$$

The horizontal section modulus is to be at least 50% of the vertical.

Figure 28: Boom required modulus section.

Data used for the calculation and the required section modulus are presented in Table 12.

Table 12: Data for boom check.

DATA			REQUIRED				
HA	9,54	[m]			F_h	44838	[N]
E	7,2	[m]			F_v	44838	[N]
d_1	1,5	[m]					
d_2	1,5	[m]			$SM_{VERTICAL} =$	266	[cm ³]
$\sigma_{0.2\%}$	240	[N/mm ²]			$SM_{HORIZONTAL} =$	133	[cm ³]
Length	8	[m]					

Catalogue from reference [5], present a series of boom sections. The one that comply to the requirements is the B290.



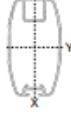
	Boom section	Dim., mm height/widht	I_y cm ⁴	I_x cm ⁴	Wall thickness mm	Weight kg/m	W_y^{min} cm ³	W_x^{min} cm ³	Sail groove mm
	B087	86/60	60.2	27.7	2.0	1.55	13.4	9.3	5.5 ± 0.6
	B104	104/60	97.5	33.6	2.0	1.71	18.5	11.2	5.5 ± 0.6
	B120	120/62	155	42.5	1.8	2.12	24.8	13.7	5.5 ± 0.75
	B135	135/71	265	70	2.0-2.8	2.66	39	19.5	5.8 ± 0.75
	B153	153/86	438	132	2.5-2.9	3.60	55.2	30.8	10 ± 0.75
	B172	171/98	720	219	2.3-3.2	4.66	81.5	44.7	10 ± 0.75
	B199	199/122	1257	407	3.1	5.90	124.6	67.00	10 ± 0.75
	B250	250/140	2706	692	3.2	7.95	200.1	101.3	6.25 ± 0.75
	B290	290/155	5209	1524	4.1	11.80	339	196	10.25 ± 0.75
	B380	380/186	12030	3283	4.5-9.0	17.80	586	353	No groove

Figure 29: Boom section chosen for the design.

7.5 Spreaders

The spreaders are used to reduce the effective unsupported length of the mast, thereby limiting the need for excessively high sectional inertia and reducing the risk of buckling.

Reference [2] also presents a methodology to dimension such element, as shown in Figure 30.

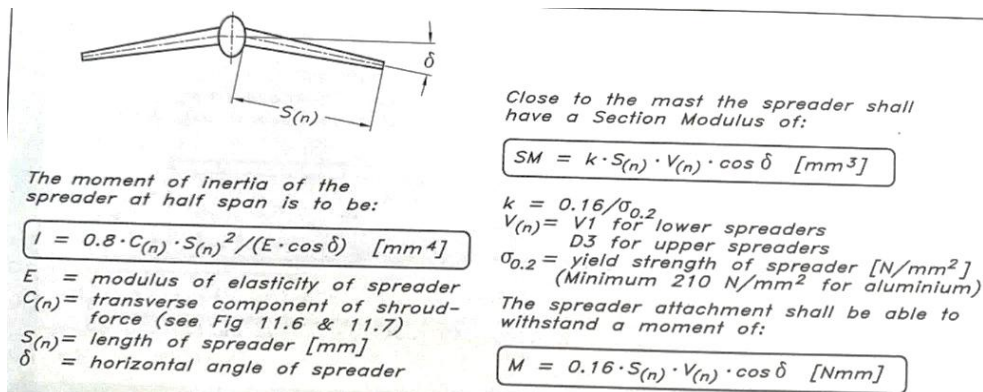


Figure 30: Spreader calculation.

The design considers two spreaders and they were calculated separately. Data is presented in Table 13 and required values on Table 14.

Table 13: Data for spreader definition.

E	70000	[MPa]
$\sigma_{0.2\%}$	240	[MPa]
k	0,000667	[MPa]
V_1	56339	[N]
D_3	36512	[N]
C_1	6692	[N]
S_1	2000	[mm]
δ_1	20	[deg]
C_2	5884	[N]
S_2	1600	[mm]
δ_2	15	[deg]

Table 14: Required values.

Middle Spreader			
	Spreader 1	Spreader 2	
I	33	18	[cm ⁴]
Close to mast			
SM	71	38	[cm ³]
I	162	87	[cm ⁴]
M	16941261	9028584	[N.mm]

The sections were taken from Sparcraft catalogue, reference [6]. Section BF5 was chosen, as shown in Figure 31.

Sections	Part number Référence	Inertias Inerties		External dimensions Dim. extérieures (mm)	Max. internal dimensions Dimensions intérieures maxi (mm)	Weight Poids kg/m	Profile length Longueur profil (m)
		XX'	YY'				
BF 2	21000026003	6	1	19 x 55	13 x 40	0,8	6
BF 3	21000036003	27	6	32 x 75	22 x 53	1,7	6
BF 4	21000046003	83	12	37 x 106	27 x 72	2,4	6
BF 5	21000056013	236	24	46 x 153	36 x 100	3,4	6
BF 6	21000066003	353	37	53 x 167	45 x 112	4,0	6

Figure 31: Spreader section chosen.

8 Structural scantling

The sailboat proposed is an unlimited ocean passage vessel, which requires some reliable structure. To comply with it, it was decided for an aluminium structure. RINA rule was chosen for the scantling, reference [7]. The sailboat is considered displacement yacht for the sake of scantling.

General data used for the calculations are presented hereafter.

Table 15: Main data.

DATA	Value	Comment
LOA [m]	18,5	
Lwl [m]	16,276	WL at Δ
L [m]	16,276	scantling length
B [m]	5,2	Beam
B_{wl} [m]	4,606	Beam at WL
D [m]	2,36	Deck height
H [m]	1,75	Depth
d [m]	0,655	Draft of canoe body
C_b	0,44	
Δ [t]	22	
ρ [t/m ³]	1,025	

8.1 Material

The aluminium alloy AL 5083 H111 was chosen for the design for its versatility, good weldability and resistance in low temperatures.

Table 16: Material properties.

MATERIAL AL 5083 H111						
Plate t<6	$\sigma_{0.2\%}$	125	MPa		K	0,880
Plate t>6	$\sigma_{0.2\%}$	115	MPa		K	0,957
Reinforcement	$\sigma_{0.2\%}$	110	MPa		K	1,000
	E	70000	MPa		v	0,33

K is the material factor obtained from Ch3,Sec2,1.6 from reference [7].

8.2 Minimum Thicknesses

The minimum thicknesses according to RINA for the design are presented in Ch3,Sec1,6 of reference [7] and are based on the scantling length (L) and the material factor K.

Table 17: Extract from RINA rule.

Member	Minimum thickness (mm)
Keel, bottom plating	$t_1 = 1,75 \cdot L^{1/3} \cdot K^{0,5}$
Side plating	$t_2 = 1,50 \cdot L^{1/3} \cdot K^{0,5}$
Open strength deck plating	$t_3 = 1,50 \cdot L^{1/3} \cdot K^{0,5}$
Lower and enclosed deck plating	$t_4 = t_3 - 0,5$
1st tier superstructure front bulkhead	$t_5 = t_1$
Superstructure bulkhead	$t_6 = t_5 - 1,5$
Watertight subdivision bulkhead	$t_7 = t_6 - 0,5$
Tank bulkhead	$t_8 = t_2$
Centre girder	$t_9 = 2,3 \cdot L^{1/3} \cdot K^{0,5}$
Floors and side girders	$t_{10} = 1,70 \cdot L^{1/3} \cdot K^{0,5}$
Tubular pillars	$t_{11} = 0,05 d$ (1)

(1) d = diameter of the pillar, in mm

Table 18: Minimum thicknesses.

Area	t _{min}
Keel & bottom plating	4,2
Side plating	3,6
Open strength deck plating	3,6
Lower and enclosed deck plating	3,1
Watertight subdivision bulkhead	3,1
Tank bulkhead	3,6
Centre girder	5,5
Floors and side girders	4,0

8.3 Loads

8.3.1 Global Loads

The values of the longitudinal bending moment and shear force are given, as a first approximation, by formulas in the Ch1,Sec5,4.4.2 of reference [7]. The total bending moments $M_{bl,H}$ (hogging conditions) and $M_{bl,S}$ (sagging conditions) and the shear Force T_t are:

$$M_{bl,H} = M_{s,H} + 0,95 \cdot S \cdot C \cdot L^2 \cdot B \cdot C_B \text{ [kN.m]}$$

$$M_{bl,S} = M_{s,S} + 0,55 \cdot S \cdot C \cdot L^2 \cdot B \cdot (C_B + 0,7) \text{ [kN.m]}$$

$$M_{bl,S} = \frac{3,1 \cdot M_{bl}}{L} \text{ [kN]}$$

Where,

$$M_{s,H} = 85 \cdot C \cdot L^2 \cdot B \cdot (C_B + 0,7) \cdot 10^{-3} \text{ (Still water hogging bending moment [kN.m])}$$

$$M_{s,S} = 63 \cdot C \cdot L^2 \cdot B \cdot (C_B + 0,7) \cdot 10^{-3} \text{ (Still water sagging bending moment [kN.m])}$$

S is a parameter taken as 0,21.

$$C = (6+0,02L).$$

M_{bl} is the maximum between $M_{bl,H}$ and $M_{bl,S}$.

Table 19: Global Loads.

GLOBAL LOADS					
Ch1,Sc5,4.2.2	BENDING MOMENTS AND SHEAR FORCE				
				M _{sH}	963
Hogging	2006	[kN.m]		M _{sS}	714
				S	0,21
Sagging	741	[kN.m]		C	6,32552
				C _b used	0,60
Shear	382	[kN]			

8.3.2 Local Loads

The pressures to be considered in the external hull and in the internal bulkheads and decks are presented in this chapter.

- Bottom Shell Pressure

$$p_1 = 0,24 \cdot L^{0,5} \cdot \left(1 - \frac{h_0}{2 \cdot T}\right) + 10 \cdot (h_0 + a \cdot L)$$

- Side Shell Pressure

$$p_1 = 66,25 \cdot (a + 0,024) \cdot (0,15 \cdot L - h_0)$$

Where,

h_0 is vertical distance from the point of reference to full load water line.

a is a coefficient function of the longitudinal position of point of reference:

- 0,036 aft of 0,5 L
- 0,04/(CB - 0,024) in way of Pp_{AV}

Pressure not be assumed smaller than 10.D, where D stands for depth.

Table 20: Local Pressures.

Ch1,Sc5,5.3.2	Design pressure for BOTTOM SHELL				
	p1	7,62	kN/m ²		h0 0,655
	Not less than	23,55	kN/m ²		a 0,036
					0,096828
Ch1,Sc5,5.4.2	Design pressure for SIDE SHELL				
	p1	7,10	kN/m ²		h0 0,655
	Not less than	17	kN/m ²		a 0,036
					h1 1,70

8.4 Plating thicknesses

The thicknesses of plating shall not be less than:

$$t_1 = k_1 \cdot k_2 \cdot k_a \cdot s \cdot (p \cdot K)^{0,5} \text{ [mm]}$$

Where,

s is span.

k_1 is 0,15.

k_a is the ratio S/s between greater panel dimension (S) and span (s).

k_2 is curvature correction factor (1-h/s), where h is the deflection between 2 reinforcements.

p is the pressure calculated in section 8.3.2.

The thickness of the bottom around the keel is increased in 2mm, as mentioned in Ch3,Sec5,2 of reference [7].

For the deck, plating shall be at least:

$$t_{deck} = 2,5 \cdot s \cdot (L \cdot K)^{0,5} \text{ [mm]}$$

To define the minimum plate thicknesses, the hull was divided into several panels, according to Figure 32.

The plating thickness check is presented in Table 21. The thickness of bottom and bilge were fixed in 8mm, except for the region around the keel, which was set to 10mm. The deck plate was defined as 6mm (minimum by rule is 4,7mm).

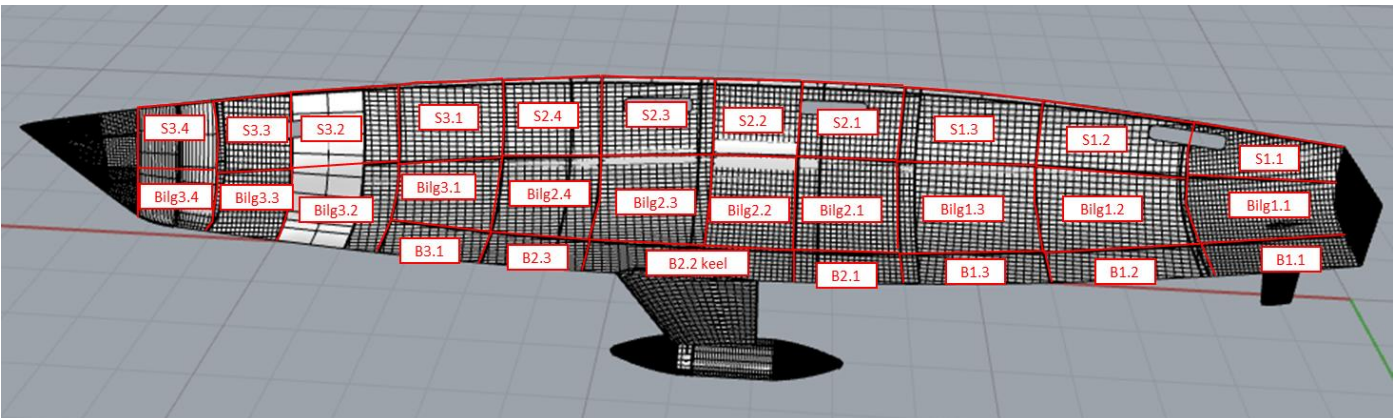


Figure 32: Hull division.

Table 21: Plating thickness check.

PLATING		PANEL SIZE		t _{chosen} [mm]	x [m]	span [mm]	pdr [mm]	h [mm]	x/L	h _o [m]	a	P [kN/m ²]	S/s	k _a	k _z	t _{1 min} [mm]	CHECK	
		length	width															
Bottom	Zone1	B1.1	1936	1003	8,00	0,22	500	481,4	6	0,01	0,174	0,036	17,50	3,87	22,40	0,99	6,80	Pass!
		B1.2	2014	1002	8,00	2,16	500	242,5	4	0,13	0,413	0,036	17,50	4,03	22,40	0,99	6,82	Pass!
		B1.3	2006	1001	8,00	4,16	500	90,0	6	0,26	0,565	0,036	17,50	4,01	22,40	0,99	6,79	Pass!
		Bilg1.1	1936	944	8,00	0,22	500	534,0	22	0,01	0,121	0,036	17,50	3,87	22,40	0,96	6,57	Pass!
		Bilg1.2	2014	1325	8,00	2,16	500	293,0	20	0,13	0,362	0,036	17,50	4,03	22,40	0,96	6,60	Pass!
		Bilg1.3	2006	1461	8,00	4,16	500	133,0	15	0,26	0,522	0,036	17,50	4,01	22,40	0,97	6,67	Pass!
	Zone2	B2.1	1540	1001	8,00	5,99	500	11,0	2	0,37	0,644	0,036	17,50	3,08	22,40	1,00	6,85	Pass!
		B2.2 KEEL	3000	1002	10,00	8,21	500	0,0	0	0,50	0,655	0,037	17,50	6,00	22,40	1,00	6,87	Pass!
		B2.3	1460	1003	8,00	10,45	500	9,7	2	0,64	0,645	0,053	17,50	2,92	22,40	1,00	6,85	Pass!
		Bilg2.1	1540	1642	8,00	5,99	500	65,0	12	0,37	0,590	0,036	17,50	3,08	22,40	0,98	6,71	Pass!
		Bilg2.2	1540	1575	8,00	7,50	500	50,1	15	0,46	0,605	0,036	17,50	3,08	22,40	0,97	6,67	Pass!
		Bilg2.3	1460	1384	8,00	9,00	500	80,0	15	0,55	0,575	0,042	17,50	2,92	22,40	0,97	6,67	Pass!
	Zone3	Bilg2.4	1460	1384	8,00	10,45	500	165,2	18	0,64	0,490	0,053	17,50	2,92	22,40	0,96	6,63	Pass!
		B3.1	1502	1009	8,00	11,90	500	25,3	6	0,73	0,630	0,064	17,50	3,00	22,40	0,99	6,79	Pass!
		Bilg3.1	1502	1065	8,00	11,90	500	161,0	25	0,73	0,494	0,064	17,50	3,00	22,40	0,95	6,53	Pass!
		Bilg3.2	1505	1650	8,00	13,40	500	131,9	32	0,82	0,523	0,075	17,50	3,01	22,40	0,94	6,43	Pass!
		Bilg3.3	1507	1266	8,00	14,90	500	251,5	40	0,92	0,404	0,087	17,50	3,01	22,40	0,92	6,32	Pass!
		Bilg3.4	688	534	8,00	15,97	500	398,2	46	0,98	0,257	0,095	17,50	1,38	20,74	0,91	5,78	Pass!
Side	Zone1	S1.1	1936	814	6,00	1,00	500	937,7	56	0,06	0,94	0,036	5,98	3,87	22,40	0,89	3,57	Pass!
		S1.2	2014	941	6,00	3,00	500	829,0	65	0,18	0,83	0,036	6,41	4,03	22,40	0,87	3,62	Pass!
		S1.3	2006	1082	6,00	5,00	500	701,2	78	0,31	0,70	0,036	6,92	4,01	22,40	0,85	3,65	Pass!
	Zone2	S2.1	1540	967	6,00	6,75	500	800,0	50	0,41	0,80	0,036	6,53	3,08	22,40	0,90	3,78	Pass!
		S2.2	1540	987	6,00	8,25	500	792,0	43	0,51	0,79	0,037	6,65	3,08	22,40	0,92	3,88	Pass!
		S2.3	1460	1021	6,00	9,75	500	800,0	32	0,60	0,80	0,048	7,84	2,92	22,40	0,94	4,31	Pass!
		S2.4	1460	1068	6,00	11,25	500	800,0	46	0,69	0,80	0,059	9,06	2,92	22,40	0,91	4,49	Pass!
	Zone3	S3.1	1502	1122	6,00	12,75	500	800,0	45	0,78	0,80	0,071	10,29	3,00	22,40	0,91	4,80	Pass!
		S3.2	1505	1044	6,00	14,25	500	800,0	31	0,88	0,80	0,082	11,51	3,01	22,40	0,94	5,23	Pass!
		S3.3	1507	1247	6,00	15,75	500	800,0	28	0,97	0,80	0,093	12,73	3,01	22,40	0,94	5,53	Pass!
		S3.4	688	100	6,00	16,00	500	800,0	26	0,98	0,80	0,095	12,94	1,38	20,74	0,95	5,19	Pass!

8.5 Girders and Reinforcements

The reinforcements shall comply section modulus calculation according to the following equations.

Bottom and side longitudinals	$Z = k_1 \cdot s \cdot S^2 \cdot K \cdot p \text{ [cm}^3\text{]}$	$k_1=1,6$
Bottom girder	$Z = k_1 \cdot b_{pc} \cdot S^2 \cdot K \cdot p \text{ [cm}^3\text{]}$	$k_1=1,6$ and $b_{pc}=500\text{mm}$
Transverse frames	$Z = k_1 \cdot s \cdot S^2 \cdot K \cdot p \text{ [cm}^3\text{]}$	$k_1=1,27$
Deck longitudinals	$Z = 14 \cdot C_1 \cdot s \cdot S^2 \cdot K \cdot h \text{ [cm}^3\text{]}$	$C_1=1,44$

The reinforcements section used for the design are presented hereafter.

Central Girder

Height [mm]	180
Web tck [mm]	8
Width [mm]	100
Flange tck [mm]	15

s [mm]	500
t [mm]	8

Requirement Check	
S _l [mm]	1000
c	0,44
A _s [cm ²]	174,4

Area [mm ²]	1320
z ₁ [mm]	82,5
Inertia [mm ⁴]	4,26E+06
Area [mm ²]	1500
z ₂ [mm]	172,5
Inertia [mm ⁴]	2,20E+07
Effective Area [mm ²]	4000
z ₃ [mm]	-4
Inertia [mm ⁴]	1,24E+07

Area total	6820	mm ²
Inertia total	3,86E+07	mm ⁴
z	51,6	mm

SM _{calculated}	300	cm ³
SM _{required}	286	cm ³
	Pass!	

Bottom Longitudinal

Height [mm]	60
Width [mm]	30
tck [mm]	6

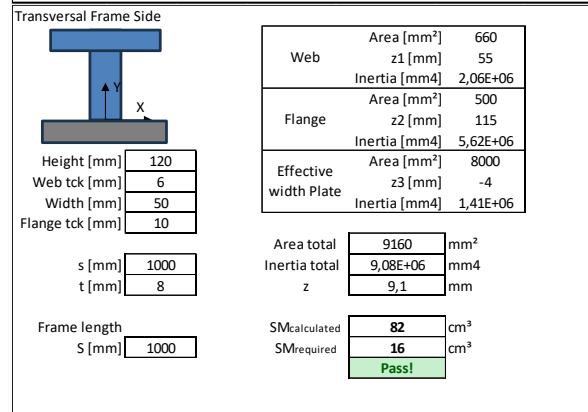
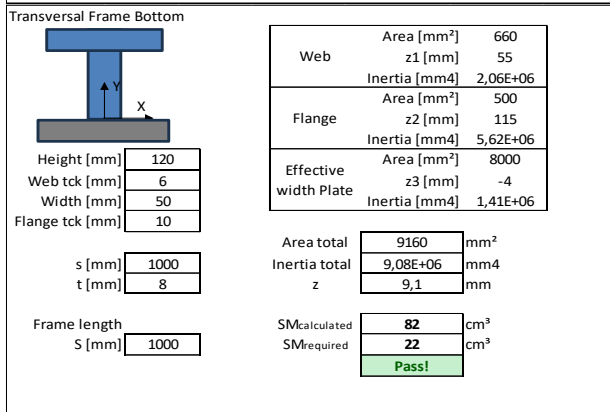
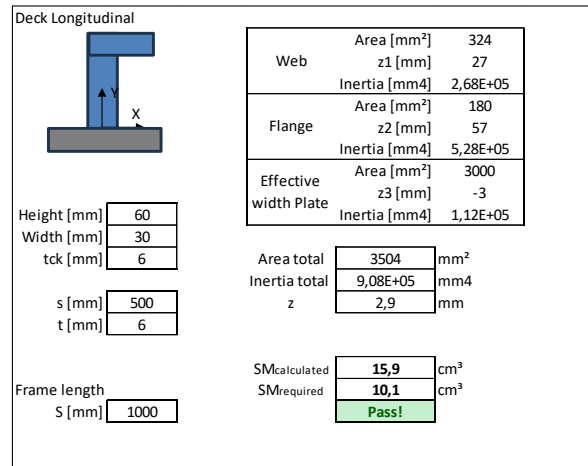
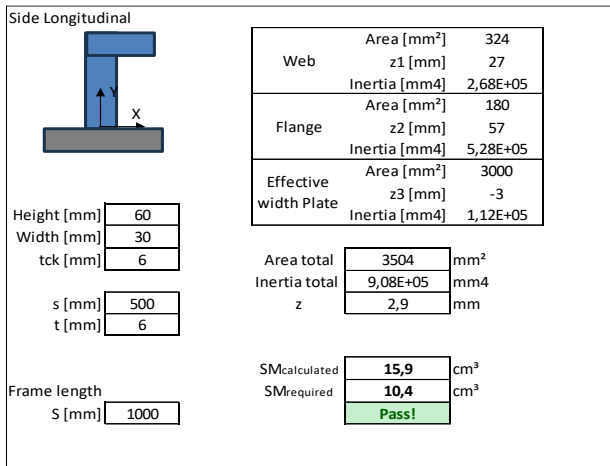
s [mm]	500
t [mm]	8

Frame length	S [mm]	1000
--------------	--------	------

Area [mm ²]	324
z ₁ [mm]	27
Inertia [mm ⁴]	3,03E+05
Area [mm ²]	180
z ₂ [mm]	57
Inertia [mm ⁴]	5,72E+05
Effective Area [mm ²]	4000
z ₃ [mm]	-4
Inertia [mm ⁴]	1,08E+05

Area total	4504	mm ²
Inertia total	9,84E+05	mm ⁴
z	0,7	mm

SM _{calculated}	16,6	cm ³
SM _{required}	14,0	cm ³
	Pass!	



8.6 Longitudinal Strength

Besides local analysis, a global behaviour of the mid-section shall be performed according to RINA. The midship section shall comply with maximum bending and shear stresses.

- Bending stresses for bottom and deck, respectively:

$$\sigma_f \leq f \cdot \sigma_s \text{ [MPa]}$$

$$\sigma_p \leq f \cdot \sigma_s \text{ [MPa]}$$

Where,

$$\sigma_f = \frac{M_t}{1000 \cdot W_f} \text{ [MPa]} \quad \text{and} \quad \sigma_p = \frac{M_t}{1000 \cdot W_p} \text{ [MPa]}$$

W_f and W_p are the midsection modulus, in m^3 .

M_t is total vertical moment taken as maximum calculated in Table 19.

$f=0,72$.

σ_s is the minimum yield stress, taken as 110 MPa.

- Moment of Inertia shall not be less than:

$$J = 18 \cdot M_T \cdot 10^{-6} \text{ [m}^4\text{]}$$

- Shear Stress shall comply with the following relation.

$$\frac{T_t}{A_t} \cdot 10^{-3} \leq \frac{f \cdot \sigma_s}{\sqrt{3}}$$

Where,

T_t is the total shear calculated in Table 19.

A_t is the area of the transverse section.

Midship section is presented in Figure 33 and calculations in Table 22.

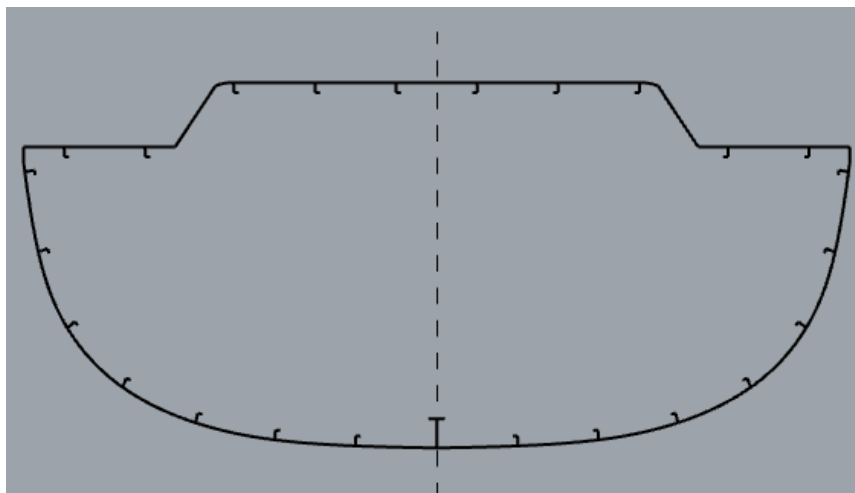


Figure 33: Midship section.

Table 22: Midship section calculation.

ID	Section	LOCAL			GLOBAL	
		z [mm]	Area [mm ²]	Inertia [mm ⁴]	Location [mm]	Inertia [mm ⁴]
Central Girder	T200x10/100x20	9,1	6820	3,86E+07	44	6,80E+09
s1	L 60x30x6	9,1	13640	7,72E+07	52	1,34E+10
s2	L 60x30x6	9,1	13640	7,72E+07	87	1,25E+10
s3	L 60x30x6	9,1	13640	7,72E+07	176	1,03E+10
s4	L 60x30x6	9,1	13640	7,72E+07	363	6,33E+09
s5	L 60x30x6	9,1	13640	7,72E+07	700	1,66E+09
s6	L 60x30x6	9,1	13640	7,72E+07	1158	2,66E+08
s7	L 60x30x6	9,1	13640	7,72E+07	1603	4,40E+09
Deck s11	L 60x30x6	2,9	7008	1,82E+06	1852	4,55E+09
Deck s12	L 60x30x6	2,9	7008	1,82E+06	2248	1,01E+10
Deck s13	L 60x30x6	2,9	7008	1,82E+06	2248	1,01E+10
Deck s14	L 60x30x6	2,9	7008	1,82E+06	2248	1,01E+10
Deck s14	L 60x30x6	2,9	7008	1,82E+06	2248	1,01E+10
Deck Plate	6	3,0	10800	6,89E+03	2100	1,20E+10

MID SECTION	Area	z	Inertia
	[mm ²]	[mm]	[mm ⁴]
	148140	1049	1,13E+11

	Area	z	Inertia	Mod Sec
	[mm ²]	[mm]	[mm ⁴]	[mm ⁵]
BOTTOM	102300	555	5,56E+10	1,00E+08
DECK	45840	2153	5,70E+10	2,65E+07

The evaluation is shown below.

Table 23: Evaluation of midship section.

Section Modulus	W	MT	σ	Required	Check
	m ³	kNm	N/mm ²	N/mm ²	
Bottom	0,10	2006	20	79	Pass!
Deck	0,03	2006	76	79	Pass!

Inertia		MT	Calculated	Required	Check
		kNm	m ⁴	m ⁴	
Midship		2006	0,113	0,036	Pass!

Shear Stress	AT	TT	Calculated	Required	Check
	m ²	kN	kN/m ²	kN/m ²	
Midship	0,148	382	2579	45,7	Pass!

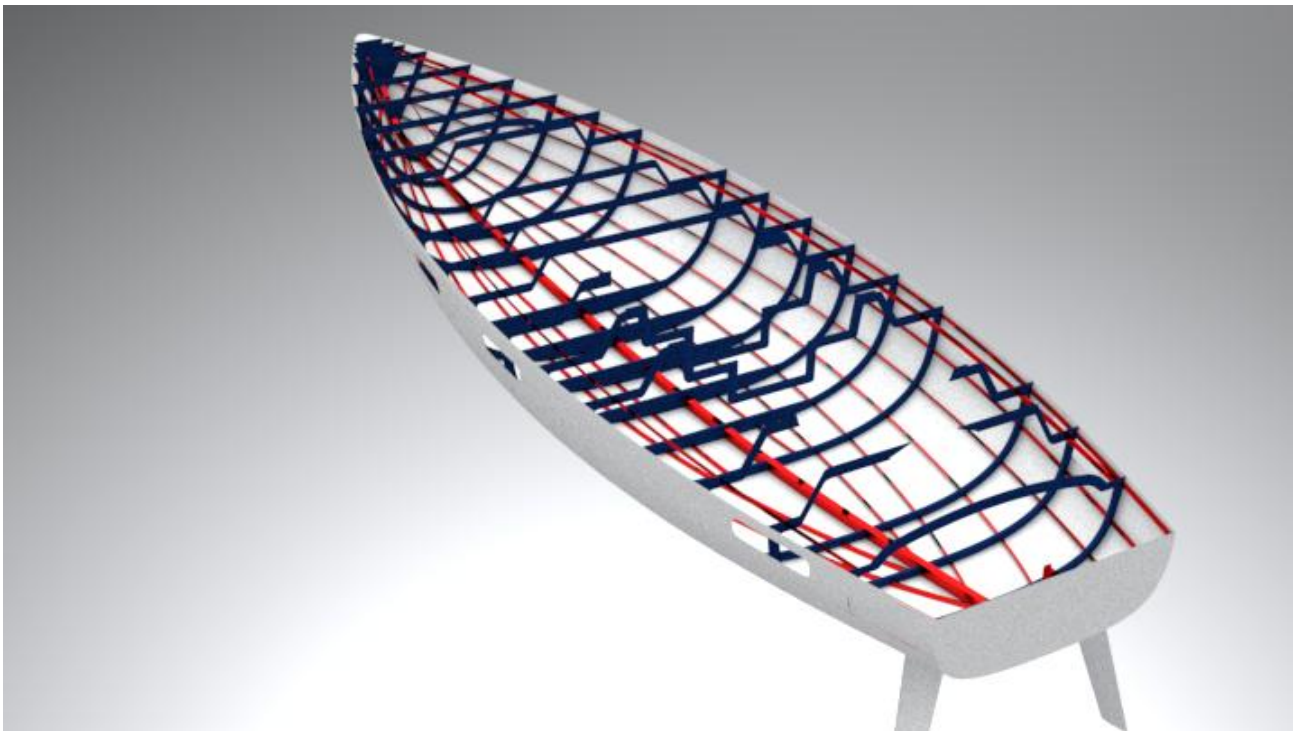


Figure 34: Final girders and reinforcements.

8.7 Keel check

This analysis will verify that the keel and its connection to the hull are strong enough to withstand heeling, pounding (vertical) and the grounding (longitudinal) loads. Following the Ch1,Sec2,3.1 of reference [7].

- **Load case a)** Longitudinal load (grounding) loads acting in the aft direction and parallel to the longitudinal hull axis. The load is to be applied to the bottom edge of the keel with boat in upright situation and canting keel in 0° and maximum degree. The value of the longitudinal loads may be calculated according to the following formula:

$$L_{GL(x)} = -1,8 \cdot g \cdot (\Delta - mk_{bulb}) \text{ [kN]} \quad L_{GL(y)} = 0,2 \cdot L_{GL(x)} \text{ [kN]}$$

- **Load case b)** Vertical load (pounding), acting upward on the bulb bottom in line with total keel center of gravity with the boat upright, canting keel with keel in 0° cant position.

$$V_{GL(z)} = 1,6 \cdot g \cdot (\Delta - mk_{total}) \text{ [kN]}$$

- **Load case c)** Heeling (lateral) the load is to be applied to the bottom edge of the keel with boat in upright situation and canting keel in 0° and maximum degree.

$$H = g \cdot mk_{total} \cdot c_d \text{ [kN]}$$

Where,

$$c_d = 1,0.$$

mk_{bulb} = mass of the keel bulb

mk_{total} = total mass of the keel

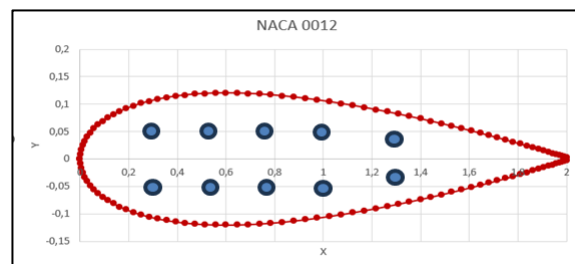
Table 24 presents the required section modulus of the keel for the loads mentioned above. It can be noted that the grounding case creates the higher load on the keel. Also, the bolts for keel attachment were checked for these cases. The safety factors are shown in green (positive values). The data from the bolts used are shown in Table 25.

Table 24: Keel verification.

k1		2,04		KEEL STRUCTURE			BOLTS					
				Arm [m]	Moment [kN.m]	SMrequired [cm³]	Tension kN	Per Bolt kN	SF	Shear kN	Per Bolt kN	SF
Longitudinal Load (Loadcase a)												
LGL(x)	251	kN	1,45	426	341	1637	164	1,3	251	25	7,0	
LGL(y)	50	kN	1,45	73	58	279	28	7,9	50	5	35,0	
Vertical Load (Loadcase b)												
VGL(z)	198	kN	1,45	288	230	1105	110	2,0	-	-	-	
Heeling (Loadcase c)												
H	92	kN	1,45	133	106	511	51	4,3	92	9	19,1	

Table 25: Bolts definition and preliminary positioning.

BOLTS:	M30 8.8		
n	10	f_y [Mpa]	640
Area [mm²]	561	f_u [Mpa]	800
Inertia [mm⁴]	1,30E+07	F_u [kN]	219,6
z [mm]	50	V_{allow} [kN]	175,7



9 Arrangement/Compartmentation

9.1 Tanks

The yacht is designed for long journeys and ocean passages. For that purpose, the tanks were dimensioned for large capacities, especially fuel and fresh water.

	Volume		CoG			Total Volume [L]	Tank Colour in Figure 35
	[m ³]	[L]	X [m]	Y [m]	Z [m]		
Fuel 1	0,494	494	6,15	0,86	0,185	988	Red
Fuel 2	0,494	494	6,15	-0,86	0,185		
Fresh water 1	0,723	723	9,22	0,7	0,182	1446	Cyan
Fresh water 2	0,723	723	9,22	0,7	0,182		
Gray water	0,25	250	9,50	1,00	0,19	250	Gray
Black water	0,20	200	9,50	-0,60	0,16	200	Black
Bilge	0,05	50	9,50	-1,11	0,19	50	Yellow

The locations of the tanks are presented in Figure 35. Moreover, the tanks pipes were defined preliminarily and presented as well.

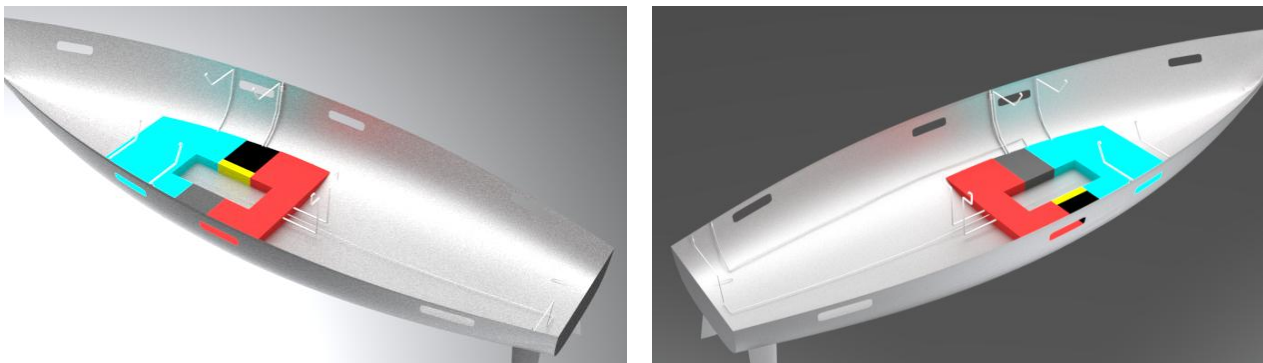


Figure 35: Location of tanks.

9.2 Arrangement

The arrangement of deck and internal areas were set following some market competitors. Moreover, the plans are presented in the Annexes.

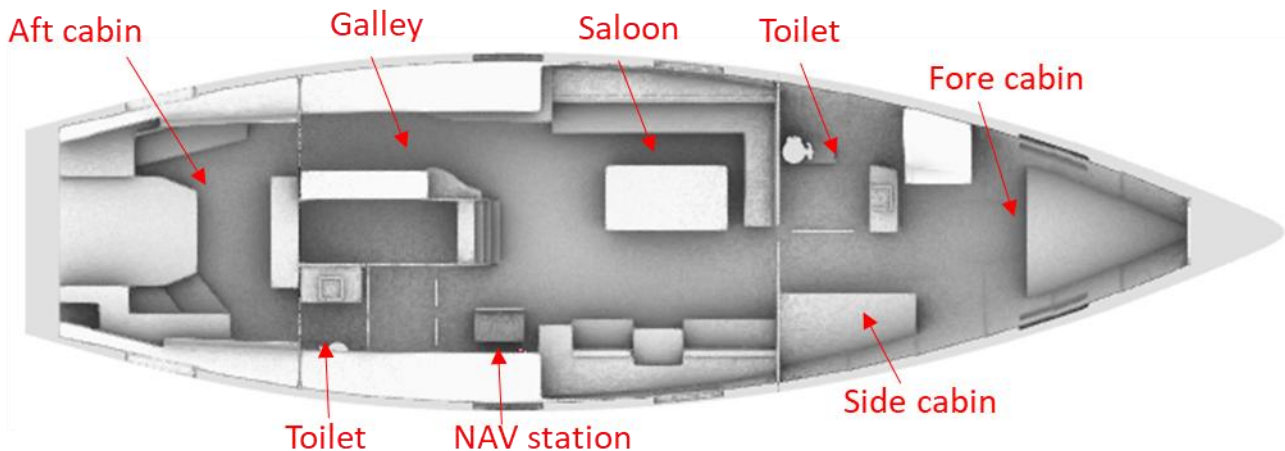


Figure 36: Internal arrangement.

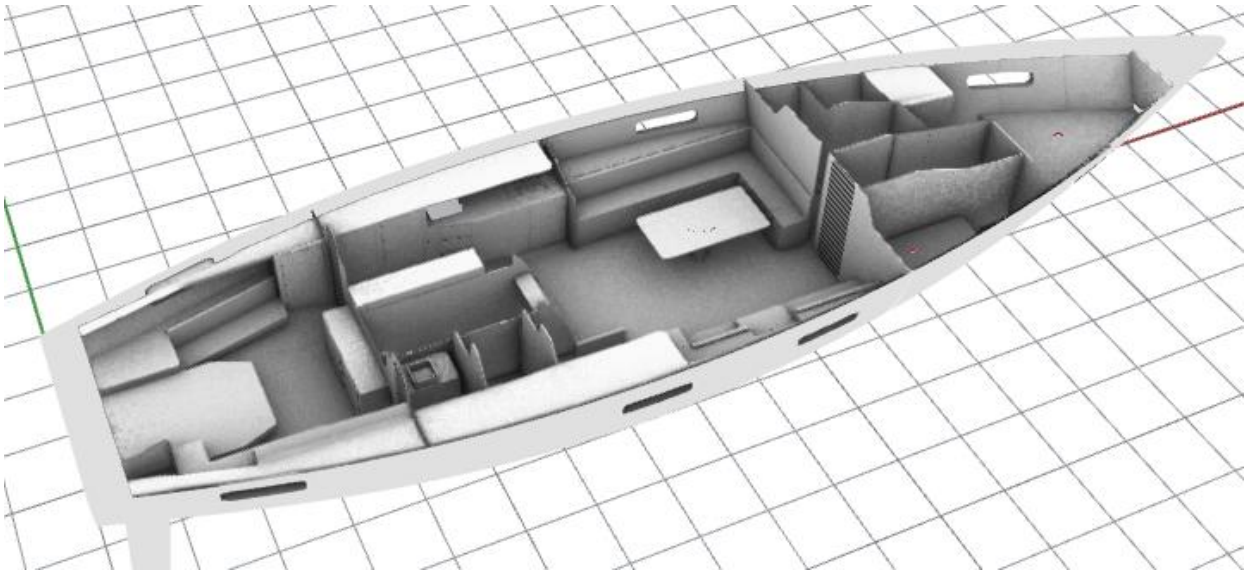


Figure 37: Figure 36: Internal arrangement (3D).

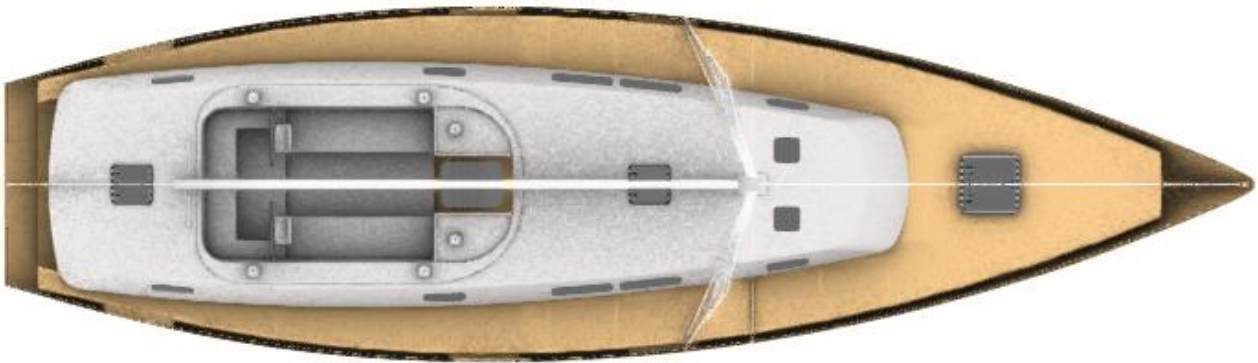


Figure 38: Deck arrangement

10 Weight Estimation

The lightship weight estimation was divided into 6 major areas: Structure, Appendages, Propulsion, Rigging, Deck additional and interior. Each weight was added with its current centre of gravity (CoG).

Since this is a preliminary design, some margins were added for each category in order to account for missing elements and refinements in the design.

The summary and final lightship weight are presented in Table 26. The detailed weight for each category is presented from Table 27 to Table 32.

Table 26: Lightship weight.

SUMMARY	Weight [t]	X [m]	Y [m]	Z [m]
Structure	5,75	8,12	0,00	1,00
Appendices	9,21	8,37	0,00	-1,37
Propulsion	0,50	4,94	0,05	0,40
Rigging	0,79	10,54	0,00	11,43
Deck Additional	0,21	10,54	0,00	11,43
Interior	1,94	18,99	-0,35	2,18
LIGHTSHIP	18,39	9,43	-0,04	0,48

Table 27: Structure weight.

	Identification	Material	Area [m ²]	tck [mm]	X[m]	Y[m]	Z[m]	W [t]	Mx [t.m]	My [t.m]	Mz [t.m]
	(or section (or length))										
Shell	Bottom	Al 5083 H111	72,20	8	7,76	0,0	0,37	1,50	11,65	0,00	0,56
	Keel	Al 5083 H111	4,20	10	9,04	0,0	0,01	0,11	0,99	0,00	0,00
	Side	Al 5083 H111	33,80	6	9,62	0,0	1,30	0,53	5,07	0,00	0,69
	Deck	Al 5083 H111	31,86	6	9,80	0,0	1,86	0,50	4,87	0,00	0,92
	Deck Top	Al 5083 H111	52,12	6	6,20	0,0	2,05	0,81	5,04	0,00	1,67
	Frames Web	Al 5083 H111	23,02	6	8,48	0,0	1,13	0,36	3,04	0,00	0,41
	Frames Flange	Al 5083 H111	8,20	10	8,27	0,0	1,22	0,21	1,76	0,00	0,26
	Longitudinal Girder	Al 5083 H111	0,003	18700	8,51	0,0	0,40	0,14	1,17	0,00	0,05
	Longitudinal String	Al 5083 H111	0,001	130000	8,79	0,0	0,95	0,34	2,99	0,00	0,33
Bulkheads	Al 5083 H111	0,46	8	17,50	0,0	1,61	0,01	0,17	0,00	0,02	
Tanks	Fuel tank1	Al 5083 H111	3,91	6	5,52	0,0	0,23	0,06	0,34	0,00	0,01
	Fuel tank2	Al 5083 H111	4,5	6	6,51	0,0	0,21	0,07	0,46	0,00	0,01
	Fresh water PS	Al 5083 H111	7,84	6	7,92	1,0	0,19	0,12	0,97	0,12	0,02
	Fresh water SB	Al 5083 H111	7,84	6	7,92	-1,0	0,19	0,12	0,97	-0,12	0,02
	Gray water	Al 5083 H111	3,37	6	9,49	1,1	0,20	0,05	0,50	0,06	0,01
	Black water	Al 5083 H111	2,85	6	9,49	-1,2	0,20	0,04	0,42	-0,05	0,01
	Bilge	Al 5083 H111	1,07	6	9,49	-0,6	0,16	0,02	0,16	-0,01	0,00
	Total				8,12	0,0	1,00	5,00	40,56	-0,01	4,99
	Total + margin (15%)	15%			8,12	0,00	1,00	5,75			

Table 28: Appendages weight.

Appendices	Identification	Material	Area [m²]	tck [mm]	X[m]	Y[m]	Z[m]	W [t]	Mx [t.m]	My [t.m]	Mz [t.m]
	Keel	Al 5083 H111	3,87	10	8,87	0,0	-0,53	0,10	0,89	0,00	-0,05
	Lead Ballast	Lead	-	-	8,45	0,0	-1,40	7,81	66,06	0,00	-10,94
	Rudders	Al 5083 H111	3,65	10	0,49	0,0	-0,03	0,09	0,05	0,00	0,00
	TOTAL				8,37	0,0	-1,37	8,01	67,00	0,00	-10,99
Total + margin (15%)	15%				8,37	0,00	-1,37	9,21			

Table 29: Propulsion weight.

Propulsion	Identification	Material	Area [m²]	tck [mm]	X[m]	Y[m]	Z[m]	W [t]	Mx [t.m]	My [t.m]	Mz [t.m]
	Engine + Gear	-	-	-	5,50	0	0,50	0,26	1,43	0,00	0,13
	Propeller	-	-	-	3,10	0	-0,05	0,02	0,06	0,00	0,00
	Axis	Stainless Steel	0,01	2000	4,19	0	0,16	0,12	0,51	0,00	0,02
	Batteries (8x - 2000Ah)	-	-	-	4,42	0,65	0,74	0,03	0,14	0,02	0,02
	TOTAL				4,94	0,05	0,40	0,43	2,15	0,02	0,17
Total + margin (15%)	15%				4,94	0,05	0,40	0,50			

Table 30: Rigging weight.

Rigging	Identification	Material	Area [m²]	L [mm]	X[m]	Y[m]	Z[m]	W [t]	Mx [t.m]	My [t.m]	Mz [t.m]
	Mast	Al 5083 H111	-	24255	10,99	0	13,28	0,39	4,25	0,00	5,14
	Boom	Al 5083 H111	-	8000	6,62	0	3,95	0,09	0,61	0,00	0,36
	Stays	Stainless Steel	-	72532	10,52	0	11,40	0,05	0,58	0,00	0,63
	Shrouds	Stainless Steel	-	45825	11,72	0	13,12	0,03	0,39	0,00	0,44
	Spreader 1	Al 5083 H111	-	2000	10,69	0	9,43	0,02	0,25	0,00	0,22
	Spreader 2	Al 5083 H111	-	1600	10,81	0	16,28	0,02	0,18	0,00	0,27
	Genoa Foresail	-	77,80	-	8,96	0	11,20	0,04	0,31	0,00	0,39
	Main Sail	-	96,00	-	15,05	0	8,90	0,04	0,65	0,00	0,38
	TOTAL				10,54	0,00	11,43	0,68	7,21	0,00	7,82
	Total + margin (15%)	15%				10,54	0,00	11,43	0,79		

Table 31: Deck additional weight.

Deck additional	Identification	Material	Area [m²]	L [mm]	X[m]	Y[m]	Z[m]	W [t]	Mx [t.m]	My [t.m]	Mz [t.m]
	Hatches	-	-	-	10,90	0	2,05	0,03	0,31	0,00	0,06
	Wheels	-	-	-	3,90	0	2,24	0,01	0,02	0,00	0,01
	Winches	Al 5083 H111	-	-	5,34	0	2,34	0,01	0,06	0,00	0,03
	Anchor	Stainless Steel	-	-	18,19	0	1,69	0,02	0,36	0,00	0,03
	Chain	Stainless Steel	-	50000	17,98	0	1,69	0,04	0,67	0,00	0,06
	Teak cover	Wood (cover)	23,90	2	9,79	0	1,85	0,02	0,23	0,00	0,04
	Guardrail	Stainless Steel	3,40	2	8,35	0	2,23	0,05	0,44	0,00	0,12
	TOTAL				11,69	0,00	1,99	0,18	2,10	0,00	0,36
Total + margin (15%)	15%				11,69	0,00	1,99	0,21			

Table 32: Interior weight.

	Identification	Material	Area [m²]	L [mm]	X[m]	Y[m]	Z[m]	W [t]	Mx [t.m]	My [t.m]	Mz [t.m]	
	Back Cabin											
	Bed	-	-	-	1,44	0,00	0,93	0,15	0,22	0,00	0,14	
	Sofa	Wood (furniture)	-	-	2,14	1,41	0,95	0,10	0,21	0,14	0,10	
	Wardrobe	Wood (cover)	6,20	1,5	3,53	0,00	1,24	0,00	0,02	0,00	0,01	
	Wardrobe2	Wood (cover)	5,26	1,5	3,80	0,00	0,85	0,00	0,01	0,00	0,00	
	Table	Wood (cover)	7,56	1,5	1,92	-1,25	1,24	0,01	0,01	-0,01	0,01	
	Floor & walls	Wood (cover)	30,64	1,5	2,30	0,00	1,31	0,02	0,05	0,00	0,03	
	Bulkheads	Wood (cover)	16,80	2,0	2,74	0,00	1,16	0,02	0,05	0,00	0,02	
	Doors	Wood (cover)	2,81	1,5	4,00	0,00	1,32	0,00	0,01	0,00	0,00	
	WC	-	-	-	4,52	-1,78	0,90	0,01	0,05	-0,02	0,01	
	Sink	-	-	-	4,46	-0,81	1,30	0,01	0,04	-0,01	0,01	
	Shower	-	-	-	5,64	-1,30	1,70	0,01	0,03	-0,01	0,01	
	Bulkheads/covers	Wood (cover)	9,11	1,5	4,75	-1,00	0,95	0,01	0,03	-0,01	0,01	
	Galley											
	Sink	-	-	-	5,87	2,00	1,18	0,01	0,06	0,02	0,01	
	Furniture	Wood (furniture)	6,64	1,5	6,59	1,56	0,91	0,01	0,07	0,02	0,01	
	Cabinets	Wood (cover)	12,37	1,5	4,91	1,28	1,05	0,01	0,05	0,01	0,01	
	Stove	-	-	-	7,24	1,80	1,12	0,03	0,18	0,05	0,03	
	Fridge	-	-	-	7,30	1,80	0,90	0,02	0,12	0,03	0,01	
	Interior	Saloon										
		Table	Wood (furniture)	-	-	9,36	0,48	0,94	0,05	0,51	0,03	0,05
		Dinner Sofa	Wood (furniture)	-	-	9,54	1,44	0,81	0,27	2,62	0,40	0,22
Second Sofa		Wood (furniture)	-	-	9,40	-1,64	0,93	0,16	1,52	-0,27	0,15	
Small table		Wood (furniture)	-	-	9,23	-1,65	0,68	0,09	0,80	-0,14	0,06	
Charting table		Wood (furniture)	-	-	7,22	-1,83	0,91	0,17	1,25	-0,32	0,16	
Equipment		-	-	-	7,22	-1,83	1,20	0,02	0,14	-0,04	0,02	
Charting armchair		-	-	-	6,93	-1,28	0,68	0,05	0,35	-0,06	0,03	
Stair		Wood (cover)	-	-	6,54	0,00	0,75	0,02	0,10	0,00	0,01	
Floor & walls		Wood (cover)	74,40	1,5	7,34	0,00	1,09	0,06	0,41	0,00	0,06	
Bulkheads		Wood (cover)	30,32	2,0	7,96	0,00	1,02	0,03	0,24	0,00	0,03	
Front Cabin												
Bed		-	-	-	15,47	0,00	0,87	0,10	1,55	0,00	0,09	
Wardrobes		Wood (furniture)	6,24	1,5	13,29	1,10	1,20	0,01	0,13	0,01	0,01	
Bulkheads		Wood (cover)	6,65	1,5	13,67	-0,34	1,12	0,00	0,07	0,00	0,01	
Floor & walls		Wood (cover)	44,81	1,5	13,49	0,00	1,23	0,03	0,45	0,00	0,04	
Doors		Wood (cover)	2,30	1,5	13,32	0,00	1,13	0,00	0,02	0,00	0,00	
Side Cabin												
Bed		-	-	-	11,90	-1,28	0,87	0,06	0,71	-0,08	0,05	
Wardrobes		Wood (furniture)	6,60	1,5	12,90	-1,34	1,20	0,01	0,14	-0,01	0,01	
Bulkhead		Wood (cover)	9,80	1,5	12,39	-0,84	1,16	0,01	0,09	-0,01	0,01	
Doors		Wood (cover)	2,30	1,5	13,54	-0,82	1,13	0,00	0,02	0,00	0,00	
Bathroom												
WC		-	-	-	11,27	1,178	0,65	0,01	0,11	0,01	0,01	
Sink		-	-	-	12,54	0,48	1,08	0,01	0,13	0,00	0,01	
Shower		-	-	-	13,54	1,2	1,70	0,01	0,07	0,01	0,01	
bulkheads		Wood (cover)	17,49	1,5	12,24	0,63	1,13	0,015	0,18	0,01	0,02	
Furniture		Wood (furniture)	4,50	1,5	12,54	0,48	0,80	0,015	0,19	0,01	0,01	
TOTAL					8,05	-0,15	0,92	1,61	13,00	-0,24	1,49	
Total + margin (20%)		20%			8,05	-0,15	0,92	1,94				

11 Loading Cases

Four loading cases were considered for the yacht design.

- 1. Depart condition:** Lightship, Fuel and fresh water 100%, 8 passenger (80kg per pax), equipment (20kg per pax) and provisioning (40kg per pax).

	Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m ³	Total Volume m ³	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m
1	Lightship	1	18,390	18,390			8,280	0,010	0,350	0,000
2	Pax	8	0,100	0,800			9,000	0,000	2,000	0,000
3	Provisioning	8	0,040	0,320			5,500	0,000	1,600	0,000
4	Fuel01	100%	0,582	0,582	0,616	0,616	7,407	0,000	0,183	0,000
5	Fuel02	100%	0,175	0,175	0,186	0,186	8,151	-1,029	0,187	0,000
6	Fuel03	100%	0,176	0,176	0,186	0,186	8,151	1,029	0,187	0,000
7	Fresh01	100%	0,555	0,555	0,555	0,555	11,035	-0,617	0,185	0,000
8	Fresh011	100%	0,168	0,168	0,168	0,168	9,844	-0,980	0,187	0,000
9	Fresh02	100%	0,555	0,555	0,555	0,555	11,034	0,617	0,185	0,000
10	Fresh021	100%	0,168	0,168	0,168	0,168	9,844	0,980	0,187	0,000
11	Total Loadcas			21,887	2,432	2,432	8,404	0,008	0,411	0,000
12	FS correction								0,000	
13	VCG fluid								0,411	

- 2. Voyage Case 1:** Lightship, Fuel 100%, fresh water 50%, 8 passenger (80kg per pax), equipment (20kg per pax) and provisioning (40kg per pax).

	Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m ³	Total Volume m ³	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m
1	Lightship	1	18,390	18,390			8,280	0,010	0,350	0,000
2	Pax	8	0,100	0,800			9,000	0,000	2,000	0,000
3	Provisioning	8	0,040	0,320			5,500	0,000	1,600	0,000
4	Fuel01	100%	0,582	0,582	0,616	0,616	7,407	0,000	0,183	0,000
5	Fuel02	100%	0,175	0,175	0,186	0,186	8,151	-1,029	0,187	0,000
6	Fresh01	50%	0,555	0,277	0,555	0,277	11,009	-0,520	0,122	0,538
7	Fresh011	50%	0,168	0,084	0,168	0,084	9,842	-0,890	0,125	0,109
8	Fresh02	50%	0,555	0,277	0,555	0,277	11,009	0,520	0,122	0,538
9	Fresh021	50%	0,168	0,084	0,168	0,084	9,842	0,890	0,125	0,109
10	Fuel03	100%	0,176	0,176	0,186	0,186	8,151	1,029	0,187	0,000
11	Total Loadcas			21,165	2,432	1,710	8,323	0,009	0,416	1,292
12	FS correction								0,061	
13	VCG fluid								0,477	

- 3. Voyage Case 2:** Lightship, Fuel 50%, fresh water 50%, 8 passenger (80kg per pax), equipment (20kg per pax) and provisioning (40kg per pax).

	Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m ³	Total Volume m ³	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m
1	Lightship	1	18,390	18,390			8,280	0,010	0,350	0,000
2	Pax	8	0,100	0,800			9,000	0,000	2,000	0,000
3	Provisioning	8	0,040	0,320			5,500	0,000	1,600	0,000
4	Fuel01	50%	0,582	0,291	0,616	0,308	7,412	0,000	0,120	3,184
5	Fuel02	50%	0,175	0,088	0,186	0,093	8,153	-0,931	0,124	0,135
6	Fresh01	50%	0,555	0,277	0,555	0,277	11,009	-0,520	0,122	0,538
7	Fresh011	50%	0,168	0,084	0,168	0,084	9,842	-0,890	0,125	0,109
8	Fresh02	50%	0,555	0,277	0,555	0,277	11,009	0,520	0,122	0,538
9	Fresh021	50%	0,168	0,084	0,168	0,084	9,842	0,890	0,125	0,109
10	Fuel03	50%	0,176	0,088	0,186	0,093	8,153	0,931	0,124	0,135
11	Total Loadcas			20,699	2,432	1,216	8,337	0,009	0,420	4,747
12	FS correction								0,229	
13	VCG fluid								0,649	

- 4. Arrival Condition:** Lightship, Fuel 10%, fresh water 10%, 8 passenger (80kg per pax), equipment (20kg per pax) and provisioning (40kg per pax).

	Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m ³	Total Volume m ³	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m
1	Lightship	1	18,390	18,390			8,280	0,010	0,350	0,000
2	Pax	8	0,100	0,800			9,000	0,000	2,000	0,000
3	Provisioning	8	0,040	0,320			5,500	0,000	1,600	0,000
4	Fuel01	10%	0,582	0,058	0,616	0,062	7,444	0,000	0,055	3,184
5	Fuel02	10%	0,175	0,018	0,186	0,019	8,163	-0,755	0,057	0,135
6	Fresh01	10%	0,555	0,055	0,555	0,055	10,881	-0,339	0,056	0,538
7	Fresh011	10%	0,168	0,017	0,168	0,017	9,832	-0,729	0,058	0,109
8	Fresh02	10%	0,555	0,055	0,555	0,055	10,881	0,339	0,056	0,538
9	Fresh021	10%	0,168	0,017	0,168	0,017	9,832	0,729	0,058	0,109
10	Fuel03	10%	0,176	0,018	0,186	0,019	8,163	0,755	0,057	0,135
11	Total Loadcas			19,748	2,432	0,243	8,279	0,009	0,434	4,747
12	FS correction								0,240	
13	VCG fluid								0,674	

12 Hydrostatics

The hydrostatic table is presented in Annex A – Hydrostatic table. Table 33 presents an extract of the full hydrostatic table. Figure 39 shows the evolution of some important hydrostatic variables as the draft grows.

Table 33: Extract of hydrostatic table.

Draft Amidships m	0,200	0,400	0,500	0,600	0,650	0,700	0,800	0,900	1,000
Displacement t	3,044	9,721	14,11	19,06	21,73	24,51	30,40	36,63	43,09
Heel deg	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Draft at LCF m	0,200	0,400	0,500	0,600	0,650	0,700	0,800	0,900	1,000
WL Length m	9,946	13,897	15,047	15,864	16,239	16,603	17,263	17,364	17,465
Beam max extents on WL m	3,287	4,073	4,321	4,514	4,598	4,672	4,797	4,896	4,974
Wetted Area m ²	27,692	44,210	50,927	57,291	60,232	63,271	68,797	73,499	77,761
Waterpl. Area m ²	24,370	39,852	45,647	50,864	53,131	55,438	59,305	61,987	63,919
Prismatic coeff. (Cp)	0,433	0,482	0,502	0,521	0,529	0,535	0,546	0,569	0,588
Block coeff. (Cb)	0,065	0,105	0,125	0,145	0,154	0,163	0,180	0,201	0,221
Max Sect. area coeff. (Cm)	0,154	0,226	0,258	0,288	0,302	0,316	0,342	0,367	0,390
Waterpl. area coeff. (Cwp)	0,746	0,704	0,702	0,710	0,712	0,715	0,716	0,729	0,736
LCB from zero pt. (+ve fwd) m	9,051	8,858	8,739	8,613	8,549	8,484	8,360	8,253	8,172
LCF from zero pt. (+ve fwd) m	8,972	8,579	8,367	8,139	8,043	7,930	7,765	7,712	7,718
KB m	0,079	0,236	0,303	0,368	0,399	0,431	0,493	0,553	0,613
KG m	0,480	0,480	0,480	0,480	0,480	0,480	0,480	0,480	0,480
BMT m	5,437	4,134	3,676	3,308	3,148	2,999	2,727	2,481	2,260
BML m	48,100	44,501	40,781	38,038	36,578	35,639	33,281	30,082	27,020
GMT m	5,036	3,890	3,499	3,196	3,067	2,949	2,740	2,555	2,393
GML m	47,699	44,258	40,604	37,925	36,498	35,590	33,293	30,156	27,153
KMt m	5,516	4,370	3,979	3,676	3,547	3,429	3,220	3,035	2,873
KML m	48,179	44,738	41,084	38,405	36,978	36,070	33,773	30,636	27,633
Immersion (TPc) tonne/cm	0,250	0,408	0,468	0,521	0,545	0,568	0,608	0,635	0,655
MTc tonne.m	0,081	0,239	0,318	0,402	0,441	0,485	0,562	0,614	0,650

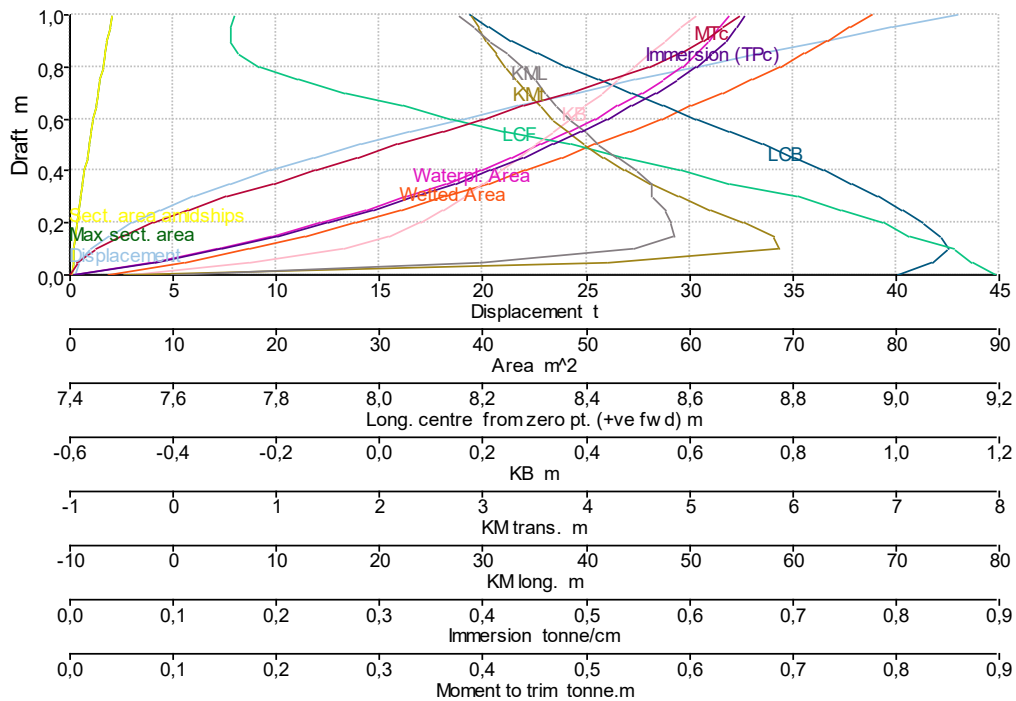


Figure 39: Evolution of important variables along draft increase.

13 Yacht Resistance

The resistance of the yacht is calculated following the reference [2]. It is based in a series of experimental data developed by Delft University of technology specific for sailboats.

Table 34: Data used for calculation.

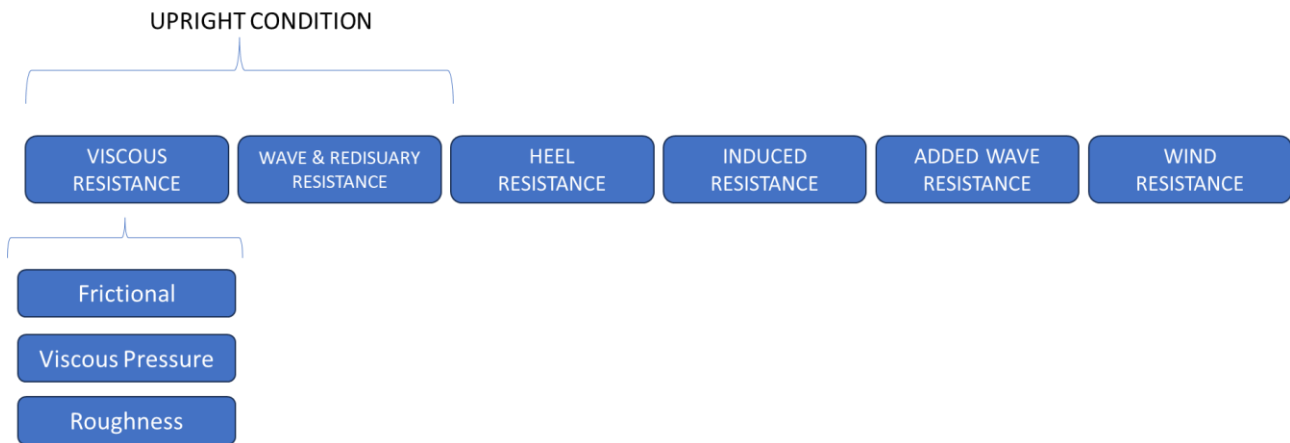
DATA	Value	Unit	Comment
L_{WL}	16,25	m	Waterline length
B_{WL}	4,60	m	Beam on waterline
T	2,35	m	Total Draft
T_c	0,65	m	Draft canoe body
∇_c	21,31	m ³	Displacement
A_w	60,36	m ²	Wetted area of canoe body
C_p	0,53		Prismatic Coefficient
C_{WP}	0,71		Waterplane area coefficient
1/2 angle of entrance	20,7	deg.	
LCB_{fpp}	8,57	m	From fore perpendicular
LCF_{fpp}	9,08	m	From fore perpendicular
LCB	8,55	m	From aft perpendicular
LCF	8,04	m	From aft perpendicular
Waterplane area	54,36	m ²	
C_M	0,759		
V_{design}	9,2	knots	
L_{hull}	11,4	m	
L_{keel}	1,6	m	
L_{bulb}	3,4	m	
L_{rudder}	0,5	m	
S_{Whull}	60,4	m ²	
S_{Wkeel}	3,87	m ²	
S_{Wbulb}	5,39	m ²	
$S_{Wrudder}$	3,65	m ²	

To be consistent with the Delft series, some hull form parameters shall be checked. Otherwise, the calculation using this method shall not be applied.

Table 35: Verification of Delft series usage.

Verifications	Value	Limits	Check
LCB_{fpp}/L_{WL}	0,53	0,5-0,582	OK
C_p	0,53	0,419-0,599	OK
$(\nabla_c^{2/3}) / A_w$	0,14	0,079-0,265	OK
B_{WL}/L_{WL}	0,28	0,17-0,366	OK
LCB_{fpp}/LCF_{fpp}	0,94	0,92-1,002	OK
$(\nabla_c^{1/3}) / L_{WL}$	0,17	0,12-0,23	OK
C_M	0,76	0,646-0,79	OK
B_{WL}/T_c	7,02	2,46-19,38	OK

The total resistance is divided into several components. Each of these contributes to different percentages in the total resistance of the yacht. They will be discussed along the chapter.



13.1 Viscous Resistance

This component of resistance arises from the yacht's immersion in water, as fluid viscosity generates drag along the hull surface. This drag is divided into frictional, roughness and viscous pressure.

$$R_V = R_F + R_{VP} + R_R$$

- **Frictional Resistance (R_F)**

This component is the most important and exists due to the direction friction between the hull surface and the water. It is calculated separately for the hull and the appendages by the following equation.

$$R_F = C_F \cdot 0,5 \cdot \rho \cdot V^2 \cdot S_w \text{ [kN]}$$

Where,

$$C_F = \frac{0,075}{(\log R_n - 2)^2}$$

Reynolds number: $R_n = \frac{V \cdot L}{\nu}$

V is yacht velocity [m/s].

L is length (For hull: $L=0,7L_{WL}$ / for keel and rudder: $L=\text{mean chord}$ / for bulb: $L=L_{\text{bulb}}$)

ν is kinematic viscosity: $1,0 \cdot 10^{-6}$ [m²/s].

ρ is water density: 1,025 [t/m³]

S_w is the wetter surface.

- **Viscous Pressure Resistance (R_{VP})**

It occurs due to the pressure distribution along the hull surface. Based on CFD computational analysis and advised by reference [2], it was taken as 7% of the frictional resistance.

- **Roughness Resistance (R_R)**

It occurs due to the surface roughness. The increase of viscous resistance due to this component can be an important part if the roughness is not controlled. Figure 40 shows an example of how the resistance increases (in % on Y axis) by the roughness (in μm on X axis). The maximum roughness (k_s) of 100 μm is set as a requirement for the design.

To calculate this part the same equation presented above for frictional resistance was used with a correction in the friction coefficient C_f .

$$C_{FR} = 0,044 \cdot \left(\frac{k_S}{L}\right)^{0,303}$$

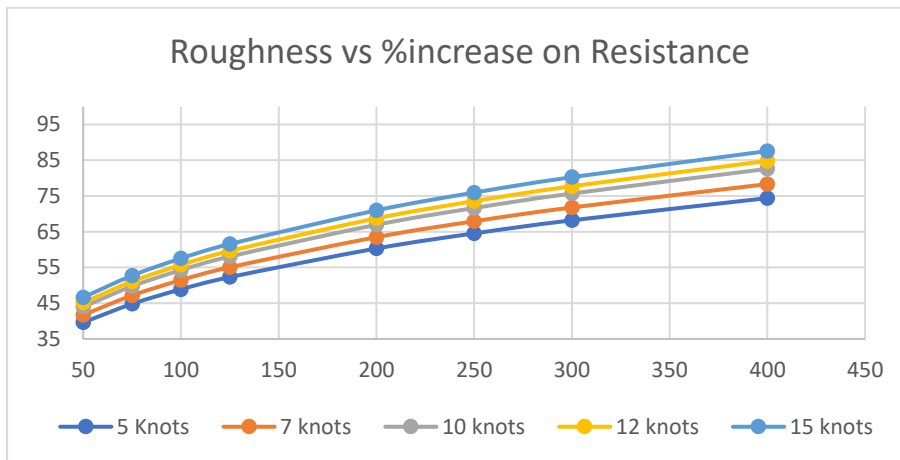


Figure 40: Resistance increase depending on roughness.

The viscous resistance calculated for several speeds of the yacht is presented in Annex B – Yacht Resistance Tables. Figure 41 shows the total frictional resistance of the yacht and Figure 42 presents the total viscous resistance, considering each component.

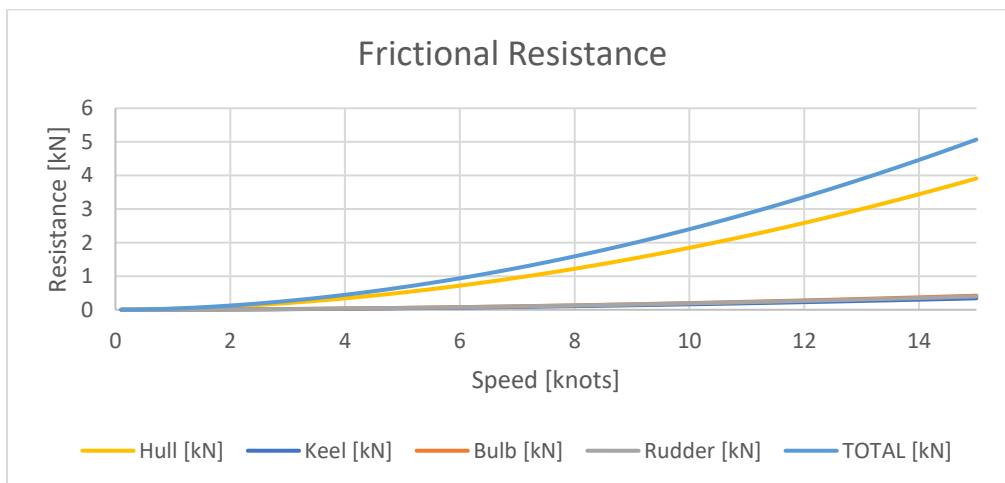


Figure 41: Frictional Resistance.

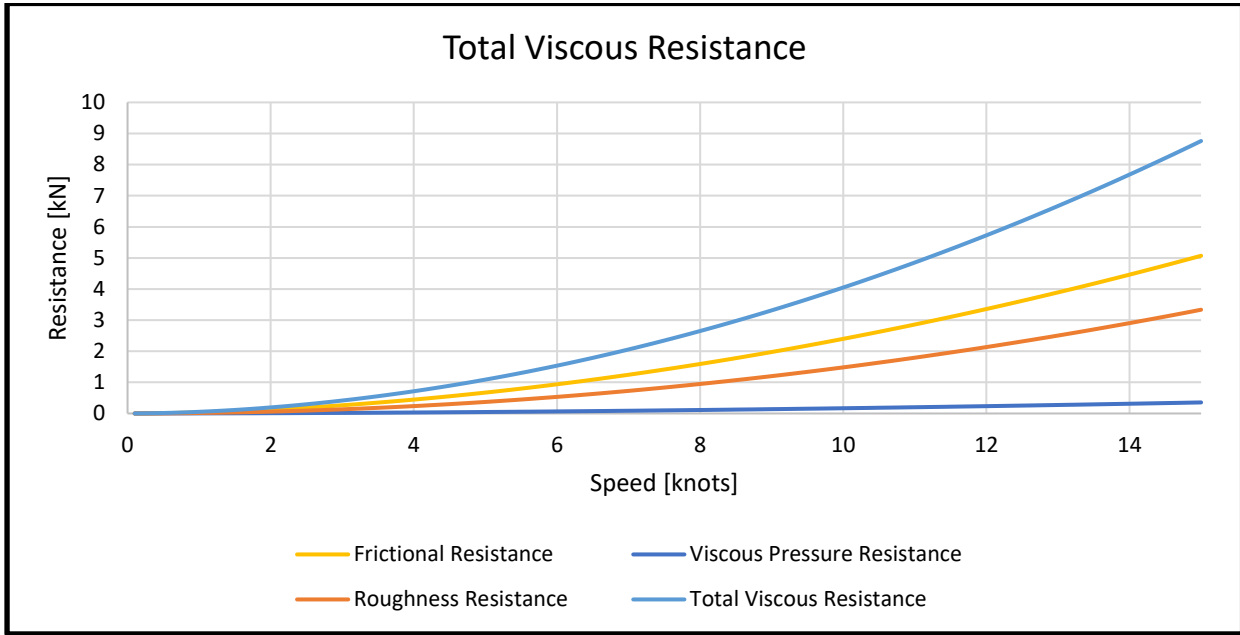


Figure 42: Total Viscous Resistance.

13.2 Wave and residuary resistance

The resistance due to wave is the second major component when analysis the whole vessel resistance. The formula for its calculation was developed by experimental data from Delft, as mentioned before.

For the hull, the formula is the following:

$$R_{WH} = (\nabla_c \cdot \rho \cdot g) \cdot \left[a_0 + \left(a_1 \cdot \frac{LCB_{fpp}}{L_{WL}} + a_2 \cdot c_p + a_3 \cdot \frac{\nabla_c^{2/3}}{A_W} + a_4 \cdot \frac{B_{WL}}{L_{WL}} \right) \cdot \frac{\nabla_c^{1/3}}{L_{WL}} + \left(a_5 \cdot \frac{LCB_{fpp}}{LCF_{fpp}} + a_6 \cdot \frac{B_{WL}}{T_c} + a_7 \cdot C_m \right) \cdot \frac{\nabla_c^{1/3}}{L_{WL}} \right]$$

The coefficients a_0 to a_7 are taken according to the following table. The other variables can be checked on Table 34.

Table 36: Coefficient data for hull residuary resistance.

Fn	a0	a1	a2	a3	a4	a5	a6	a7
0,15	-0,0005	0,0023	-0,0086	-0,0015	0,0061	0,0010	0,0001	0,0052
0,2	-0,0003	0,0059	-0,0064	0,007	0,0014	0,0013	0,0005	-0,002
0,25	-0,0002	-0,0156	0,0031	-0,0021	-0,007	0,0148	0,001	-0,0043
0,3	-0,0009	0,0016	0,0337	-0,0285	-0,0367	0,0218	0,0015	-0,0172
0,35	-0,0026	-0,0567	0,0446	-0,1091	-0,0707	0,0914	0,0021	-0,0078
0,4	-0,0064	-0,4034	-0,125	0,0273	-0,1341	0,3578	0,0045	0,1115
0,45	-0,0218	-0,5261	-0,2945	0,2485	-0,2428	0,6293	0,0081	0,2086
0,5	-0,0388	-0,5986	-0,3038	0,6033	-0,043	0,8332	0,0106	0,1336
0,55	-0,0347	-0,4764	-0,2361	0,8726	0,4219	0,899	0,0096	-0,2272
0,6	-0,0361	0,0037	-0,296	0,9661	0,6123	0,7534	0,01	-0,3352
0,65	0,0008	0,3728	-0,3667	1,3957	1,0343	0,323	0,0072	-0,4632
0,7	0,0108	-0,1238	-0,2026	1,1282	1,1836	0,4973	0,0038	-0,4477
0,75	0,1023	0,7726	0,504	1,7867	2,1934	-1,5479	-0,0115	-0,0977

For the appendages, the formula is the following:

$$R_{WK} = (\nabla_K \cdot \rho \cdot g) \cdot \left[a_0 + \left(a_1 \cdot \frac{T}{B_W} \right) + a_2 \cdot \frac{T_c + Z_{CBk}}{\nabla_K^{1/3}} + a_3 \cdot \frac{\nabla_c}{\nabla_K} \right]$$

The coefficients a_0 to a_3 are taken according to the following table. The other variables can be checked on Table 34.

∇_K is the volume of the appendage.

Z_{CBk} is the distance from the appendage centre of buoyance to the bottom of hull.

Table 37: Coefficient data for appendages residuary resistance.

Fn	A0	A1	A2	A3
0,2	-0,00104	0,00172	0,00117	-0,00008
0,25	-0,0055	0,00597	0,0039	-0,00009
0,3	-0,0111	0,01421	0,0069	0,00021
0,35	-0,00713	0,02632	-0,00232	0,00039
0,4	-0,03581	0,08649	0,00999	0,00017
0,45	-0,0047	0,11592	-0,00064	0,00035
0,5	0,00553	0,07371	0,05991	-0,00114
0,55	0,04822	0,0066	0,07048	-0,00035
0,6	0,01021	0,14173	0,06409	-0,00192

The waves and residuary resistance calculated for several speeds of the yacht is presented in Annex B – Yacht Resistance Tables. The Figure 43 presents the graph summarizing the data.

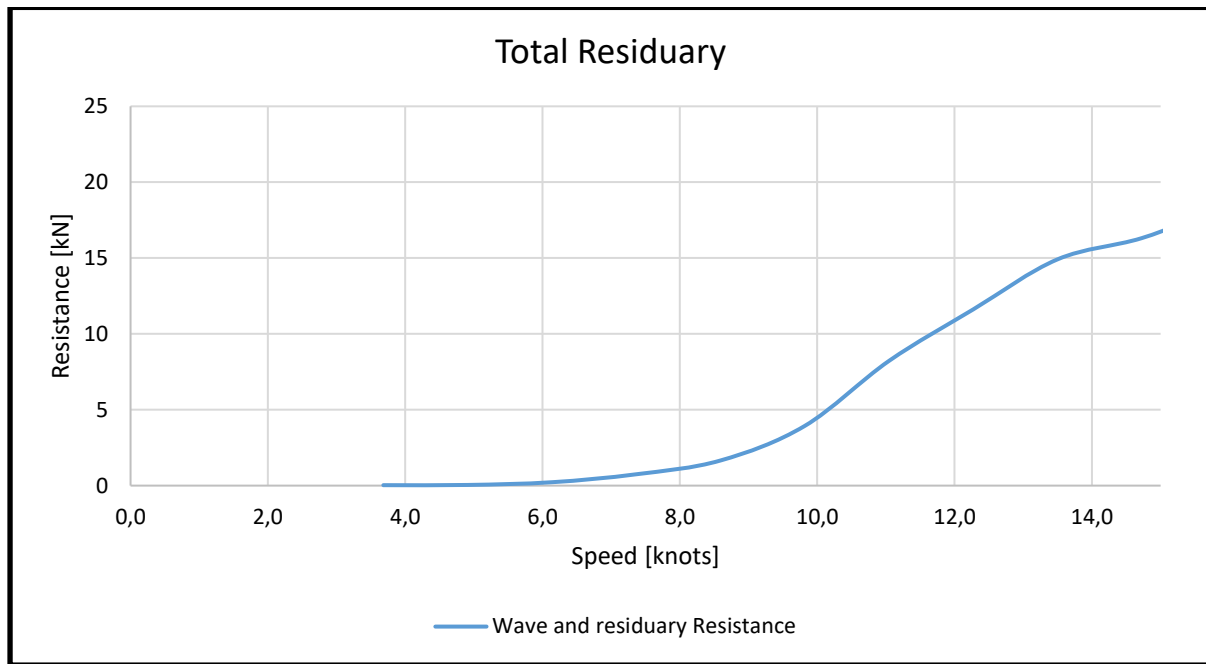


Figure 43: Total wave residuary resistance.

13.3 Heel resistance

When the hull heels due to side force, two resistance components develop. The heel resistance, that is the sum of changes in the viscous and wave resistance due to heel and the induced resistance, presented later.

The change in the hull friction is basically a change in the wetted area. It can be obtained by the following equation.

$$S_{Wc\phi} = S_{Wc} \cdot \left[1 + 0,01 \cdot \left(s_0 + s_1 \cdot \frac{B_{WL}}{T_C} + s_2 \cdot \left(\frac{B_{WL}}{T_C} \right)^2 + s_3 \cdot C_{Mc} \right) \right]$$

The coefficients s_0 to s_3 can be determined from the following table (varying with heel angles).

Table 38: Coefficients for wetter surface change.

Φ	s0	s1	s2	s3
5	-4,112	0,054	-0,027	6,329
10	-4,522	-0,132	-0,077	8,738
15	-3,291	-0,389	-0,118	8,949
20	1,85	-1,2	-0,109	5,364
25	6,51	-2,305	-0,066	3,443
30	12,334	-3,911	0,024	1,767
35	14,648	-5,182	0,102	3,497

Change in hull residuary resistance is obtained by the following equation for a 20deg heel and then extrapolated for other angles.

$$\Delta_{RC(\varphi=20^\circ)} = (\nabla_C \cdot \rho \cdot g) \cdot \left[u_0 + u_1 \cdot \frac{L_{WL}}{B_{WL}} + u_2 \cdot \frac{B_{WL}}{T_C} + u_3 \cdot \left(\frac{B_{WL}}{T_C} \right)^2 + u_4 \cdot LCB + u_5 \cdot LCB^2 \right]$$

$$\Delta_{RC(\varphi)} = \Delta_{RC(\varphi=20^\circ)} \cdot 6,0 \cdot (\varphi)^{1,7}$$

φ is the heel angle in [rad]

Coefficients u_0 to u_5 are obtained from the following table and multiplied by 1000 to be used in the formula.

Table 39: Coefficients for hull equation.

F_n	u0	u1	u2	u3	u4	u5
0,25	-0,0268	-0,0014	-0,0057	0,0016	-0,007	-0,0017
0,3	0,6628	-0,0632	-0,0699	0,0069	0,0459	-0,0004
0,35	1,6433	-0,2144	-0,164	0,0199	-0,054	-0,0268
0,4	-0,8659	-0,0354	0,2226	0,0188	-0,58	-0,1133
0,45	-3,2715	0,1372	0,5547	0,0268	-1,0064	-0,2026
0,5	-0,1976	-0,148	-0,6593	0,1862	-0,7489	-0,1648
0,55	1,5873	-0,3749	-0,7105	0,2146	-0,4818	-0,1174

The change in the keel residuary resistance coefficient is by the following equation:

$$C_H = -3,5837 \cdot \frac{T_C}{T} - 0,0518 \cdot \frac{B_{WL}}{T_C} + 0,05958 \cdot \frac{T_C}{T} \cdot \frac{B_{WL}}{T_C} + 0,2055 \cdot \frac{L_{WL}}{\nabla_C^{1/3}}$$

And the change in the resistance shall follow:

$$\Delta R_{RK\varphi} = \nabla_K \cdot \rho \cdot g \cdot C_H \cdot F_n^2 \cdot \varphi$$

The table with the calculation is presented in Annex B – Yacht Resistance Tables.

13.4 Induced resistance

The induced resistance is caused by the slightly side moving of the yacht and it is most caused by keel and rudder. First the side forces need to be calculated. The coefficient of Lift is obtained by the following equation.

Indices “k” referred to keel and “r” to rudders.

$$C_L = \frac{5,7 \cdot AR_e}{\alpha \cdot \left(1,8 + \cos \Lambda \cdot \left(\frac{AR_e^2}{\cos^4 \Lambda} + 4 \right)^{0,5} \right)}$$

$$AR_e = 2 \cdot AR$$

$$\alpha_k = \beta \quad \text{and} \quad \alpha_r = \beta - \varepsilon + \delta_r \quad / \quad \varepsilon = a_0 \cdot (C_{L,k} / AR_{e,k})^{0,5}$$

Lift Force can be calculated by:

$$L_k = C_{L,k} \cdot 0,5 \cdot \rho \cdot V^2 \cdot A_k \quad \text{and} \quad L_r = C_{L,r} \cdot 0,5 \cdot \rho \cdot V^2 \cdot A_r$$

Finally hydrodynamic side forces are calculated:

$$F_{h,k} = L_k \cdot C_{hull} \cdot C_{heel} \quad \text{and} \quad F_{h,r} = L_r \cdot C_{hull} \cdot C_{heel}$$

$$F_h = F_{h,k} + F_{h,r}$$

$$C_{\text{hull}} = 1,8 \cdot (T_c / T_k) + 1$$

$$C_{\text{heel}} = 1 - 0,382 \cdot \phi$$

A is planform area [m²]

Λ is the sweep angle [rad]

β is the leeway angle [rad]

ϕ is the heel angle [rad]

ε is downwash angle [rad]

δ_r is rudder angle [rad]

Table 40: Data used.

AR _{keel}	0,75
AR _{rudder}	3,6
A _k	1,92
A _r	0,9
Sweep _k	26,57
Sweep _{rud}	4,76

The induced resistance coefficient is:

$$\text{for keel: } C_{DI,k} = \frac{C_{L\phi,k}^2}{\pi \cdot AR_{Ee,k}} \quad \text{with } C_{L\phi,k} = \frac{F_{\phi,k}}{0,5 \cdot \rho \cdot V^2 \cdot A_{E,k}} \quad \text{and } F_{\phi,k} = \frac{F_{h,k}}{\cos \phi}$$

$$\text{for rudder: } C_{DI,r} = \frac{C_{L\phi,r}^2}{\pi \cdot AR_{Ee,r}} \quad \text{with } C_{L\phi,r} = \frac{F_{\phi,r}}{0,5 \cdot \rho \cdot V^2 \cdot A_{E,r}} \quad \text{and } F_{\phi,r} = \frac{F_{h,r}}{\cos \phi}$$

The resistance is:

$$\text{for keel: } R_{I,k} = C_{DI,k} \cdot 0,5 \cdot \rho \cdot V^2 \cdot A_{E,k}$$

$$\text{for rudder: } R_{I,r} = C_{DI,r} \cdot 0,5 \cdot \rho \cdot V^2 \cdot A_{E,r}$$

A_E is lateral area of extended blade [m²]

AR_{Ee} Effective aspect ratio [m]

ϕ is heel angle [deg]

The table with the calculation is presented in Annex B – Yacht Resistance Tables.

13.5 Added wave resistance

For this resistance calculation, 3 sea states were defined in order to have the resistance calculated to calm seas and rough weather.

Sea State	H _{1/3} [m]	T ₁ [s]
SS1 – Calm Sea	1,50	4,51
SS2 – Moderate Sea	3,00	5,80
SS3 – Rough Sea	4,50	7,73

The added resistance caused by waves can be calculated by the following equation:

$$R_{AW} = \rho \cdot g \cdot L_{WL} \cdot H_{1/3}^2 \cdot 10^{-2} \cdot a \cdot \left[10^2 \cdot \frac{\nabla^{1/3}}{L_{WL}} \cdot \frac{k_{yy}}{L_{WL}} \right]^b$$

T_1 =wave period

$$T'_1 = T_1 \cdot \sqrt{\frac{g}{L_{WL}}}$$

$H_{1/3}$ is the wave significant height

k_{yy} is the longitudinal radius of gyration

Coefficients a and b are taken from the following table.

T1'	a	b	F _n =0.15	F _n =0.15 b	F _n =0.25	F _n =0.25 b	F _n =0.35	F _n =0.35 b	F _n =0.45	F _n =0.45 b	F _n =0.60	F _n =0.60 b
2.0	100	0,006	1,801	0,009	1,608	0,013	1,426	0,017	1,270	0,000	0,000	0,000
2.0	115	0,010	1,235	0,125	1,066	0,202	0,711	0,236	0,476	0,000	0,000	0,000
2.0	125	0,178	0,370	0,292	0,719	0,463	0,437	0,638	0,158	0,000	0,000	0,000
2.0	135	0,337	0,752	0,479	0,535	0,736	0,229	0,000	0,000	0,000	0,000	0,000
2.0	145	0,535	0,588	0,739	0,387	1,142	0,063	0,000	0,000	0,000	0,000	0,000
2.5	100	0,002	2,144	0,003	1,375	0,004	1,793	0,006	1,656	0,007	1,477	0,000
2.5	115	0,022	1,684	0,038	1,465	0,061	1,260	0,088	1,076	0,128	0,844	0,000
2.5	125	0,054	1,467	0,088	1,293	0,141	1,078	0,205	0,871	0,309	0,538	0,000
2.5	135	0,100	1,309	0,152	1,173	0,240	0,947	0,354	0,716	0,546	0,401	0,000
2.5	145	0,136	1,287	0,220	1,080	0,344	0,844	0,512	0,593	0,804	0,240	0,000
3.0	100	0,001	2,304	0,001	2,127	0,002	1,971	0,003	1,797	0,003	1,645	0,000
3.0	115	0,009	1,881	0,016	1,688	0,026	1,503	0,037	1,338	0,052	1,141	0,000
3.0	125	0,023	1,630	0,037	1,552	0,059	1,369	0,085	1,193	0,123	0,974	0,000
3.0	135	0,042	1,556	0,063	1,465	0,099	1,281	0,145	1,092	0,215	0,849	0,000
3.0	145	0,064	1,459	0,091	1,402	0,142	1,214	0,209	1,013	0,313	0,743	0,000
3.5	100	0,001	2,381	0,001	2,214	0,001	2,025	0,001	1,895	0,002	1,700	0,000
3.5	115	0,005	1,985	0,008	1,795	0,013	1,622	0,018	1,463	0,026	1,279	0,000
3.5	125	0,012	1,800	0,019	1,676	0,029	1,511	0,042	1,351	0,061	1,155	0,000
3.5	135	0,021	1,678	0,032	1,608	0,050	1,447	0,072	1,276	0,105	1,068	0,000
3.5	145	0,032	1,589	0,046	1,560	0,071	1,399	0,104	1,222	0,152	1,000	0,000
4.0	100	0,000	2,405	0,000	2,235	0,001	2,081	0,001	1,947	0,001	1,733	0,000
4.0	115	0,003	2,036	0,005	1,853	0,007	1,682	0,010	1,533	0,015	1,349	0,000
4.0	125	0,007	1,855	0,011	1,745	0,017	1,587	0,024	1,434	0,034	1,250	0,000
4.0	135	0,012	1,743	0,018	1,681	0,028	1,524	0,041	1,374	0,059	1,180	0,000
4.0	145	0,018	1,660	0,026	1,642	0,040	1,498	0,059	1,334	0,085	1,131	0,000

The table with the calculation is presented in Annex B – Yacht Resistance Tables.

13.6 Wind resistance

In rough weather when the wind is strong, the area of windage plays an important role in the resistance. This resistance in air is calculated summing the windage of the hull, the mast and rig.

$$\text{Hull: } R_{AH} = 0,5 \cdot \rho_a \cdot V_a^2 \cdot C_D \cdot BMAX \cdot FA$$

$$\text{Mast: } R_{AM} = 0,5 \cdot \rho_a \cdot V_a^2 \cdot C_D \cdot EMDC \cdot EHM$$

$$\text{Rig: } R_{AR} = 0,5 \cdot \rho_a \cdot V_a^2 \cdot C_D \cdot t_R \cdot L_R$$

V_a is apparent wind velocity [m/s]

C_D is wind coefficient resistance (1.13 used)

$BMAX$ is yacht beam [m]

FA is freeboard [m]

$EMDC$ is mast diameter [m]

EHM is mast height above deck [m]

t_R is thicknesses of stays and shrouds [m]

L_R is length of stays and shrouds [m]

The table with the calculation is presented in Annex B – Yacht Resistance Tables.

13.7 Total yacht resistance

The final resistance of the yacht depends on the sailing condition that it is navigating. Some examples will be created in order to estimate it.

- On an upright condition, there is no heeling angle, so total resistance (R_T) is only composed of viscous and wave resistance. Figure 44 shows the Resistance for several speed.

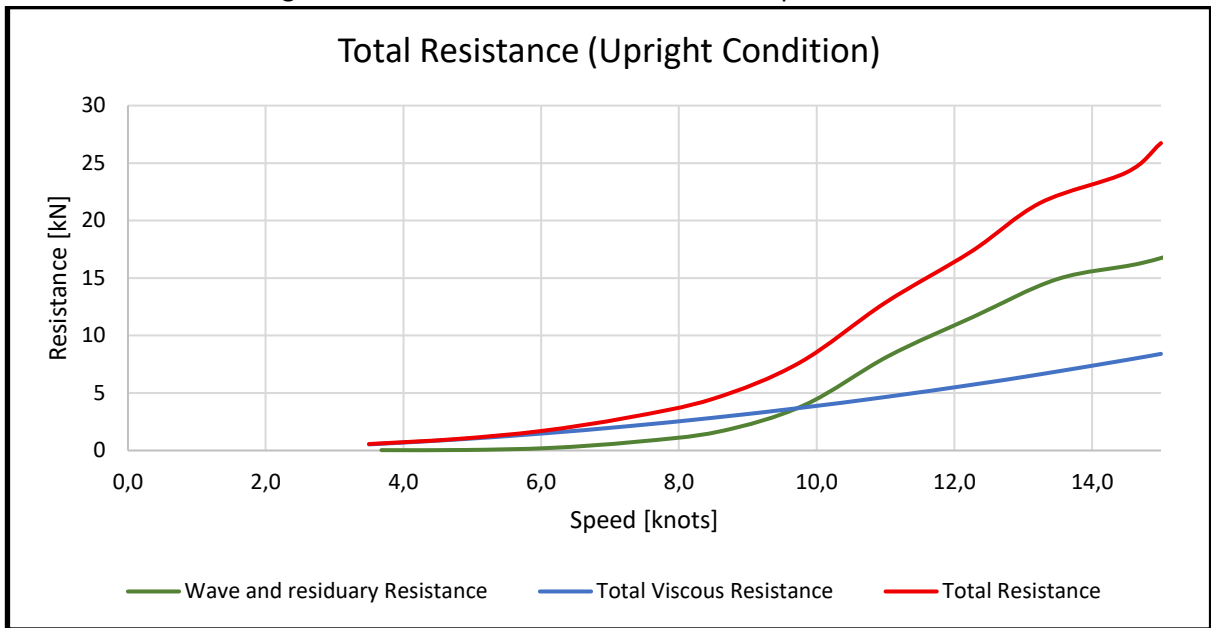
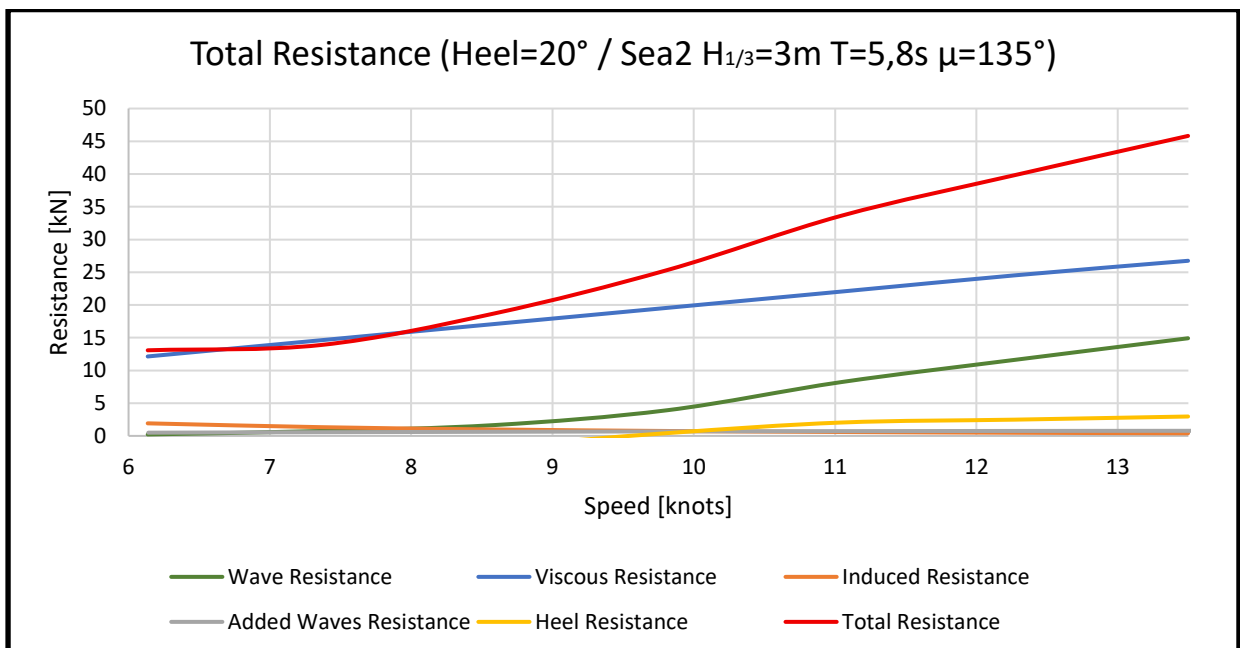
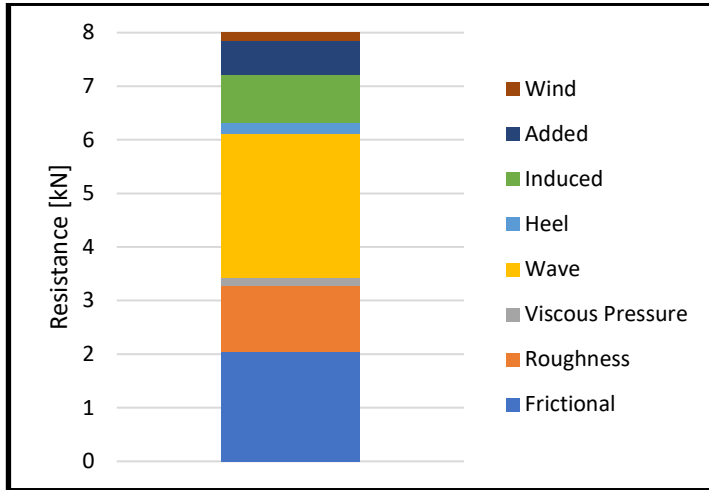


Figure 44: Total Resistance on a Upright condition.

- Specifying some heeling condition and sea state is possible to see how the resistance evolves along several yacht speed.
 - Heel= 20°
 - Sea State SS2 ($H_{1/3}=3m/T=5,8s$) with heading waves $\mu=135^\circ$



- Considering some specific condition of speed and apparent wind to exemplify, it is possible to understand how the resistance components behave.
 - Yacht speed of 9,2 knots
 - Heel= 20°
 - Sea State SS1 ($H_{1/3}=1,5m/T=4,51s$) with heading waves $\mu=135^\circ$
 - Apparent wind of 10 knots



Resistance Component	Percentage
Wind	3%
Added	8%
Induced	11%
Heel	3%
Wave	33%
Viscous Pressure	2%
Roughness	15%
Frictional	25%
Total	100%

Figure 45: Distribution of resistance components for a specific navigating condition.

Finally, two conditions (calm and rough sea) were select to continue the analysis for the propulsion dimensioning. Figure 46 shows these 2 conditions. Moreover, the region between the 2 curves of Figure 46 is expected to be the yacht resistance during most of its navigation time.

- Calm weather: No heel, calm sea and apparent wind of 5knots.
- Rough weather: Heel 20°, SeaState3 ($H_{1/3}=4,5m/T=7,73s$), heading waves $\mu=145^\circ$ and apparent wind of 30knots.

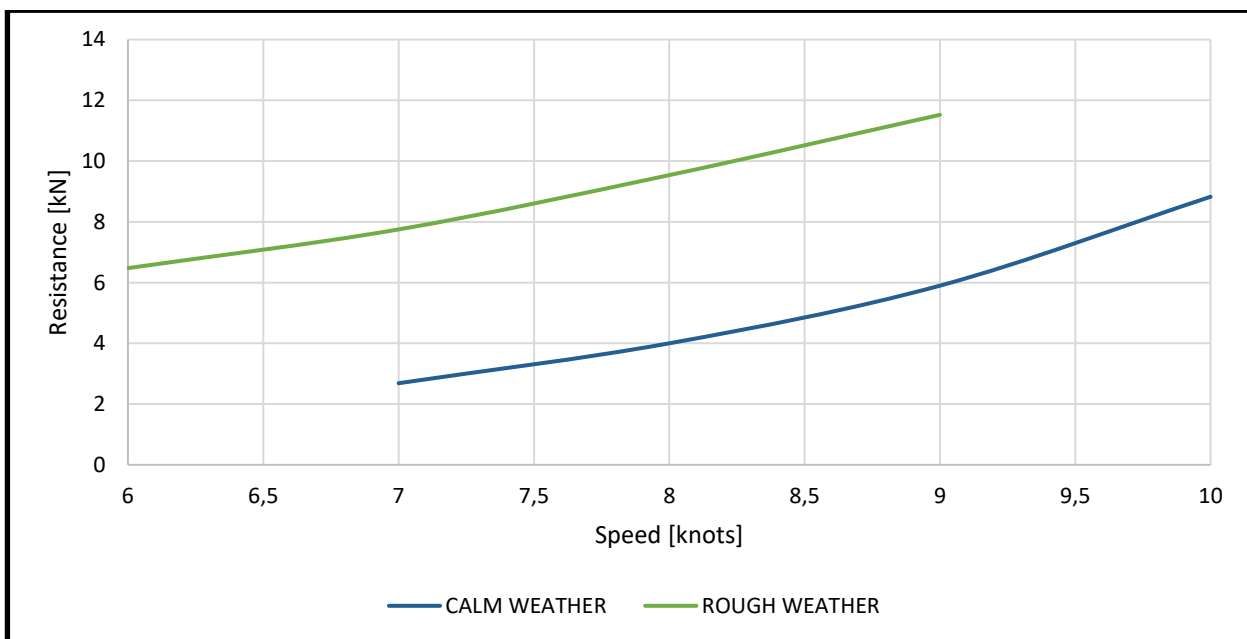


Figure 46: Resistance compute for calm and rough weather cases.

14 Propulsion

After determining the resistance of the yacht, it is possible to define the propulsion system. First, some conditions were established:

1. In calm sea, the yacht would be able to achieve 9,5knots (Design speed).
2. In rough weather, the yacht would be able to achieve 7knots.

The propeller thrust (T) is obtained by the equation:

$$T = \frac{R_T}{(1 - t)} [kN]$$

Where t is the thrust deduction factor (usually taken 0,05 to 0,10). For cruising monohulls, the typical value taken is 0,08.

Table 41: Required thrust calculated for the design sea conditions.

	Calm Weather				Rough Weather	
V [knots]	7,0	8,0	9,0	9,5	6,0	7,0
V [m/s]	3,6	4,1	4,6	4,9	3,1	3,6
R _T [kN]	2,7	4,0	5,9	7,4	6,5	7,8
T [kN]	2,9	4,3	6,4	8,0	7,0	8,4

A propeller from volvo penta catalogue, reference [8] was chosen for the design. The propeller has 4 blades with diameter D=0,559m and pitch ratio P/D=0,73.





Blade kits						
	S-Drive & Shaft		Shaft		S-Drive & Shaft	
Ø x PITCH			Ø x PITCH			
	LH	RH		LH	RH	
20 x 14	3583917	3583918	22 x 18	3583923	3583924	
21 x 15	3583919	3583920	22 x 20	3583925	3583926	
22 x 16	3583921	3583922				

Figure 47: Chosen propeller.

To enter in the K_T,K_Q curves from Wageningen B-series, it is necessary the diameter (D) of the propeller, pitch ratio (P/D) and blade area ratio (A_e/A₀).

The expanded area A_e was checked as 0,135m², making A_e/A₀=0,55.

Following the K_T,K_Q and efficiency curves from Wageningen B-series paper, reference [9], with the data obtained before the curves can be created for this exact propeller by the following polynomial.

$$K_T = \sum_{s,t,u,v} C_{s,t,u,v}^T (J)^s (P/D)^t (A_E/A_0)^u (Z)^v$$

$$K_Q = \sum_{s,t,u,v} C_{s,t,u,v}^Q (J)^s (P/D)^t (A_E/A_0)^u (Z)^v$$

The coefficients C_{s,t,u} and v are obtained in the following table.

K_T	$C_{S, t, u, v}$	s	t	u	v	$C_{S, t, u, v}^0$	s^0	t^0	u^0	v^0
		(J)	(P/D)	(A_B/A_0)	(Z)		(J)	(P/D)	(A_B/A_0)	(Z)
+0.00880496	0	0	0	0	0	+0.00379368	0	0	0	0
-0.204554	1	0	0	0	0	+0.00886523	2	0	0	0
+0.166351	0	1	0	0	0	-0.032241	1	1	0	0
+0.158114	0	2	0	0	0	+0.00344778	0	2	0	0
-0.147581	2	0	1	0	0	-0.0409811	0	1	0	0
-0.481497	1	1	1	0	0	-0.108009	1	1	1	0
+0.415437	0	2	1	0	0	-0.0885381	2	1	1	0
+0.0144043	0	0	0	1	1	+0.188561	0	2	1	0
-0.0530054	2	0	0	1	1	-0.00370871	1	0	0	1
+0.0143481	0	1	0	1	1	+0.00513696	0	1	0	1
+0.0606826	1	1	0	1	1	+0.0209449	1	1	0	1
-0.0125894	0	0	1	1	1	+0.00474319	2	1	0	1
+0.0109689	1	0	1	1	1	-0.00723408	2	0	1	1
-0.133698	0	3	0	0	0	+0.00438388	1	1	1	1
+0.00638407	0	6	0	0	0	-0.0269403	0	2	1	1
-0.00132718	2	6	0	0	0	+0.0558092	3	0	1	0
+0.168496	3	0	1	0	0	+0.0161896	0	3	1	0
-0.0507214	0	0	2	0	0	+0.00318086	1	3	1	0
+0.0854559	2	0	2	0	0	+0.015896	0	0	2	0
-0.0504475	3	0	2	0	0	+0.0471729	1	0	2	2
+0.010465	1	6	2	0	0	+0.0196283	3	0	0	0
-0.00648272	2	6	2	0	0	-0.0502782	0	1	2	0
-0.00841728	0	3	0	1	1	-0.030055	3	1	2	0
+0.0168424	1	3	0	1	1	+0.0417122	2	2	2	0
-0.00102296	3	3	0	1	1	-0.0397722	0	3	2	0
-0.0317791	0	3	1	1	1	-0.00350024	0	6	2	0
+0.018604	1	0	2	1	1	-0.0106854	3	0	0	1
-0.00410798	0	2	2	1	1	+0.00110903	3	3	0	1
-0.000606848	0	0	0	2	2	-0.000313912	0	6	0	1
-0.0049819	1	0	0	2	2	+0.0035985	3	0	1	1
+0.0025983	2	0	0	2	2	-0.00142121	0	6	1	1
-0.000560528	3	0	0	2	2	-0.00383637	1	0	2	1
-0.00163652	1	2	0	2	2	+0.0126803	0	2	2	1
-0.00328787	1	6	0	2	2	-0.00318278	2	3	2	2
+0.000116502	2	6	0	2	2	+0.00334268	0	6	2	1
+0.000690904	0	0	1	2	2	-0.00183491	1	1	0	2
+0.00421749	0	3	1	2	2	+0.000112451	3	2	0	2
+0.0000565229	3	6	1	2	2	-0.000297228	3	6	0	2
-0.00146564	0	3	2	2	2	+0.000269551	1	0	1	2
						+0.00083265	2	0	1	2
						+0.00155334	0	2	1	2
						+0.000302683	0	6	1	2
						-0.0001843	0	0	2	2
						-0.000425399	0	3	2	2
						+0.000869243	3	3	2	2
						-0.0004659	0	6	2	2
						+0.0000554194	1	6	2	2

$R_{\eta} = 2 \times 10^6$

Figure 48: Coefficients to create K_t, K_q curves.

The curve for K_t, K_q are the following:

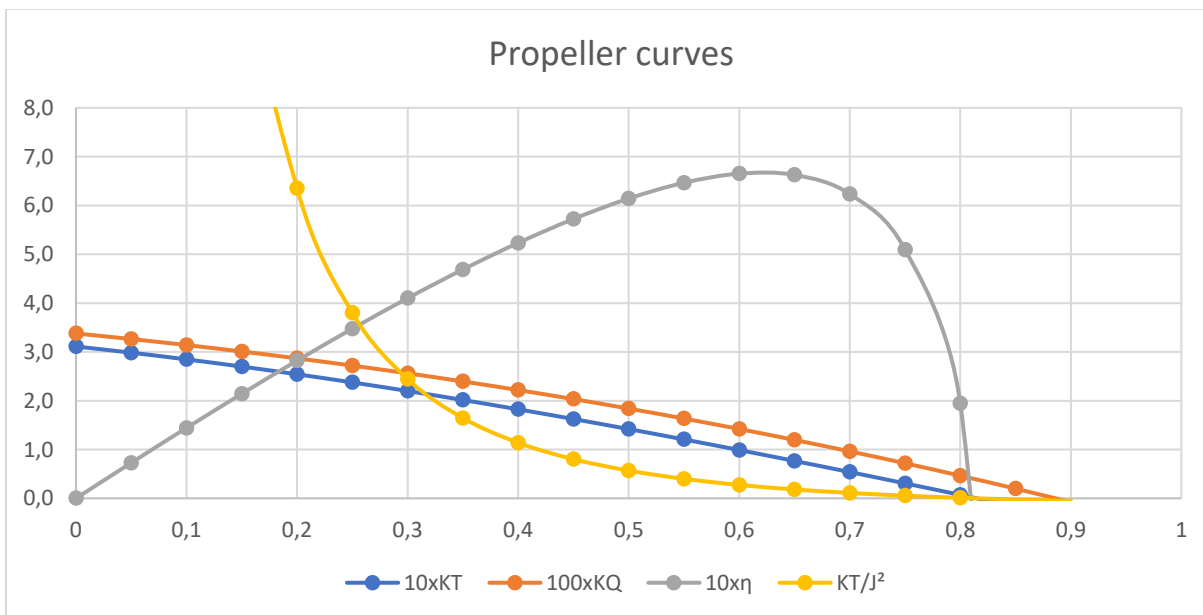


Figure 49: K_t, K_q curves.

After achieving the propeller curve, the matching with the hull can be done.

$$\left(\frac{K_T}{J^2}\right)_{hull} = \frac{T}{\rho \cdot D^2 \cdot V^2 \cdot (1-w)^2}$$

Where, w is the wake fraction (taken as 0.20 – common value for cruiser sailboats)

After calculating the $\left(\frac{K_T}{J^2}\right)_{hull}$, it is compared with the $\left(\frac{K_T}{J^2}\right)_{propeller}$ to obtain the equilibrium J (J_{eq}) to calculate the revolutions that the propeller must achieve in order to generate the necessary thrust.

The revolutions (n) and the delivered power (P_D) can be calculated by the following equations.

$$n = \frac{V_a}{D \cdot J_{eq}} \text{ [rps]} \quad P_D = 2 \cdot \pi \cdot K_Q \cdot \rho \cdot D^5 \cdot n^3 \text{ [kW]}$$

The results for the yacht designed is presented in Table 42.

Table 42: Results for propeller dimensioning.

	Calm Weather				Rough Weather	
V [knots]	7,0	8,0	9,0	9,5	6,0	7,0
V [m/s]	3,6	4,1	4,6	4,9	3,1	3,6
R _T [kN]	2,7	4,0	5,9	7,4	6,5	7,8
T [kN]	2,9	4,3	6,4	8,0	7,0	8,4
D [m]	0,56	0,56	0,56	0,56	0,56	0,56
(K _T /J ²) _{hull}	1,10	1,25	1,46	1,64	3,61	3,17
J _{EQ}	0,406	0,388	0,368	0,351	0,257	0,272
K _Q	0,021	0,021	0,022	0,023	0,026	0,026
n [rps]	15,9	19,0	22,5	24,9	21,5	23,7
P _D [kW]	29,0	51,0	88,7	123,4	92,2	120,0

14.1 Cavitation check

Cavitation in the blades occurs when the local pressure on the blade surface falls below the vapor pressure of water, leading to the formation of vapor bubbles. As these vapor bubbles moves to regions of higher pressure, they collapse violently, producing localized shock waves.

The diagram of Burril is used to evaluate the cavitation on the blades. It relates the cavitation number (σ) and a coefficient (τ_c) that express the thrust loading in the blades.

$$\sigma_{0.7R} = \frac{p_0 - p_v + \rho \cdot g \cdot h}{0,5 \cdot \rho \cdot V_r^2} \quad \tau_c = \frac{\frac{T}{A_p}}{0,5 \cdot \rho \cdot V_r^2}$$

where,

p_a is atmospheric pressure [Pa] ; p_v is the vaporization pressure [Pa] (=2300Pa)

$$V_r^2 = (V_a^2 + (0,7 \cdot \pi \cdot n \cdot D)^2) \text{ [m}^2\text{/s}^2\text{]}$$

$$A_p = (1,067 - 0,229 \cdot P/D) A_e \text{ [m}^2\text{]}$$

Table 43: Parameter for cavitation check.

	Calm Weather				Rough Weather	
V [knots]	7,0	8,0	9,0	9,5	6,0	7,0
V [m/s]	3,6	4,1	4,6	4,9	3,1	3,6
T [kN]	2,9	4,3	6,4	8,0	7,0	8,4
D [m]	0,6	0,6	0,6	0,6	0,6	0,6
n [rps]	15,9	19,0	22,5	24,9	21,5	23,7
V _r	20	24	28	31	27	29
σ _{0.7R}	0,53	0,37	0,26	0,22	0,29	0,24
τ	0,12	0,12	0,13	0,13	0,16	0,16

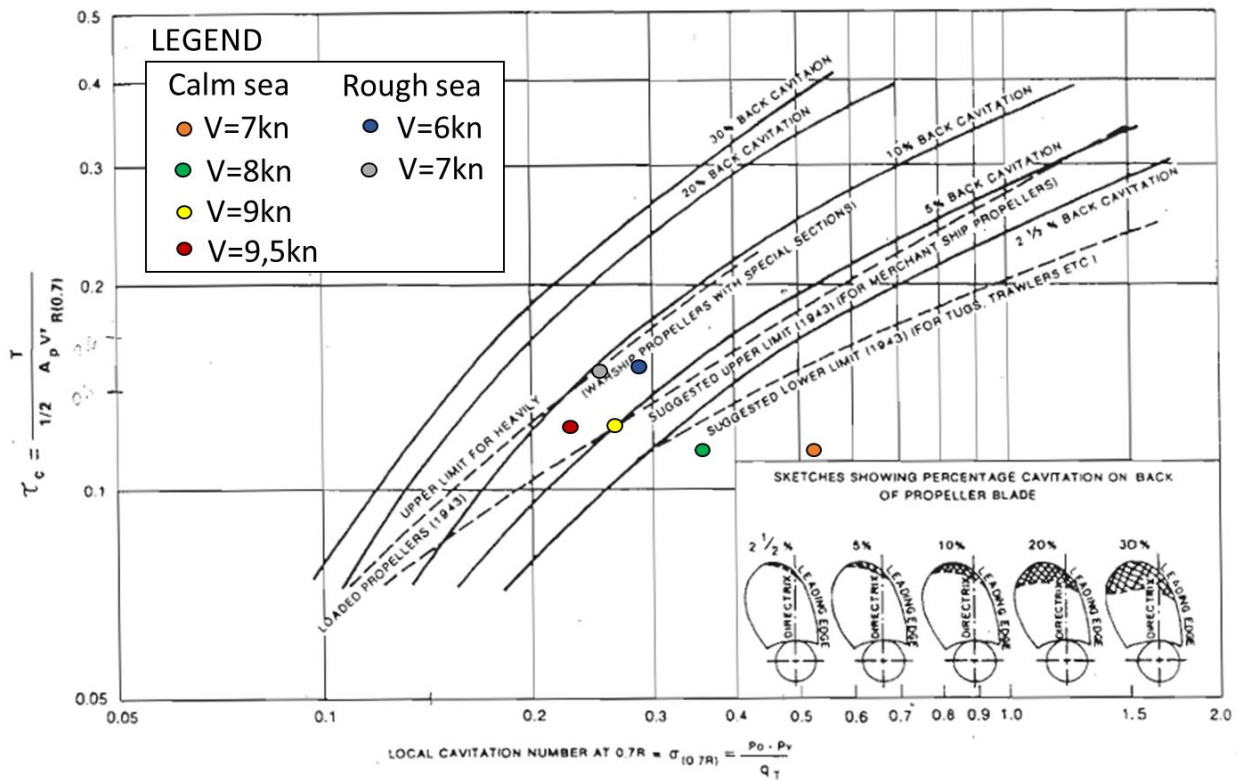


Figure 50: Burrill Diagram.

It can be noticed from the Burrill diagram that all the cases designed and presented in Table 43, show cavitation below the curve representing 10% on the back of the blade cavitation.

14.2 Engine

The engine for the yacht can be selected after the required power (P_D) was calculated.

$$P_{REQ} = \frac{P_D}{\eta_R \cdot \eta_S \cdot \eta_G} \text{ [kW]}$$

where,

η_R is the rotative efficiency (=1,00)

η_S is the shaft efficiency (=0,98)

η_G is the gearing efficiency (=0,99)

The values were calculated and presented in Table 44.

Table 44: Power required by the engine (P_{REQ})

	Calm Weather				Rough Weather	
V [knots]	7,0	8,0	9,0	9,5	6,0	7,0
V [m/s]	3,6	4,1	4,6	4,9	3,1	3,6
n [rps]	15,9	19,0	22,5	24,9	21,5	23,7
n [rpm]	953	1138	1353	1496	1292	1421
P_R [kW]	29,0	51,0	88,7	123,4	92,2	120,0
P_{REQ} [kW]	29,9	52,6	91,5	127,2	95,0	123,7

The engine was select from the catalogue of Yanmar, reference [10].

4LV195 (Z)

Specifications

RATED OUTPUT	143 kW / 195 mhp
RATED SPEED	3500 rpm
DISPLACEMENT	2.755 L / 168 cu. in
NO. OF CYLINDERS	4 cylinders
CYLINDER BORE X STROKE	92 mm x 103.6 mm / 3.6 in x 4 in



Figure 51: Engine selected.

After selecting the engine, the rotational speeds of the engine and propeller shaft must be properly matched. A gearbox is therefore required to adjust the rotational speed and ensure an appropriate mechanical coupling between the engine and the propeller. Reduction factor is set in 2,3:1.

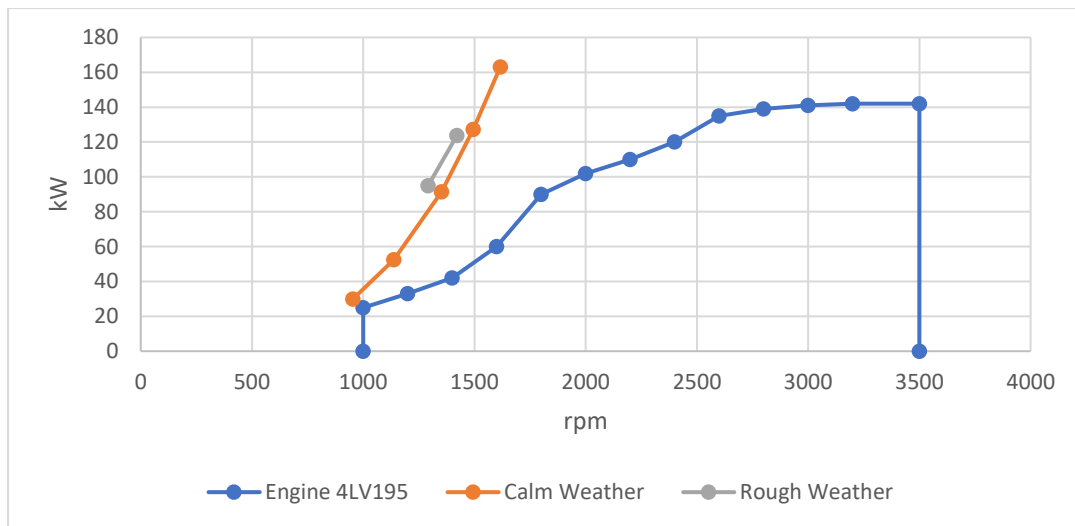


Figure 52: Propeller and engine rotation BEFORE matching.

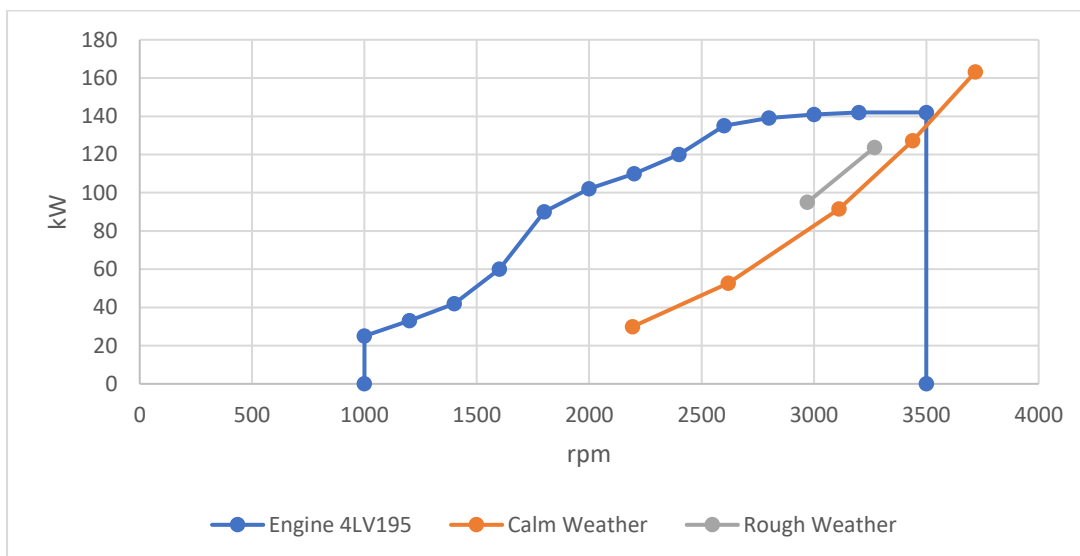


Figure 53: Propeller and engine rotation AFTER matching.

14.3 Operational range

To verify the operational range of the yacht when operating only with engine on, the consumption needs to be checked. The Arpex sailboat is design for long journeys and ocean passages, assuming high capacity of fuel, 1080 litres.

Three conditions were considered for the check: minimum, mid and maximum rotations. For these three, the consumption is analysed in terms of hours and the operational range (OR) can be described in hours of engine.

$$OR = \frac{V}{FC} [h]$$

4LV195 Fuel consumption (load exp. 2.5)

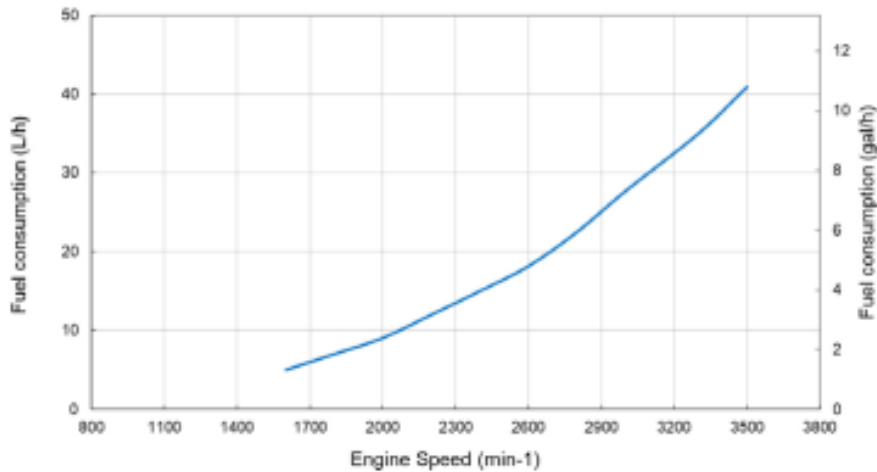


Figure 54: Engine fuel consumption.

Table 45: Yacht operating range.

		nE	FC	Tank	P _B *	V*	RANGE		
		[rpm]	[L/h]	[L]	[kW]	[knots]	OR [h]	[days]	NM
Case A	Minimum	1700	7	971,5	17,4	3,69	138,8	6	512
Case B	Mid rotation	2600	18	971,5	49,5	8,48	54,0	2	458
Case C	Maximum	3500	40	971,5	96,2	14,39	24,3	1	350

15 Stability Check

15.1 Equilibrium

Before the static stability check, the equilibrium conditions of the loading cases are checked.

Table 46: Equilibrium of loading cases.

	Depart case	MidCase 1	MidCase 2	Arrival
Draft Amidships [m]	0,649	0,633	0,633	0,625
Displacement [t]	21,89	21,17	21,17	20,7
Heel [deg]	0,2	0,2	0,2	0,2
Trim (+ by stern) [m]	0,069	0,115	0,114	0,15
Trim angle (+ by stern) [deg]	0,2192	0,3666	0,3614	0,4775
WL Length [m]	16,396	16,386	16,316	16,248
LCB [m]	8,404	8,322	8,335	8,276
LCF [m]	7,925	7,878	7,899	7,875

The trim angle remains below 0.5 degrees by the stern (Bow up). This is acceptable for cruising sailboats and ensures a balanced hull with limited impact on resistance and sailing performance.

15.2 Stability assessment

The stability assessment is carried out by evaluating the righting arm curve (GZ curve). This curve is obtained by rotating the yacht (heel) and, for each heel angle, recalculating the position of the center of buoyancy (B). The resulting distance between the center of gravity (G) and the center of buoyancy defines the righting arm (GZ), from which the GZ versus heel angle curve is constructed.

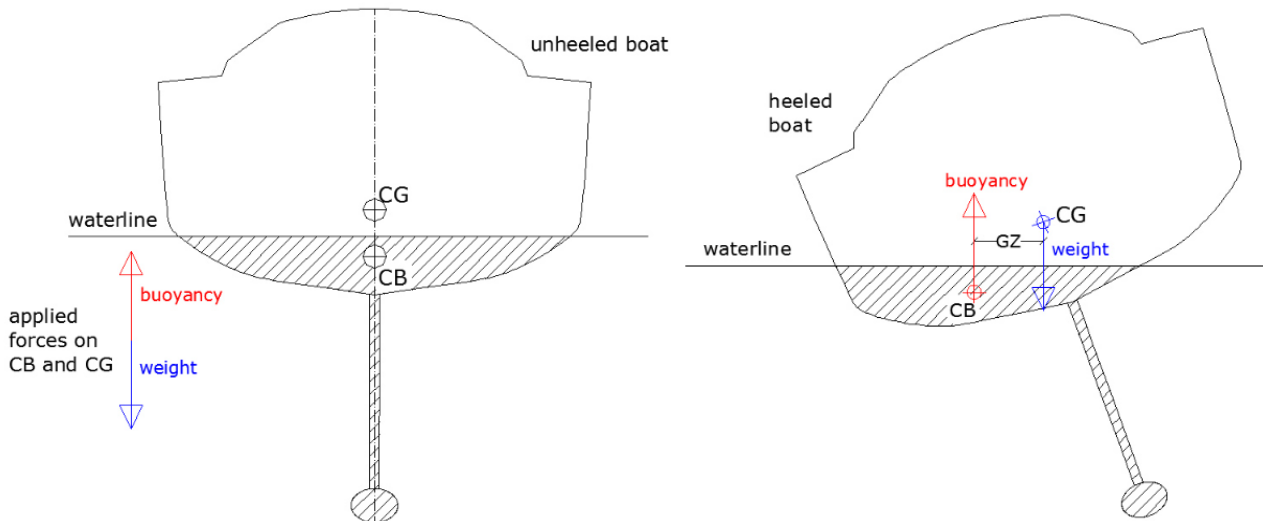


Figure 55: GZ arm.

The following equations are used:

$$GZ = GM_T \cdot \sin \theta \quad [m]$$

$$GM_T = BM_T - (KG + FS - KB) \quad [m]$$

$$BM_T = \frac{I_T}{\nabla} \quad [m]$$

$$FS = \frac{\sum \rho \cdot i_t}{\Delta} \quad [m]$$

The free surface correction (FS) is needed for the partially filled tanks. For each tank, it is calculated multiplying the density of the liquid by the transversal inertia of the tank (i_t). Then, dividing the sum of the corrections by the yacht displacement (Δ).

	Depart case	MidCase 1	MidCase 2	Arrival
Draft Amidships m	0,649	0,633	0,633	0,625
Displacement t	21,89	21,17	21,17	20,7
Heel deg	0,2	0,2	0,2	0,2
LCB m	8,404	8,322	8,335	8,276
KB m	0,401	0,393	0,388	0,377
KG fluid (KG+FS) m	0,411	0,477	0,649	0,674
BM_T m	3,166	3,227	3,255	3,332
GM_T m	3,157	3,144	2,994	3,035

The GZ curves are presented in Figure 56. The condition with lower stability can be seen as the curve with the lower area below the graph (Arrival case).

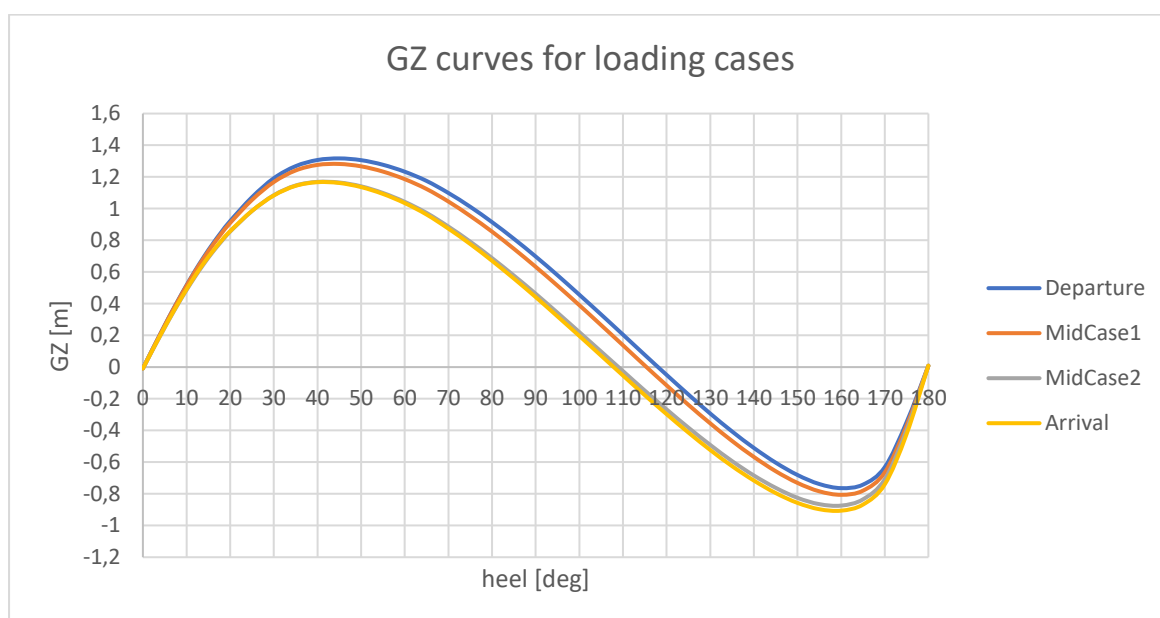


Figure 56: GZ curves for all loading conditions.

15.3 Stability Criteria

The ISO 12217-2, reference [11], establishes some criteria for sailboats stability.

Table 47: Criteria compliance.

Criteria	Description	Required value	Value	Check
Downflooding height	Downflooding height (h_D) at equilibrium shall be greater than $L_H/17$	1,420 m	2,000 m	OK!
Downflooding angle	Downflooding angle (ϕ_{DF}) shall be greater than 40°	40 deg	78,4 deg	OK!
Vanishing angle	Vanishing angle (ϕ_V) shall be greater than 100°	100 deg	107,9 deg	OK!
Righting energy	The minimum righting energy ($\Delta x A_{GZ}$) shall be greater than 172000kg.m.deg	172000 kg.m.deg	1577603 kg.m.deg	OK!

15.4 STIX index

The STIX (Stability Index) is a measure of a sailboat's offshore safety, combining its stability, seakeeping behavior and the effects of rig and loading. It is based mostly on the righting arm (GZ) curve but also accounts for hull shape, displacement, and sail plan, providing a single number to assess whether the yacht is seaworthy.

$$STIX = (7 + 2,25 \cdot L_{BS}) \cdot (FDL \cdot FBD \cdot FKR \cdot FIR \cdot FDS \cdot FWM \cdot FDF)^2$$

where,

- L_{BS} Base length factor $((L_H + 2 \cdot L_{WL})/3)$ [m]
- FDL Displacement Length factor
- FBD Beam Displacement factor
- FKR Knockdown Recovery factor
- FIR Inversion Recovery factor
- FDS Dynamic Stability factor
- FWM Wind Moment factor
- FDF Downflooding factor

The factors are calculated according to the Figure 57.

<p>Displacement Length Factor : [0.905]</p> $FDL = \left[0.6 + \frac{15 \cdot m \cdot F_L}{L_{BS}^3 \cdot (333 - 8 \cdot L_{BS})} \right]^{0.5} \quad 0.75 < FDL < 1.25$ $F_L = (L_{BS}/11)^{0.2}$	<p>Knockdown Recovery Factor : [1.216]</p> $F_R = GZ_{90} \cdot m / (2 \cdot A_S \cdot h_{CE}) \quad 0.5 < FKR < 1.5$ $FKR = 0.875 + 0.0883 \cdot F_R \quad \text{if } F_R \geq 1.5$ $FKR = 0.5 + 0.333 \cdot F_R \quad \text{if } F_R < 1.5$ $FKR = 0.5 \quad \text{if } \phi_V < 90^\circ$
<p>Beam Displacement Factor : [0.831]</p> $F_B = \frac{3,3 \cdot B_H}{(0,03 \cdot m)^{1/3}} \quad 0.75 < FBD < 1.25$ $FBD = \left[\frac{13,31 \cdot B_{WL}}{B_H \cdot F_B^2} \right]^{0.5} \quad \text{if } F_B > 2.2$ $FBD = \left[\frac{B_{WL} \cdot F_B^2}{1,682 \cdot B_H} \right]^{0.5} \quad \text{if } F_B < 1.45$ $FBD = 1.118 \cdot (B_{WL}/B_H)^{0.5} \quad \text{if } 1.45 \leq F_B \leq 2.2$	<p>Inversion Recovery Factor : [1.090]</p> $FIR = \phi_V / (125 - m/1600) \quad \text{if } m < 40000 \quad 0.4 < FIR < 1.5$ $FIR = \phi_V / 100 \quad \text{if } m \geq 40000$
	<p>Dynamic Stability Factor : [1.183]</p> $FDS = (A_{GZ} / (15,81 \cdot \sqrt{L_H}))^{0.3} \quad 0.5 < FDS < 1.5$ <p>A_{GZ} = the positive area under the GZ-curve (m.deg.) as follows: from upright to ϕ_V, for the appropriate loading condition</p>
	<p>Wind Moment Factor : [1.00]</p> $FWM = 1.0 \quad \text{if } \phi_D > 90^\circ \quad 0.5 < FWM < 1.0$ $FWM = V_{AW} / 17 \quad \text{if } \phi_D < 90^\circ$ <p>V_{AW} = the steady apparent windspeed to heel the vessel to ϕ_D when carrying full sail = $(13 \cdot m \cdot GZ_D / (A_S \cdot (h_{CE} + h_{LP}) \cdot \cos \phi_D^{1.3}))^{0.5}$</p>
	<p>Downflooding Factor : [1.25]</p> $FDF = \phi_D / 90 \quad 0.5 < FDF < 1.25$

Figure 57: Factor calculation.

The data used for the calculation are shown in Table 48.

Table 48: data for STIX check.

	Description	Unit	Departure Case	MidCase2	Arrival Case
L_H	hull length	[m]	18,5	18,5	18,5
L_{WL}	Water length	[m]	16,396	20,7	16,25
B_H	hull width	[m]	5,2	5,2	5,20
B_{WL}	beam waterline	[m]	4,608	4,576	4,55
m	mass of the boat	[kg]	21887	21887	21887
m_{M0}	mass of boat on minimum operational condition	[kg]	20699	20699	20699
m_{LA}	mass of boat on loaded arrival condition	[kg]	19750	19750	19750
A_S	Sail area	[m ²]	173,8	173,8	173,8
h_{CE}	height of centre of sail, above waterline	[m]	9,54	9,567	9,583
h_{LP}	height of centre of lateral area below waterline	[m]	0,385	0,38	0,365

	Description	Unit	Departure Case	MidCase2	Arrival Case
A _{GZ}	Area until vanish angle	[m ²]	98,85	80,7	79,8867
GZ ₉₀	righting arm at 90°	m	0,698	0,463	0,442
GZ _D	righting arm at downflooding angle	[m]	1,012	0,76	0,703
V _{AW}	apparent wind to heel to downflooding angle	[m/s]	30,46356	28,92946	30,51145
φ _V	Vanish Angle	[deg]	117,98	108,82	107,9
φ _D	Downflooding angle	[deg]	74,5	76,6	78,4

The results for STIX are presented in Table 49.

Table 49: Results for STIX.

	Departure Case	MidCase2	Arrival Case	STIX CHECK	
data	Value	Value	Value		
LBS	17,10	19,97	17,00		
FB	1,97	2,01	2,04		
FR	4,61	2,88	2,62		
Factor	Value	Value	Value	Limits	Check
FDL	0,98	0,92	0,97	0,75<FDL<1,25	OK
FBD	1,05	1,05	1,05	0,75<FBD<1,25	OK
FKR	1,28	1,13	1,11	0,5<FKR<1,5	OK
FIR	1,06	0,97	0,96	0,4<FIR<1,5	OK
FDS	1,12	1,05	1,05	0,5<FDS<1,5	OK
FWM	1,00	1,00	1,00	0,5<FWM<1	OK
PDF	0,83	0,85	0,87	0,5<PDF<1,25	OK
STIX	52	51	45		

The design categories and the associated STIX are presented in Figure 58. As can be seen in Table 49 and Figure 58., the Arpex sailboat is a Design Category A – “Ocean”, meaning that it is considered seaworthy for extended offshore voyages.

Design Categories :	A	B	C	D
STIX Lower Limits :	32	23	14	5

Figure 58: Design category vs STIX.

16 Velocity Prediction (VPP)

The Velocity Prediction Program (VPP) is a numerical tool used to estimate the sailing performance of a yacht under sailing conditions. It determines the boat speed by solving the equilibrium between aerodynamic forces, generated by the sails, and hydrodynamic forces acting on the hull, keel and rudder. For a given true wind speed and angle, the VPP iteratively balances driving force, resistance, side force, and heeling moment to predict boat behaviour.

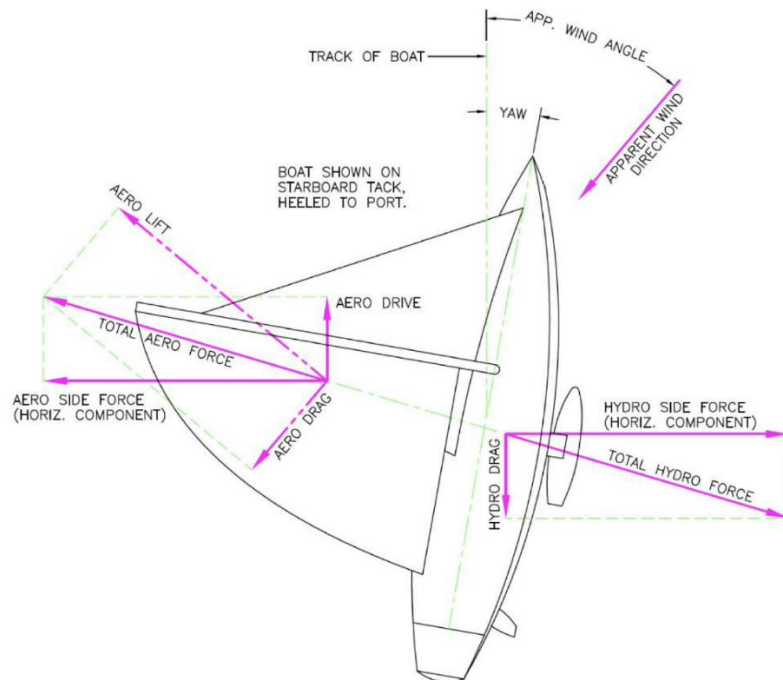


Figure 59: Wind and hydro forces.



Figure 60: Model set in VPP software.

16.1 Results

The results are typically presented in the form of polar diagrams, relating true wind angle (β_{TW}) and hull speed, which provide an overview of the yacht's expected performance across different wind conditions. Figure 61 presents the results for upwind and downwind configuration.

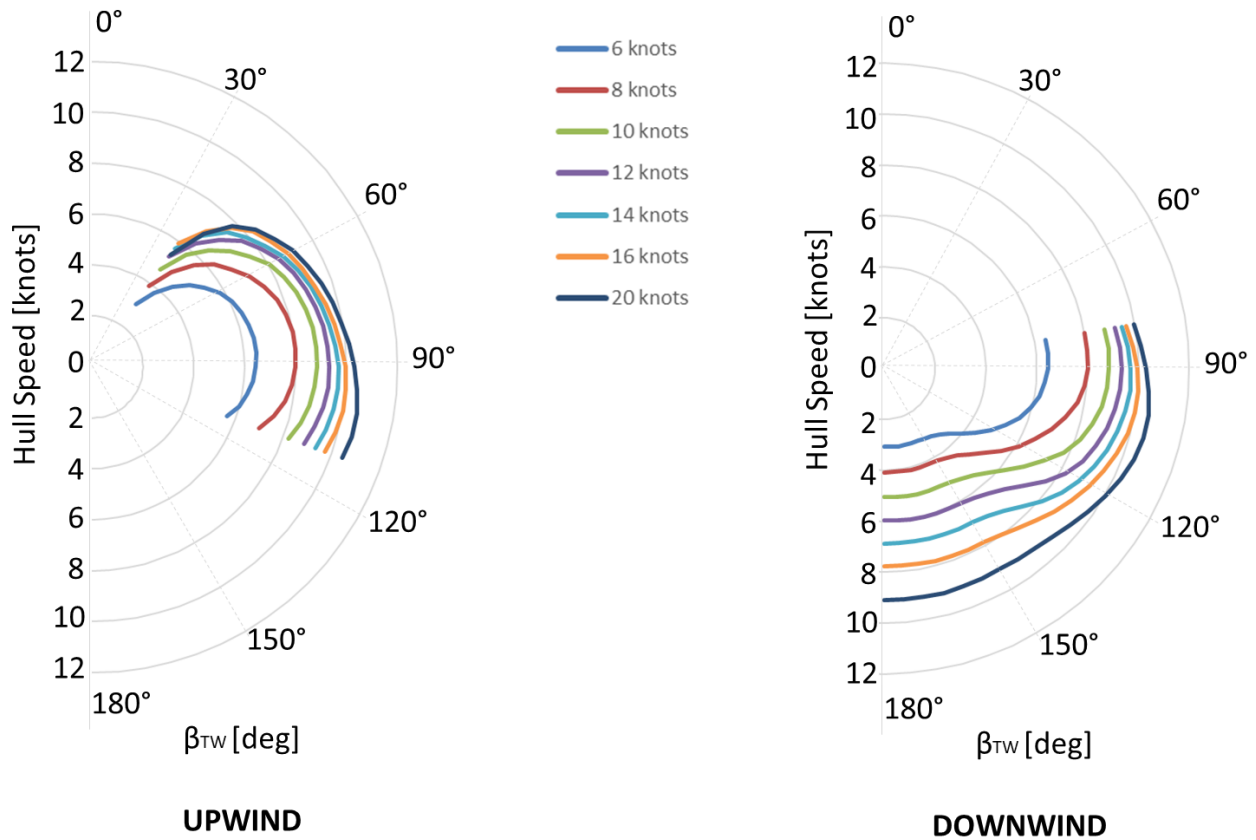


Figure 61: Results of velocity prediction.

17 Renders

Some renders from the design are shown in this chapter.





18 Cost Estimation

Some cost estimation is proposed for the yacht. The values were based in some quotations online and experience with some suppliers. It shall be considered a very rough estimation, missing some important parts, such as technological equipment. The total cost of lightship is estimated in around €200.000, as shown in Table 50. Table 51 to Table 56 detailed a bit more the estimated costs per category.

Table 50: Summary of lightship costs.

SUMMARY	Weight [t]	X [m]	Y [m]	Z [m]	Price [€]
Structure	5,75	8,12	0,00	1,00	€ 57.472
Appendices	9,21	8,37	0,00	-1,37	€ 20.220
Propulsion	0,50	4,94	0,05	0,40	€ 42.481
Rigging	0,79	10,54	0,00	11,43	€ 34.658
Deck Additional	0,21	10,54	0,00	11,43	€ 21.650
Interior	1,94	8,05	-0,15	0,92	€ 18.526
LIGHTSHIP	18,39	8,28	-0,01	0,35	€ 195.007

Table 51: Structure costs.

	Identification	Material	X[m]	Y[m]	Z[m]	W [t]	€/t	Price [€]
Shell	Bottom	Al 5083 H111	7,76	0,0	0,37	1,50	€ 10.000	€ 15.018
	Keel	Al 5083 H111	9,04	0,0	0,01	0,11	€ 10.000	€ 1.092
	Side	Al 5083 H111	9,62	0,0	1,30	0,53	€ 10.000	€ 5.273
	Deck	Al 5083 H111	9,80	0,0	1,86	0,50	€ 10.000	€ 4.970
	Deck Top	Al 5083 H111	6,20	0,0	2,05	0,81	€ 10.000	€ 8.131
	Frames Web	Al 5083 H111	8,48	0,0	1,13	0,36	€ 10.000	€ 3.591
	Frames Flange	Al 5083 H111	8,27	0,0	1,22	0,21	€ 10.000	€ 2.132
	Longitudinal Girder	Al 5083 H111	8,51	0,0	0,40	0,14	€ 10.000	€ 1.371
	Longitudinal String	Al 5083 H111	8,79	0,0	0,95	0,34	€ 10.000	€ 3.407
	Bulkheads	Al 5083 H111	17,50	0,0	1,61	0,01	€ 10.000	€ 96
Tanks	Fuel tank1	Al 5083 H111	5,52	0,0	0,23	0,06	€ 10.000	€ 610
	Fuel tank2	Al 5083 H111	6,51	0,0	0,21	0,07	€ 10.000	€ 702
	Fresh water PS	Al 5083 H111	7,92	1,0	0,19	0,12	€ 10.000	€ 1.223
	Fresh water SB	Al 5083 H111	7,92	-1,0	0,19	0,12	€ 10.000	€ 1.223
	Gray water	Al 5083 H111	9,49	1,1	0,20	0,05	€ 10.000	€ 526
	Black water	Al 5083 H111	9,49	-1,2	0,20	0,04	€ 10.000	€ 445
	Bilge	Al 5083 H111	9,49	-0,6	0,16	0,02	€ 10.000	€ 167
	Total		8,12	0,0	1,00	5,00		€ 49.975
	Total + margin (15%)	15%	8,12	0,00	1,00	5,75		€ 57.472

Table 52: Appendages costs.

	Identification	Material	X[m]	Y[m]	Z[m]	W [t]	€/t	Price [€]
Appendices	Keel	Al 5083 H111	8,87	0,0	-0,53	0,10	€ 10.000	€ 1.007
	Lead Ballast	Lead	8,45	0,0	-1,40	7,81	€ 2.000	€ 15.627
	Rudders	Al 5083 H111	0,49	0,0	-0,03	0,09	€ 10.000	€ 950
	TOTAL		8,37	0,0	-1,37	8,01		€ 17.583
	Total + margin (15%)	15%	8,37	0,00	-1,37	9,21		€ 20.220

Table 53: Propulsion costs.

Propulsion	Identification	Material	X[m]	Y[m]	Z[m]	W [t]	€/t	Price [€]
	Engine + Gear	-	5,50	0	0,50	0,26	-	€ 27.000
	Propeller	-	3,10	0	-0,05	0,02	-	€ 4.900
	Axis	Stainless Steel	4,19	0	0,16	0,12	-	€ 40
	Batteries (8x - 2000Ah)	-	4,42	0,65	0,74	0,03	-	€ 5.000
	TOTAL		4,94	0,05	0,40	0,43		€ 36.940
	Total + margin (15%)	15%	4,94	0,05	0,40	0,50		€ 42.481

Table 54: Rigging costs.

Rigging	Identification	Material	X[m]	Y[m]	Z[m]	W [t]	€/t	Price [€]
	Mast	Al 5083 H111	10,99	0	13,28	0,39	-	€ 8.500
	Boom	Al 5083 H111	6,62	0	3,95	0,09	-	€ 5.800
	Stays	Stainless Steel	10,52	0	11,40	0,05	-	€ 1.007
	Shrouds	Stainless Steel	11,72	0	13,12	0,03	-	€ 1.030
	Spreader 1	Al 5083 H111	10,69	0	9,43	0,02	-	€ 250
	Spreader 2	Al 5083 H111	10,81	0	16,28	0,02	-	€ 250
	Genoa Foresail	-	8,96	0	11,20	0,04	-	€ 5.800
	Main Sail	-	15,05	0	8,90	0,04	-	€ 7.500
	TOTAL		10,54	0,00	11,43	0,68		€ 30.137
	Total + margin (15%)	15%	10,54	0,00	11,43	0,79		€ 34.658

Table 55: Deck additional costs.

Deck additional	Identification	Material	X[m]	Y[m]	Z[m]	W [t]	€/t	Price [€]
	Hatches	-	10,90	0	2,05	0,03	€ 136	€ 3.818
	Wheels	-	3,90	0	2,24	0,01	-	€ 1.000
	Winches	Al 5083 H111	5,34	0	2,34	0,01	€ 450	€ 2.700
	Anchor	Stainless Steel	18,19	0	1,69	0,02	-	€ 500
	Chain	Stainless Steel	17,98	0	1,69	0,04	-	€ 800
	Teak cover	Wood (cover)	9,79	0	1,85	0,02	-	€ 9.558
	Guardrail	Stainless Steel	8,35	0	2,23	0,05	-	€ 450
	TOTAL		11,69	0,00	1,99	0,18		€ 18.826
Total + margin (15%)	15%	11,69	0,00	1,99	0,21		€ 21.650	

Table 56: Interior costs.

	Identification	Material	X[m]	Y[m]	Z[m]	W [t]	€/t	Price [€]
Interior	Back Cabin							
	Bed	-	1,44	0,00	0,93	0,15	-	€ 600
	Sofa	Wood (furniture)	2,14	1,41	0,95	0,10	-	€ 500
	Wardrobe	Wood (cover)	3,53	0,00	1,24	0,00	€ 20	€ 124
	Wardrobe2	Wood (cover)	3,80	0,00	0,85	0,00	€ 20	€ 105
	Table	Wood (cover)	1,92	-1,25	1,24	0,01	€ 20	€ 151
	Floor & walls	Wood (cover)	2,30	0,00	1,31	0,02	€ 20	€ 613
	Bulkheads	Wood (cover)	2,74	0,00	1,16	0,02	€ 20	€ 336
	Doors	Wood (cover)	4,00	0,00	1,32	0,00	€ 20	€ 56
	WC	-	4,52	-1,78	0,90	0,01		€ 50
	Sink	-	4,46	-0,81	1,30	0,01		€ 55
	Shower	-	5,64	-1,30	1,70	0,01		€ 23
	Bulkheads/covers	Wood (cover)	4,75	-1,00	0,95	0,01	€ 40	€ 364
	Galley							
	Sink	-	5,87	2,00	1,18	0,01		€ 55
	Furniture	Wood (furniture)	6,59	1,56	0,91	0,01	€ 40	€ 266
	Cabinets	Wood (cover)	4,91	1,28	1,05	0,01	€ 20	€ 247
	Stove	-	7,24	1,80	1,12	0,03		€ 850
	Fridge	-	7,30	1,80	0,90	0,02		€ 750
	Saloon							
	Table	Wood (furniture)	9,36	0,48	0,94	0,05	-	€ 250
	Dinner Sofa	Wood (furniture)	9,54	1,44	0,81	0,27	-	€ 1.200
	Second Sofa	Wood (furniture)	9,40	-1,64	0,93	0,16	-	€ 540
	Small table	Wood (furniture)	9,23	-1,65	0,68	0,09	-	€ 540
	Charting table	Wood (furniture)	7,22	-1,83	0,91	0,17	-	€ 220
	Equipment	-	7,22	-1,83	1,20	0,02		€ 1.500
	Charting armchair	-	6,93	-1,28	0,68	0,05	-	€ 360
	Stair	Wood (cover)	6,54	0,00	0,75	0,02	€ 20	€ 250
	Floor & walls	Wood (cover)	7,34	0,00	1,09	0,06	€ 20	€ 1.488
	Bulkheads	Wood (cover)	7,96	0,00	1,02	0,03	€ 20	€ 606
	Front Cabin							
	Bed	-	15,47	0,00	0,87	0,10	-	€ 250
	Wardrobes	Wood (furniture)	13,29	1,10	1,20	0,01	€ 40	€ 250
	Bulkheads	Wood (cover)	13,67	-0,34	1,12	0,00	€ 20	€ 133
	Floor & walls	Wood (cover)	13,49	0,00	1,23	0,03	€ 20	€ 896
	Doors	Wood (cover)	13,32	0,00	1,13	0,00	€ 20	€ 46
	Side Cabin							
	Bed	-	11,90	-1,28	0,87	0,06	-	€ 250
	Wardrobes	Wood (furniture)	12,90	-1,34	1,20	0,01	€ 40	€ 264
	Bulkhead	Wood (cover)	12,39	-0,84	1,16	0,01	€ 20	€ 196
	Doors	Wood (cover)	13,54	-0,82	1,13	0,00	€ 20	€ 46
	Bathroom							
	WC	-	11,27	1,178	0,65	0,01		€ 50
	Sink	-	12,54	0,48	1,08	0,01		€ 55
	Shower	-	13,54	1,2	1,70	0,01		€ 23
	bulkheads	Wood (cover)	12,24	0,63	1,13	0,015	€ 40	€ 700
	Furniture	Wood (furniture)	12,54	0,48	0,80	0,015	€ 40	€ 180
	TOTAL		8,05	-0,15	0,92	1,61		€ 15.439
	Total + margin (20%)	20%	8,05	-0,15	0,92	1,94		€ 18.526

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Annex A – Hydrostatic table

Draft Amidships m	0,000	0,050	0,100	0,150	0,200	0,250	0,300	0,350	0,400	0,450	0,500	0,550	0,600	0,650	0,700	0,750	0,800	0,850	0,900	0,950	1,000
Displacement t	0,2490	0,4583	1,036	1,910	3,044	4,412	5,992	7,768	9,721	11,84	14,11	16,52	19,06	21,73	24,51	27,40	30,40	33,48	36,63	39,83	43,09
Heel deg	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Draft at FP m	0,000	0,050	0,100	0,150	0,200	0,250	0,300	0,350	0,400	0,450	0,500	0,550	0,600	0,650	0,700	0,750	0,800	0,850	0,900	0,950	1,000
Draft at AP m	0,000	0,050	0,100	0,150	0,200	0,250	0,300	0,350	0,400	0,450	0,500	0,550	0,600	0,650	0,700	0,750	0,800	0,850	0,900	0,950	1,000
Draft at LCF m	0,000	0,050	0,100	0,150	0,200	0,250	0,300	0,350	0,400	0,450	0,500	0,550	0,600	0,650	0,700	0,750	0,800	0,850	0,900	0,950	1,000
Trim (+ve by stern) m	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
WL Length m	1,993	5,242	7,184	8,676	9,946	11,062	12,075	13,009	13,897	14,605	15,047	15,465	15,864	16,239	16,603	16,959	17,263	17,314	17,364	17,415	17,465
Beam max extents on WL m	0,237	2,004	2,599	2,980	3,287	3,534	3,740	3,919	4,073	4,205	4,321	4,423	4,514	4,598	4,672	4,738	4,797	4,849	4,896	4,937	4,974
Wetted Area m ²	3,739	11,089	17,413	22,900	27,692	32,198	36,330	40,533	44,210	47,654	50,927	54,264	57,291	60,232	63,271	66,098	68,797	71,244	73,499	75,658	77,761
Waterpl. Area m ²	0,312	8,012	14,295	19,701	24,370	28,705	32,610	36,528	39,852	42,871	45,647	48,420	50,864	53,131	55,438	57,469	59,305	60,795	61,987	63,012	63,919
Prismatic coeff. (Cp)	0,567	0,303	0,354	0,401	0,433	0,454	0,468	0,477	0,482	0,490	0,502	0,513	0,521	0,529	0,535	0,540	0,546	0,558	0,569	0,579	0,588
Block coeff. (Cb)	0,432	0,034	0,042	0,054	0,065	0,076	0,087	0,097	0,105	0,115	0,125	0,135	0,145	0,154	0,163	0,171	0,180	0,191	0,201	0,211	0,221
Max Sect. area coeff. (Cm)	0,876	0,114	0,120	0,136	0,154	0,173	0,191	0,208	0,226	0,242	0,258	0,273	0,288	0,302	0,316	0,329	0,342	0,355	0,367	0,378	0,390
Waterpl. area coeff. (Cwp)	0,660	0,763	0,766	0,762	0,746	0,734	0,722	0,716	0,704	0,698	0,702	0,708	0,710	0,712	0,715	0,715	0,716	0,724	0,729	0,733	0,736
LCB from zero pt. (+ve fwd) m	9,004	9,072	9,102	9,085	9,051	9,009	8,962	8,912	8,858	8,801	8,739	8,676	8,613	8,549	8,484	8,422	8,360	8,303	8,253	8,209	8,172
LCF from zero pt. (+ve fwd) m	9,193	9,147	9,111	9,024	8,972	8,891	8,807	8,674	8,579	8,473	8,367	8,238	8,139	8,043	7,930	7,840	7,765	7,723	7,712	7,711	7,718
KB m	-0,481	-0,253	-0,069	0,020	0,079	0,124	0,164	0,201	0,236	0,270	0,303	0,336	0,368	0,399	0,431	0,462	0,493	0,523	0,553	0,583	0,613
KG m	0,480	0,480	0,480	0,480	0,480	0,480	0,480	0,480	0,480	0,480	0,480	0,480	0,480	0,480	0,480	0,480	0,480	0,480	0,480	0,480	0,480
BMt m	0,004	4,465	5,935	5,805	5,437	5,060	4,715	4,408	4,134	3,891	3,676	3,483	3,308	3,148	2,999	2,859	2,727	2,601	2,481	2,367	2,260
BML m	0,308	30,070	44,766	48,485	48,100	47,495	46,152	46,069	44,501	42,641	40,781	39,558	38,038	36,578	35,639	34,484	33,281	31,755	30,082	28,489	27,020
GMt m	-0,957	3,731	5,387	5,345	5,036	4,704	4,399	4,129	3,890	3,681	3,499	3,339	3,196	3,067	2,949	2,841	2,740	2,645	2,555	2,471	2,393
GML m	-0,653	29,337	44,217	48,026	47,699	47,140	45,836	45,791	44,258	42,432	40,604	39,414	37,925	36,498	35,590	34,466	33,293	31,798	30,156	28,592	27,153
KMt m	-0,477	4,211	5,867	5,825	5,516	5,184	4,879	4,609	4,370	4,161	3,979	3,819	3,676	3,547	3,429	3,321	3,220	3,125	3,035	2,951	2,873
KML m	-0,173	29,817	44,697	48,506	48,179	47,620	46,316	46,271	44,738	42,912	41,084	39,894	38,405	36,978	36,070	34,946	33,773	32,278	30,636	29,072	27,633
Immersion (TPc) tonne/cm	0,003	0,082	0,147	0,202	0,250	0,294	0,334	0,374	0,408	0,439	0,468	0,496	0,521	0,545	0,568	0,589	0,608	0,623	0,635	0,646	0,655
MTc tonne.m	0,000	0,007	0,025	0,051	0,081	0,116	0,153	0,198	0,239	0,279	0,318	0,362	0,402	0,441	0,485	0,525	0,562	0,591	0,614	0,633	0,650
RM at 1deg = GMt.Disp.sin(1) tonne.m	-0,004	0,030	0,097	0,178	0,268	0,362	0,460	0,560	0,660	0,761	0,862	0,963	1,063	1,163	1,262	1,359	1,454	1,545	1,633	1,718	1,800

Annex B – Yacht Resistance Tables

Viscous Resistance

						Frictional Resistance					Viscous Pressure Resistance					Roughness Resistance					Viscous Resistance	
Speed	Froud number	Hull Reynolds	Keel Reynolds	Bulb Reynolds	Rudder Reynolds	Hull	Keel	Bulb	Rudder	TOTAL	Hull	Keel	Bulb	Rudder	TOTAL	Hull	Keel	Bulb	Rudder	TOTAL		[kN]
[knots]	[-]	[-]	[-]	[-]	[-]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]
0,1	0,004	5,86E+05	8,23E+04	1,75E+05	2,57E+04	0,000	0,000	0,000	0,000	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,001
0,25	0,010	1,47E+06	2,06E+05	4,37E+05	6,43E+04	0,002	0,000	0,000	0,000	0,003	0,000	0,000	0,000	0,000	0,000	0,001	0,000	0,000	0,000	0,000	0,001	0,004
0,5	0,020	2,93E+06	4,12E+05	8,75E+05	1,29E+05	0,007	0,001	0,001	0,001	0,010	0,001	0,000	0,000	0,000	0,001	0,003	0,000	0,000	0,000	0,000	0,004	0,014
0,75	0,031	4,40E+06	6,17E+05	1,31E+06	1,93E+05	0,015	0,002	0,002	0,002	0,021	0,001	0,000	0,000	0,000	0,001	0,006	0,001	0,001	0,001	0,000	0,008	0,030
1	0,041	5,86E+06	8,23E+05	1,75E+06	2,57E+05	0,026	0,003	0,003	0,003	0,035	0,002	0,000	0,000	0,000	0,002	0,010	0,001	0,001	0,002	0,014	0,051	
1,25	0,051	7,33E+06	1,03E+06	2,19E+06	3,22E+05	0,039	0,004	0,005	0,005	0,052	0,003	0,000	0,000	0,000	0,004	0,016	0,002	0,002	0,003	0,022	0,078	
1,5	0,061	8,79E+06	1,23E+06	2,62E+06	3,86E+05	0,054	0,005	0,006	0,006	0,072	0,004	0,000	0,000	0,000	0,005	0,023	0,003	0,003	0,004	0,032	0,110	
1,75	0,071	1,03E+07	1,44E+06	3,06E+06	4,50E+05	0,072	0,007	0,008	0,009	0,096	0,005	0,000	0,001	0,001	0,007	0,031	0,004	0,004	0,005	0,044	0,146	
2	0,081	1,17E+07	1,65E+06	3,50E+06	5,14E+05	0,092	0,009	0,011	0,011	0,122	0,006	0,001	0,001	0,001	0,009	0,041	0,005	0,005	0,007	0,058	0,188	
2,25	0,092	1,32E+07	1,85E+06	3,94E+06	5,79E+05	0,114	0,011	0,013	0,013	0,151	0,008	0,001	0,001	0,001	0,011	0,051	0,006	0,007	0,008	0,073	0,234	
2,5	0,102	1,47E+07	2,06E+06	4,37E+06	6,43E+05	0,138	0,013	0,016	0,016	0,183	0,010	0,001	0,001	0,001	0,013	0,063	0,008	0,009	0,010	0,090	0,286	
2,75	0,112	1,61E+07	2,26E+06	4,81E+06	7,07E+05	0,164	0,016	0,019	0,019	0,218	0,011	0,001	0,001	0,001	0,015	0,077	0,009	0,010	0,012	0,109	0,342	
3	0,122	1,76E+07	2,47E+06	5,25E+06	7,72E+05	0,192	0,018	0,022	0,022	0,255	0,013	0,001	0,002	0,002	0,018	0,091	0,011	0,012	0,015	0,129	0,402	
3,25	0,132	1,90E+07	2,68E+06	5,68E+06	8,36E+05	0,223	0,021	0,026	0,026	0,295	0,016	0,001	0,002	0,002	0,021	0,107	0,013	0,014	0,017	0,152	0,468	
3,5	0,143	2,05E+07	2,88E+06	6,12E+06	9,00E+05	0,255	0,024	0,029	0,029	0,338	0,018	0,002	0,002	0,002	0,024	0,124	0,015	0,017	0,020	0,176	0,538	
3,75	0,153	2,20E+07	3,09E+06	6,56E+06	9,65E+05	0,290	0,027	0,033	0,033	0,383	0,020	0,002	0,002	0,002	0,027	0,143	0,017	0,019	0,023	0,202	0,612	
4	0,163	2,34E+07	3,29E+06	7,00E+06	1,03E+06	0,326	0,031	0,037	0,037	0,432	0,023	0,002	0,003	0,003	0,030	0,162	0,020	0,022	0,026	0,230	0,692	
4,25	0,173	2,49E+07	3,50E+06	7,43E+06	1,09E+06	0,365	0,034	0,042	0,041	0,482	0,026	0,002	0,003	0,003	0,034	0,183	0,022	0,025	0,030	0,260	0,776	
4,5	0,183	2,64E+07	3,70E+06	7,87E+06	1,16E+06	0,405	0,038	0,046	0,046	0,535	0,028	0,003	0,003	0,003	0,037	0,205	0,025	0,028	0,033	0,291	0,864	
4,75	0,193	2,78E+07	3,91E+06	8,31E+06	1,22E+06	0,448	0,042	0,051	0,050	0,591	0,031	0,003	0,004	0,004	0,041	0,229	0,028	0,031	0,037	0,324	0,957	
5	0,204	2,93E+07	4,12E+06	8,75E+06	1,29E+06	0,492	0,046	0,056	0,055	0,649	0,034	0,003	0,004	0,004	0,045	0,253	0,031	0,034	0,041	0,359	1,054	

5,25	0,214	3,08E+07	4,32E+06	9,18E+06	1,35E+06	0,538	0,051	0,061	0,060	0,710	0,038	0,004	0,004	0,004	0,050	0,279	0,034	0,038	0,045	0,396	1,156
5,5	0,224	3,22E+07	4,53E+06	9,62E+06	1,41E+06	0,586	0,055	0,067	0,065	0,773	0,041	0,004	0,005	0,005	0,054	0,307	0,037	0,041	0,050	0,435	1,262
5,75	0,234	3,37E+07	4,73E+06	1,01E+07	1,48E+06	0,637	0,060	0,072	0,071	0,839	0,045	0,004	0,005	0,005	0,059	0,335	0,041	0,045	0,055	0,475	1,373
6	0,244	3,52E+07	4,94E+06	1,05E+07	1,54E+06	0,688	0,064	0,078	0,076	0,907	0,048	0,005	0,005	0,005	0,064	0,365	0,044	0,049	0,059	0,518	1,488
6,25	0,254	3,66E+07	5,14E+06	1,09E+07	1,61E+06	0,742	0,069	0,084	0,082	0,978	0,052	0,005	0,006	0,006	0,068	0,396	0,048	0,053	0,064	0,562	1,608
6,5	0,265	3,81E+07	5,35E+06	1,14E+07	1,67E+06	0,798	0,074	0,091	0,088	1,051	0,056	0,005	0,006	0,006	0,074	0,428	0,052	0,058	0,070	0,607	1,732
6,75	0,275	3,96E+07	5,56E+06	1,18E+07	1,74E+06	0,855	0,080	0,097	0,094	1,126	0,060	0,006	0,007	0,007	0,079	0,462	0,056	0,062	0,075	0,655	1,860
7	0,285	4,10E+07	5,76E+06	1,22E+07	1,80E+06	0,915	0,085	0,104	0,101	1,204	0,064	0,006	0,007	0,007	0,084	0,497	0,060	0,067	0,081	0,704	1,993
7,25	0,295	4,25E+07	5,97E+06	1,27E+07	1,86E+06	0,976	0,091	0,111	0,107	1,284	0,068	0,006	0,008	0,007	0,090	0,533	0,065	0,072	0,087	0,756	2,130
7,5	0,305	4,40E+07	6,17E+06	1,31E+07	1,93E+06	1,039	0,097	0,118	0,114	1,367	0,073	0,007	0,008	0,008	0,096	0,570	0,069	0,077	0,093	0,809	2,271
7,75	0,316	4,54E+07	6,38E+06	1,36E+07	1,99E+06	1,104	0,102	0,125	0,121	1,452	0,077	0,007	0,009	0,008	0,102	0,609	0,074	0,082	0,099	0,863	2,417
8	0,326	4,69E+07	6,58E+06	1,40E+07	2,06E+06	1,171	0,109	0,132	0,128	1,539	0,082	0,008	0,009	0,009	0,108	0,649	0,079	0,087	0,106	0,920	2,567
8,25	0,336	4,84E+07	6,79E+06	1,44E+07	2,12E+06	1,239	0,115	0,140	0,135	1,629	0,087	0,008	0,010	0,009	0,114	0,690	0,084	0,093	0,112	0,978	2,722
8,5	0,346	4,98E+07	7,00E+06	1,49E+07	2,19E+06	1,309	0,121	0,148	0,143	1,721	0,092	0,008	0,010	0,010	0,120	0,732	0,089	0,098	0,119	1,039	2,880
8,75	0,356	5,13E+07	7,20E+06	1,53E+07	2,25E+06	1,381	0,128	0,156	0,150	1,815	0,097	0,009	0,011	0,011	0,127	0,776	0,094	0,104	0,126	1,101	3,043
9	0,366	5,28E+07	7,41E+06	1,57E+07	2,32E+06	1,455	0,135	0,164	0,158	1,912	0,102	0,009	0,012	0,011	0,134	0,821	0,100	0,110	0,134	1,164	3,210
9,25	0,377	5,42E+07	7,61E+06	1,62E+07	2,38E+06	1,531	0,141	0,173	0,166	2,011	0,107	0,010	0,012	0,012	0,141	0,867	0,105	0,117	0,141	1,230	3,382
9,5	0,387	5,57E+07	7,82E+06	1,66E+07	2,44E+06	1,608	0,148	0,181	0,174	2,112	0,113	0,010	0,013	0,012	0,148	0,915	0,111	0,123	0,149	1,297	3,557
9,75	0,397	5,71E+07	8,03E+06	1,71E+07	2,51E+06	1,687	0,156	0,190	0,182	2,216	0,118	0,011	0,013	0,013	0,155	0,963	0,117	0,129	0,157	1,367	3,737
10	0,407	5,86E+07	8,23E+06	1,75E+07	2,57E+06	1,768	0,163	0,199	0,191	2,321	0,124	0,011	0,014	0,013	0,163	1,013	0,123	0,136	0,165	1,438	3,922
10,25	0,417	6,01E+07	8,44E+06	1,79E+07	2,64E+06	1,851	0,171	0,209	0,200	2,430	0,130	0,012	0,015	0,014	0,170	1,065	0,129	0,143	0,173	1,510	4,110
10,5	0,428	6,15E+07	8,64E+06	1,84E+07	2,70E+06	1,935	0,178	0,218	0,209	2,540	0,135	0,012	0,015	0,015	0,178	1,117	0,136	0,150	0,182	1,585	4,303
10,75	0,438	6,30E+07	8,85E+06	1,88E+07	2,77E+06	2,021	0,186	0,228	0,218	2,652	0,141	0,013	0,016	0,015	0,186	1,171	0,142	0,157	0,191	1,661	4,499
11	0,448	6,45E+07	9,05E+06	1,92E+07	2,83E+06	2,109	0,194	0,237	0,227	2,767	0,148	0,014	0,017	0,016	0,194	1,226	0,149	0,165	0,200	1,739	4,700
11,25	0,458	6,59E+07	9,26E+06	1,97E+07	2,89E+06	2,199	0,202	0,247	0,236	2,884	0,154	0,014	0,017	0,017	0,202	1,283	0,156	0,172	0,209	1,819	4,906
11,5	0,468	6,74E+07	9,47E+06	2,01E+07	2,96E+06	2,290	0,210	0,258	0,246	3,004	0,160	0,015	0,018	0,017	0,210	1,340	0,163	0,180	0,218	1,901	5,115
11,75	0,478	6,89E+07	9,67E+06	2,06E+07	3,02E+06	2,383	0,219	0,268	0,256	3,125	0,167	0,015	0,019	0,018	0,219	1,399	0,170	0,188	0,228	1,985	5,329
12	0,489	7,03E+07	9,88E+06	2,10E+07	3,09E+06	2,478	0,227	0,279	0,265	3,249	0,173	0,016	0,019	0,019	0,227	1,459	0,177	0,196	0,238	2,070	5,546
12,25	0,499	7,18E+07	1,01E+07	2,14E+07	3,15E+06	2,574	0,236	0,289	0,275	3,375	0,180	0,017	0,020	0,019	0,236	1,521	0,185	0,204	0,248	2,157	5,768
12,5	0,509	7,33E+07	1,03E+07	2,19E+07	3,22E+06	2,672	0,245	0,300	0,286	3,503	0,187	0,017	0,021	0,020	0,245	1,583	0,192	0,213	0,258	2,246	5,995
12,75	0,519	7,47E+07	1,05E+07	2,23E+07	3,28E+06	2,772	0,254	0,311	0,296	3,633	0,194	0,018	0,022	0,021	0,254	1,647	0,200	0,221	0,268	2,337	6,225

13	0,529	7,62E+07	1,07E+07	2,27E+07	3,34E+06	2,873	0,263	0,323	0,307	3,766	0,201	0,018	0,023	0,021	0,264	1,713	0,208	0,230	0,279	2,430	6,459
13,25	0,540	7,77E+07	1,09E+07	2,32E+07	3,41E+06	2,977	0,272	0,334	0,317	3,901	0,208	0,019	0,023	0,022	0,273	1,779	0,216	0,239	0,290	2,524	6,698
13,5	0,550	7,91E+07	1,11E+07	2,36E+07	3,47E+06	3,082	0,282	0,346	0,328	4,038	0,216	0,020	0,024	0,023	0,283	1,847	0,224	0,248	0,301	2,620	6,940
13,75	0,560	8,06E+07	1,13E+07	2,41E+07	3,54E+06	3,188	0,292	0,358	0,339	4,177	0,223	0,020	0,025	0,024	0,292	1,916	0,233	0,257	0,312	2,718	7,187
14	0,570	8,21E+07	1,15E+07	2,45E+07	3,60E+06	3,296	0,301	0,370	0,351	4,318	0,231	0,021	0,026	0,025	0,302	1,986	0,241	0,267	0,323	2,818	7,438
14,25	0,580	8,35E+07	1,17E+07	2,49E+07	3,67E+06	3,406	0,311	0,382	0,362	4,462	0,238	0,022	0,027	0,025	0,312	2,058	0,250	0,276	0,335	2,919	7,693
14,5	0,590	8,50E+07	1,19E+07	2,54E+07	3,73E+06	3,518	0,321	0,394	0,374	4,607	0,246	0,022	0,028	0,026	0,323	2,131	0,259	0,286	0,347	3,023	7,952
14,75	0,601	8,65E+07	1,21E+07	2,58E+07	3,79E+06	3,631	0,331	0,407	0,385	4,755	0,254	0,023	0,028	0,027	0,333	2,205	0,268	0,296	0,359	3,128	8,216
15	0,611	8,79E+07	1,23E+07	2,62E+07	3,86E+06	3,746	0,342	0,420	0,397	4,905	0,262	0,024	0,029	0,028	0,343	2,280	0,277	0,306	0,371	3,235	8,483

Wave and Residuary Resistance

						Wave and residuary Resistance			
Speed	Froud number					Hull	Keel + bulb	Rudder	TOTAL
[knots]	[-]	Volkeel	Volrudder	Zkeel	Zrudder	[kN]	[kN]	[kN]	[kN]
3,7	0,15	0,21	0,029	0,55	0,84	0,03	0,00	0,00	0,03
4,9	0,2					0,09	-0,02	-0,03	0,04
6,1	0,25					0,28	-0,02	-0,04	0,22
7,4	0,3					0,62	0,04	0,09	0,75
8,6	0,35					1,39	0,09	0,17	1,65
9,8	0,4					3,78	0,07	0,08	3,93
11,0	0,45					7,85	0,19	0,18	8,22
12,3	0,5					12,12	-0,06	-0,45	11,61
13,5	0,55					14,87	0,14	-0,10	14,91
14,7	0,6					17,21	-0,14	-0,76	16,31
16,0	0,65					18,34	0,00	0,00	18,34
17,2	0,7					19,80	0,00	0,00	19,80
18,4	0,75					19,39	0,00	0,00	19,39

Heel Resistance

						Heel Resistance (Changes in FRICTION)							Heel Resistance (Changes in RESIDUARY)							
Speed	Froud number	Wetted surface in heeled condition				Hull Reynolds	5deg	10deg	15deg	20deg	25deg	30deg	35deg	5deg	10deg	15deg	20deg	25deg	30deg	35deg
				Vol _{keel}	Vol _{rudder}															
[knots]	[-]	deg	[m ²]	0,21	0,029	[-]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]
6,1	0,25	5	60,20			3,60E+07	0,75	0,73	0,71	0,69	0,67	0,65	0,64	0,01	0,01	0,02	0,01	0,01	0,00	-0,01
7,4	0,3	10	58,78			4,32E+07	1,05	1,02	1,00	0,97	0,94	0,92	0,90	0,03	0,08	0,14	0,22	0,30	0,39	0,50
8,6	0,35	15	57,31			5,03E+07	1,39	1,36	1,32	1,28	1,25	1,22	1,20	-0,01	-0,06	-0,15	-0,26	-0,41	-0,57	-0,77
9,8	0,4	20	55,60			5,75E+07	1,78	1,74	1,69	1,64	1,60	1,56	1,53	-0,20	-0,71	-1,44	-2,38	-3,51	-4,82	-6,29
11,0	0,45	25	54,13			6,47E+07	2,21	2,16	2,11	2,04	1,99	1,94	1,91	-0,38	-1,30	-2,63	-4,33	-6,37	-8,71	-11,36
12,3	0,5	30	52,75			7,19E+07	2,69	2,62	2,56	2,48	2,42	2,36	2,32	-0,24	-0,86	-1,76	-2,92	-4,32	-5,93	-7,75
13,5	0,55	35	51,87			7,91E+07	3,21	3,13	3,05	2,96	2,88	2,81	2,76	-0,08	-0,32	-0,71	-1,21	-1,83	-2,54	-3,35

Induced Resistance

					L _k [kN]							L _r [kN]						
					Cl							Cl						
Heel angle	Cheel	Chull	1,98		0,105	0,175	0,351	0,526	0,702	0,877	1,053	0,228	0,382	0,766	1,150	1,534	1,919	2,303
		F _k	F _r	F _h	Leeway Angle [deg]							Leeway Angle [deg]						
[deg]	[-]	[kN]	[kN]	[kN]	3	5	10	15	20	25	30	3	5	10	15	20	25	30
5	0,97	3	3	6	1,0	1,7	3,4	5,2	6,9	8,6	10,3	0,9	1,4	2,8	4,3	5,7	7,1	8,6
10	0,93	5	4	8	1,5	2,5	5,0	7,4	9,9	12,4	14,9	1,2	2,0	4,1	6,2	8,2	10,3	12,3
15	0,90	6	5	11	2,0	3,4	6,7	10,1	13,5	16,9	20,2	1,7	2,8	5,6	8,4	11,2	14,0	16,8
20	0,87	8	6	14	2,6	4,4	8,8	13,2	17,6	22,0	26,4	2,2	3,6	7,3	11,0	14,6	18,3	21,9
25	0,83	9	8	17	3,3	5,6	11,1	16,7	22,3	27,9	33,4	2,8	4,6	9,2	13,9	18,5	23,1	27,8
30	0,80	11	9	20	4,1	6,9	13,8	20,6	27,5	34,4	41,3	3,4	5,7	11,4	17,1	22,8	28,6	34,3
35	0,77	13	10	23	5,0	8,3	16,7	25,0	33,3	41,6	50,0	4,1	6,9	13,8	20,7	27,6	34,6	41,5

Speed	Froud number	Hull Reynolds	Keel Reynolds	Bulb Reynolds					Induce Resistance		
					CLkphi	CLrphi	CDIk	CDIr	Keel + bulb	Rudder	TOTAL
[knots]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[kN]	[kN]	[kN]
6,1	0,25	3,60E+07	5,05E+06	1,07E+07	0,82	1,78	0,143	0,141	1,4	0,5	1,9
7,4	0,3	4,32E+07	6,06E+06	1,29E+07	0,57	1,24	0,069	0,068	1,0	0,4	1,3
8,6	0,35	5,03E+07	7,07E+06	1,50E+07	0,42	0,91	0,037	0,037	0,7	0,3	1,0
9,8	0,4	5,75E+07	8,08E+06	1,72E+07	0,32	0,70	0,022	0,021	0,5	0,2	0,7
11,0	0,45	6,47E+07	9,09E+06	1,93E+07	0,25	0,55	0,014	0,013	0,4	0,2	0,6
12,3	0,5	7,19E+07	1,01E+07	2,15E+07	0,20	0,45	0,009	0,009	0,3	0,1	0,5
13,5	0,55	7,91E+07	1,11E+07	2,36E+07	0,17	0,37	0,006	0,006	0,3	0,1	0,4

Wind Resistance

B _{max} [m]	5,20
FA [m]	1,10
EMDC [m]	0,20
EHM [m]	20,61
A _{rearig} [m ²]	1,142505

Apparent wind		Windage of hull	Windage of mast	Windage of rig	Total
[knots]	[m/s]	[kN]	[kN]	[kN]	[kN]
5,0	2,57	0,03	0,02	0,01	0,05
7,5	3,86	0,06	0,04	0,01	0,11
10,0	5,14	0,11	0,08	0,02	0,20
12,5	6,43	0,16	0,12	0,03	0,32
15,0	7,72	0,24	0,17	0,05	0,46
17,5	9,00	0,32	0,24	0,06	0,62
20,0	10,29	0,42	0,31	0,08	0,81
22,5	11,58	0,53	0,39	0,11	1,03
25,0	12,86	0,66	0,48	0,13	1,27
27,5	14,15	0,79	0,58	0,16	1,54
30,0	15,43	0,95	0,70	0,19	1,83
32,5	16,72	1,11	0,82	0,22	2,15
35,0	18,01	1,29	0,95	0,26	2,49

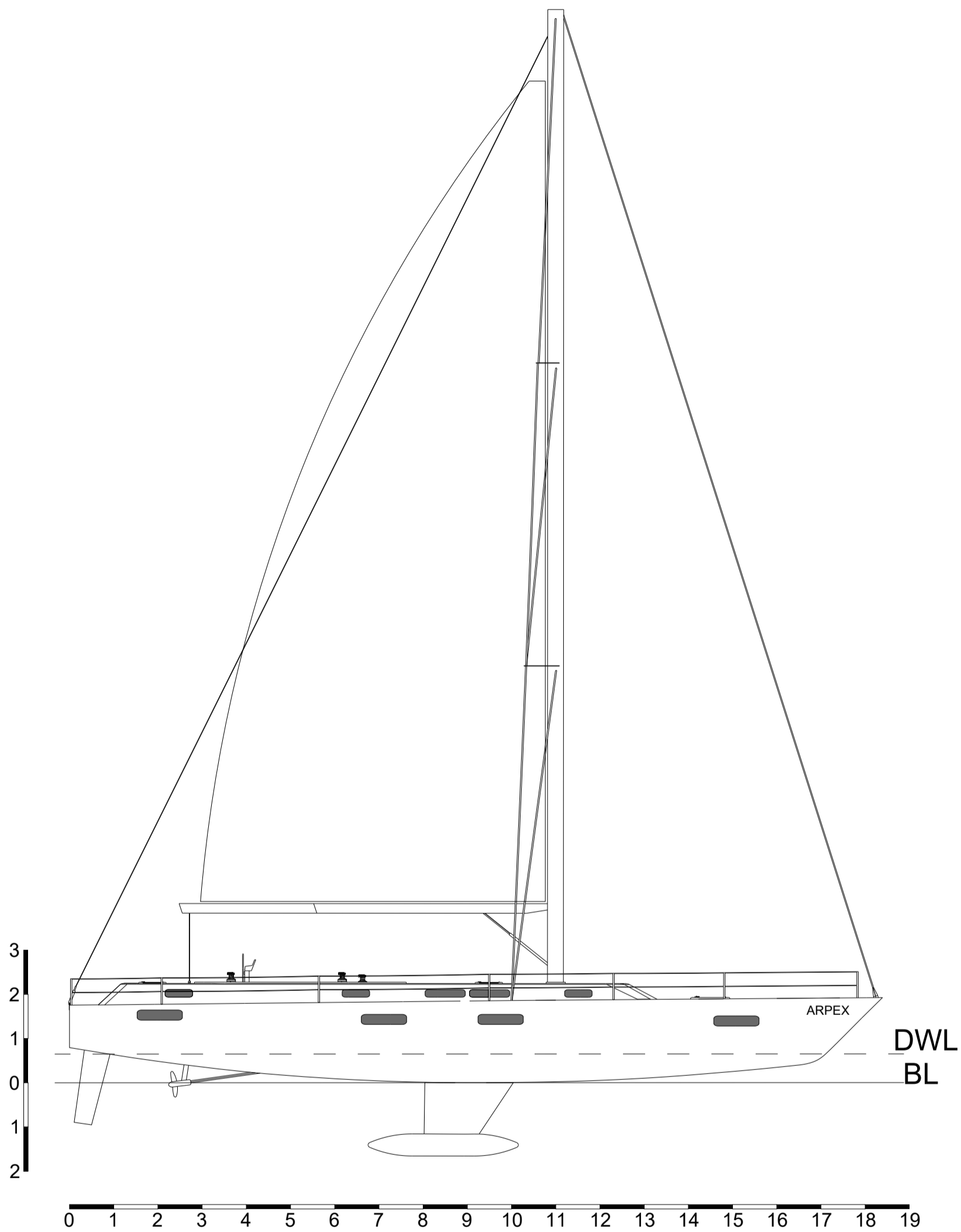
Added wave Resistance

ADDED WAVE		H1/3	T	T'			
k _{yy} (25%Lwl)		Sea 1	1,50	4,51	3,50		
4,0635		Sea 2	3,00	5,80	4,51		
		Sea 3	4,50	7,73	6,00		
Speed	[knots]	3,7	6,1	8,6	11,0	14,7	
Froud number	[-]	0,15	0,25	0,35	0,45	0,6	
ADDED WAVE RESISTANCE [kN]							
T'=3,5 / T=4,5	μ=100°	0,06	0,06	0,07	0,07	0,07	
	μ=115°	0,30	0,41	0,50	0,56	0,61	
	μ=125°	0,57	0,78	0,97	1,10	1,19	
	μ=135°	0,88	1,20	1,49	1,69	1,82	
	μ=145°	1,19	1,61	1,99	2,25	2,38	
T'=4,5 / T=5,79	μ=100°	0,10	0,03	0,03	0,03	0,03	
	μ=115°	0,49	0,16	0,20	0,23	0,25	
	μ=125°	0,92	0,31	0,39	0,46	0,50	
	μ=135°	1,42	0,49	0,63	0,73	0,80	
	μ=145°	1,93	0,67	0,86	1,00	1,09	
T'=6 / T=7,72	μ=100°	0,06	0,07	0,08	0,06	0,08	
	μ=115°	0,33	0,48	0,59	0,68	0,74	
	μ=125°	0,65	0,93	1,18	1,39	1,52	
	μ=135°	1,03	1,49	1,91	2,23	2,47	
	μ=145°	1,42	2,04	2,65	3,12	3,44	

Annex C – Technical drawings

The following drawings are presented in this annex.

1. Profile
2. Deck View
3. Bow and stern views
4. Lines Plan
5. General Plan
6. Longitudinal Section
7. Transverse Sections



UNIVERSITÀ DEGLI STUDI DI GENOVA
CORSO DI LAUREA MAGISTRALE IN YACHT DESIGN

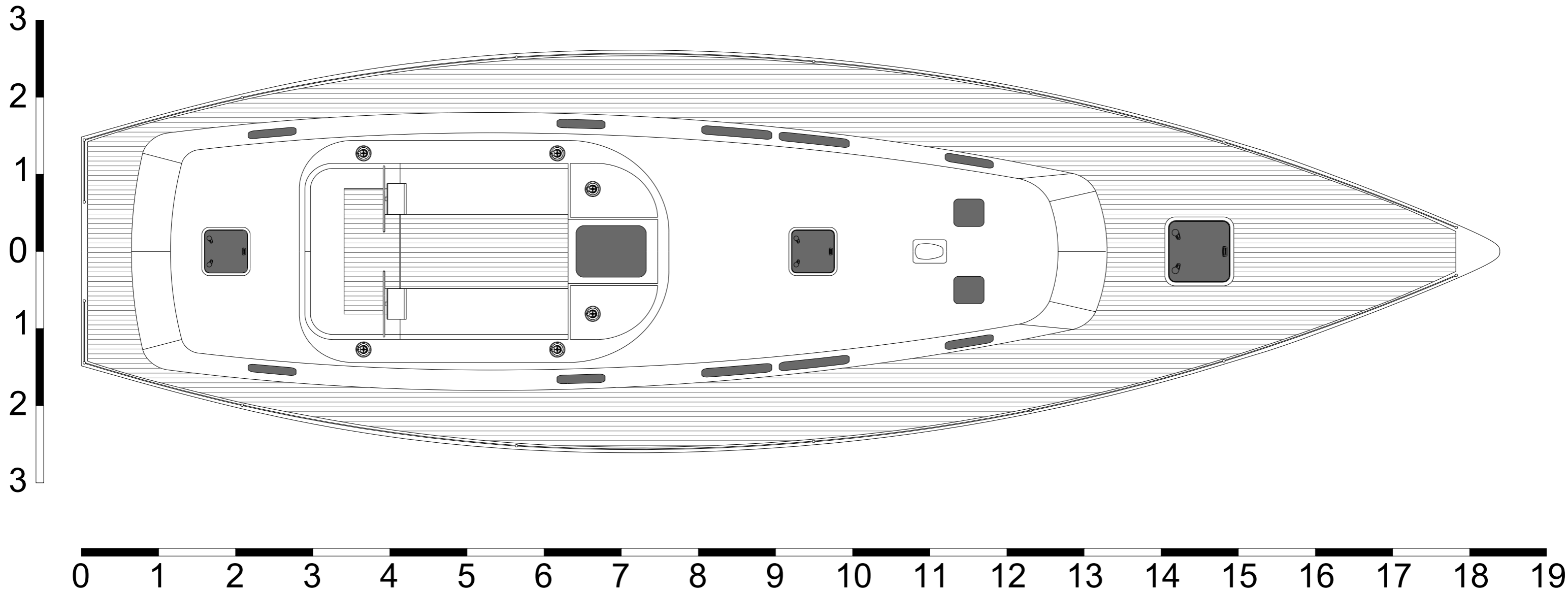
PROFILE DRAWING

STUDENT:
Alexandre Azevedo

ARPEX 60'

A3 format

Scale: 1:100



UNIVERSITÀ DEGLI STUDI DI GENOVA
CORSO DI LAUREA MAGISTRALE IN YACHT DESIGN

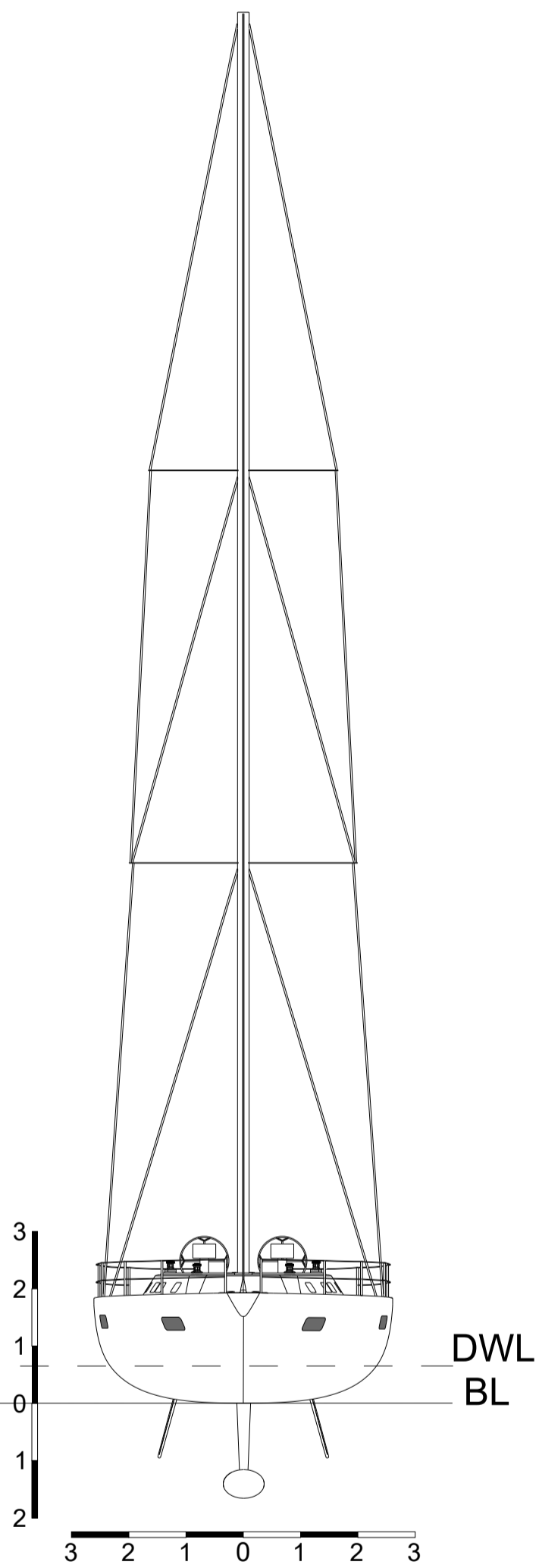
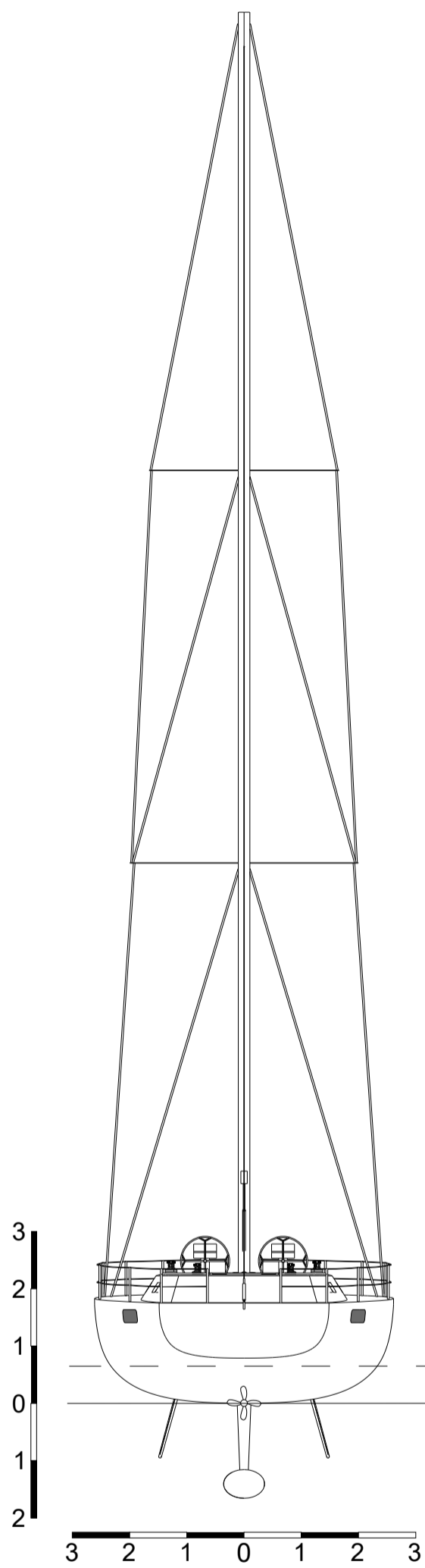
DECK VIEW

STUDENT:
Alexandre Azevedo

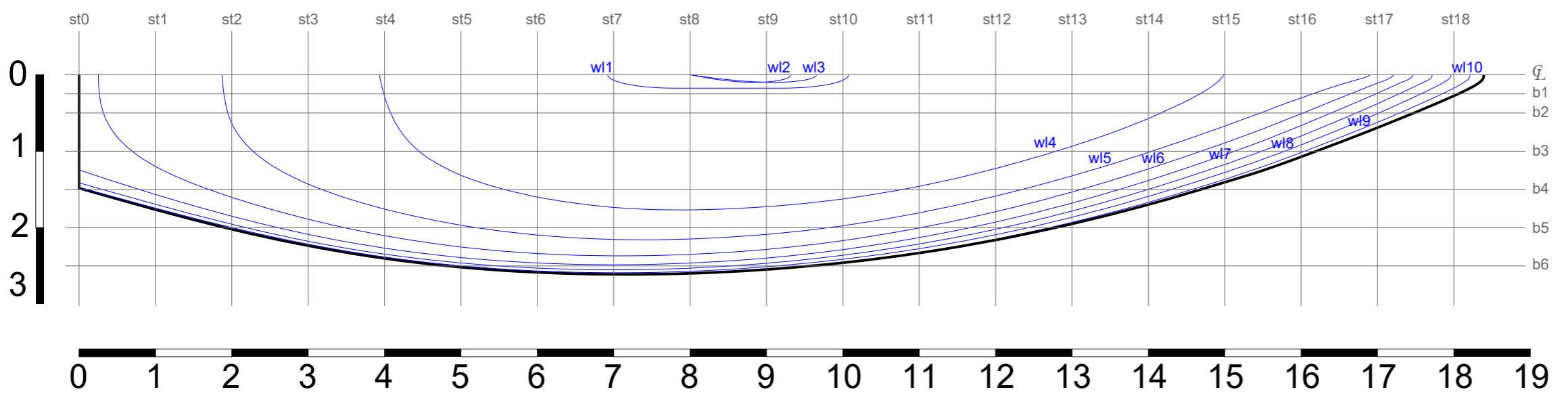
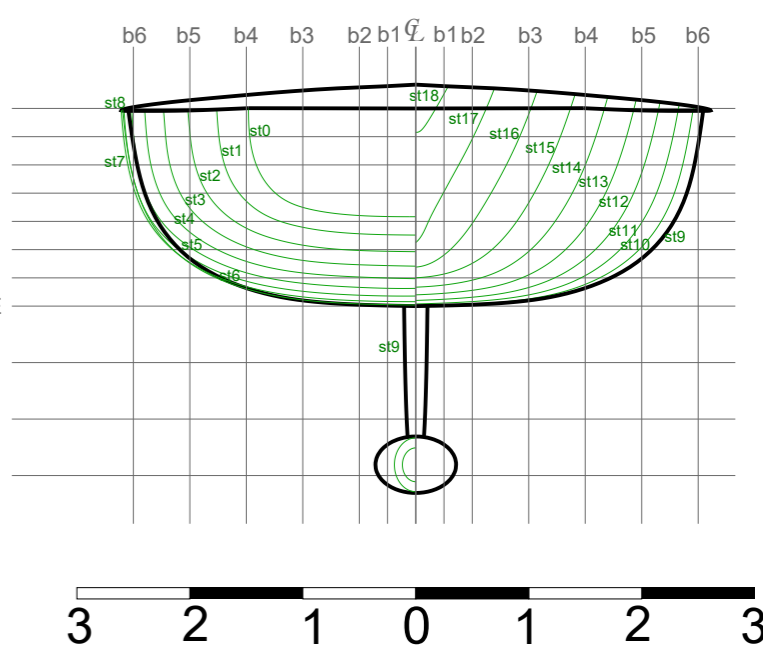
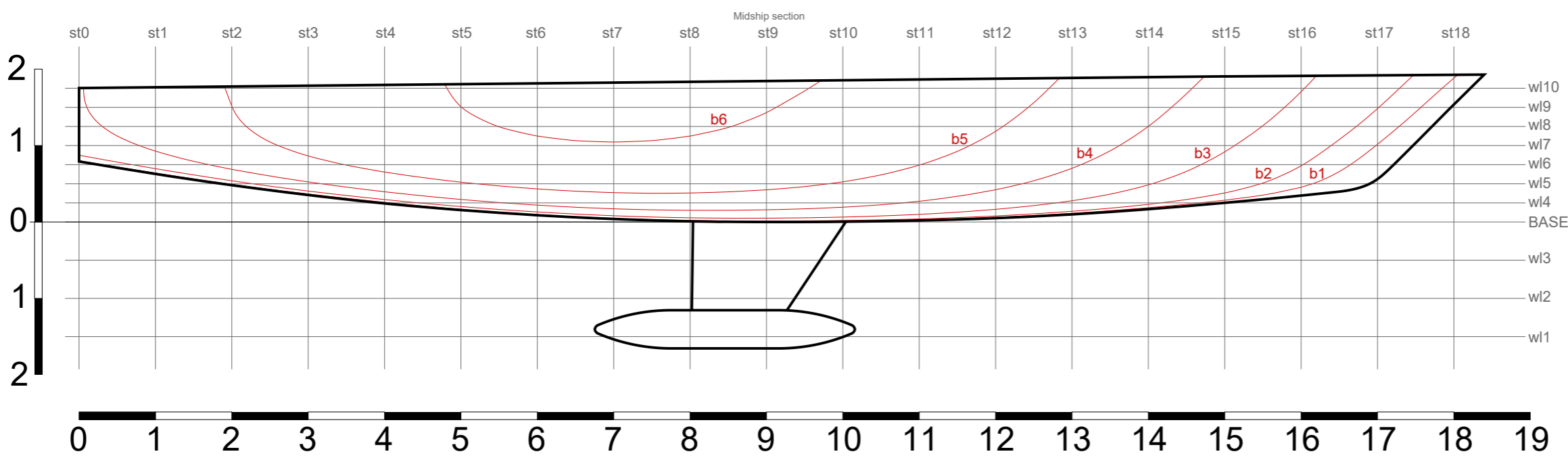
ARPEX 60'

A3 format

Scale: 1:50

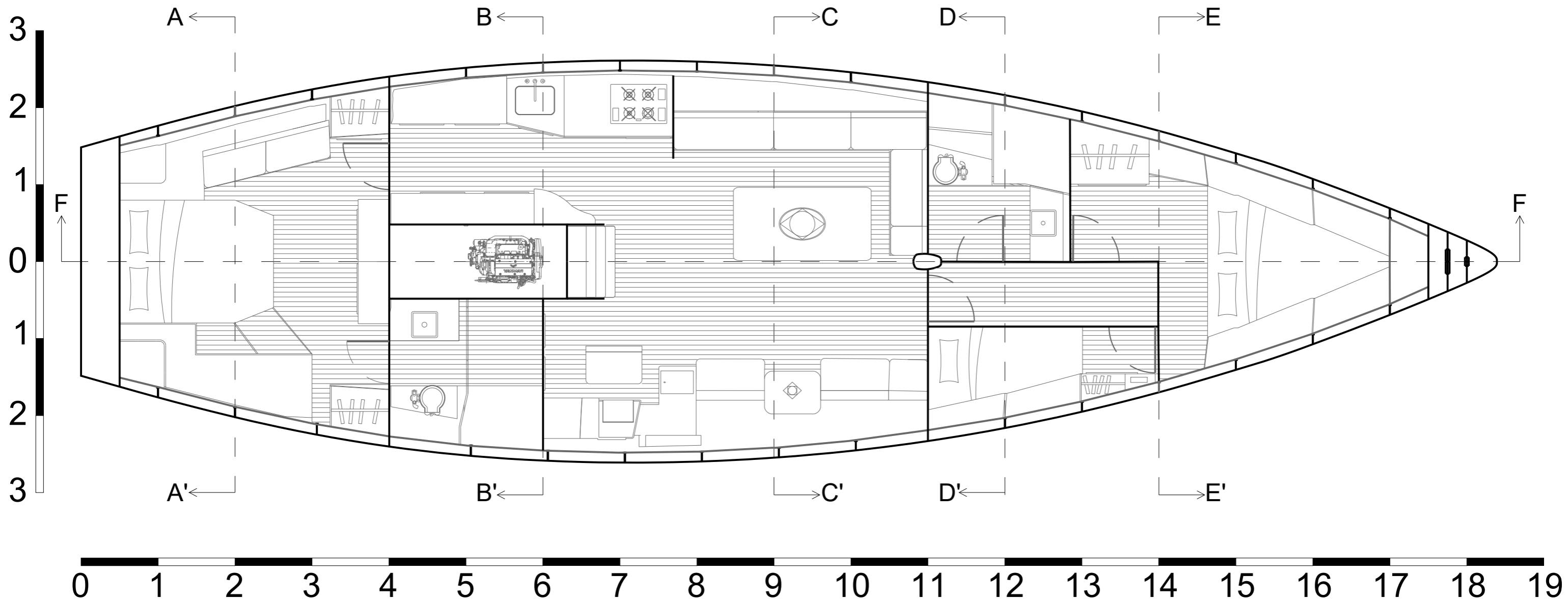


UNIVERSITÀ DEGLI STUDI DI GENOVA CORSO DI LAUREA MAGISTRALE IN YACHT DESIGN	
BOW & STERN VIEWS	
STUDENT: Alexandre Azevedo	ARPEX 60'
A3 format	Scale: 1:100



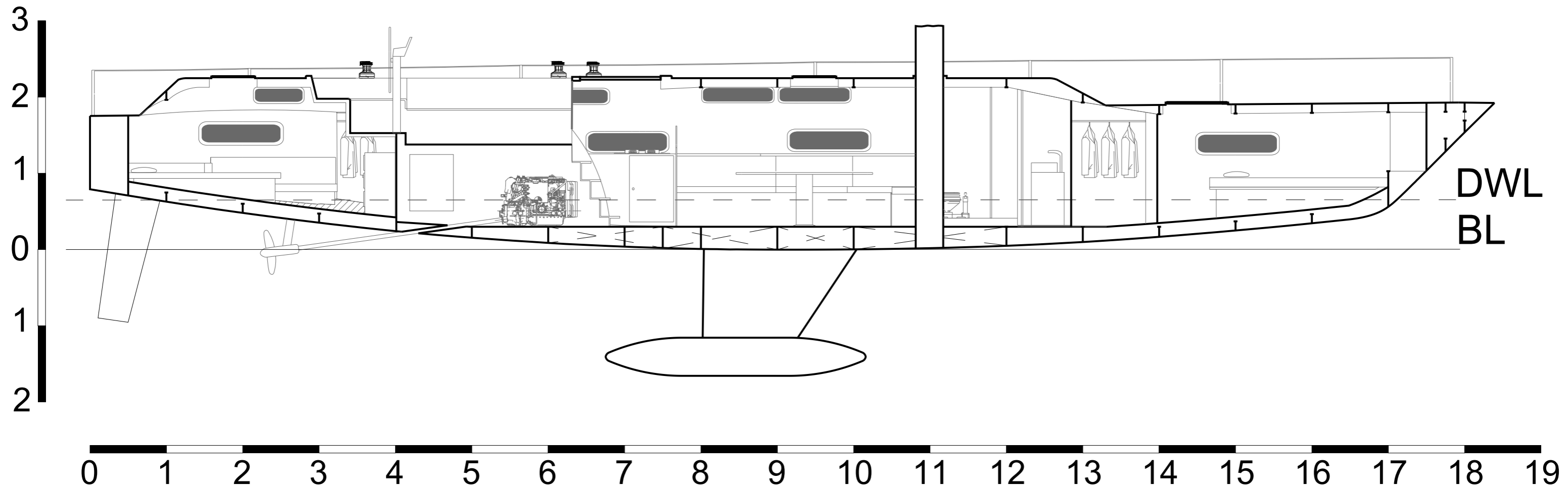
Main Dimensions	
LOA [m]	18,5
Beam [m]	5,2
Depth [m]	1,9
DWL [m]	0,65

UNIVERSITÀ DEGLI STUDI DI GENOVA CORSO DI LAUREA MAGISTRALE IN YACHT DESIGN	
LINES PLAN	
STUDENT: Alexandre Azevedo	ARPEX 60'
A3 format	Scale: 1:75



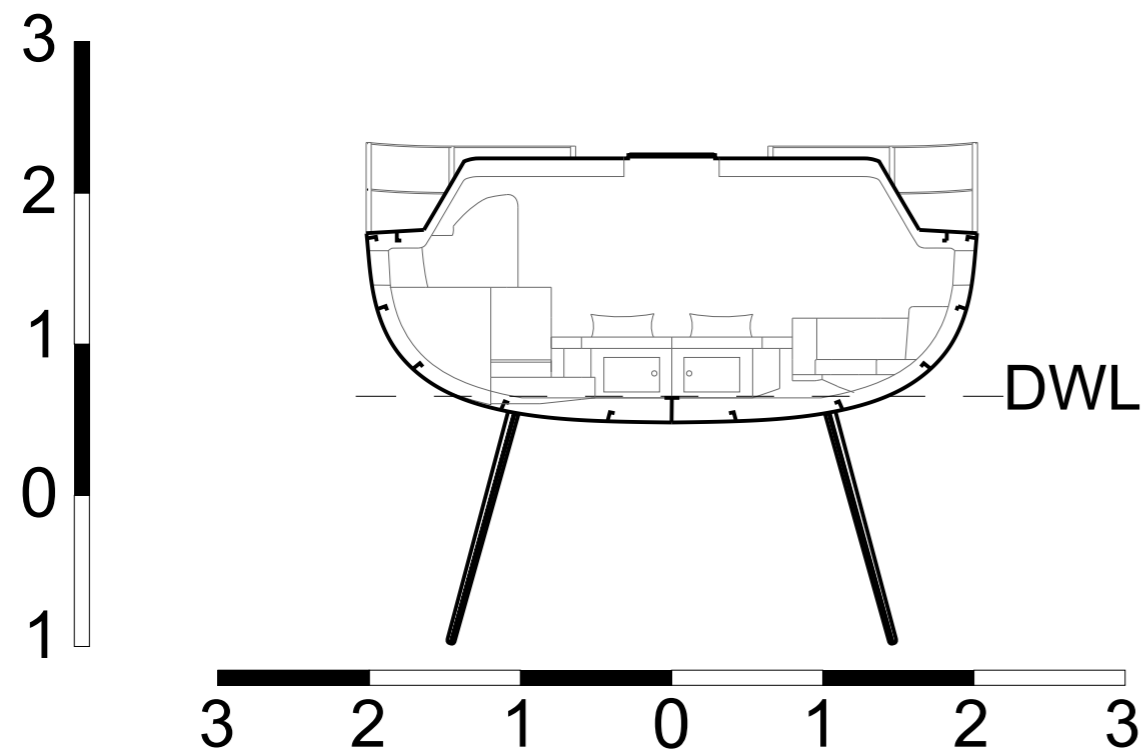
UNIVERSITÀ DEGLI STUDI DI GENOVA CORSO DI LAUREA MAGISTRALE IN YACHT DESIGN	
GENERAL PLAN	
STUDENT: Alexandre Azevedo	ARPEX 60'
A3 format	Scale: 1:50

SECTION E-E'

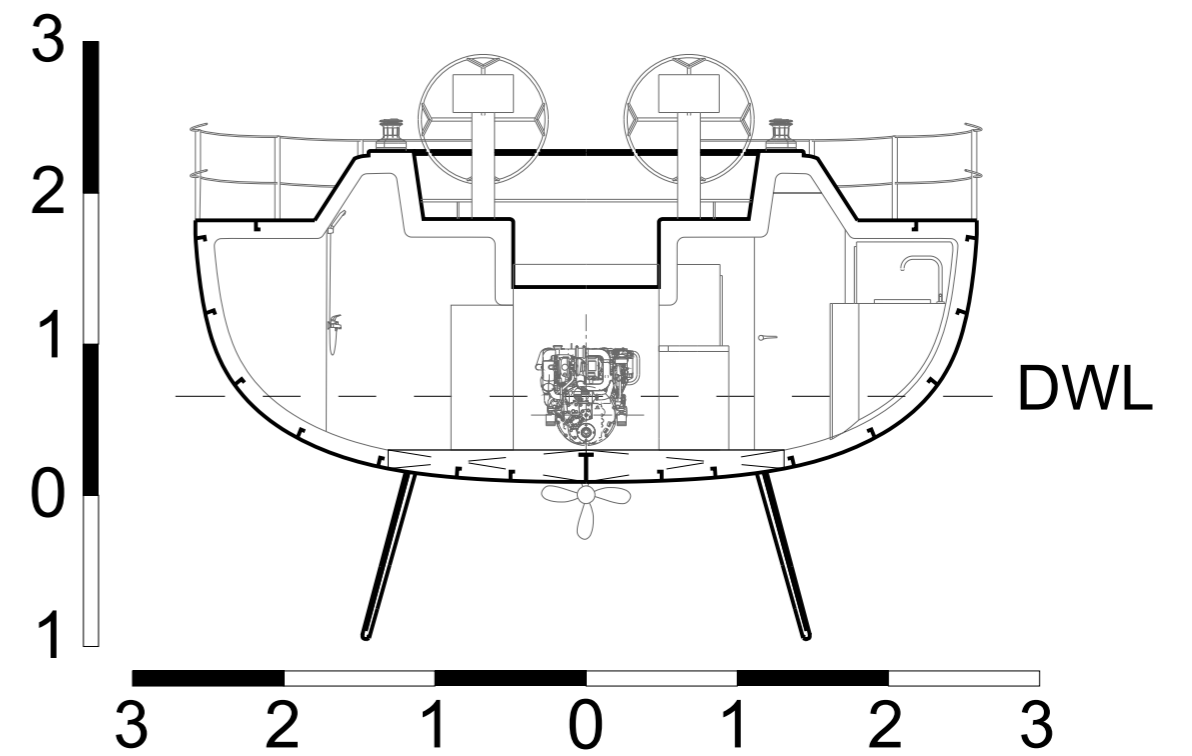


UNIVERSITÀ DEGLI STUDI DI GENOVA CORSO DI LAUREA MAGISTRALE IN YACHT DESIGN	
LONGITUDINAL SECTION	
STUDENT: Alexandre Azevedo	ARPEX 60'
A3 format	Scale: 1:50

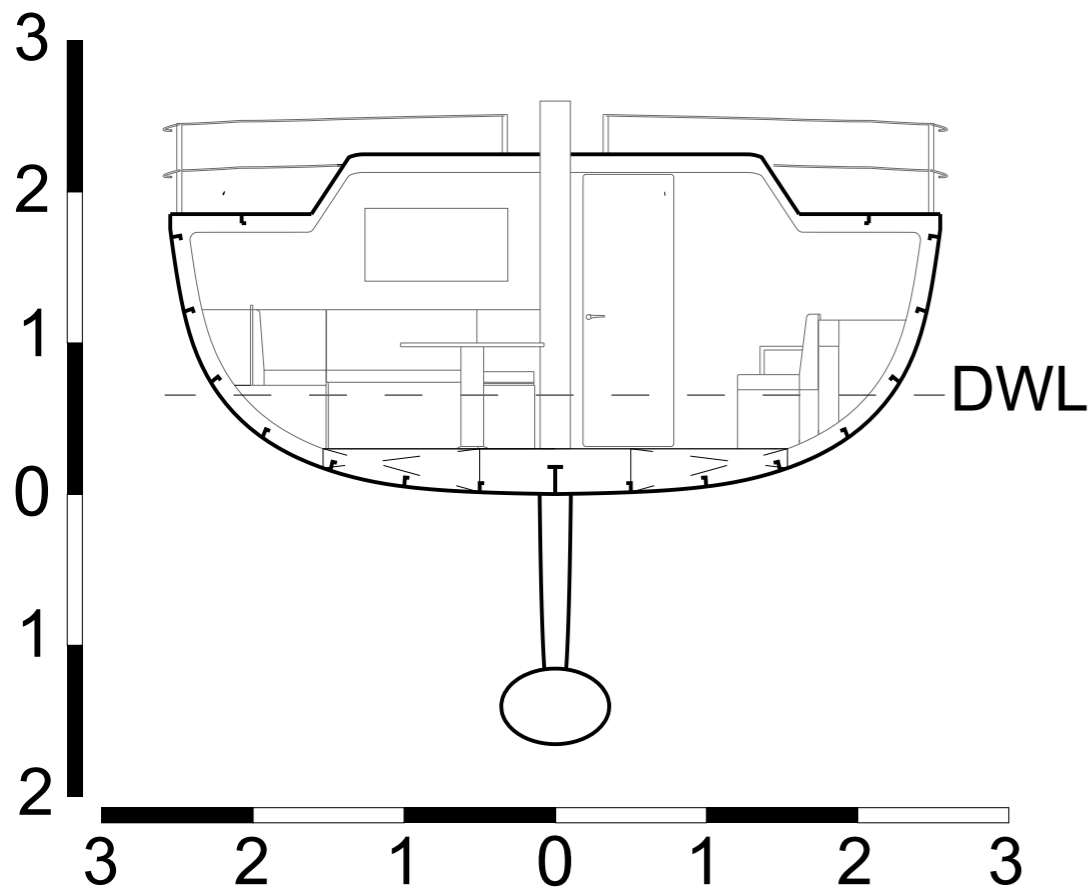
SECTION A-A'



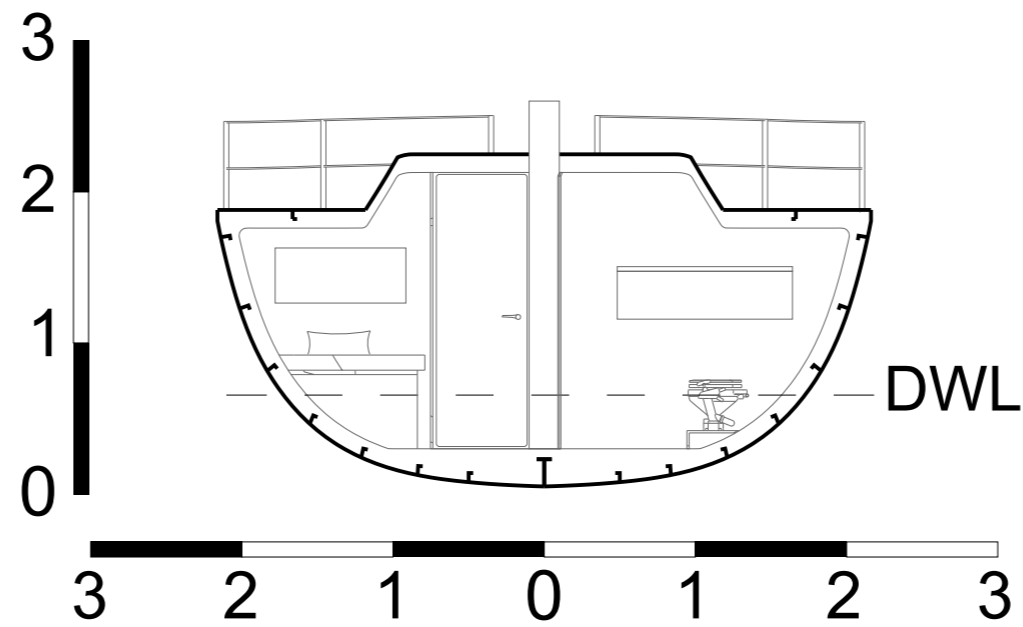
SECTION B-B'



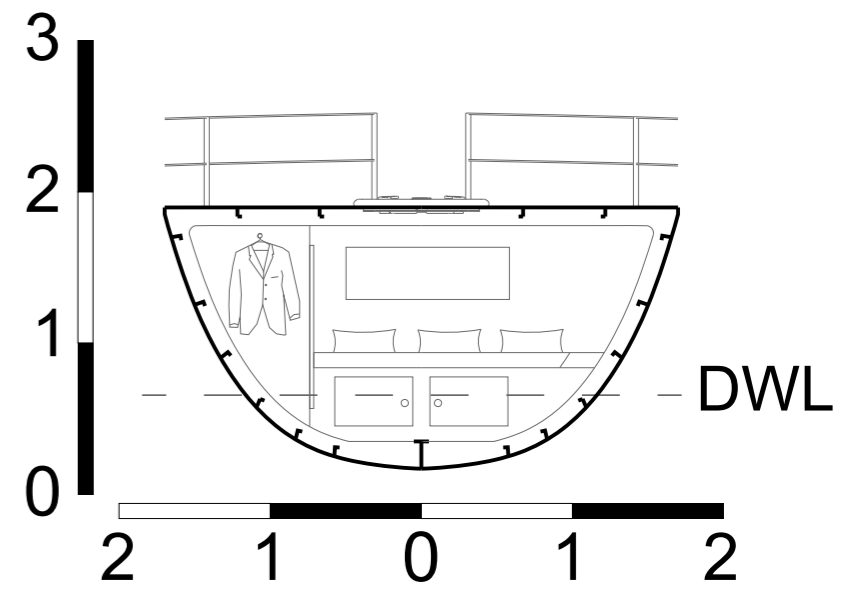
SECTION C-C'



SECTION D-D'



SECTION E-E'



UNIVERSITÀ DEGLI STUDI DI GENOVA
CORSO DI LAUREA MAGISTRALE IN YACHT DESIGN

TRANSVERSAL SECTIONS

STUDENT:
Alexandre Azevedo

ARPEX 60'

A3 format

Scale: 1:50