A Study of Basalt Fibres Composite on 23m Cruise Sailing Yacht

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ABBREVIATIONS and NOTATIONS

AR	Aspect ratio	Re	Reynolds number
AE/Ao	Blade area ratio	RM	Righting moment (kg.m)
BOA	Beam over all (m)	SA	Sail area (m^2)
BFRP	Basalt fibre reinforced plastic	SSF	Sail side force (N)
BR	Ballast ratio	t/c	Thickness/chord ratio
C	Chord length (m)	Tc	Canoe body draft (m)
CSM	Chopped Strand Mat	Tk	Keel draft (m)
Cb	Block coefficient	Te	Effective draft (m)
Cd	Drag coefficient	Vf	Volume fibre fraction
Cl	Lift coefficient	Va	Apparent wind speed (m/s)
Cm	Midship Coefficient	Vt	True wind speed (m/s)
Cp	Prismatic Coefficient	VCB	Vertical Centre buoyancy (m)
Fn	Froude number	VCG	Vertical Centre gravity(m)
GZ	Righting arm (m)	WPA	Water plane area (m^2)
GFRP	Glass fibre reinforced plastic	WR	Woven roving
HA	Heeling arm (m)	α	Angle of attack (^{0})
KA	Keel area (m^2)	βa	Apparent wind angle (^{0})
KSF	Keel side force (N)	βt	True wind angle (^{0})
LCB	Longitudinal Centre buoyancy (m)	Δ	Displacement (kg)
LCG	Longitudinal Centre of gravity (m)	ρ	Density (kg/m^3)
LOA	Length overall (m)	θ	Heeling angle (^{0})

ABSTRACT

A number of materials are now available to promote a sustainable small craft industry, such as basalt fibre, the primary focus of this work. In terms of mechanical properties, basalt fibre has a higher elastic modulus and tensile strength than fibreglass, the most common material currently used. However, at present, no mechanical properties are available to develop the scantlings of yachts using basalt fibre. Nevertheless, it is hoped by the industry that basalt fibre could lead to the lighter boat for the same strength.

This master thesis will investigate the structural benefits and inherent hull weight reduction that can be achieved by basalt fibre, in accordance with small craft regulation; namely the ISO 12215-5. In order to assess the mechanical properties of the novel composite material, tensile, compressive and flexural tests have been undertaken based on the relevant composite testing standards (ISO 527-5, ISO 14126, and ISO 14125). Validation will also be undertaken using finite element method, considering the Tsai-Wu failure criteria of the basalt fibre laminate.

The research then continues to the real application and comparison of fibreglass and basalt fibre, applied to the design of a 24m sailing yacht, aimed at recreational cruising. The preliminary design developed a structural analysis, weights and centres, stability, resistance and a velocity prediction. All aspect regarding the materials, as well as the preliminary design calculations, are then evaluated by using multiple attribute decision making (MADM) to find the rating of basalt material and ascertain the suitability of its applications in sailing yachts.

Basalt fibre having better mechanical properties than fibreglass, it was demonstrated that a lighter, and therefore faster boat could be achieved, in a more sustainable way, thus showing that basalt fibre is a viable alternative to fibreglass in the small craft industry

1. INTRODUCTION

1.1 General

Nowadays academics and industrials focus on the development of sustainable material for the regular or industrial application. One of the ways is to use the natural fibres as reinforcement in the composite material. An example of natural fibres which increase in industry use is basalt fibres. Indeed, basalt fibres come from basalt based molten volcanic rock. The advantages of basalt fibres are easier to produce than carbon fibres and have better mechanical properties than glass fibres. Because of its strong material properties, resistance to impact and temperature, and good from the economical point of view basalt fibres now widely used in Industry.

In the marine industry, Basalt fibres is not widely used since less research has been undertaken. Shipyards are now looking at basalt fibres as an alternative material which is stronger, cheaper and safer for the worker than glass fibres. A research conducted by V.Fiore et al [1] studied the effect of basalt fibre on hybrid glass laminate for marine application. The result showed that the layer of basalt fibre increases the mechanical properties and basalt fibre may be considered as new material for the marine application.

For now, there is no standard of using basalt fibres for manufacturing process in the shipyard, as it is unknown how many layers of material and thickness required for the hull if basalt fibres are used. The logical thinking is that if basalt fibres are stronger than glass fibres the weight of the laminate can be reduced. In this master thesis, the study will use the ISO rules to investigate the reduction in thickness and layer of the basalt fibres composite hull. Since the ISO rules only covers the regulation for glass and carbon fibres, the study will compare glass fibres hull with basalt fibres based on the mass content. The study will use 24m cruise sailing yacht as an object of comparison.

This project is realized in partnership with the “Ant-Arctic-Lab” vessel, that has the lofty goal yet ambitious to develop and give a real solution in term of sustainable and environment awareness in yacht and sailing industry. The project whom lead by professional skipper Norbert Sedlacek and Marion Koch aims at pioneering the production of basalt fibre sailing yacht. Besides the use of basalt fibre, the production also uses bio resin which will generate 100% sustainable and recyclable materials. Norbert himself will take the challenge to sail more than 34.000 nautical miles using a 60 ft racing yacht from July 2018 until February 2019. His action to remind the world if global warming is a real situation and people should start to use more sustainable and environmentally friendly material to save the planet [1].

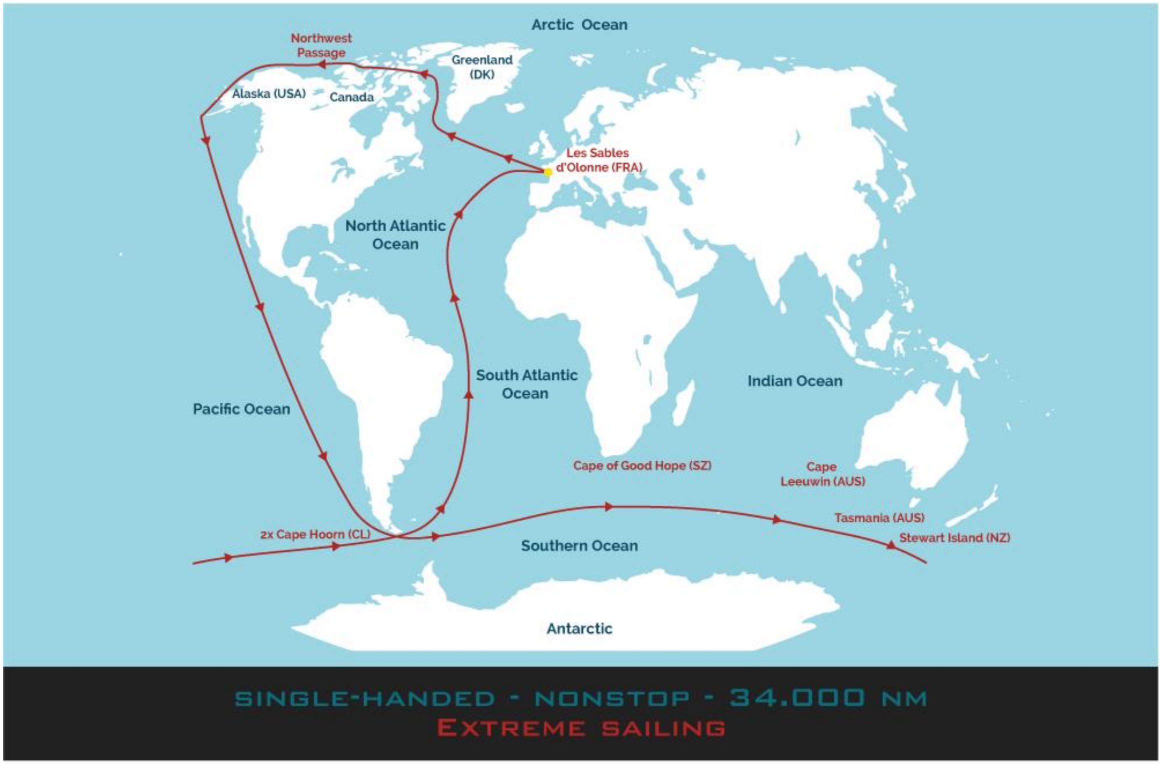


Figure 1 ANT-ARCTIC-LAB project. "ANT-ARCTIC stand for both polar regions on the earth, LAB represent the 'floating Open 60ft. Laboratory" [2]

1.2 Objectives and Benefits of Research

The objectives of the research are:

1. Comparison of mechanical properties Basalt fibres and glass fibres composite based on mass content.
2. The weight of basalt composite hull based on ISO Rules.
3. Ultimate tensile and compressive strength and failure analysis of Basalt composite laminate in boat structures.
4. Comparison of weight, stability, resistance, and cost between basalt fibres and glass fibres.
5. Preliminary design of sailing yacht with basalt composite hull.

The benefits of the research are:

1. Better understanding on the use of basalt fibres in the marine industry.
2. The use of sustainable material in marine industry.

3. The impact of use basalt fibres in boat stability, weight, cost saving, health and safety of workers. Lighter hull than glass fibres composite hull.

1.3 Limitation of the study

The research will respect the ISO rules for composite by comparing the mass content of glass and Basalt composite. Epoxy will be used as a matrix. A microanalysis on lamina will be conducted to find the mechanical properties of glass fibre reinforced plastic (GFRP) and Basalt fibre reinforced plastic (BFRP) by using destructive test analysis. Both of sample will be built from unidirectional clothes, using vacuum infusion method. For real application in the cruising yacht, the sandwich composite is used for the ship structures arrangement. The research will be based on 24 m cruising yacht that will respect the classification rules. A preliminary design work will be completed, including stability, resistance and wind velocity prediction will be done in this project. The dimension of the sailing yacht will be based on forecasting of market share and the sister ship. Besides that, the hull design be inspired by the Open 60 hull of the Ant-Arctic-Lab project [2]. The design of cruise sailing yacht need to be luxury, comfortable, seaworthy, and safe.

1.4 Methodology of Research

To achieve the goal, then the overall research activities designed to follow the flow chart as shown in Figure 2 . In general, the first stage is of this research is to read literature related to the research. Secondly, the data collection stage will start by collecting the mechanical and chemical properties of Basalt fibre and epoxy. At this stage, the preliminary design of 24 m cruising yacht start. After the preliminary design, scantling calculation will be undertaken based on the ISO 12215-5 to define the thickness of sandwich glass fibres and basalt fibres composite in the bottom, side, decks, and superstructures. Since the strength of basalt fibres is bigger than glass fibres the thickness requirement will be lower.

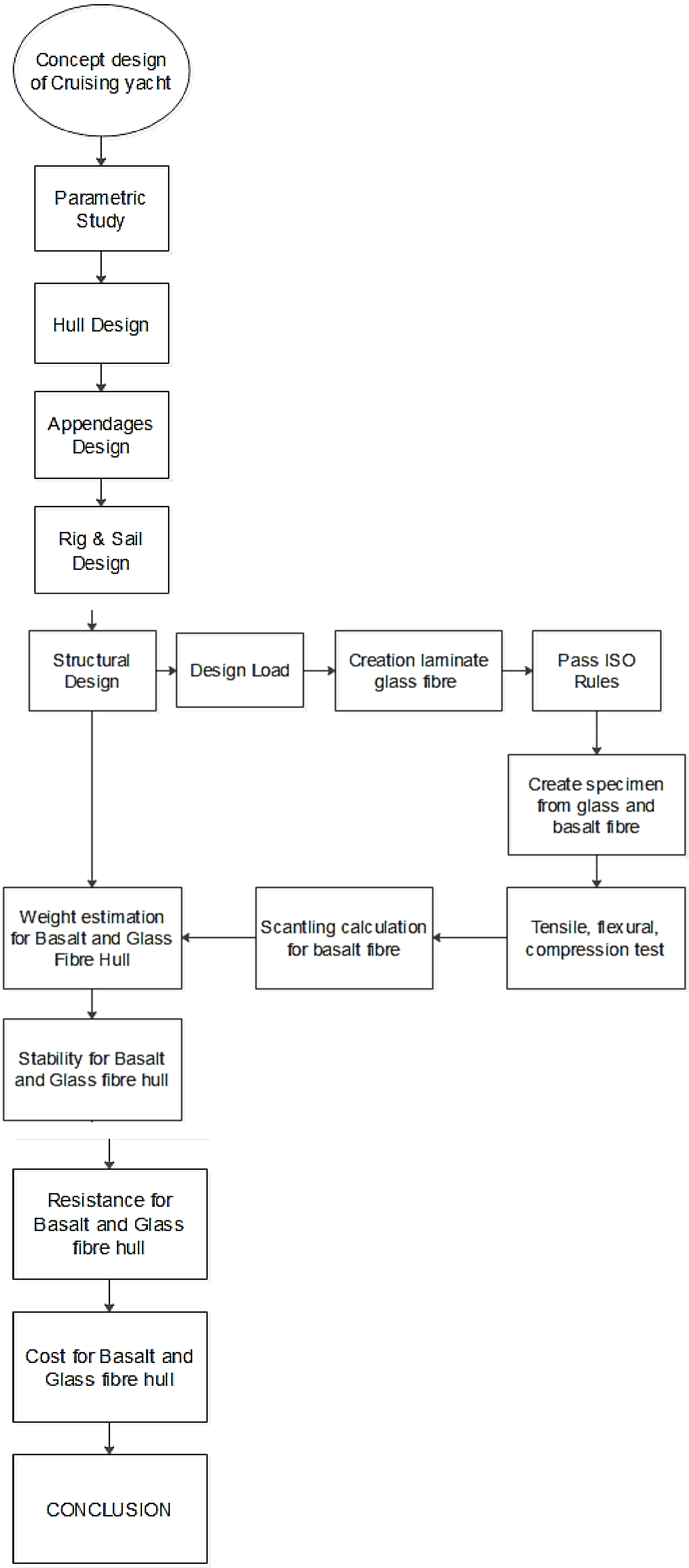


Figure 2 Flow chart of research

To verify the strength of composite laminate, tensile, compression, and the flexural test will be conducted using ISO 527-5, ISO 14126, and ISO 14125. Verification will also be done using finite element method to assess the Tsai wu failure criteria of basalt laminate composites [3]. Based on the results, the basalt fibre laminate can be designed. The research will also ascertain the reduction in weight and cost saving on material achieved by using basalt fibres instead of glass fibres.

2. BASALT and GLASS COMPOSITES

A composite material structure consists of a combination of two or more constituents mixed on a macro level and not mutually dissolve each other. Generally, the composite consists of two types of elements, reinforcement, and matrix. Composite materials are nonhomogeneous material. Composites can be classified based on the geometry of the amplifier (particular, flake, fibres) or under complete matrix (polymer, metal, ceramic, carbon). On the ship, a composite material that is often used is reinforcement in the form of fibre and matrix-based polymer. Each constituent of the composite material has different mechanical properties. Here is an explanation of constituent composite material consist of reinforcement and the matrix.

2.1 Reinforcement: Glass fibres

The most common reinforcement used for the marine application is E-glass because of its ability to produce good structural strength with production costs that are not expensive. Polymer fibres such as aramid and carbon fibre are also used in this area when the engineering is done at a very high structure and requires optimum efficiency. More than 90% of small craft industy uses fibreglaas because it is cheap to produce and relatively have a good strength. Besides fibreglass also has excellent chemical resistance, and has good insulation properties. The disadvantages of fibreglass are the low modulus of elasticity, poor adhesion properties of the polymer, high sensitivity to abrasion, and has particularly low fatigue strength. In addition to E-glass, there is also S-glass which contains more silica. Compared to E-glass, S-glass is stronger at high temperature and exhibits better at fatigue strength.

Table 1 E-glass and S-glass material properties [3]

Property	Units	E-Glass	S-Glass
Specific gravity	**-**	**2.54**	**2.49**
Young’s modulus	**GPa**	**72.40**	**85.50**
Ultimate tensile strength	**MPa**	**3447**	**4585**
Coefficient of thermal expansion	**µm./m/^{0}C**	**5.04**	**5.58**

In the market, fibreglass has different types of cloth. The most common clothes are Chopped Strand Mat (CSM), Woven roving (WR), unidirectional, and multi-axial. CSM or commonly known as the "MAT" is made of fibreglass chopped glass fibres that spread follows the pattern straw spill random direction. CSM that has been moistened with the matrix, after hardening, will have the tensile strength (tensile strength) and flexural strength (flexural strength) almost 2 times compared with matrix without reinforcement. CSM usually have a code such as 300 which means that the CSM contain a weight of ‘{300 gram per square meter (gsm). Woven Roving is a form of webbing fibres. Usually woven roving consist of amount fibre with 2 different fibre direction. Because WR is made of two glass fibre direction continue with directions 0^0 and 90^0. WR without resin has fairly high tensile strength in longitudinal and transversal. Another type is Unidirectional. Unidirectional is a ply of fibre which has 1 direction (0^0), this type of fibre has a lack of transverse strength. In order to have better strength in all direction, multi-axial fibre can be used. Multi-axial consists of two or more layers of fibres with a different orientation (0^0, 90^0, 45^0, -45^0) which stitched with smooth yarn from polymers. Manufactures process of glass fibre can be seen in picture **Figure 3**

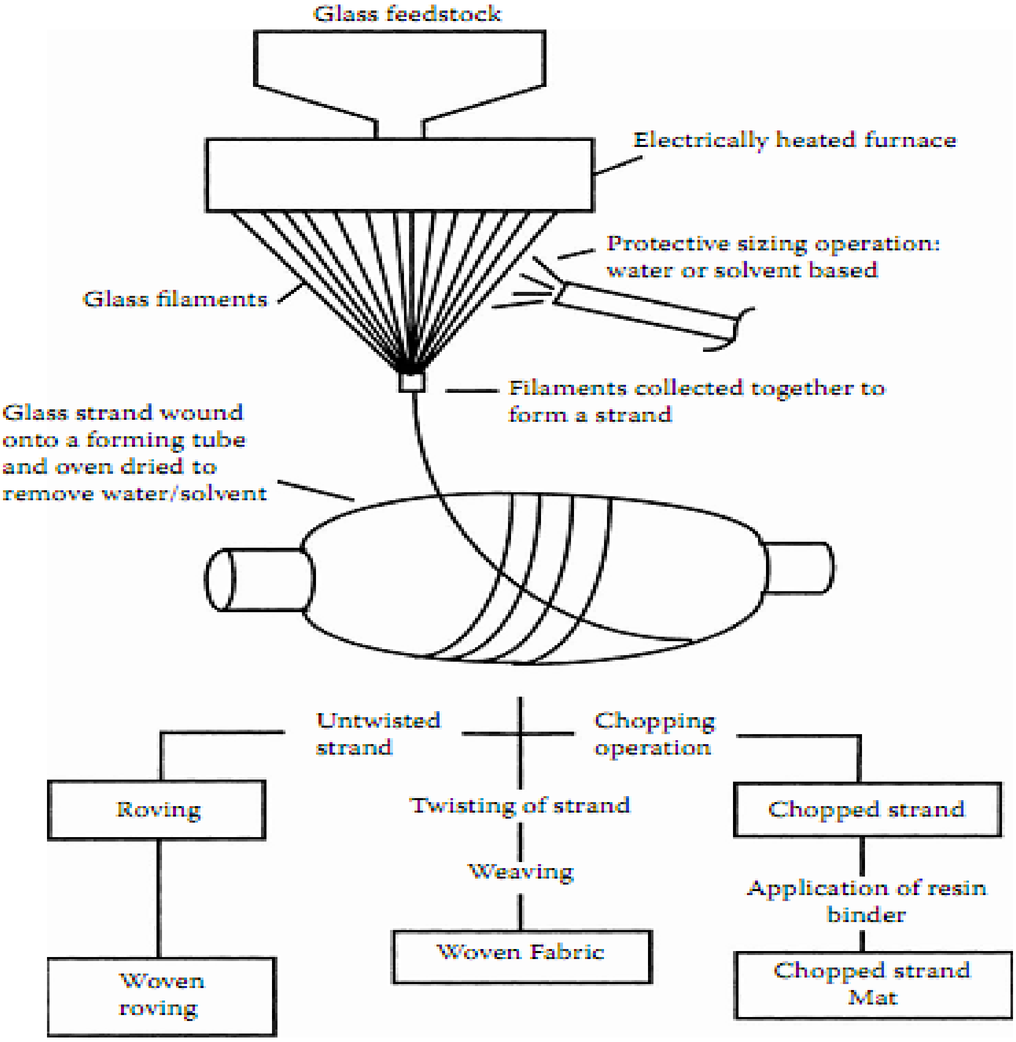


Figure 3 schematic of manufacturing process fibre glass (from Bishop W.,in advanced Composites, Partidge, I.K. Ed., Kluwer Academic Publishers, Lonson,1990)

2.2 Reinforcement: Basalt fibres

Basalt is natural fibres which can be found in volcanic rocks originated from hardened lava, with a melting temperature comprised between 1400 and 1500 ^{0}C [4]. Basalt fibres manufacturing process is similar with glass fibres but with less energy consumed. Because of that, the cost of basalt fibres is cheaper than glass or carbon fibres [5].

Table 2 Composition of Basalt fibres [4]

Constituent	**Content [wt%]**
SiO_2	43.3-47
Al_2O_3	11-13
Fe_2O_3	<5
CaO	10-12
MgO	8-11
Na_2O	<5
TiO_2	<5
K_2O	<5

Basalt fibres are safe for human even they have a similar composition with asbestos. Kogan et al. [6] conduct investigation of basalt fibre on rats, as long the fibres diameter are higher than 3.5 μm so it is irrespirable.

In terms of mechanical properties, basalt fibre has a higher elastic modulus and tensile strength than glass fibres but basalt fibre is heavier than E-glass. An initial research study different properties of carbon, E-glass, basalt with fibre composition 63.5% for carbon, 56.3% for E-glass, and 61.3% for basalt give result if basalt fibre has better elastic modulus and tensile strength than glas fibre and near the carbon fibre . Research conduct in same fibre weight 200 g/m2 [7]. From Figure 4 we can see if basalt fibre with epoxy 30% stronger than glass fibres with epoxy.

Currently, manufacturers create a different quality of basalt fibre. For example the Belgian manufacturer ISOMATEX manufactures a product called Filava which comes from a homogenous mixture of volcanic fibres. As a result, Filava is a reliable product that has better mechanical properties and the quality stay same for one filament to another filament. The filava fibre can resist the range temperature until 850^0 C [8].

Another study has been conducted by Fiore et al. [9], tackling the effect of basalt fibres & glass fibre in hybrid composite for marine application. The results highlight that basalt fibres may be considered as a possible alternative to glass fibres in the nautical application such as boatbuilding because it’s increasing the strength of hybrid laminates [10] .

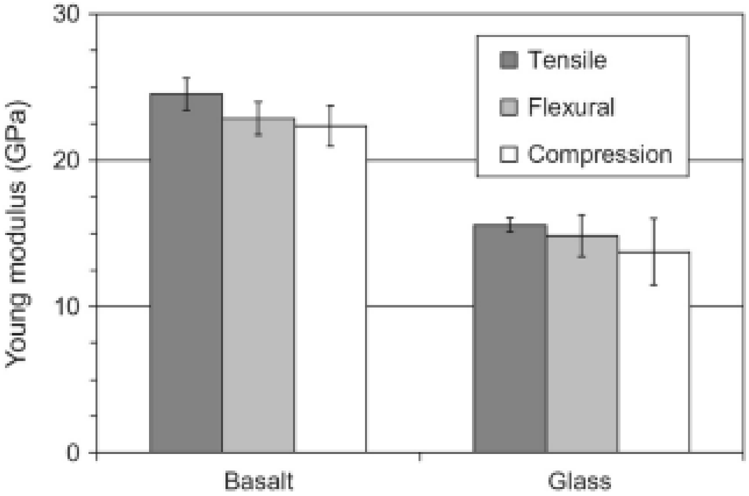


Figure 4 Comparison tensile, flexural, and compression of Basalt and Glass fibres with epoxy resin [7]

2.3 Matrix: Epoxy

In order to stick one layer of fibre to another layer a matrix needs to be used. A matrix can take the form of polymer, metal, ceramic, carbon, etc. The liquid epoxy resin will be mixed with the hardener that will lead to a chemical reaction which is known as curing. This process will result in a combination of resin and fibreglass into a rigid material and ultimately form the hull as a whole solid body. Epoxy Resin demonstrates the best performance characteristics of all the resins used in the marine industry. Epoxy resin has advantages such as the low shrinkage percentage during cure, good impact resistance, and has a suitable viscosity for vacuum infusion. For the purpose of this project, an epoxy resin named IR 77.31 has been used as a matrix for the composite. This type of resin is very safe and not poisoning the worker and environment.

Table 3 Mechanical properties of Epoxy resin [11]

Density (g/cm^3)	1.134-1.154	20^{0}C
Viscosity (mPas)	650-1.350	25^{0}C
Color	Slightly turbid	
Storage	+10 to +25 ^{0}C	

2.4 Vacuum Infusion

There are several processes that can be used to manufacture composite, such as hand layup, Vacuum infusion takes advantage of a pressure pump that generates a vacuum so that the blend of resin and fibres can be pressed evenly, and at a much greater pressure than in open moulds. The advantage of this approach is the laminate results will be thinner and stronger because the increment of fibre fraction. The other advantage is lower labor cost, as infusion can be performed faster than hand lamination. However, the drawback is the cost for preparation of the set up and consumable is more expensive than the hand layup method but this shortfall can be covered by the reduction of the amount of resin which use in this process. In resin transfer moulding, resin is injected into a certain mold and then the top covered with a rigid mold. In vacuum infusion, the upper part fill with plastic film (plastic sheeting) and resin media distribution. By using vacuum infusion the fibre weight content will be increased since in vacuum infusion the amount of resin that is needed is decrease. Resin will fill the voids between fibres more efficiently than the hand layup process. Using vacuum infusion the fibre content of CSM glass can be increased up to 0.35, 0.5 for WR, and up to 0.7 for unidirectional fibre.

Table 4 Nominal glass fibre content by mass from ISO 12215-5:2008 [12]

Type of ply reinforcement	Open mold, Simple surface	Open mold, Complex surface	Vacuum bag
Chopped strand mat (CSM) sprayed up	0.3-0.18	0.25	0.36
Chopped strand mat (CSM) hand lay up	0.3	0.25	0.36
Woven roving (WR)	0.48	0.36	0.58
Multidirectional fabric	0.50	0.38	0.60
Unidirectional fabric	0.55	0.41	0.66

2.5 Mechanism of lamina failure

A good structural design requires the use of efficient and reliable materials. In order to have a safe design, the composite material should be checked with the material failure criteria. It should be noted that the failure theory and its application need validation from the experiment. For a laminate, strength relates to the power of each lamina. Various theories have been developed to study the failure of every ply of the laminate. The theory is based on normal strength and shear strength of unidirectional lamina. However, in the lamina, the theory is not based on the principal failure of normal stress and maximum shear stresses rather based on the stress in each axis because it is an orthotropic character. Moreover, the character will be different from different angles, unlike the isotropic material. In the case of the unidirectional lamina, there are 2-axis material, one that is parallel to the fibre and the other perpendicular to the fibre. So there are four parameters of normal strength a unidirectional lamina, one for tension and compression for each direction of the axis of the material, and the shear stress of unidirectional lamina.

$(\sigma_1^T)_{ult} = Ultimate\ longitudinal\ tensile\ strength\ (in\ direction\ 1)$
$(\sigma_1^C)_{ult} = Ultimate\ longitudinal\ compressive\ strength\ (in\ direction\ 1)$
$(\sigma_2^T)_{ult} = Ultimate\ longitudinal\ tensile\ strength\ (in\ direction\ 2)$
$(\sigma_2^C)_{ult} = Ultimate\ longitudinal\ compressive\ strength\ (in\ direction\ 2)$
$(\tau_{12})_{ult} = Ultimate\ in\ plane\ shear\ strength\ (in\ plane\ 12)$

One theory to predict the failure of the lamina is the Tsai-Wu failure theory. Tsai-Wu failure theory has a value that resembles the experimental values is based on the failure of the total strain energy. Tsai-Wu failure theory applies the failure of lamina in plane stress. A lamina will be considered as failed if the value below is violated **[3]**.

$$H_1\sigma_1 + H_2\sigma_2 + H_6\tau_{12} + H_{11}\sigma_1^2 + H_{22}\sigma_2^2 + H_{66}\tau_{12}^2 + 2H_{12}\sigma_1\sigma_2 < 1 \qquad \text{Eq 1}$$

The H components can be found by using five parameter for unidirectional lamina as follow:

1. Apply $\boldsymbol{\sigma_1 = (\sigma_1^T)_{ult}\ , \sigma_2 = 0\ , \tau_{12} = 0}$ for unidirectional lamina so the equation becomes, $\boldsymbol{H_1(\sigma_1^T)_{ult} + H_{11}(\sigma_1^T)_{ult}^2 = 1}$

2. Apply $\boldsymbol{\sigma_1 = -(\sigma_1^C)_{ult}\ , \sigma_2 = 0\ , \tau_{12} = 0}$ for unidirectional lamina so the equation becomes, $\boldsymbol{-H_1(\sigma_1^C)_{ult} + H_{11}(\sigma_1^C)_{ult}^2 = 1}$

   From both equation the values become;

   $$\boldsymbol{H_1 = \frac{1}{(\sigma_1^T)_{ult}} - \frac{1}{(\sigma_1^C)_{ult}}}$$

   $$\boldsymbol{H_{11} = \frac{1}{(\sigma_1^T)_{ult}\ (\sigma_1^C)_{ult}}}$$

3. Apply $\boldsymbol{\sigma_1 = 0, \sigma_2 = (\sigma_2^T)_{ult}}$, $\boldsymbol{\tau_{12} = 0}$ for unidirectional lamina so the equation becomes, $\boldsymbol{H_2(\sigma_2^T)_{ult} + H_{22}(\sigma_2^T)_{ult}^2 = 1}$

4. Apply $\boldsymbol{\sigma_1 = 0, \sigma_2 = -(\sigma_2^C)_{ult}}$, $\boldsymbol{\tau_{12} = 0}$ for unidirectional lamina so the equation becomes, $\boldsymbol{-H_2(\sigma_2^C)_{ult} + H_{22}(\sigma_2^C)_{ult}^2 = 1}$

   From both equation the values become

$$\boldsymbol{H_2 = \frac{1}{(\sigma_2^T)_{ult}} - \frac{1}{(\sigma_2^C)_{ult}}}$$

$$\boldsymbol{H_{22} = \frac{1}{(\sigma_2^T)_{ult}\,(\sigma_2^C)_{ult}}}$$

5. Apply $\boldsymbol{\sigma_1 = 0, \sigma_2 = 0}$, $\boldsymbol{\tau_{12} = (\tau_{12})_{ult}}$ for unidirectional lamina so the equation becomes, $\boldsymbol{H_6(\tau_{12})_{ult} + H_{66}(\tau_{12})_{ult}^2 = 1}$

6. Apply $\boldsymbol{\sigma_1 = 0, \sigma_2 = 0}$, $\boldsymbol{\tau_{12} = -(\tau_{12})_{ult}}$ for unidirectional lamina so the equation becomes, $\boldsymbol{-H_6(\tau_{12})_{ult} + H_{66}(\tau_{12})_{ult}^2 = 1}$

   From both equation the values become

$$\boldsymbol{H_6 = 0}$$

$$\boldsymbol{H_{66} = \frac{1}{(\tau_{12})_{ult}^2}}$$

Value of $\boldsymbol{H_{12}}$ can be found by using the empirical equations below **[3]**.

$$\boldsymbol{H_{12} = -\frac{1}{2(\sigma_1^T)_{ult}^2}}$$, per Tsai-Hill failure theory

$$\boldsymbol{H_{12} = -\frac{1}{2(\sigma_1^T)_{ult}\,(\sigma_1^C)_{ult}}}$$, per Hoffman criterion

$$\boldsymbol{H_{12} = -\frac{1}{2}\sqrt{\frac{1}{(\sigma_1^T)_{ult}\,(\sigma_1^C)_{ult}\,(\sigma_2^T)_{ult}\,(\sigma_2^C)_{ult}}}}$$, Mises-Hencky criteria

3. MATERIAL TESTING

In order to study the characteristics of basalt fibre, a destructive material testing will be implemented. The test include: tensile test, flexural test, and compression test. Samples are created using the vacuum infusion method with the intention to compare the performance of basalt composite and glass composite, hence the motivation to undertake the destructive test samples testing for both materials.

3.1 Material, Manufacturing, and Test Procedures

3.1.1 Material

The basalt fibre type used for the test is filava fibre from ISOMATEX with weight 400 g/m^2. On the other hand, the E-glass UD cloth had a weight of 250 g/m^2. The form of the material can be seen in **Figure 5** and **Figure 6**. The epoxy matrix and hardener are respectively the IR 77.31 and the IH 77.15. The mechanical properties of each material can be seen in **Table 5**.

Table 5 Mechanical Properties of reinforcement and matrix

Properties			E-Glass	Filava	Resin Epoxy IR 77.31 + IH 77.15
name	**symbols**	**unit**			
Volume Fraction	V		0.69	0.69	
Density	ρ	kg/m^3	2500	2600	1.134
Elastic Modulus	E	GPa	85	86	3
Poisson's Ratio	v	-	0.2	0.24	
Tensile Strength	σ^T	MPa	1550	3400	65
Tensile strain	ε^T	%	-	-	6
Flexural Strength	σ^F	MPa	-	-	105
Compressive Strength	σ^c	MPa	1999	-	-
Compressive strain	ε^c	%	-	-	-
Shear Strength	τ	MPa	35	-	-
Shear modulus	G	GPa	35.416	34.677	-
Shearing strain	γ_{12}	%	-	-	-
Bulk modulus	K	GPa	-	-	-
Price	EUR	Eur/kg	8.32	15	-

Figure 5 Filava fibre [8]

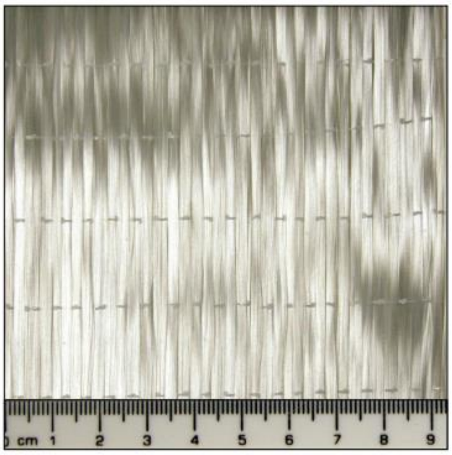


Figure 6 Glass Fibre 250 g/m2 [13]

3.1.2 Manufacturing Process

For basalt fibre reinforced plastic (BFRP), the composite panel was built in Ant-Arctic-Lab workshop by Norbert Sedlacek team [1]. Conversely, Glass fibre reinforced plastic (GFRP) was built in the composite Laboratory of Solent Southampton University [14].

In order to make lamination possible, a number of additional layers are required. First, the mould should be waxed, which will prevent the fibre and resin from sticking to the mould. The second layer is the reinforcement layers. Then a peel-ply is applied; it is needed to prevent the reinforcement layer from sticking to the transfusion layer. The infusion mesh is added to allow the resin to flow. The last layer is vacuum bag, sealed using vacuum tape. The important part is to make sure that the vacuum bag sealed perfectly. The system is full sealed only if the pressure gauge in the catch pot is zero when the inlet is in fully closed condition. When the resin is ready to infuse, the clamp at the resin inlet need to be open, and resin will spread into the reinforcement. The setup is presented in figure 6.

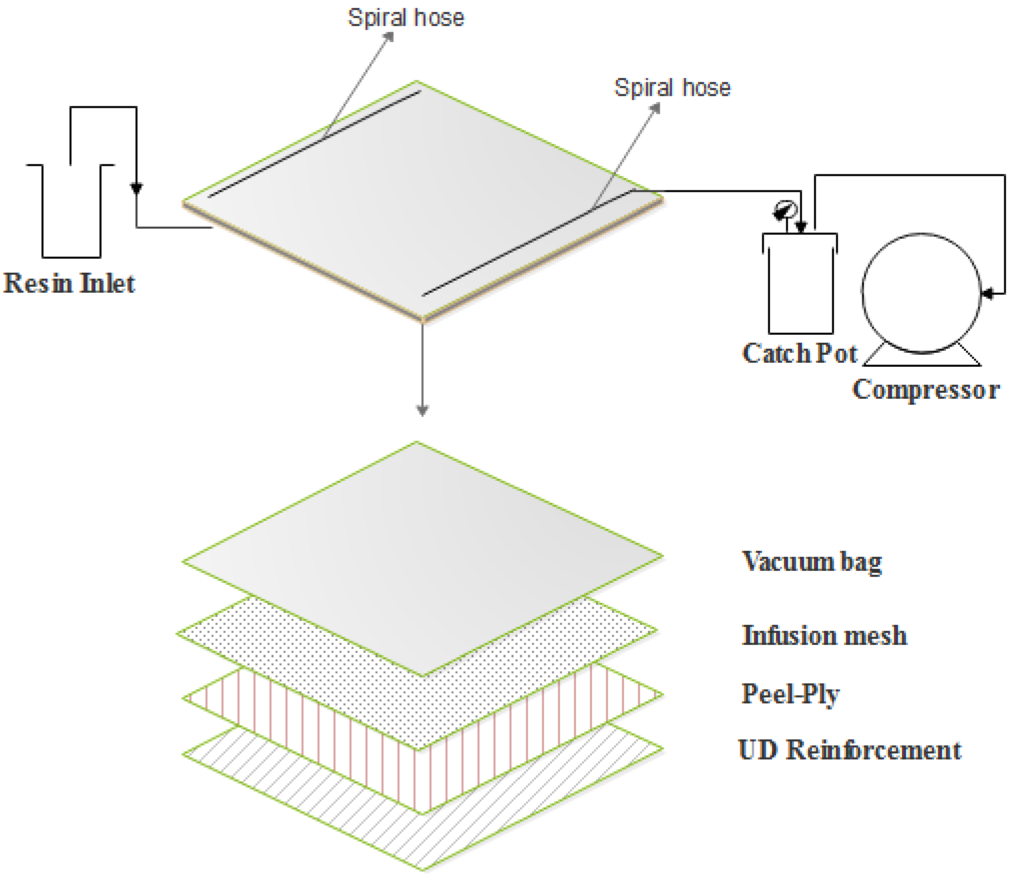


Figure 7 vacuum infusion experimental setup

The analytical formulation for the thickness of a layer of GFRP and a layer of BFRP can be found using the formula below:

$$t = \frac{wf}{\rho_f \; \rho_r \; \; 1000}\left[\frac{\rho_f}{V_f} - \left(\rho_f \; \rho_r\right)\right] \qquad \text{Eq 2}$$

Which :w_f : Fibre weight (g/m^2),

ρ_f : Density of the fibre (gr/m^3)

ρ_r : Density of the resin (gr/m^3)

V_f : Fibre volume fraction

With assumption V_f is 0.7 the thickness of 1 layer of GFRP with a fibre weight of 250 gr/m^2 is 0.1958 mm. Moreover, the thickness of 1 layer BFRP with fibre weight of 400 gr/m^2 is 0.3109 mm. The composition of the layer for each panel can be seen in **Table 6** until **Table 8.**

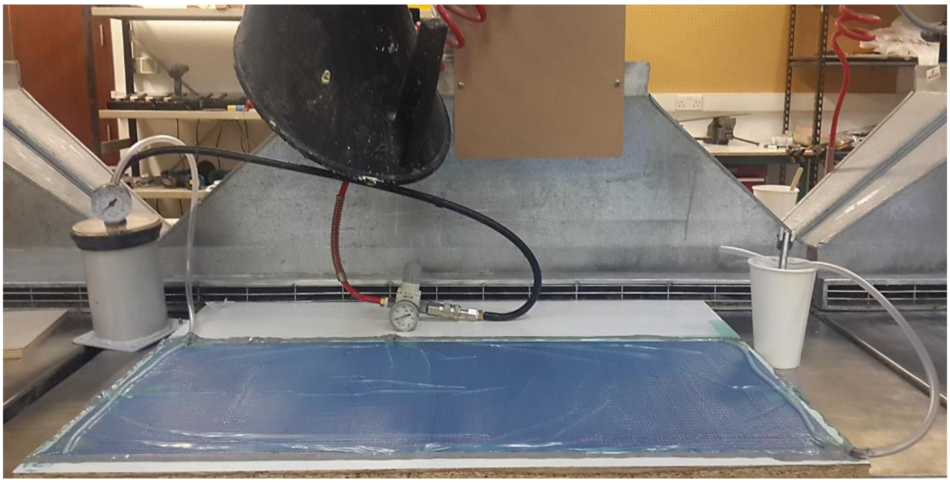


Figure 8 Vacuum infusion process in Composite lab Solent Southampton University, United Kingdom [14]

Table 6 layer composition for composite with panel size 405 x 635 mm and thickness 1 ± 0.2 mm.

Reinforcement				Resin bto -epoxy		Catalist (gr)
Material	thickness (mm)	Fibre Weight (gr/m2)	Fibre ratio	Resin density (g/mm3)	Resin Weight (gr)	
glass UD	0.1958	250	0.7	0.001134	102.791	30.837
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
Total	**1.1749**	**1500**	**0.7**			
filava UD	0.3109	400	0.7	0.001134	108.803	32.640
	0.3109	400	0.7			
	0.3109	400	0.7			
	0.3109	400	0.7			
Total	**1.2436**	**1600**	**0.7**			

Table 7 layer composition for composite with panel size 272 x 585 mm and thickness 2 ± 0.2 mm.

Reinforcement				Resin bto -epoxy		Catalist (gr)
Material	thickness (mm)	Fibre Weight (gr/m2)	Fibre ratio	Resin density (g/mm3)	Resin Weight (gr)	
glass UD	0.1958	250	0.7	0.001134	105.999	31.800
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			

	0.1958	250	0.7			
	0.1958	250	0.7			
Total	**1.958**	**2500**	**0.7**			
filava UD	0.3109	400	0.7	0.001134	134.638	40.391
	0.3109	400	0.7			
	0.3109	400	0.7			
	0.3109	400	0.7			
	0.3109	400	0.7			
	0.3109	400	0.7			
	0.3109	400	0.7			
	0.3109	400	0.7			
Total	**2.287**	**3200**	**0.7**			

Table 8 layer composition for composite with panel size 195 x 170 mm and thickness 4 ± 0.2 mm.

Reinforcement				Resin bto -epoxy		Catalist (gr)
Material	thickness (mm)	Fibre Weight (gr/m2)	Fibre ratio	Resin density (g/mm3)	Resin Weight (gr)	
glass UD	0.1958	250	0.7	0.001134	44.166	13.249
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
	0.1958	250	0.7			
Total	**3.916**	**5000**	**0.7**			
filava UD	0.3109	400	0.7	0.001134	134.638	40.391
	0.3109	400	0.7			
	0.3109	400	0.7			
	0.3109	400	0.7			
	0.3109	400	0.7			
	0.3109	400	0.7			
	0.3109	400	0.7			

	0.3109	400	0.7			
	0.3109	400	0.7			
	0.3109	400	0.7			
	0.3109	400	0.7			
	0.3109	400	0.7			
	0.3109	400	0.7			
Total	**4.041**	**5200**	**0.7**			

3.1.3 Tensile, Flexural, and Compression test

There are 3 types of test which have been conducted in the Mechanical testing laboratory Solent Southampton University. They are a tensile test, flexural test, and compression test. The machine used for the tests is the universal testing machine manufactured by Llyod instrument with a capacity 30 KN. The set up used is depicted in **Figure 9**.

Figure 9 Universal testing machine, Solent Southampton University, United Kingdom

The tensile test is realized under the guidance of the relevant standard, namely the ISO 527-5. For GFRP and BFRP there are three types of sample, laminates at 0^0, +/- 45^0, and 90^0. A minimum of 5 samples for each material and test should be provided. For unidirectional specimens the end tab should have a fibre orientation of 45^0. The machine speed for 0^0 and 45^0 sample should be 2 mm/min while 90^0 samples should be tested at 1 mm/min. The dimensions of the samples can be seen in **Table 9**.

Table 9 Tensile test setup

Direction	NOS	sample			tab			No. Of Layers	
		length (mm)	width (mm)	t (mm)	Length (mm)	width (mm)	t (mm)	GFRP	BFRP
0	5	250	15	1	50	15	2	6	4
45	5	250	15	1	50	15	2	6	4
90	5	250	25	2	50	25	2	10	8

For the flexural test, ISO 178 is used. Conversely to the tensile test, flexural tests for unidirectional fibre do not require the use of end tabs. Again, 3 types of samples are tested (0^0, +/- 45^0, and 90^0), with a minimum of 5 samples for each test. The dimensions of the samples can be seen in **Table 10**.

Table 10 Flexural test setups

Direction	NOS	sample			No. Of Layers	
		length (mm)	width (mm)	t (mm)	GFRP	BFRP
0	5	80	10	4	20	13
45	5	80	10	4	20	12
90	5	80	10	4	20	13

The span of specimen or length between two support points should comply with the ISO equation given below

$$L = (16 \pm 1)h \qquad \text{Eq 3}$$

Where: h : the thickness of samples (mm)

L : span (mm). Fixed at 66 mm for all samples.

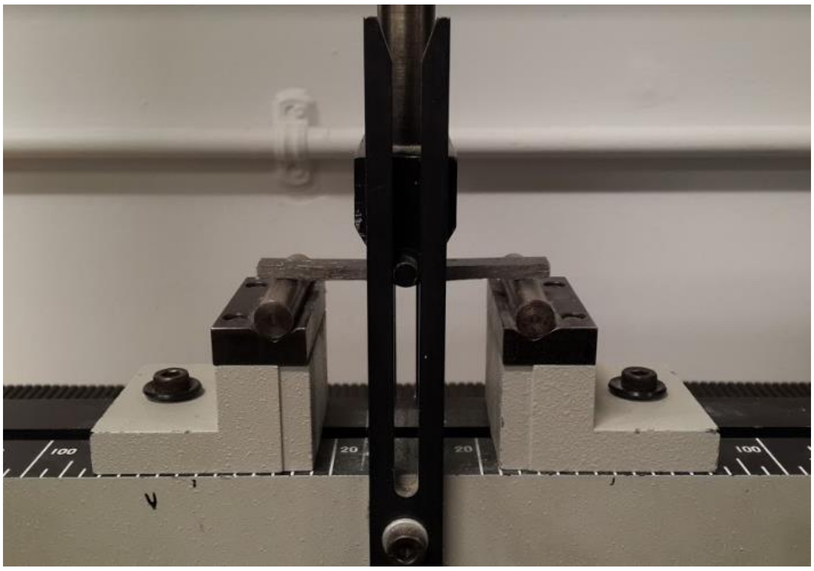


Figure 10 Flexural test set up

For the compressive test, ISO 14126 is followed. There are 3 types of sample, a laminate in 0^0, +/- 45^0, and 90^0. A minimum of 5 samples for each direction should be provided as can be seen in **Table 11**.

Table 11 Compressive test setup

Direction	NOS	sample			tab			No. Of Layers	
		length (mm)	width (mm)	t (mm)	Length (mm)	width (mm)	t (mm)	GFRP	BFRP
0	5	110	10	2	50	10	2	10	8
45	5	110	10	2	50	10	2	10	8
90	5	110	10	2	50	10	2	10	8

3.1.4 Burn off Test

Mechanical properties of composite more or less will depend on its fibre-resin ratio. In order to verify the mechanical properties value after the completed mechanical testing, an experiment should be conducted to verify the fibre –resin ratio. Such an experiment is called a burn off test. A burn off test has therefore been conducted in the composite laboratory of University of Liege, Belgium. The principle of the burn off test is to weight the composite sample and burn the sample until all resin is gone and then weight again the fibre left. With the comparison of fibre weight before and after burn off test, the fibre weight fraction can be deduced. Following the ISO 2782 method 107K, the two specimens should be used for each test, with the mass of each specimen not less than 5g and an area not less than 400 mm^2. The steps to conduct the burn off test are detailed hereafter:

1. Heated samples at 575 ± 25^0C for 15 min, cooled in a desiccator and weighed (W_1).
2. Heated sample again at 105^0C-110^0C for 2 hours, cooled in a desiccator and weighed.
3. Heated sample again at 105^0C-110^0C for 30 minutes, cooled in and reweighed. Repeat the procedure until the mass of cubicle and specimen become constant within 0.01 g (W_2).
4. Heated samples at 575 ± 25^0C until the residue of fibre is white in colour (approx. for 30 min), cooled in a desiccator and weighed (W_3). Repeat the procedure until the mass of cubicle and specimen become constant within 0.01 g.

The percentage of resin content then can be calculated follow below equation

$$Percentage\ resin\ content = 100\ \frac{(W_2 - W_3\ )}{(W_2 - W_1\ )} \qquad \text{Eq 4}$$

Table 12 Burn off test samples

Burn off test	BS ISO 2782-Part 1 methods 107K. Resin content of glass-Reinforced laminates			
Type	thickness (mm)	Number of samples	sample	
			length (mm)	width (mm)
Filava/Epoxy	1	2	30	15
Filava/Epoxy	2	2	18	25
Filava/Epoxy	4	2	40	10
Glass/Epoxy	1	2	30	15
Glass/Epoxy	2	2	18	25
Glass/Epoxy	4	2	30	15
Total Samples		**12**		

3.2 Result and Analysis

3.2.1 Burn off test results

The burn off test revealed a huge difference in fibre weight ratio between BFRP and GFRP. The detail of the result can be seen in Appendix A, and are summarised in Table 13 for 1, 2, and 4 mm thickness of composite the difference between materials is 23%, 12%, and 17%.

Table 13 Burn off test result

Item	Thickness (mm)		
	1	2	4
Filava fibre content	56%	67%	57%
Glass fibre content	79%	79%	74%

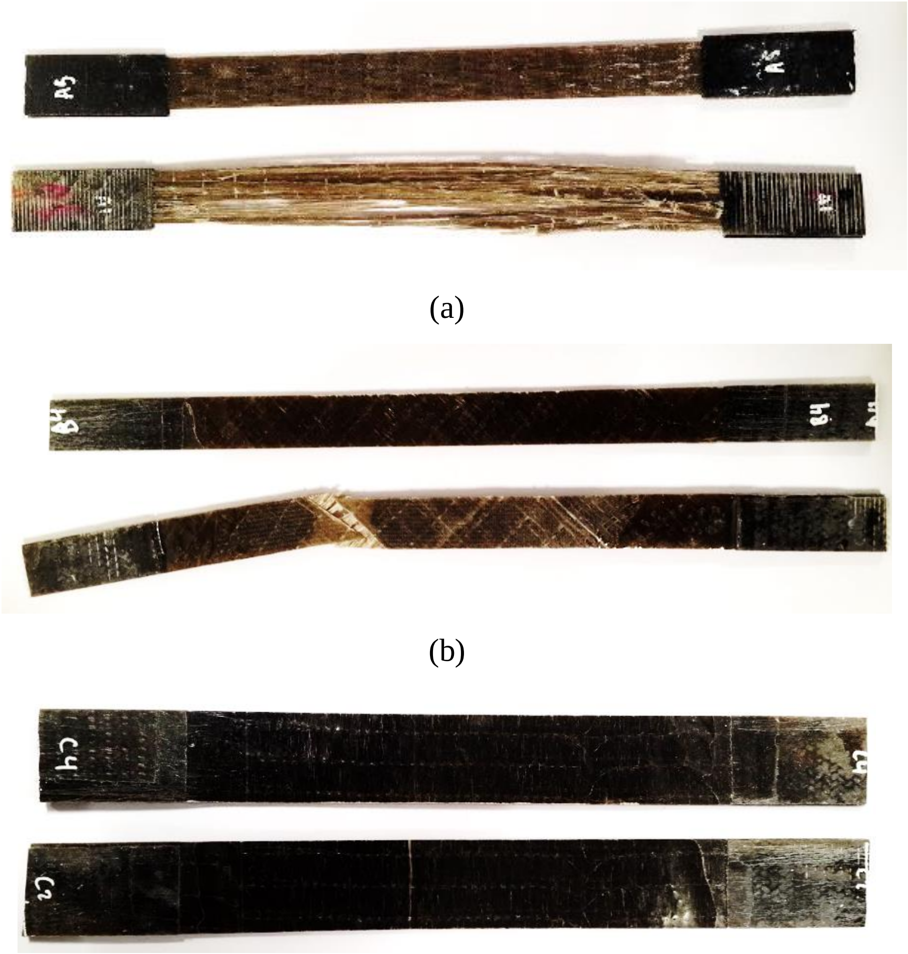
In general infusion, creates a composite laminate with higher fibre weight fraction than hand layup. Layup, due to the homogenous flow & pressure of resin, the resin will fully penetrate to fibre layup. Beside increase the fibre weight ratio, it will also make the laminate thinner than hand layup process. The other factor which affects the fibre weight fration is the form of material. A unidirectional cloth has been used for BFRP and GFRP. For UD, the expected fibre weight fraction is 66%, as opposed 36%-58% for CSM and WR respectively [12]. The different values for the fibre weight fraction between BFRP and GFRP can be explained by several reasons. First, it indicates the glass fibre and basalt fibre have different resin absorption. And suggest there is a greater void content in the BFRP. The other reason is that the BFRP and GFRP panel were manufactured in a different place. Indeed, the BFRP was made at Ant-Arctic-Lab workshop by Norbert Sedlacek's team [1] while the GFRP was made in the Composite Laboratory of Solent Southampton University [14]. The different workshop can lean many factors that will make the fibre content different such as flow rate, vacuum condition, pressure, etc. In **Table 13**, GFRP has a fibre content up to 79%. The value indicates the only small amount of resin stick inside the fibre layup. The good fibre fraction for UD glass is about 60%-70%, above those value, it will increase the delamination among the stack of fibre. Moreover, the shear stress on all fibres axis will increase due to stress transfer between the fibre and resin. This is because insufficient resin inside the structure will create premature failure. The high fibre content would only possible in the small flat panel realized. However, when it comes to application in shipbuilding, the average value for infusion will be about 66%.

3.2.2 Tensile, Flexural, and Compression Test Result

The detaile test results for each specimen can be seen in Appendix A. The results for tensile, flexural, and compression test is an average value from minimum five samples. The modulus was defined manually by using the chord slope of the stress-strain graph in the range of strain 0.05% and 0.25%.

Table 14 Tensile test result for BFRP and GFRP

	BASALT FIBRE + BTO EPOXY			GLASS FIBRE + BTO EPOXY		
	0	**+/-45**	**90**	**0**	**+/-45**	**90**
UTS (MPa)	770.73	75.17	15.53	632.62	280.57	21.57
Tensile Modulus (GPa)	18.97	4.90	2.62	11.10	6.31	2.97



(a)

(b)

(c)

Figure 11 Tensile test result for BFRP with fibre orientation (a) 0^0, (b) ± 45^0, and (c) 90^0.

Refering to composite mixture material theories, a material with higher fibre fraction will have a higher tensile strength and modulus. For the tensile test, BFRP has a higher tensile strength than GFRP (**Table 14**) even though the fibre fraction is lower than GFRP. Indeed, theGFRP fibre weight fraction for tensile test in is 79% while the BFRP fibre fraction is 56%, 56%, and 67% at 0^0, $\pm45^0$,90^0 respectively. However, the Elastic modulus value for the BFRP is lower than for the GFRP at $\pm45^0$, and 90^0. This is because the fibre fraction of GFRP is too high. As specified in composite mixture material theory, if BFRP and GFRP has same fibre weight fraction, the elastic modulus of BFRP could be achieve a higher value than GFRP in all fibre directions.

Table 15 Flexural test result for BFRP and GFRP

	BASALT FIBRE + BTO EPOXY			GLASS FIBRE + BTO EPOXY		
	0	+/-45	90	0	+/-45	90
UFS (MPa)	562.66	129.91	35.61	499.97	87.17	26.13
Flexural Modulus (GPa)	28.60	10.46	4.06	40.77	20.09	5.25

For the flexural test, BFRP has a higher flexural strength than GFRP in all fibre orientation (**Table 15**), the difference more than 30% for flexural strength in the $\pm 45^0$ direction even though the fibre weight fraction is lower than GFRP. However, the Elastic modulus value of BFRP is almost 50% lower than GFRP in all direction. This is because the fibre fraction of GFRP is too high, with a 17% difference in weight fraction. GFRP and BFRP fibre weight fraction for the flexural test is 74% and 57% respectively. If the BFRP and GFRP hasve the same fibre fraction, the elastic modulus of the BFRP can achieve the same or even a higher value than GFRP in all fibre directions.

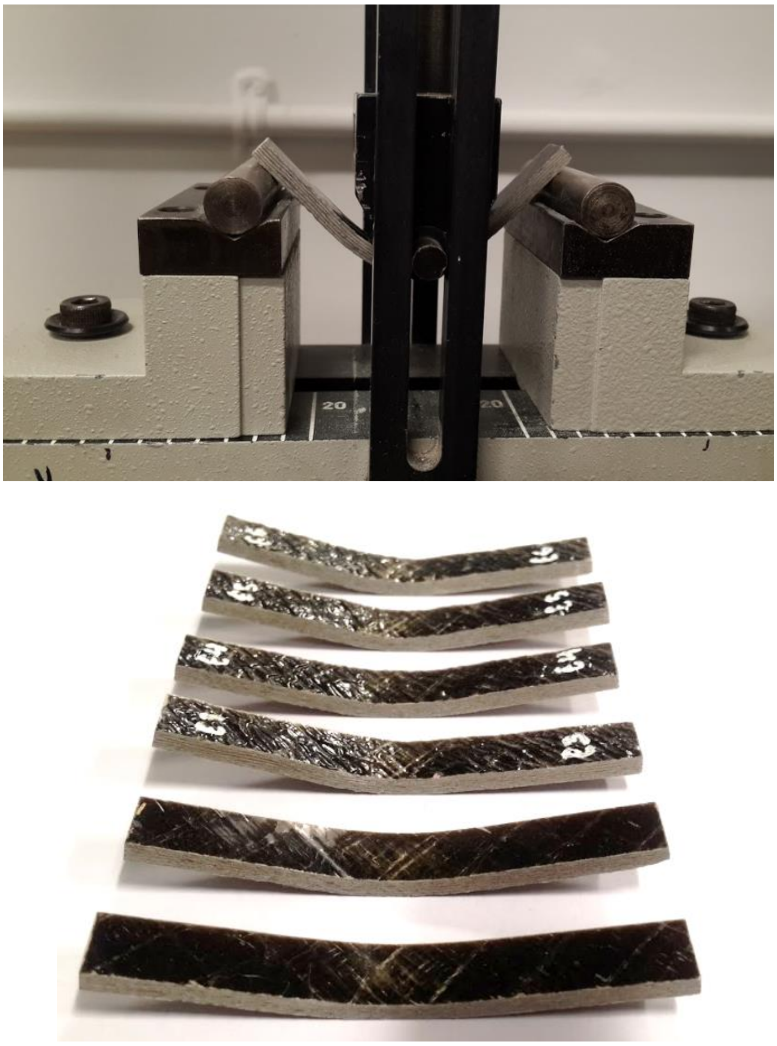


Figure 12 flexural test result

Compression test is the hardest part of the test because some samples buckled during the test. For the compression test, BFRP also has higher compression strength than GFRP in all fibre orientation (**Table 16**). In the 90^0 directions the difference in compressive strength more than 30%, with a fibre weight fraction difference of 17% (79% for GFRP against BFRP at 67%). to mixture theory, if BFRP and GFRP have the same weight fraction, the compressive strength of BFRP can only be than GFRP in all fibre directions.

Table 16 Compression test result for BFRP and GFRP

	GLASS FIBRE + BTO EPOXY			GLASS FIBRE + BTO EPOXY		
	0	**+/-45**	**90**	**0**	**+/-45**	**90**
UCS (MPa)	129.947	60.352	45.980	104.549	49.297	31.061

In order to fully understand the differences, advantages, disadvantages of both materials, the test results need to be applied to a real scenario. The application not only in the strength of the material but also includes the economic, and sustainability aspects. The comparison between GFRP and BFRP will use an ocean going cruising yacht as an example. Hence the next chapter will present the design process for a cruising yacht which includes the hull, rig, sail design, weight estimation, stability, resistance, cost, and sustainability for both materials.

4. CRUISE SAILING YACHT 24M

4.1 Concept Design

The objective of this project is to study the application of basalt fibre in a cruise sailing yacht. In order to do so, a cruising yacht will be designed. The hull form of the sailing yacht is inspired by the open 60 design for Ant-Arctic-Lab project [2]. The length of the boat is constrained to 24 m to avoid more regulation that will come from ship classification society as opposed to small craft regulation under 24m. The dimension of the boat originates from a parametric study of the similar boat in the range 20-24 meters and presented in Appendix B.

Figure 13 open 60 Ant-Arctic-Lab project [2]

4.1.1 Owners Requirement

The owner’s requirements were to design a cruising yacht which has a luxury interior and exterior designed with a waterline length between 18-24 m. The yacht is a monohull with sloop rig. The cruising yacht should have three cabins: an owner cabin, a guest and a crew cabin; a saloon inside and outside, an office area, a kitchen, and a place to store the inflatable lift-raft in a vertical position. For the appendages, the requirements are to have one fixed keel with bulb, and two rudders. The capacity of the tank should be at least 1500 litres of fresh water and 1500 litres of fuel. The yacht needs to be designed so that it will reach 15-20 knots with sail. And the operating range is 2000 nautical miles.

4.1.2 Market Share

Before starting the concept design stages, it is crucial to know the trends in the yacht market. They can assist the designer in deciding upon the type of hull, the number of cabins, and the top cruising destinations which lead to the calculation of fuel and fresh water tank capacity. According to reference [15] , there will be a compound annual growth rate (CAGR) of 6.5% through 2020 for the sail yacht market, while motor yachts are expected to exhibit the highest CAGR during the forecast period.

There are several types of sailing yachts based on its hull and the rig: Schooner, Sloop, and multi-hulls for instance. **Figure 14** shows the market share for cruising yachts by hull type for the year 2014. From **Figure 14**, can be seen if sloop leads the market share for sailing yacht while catamaran vessels have the smallest market share. Sloop also will lead CAGR growth rate from 2015 to 2020.

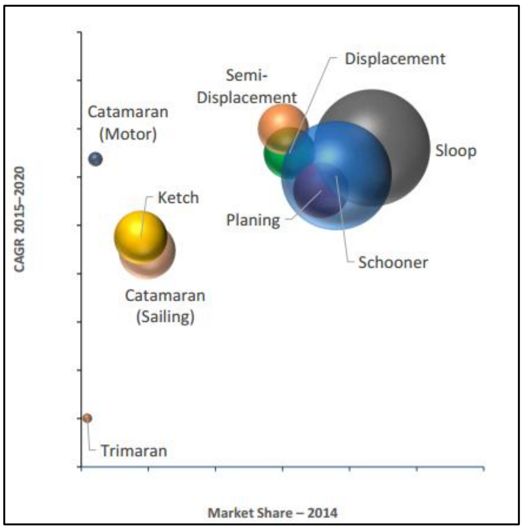


Figure 14 Market share of cruising yachts by hull type [15]

Based on their size, yachts can be classified as large yachts when they have a length bigger than 50m. Yachts are classified as medium yachts when having lengths of 30m to 50m. While it considered as small yachts when lengths is less than 30m. Demand for large-sized yachts is increasing due to growing consumer inclination towards visiting charter destinations in large groups, as it is more cost-effective, but the sales of small yachts still lead the market share in 2014. According to forecasting by reference [15] small yachts will lead the CAGR growth rate in the period between 2015 and 2020, as it can be seen in **Figure 15**.

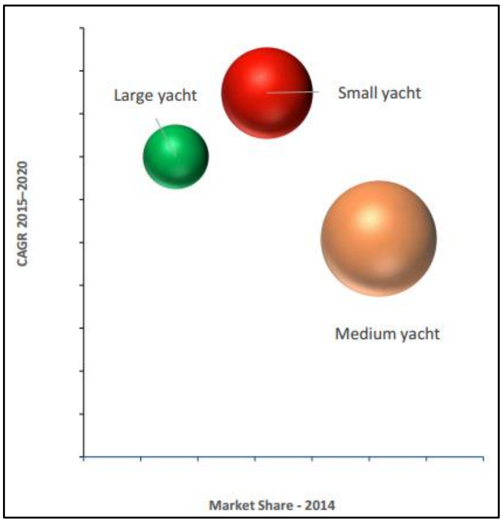


Figure 15 Market share of yacht by the size [15]

4.2 Hull Design

In order to reduce time on “trial and error” when defining the dimensions of the vessel, the parent design method is used. This method allows designers to estimate the physical and performance characteristics based on statistical data of existing similar boat. If the yacht is for construction purpose, the project would be able to start earlier, and the design and construction costs would reduced. For this design, the existing ships listed in Appendix B will refer to parent cruising yachts. There are critical parameters to choose in the analysis of the parent crafts, such as the length overall (LOA) and length of waterline (L_{WL}). There is a constraint from the owner’s requirements to have an L_{WL} from 18 to 24 m because a vessel with a length of waterline more 24 m has more complex regulation to follow. Besides the LOA and Lwl, The other parameters that designer needs to know are the beam (BOA), canoe body and keel draft (T), displacement, and engine power.

Table 17 Open 60 Ant-Arctic-Lab Project Hull dimension and design ratio [2]

Name	ant arctic lab 60.'
LOA (m)	18.318
B (m)	5.797
T (m)	4.5
H superstructures (m)	1.915
L/B	3.160
B/H	3.027
L/H	9.566
Displacement (ton)	9.5

Main sail, Am (m^2)	170
Foretriangle sail, Af (m^2)	140

A statistical measure was needed to filter the information from the parent data. It is critical to find the strength between dependent variables and changing variables. A linear regression was used to conclude on that relation. In this design, the LOA is set as fixed variables and the beam, draft, displacement weight, engine power as changing variable. The linear regression results in a line equation that minimises the distance between the fitted line and all of the data points using the least squares method. It means that an R^2 coefficient of determination is found, which defines the precision of the regression, or how close the data is to the regression line. An R^2 value equal to 1 would mean that all data points were on the line. The linear regression can be found in Appendix B. The hull dimension based on statistical measurement can be seen in **Table 18**. Another important design parameter is the ratio of some parameter to check initially if the sailboat will have a suitable performance. The first design ratio is the DLR or displacement – length ratio. DLR value under 90 indicates the boat is ultra-light.

$$DLR = \frac{\Delta/2240}{(0.1\,.Lwl)^3} \qquad \text{Eq 5}$$

Where: Δ : Displacement (ton)

Lwl : Length of waterline (m)

The other critical ratio is the sail area displacement ratio. It will show the sail performance based on boat displacement. The value above 20 indicates a good performance.

$$SA/\Delta = \frac{SA}{\Delta^{2/3}} \qquad \text{Eq 6}$$

Where: SA : Sail area (m^2)

Δ : Displacement (ton)

Beside that there is also the ballast ratio (Br), the higher the ballast ratio, the greater its ability to resist heeling. Normally the ballast ratio represents 25%-50% of the displacement [16].

Table 18 Hull dimension and design ratio based on statistical measurement

Dimension		**Design ratio**	
LOA (m)	23	Slenderness	7.58
BOA (m)	5.77	DLR	65.47
LWL (m)	24.58	SA/Disp$^{2/3}$	32.08
T (m)	3.57	BR(%)	45
Displacement(ton)	28.6	Loa/Boa	3.98
Ballast(ton)	12.86	Main sail, Am (m^2)	135.08

Foretriangle, Af (m^2)	131.09		

The hull design will be inspired by the open 60 Ant-Arctic-Lab project design, presented in **Table 17**. There will be a 25% increment in length. Larsson and Eliasson [16] specifies that the hull could not just rescale based on the old LOA/BOA design ratio because the stability will increase faster than its heeling moment from the sail. They suggest beam should scale with length$^{2/3}$ and this results in an increase 25%. In this case, the beam value from statistical measurement will fit the criteria. However, the open 60 Ant-Arctic-Lab is a racing boat while the new boat is for cruising purpose. Indeed more space and more stability will be required. Because of this reason the beam chosen is 6.1 meters. After several processes in design spiral including hydrostatic and stability calculation, the creation of the general arrangement, weight estimation, keel design, sail and rigging design, and structure, the final specification of the boat can be seen in **Table 19**.

Table 19 Final specification Ant-Arctic-Lab 78'

Dimension		**Design ratio**	
LOA (m)	24	Slenderness	7.25
B (m)	6.1	DLR	74.74
LWL (m)	22.962	SA/Disp$^{2/3}$	29.37
T (m)	4.115	BR(%)	35.9
Tc (m)	0.439	Loa/Boa	3.98
Tk (m)	3.676	Boa/H	2.537
Displacement(ton)	32.63	L/H	9.56
Ballast(ton)	11.72	LCB %	43.41
Main sail ,Am (m^2)	135.08	LCF %	40.56
Foretriangle, Af (m^2)	131.09	CP	0.54

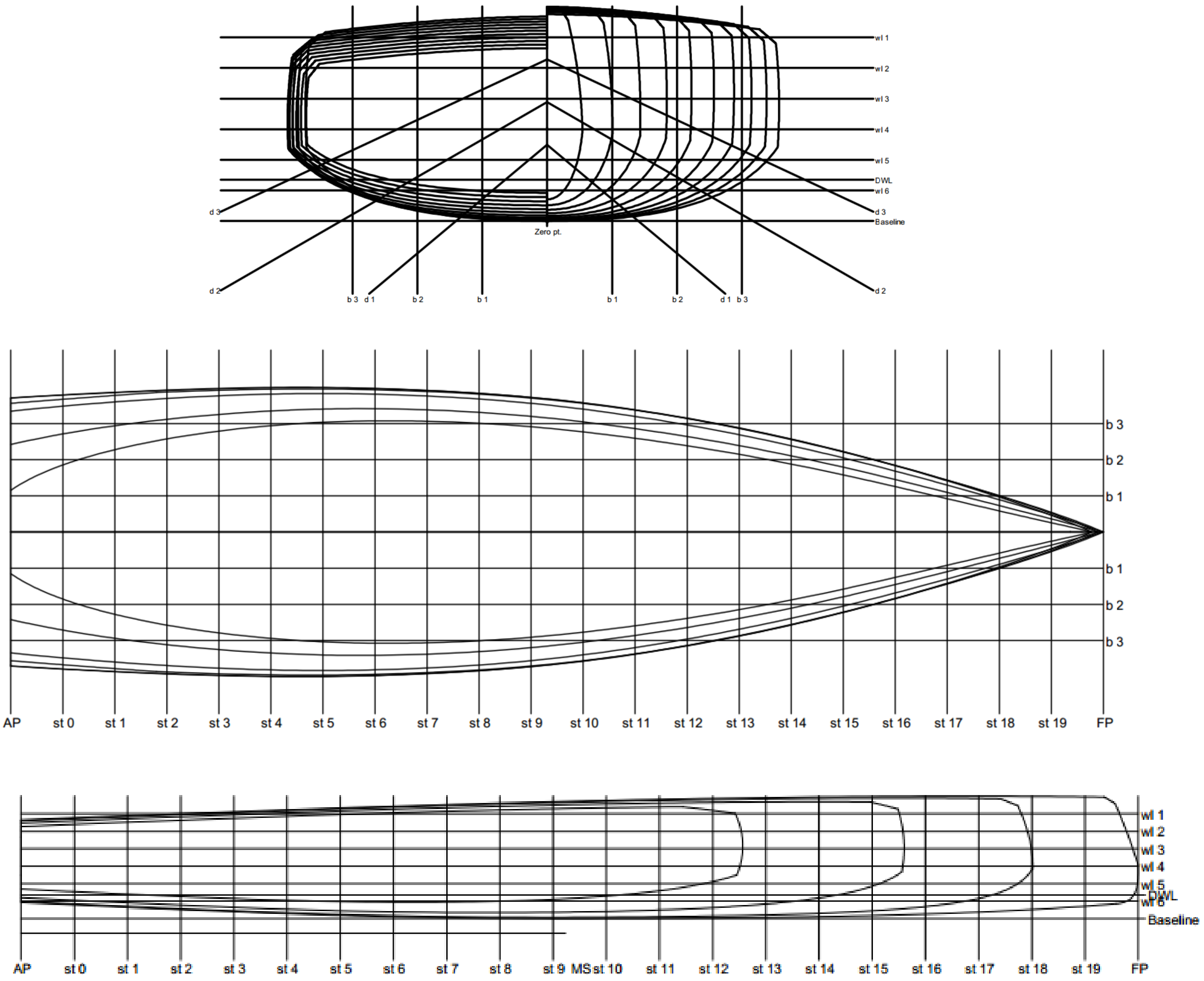


Figure 16 Lines plan of Ant-Arctic-Lab 78' hull

4.3 Appendages Design

4.3.1 Keel Design

After designing the hull, the other important thing to be designed is the appendages. It includes the keel and rudder design. For the keel, the hydrodynamic force should be the same as sail side force to create the equilibrium [17]. Using empirical calculation the keel area for cruising yacht can be estimated using Equation 3 and the result is 7.87 m^2.

$$\frac{KA}{SA} = 0.39\,\frac{Tk}{LOA} + 0.020 \tag{Eq 7}$$

Where: KA : Keel area (m^2)

SA : Sail area (m^2)

Tk : Draft of the keel (m)

Tc : Draft of the canoe body (m)

Assuming sail lift coefficient 1.2 [18] with typical leeway angle (α) of 5^0 and lift coefficient per degree in two-dimensions of 0.1, and an aspect ratio, AR = 3 as a common value for the keel aspect ratio, the initial lift coefficient found is 0.3. Assumption at the moment are a boat speed Vb of 4 knots, and a true wind speed *Vt* of 16 knots, at a true wind angle βt of 60^0, the apparent wind speed Va is 16.12 knots calculated by using equation 5 [17].

$$V_a = \sqrt{(V_b + V_t \, cos \, \beta t)^2 + (V_t + \; sin \, \beta t \;)^2} \qquad \text{Eq 8}$$

Where: V_a : Apparent wind speed (m/s)

V_t : True wind speed (m/s)

Bt : True wind angle (^{0})

Lift force generate by the sail is 903.53 N by using equation 6.

$$L = 0.5 \, \rho_{air} \, KA \;\; Va^2 \, C_L \qquad \text{Eq 9}$$

Where: $\boldsymbol{L}$: Lift force (N)

ρ_{air} : Density of air, 1.225 (kg/m^3)

KA : Keel area (m^2)

This lift force is when the boat does not have any heeling angle. Then this value should be corrected with the boat heeling angle to become the Sail side force (SSF). SSF value should be equal to keel side Force (KSF). To find equilibrium between SSF and KSF an iteration process of heel angle (θ) should be done in equation 10 and equation 11 [19]. Where RM is righting arm in meter, HA is a heeling arm at a certain heeling angle; GM is metacentric height in m.

$$SSF = L \;\; Cos \, \theta \qquad \text{Eq 10}$$

$$KSF = \frac{RM}{HA} \cos\theta = \frac{GM \;\Delta\; g \;\sin\theta\; \cos\theta}{HA} \cos\theta \qquad \text{Eq 11}$$

Where: RM : Righting moment (kg.m)

θ : Heel Angle (^{0})

HA : Heeling arm at certain heeling angle (m)

GM : Metacentric height (m)

Δ : Displacement (ton)

SSF : Sail side force (N)
KSF : Keel side force (N)

After several iterations, the heel angle of this boat is 21^0 and create the SSF=KSF= 842.66 N. because of this heel angle the draft of the keel will change significantly. New draft after heeling (Te) can be calculated use Delft systematic yacht hull series [20]. Te value is 3.17 m.

$$\frac{Te}{Tk} = \left[A_1\left(\frac{Tc}{Tk}\right) + A_2\left(\frac{Tc}{Tk}\right)^2 + A_3\left(\frac{Bwl}{Tc}\right) + A_4 Tr\right](B_0 + B_1 Fn) \qquad \text{Eq 12}$$

In which: Te : draft in heeling angle (m)
Tk : keel draft (m)
Tc : canoe body draft (m)
Tr : Taper ratio, 1
A1, A2,A3,A4,B0,B1 : coefficient for the polynomial (see Appendix C: Appendages & Sail Design)

The changing of the draft due to heeling will also change the aspect ratio, new aspect ratio due to heeling (Ae) can be calculated as follow [19]:

$$Ae = 2\,\frac{Te^2}{KA} \qquad \text{Eq 13}$$

Where: Ae : Aspect ratio at heel angle
KA : Keel area (m^2)

The heeling also change the lift coefficient which can be calculated as follow:

$$C_L = \frac{C_{L,2D,1}}{1+\frac{2}{AR}}\,\alpha \qquad \text{Eq 14}$$

Where: C_L : Lift coefficient
AR : Keel aspect ratio
α : Leeway angle (^{0})

The new aspect ratio value is 2.56, and keel lift coefficient is 0.75.With the assumption that, the keel will create 80% of the hydrodynamic force the keel area can be calculated by using equation 12 [17].

The result of keel area is 3.03 m^2 or 1.01% of the sail area. Since the ratio of keel area to sail area is too small, the keel area increases become 3.31 m^2 or 1.1% of sail area.

$$KA = \frac{0.8\ x\ L}{0.5\ \rho_{sw}\ V^2\ Cl} \qquad \text{Eq 15}$$

Where: KA : Keel area (m^2)

L : Lift force (N)

ρ_{sw} : Density of sea water, 1.025 (kg/m^3)

C_L : Lift coefficient

After establishing the keel area the next thing is to find the best section for the keel. A NACA section series 65 has been choosen because it gives larger area coefficient, plus the 65 series have less drag coefficient in the drag bucket area. The bucket area is less than the 63 series but larger than the 66 series.

Table 20 Keel dimension

Thickness (mm)	0.2	t/c root	0.15
C1,root (mm)	1.33	t/c tip	0.25
C2,tip (mm)	0.798	density(kg/m3)	7800
Mean chord, C (mm)	1.064	Weight (kg)	5164.59

The thickness and chord of the keel should have a good ratio to minimise the resistance (Chapter 4.9). In this case the thickness/chord is 15% at the root and 25% at the tip. With a density of 7800 kg/m3 typical for a cast iron keel, the keel will have a weight 5164.59 Kg or 20.35% of displacement weight.

4.3.2 Bulb Design

From reference [16] it was explained that for sailing yachts a good ballast ratio is 40-50 % of the displacement. For this yacht, a value of 46.2 % has been achieved. The value is coming from the regression analysis. Since keel weight ratio is 20.35% of displacement weight, the bulb should accommodate 25.83% or 6555.4 kg. With a lead density of 11,340 kg/m^3 the volume of the bulb is about 0.59 m^3. Using same NACA section as the keel, NACA65 series [21] below the bulb dimension:

Table 21 Bulb dimension

Thickness (mm)	0.5	t/c	0.1
Lenght, C (mm)	3890	density(kg/m3)	11340
C2 (mm)	0.798	Weight (kg)	6555.4

NACA 65 has been chosen since the lift coefficient which can be known from leeway angle (less than 5) is in the drag bucket which shows the drag coefficient in a lower point than NACA 63 or NACA 66 [17].

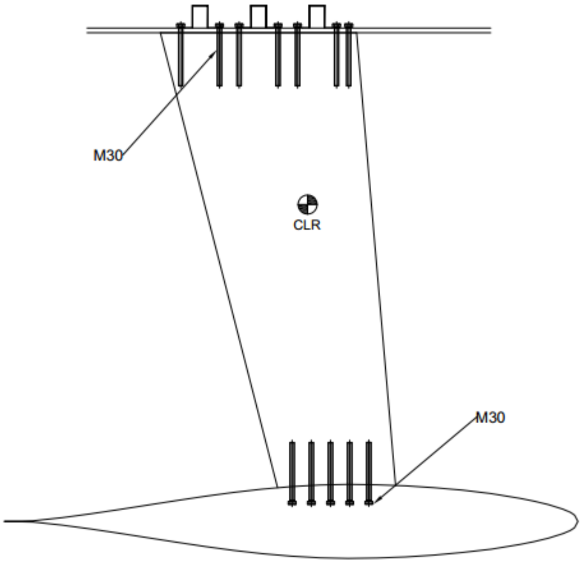


Figure 17 keel and bulb

4.3.3 Keel Bolts

A chain plate is for attaching the shrouds to the hull and the bolts need to be used in keel structures to reinforce the connection between the keel and the hull. ISO 12215-9:2012 [22] controls the specification of the bolts that need to be used for the keel. Beside that the ISO rules also assess the calculation of the bottom shell plating which connects the hull and the keel. Furthermore, there are several load case which ISO provides for keel load calculation. For this yacht, load case 1 has been used. Load case 1 corresponded to "a 90^0 knockdown case, which is usually the most severe transverse bending load for fixed ballast keels." [23]. From the calculation procedure, an M30 bolt has been adopted. The bolt will also connect keel to the bulb.

Because the keel/bulb junction carries the heaviest and most vital part of the boat, the connection should be strong enough. Otherwise, the structure will fail. Moreover, additional transverse structural elements need to be installed to support the hull-keel connection. Calculation of transverse floor can be found in Annex C of ISO 12215-9:2012. In this case, the floors will be between two engine girders. Using the assumption that the floors simply supported beams, the height of the floor is found to be 150 mm and the thickness is 6 mm. the slenderness ratio of top hat section h/(tw/2) is 30, and d/tf is 17.67. The value satisfies regulation of ISO 12215-5:2008. The calculation detail of keel bolt and floor can be found in Appendix C: Appendages & Sail Design.

4.3.4 Rudder design

To control the direction of the sailing boat, a rudder and steering system need to be designed in such a way so that it will have a good response in all conditions. For the rudder one of important aspect is the aspect ratio. The right aspect ratio for sailing boat is about 2.2-3.5 or even 3.5-4.5 for racing boat [24]. Higher aspect ratio will increase the rudder efficiency but also increase the bending of the rudder. The rudder area itself will depend on the lateral sail area and the length of the boat [16]. The ratio of rudder area to the sail area for this boat with Lwl 22.9 m is 2%. Since the sail area is 299.93 m^2, the area needed for each rudder is 0.68 m^2.

Table 22 Rudder dimension

Rudder Area (m^2)	0.686	Ar	4.111
Tr (m)	1.68	TR	0.408
C1,root (m)	0.49	t, thickness (m)	0.05
C2,tip (m)	0.2	t/c root	0.102
C,mean chord (m)	0.345	t/c tip	0.25

A profile of NACA 65 has been chosen for rudder profile with the same reason as bulb and keel section. For excellent manoeuvrability, the position of LCG should be same or vertically near (3%) with the submerged area (LCF). If the position is far, it will cause the skipper to adjust the rudder regularly to have good direction. The LCG in this boat equal to 43.41% Lwl and the LCF 40.56% Lwl from after peak (AP). The gap between the 2 points is 2.85%, and thus the yacht will have excellent manoeuvrability.

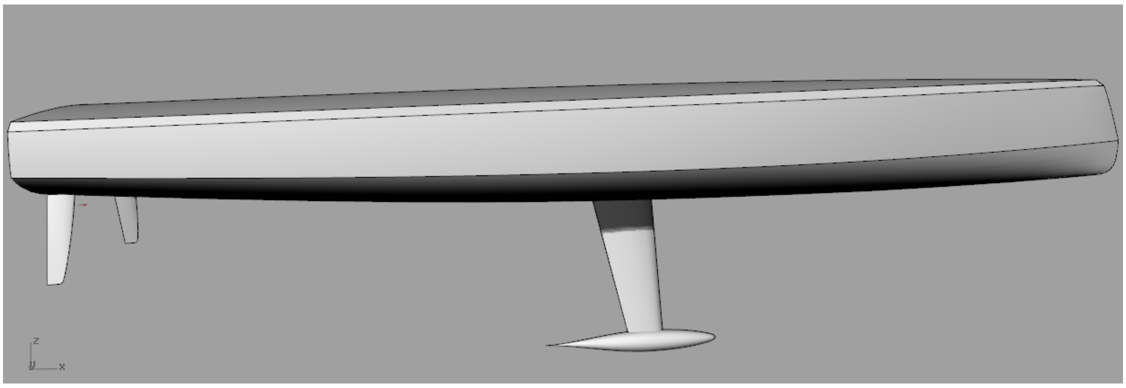


Figure 18 Hull and appendages

4.4 Rig and Sail Design

4.4.1 Sail Area

A parametric study has been done to define the sail area for cruising yacht (Appendix B). The rig structure itself has one mast with three sails namely, main sail, fore triangle, and asymmetric spinnaker. The height of mast is 30.8 m from the deck, and size of sail area using equation 16, 17, 18 [16]:

$$Main\ sail = \frac{P\ E}{2} \qquad \text{Eq 16}$$

$$Foretriangle\ sail = \frac{IG\ \ J}{2} \qquad \text{Eq 17}$$

$$Spinnaker = 1.15\ J\ SL \qquad \text{Eq 18}$$

Table 23 Sail dimension

IG (m)	29.5	Main Sail, Am (m^2)	135.08
J (m)	8.9	Fore triangle, Af (m^2)	131.09
P (m)	27.3	Spinnaker, As (m^2)	301.50
E (m)	9.9	SA upstream (m^2)	299.93
SL (m)	29.54	BAD (m)	2.5

To fulfil satisfaction of passenger and crew, the space between deck and boom section (BAD) is 2.5 m so the crew or passenger can stand up freely on the deck. The centre of effort for each sail area can be found using the equations below [16].

$$COE_M = 0.39P + BAD \qquad \text{Eq 19}$$

$$COE_F = 0.39I \qquad \text{Eq 20}$$

$$COE_S = 0.59I \qquad \text{Eq 21}$$

With this sail arrangement, the lift coefficient and total sail side force can be calculated by using equation 11 and 12 presented earlier in the keel calculation section. The lift coefficient value is 0.75 with sail side force (SSF) 903.53 N at heel angle 21^0.

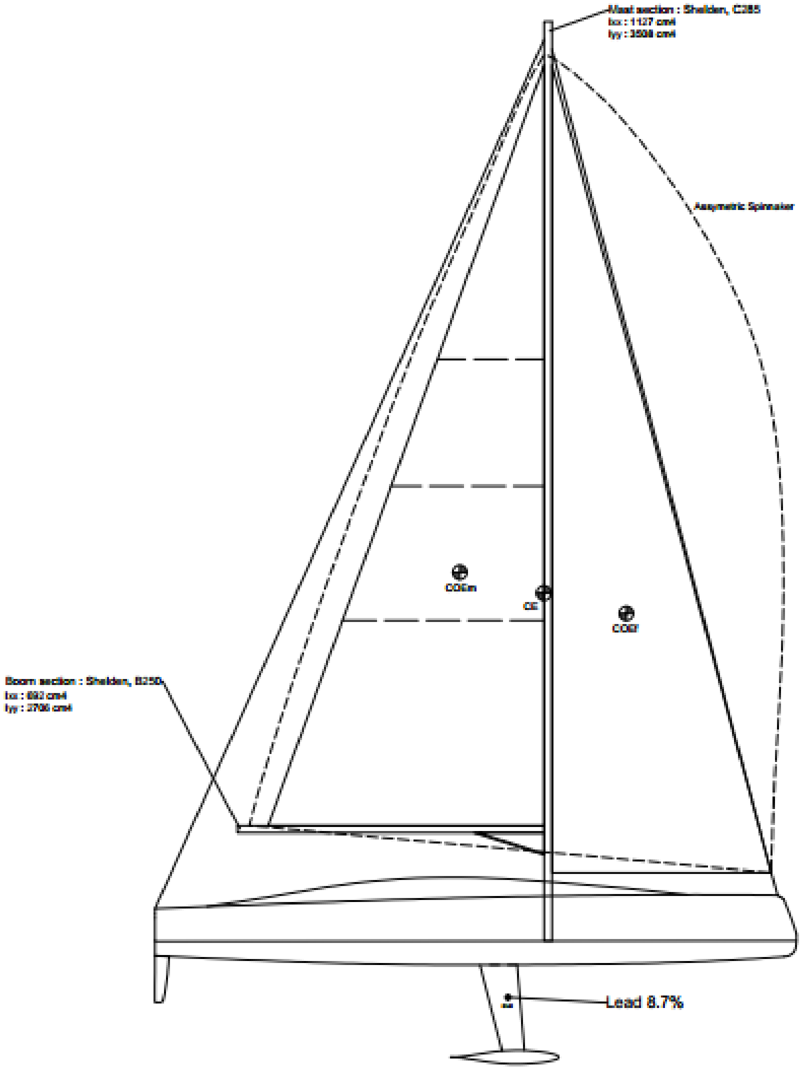


Figure 19 sail arrangement with its balance

When the wind speed increases, and in order to have safe heel angle, the reef system is applied to reduce the sail area. The reef system will describe in more detail after Velocity Volume Processing (VVP) chapter.

The other important aspect deuced from the sail and keel area is the stability. To define stability, there is a quick formula to define if the yacht is in the stiff or tender region. The formula called Dellenbaugh angle [16].

$$Dellenbaugh\ angle = 279\ \frac{A_S\ x\ HA}{\Delta\ \overline{GM}} \qquad \text{Eq 22}$$

The Dellenbaugh angle value for this cruise boat is 9.6^0, according to Larsson [16] the boat in the stiff region. However, besides stability, a balance between the aerodynamics sail forces and hydrodynamics keel forces all heel angle need to be considered. Unbalance between those two can induced too much weather or lee helm. Weather helm is critical to keep the boat heading into the wind while Lee helm is keeping the boat away from the wind. The balance between weather and lee helm will create an efficient sail. The balance can be known by measure the lead. Lead is the lateral distance between the centre of effort of sail and the centre of lateral. The lead value will depend on sail size and keel size. For fin-keel yacht with frictional rig , Larsson [16] suggests the lead should be 2-6 % of the length of waterline. To have good balance. The lead for this boat is designed to have 5.6% of Length of the waterline.

4.4.2 Rigging Construction

The rig structure should be strong enough to handle the forces created by the sails. To define the structure type and dimension of the rigging system such a mast, spreader, boom, shrouds and stays some class society have developed regulations. For this boat, the Nordic Boat Standard (NBS) is applied. The rig regulation from NBS applies for a sailing boat with length less than 15 m, but in practice it is used up to 24 m. The calculation of rigging system is based on the righting moment at heel angle of 30^0. Moreover, Larsson [16] specifies that the calculation of forces in shrouds stays, and mast will depend on the number of spreaders. More spreader stiffen the mast, so it is possible to use a thinner and lighter mast. While less spreader will increase the diameter and weight of mast but lowering the cost and better ability for trim. After an iterative process, four spreaders has been choosing as the best arrangement for the yacht which has a frictional mast.

4.4.2.1 Shrouds and Stays

The forces in the shrouds will depend on the value of righting moment and the angle of the diagonal or vertical shrouds. There is two load case that should be considered to define the load according to Larsson [16]. First, if the load only comes from the foresail. Second if the load comes from reefed mainsail.

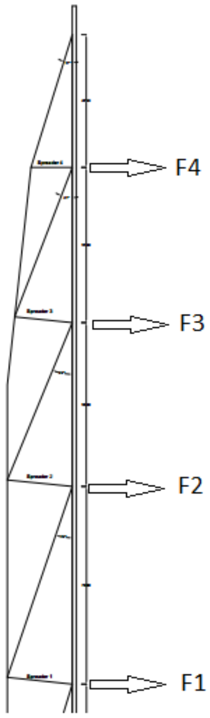


Figure 20 Force in the shrouds with four spreaders

After calculating the forces, the load in vertical and diagonal shrouds can be calculated using the equation below:

$$T1 = \frac{RM}{a1} \qquad \text{Eq 23}$$

$$Thu = 0.4\ \frac{RM}{0.6\ P}\ d_1/(d_1 + d_2) \qquad \text{Eq 24}$$

$$Thl = 0.4\ \frac{RM}{0.6\ P}\ d_2/(d_1 + d_2) \qquad \text{Eq 25}$$

$$Tbu = 0.33\ \frac{RM}{0.6\ P}\ BAD/l \qquad \text{Eq 26}$$

Where: RM : Righting moment at 30^0 (kg.m)
L : Panel length (m)
D1 : 1/3 panel length (m)
D2 : 2/3 panel length (m)
BAD : space between deck and boom (m)
T1 : transverse force (N)
Thu : forces on the upper shrouds (N)
Thl : forces on the lower shrouds (N)
Tbu : forces on fraction boom (N)

Between the two load cases, the biggest value has been choose as the design load for each shroud. According to Larrson [16] the value of F1,F2,F3 in load case 1 and F4 in load case 4 are not applicable because of the rig has more than 2 spreaders (**Table 24**). Besides that, another important element is to calculate the for and back stays requirements.

Table 24 Force in shrouds

	load case 1 (N)	load case 2 (N)
F1	N/A	Thl+Tbu =2414.672
F2	N/A	Thu = 1998.349
F3	N/A	Thu = 1998.349
F4	T1 = 2889.357	N/A

The results of calculating the load in shrouds and stays are the diameter of wire needed to handle the load, taking into account the relevant safety factor. Below are the diameter for vertical and diagonal shrouds, aft stays, and forestay.

Table 25 Diameter of Shrouds and stays

	Tension (N)		Load (N)		**max (N)**	Diameter (mm)
	case 1	case 2	case 1	case 2		
D1	149.223	13491.405	417.825	37775.934	**37775.934**	7
D2	935.554	9611.530	2151.775	22106.520	**22106.520**	
D3	935.554	9611.530	2151.775	22106.520	**22106.520**	
D4	2233.648	N/A	6700.944	N/A	**6700.944**	
V1	3076.934	9577.460	9846.188	30647.872	**30647.872**	7
V2	3076.934	9577.460	9846.188	30647.872	**30647.872**	
V3	2225.730	N/A	6677.191	N/A	**6677.191**	
C1	28.473	159.609	-			-
C2	39.712	0.000	-			-
Forestay					**44476.603**	8
Aftstay					**33280.430**	7

4.4.2.2 Mast and Boom

The mast of sailing yacht can be defined by its ability to hold the compression force transversally and longitudinally as well as bending and torsion. Transverse and longitudinal moment of inertia can be calculated as follow:

$$I_x = 2.6.m\,PT\,l(n)^2 \qquad \text{Eq 27}$$

$$I_y = 0.85\,1\,m\,PT\,h^2 \qquad \text{Eq 28}$$

Where: Ix : Transversal moment of inertia (m^4)
PT : 1.5 RM/b (N)
b : Breadth of spreader (cm)
l(n) : Actual panel length (m)
Iy : longitudinal moment of inertia (m^4)
h : height above deck of superstructure (m)

The value of moment inertia for each panel can be different. For this sailboat the size of the mast is decided to be same from the bottom to the top. Therefore the biggest moment of inertia has been chosen. The highest value of the transverse moment of inertia I_x is 898 cm^4 and longitudinal I_y is 3272 cm^4 which includes a 1.5 factor of safety. A suitable mast section form the Selden manufacturer (section c285) with then selected accordingly. The section has dimension 285/147 mm, I_x 1127 cm^4 and I_y 3508 cm^4.

Table 26 Moment inertia of mast section

Panel	Height (m)	Spreader width (m)	Ix (cm^4)	Iy (cm^4)
1	7.4	2.30	898.953	2067.230
2	7	2.30	805.446	2069.929
3	5.8	2.30	776.476	2069.929
4	5.5	2.04	788.328	2336.427
5	4.7	1.45	799.018	3272.284

Beside the mast, another important component is the boom. The boom section size also depends on the righting moment of the boat. The method to define the boom size is based on the vertical section modulus required, as given in the equation below.

$$SM = 600\, RM\, (E - d1)/(\sigma_{0.2}.HA) \qquad \text{Eq 29}$$

Where: SM : Section modulus (m^3)

RM : Righting moment (kg.m)

HA : distance from waterline to centre of effort (m)

E : length of the boom, 9.9 (m)

d1 : distance between boom to the gooseneck, 2.5 (m)

The section modulus from equation 30 of the boom is 90.89 cm^3. Then the boom section B250 from Selden with a 250/140 mm section, I_x = 692 cm^4 and I_y = 2706 cm^4 has been adopted.

4.5 General Arrangement

The general arrangement of the sailing yacht is coming from the owner's requirements. Indeed, the owner wants to have a sailing yacht with luxury in interior and exterior. The sailing yacht has only two decks, the lower deck, and main deck.

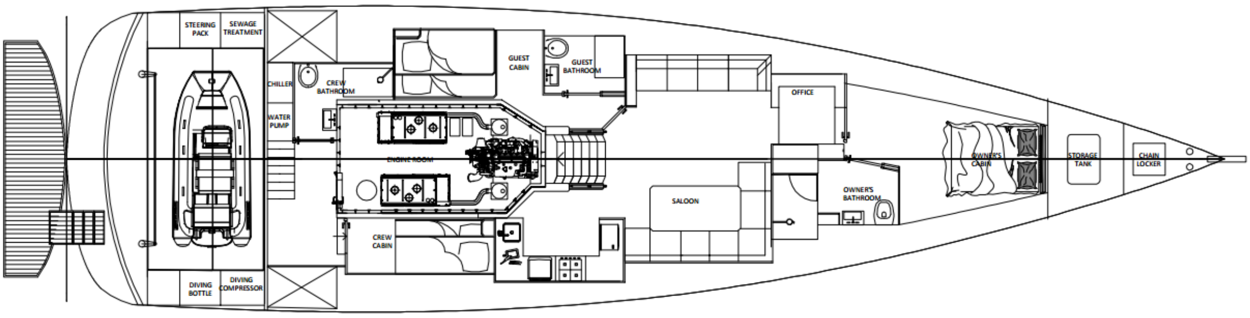


Figure 21 Lower deck

One owner cabin is placed in the fore part of the lower deck. The room includes a private bathroom with a bathtub. Next to the owner's cabin, there is an office area and a saloon. From the saloon, people will have direct access to the deck. An open galley and guest cabin is available beside the saloon. The guest cabin has two beds with private bathroom. The ceiling height of the lower deck is 2 meters, thus providing the necessary level of comfort. In the lower deck, there is also an engine room with two generator set for electricity and one engine for propulsion. The engine room can be accessed from the main deck through the crew cabin hall.

For the crew, there is a cabin with two beds and a bathroom. One garage room is available to put the inflatable boat and diving equipment. The aft part of the sailing yacht can be expanded into a swimming deck. The main deck also features one saloon and two cockpits. Since the crew is only two people, it will be very helpful if the sail winches can be reached within hand distance.

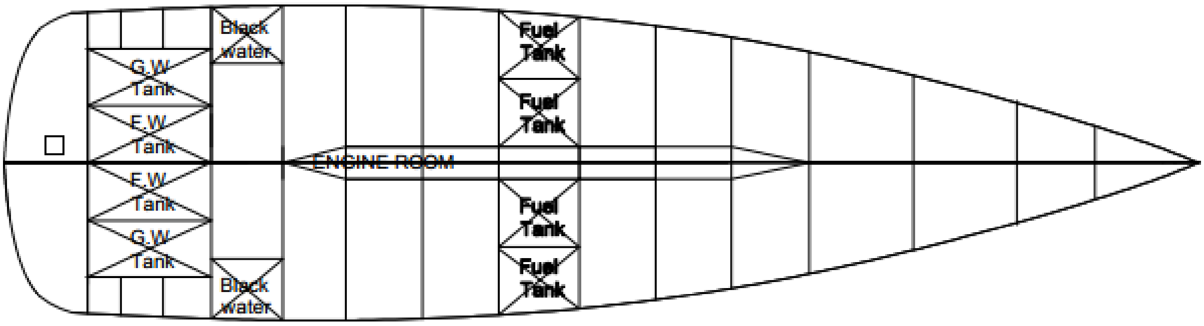


Figure 22 Tank arrangement

All tanks are located below the lower deck. There are the fuel tank, fresh water tank, grey water tank, and black water tank. From the owner's requirement, the capacity of the tank should be at least 1500 litres of fresh water and 1500 litres of fuel. Moreover,t yacht needs to be designed so that it will reach 15-20 knots with sail. And the operating range is 2000 nautical miles. From the **Table 27** it can be seen that the tanks can fulfil the owner's requirement for the capacity of the tank. Besides that, the position of the tank should be placed in such a way that it will not affect the stability of the boat. The fresh water tank and the grey water tank is side by side, once the fresh water tank volume decreases the grey water tank volume will increase. So it will keep the boat in a level condition.

Table 27 Capacity of tank

Tank	Weight (ton)	LCG (m)	TCG (m)	VCG (m)
grey water tank SB	1.425	3.971	-1.099	3.538
Fresh water PS	0.938	2.831	0.544	3.899
Black water SB	0.575	5.35	-1.914	3.61
Black water PS	0.575	5.35	1.914	3.61
Fuel Tank SB1	0.9	10.296	-0.943	3.671
Fuel Tank PS 1	0.9	10.296	0.943	3.671

grey water tank PS	1.425	3.971	1.099	3.538
Fresh water SB	0.938	2.831	-0.544	3.899
Fuel Tank SB2	0.358	10.275	-2.003	3.778
Fuel Tank PS 2	0.358	10.275	2.003	3.778

4.6 Structures

The ISO 12215-5 was used to define the structure arrangement of the cruising yacht. The regulation works for monohull craft with length more than 2.5 m and less than 24 m. To use the regulation, a designer needs to define the category of the craft. There are four categories which can be utilised, “ocean”, “offshore”, “inshore”, and “sheltered waters” as can be seen in **Table 28**. The categories will influence the scantling calculation because they refer to different environment conditions and therefore loads. For this sailing yacht, the design category A “Ocean” was selected. It means the boat’s structure will be able to cruise in significant wave height up to 4 m and wind speed more than Beaufort Force 8 [12]. For the purpose of the structural calculations, a software called “Hullscant” which able to calculate the hull scantling requirements based on ISO 12215 was used [25].

Table 28 Design load category [12]

Category	Wave	Wind (Beaufort scale)
A “Ocean”	> 4 m	> 8
B “Offshore.”	Up to 4 m	8 or less
C “Inshore.”	Up to 2 m	6 or less
D “Sheltered waters.”	0.3-0.5 m	4 or less

4.6.1 Design load

For sailing yacht, the pressure value will be different in several parts. The bottom part the highest pressure. In the ISO rules the base pressure can be calculated from the category. From the base pressure, the pressure in another part can be defined easily by length of waterline or pressure adjusting factors. The base pressure for this cruise can be seen in **Table 29.**

Table 29 Pressure base

Category	Formulation	Value
Design Category factor, k_{DC}	-	1,00
Displacement in kg, m_{LDC}	-	32630 kg
Base Bottom Pressure, P_{BSBASE}	$(2\ m_{LDC}{}^{0.33} + 18) x \mathrm{k}_{SLS}$	149.96 kN/m^2
Base Deck Pressure, P_{DSBASE}	$(0.5\ m_{LDC}{}^{0.33} + 12)$	27.433 kN/m^2

The value above is just the base pressure. The value can be varied depending on the position of the structural element. The highest pressure can be found in the forepeak area of the bottom plate this is because of the longitudinal pressure distribution factor is quite significant in the area due slamming loads. Hence more stiffener will be required in forepeak area to reduce the pressure load.

4.6.2 Structure arrangements

Beside the plate, the boat structures is reinforced by longitudinal and transversal stiffeners. The structure will use composite sandwich and can be seen in **Figure 23**. Since the length of the boat is less than 24 m, a transverse construction system is used to reinforce the structure. Besides the transverse frames, a longitudinal girder is also used. For this research three laminate arrangement will be presented. 1 GFRP lamination arrangement with code A and 2 BFRP lamination arrangement with code B and C. the laminate is made of 600 gr/m^2 of fibre with bto epoxy as a matrix. Using eq 2 the thickness of 1 layer of GFRP and BFRP is respectively 0.492 and 0.663 mm. Beside UD layer a CSM and WR layer are also used as an outer layer for water resistance of the structure, both layers have a weight 200 gr/m^2.

Table 30 Panel laminate arrangement

Part	GFRP(A) & BFRP(B)	BFRP(C)
Bottom plating	$[0^0{}_4, \pm45^0, 90^0, 0^0{}_4]_{outer}$ $[\mathrm{balsa,27mm}]_{core}$ $[\pm45^0, 0^0, \pm45^0, 0^0, \mathrm{WR,CSM}]_{inner}$	$[0^0{}_2, \pm45^0, 90^0, 0^0{}_2]_{outer}$ $[\mathrm{balsa,27mm}]_{core}$ $[\pm45^0, 0^0, \pm45^0, 0^0, \mathrm{WR,CSM}]_{inner}$
Side plating	$[0^0{}_2, \pm45^0, 90^0, \pm45^0, 0^0{}_2]_{outer}$ $[\mathrm{balsa,20mm}]_{core}$ $[0^0, \pm45^0, 0^0, \mathrm{WR,CSM}]_{inner}$	$[0^0, \pm45^0, 90^0, \pm45^0, 0^0]_{outer}$ $[\mathrm{balsa,20mm}]_{core}$ $[0^0, \pm45^0, 0^0, \mathrm{WR,CSM}]_{inner}$

Deck plating	$[0^0, \pm45^0, 0^0, 90^0, 0^0]_{outer}$ $[balsa,12mm]_{core}$ $[0^0, \pm45^0, 0^0, WR,CSM]_{inner}$	$[0^0, \pm45^0, 0^0]_{outer}$ $[balsa,12mm]_{core}$ $[0^0, \pm45^0, 0^0, WR,CSM]_{inner}$

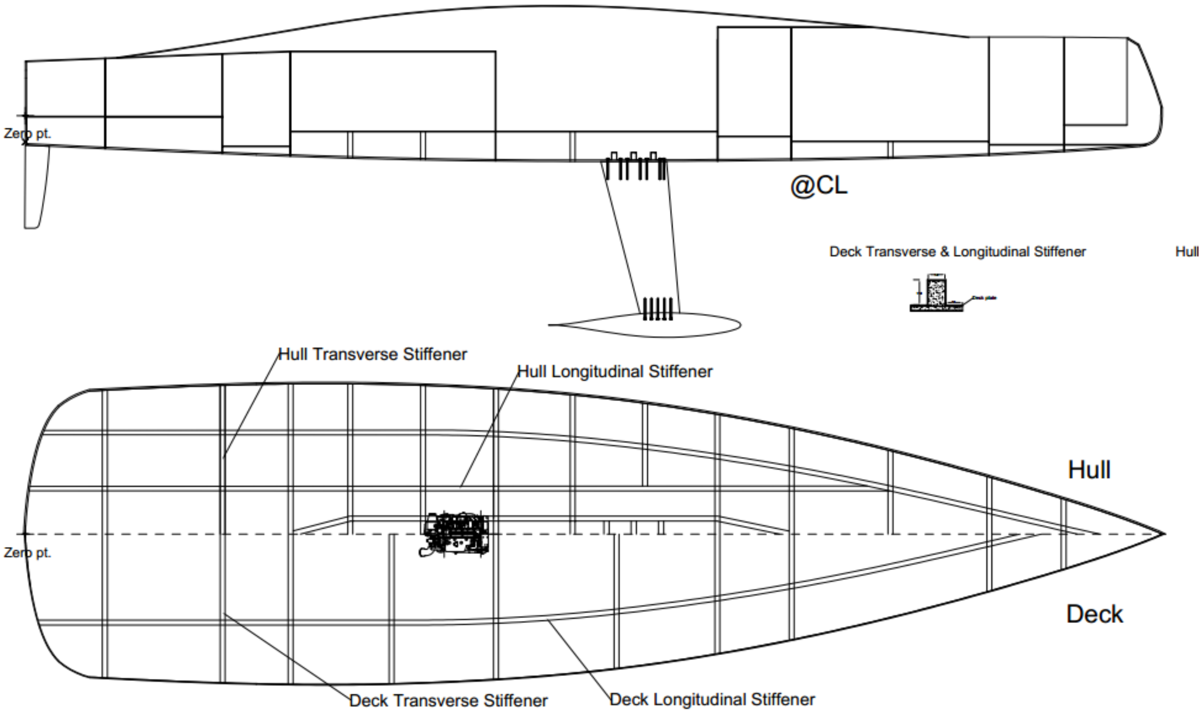


Figure 23 Structure Arrangement

To obtain a preliminary idea of the thickness and weight of the structure, Dave Gerr [24] method has been applied The method is very useful to predict whether the composite structure has a normal weight or is too heavy. Dave Gerr's formulation is using the scantling number as a base value to calculate the thickness and the weight of the structure. The thickness of plating suggested by David Gerr is quite thick; this is because the formula is based on woven roving material, not UD.

Table 31 Comparison of thickness and composite weight

	Bottom (mm)			
	Dave Gerr	GFRP (A)	BFRP (B)	BFRP (C)
Inner	5.0	2.789	3.47	3.47
Core	37	27	27	27
Outer	6.67	4.92	6.63	3.978
Total thickness	48.67	34.71	37.10	34.451
Total weight (kg/m2)	16.8	15.77	17.84	14.11

	Side (mm)			
	Dave Gerr	GFRP (A)	BFRP (B)	BFRP (C)

Inner	4.35	2.29	2.81	2.81
Core	32	20	20	20
Outer	5.8	3.44	4.64	3.315
Total thickness	42.15	25.74	27.45	26.12
Total weight (kg/m2)	11,21	11.57	13.08	11.22

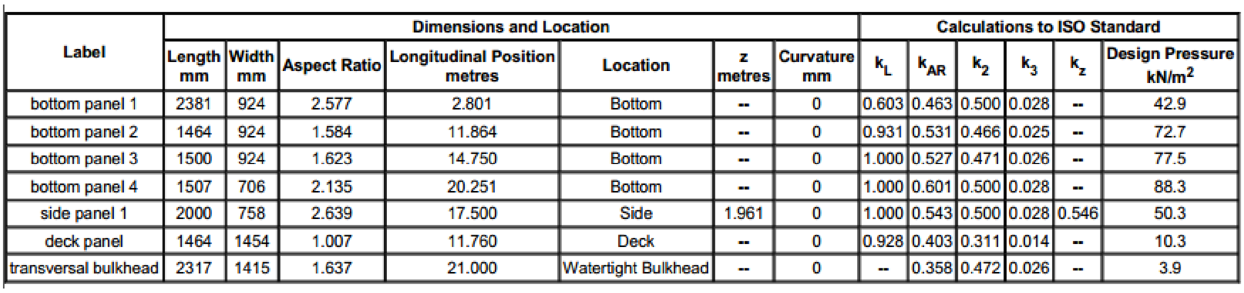
	Deck (mm)			
	Dave Gerr	GFRP (A)	BFRP (B)	BFRP (C)
Inner	3.7	1.80	2.147	1.98
Core	27	12	12	12
Outer	4.93	2.46	3.315	2.81
Total thickness	35.62	16.26	17.46	16.79
Total weight (kg/m2)	9.53	8.02	9.01	8.17

From **Table 16** it can be seen that lamination type B has more weight than lamination type A. It is because BFRP has a higher density and smaller fibre content than GFRP. More resin will fill the structure and create a thicker plate. Since the mechanical properties of BFRP are better than GFRP, it is possible to reduce the number of layers of BFRP to reduce its weight (structure C). However, laminate C needs to be checked for its compliance with the ISO rules using hullscant. Besides the panels, the sandwich structure also uses laminated stiffeners, both longitudinally and transversally. The dimensions of the longitudinal and transverse stiffeners is the same on the bottom and the deck, with however a laminate schedule. The details can be seen in the profile and deck plan drawing.

4.6.3 Structure Compliance

In order to check compliance with the ISO 12215-5, some panels and stiffeners were selected for assessment. Four bottom panels, one side and deck panels, a longitudinal and a transverse stiffener design will be checked in Hullscant as per **Figure 24**. The biggest pressure happens in the bottom panel number 4, furthest forwards, because of the longitudinal pressure distribution factor. Therefore the panel size in this area reduced by adding more stiffeners.

Table 32 design pressure of panel and stiffener



Label	Dimensions and Location							Calculations to ISO Standard					
	Length mm	Width mm	Aspect Ratio	Longitudinal Position metres	Location	z metres	Curvature mm	k_L	k_{AR}	k_2	k_3	k_z	Design Pressure kN/m^2
bottom panel 1	2381	924	2.577	2.801	Bottom	--	0	0.603	0.463	0.500	0.028	--	42.9
bottom panel 2	1464	924	1.584	11.864	Bottom	--	0	0.931	0.531	0.466	0.025	--	72.7
bottom panel 3	1500	924	1.623	14.750	Bottom	--	0	1.000	0.527	0.471	0.026	--	77.5
bottom panel 4	1507	706	2.135	20.251	Bottom	--	0	1.000	0.601	0.500	0.028	--	88.3
side panel 1	2000	758	2.639	17.500	Side	1.961	0	1.000	0.543	0.500	0.028	0.546	50.3
deck panel	1464	1454	1.007	11.760	Deck	--	0	0.928	0.403	0.311	0.014	--	10.3
transversal bulkhead	2317	1415	1.637	21.000	Watertight Bulkhead	--	0	--	0.358	0.472	0.026	--	3.9

For the sandwich panel, there are five criteria which should comply with a minimum value, namely the bending moment, stiffness, the weight of the outer skins, the weight of the inner skins, and the shear force.

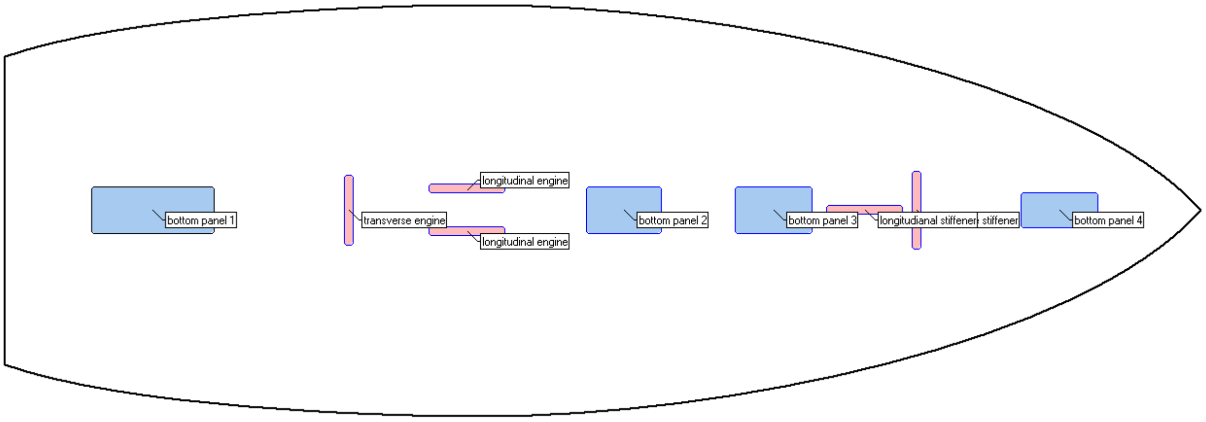
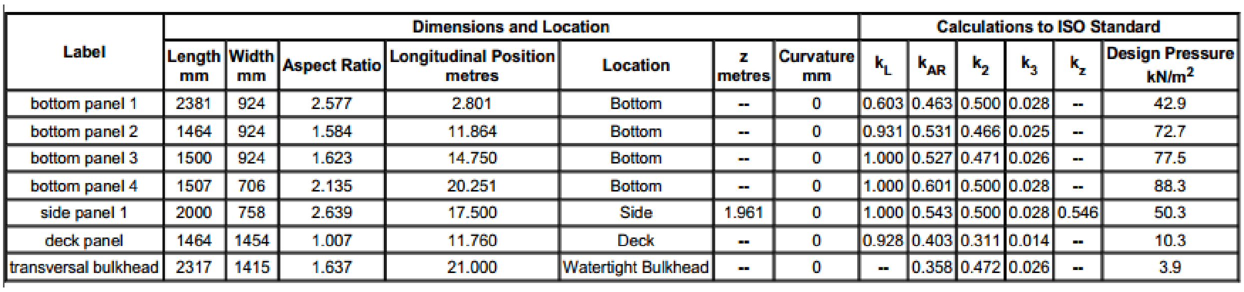


Figure 24 panel and stiffener in Hullscant

Table 33 design pressure of panel and stiffener



Label	Dimensions and Location							Calculations to ISO Standard					
	Length mm	Width mm	Aspect Ratio	Longitudinal Position metres	Location	z metres	Curvature mm	k_L	k_{AR}	k_2	k_3	k_z	Design Pressure kN/m^2
bottom panel 1	2381	924	2.577	2.801	Bottom	--	0	0.603	0.463	0.500	0.028	--	42.9
bottom panel 2	1464	924	1.584	11.864	Bottom	--	0	0.931	0.531	0.466	0.025	--	72.7
bottom panel 3	1500	924	1.623	14.750	Bottom	--	0	1.000	0.527	0.471	0.026	--	77.5
bottom panel 4	1507	706	2.135	20.251	Bottom	--	0	1.000	0.601	0.500	0.028	--	88.3
side panel 1	2000	758	2.639	17.500	Side	1.961	0	1.000	0.543	0.500	0.028	0.546	50.3
deck panel	1464	1454	1.007	11.760	Deck	--	0	0.928	0.403	0.311	0.014	--	10.3
transversal bulkhead	2317	1415	1.637	21.000	Watertight Bulkhead	--	0	--	0.358	0.472	0.026	--	3.9

The results allowed to demonstrate compliance with ISO category A. GFRP A panels exhibit a compliance factor of 1.0, and 1.1. There is an increment on strength of structure BFRP B. The compliance factor is increasing with minimum value 1.3 as compliance factor stress ratio in the bottom panel. However, the increment of strength due to bending moment is not followed by the structure stiffness. Because of elastic modulus of BFRP is lower than GFRP. Moreover, the way to increase the structure's stiffness is by adding more layer, so the moment of inertia will increase. However, hullscant shows compliance factor as quite high, so it is not necessary to add more layer in the panel structure because it will increase the weight of the structure.

Table 34 Structure test in Hullscant

Requirement/Offered GFRP (A)				Results GFRP (A)				
Label	**Mdb N.mm/mm**	**EIb N.mm²/mm**	**Shear N/mm**	**Stress ratio**	**EIb ratio**	**Shear ratio**	**Plating comply**	**Core comply**
Bottom Panel 1	3052 , 5363	4.646 , 46.69	19.2 , 40.1	1.757	10.05	2.093	Yes	Yes
Bottom Panel 2	4818, 5363	7.095 , 46.69	29.1 , 40.1	1.113	6.582	1.379	Yes	Yes
Bottom Panel 3	5189 , 5363	7.679 , 46.69	31.3 , 40,1	1.034	6.082	1.281	Yes	Yes
Bottom Panel 4	3669 , 5363	4.267 , 46.69	29,2 , 40.1	1.462	10.94	1.372	Yes	Yes
Side Panel 1	2409 , 2480	3.008 , 19.25	18.5 , 29.7	1.030	6.402	1.607	Yes	Yes
Deck panel	1123 , 1124	2.186 , 6.588	5.1 , 18.7	1.001	3.014	3.681	Yes	Yes

Requirement/Offered BFRP (B)				Results BFRP (B)				
Label	**Mdb N.mm/mm**	**EIb N.mm²/mm**	**Shear N/mm**	**Stress ratio**	**EIb ratio**	**Shear ratio**	**Plating comply**	**Core comply**
Bottom Panel 1	3052 , 6984.6	4.646 , 45.84	19.2 , 41.7	2.288	9.867	2.175	Yes	Yes
Bottom Panel 2	4818, 6984.6	7.095 , 45.84	29.1 , 41.7	1.450	6.461	1.432	Yes	Yes
Bottom Panel 3	5189 , 6984.6	7.679 , 45.84	31.3 , 41.7	1.346	5.970	1.332	Yes	Yes
Bottom Panel 4	3669 , 6984.6	4.267 , 45.84	29,2 , 41.7	1.903	10.74	1.426	Yes	Yes
Side Panel 1	2409 , 3947.5	3.008 , 19.03	18.5 , 30.8	1.639	6.327	1.667	Yes	Yes
Deck panel	1123 , 1841.9	2.186 , 6.701	5.1 , 19.6	1.640	3.066	3.856	Yes	Yes

Requirement/Offered BFRP (C)	Results BFRP (C)

Label	Mdb N.mm/mm	EIb N.mm²/mm	Shear N/mm	Stress ratio	EIb ratio	Shear ratio	Plating comply	Core comply
Bottom Panel 1	3052 , 5191.8	4.646 , 33.579	19.2 , 39.9	1.701	7.228	2.085	Yes	Yes
Bottom Panel 2	4818, 5191.8	7.095 , 33.579	29.1 , 39.9	1.078	4.733	1.373	Yes	Yes
Bottom Panel 3	5189 , 5191.8	7.679 , 33.579	31.3 , 39.9	1.001	4.373	1.276	Yes	Yes
Bottom Panel 4	3669 , 5191.8	4.267 , 33.579	29,2 , 39.9	1.415	7.870	1.367	Yes	Yes
Side Panel 1	2409 , 2488.5	3.008 , 14.230	18.5 , 30.0	1.033	4.731	1.621	Yes	Yes
Deck panel	1123 , 1295.9	2.186 , 4.976	5.1 , 18.7	1.154	2.277	3.686	Yes	Yes

BFRP B structure is stronger than GFRP A because if's offer lower value on the bending stress, but it has more weight. It is not the best choice to be chosen for the structure arrangement. BFRP C on the other hand offers a lighter structure than BFRP B in all panel and has the same strength as GFRP A; it is therefore the be the best choice. However after the use of fibre is reduced in BFRP C, there is a need to do verify the process to see if it is compliant with lamina failure theory.

4.6.4 Tsai-Wu failure analysis

The verification process has been done using the Ansys software [26] by modelling symmetry plate in the bottom, side, and deck. Unidirectional Basalt fibre was assumed as orthotropic material while balsa core, CSM and woven roving of E-glass were assumed as isotropic material. The boundary condition applied is fixed support at 2 edges, and a symmetry boundary condition in other edges. The design pressures used are those of the ISO standard, presented earlier in **Table 33**. For the meshing process, the mesh was done by using quad4. To get the convergence result, several meshes have been tried, and the quality of meshes have been checked. For example in the bottom panel, the final simulation comprises 2741 nodes with 2630 element. The quality of the mesh can be seen in **Figure 26**. An element with a value near 1 indicates the good element. If the mesh in structure shows many elements with values near one, it indicates the structure will have less error in numerical calculation.

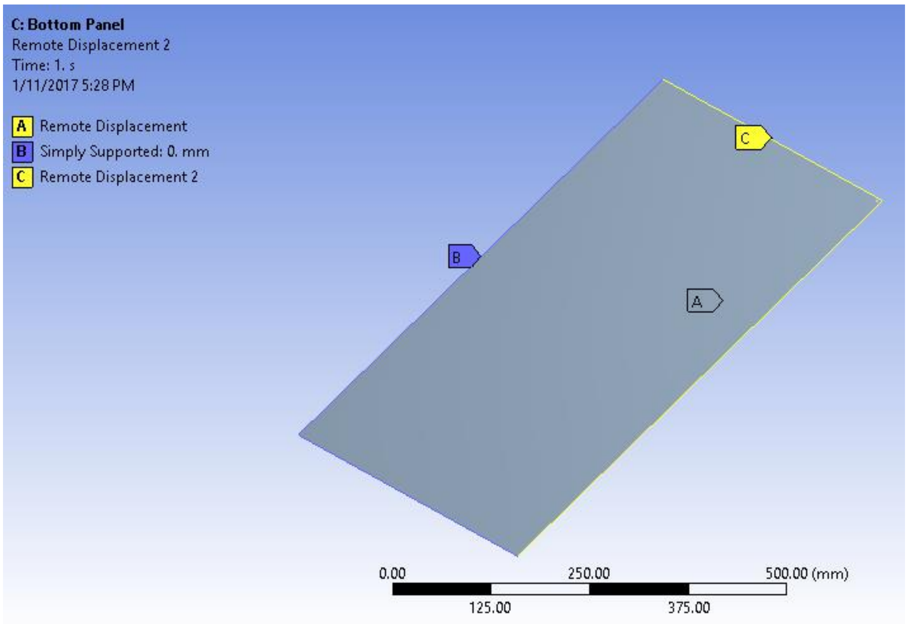


Figure 25 Boundary condition

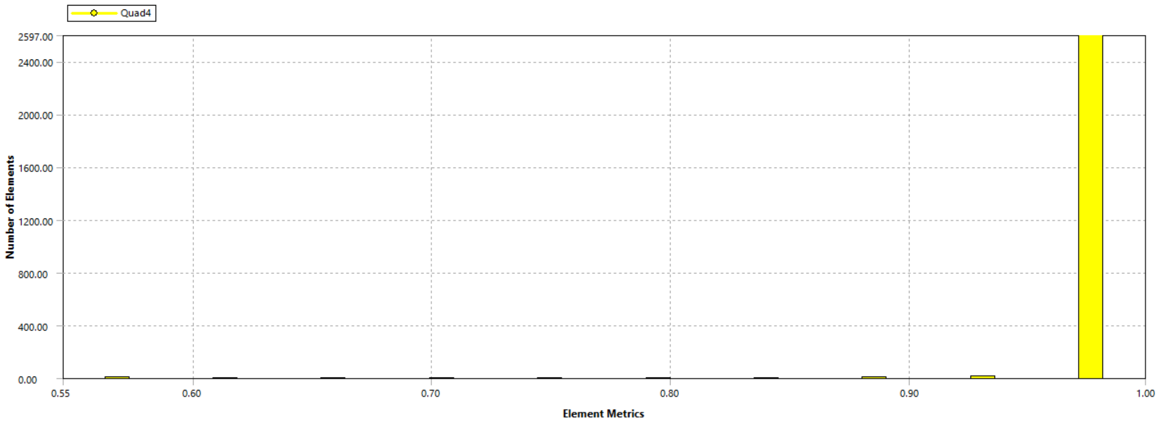


Figure 26 Mesh metric

To have a safe design, the composite material should be checked with a material failure criteria. In real application the failure theory in the structures should be validate by an experiment. Moreover, laminate strength is related to the strength of each lamina. If there is a failure in a lamina, then the composite is failed. In this study Tsai-Wu failure criteria has been appointed for the failure analysis of the hull laminate.

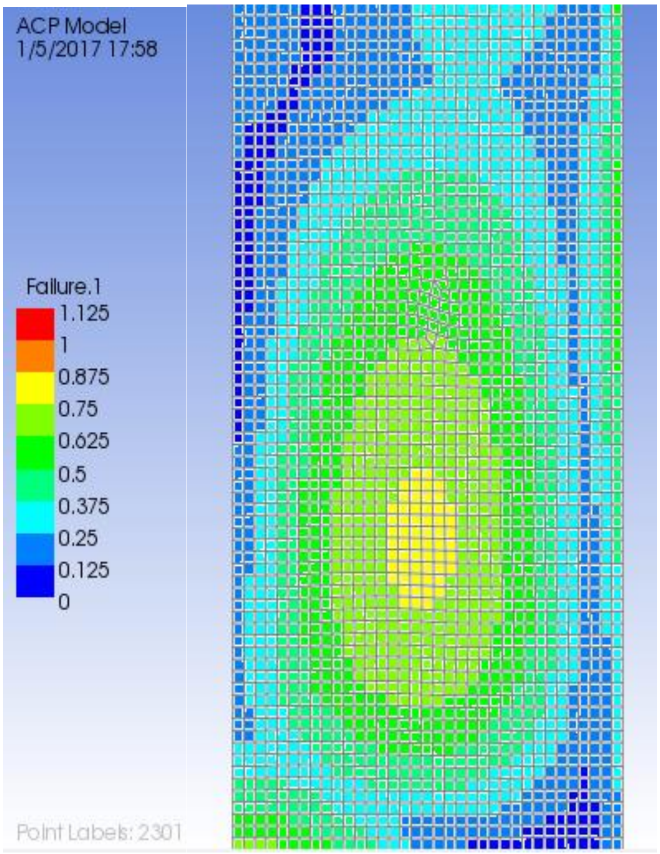


Figure 27 Failure analysis in Bottom structure

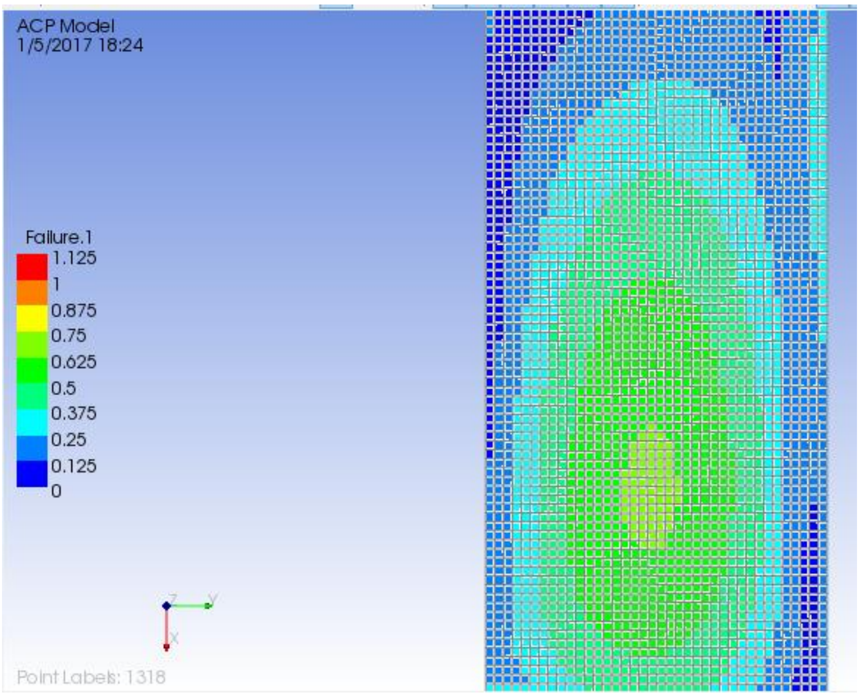


Figure 28 Failure analysis in Side structure

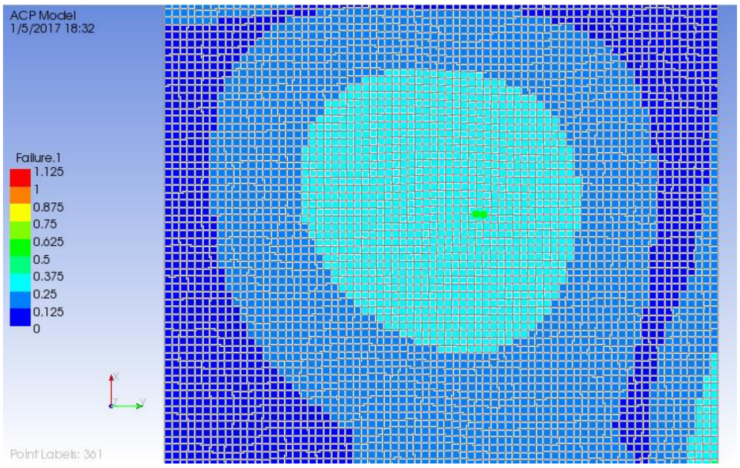


Figure 29 Failure analysis in deck structure

From all parts of the ship's structure, it can be seen clearly if all structures do not have value more than 1. For example in the bottom panel, from the experiment, it can be known if the tensile strength of lamina in the fibre direction towards 90^0 then 45^0 is the weakest. Tsai-Wu criteria not only take into account the strength of the lamina in the longitudinal direction but also in the transversal direction of the fibres. It can conclude if fibre direction 45^0 becomes the weakest layer because it has the same tensile strength in longitudinal and transverse directions. Besides that the first layer also becomes the weakest part because the influence of its position which very first to receive the load. It can conclude the position and direction of the fibre layers affect the value of Tsai-Wu criteria. In case there is a failure of the structure, the way to fix the problem by increasing the layer and change orientation of fibre. The highest c criteria happen on bottom panel with value 0.6. From this simulation, it can be concluded if the new structure arrangement (BFRP C) with less fibre pass the ISO rules and Tsai-Wu failure criteria.

4.7 Weight Calculation

4.7.1 Lightship Weight

The lightship weight is the actual weight of a ship when the cargo and consumable are empty and not includes the crew. It includes the weight of structure, painting, furniture, all machinery, propulsion, mooring, piping, and electrical systems.

The yacht hull was designed using sandwich fibreglass composite. The thicknesses of the laminates are different in bottom, side, deck and superstructure, and also in the bulkheads (longitudinal and transversal). The weight of the laminates depends on the fibre content, density of fibre, fibre mass per area, resin content and total thickness. Using the Law of Mixture [3] for composite materials, the mass per area of fibre and resin was calculated by using following equation.

$$\rho_C = V_R\rho_R + V_F\rho_F \qquad \text{Eq 30}$$

Where: ρ_C, ρ_R and ρ_R are the density of the composite, of the resin and the fibre, respectively, in g/cm^3, and V_R and V_F are the volume contents of resin and fibre, respectively, in percentage. All calculations can be found in Appendix D. The centre of gravity (LCG, TCG, VCG) of the structure were taken from the maxsurf software [27].

All furniture in cabins, garage, cockpit, kitchen, living room, open leisure space, hallway, fly bridge, swimming deck were listed along with each item's weight and LCG, TCG, and VCG from the origin of the reference system (at aftmost part of the hull, centerline, baseline). The navigation system and lifesaving and safety equipment for prevention of fire is also included in the calculation. For some items such as the beds, toilets, doors and others the weights and sizes were based on commercial marine catalogues since they can differ from general house furniture.

One part of the lightweight is the mooring equipment. All yachts need to provide anchor and chain cable in line with Classification Society rules. The assigned number of anchors and length of the chain depends on the dynamic force endured by the yacht. Calculation of anchor and chain was based on Bureau Veritas's rules [28].

For a hull made of composite material, a gel coat layer should be applied to give watertight resistance to the laminate. Two layers of gel coat were applied, one on the outer side and 1 in the inner side. Besides gel coat, two layers of paint also have to be applied to the hull. In fibre composite, usually, the mechanical characteristic of gel coat and paint will be the same. The difference is usually only in colour. Gel coat sometimes has a transparent colour. The density of gel coat and paint was taken as 1056 kg/m^3, with the thickness of each layer of gel coat being 0.6mm, and of paint, 0.5mm. The paint was applied to all the structure except the bulkheads, which only need the gel coat.

In a preliminary design, there is no need for a detailed drawing of the piping system. Therefore we can only estimate the weight of this. There are some empirical formulations to estimate the total weight of machinery and piping, but in this case, it was decided not to use that method. The size of the pipe and the length which would cross the vessel was manually estimated. With the weight per meter of pipe, the total weight of piping was estimated. After summing, all the values, the total weight of lightship using GFRP is 26568 Kg, and BFRP is 26063 Kg. It indicates a 504 Kg lighter structure cab be achieved with basalt fibre.

4.7.2 Deadweight

The deadweight is the weight of cargo including the people, the consumables, fresh water, and fuel. The weight of fresh water and fuel was presented in **Table 27**. For consumable, the weight will depend on the number of passenger and crew. The designed yacht has the maximum capability to bring four passengers and two crew members. The very conservative assumption made is that one person has a weight of 100 kg. In total, the weight of people is of 600kg. Each person is assumed to bring luggage of around 65kg, and the food assumed each person was taken as 7.8kg/day. With a maximum sailing journey of 12 days, the total weight of consumables was calculated as 560 Kg. After calculating the lightweight and the deadweight the displacement and the centre of gravity the sailing yacht can be seen in **Table 35**

Table 35 – Displacement

Item	GFRP	BFRP
Lightship (Kg)	**26,568**	**26,063**
Deadweight (Kg)	**7,574**	**7.574**
Displacement (Kg)	**32,628**	**32,123**
LCG (m)	**10.47**	**10.48**
TCG (m)	**-0.01**	**-0.01**
VCG (m)	**3.03**	**3.02**
Th (m)	**4.115**	**4.110**

The displacement of BFRP yachts lighter than the GFRP by 1.9%. It causes a waterline reduction of only 5 mm. Since there is no significant difference in weight and waterline, the power and stability calculation will only be performed one time for the GFRP structures.

4.8 Electrical Load Balance

In order to determine the power requirement for the vessel, there is a need to calculate the power consumption for each electrical appliance. For every electrical appliance, the designer needs to define the power rating or the load factor for a 24-hour period. High rating leads to increased costs of equipment and maintenance. Too low rating affects the normal operation condition and reduces the comfortability. The procedure to calculate electrical load balance was as follows:

4.8.1 Electrical Load list

From the General Arrangement, every electrical appliance was listed. It includes all lighting system, sensor systems, all sockets, entertaining devices, all pumps, HVAC systems, navigation systems, cooking appliances, and all pneumatic systems.

4.8.2 Load Data

For each electrical appliance that is already listed, the manufacturer's data was collected to assess the power (kW). It is also crucial to know the max load data in every extreme condition (temperature, humidity.).

4.8.3 Load Cases

Several load conditions need to be considered. The load cases are:

a. Harbour

   In harbor, the yacht can get the electrical source from onshore, and some items will totally off. Some items like normal lighting, pumps will be on but not 100% since usually the guest will not stay in yacht but enjoying the island.

b. Manoeuvring

   The first time maneuvering, some appliance like cooking appliances, garage appliance will be off. This condition actually will have load result not far from a sailing condition.

c. Sailing

   When sailing all machinery systems and home appliances will be on. The load result will be maximum during this load case. Not like in the harbor, the vessel will need the generator system to cover all electrical load.

d. Emergency

   During emergency only emergency light, navigation system, and some pump will go on. The heating or cooling and lighting system in the rooms will be totally off.

Since this is a cruising yacht, the presence of guest will much affect the use of electrical.

4.8.4 Load Factor

Load power can be used to calculate the 24-hour average load use. For each load in the electrical load list, the load factor becomes a combination of temperature/relative humidity and operating condition. For electrical appliance which seldom uses, the load factorhas small value. Electrical appliances which have higher operating load should have big value. The range of load factor from 0 until 1. Detailed calculation of Electrical load balance for every case can be found in Appendix E. In summary, the power requirement for every load condition can be seen in Table

36. Based on the calculation, in the sailing condition, the ship will have a maximum normal power consumption of 36.6 kW and emergency consumption of 4.00 kW. For normal condition, the electrical power will be delivered by the two generators. The batteries will be needed during an emergency situation. The additional assumption parameter is that batteries should be capable of handling the power consumption for 5 hours.

Table 36 Summary of Electrical Load Balance

Load Case	Condition	Total (kW)	Generator	Battery
Harbor	Crew	10.08	2x20 kW/60 Hz, ONAN MDDCL (1734x822x994 mm) 422 Kg,	-
	Crew+Guests	16.89		
Maneuvering	Crew	21.41		
	Crew+Guests	32.63		
Sailing	Crew	22.97		
	Crew+Guests	**36.60**		
Emergency		4.02	-	1x7 kVA/5 kW EATON UPS RK340AA0A0 (482x406x66675mm), 263 Kg

4.9 Propulsion systems

For propulsion systems besides the sail set, the vessel also features a propeller and engine. The onboard engine will help the boat to leave the marina and as an emergency power when there is no wind. The propeller and the onboard engine will be chosen after calculation of total resistance. The wageningen B-series is then used to find the perfect propeller dimensions.

4.9.1 Resistance Calculation

The resistance of the sailboat was performed using Delft series, which is an empirical methods that investigated over 80 models and developed regression equations to assess hydrodynamics force acting on a sailing boat [29]. There is a number of software which offers the capability to calculate the resistance use Delft series method such as maxsurf, and wind VPP (velocity prediction program). To compare the calculation three types of calculation has been used. First, calculation using Win VPP. In win VPP the resistance calculation includes hull and the appendages. Secondly, a manual calculation based on Delft series [29]. Thirdly, resistance calculation using maxsurf. In maxsurf, only the hull resistance was calculated, the appendages resistance was added manually using the Delft series formulation. The result can be seen in figure 29. From Win VPP Tthe maximum resistance of the boat at 18 Knot is 30.82 kN. From the three results, it can be seen that resistance from maxsurf has smalle value than win VPP, it is because, the air draf has not been takn into account" [30].

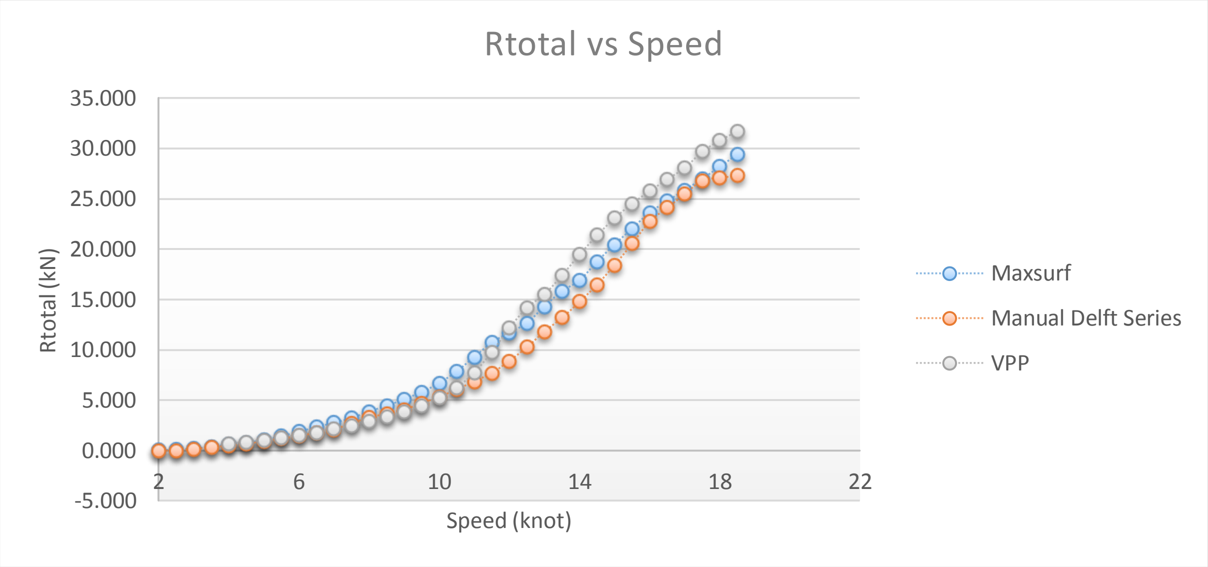


Figure 30 Resistance curve

4.9.2 Propeller and engine selection

A good propeller will produce thrust, require lower power from the engine, and minimised the cavitation. To find the best propeller with the highest efficiency the Wageningen-B-series method is used [31]. The sailing yacht supposed to have a single propeller with 3 blades (Z). The diameter of the propeller can be found by measure the distance between centres of the immersed shaft and hull and between the propeller and hull. After measurement process, it is found that the propeller diameter is 0.75 m with a shaft immersion depth of 2.3 m. By taking into account the wake factor (k) as 0.2, Atmospheric Pressure as $\rho_{atm} = 105000\ Pa$, and a Vapor pressure $\rho_v = 1700\ Pa$ the minimum expanded area ratio (EAR) can be calculated by using eq 32.

$$EAR = \frac{A_E}{A_O} = \frac{(1.3+0.3Z)T}{(\rho_O-\rho_v)D^2} + k \qquad \text{Eq 31}$$

The value of EAR is 1.06 but the B-series with EAR 1.05 value is used since the highest EAR for three blades in Wageningen-B-series is 1.05. To find the propeller from B-series, a curve based on dimensionless value as presented in eq 32 is made. The intersection of the curve with the Thrust coefficient (KT), advance coefficient (J), torques coeffcient (KQ), and propeller efficiency (η_o) in every pitch will lead to the propeller rotation, torque power, and propeller power. The red curve based on $K_T = 0.84\,J^2$ can be seen in **Figure 31**. Wherever the function touch K_T in each P/D it will become the value of K_T, J, K_Q and η_o.

$$\frac{K_T}{J^2} = \frac{T}{\rho V^2 D^2} \qquad \text{Eq 32}$$

$$J = \frac{V_A}{J\,D\,n} \qquad \text{Eq 33}$$

$$K_Q = \frac{Q}{\rho n^2 D^5} \qquad \text{Eq 34}$$

$$P_D = \frac{2\,\pi\,n\,Q}{1000} \qquad \text{Eq 35}$$

From the curve, the intersection in each pitch can be found as seen in **Table 37**. The value shows the high efficiency can be achieved is 0.61 and it is in pitch/diameter value 1.4.

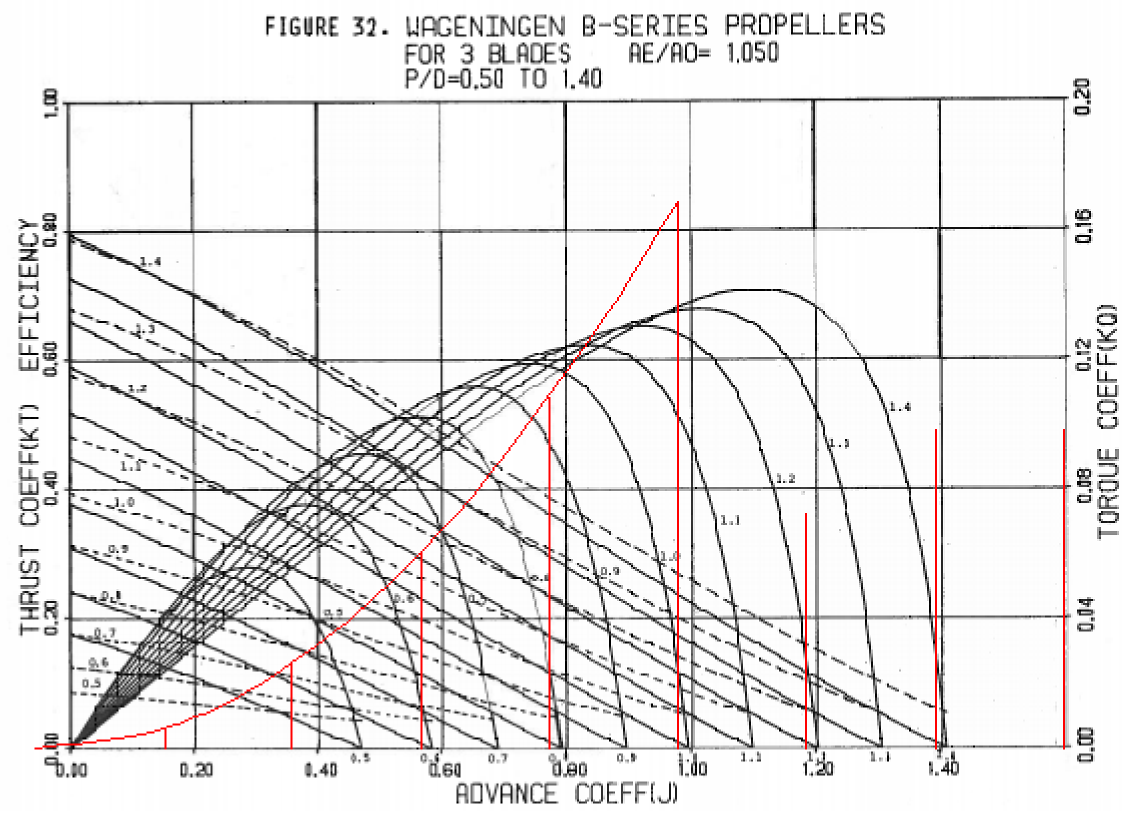


Figure 31 B-Series propeller for three blades, EAR=1.05 [31]

By using equation 33-35, the propeller rotation value is found to be 14.35 rps or 862 rpm. With torque value of 3797.62 N.m and a power to be delivered of 342.81 kW.

Table 37 Intersection B-series propeller with dimensionless function

P/D	J	KT	KQ	η_o
0.5	0.2974	0.096	0.01198	0.2183
0.6	0.3535	0.1015	0.015	0.3739
0.7	0.4053	0.1359	0.01974	0.4394
0.8	0.4512	0.1697	0.02578	0.4749
0.9	0.4945	0.2047	0.03308	0.4947

1	0.5359	0.2445	0.04124	0.5108
1.1	0.5781	0.2814	0.05112	0.512
1.2	0.6159	0.3204	0.06164	0.5152
1.3	0.6552	0.3639	0.06478	0.5888
1.4	0.7639	0.38	0.07564	0.61

The power that should be delivered by the engine is quite high, this is because the engine for cruise sailing yacht can reach a speed of 18 knot. This choice is taken for safety reason. Indeed this choice will increase weight, price, tank capacity for the engine, and fuel consumption. Analysing the optimise propulsion system will take a long time and computation cost. Therefore the engine selection will base on the power needed by the propeller. An engine from Cummin with power 350 kW, type QSB6.7 has been selected. This engine has weight a 658 Kg with length 1263.8 mm, breadth 748 mm, and height 857 mm.

4.10 Stability

The hydrostatic for the vessel at presented in **Table 38**. The hydrostatic and stability calculation were performed with the naval architecture software Maxsurf v.20.0 [27].

Table 38 Hydrostatic at design draft

Displacement t	33.44
Heel deg	0
Draft at FP (m)	3.9
Draft at AP (m)	3.9
Trim (+ve by stern) m	0
WL Length (m)	22.946
Wetted (Area m^2)	109.294
Waterpl. (Area m^2)	91.462
Prismatic coeff. (Cp)	0.522
Max Sect. Area coeff. (Cm)	0.134
Waterpl. Area coeff. (Cwp)	0.734
LCB from zero pt. (+ve fwd) (m)	9.961
LCF from zero pt. (+ve fwd) (m)	9.306
KB (m)	3.632
BMt (m)	5.182
BML (m)	86.298
KMt (m)	8.814
KML (m)	89.93
Immersion (TPc) (tonne/cm)	0.937

To check the stability of the yacht in several loading conditions, different cruising scenarios have been considered. Three conditions were considered, full load (100% condition), half load (50%), and empty load (10%). From departure to arrival condition, water tank weight switch into the gray and black water. The equilibrium found between the buoyancy and the weight for each loading condition as shown in **Table 39**.

The larger angle intact stability was calculated using heel angles from 0^0 to 140^0 with 10^0 step. As a result, the GZ curve for the three loading conditions can be seen in **Error! Reference ource not found.**.

Table 39 Equilibrium of Yacht

	100%	50%	10%
Displacement (t)	33.44	29.96	29
Heel (deg)	-0.2	-0.2	-0.2
Draft at FP (m)	3.84	3.84	3.843
Draft at AP (m)	3.84	3.84	3.843
Draft at LCF (m)	3.891	3.862	3.851
Trim angle (+ve by stern) (deg)	0	0	0

The curve show that the displacement plays an important part in stability, in lighter yacht condition the righting moment arm is smaller than the heavier one. It means the boat will more stable in 100% condition than in 10% condition. However, the stability of yacht in all circumstances should comply with ISO 12217-2:2015.

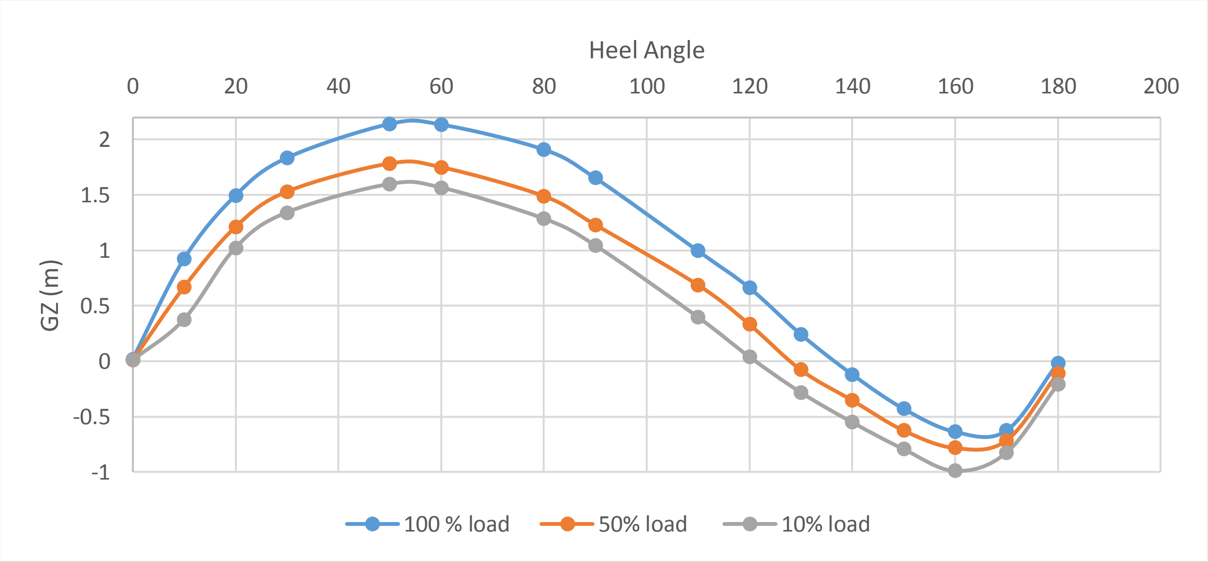


Figure 32 GZ curves for all loading conditions

One of the criteria is the angle of vanishing stability. Yacht should have an angle of vanishing stability greater than 130^0. In 100% condition, the angle of vanishing stability is 136.6^0. The other important criteria is the stability index or STIX, which takes into account of the dimension of the yacht, the angle of vanishing stability, down flooding, and other things related to stability. For this category A cruising yacht, the STIX value should be larger than 32. Other stability criteria can be seen in Appendix F. All ISO 12217 appear to be satisfied, this mean the yacht is safe and stable in all cruising conditions.

4.11 Velocity Prediction

To see the performance of the sailing yacht in every wind direction, a velocity prediction using Win VPP software was performed. The performance was evaluate based on the hydrodynamic forces of the hull and the appendages at full load. The polar plot from WinVPP shows the best speed of the boat based on the wind angle and wind speed. The polar plot will help the skipper pointing the sail to specific wind angle to get the desired speed. From WinVPP predict the boat speed can reach up to 11.55 knot in the calm sea (the wind speed about 10 knots) and even 20 knots in the strong wind.

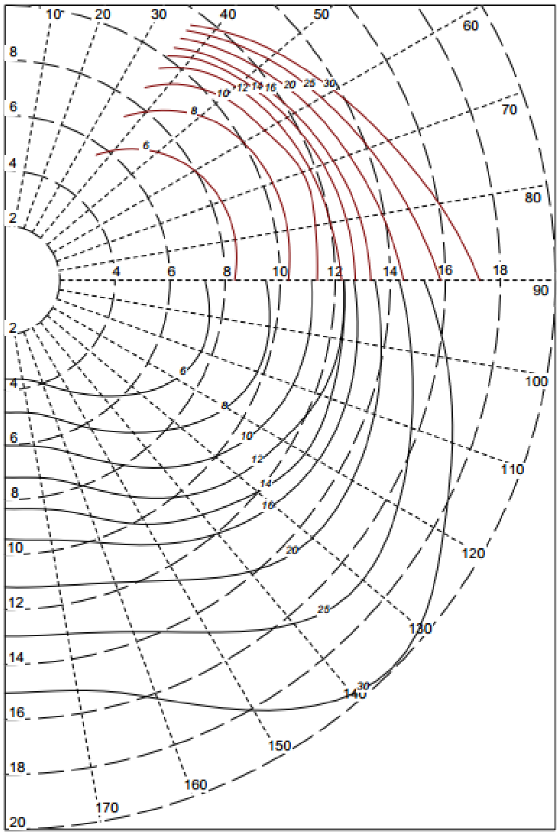


Figure 33 Boatspeed and leeway prediction from WinVPP

Beside the boat speed, WinVPP also predicts the leeway angle, number of reefs, and sail flatness. The current prediction, the maximum leeway angle of the boat is 4^0. It indicates the boat manoeuvring system is very efficient. Detail of the VPP results can be seen in Appendix F.

5. BASALT and GLASS FIBRES HULL COMPARISON

After getting the material characteristics and assessing the applications to a cruising yacht, the next step is an evaluation of both materials to select the most suitable. There are many approaches to select materials. One of them is multiple attribute decision making (MADM). Rao and Patel [32] proposed a MADM method which considers the objective and subjective weight of attributes for the decision maker. Objective weight attributes have quantitative data which can be used to compare the value among other objects. There is no a qualitative data for the subjective weight of attribute. Hence there is a need to change subjective weight to qualitative data so it is measurable. In MADM method, Rao and Patel [32] proposed 11 point scale fuzzy set theory logic to describe the subjective weight attribute. The qualitative value from fuzzy logic for subjective attribute is shown in Table 40.

Table 40 Values of subjective attribute [32]

Qualitative measures of selection attribute	**Fuzzy number**	**Assigned crisp score**
Exceptionally low	M_1	0.0455
Extremely low	M_2	0.1364
Very low	M_3	0.2273
Low	M_4	0.3182
Below Average	M_5	0.4091
Average	M_6	0.5000
Above Average	M_7	0.5909
High	M_8	0.6818
Very High	M_9	0.7727
Extremely High	M_{10}	0.8636
Exceptionally High	M_{11}	0.9545

The attributes taken into account for the comparison of materials will depend on the function of the object itself. For cruising yacht the structure should be light, strong and require high stability. Considering the matter, the attributes which will use for material ranking are Young Modulus (YM), Tensile Strength (TS), Flexural Strength (FS), Density (D), Weight Saving (W), Cost (C), Reduction of Resistance (R), and sustainability (ST). The first four attributes are quantitative the rest are qualitative attributes. Qualitative attributes converted to quantitative attributes by using the fuzzy scale in **Table 40**.

Table 41 Properties of GFRP and BFRP

Material	YM	TS	FS	D	W	C	R	ST
GFRP	11.10	632.62	499.97	2500	0	8.32	0	M3(0.2273)
BFRP	18.97	770.73	562.66	2600	M2(0.1364)	15	M2(0.1364)	M8(0.6818)

The properties of each material in **Table 41** show different units. Therefore normalisation is needed for all properties by using eq 37. After normalisation the next step is to determine the weight of the attributes by calculating the variance ($\boldsymbol{V_j}$) and weight attributes ($\boldsymbol{w_j^0}$) .

$$X_{ij}^{*} = X_{ij} / \sum_{i=1}^{n} X_{ij} \qquad \text{Eq 36}$$

$$V_j = (\frac{1}{n}) / \sum_{i=1}^{n} (X_{ij}^{*} - (X_{ij}^{*})_{mean})^2 \qquad \text{Eq 37}$$

$$w_j^0 = V_j / \sum_{i=1}^{m} V_j \qquad \text{Eq 38}$$

Table 42 Normalization, variance of material

Material	YM	TS	FS	D	W	C	R	ST
GFRP	0.369	0.451	0.471	0.490	0.000	0.357	0.000	0.250
BFRP	0.631	0.549	0.529	0.510	1.000	0.643	1.000	0.750
Variance	0.0171	0.0024	0.0009	0.0001	0.2500	0.0205	0.2500	0.0625
$\boldsymbol{w_j^0}$	0.0284	0.0040	0.0014	0.0002	0.4142	0.0340	0.4142	0.1035

After finding the weight attributes for all properties, the next step is to evaluate overall performance score by calculating the preference index. The preference index ($\boldsymbol{P_i^0}$) is calculated based on beneficial and non-beneficial attributes. YM, TS, FS, C, and ST are beneficial attributes, while others are non-beneficial. For beneficial attributes, the comparison is made between its material attribute value divide the maximum attribute value. Whilst for non-beneficial attributes the comparison is made between the minimum attribute and its attribute value.

$$P_i^0 = \sum_{j=1}^{m} w_j^0 X_{ij}^{**} \qquad \text{Eq 39}$$

Table 43 preference index

Material	**YM**	**TS**	**FS**	**D**	**W**	**C**	**R**	**ST**	$\boldsymbol{P_i^0}$	**Rank**
GFRP	0.01660	0.00329	0.00128	0.00016	0.00000	0.03399	0.00000	0.03452	0.0898	2
BFRP	0.02838	0.00401	0.00144	0.00015	0.00000	0.01885	0.00000	0.10354	0.1564	1

From the preference index calculation it can be seen that BFRP occupies the first position or the best material. The BFRP cost per kilogram is higher than E-glass but similar to S-glass.

From rough calculation on the raw materials of the hull, the BFRP hull will cost around EUR 44,557 while GFRP hull will cost EUR 41,355. Although the use of fibre is reduce but the use of resin is increased so the price of BFRP hull is higher than GFRP hull. However, the gap on the price is not a big thing compare to the other advantages of BFRP.

In term of structure, BFRP offered higher value in tensile strength, flexural strength, and the young modulus. This has been proved by destructive test and also composite failure criteria using finite element method. In term of its application to a sailing yacht, there is no significant changes in weight, resistance, and stability. It is because the density of BFRP is higher than GFRP. Even though there are significant reduction in the number of layer of BFRP, it does not make a drastic reduction in lightweight. Besides, the reduction on number of layers will make the boat faster to build. There is not huge difference

However, in term of sustainability, basalt fibre has the most advantages compared glass fibre. Basalt fibre comes from renewable material, and it can be 100% recycled and reused and during production basalt fibre also require less energy than glass fibre [4]. Its means basalt fibre will bring less damage to the environment than glass fibre and the Yacht industry can start to use more sustainable and environmentally friendly material to save the planet. Change the GFRP material into BFRP will not bring huge changes into design process, therefore many yards could easily change to basalt fibre.

6. Conclusion and Recommendations

From the research it can be concluded if that basalt offered a reliable and sustainable material for yacht industrial application. Basalt fibre reinforced plastic (BFRP) offers more advantages than glass fibre reinforced plastic (GFRP) as proven with the mechanical testing. BFRP has a higher value in tensile, flexural, and compression strength even though BFRP has a lower fibre content than GFRP. BFRP tensile strength and Young modulus result is 17.92%, and 41.5% higher than GFRP. However, the fibre weight fraction of BFRP panel in this experiment is less than GFRP panel; this affected the young modulus value especially the flexural modulus. The flexural modulus of GFRP is higher up to 42% than BFRP. In accordance with the composite mixture theory if fibre weight content of BFRP equal or more than GFRP, the flexural modulus of BFRP might be higher than GFRP.

In term of its application to 24m sailing yacht, a proper preliminary design has been performed to study the comparison of GFRP and BFRP. Because of BFRP stronger than GFRP, the number of basalt fibre layers can be reduced and still passed small craft regulation; ISO 12215-5. From this research it was also found what the minimum number of basalt fibre layer which should apply in the hull. Indeed, using less of fibre leads to a reduction of structural weight, 1.9% in this case.

The most significant advantages of BFRP is in sustainable term. Basalt fibre comes from a renewable source which 100% recyclable, and reusable. Basalt fibre also more safety for the environment and worker than GFRP. The only disadvantage of basalt fibre is the price. The price is higher than E-glass but equal to S-glass. However, from all attributes comparison using multiple attribute decision making (MADM), it shows Basalt fibre is superior to GFRP for designed cruising yacht.

Certainly, further research for BFRP and GFRP should be done in the future. It is recommended to have a mechanical test with same mass and fibre content on the panel. It is also highly recommended to create the composite panel in the same place, so it will minimise the different working condition that will lead to high different mass content. It would be better if the number of samples is increased so the standard deviation of the value is smaller. The other important aspect is to test the BFRP in different type and size of craft before it can be concluded if the BFRP better than GFRP. Indeed basalt fibre is a tough, reliable and sustainable material, and it has a significant potential in becoming the primary material in the small craft boatbuilding industry.

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Appendix A: Destructive Test Results

Tensile test

Type UD_Eglass/Bto Epoxy
Orientation 0

Spesimen	Thickness (mm)	Width (mm)	Area (mm^2)	Maximum Load (N)	Deflection at max load (mm)	Load at yield point (N)	Deflection at yield point (mm)	UTS (Mpa)	Yield stress(Mpa)	Strain 1	Strain 2	Stress 1 (Mpa)	Stress 2 (Mpa)	Tensile Modulus (GPa)
A1	0.97	14.82	14.3754	11294	7.7152	9786	6.630	785.648	680.746	0.001	0.003	9.391	55.651	23.130
A2	0.95	14.85	14.1075	10741	7.4388	10570	6.810	761.368	749.247	0.001	0.003	0.709	38.278	18.784
A3	1.03	14.69	15.1307	10828	7.1559	10220	6.650	715.631	675.448	0.001	0.003	9.649	38.994	14.672
A4	0.97	14.97	14.5209	11147	7.2294	10860	7.030	767.652	747.888	0.001	0.003	9.366	41.320	15.977
A5	0.87	14.65	12.7455	10775	7.2254	10460	6.750	845.396	820.682	0.001	0.003	10.200	45.820	17.810
A6	0.95	14.94	14.193	10626	6.9219	10600	7.600	748.679	746.847	0.001	0.003	9.441	56.366	23.462
Average	0.957	14.820	14.179	10901.833	7.281	10416.000	6.912	770.729	736.810	0.001	0.003	8.126	46.071	18.973
Std. Deviation	0.052	0.129	0.790	259.766	0.270	372.011	0.367	43.398	53.518	0.000	0.000	3.647	8.139	3.641

Type UD_Eglass/Bto Epoxy
Orientation +/-45

Spesimen	Thickness (mm)	Width (mm)	Area (mm^2)	Maximum Load (N)	Deflection at max load (mm)	UTS (Mpa)	Strain 1	Strain 2	Stress 1 (Mpa)	Stress 2 (Mpa)	Tensile Modulus (GPa)
B1	1.340	14.970	20.060	1467.800	9.700	73.171	0.001	0.003	2.707	11.067	4.180
B2	1.350	14.820	20.007	1482.400	8.960	74.094	0.001	0.003	3.024	14.995	5.985
B3	1.420	15.190	21.570	1681.900	11.768	77.975	0.001	0.003	2.911	12.518	4.803
B4	1.540	15.010	23.115	1570.500	10.275	67.942	0.001	0.003	2.358	10.815	4.229
B5	1.480	15.150	22.422	1642.100	12.883	73.236	0.001	0.003	2.761	12.488	4.864
B6	1.300	15.140	19.682	1665.200	11.900	84.605	0.001	0.003	3.490	14.226	5.368

Average	1.405	15.047	21.143	1584.983	10.914	75.171	0.001	0.003	2.875	12.685	4.905
Std. Deviation	0.092	0.140	1.436	93.333	1.502	5.622	0.000	0.000	0.377	1.667	0.689

Type UD_Eglass/Bto Epoxy

Orientation 90

Spesimen	Thickness (mm)	Width (mm)	Area (mm^2)	Maximum Load (N)	Deflection at max load (mm)	UTS (Mpa)	Strain 1	Strain 2	Stress 1 (Mpa)	Stress 2 (Mpa)	Tensile Modulus (GPa)
C1	2.040	24.950	50.898	642.720	0.460	12.628	0.0005	0.0025	2.725	10.217	3.746
C2	2.030	25.010	50.770	742.210	0.648	14.619	0.0005	0.0025	2.423	9.257	3.417
C3	2.090	24.990	52.229	850.540	0.860	16.285	0.0005	0.0025	2.455	8.080	2.813
C4	2.070	24.930	51.605	775.300	1.000	15.024	0.0005	0.0025	1.149	3.159	1.005
C5	2.060	24.910	51.315	799.550	0.920	15.581	0.0005	0.0025	0.359	6.158	2.900
C6	2.030	24.930	50.608	963.680	0.940	19.042	0.0005	0.0025	0.405	4.110	1.852
Average	2.053	24.953	51.238	795.667	0.805	15.530	0.001	0.003	1.586	6.830	2.622
Std. Deviation	0.024	0.039	0.609	107.629	0.208	2.117	0.000	0.000	1.081	2.837	1.021

Type UD_Basalt/Bto Epoxy

Orientation 0

Spesimen	Thickness (mm)	Width (mm)	Area (mm^2)	Maximum Load (N)	Deflection at max load (mm)	UTS (Mpa)	Strain 1	Strain 2	Stress 1 (Mpa)	Stress 2 (Mpa)	Tensile Modulus (GPa)
A2'	1.020	15.430	15.739	9331.200	10.783	592.886	0.001	0.003	7.383	33.726	13.171
A3'	1.100	15.370	16.907	12575.000	0.641	743.775	0.001	0.003	5.572	25.717	10.073
A4'	1.060	14.940	15.836	10638.000	8.656	671.744	0.001	0.003	6.864	32.419	12.778
A5'	1.100	14.880	16.368	9052.700	8.569	553.073	0.001	0.003	6.995	19.544	6.274
A6'	1.030	15.010	15.460	9301.500	11.158	601.638	0.001	0.003	7.503	33.919	13.208
Average	1.062	15.126	16.062	10179.680	7.961	632.623	0.001	0.003	6.863	29.065	11.101

Std. Deviation	0.038	0.255	0.576	1475.535	4.261	75.420	0.000	0.000	0.769	6.293	2.995

Type UD_Basalt/Bto Epoxy
Orientation +/-45

Spesimen	Thickness (mm)	Width (mm)	Area (mm^2)	Maximum Load (N)	Deflection at max load (mm)	UTS (Mpa)	Strain 1	Strain 2	Stress 1 (Mpa)	Stress 2 (Mpa)	Tensile Modulus (GPa)
B1'	1.12	15.04	16.8448	4777.7	4.5718	283.630557	0.0005	0.0025	2.986	13.915	5.465
B2'	1.17	15.31	17.9127	4926.2	2.4256	275.011584	0.0005	0.0025	2.808	13.337	5.264
B3'	1.13	14.57	16.4641	5056.7	4.4088	307.134918	0.0005	0.0025	3.790	18.039	7.125
B4'	1.13	14.57	16.4641	4486.5	6.4	272.501989	0.0005	0.0025	1.063	16.533	7.735
B5'	1.17	15.06	17.6202	4661.8	5.1389	264.571344	0.0005	0.0025	1.249	13.167	5.959
Average	1.144	14.910	17.061	4781.780	4.589	280.570	0.001	0.003	2.379	14.998	6.310
Std. Deviation	0.024	0.328	0.670	222.509	1.440	16.333	0.000	0.000	1.178	2.173	1.075

Type UD_Basalt/Bto Epoxy
Orientation 90

Spesimen	Thickness (mm)	Width (mm)	Area (mm^2)	Maximum Load (N)	Deflection at max load (mm)	UTS (Mpa)	Strain 1	Strain 2	Stress 1 (Mpa)	Stress 2 (Mpa)	Tensile Modulus (GPa)
C1	1.83	25.3	46.299	908.320	1.362	19.619	0.0005	0.0025	1.328	5.205	1.938
C2	1.82	24.9	45.318	1060.700	1.055	23.406	0.0005	0.0025	2.840	11.916	4.538
C3	1.83	25.6	46.848	936.530	1.140	19.991	0.0005	0.0025	1.185	4.290	1.553
C4	1.82	25.7	46.774	1000.100	0.849	21.382	0.0005	0.0025	0.494	10.027	4.767
C5	1.81	24.9	45.069	1058.500	1.426	23.486	0.0005	0.0025	1.427	5.503	2.038
Average	1.822	25.280	46.062	992.830	1.166	21.577	0.001	0.003	1.455	7.388	2.967

Std. Deviation	0.008	0.377	0.825	69.432	0.234	1.829	0.000	0.000	0.856	3.368	1.551

Flexural test

Type UD_Eglass/Bto Epoxy
Orientation 0

Spesimen	Thickness (mm)	Width (mm)	L,Span (mm)	Maximum Load (N)	UFS (Mpa)	Max strain	Flexural Modulus (GPa)
D1'	3.3	9.85	66.000	546.420	504.310	0.017	43.996
D2'	3.33	9.89	66.000	553.560	499.707	0.016	40.475
D3'	3.38	10.17	66.000	519.660	442.792	0.017	41.813
D4'	3.37	10.94	66.000	639.630	509.667	0.017	38.384
D5'	3.26	9.87	66.000	575.740	543.387	0.021	39.163
Averge	3.328	10.144	66.000	567.002	499.973	0.018	40.766
Std. Deviation	0.050	0.464	0.000	45.268	36.288	0.002	2.228

Type UD_Eglass/Bto Epoxy
Orientation +/-45

Spesimen	Thickness (mm)	Width (mm)	L,Span (mm)	Maximum Load (N)	UFS (Mpa)	Max strain	Flexural Modulus (GPa)
E1'	4	10.64	66.000	166.640	96.906	0.159	11,778
E2'	3.85	10.63	66.000	150.080	94.298	0.045	20.792
E3'	4.4	10.46	66.000	132.460	64.756	0.079	17.970
E4'	4.21	10.55	66.000	170.690	90.370	0.055	21.139
E5'	4.16	10.6	66.000	165.890	89.529	0.025	20.458

Averge	4.124	10.576	66.000	157.152	87.172	0.073	20.090
Std. Deviation	0.209	0.074	0.000	15.885	12.882	0.052	1.440

Type UD_E-glass/Bto Epoxy

Orientation 90

Spesimen	Thickness (mm)	Width (mm)	L,Span (mm)	Maximum Load (N)	UFS (Mpa)	Max strain	s1	s2	Stress at s1 (Mpa)	Stress at s2 (Mpa)	Flexural Modulus (GPa)
F1'	3.4	11	66.000	24.980	19.448	0.004	0.107	0.534	2.733	11.834	4.551
F2'	3.34	12.02	66.000	34.262	25.296	0.004	0.109	0.543	4.135	18.089	6.977
F3'	3.5	10.72	66.000	29.337	22.117	0.003	0.104	0.519	6.385	15.832	4.723
F4'	3.34	10.98	66.000	40.259	32.539	0.004	0.109	0.543	0.412	12.932	6.260
F5'	3.51	10.97	66.000	42.665	31.253	0.004	0.103	0.517	3.362	10.863	3.750
Averge	3.418	11.138	66.000	34.301	26.130	0.004	0.106	0.531	3.405	13.910	5.252
Std. Deviation	0.083	0.506	0.000	7.365	5.674	0.001	0.003	0.013	2.169	2.988	1.325

Type UD_Basalt/Bto Epoxy

Orientation 0

Spesimen	Thickness (mm)	Width (mm)	L,Span (mm)	Maximum Load (N)	UFS (Mpa)	Max strain	Flexural Modulus (GPa)
D1	4.110	9.950	66.000	975.760	574.740	0.027	29.918
D2	3.800	9.630	66.000	710.310	505.696	0.025	25.532
D3	4.020	9.720	66.000	873.570	550.573	0.025	29.234
D4	3.900	9.750	66.000	922.360	615.746	0.028	29.638
D5	3.820	9.700	66.000	775.620	542.483	0.024	28.301
D6	3.900	9.800	66.000	883.370	586.709	0.025	28.949
Average	3.925	9.758	66.000	856.832	562.658	0.026	28.595

Std. Deviation	0.119	0.109	0.000	97.454	38.316	0.001	1.603

Type UD_Basalt/Bto Epoxy

Orientation +/-45

Spesimen	Thickness (mm)	Width (mm)	L,Span (mm)	Maximum Load (N)	UFS (Mpa)	Max strain	Flexural Modulus (GPa)
E1	3.81	10.09	66	172.040	116.285	0.051	9.999
E2	3.91	10.16	66	204.440	130.303	0.070	9.151
E3	3.96	10.05	66	202.870	127.437	0.065	6.613
E4	3.8	10.07	66	201.730	137.344	0.049	12.826
E5	3.91	10.12	66	203.830	130.428	0.049	13.878
E6	3.87	10.18	66	212.030	137.677	0.052	10.299
Average	3.877	10.112	66.000	199.490	129.912	0.056	10.461
Std. Deviation	0.063	0.051	0.000	13.932	7.846	0.009	2.609

Type UD_Basalt/Bto Epoxy

Orientation 90

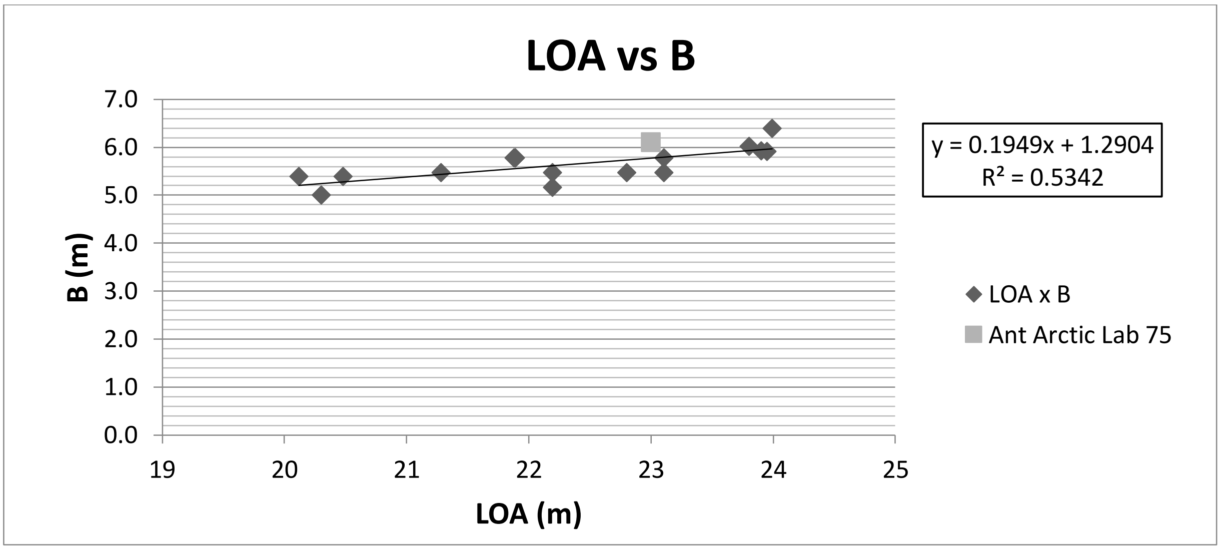
Spesimen	Thickness (mm)	Width (mm)	L,Span (mm)	Maximum Load (N)	UFS (Mpa)	Max strain	s1	s2	Stress at s1 (Mpa)	Stress at s2 (Mpa)	Flexural Modulus (GPa)
F1	3.91	9.72	66	25.727	17.140	0.009	0.093	0.464	2.005	7.928	2.961
F2	3.98	9.71	66	65.221	41.980	0.009	0.091	0.456	1.023	7.659	3.318
F3	3.91	9.7	66	26.371	17.605	0.009	0.093	0.464	0.000	7.343	3.672
F4	3.8	9.8	66	63.358	44.324	0.007	0.096	0.478	1.644	14.761	6.559
F5	3.97	9.71	66	62.992	40.749	0.008	0.091	0.457	7.646	12.356	2.355
F6	3.81	9.71	66	67.733	47.574	0.008	0.095	0.476	0.253	11.238	5.493
F7	3.85	9.8	66	58.507	39.875	0.006	0.094	0.471	4.587	16.561	5.987

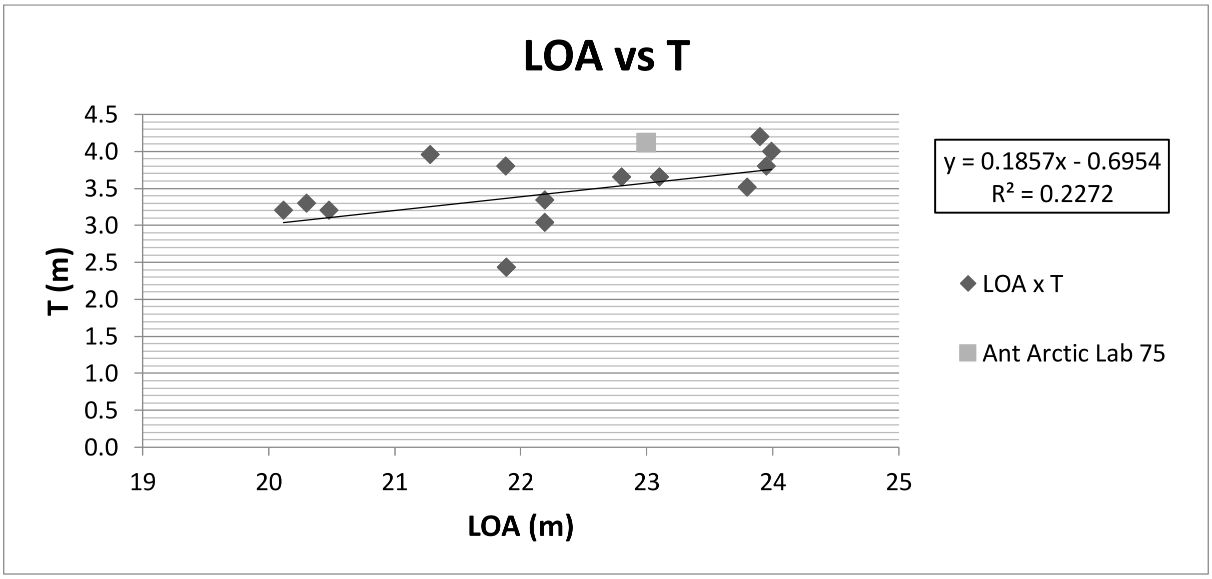
Average	3.890	9.736	66.000	52.844	35.607	0.008	0.093	0.466	2.095	10.214	4.059
Std. Deviation	0.072	0.044	0.000	18.514	12.712	0.001	0.002	0.009	2.747	3.670	1.648

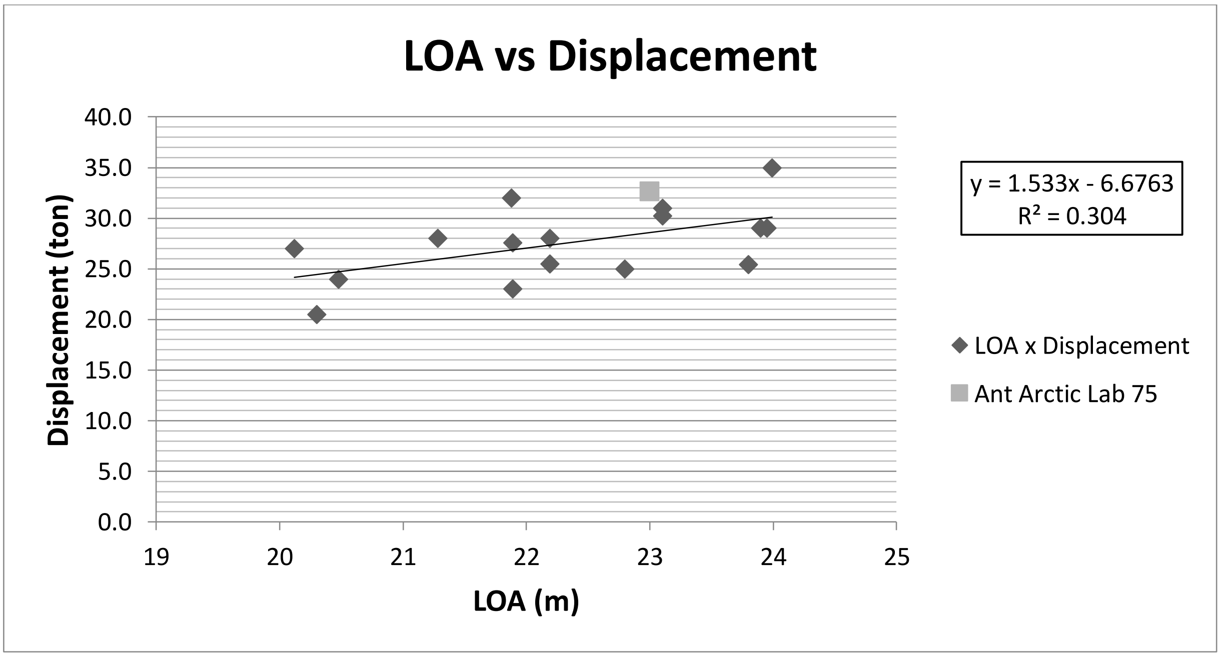
Appendix B: Regression analysis

Name	LOA (m)	B (m)	T (m)	Displacement (full) (ton)*	Hull material	Engines	Engine power (hp)
Swan 78	23.99	6.4	4	35	arbon sandwich	-	190
Swan 62 FD	20.12	5.39	3.2	27	-	volvo	163
CN Yacht 2000-sloop 78	23.8	6.02	3.51	25.4	-	cummin	320
78' idea	23.9	5.93	4.2	29	-	yanmar	170
Franchini Yachts	23.104	5.472	3.648	31	fiberglass	yanmar	250
Baltic Custom 76	23.104	5.776	3.648	30.25	fiberglass	mercedes benz	280
Little Harbor Pilothouse 75ft	22.8	5.472	3.648	25	fiberglass	cummin	165
Royal Huisman	22.192	5.168	3.344	25.5	fiberglass	mercedes benz	190
Ron Holland Opus	22.192	5.472	3.04	28	fiberglass	cummins	235
Dixon 72 72ft	21.888	5.776	2.432	27.604	fiberglass	yanmar	230
Southern Wind	21.888	5.776	2.432	23	fiberglass	john deere	213
Little Harbor	21.28	5.472	3.952	28	fiberglass	cummins	210
ph3	21.88	5.78	3.8	32	fiberglass	perkins	216
Nauta 66' advanced	20.48	5.4	3.2	24	-	-	-
marten yacht Nz farr sloop	20.3	5	3.3	20.5	carbon	yanmar	125
Southern wind-78' nauta pugh	23.95	5.91	3.8	29	composite	yanmar	230

LOA	23		23.99	20.12	23	24	22	22	23
IG (m)	29.541		33.2	27.8	28	33.5	27.5	27	25.75
J (m)	8.874		9.85	7.45	9.5	8.5	7.75	8	9.5
P (m)	27.291		32.8	25.2	23	28.5	23.5	28.75	25.75
E (m)	9.8988		10.25	7.6	7.5	12.08	9.42	10.4	8
main sail (m2)	135.075		207.5	121.6	86.25	172.14	110.685	149.5	103
fore triangle (m2)	131.086		163.7	102.4	133	142.375	106.5625	108	122.3125


LOA vs B
B (m)
LOA (m)
y = 0.1949x + 1.2904
R² = 0.5342
◆ LOA x B
■ Ant Arctic Lab 75
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
19
20
21
22
23
24
25


LOA vs T
T (m)
LOA (m)
y = 0.1857x - 0.6954
R² = 0.2272
◆ LOA x T
■ Ant Arctic Lab 75
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
19
20
21
22
23
24
25


LOA vs Displacement
Displacement (ton)
LOA (m)
y = 1.533x - 6.6763
R² = 0.304
◆ LOA x Displacement
■ Ant Arctic Lab 75
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
19
20
21
22
23
24
25

Appendix C: Appendages & Sail Design

Rig and Sail

IG (m)	29.5	**BAD(m)**	**2.5**
J (m)	8.9	Rig height	31.434
P (m)	27.3	VCG	3.24
E (m)	9.9	Rm@30 (N.m)	93228
foretraingle,Af(m2)	131.09	Rm@1	36.5
SAup(m2)	299.93	IJ/EP	0.97
Main, Am(m2)	135.08	Spinnaker,As (m2)	301.50
Jib, Aj(m2)	237.61	An(m2)	266.16
LPG (m)	15.41	Cl	2.10
SL(m)	29.54	CDP	0.03
EHM	31.40	AR	4.95
FA	1.60	Cdo	0.09
EMDC(m)	0.40	Cdi	0.31
air density (kg/m3)	1.23	Cd	0.43
Vb(m/s)	7.71	Lift (N)	199466.46
Drag (N)	40692.76	side force,As (N)	190721.03
n	8.00	Delta RM	6858.00
Fs	1.90	Rm	266400.93
l(m)	6.15	main AR	5.51
a	3.03	jib AR	6.66
HA	18.212	Dellenbaugh angle	9.61

Keel

Tk (m)	3.176	Ar	3.04684026
Ak (m2)	3.311	TR	0.6
C	1.042	t/c root	0.15037594
C1	1.33	t/c tip	0.25062657
C2	0.798	density(kg/m3)	7800
C	1.064	Weight	5164.5906
t	0.2		15.8287073

Bulb		**Rudder**	
Weight (kg)	6555.4	Ar (m2)	0.686541359
lead Density (kg/m3)	11000.0	Tr	1.68
Volume (m3)	0.596	C1	0.49
Ab (m2)	1.169	C2	0.2
t(m)	0.510	C	0.345
c(m)	3.890	t	0.05
Tb(m)	0.500	Ar	4.111
Ab (m2)	1.210	TR	0.408
t/c	0.1	t/c root	0.102
section	naca 652215	t/c tip	0.25

Chainplates and Keelbolts

Load case	1	
g	9.81	m/s2
mkeel	5164.590	kg
F1	50664.633	N
a	1.552	m
c	0.5	m
M11	78631.51167	N.m
M12	103963.82	N.m
stu	800	N/mm2
sty	600	N/mm2
kMAT	0.75	
kLC	0.67	
kDC	1	
ISO class	80	
bi	200	mm
stressd	201.1	N/mm2
dneck	24.94373509	mm
dbolt	29.4336074	mm
choose	M30	
pitch	2	mm
diameter	30.49	mm
Washer ID	33	mm
washer OD	58	mm
washer thickness	4	mm
nut	M30-3.5	
nut thickness	24	mm

Floors

LF1-3	0.314	m
kEF	1	
b	314	mm
kc	1	
Pbottom	157.613	kN/m2
k3	0.028	
k1	0.017	
EI	669744.01	Nmm2/mm
Kfloor	21633156.9	
Kb	1	
Ffllor	21633156.9	
i	3	
Mi	34654.6095	N.m
f A/D	110364.998	N.m
bi	2.52866242	
f B/C	66719.3946	N.m
mA/D	0	N.m
mB/C	-26487.5996	N.m
hw	150	mm
tw/2	6	mm
check,H/(tw/2)	30	
check,d/tf	17.6666667	

Appendix D: Weight Estimation

No.	Item	Exact weight (kg)	LCG (m)	TCG (m)	VCG (m)	LCG*w (kg.m)	TCG*w (kg.m)	VCG*w (kg.m)
1 – HULL with E_glass/Bto Epoxy								
1.00	Bottom plating (fiber)	1869.6	9.845	0.000	3.315	2E+04	0E+00	6E+03
1.01	Side plating (fiber)	738.1	12.341	0.000	4.52	9E+03	0E+00	3E+03
1.02	Deck plating (fiber)	776.5	9.054	0.000	5.772	7E+03	0E+00	4E+03
1.03	Transversal Blkhd plating (fiber) 42	21.6	21.000	0.000	4.664	5E+02	0E+00	1E+02
1.04	Transversal Blkhd plating (fiber) 39	37.4	19.500	0.000	4.628	7E+02	0E+00	2E+02
1.05	Transversal Blkhd plating (fiber) 31	72.1	15.500	0.000	4.567	1E+03	0E+00	3E+02
1.06	Transversal Blkhd plating (fiber) 28	80.9	14.000	0.000	4.548	1E+03	0E+00	4E+02
1.07	Transversal Blkhd plating (fiber) 19	93.5	9.520	0.000	4.511	9E+02	0E+00	4E+02
1.08	Transversal Blkhd plating (fiber) 11	87.5	5.367	0.000	4.478	5E+02	0E+00	4E+02
1.09	Transversal Blkhd plating (fiber) 8	82.1	3.992	0.000	4.478	3E+02	0E+00	4E+02
1.10	Transversal Blkhd plating (fiber) 3	71.1	1.610	0.000	3.892	1E+02	0E+00	3E+02
1.11	Longitudinal Blkhd plating (fiber)	267.8	11.500	0.000	3.609	3E+03	0E+00	1E+03
1.12	Chain locker walls (fiber)	25.1	24.283	0.000	4.924	6E+02	0E+00	1E+02
	Total without margin	**4223.2**	**10.293**	**0.000**	**4.152**	**4E+04**	**0E+00**	**2E+04**
	Margin (>1)	1.1	1	1	1.05			
	Total with margin	**4645.5**	**10.293**	**0.000**	**4.360**	**47815.1**	**0.0**	**20252.6**

No.	Item	Exact weight (kg)	LCG (m)	TCG (m)	VCG (m)	LCG*w (kg.m)	TCG*w (kg.m)	VCG*w (kg.m)
1 – HULL with Basalt/Bto Epoxy								
1.00	Bottom plating (fiber)	1672.8	9.845	0.000	3.315	2E+04	0E+00	6E+03
1.01	Side plating (fiber)	715.7	12.341	0.000	4.52	9E+03	0E+00	3E+03
1.02	Deck plating (fiber)	791.1	9.054	0.000	5.772	7E+03	0E+00	5E+03
1.03	Transversal Blkhd plating (fiber) 42	14.8	21.000	0.000	4.664	3E+02	0E+00	7E+01
1.04	Transversal Blkhd plating (fiber) 39	25.7	19.500	0.000	4.628	5E+02	0E+00	1E+02
1.05	Transversal Blkhd plating (fiber) 31	49.5	15.500	0.000	4.567	8E+02	0E+00	2E+02
1.06	Transversal Blkhd plating (fiber) 28	55.7	14.000	0.000	4.548	8E+02	0E+00	3E+02
1.07	Transversal Blkhd plating (fiber) 19	64.3	9.520	0.000	4.511	6E+02	0E+00	3E+02

1.08	Transversal Blkhd plating (fiber) 11	60.2	5.367	0.000	4.478	3E+02	0E+00	3E+02
1.09	Transversal Blkhd plating (fiber) 8	56.4	3.992	0.000	4.478	2E+02	0E+00	3E+02
1.10	Transversal Blkhd plating (fiber) 3	48.9	1.610	0.000	3.892	8E+01	0E+00	2E+02
1.11	Longitudinal Blkhd plating (fiber)	184.1	11.500	0.000	3.609	2E+03	0E+00	7E+02
1.12	Chain locker walls (fiber)	25.1	24.283	0.000	4.924	6E+02	0E+00	1E+02
	Total without margin	**3764.3**	**10.304**	**0.000**	**4.198**	**4E+04**	**0E+00**	**2E+04**
	Margin (>1)	1.1	1	1	1.05			
	Total with margin	**4140.8**	**10.304**	**0.000**	**4.408**	**42668.3**	**0.0**	**18254.2**

No.	**Item**	**Exact weight (kg)**	**LCG (m)**	**TCG (m)**	**VCG (m)**	**LCG*w (kg.m)**	**TCG*w (kg.m)**	**VCG*w (kg.m)**
2 - Owner's cabin								
2.00	Queen bed	81.6	18.450	0.000	4.047	2E+03	0E+00	3E+02
2.01	Toilet	30.0	16.218	-1.087	4.111	5E+02	-3E+01	1E+02
2.02	Sink metal	20.0	15.626	-1.170	4.346	3E+02	-2E+01	9E+01
2.03	shower	40.0	14.490	-1.046	4.534	6E+02	-4E+01	2E+02
2.04	Toilet door, oak	35.2	15.850	-0.038	4.566	6E+02	-1E+00	2E+02
2.05	Cabin door,oak	35.2	15.480	0.700	4.566	5E+02	2E+01	2E+02
2.06	Office table	35.2	15.480	0.700	4.566	5E+02	2E+01	2E+02
	Total without margin	**277.2**	**16.349**	**-0.180**	**4.343**	**5E+03**	**-5E+01**	**1E+03**
	Margin (>1)	1.1	1	1	1			
	Total with margin	**304.9**	**16.349**	**-0.180**	**4.343**	**4985.0**	**-54.9**	**1324.4**
3 - Guest cabin								
3.00	Bunk bed	50.0	7.516	2.128	4.878	4E+02	1E+02	2E+02
3.01	Toilet	30.0	9.674	2.200	4.211	3E+02	7E+01	1E+02
3.02	Sink metal	20.0	9.634	1.665	4.446	2E+02	3E+01	9E+01
3.03	shower	40.0	10.788	2.290	4.634	4E+02	9E+01	2E+02
3.04	Toilet door, oak	35.2	10.247	1.314	4.666	4E+02	5E+01	2E+02
3.05	Cabin door,oak	35.2	10.896	0.804	4.666	4E+02	3E+01	2E+02
	Total without margin	**210.4**	**9.669**	**1.767**	**4.625**	**2E+03**	**4E+02**	**1E+03**
	Margin (>1)	1.1	1	1	1			
	Total with margin	**231.4**	**9.669**	**1.767**	**4.625**	**2237.7**	**409.0**	**1070.2**
4 - Crew CABIN								
4.00	Bunk bed	50.0	7.532	-1.902	4.878	4E+02	-1E+02	2E+02
4.01	Toilet	30.0	4.799	1.604	4.211	1E+02	5E+01	1E+02

4.02	Sink metal	20.0	5.277	0.779	4.446	1E+02	2E+01	9E+01
4.03	shower	40.0	5.989	1.521	4.634	2E+02	6E+01	2E+02
4.04	Toilet door, oak	35.2	4.935	0.383	4.666	2E+02	1E+01	2E+02
4.05	Cabin door,oak	35.2	5.529	-1.568	4.666	2E+02	-6E+01	2E+02
	Total without margin	**210.4**	**5.865**	**-0.058**	**4.625**	**1E+03**	**-1E+01**	**1E+03**
	Margin (>1)	1.1	1	1	1			
	Total with margin	**231.4**	**5.865**	**-0.058**	**4.625**	**1357.3**	**-13.5**	**1070.2**
5- Saloon								
5.00	Big Sofa	150.0	12.545	-1.051	4.234	2E+03	-2E+02	6E+02
5.01	Coffee Table	48.0	11.920	-0.983	4.234	6E+02	-5E+01	2E+02
5.02	Small sofa	80.0	12.659	1.663	4.234	1E+03	1E+02	3E+02
5.03	Door to engine room (A0 to A60)	100.0	5.033	0.110	5.478	5E+02	1E+01	5E+02
	Total without margin	**378.0**	**10.502**	**-0.161**	**4.563**	**4E+03**	**-6E+01**	**2E+03**
	Margin (>1)	1.1	1	1	1			
	Total with margin	**415.8**	**10.502**	**-0.161**	**4.563**	**4366.9**	**-66.8**	**1897.3**

No.	**Item**	**Exact weight (kg)**	**LCG (m)**	**TCG (m)**	**VCG (m)**	**LCG*w (kg.m)**	**TCG*w (kg.m)**	**VCG*w (kg.m)**
6 - Kitchen								
6.00	Kitchen table 1	24.0	10.824	-1.815	4.234	3E+02	-4E+01	1E+02
6.01	Kitchen table 2	24.0	9.828	-2.179	4.234	2E+02	-5E+01	1E+02
6.02	Diswasher machine	50.0	9.400	-2.167	4.234	5E+02	-1E+02	2E+02
6.03	Cooker electric	60.0	10.014	-2.167	4.234	6E+02	-1E+02	3E+02
6.04	Kitchen table 3+sink	44.0	8.797	-1.800	4.234	4E+02	-8E+01	2E+02
6.05	Refigerator	45.0	10.770	-1.500	4.234	5E+02	-7E+01	2E+02
	Total without margin	**247.0**	**9.871**	**-1.947**	**4.234**	**2E+03**	**-5E+02**	**1E+03**
	Margin (>1)	1.1	1	1	1			
	Total with margin	**271.7**	**9.871**	**-1.947**	**4.234**	**2682.0**	**-529.0**	**1150.4**
7 - RIB BOAT								
7.00	RIB boat	350.0	2.765	0.000	4.477	1E+03	0E+00	2E+03
	Total without margin	**350.0**	**2.765**	**0.000**	**4.477**	**1E+03**	**0E+00**	**2E+03**
	Margin (>1)	1.1	1	1	1			
	Total with margin	**385.0**	**2.765**	**0.000**	**4.477**	**1064.5**	**0.0**	**1723.6**

8 - ENGINE ROOM (INCLUDING PROPULSION SYSTEM)								
8.00	Engine	658.0	8.815	0.000	4.335	6E+03	0E+00	3E+03
8.01	Genset PS	422.0	6.941	0.587	4.243	3E+03	2E+02	2E+03
8.02	Genset SB	422.0	6.941	-0.587	4.243	3E+03	-2E+02	2E+03
8.03	Rudder PS	20.0	0.920	1.200	2.539	2E+01	2E+01	5E+01
8.04	Rudder PS	20.0	0.920	-1.200	2.539	2E+01	-2E+01	5E+01
8.05	Rudder equipment PS	50.0	0.165	1.200	2.539	8E+00	6E+01	1E+02
8.06	Rudder equipment PS	50.0	0.165	-1.200	2.539	8E+00	-6E+01	1E+02
	Keel	5164.6	11.373	0.000	1.755	6E+04	0E+00	9E+03
	Bulb	6555.4	11.833	0.000	0.000	8E+04	0E+00	0E+00
8.07	Other machinery (pumps, valves)	100.0	8.815	0.000	4.335	9E+02	0E+00	4E+02
	Total without margin	**13462.0**	**11.061**	**0.000**	**1.210**	**1E+05**	**0E+00**	**2E+04**
	Margin (>1)	1.1	1	1	1.05			
	Total with margin	**14808.2**	**11.061**	**0.000**	**1.270**	**163790.2**	**0.0**	**18810.7**
9 -Main deck								
9.00	Steering Wheel 1	4.0	5.719	1.579	6.144	2E+01	6E+00	2E+01
9.01	Steering Wheel 2	4.0	5.719	-1.579	6.144	2E+01	-6E+00	2E+01
9.02	1-Captain Seat	79.4	5.166	1.784	5.779	4E+02	1E+02	5E+02
9.03	2-Captain Seat	79.4	5.166	-1.784	5.779	4E+02	-1E+02	5E+02
9.04	1-Sofa	110.0	8.530	1.578	6.059	9E+02	2E+02	7E+02
9.05	2-Sofa	110.0	8.530	-1.578	6.059	9E+02	-2E+02	7E+02
	Total without margin	**386.8**	**7.091**	**0.000**	**5.946**	**3E+03**	**0E+00**	**2E+03**
	Margin (>1)	1.1	1	1	1.05			
	Total with margin	**425.5**	**7.091**	**0.000**	**6.243**	**3017.0**	**0.0**	**2656.3**
10 - Deck HALLWAY (include sail & rigging)								
10.00	Bollard-Port	7.0	22.313	0.148	5.794	2E+02	1E+00	4E+01
10.01	Bollard-Starboard	7.0	22.313	-0.148	5.794	2E+02	-1E+00	4E+01
10.02	Hatch Cover	6.0	21.519	0.000	5.794	1E+02	0E+00	3E+01
10.03	Mast	122.4	14.225	0.000	20.679	2E+03	0E+00	3E+03
10.04	Boom	26.6	9.275	0.000	8.307	2E+02	0E+00	2E+02
10.05	shrouds	35.0	14.225	0.000	20.961	5E+02	0E+00	7E+02
10.06	Spreaders	25.0	14.225	0.000	20.961	4E+02	0E+00	5E+02
10.07	Main	41.2	11.029	0.000	17.121	5E+02	0E+00	7E+02
10.08	Jib	40.3	16.816	0.000	15.963	7E+02	0E+00	6E+02
10.09	Spinnaker	51.3	16.816	0.000	15.963	9E+02	0E+00	8E+02
	Total without margin	**270.2**	**19.528**	**0.000**	**23.287**	**5E+03**	**0E+00**	**6E+03**

	Margin (>1)	1.1	1	1	1			
	Total with margin	**297.3**	**19.528**	**0.000**	**23.287**	**5804.8**	**0.0**	**6922.2**
11- CHAIN LOCKER (INCLUDING MOORING CHAINS, CABLES)								
11.00	Anchor PS	54.0	21.519	0.000	5.794	1E+03	0E+00	3E+02
11.01	Anchor SB	38.0	21.519	0.000	5.794	8E+02	0E+00	2E+02
11.02	Mooring chain PS	340.0	21.519	0.000	5.794	7E+03	0E+00	2E+03
11.03	Mooring chain SB	293.0	21.519	0.000	5.794	6E+03	0E+00	2E+03
11.04	Mooring winch PS	16.5	22.313	0.148	5.794	4E+02	2E+00	1E+02
11.05	Mooring winch SB	16.5	22.313	-0.148	5.794	4E+02	-2E+00	1E+02
11.06	General ropes/cables for docking	100.0	21.519	0.000	5.794	2E+03	0E+00	6E+02
	Total without margin	**858.0**	**21.550**	**0.000**	**5.794**	**2E+04**	**0E+00**	**5E+03**
	Margin (>1)	1.1	1	1	1.05			
	Total with margin	**943.8**	**21.550**	**0.000**	**6.084**	**20338.5**	**0.0**	**5741.8**
12 - SUPERSTRUCTURE								
12.00	Superstructure plating (fiber)	126.9	10.500	0.000	8.307	1E+03	0E+00	1E+03
12.01	Superstructure plating (foam)	19.8	10.500	0.000	8.307	2E+02	0E+00	2E+02
	Total without margin	**146.8**	**10.500**	**0.000**	**8.307**	**2E+03**	**0E+00**	**1E+03**
	Margin (>1)	1.1	1	1	1.05			
	Total with margin	**161.4**	**10.500**	**0.000**	**8.722**	**1695.2**	**0.0**	**1408.2**
13 - SWIMMING DECK (INCLUDING HYDRAULIC SYSTEM FOR RAISING IT)								
13.00	Platform	150	0.726	0.000	5.394	1E+02	0E+00	8E+02
13.01	Hydraulic jack	50	0.726	-2.198	4.207	4E+01	-1E+02	2E+02
	Total without margin	**200.0**	**0.726**	**-0.550**	**5.097**	**1E+02**	**-1E+02**	**1E+03**
	Margin (>1)	1.1	1	1	1.05			
	Total with margin	**220.0**	**0.726**	**-0.550**	**5.352**	**159.7**	**-120.9**	**1177.5**
14- painting								
18.00	Bottom plating (fiber)	150.2	9.845	0.000	3.315	1E+03	0E+00	5E+02
18.01	Side plating (fiber)	80.8	12.341	0.000	4.52	1E+03	0E+00	4E+02
18.02	Deck plating (fiber)	122.7	9.054	0.000	5.772	1E+03	0E+00	7E+02
18.03	Transversal bkhds plating (fiber) 42	3.6	21.000	0.000	4.664	8E+01	0E+00	2E+01

18.04	Transversal bkhds plating (fiber) 39	6.2	19.500	0.000	4.628	1E+02	0E+00	3E+01
18.05	Transversal bkhds plating (fiber) 31	11.9	15.500	0.000	4.567	2E+02	0E+00	5E+01
18.06	Transversal bkhds plating (fiber) 28	13.4	14.000	0.000	4.548	2E+02	0E+00	6E+01
18.07	Transversal bkhds plating (fiber) 19	15.5	9.520	0.000	4.511	1E+02	0E+00	7E+01
18.08	Transversal bkhds plating (fiber) 11	14.5	5.367	0.000	4.478	8E+01	0E+00	6E+01
18.09	Transversal bkhds plating (fiber) 8	13.6	3.992	0.000	4.478	5E+01	0E+00	6E+01
18.10	Transversal bkhds plating (fiber) 3	11.8	1.610	0.000	3.892	2E+01	0E+00	5E+01
18.11	Longitudinal bkhds plating (fiber)	44.4	11.500	0.000	3.609	5E+02	0E+00	2E+02
18.12	Chain locker walls (fiber)	2.9	24.283	0.000	4.924	7E+01	0E+00	1E+01
	Total without margin	**491.5**	**10.246**	**0.000**	**4.371**	**5E+03**	**0E+00**	**2E+03**
	Margin (>1)	1.1	1	1	1.05			
	Total with margin	**540.7**	**10.246**	**0.000**	**4.590**	**5539.7**	**0.0**	**2481.5**
19 - PIPING								
19.00	FW system	200.0	10.470	-0.010	3.030	2E+03	-2E+00	6E+02
19.01	GW system	200.0	10.470	-0.010	3.030	2E+03	-2E+00	6E+02
19.02	Fuel system	250.0	10.470	-0.010	3.030	3E+03	-3E+00	8E+02
19.03	Hydrolic system	150.0	10.470	-0.010	3.030	2E+03	-2E+00	5E+02
19.04	Lubrication	65.5	10.470	-0.010	3.030	7E+02	-7E-01	2E+02
19.05	Bilge system	98.2	10.470	-0.010	3.030	1E+03	-1E+00	3E+02
19.06	Sounding pipes	5.2	10.470	-0.010	3.030	5E+01	-5E-02	2E+01
19.07	Air Pipes	5.2	10.470	-0.010	3.030	5E+01	-5E-02	2E+01
19.08	Exhaust	23.9	10.470	-0.010	3.030	3E+02	-2E-01	7E+01
19.09	Compressed air system	15.5	10.470	-0.010	3.030	2E+02	-2E-01	5E+01
19.10	Ventilation system	10.3	10.470	-0.010	3.030	1E+02	-1E-01	3E+01
19.11	Cooling system	78.6	10.470	-0.010	3.030	8E+02	-8E-01	2E+02
19.12	AC Compressor	30.0	10.470	-0.010	3.030	3E+02	-3E-01	9E+01
19.13	Ventilation Duct	150.0	10.470	-0.010	3.030	2E+03	-2E+00	5E+02
19.14	Fan	20.0	10.470	-0.010	3.030	2E+02	-2E-01	6E+01
19.15	Heater	200.0	10.470	-0.010	3.030	2E+03	-2E+00	6E+02
19.16	Main power pump	10.0	10.470	-0.010	3.030	1E+02	-1E-01	3E+01
19.17	Emergency pump	10.0	10.470	-0.010	3.030	1E+02	-1E-01	3E+01
19.18	Fire hoses 18 m	24.0	10.470	-0.010	3.030	3E+02	-2E-01	7E+01
19.19	Portable fire extinguisher in eng. r.	24.0	10.470	-0.010	3.030	3E+02	-2E-01	7E+01

19.20	Automatic sprinkler with alarm	50.0	10.470	-0.010	3.030	5E+02	-5E-01	2E+02
19.21	Portable fire extinguher in accom. room	18.0	10.470	-0.010	3.030	2E+02	-2E-01	5E+01
19.22	Portable fire extinguher in galley	6.0	10.470	-0.010	3.030	6E+01	-6E-02	2E+01
19.23	Lifebuoy	25.0	10.470	-0.010	3.030	3E+02	-3E-01	8E+01
19.24	Life jacket	40.0	10.470	-0.010	3.030	4E+02	-4E-01	1E+02
	Total without margin	**1709.3**	**10.470**	**-0.010**	**3.030**	**2E+04**	**-2E+01**	**5E+03**
	Margin (>1)	1.1	1	1	1.05			
	Total with margin	**1880.2**	**10.470**	**-0.010**	**3.182**	**19685.8**	**-18.8**	**5981.9**
20 - ELECTRICAL SYSTEM								
20.00	Invertor	30	10.470	-0.010	3.030	3E+02	-3E-01	9E+01
20.01	Convertor	8	10.470	-0.010	3.030	8E+01	-8E-02	2E+01
20.02	Alternator	12	10.470	-0.010	3.030	1E+02	-1E-01	4E+01
20.03	Batteries (Starter)	76	10.470	-0.010	3.030	8E+02	-8E-01	2E+02
20.04	Battery Master Switch	26	10.470	-0.010	3.030	3E+02	-3E-01	8E+01
20.05	Panel	50	10.470	-0.010	3.030	5E+02	-5E-01	2E+02
20.06	DC Box	13.5	10.470	-0.010	3.030	1E+02	-1E-01	4E+01
20.07	AC Box	13.5	10.470	-0.010	3.030	1E+02	-1E-01	4E+01
20.08	Shore Supply	3	10.470	-0.010	3.030	3E+01	-3E-02	9E+00
20.09	Electrical Equipments	200	10.470	-0.010	3.030	2E+03	-2E+00	6E+02
	Total without margin	**432.0**	**10.470**	**-0.010**	**3.030**	**5E+03**	**-4E+00**	**1E+03**
	Margin (>1)	1.1	1	1	1.05			
	Total with margin	**475.2**	**10.470**	**-0.010**	**3.182**	**4975.3**	**-4.8**	**1511.8**
21 - INSULATION								
21.00	Insulation	300	10.470	-0.010	3.030	3E+03	-3E+00	9E+02
	Total without margin	**300.0**	**10.470**	**-0.010**	**3.030**	**3E+03**	**-3E+00**	**9E+02**
	Margin (>1)	1.1	1	1	1.05			
	Total with margin	**330.0**	**10.470**	**-0.010**	**3.182**	**3455.1**	**-3.3**	**1049.9**
22 - PEOPLE (NOT PART OF LIGHTSHIP)								
22.00	6persons	600.0	10.470	-0.010	3.030	6E+03	-6E+00	2E+03
	Total without margin	**600.0**	**10.470**	**-0.010**	**3.030**	**6E+03**	**-6E+00**	**2E+03**
	Margin (>1)	1.1	1	1	1.05			

	Total with margin	**660.0**	**10.470**	**-0.010**	**3.182**	**6910.2**	**-6.6**	**2099.8**
23- Tanks							
23.00	Grey water tank SB	0.0	3.971	-1.648	3.538	0E+00	0E+00	0E+00
23.01	Grey water tank PS	0.0	3.971	1.648	3.538	0E+00	0E+00	0E+00
23.02	Fresh water PS	938.2	2.831	0.549	3.899	3E+03	5E+02	4E+03
23.03	Fresh water SB	938.2	2.831	-0.549	3.899	3E+03	-5E+02	4E+03
23.04	Fuel tank PS 1	900.0	10.296	0.970	3.671	9E+03	9E+02	3E+03
23.05	Fuel tank PS 2	358.0	10.275	2.248	3.778	4E+03	8E+02	1E+03
23.06	Fuel tank SB 1	900.0	10.296	-0.970	3.671	9E+03	-9E+02	3E+03
23.07	Fuel tank SB 2	358.0	10.311	-2.248	3.778	4E+03	-8E+02	1E+03
23.08	Black water PS	0.0	5.350	1.914	3.610	0E+00	0E+00	0E+00
23.09	Black water SB	0.0	5.350	-1.914	3.610	0E+00	0E+00	0E+00
	Total without margin	**4392.4**	**7.106**	**0.000**	**3.786**	**3E+04**	**0E+00**	**2E+04**
	Margin (>1)	1	1	1	1.05			
	Total with margin	**4392.4**	**7.106**	**0.000**	**3.975**	**31214.8**	**0.0**	**17460.5**
24- Consumable								
24.00	Food	560	10.470	-0.010	3.030	6E+03	-6E+00	2E+03
24.01	Luggage	400	10.470	-0.010	3.030	4E+03	-4E+00	1E+03
	Total without margin	**960.0**	**10.470**	**-0.010**	**3.030**	**1E+04**	**-1E+01**	**3E+03**
	Margin (>1)	1.05	1	1	1.05			
	Total with margin	**1008.0**	**10.470**	**-0.010**	**3.182**	**10553.8**	**-10.1**	**3207.0**

Item	**Exact weight (kg)**	**LCG (m)**	**TCG (m)**	**VCG (m)**	**LCG*w (kg.m)**	**TCG*w (kg.m)**	**VCG*w (kg.m)**
Total Lightship E-glass	26568.06	11.03	-0.02	2.87	292969.84	-402.99	76230.53
Total Lightship Basalt	26063.28	11.04	-0.02	2.85	287849.98	-402.99	74203.94
Total Loaded E-Glass	32628.50	10.47	-0.01	3.03	341648.59	-419.67	98997.81
Total Loaded E-Glass	32123.72	10.48	-0.01	3.02	336545.41	-419.67	96953.71

Appendix E: Electrical Load Balance

						HARBOUR				MANOEUVRING				SAILING				EMERGENCY	
						Crew		**Crew and Guests**		**Crew**		**Crew and Guests**		**Crew**		**Crew and Guests**		**Crew**	
No.	**Item**	**Quantity**	**Max Load (kW)**	**Load Factor**	**Used Load (kW)**	**% MAX**	**Load (kW)**	**% MAX**	**Load (kW)**	**% MAX**	**Load (kW)**	**% MAX**	**Load (kW)**	**% MAX**	**Load (kW)**	**% MAX**	**Load (kW)**	**% MAX**	**Load (kW)**
1 - Owner cabin																			
1.00	Room Lighting	5	0.020	0.900	0.090	0	0.000	25	0.023	0	0.000	75	0.068	0	0.000	100	0.090	0	0.000
1.01	Bathroom Lighting	2	0.020	0.900	0.036	0	0.000	25	0.009	0	0.000	75	0.027	0	0.000	100	0.036	0	0.000
1.02	Automatic Curtains	2	0.185	0.800	0.296	0	0.000	25	0.074	0	0.000	75	0.222	0	0.000	100	0.296	0	0.000
1.03	Cabin Socket	4	0.300	0.800	0.960	0	0.000	25	0.240	0	0.000	75	0.720	0	0.000	100	0.960	0	0.000
1.04	Television + sound system	1	0.273	0.800	0.218	0	0.000	25	0.055	0	0.000	75	0.164	0	0.000	100	0.218	0	0.000
1.05	Bathroom Socket	2	0.300	0.800	0.480	0	0.000	25	0.120	0	0.000	75	0.360	0	0.000	100	0.480	0	0.000
	Total without margin						**0.000**		**0.520**		**0.000**		**1.560**		**0.000**		**2.080**		**0.000**
	Margin (>1)						1.020		1.020		1.020		1.020		1.020		1.020		1.020
	Total with margin						**0.000**		**0.530**		**0.000**		**1.591**		**0.000**		**2.122**		**0.000**

2 - Guest cabin																			
2.00	Room Lighting	4.000	0.02	0.90	0.07	0	0.00	25	0.02	0	0.00	75	0.05	0	0.00	100	0.07	0	0.00
2.01	Bathroom Lighting	2.000	0.02	0.90	0.04	0	0.00	25	0.01	0	0.00	75	0.03	0	0.00	100	0.04	0	0.00
2.02	Cabin Socket	4.000	0.30	0.80	0.96	0	0.00	25	0.24	0	0.00	75	0.72	0	0.00	100	0.96	0	0.00
2.03	Television + sound system	1.000	0.27	0.80	0.22	0	0.00	25	0.05	0	0.00	75	0.16	0	0.00	100	0.22	0	0.00
2.04	Bathroom Socket	2.000	0.30	0.80	0.48	0	0.00	25	0.12	0	0.00	75	0.36	0	0.00	100	0.48	0	0.00

	Total without margin						**0.00**		**0.44**		**0.00**		**1.32**		**0.00**		**1.77**		**0.00**
	Margin (>1)						1.02		1.02		1.02		1.02		1.02		1.02		1.02
	Total with margin						**0.00**		**0.45**		**0.00**		**1.35**		**0.00**		**1.80**		**0.00**
3 - CREW CABIN																			
3.00	Room Lighting	2	0.020	0.900	0.036	50	0.018	50	0.018	50	0.018	50	0.018	100	0.036	100	0.036	0	0.000
3.01	Bathroom Lighting	2	0.020	0.900	0.036	50	0.018	50	0.018	50	0.018	50	0.018	100	0.036	100	0.036	0	0.000
3.02	Cabin Socket	2	0.300	0.800	0.480	50	0.240	50	0.240	50	0.240	50	0.240	100	0.480	100	0.480	0	0.000
3.03	Bathroom Socket	2	0.300	0.800	0.480	50	0.240	50	0.240	50	0.240	50	0.240	100	0.480	100	0.480	0	0.000
	Total without margin						**0.516**		**0.516**		**0.516**		**0.516**		**1.032**		**1.032**		**0.000**
	Margin (>1)						1.020		1.020		1.020		1.020		1.020		1.020		1.020
	Total with margin						**0.526**		**0.526**		**0.526**		**0.526**		**1.053**		**1.053**		**0.000**
4 - RIB BOAT																			
4.00	Garage Lighting	3	0.020	0.900	0.054	0	0.000	25	0.014	0	0.000	0	0.000	0	0.000	100	0.054	0	0.000
4.01	Garage Socket	2	0.300	0.800	0.480	0	0.000	25	0.120	0	0.000	0	0.000	0	0.000	100	0.480	0	0.000
	Total without margin						**0.000**		**0.134**		**0.000**		**0.000**		**0.000**		**0.534**		**0.000**
	Margin (>1)						1.020		1.020		1.020		1.020		1.020		1.020		1.020
	Total with margin						**0.000**		**0.136**		**0.000**		**0.000**		**0.000**		**0.545**		**0.000**
5 - ENGINE ROOM (INCLUDING PROPULSION SYSTEM)																			
5.00	Engineroom Lighting	6	0.020	0.900	0.108	20	0.022	20	0.022	100	0.108	100	0.108	100	0.108	100	0.108	0	0.000
5.01	Engineroom Socket	10	0.300	0.900	2.700	20	0.540	20	0.540	100	2.700	100	2.700	100	2.700	100	2.700	0	0.000
5.02	Bilge Pump	1	1.000	0.800	0.800	10	0.080	10	0.080	100	0.800	100	0.800	100	0.800	100	0.800	0	0.000
5.03	Fire Pump	1	0.500	0.800	0.400	20	0.080	20	0.080	50	0.200	50	0.200	50	0.200	50	0.200	100	0.400

5.04	Steering gear pump	1	0.700	0.800	0.560	10	0.056	10	0.056	100	0.560	100	0.560	100	0.560	100	0.560	100	0.560
5.05	Battery charger	1	1.000	0.800	0.800	100	0.800	100	0.800	20	0.160	20	0.160	20	0.160	20	0.160	0	0.000
5.06	GW pump	1	1.000	0.800	0.800	10	0.080	30	0.240	75	0.600	75	0.600	75	0.600	75	0.600	0	0.000
5.07	FW Pump	1	1.000	0.800	0.800	10	0.080	30	0.240	75	0.600	75	0.600	75	0.600	75	0.600	0	0.000
5.08	FO Pump	1	1.100	0.800	0.880	10	0.088	10	0.088	100	0.880	100	0.880	100	0.880	100	0.880	75	0.660
5.09	Engine room ventilation fans	1	1.000	0.800	0.800	20	0.160	20	0.160	100	0.800	100	0.800	100	0.800	100	0.800	0	0.000
5.10	Lubrication Pump	2	1.000	0.800	1.600	10	0.160	10	0.160	100	1.600	100	1.600	100	1.600	100	1.600	50	0.800
5.11	Heater	1	1.000	0.800	0.800	25	0.200	25	0.200	75	0.600	100	0.800	75	0.600	75	0.600	0	0.000
5.12	Compressor	1	1.000	0.800	0.800	25	0.200	25	0.200	75	0.600	100	0.800	75	0.600	75	0.600	0	0.000
5.13	Cooling systems	1	1.000	0.800	0.800	25	0.200	50	0.400	75	0.600	100	0.800	75	0.600	75	0.600	0	0.000
	Total without margin						**2.746**		**3.266**		**10.808**		**11.408**		**10.808**		**10.808**		**2.420**
	Margin (>1)						1.020		1.020		1.020		1.020		1.020		1.020		1.020
	Total with margin						**2.801**		**3.331**		**11.024**		**11.636**		**11.024**		**11.024**		**2.468**
	6 - COCKPIT (+24 - NAVIGATION-ELECTRONICS)																		
6.00	Radar	1	0.050	0.900	0.045	0	0.000	0	0.000	100	0.045	100	0.045	100	0.045	100	0.045	100	0.045
6.01	Intercom system	1	0.025	0.900	0.023	10	0.002	10	0.002	100	0.023	100	0.023	100	0.023	100	0.023	100	0.023
6.02	Steering panel	1	0.100	0.800	0.080	10	0.008	10	0.008	100	0.080	100	0.080	100	0.080	100	0.080	100	0.080
6.03	Horn	1	0.100	0.800	0.080	5	0.004	5	0.004	100	0.080	100	0.080	100	0.080	100	0.080	100	0.080
6.04	Compass	1	0.100	0.800	0.080	0	0.000	0	0.000	100	0.080	100	0.080	100	0.080	100	0.080	100	0.080
6.05	GPS/Echo sounder	1	0.050	0.800	0.040	0	0.000	0	0.000	100	0.040	100	0.040	100	0.040	100	0.040	100	0.040
6.06	Socket	3	0.300	0.800	0.720	10	0.072	10	0.072	100	0.720	100	0.720	100	0.720	100	0.720	100	0.720
6.07	Alarm System	1	0.100	0.800	0.080	10	0.008	10	0.008	100	0.080	100	0.080	100	0.080	100	0.080	100	0.080

6.08	Port & Stb Lamp	4	0.050	0.800	0.160	10	0.016	10	0.016	75	0.120	75	0.120	100	0.160	100	0.160	75	0.120
6.09	Stern Lamp	2	0.050	0.800	0.080	10	0.008	10	0.008	75	0.060	75	0.060	100	0.080	100	0.080	75	0.060
6.10	Other light	5	0.050	0.800	0.200	10	0.020	10	0.020	75	0.150	75	0.150	100	0.200	100	0.200	100	0.200
	Total without margin						**0.138**		**0.138**		**1.478**		**1.478**		**1.588**		**1.588**		**1.528**
	Margin (>1)						1.020		1.020		1.020		1.020		1.020		1.020		1.020
	Total with margin						**0.141**		**0.141**		**1.507**		**1.507**		**1.619**		**1.619**		**1.558**
7 - KITCHEN																			
7.00	Kitchen Lighting	4	0.020	0.900	0.072	20	0.014	40	0.029	30	0.022	70	0.050	30	0.022	100	0.072	0	0.000
7.01	Kitchen socket	2	0.020	0.900	0.036	20	0.007	40	0.014	30	0.011	50	0.018	30	0.011	80	0.029	0	0.000
7.02	Diswasher machine	1	1.100	0.800	0.880	30	0.264	30	0.264	30	0.264	40	0.352	30	0.264	80	0.704	0	0.000
7.03	Cooker electric	1	8.000	0.800	6.400	20	1.280	60	3.840	20	1.280	70	4.480	20	1.280	85	5.440	0	0.000
7.04	Microwave	1	0.400	0.800	0.320	10	0.032	50	0.160	10	0.032	60	0.192	10	0.032	80	0.256	0	0.000
7.05	ice cube maker	1	0.400	0.800	0.320	20	0.064	30	0.096	20	0.064	40	0.128	20	0.064	60	0.192	0	0.000
7.06	Refrigerator	1	1.000	0.800	0.800	100	0.800	100	0.800	100	0.800	100	0.800	100	0.800	100	0.800	0	0.000
	Total without margin						**2.462**		**5.203**		**2.472**		**6.020**		**2.472**		**7.493**		**0.000**
	Margin (>1)						1.020		1.020		1.020		1.020		1.020		1.020		1.020
	Total with margin						**2.511**		**5.307**		**2.522**		**6.141**		**2.522**		**7.643**		**0.000**
8 - LIVING ROOM																			
8.00	Living room Lighting	6	0.020	0.900	0.108	10	0.011	30	0.032	50	0.054	100	0.108	50	0.054	100	0.108	0	0.000
8.01	Living room socket	6	0.300	0.900	1.620	10	0.162	30	0.486	50	0.810	100	1.620	50	0.810	100	1.620	0	0.000

8.02	LCD TV + sound systems	1	0.400	0.800	0.320	10	0.032	50	0.160	30	0.096	100	0.320	30	0.096	100	0.320	0	0.000
8.03	Juicer	1	0.250	0.800	0.200	5	0.010	25	0.050	25	0.050	100	0.200	25	0.050	100	0.200	0	0.000
8.04	Automatic Curtains	2	0.185	0.800	0.296	5	0.015	25	0.074	25	0.074	100	0.296	25	0.074	100	0.296	0	0.000
8.05	Coffee Maker	1	0.600	0.800	0.480	5	0.024	25	0.120	25	0.120	100	0.480	25	0.120	100	0.480	0	0.000
8.06	Toaster Oven	1	0.300	0.800	0.240	5	0.012	25	0.060	25	0.060	100	0.240	25	0.060	100	0.240	0	0.000
8.07	Ice maker	1	0.400	0.800	0.320	5	0.016	25	0.080	25	0.080	100	0.320	25	0.080	100	0.320	0	0.000
8.08	Fridge	1	1.000	0.800	0.800	5	0.040	25	0.200	25	0.200	100	0.800	25	0.200	100	0.800	0	0.000
	Total without margin						**0.322**		**1.262**		**1.544**		**4.384**		**1.544**		**4.384**		**0.000**
	Margin (>1)						1.020		1.020		1.020		1.020		1.020		1.020		1.020
	Total with margin						**0.328**		**1.288**		**1.575**		**4.472**		**1.575**		**4.472**		**0.000**
9 - OPEN LEISURE SPACE, HALLWAY, CHAIN LOCKER (INCLUDING MOORING CHAINS, CABLES AND BOLLARDS)																			
9.00	Lighting	10	0.250	0.800	2.000	50	1.000	50	1.000	100	2.000	100	2.000	100	2.000	100	2.000	0	0.000
9.01	Socket	7	0.185	0.800	1.036	25	0.259	50	0.518	100	1.036	100	1.036	100	1.036	100	1.036	0	0.000
9.02	Hydraulic Mooring winch PS	1	1.000	0.800	0.800	100	0.800	100	0.800	50	0.400	50	0.400	75	0.600	75	0.600	0	0.000
9.03	Hydraulic Mooring winch SB	1	1.000	0.800	0.800	100	0.800	100	0.800	50	0.400	50	0.400	75	0.600	75	0.600	0	0.000
	Total without margin						**2.859**		**3.118**		**3.836**		**3.836**		**4.236**		**4.236**		**0.000**
	Margin (>1)						1.020		1.020		1.020		1.020		1.020		1.020		1.020
	Total with margin						**2.916**		**3.180**		**3.913**		**3.913**		**4.321**		**4.321**		**0.000**
10 - open Saloon																			
10.00	lighting	5	0.250	0.800	1.000	20	0.200	75	0.750	20	0.200	75	0.750	20	0.200	75	0.750	0	0.000

10.01	socket	4	0.185	0.800	0.592	20	0.118	80	0.474	20	0.118	80	0.474	20	0.118	80	0.474	0	0.000
10.02	Speakers	1	0.300	0.800	0.240	10	0.024	100	0.240	10	0.024	100	0.240	10	0.024	100	0.240	0	0.000
	Total without margin						**0.342**		**1.464**		**0.342**		**1.464**		**0.342**		**1.464**		**0.000**
	Margin (>1)						1.020		1.020		1.020		1.020		1.020		1.020		1.020
	Total with margin						**0.349**		**1.493**		**0.349**		**1.493**		**0.349**		**1.493**		**0.000**
11 - SWIMMING DECK (INCLUDING HYDRAULIC SYSTEM FOR RAISING IT)																			
11.00	Hydraulic jack	1	1.000	0.500	0.500	100	0.500	100	0.500	0	0.000	0	0.000	100	0.500	100	0.500	0	0.000
	Total without margin						**0.500**		**0.500**		**0.000**		**0.000**		**0.500**		**0.500**		**0.000**
	Margin (>1)						1.020		1.020		1.020		1.020		1.020		1.020		1.020
	Total with margin						**0.510**		**0.510**		**0.000**		**0.000**		**0.510**		**0.510**		**0.000**
	Total kW						**10.082**		**16.893**		**21.416**		**32.630**		**22.973**		**36.602**		**4.026**

Appendix F: Resistance & Stability

Vs	Fn	Rw	Rvc	Rva	Rtu	Cr	Rh22.5	RT (kN)
kt		kg	kg	kg	kg		kg	
4.00	0.137	2.4	52.1	12.5	67.0	3.3	3.0	0.6566
4.50	0.154	4.8	64.7	15.4	85.0	5.3	4.5	0.833
5.00	0.171	7.9	78.6	18.6	105.2	7.1	6.3	1.03096
5.50	0.189	11.7	93.8	22.1	127.7	8.7	8.5	1.25146
6.00	0.206	17.4	110.2	25.9	153.5	10.8	11.4	1.5043
6.50	0.223	25.6	127.7	30.0	183.3	13.6	15.4	1.79634
7.00	0.240	36.1	146.5	34.2	216.9	16.5	20.4	2.12562
7.50	0.257	49.6	166.5	38.8	254.9	19.7	26.6	2.49802
8.00	0.274	66.7	187.6	43.6	297.9	23.3	34.3	2.91942
8.50	0.291	87.0	209.9	48.6	345.6	27.0	43.3	3.38688
9.00	0.308	108.3	233.4	53.9	395.6	29.9	52.8	3.87688
9.50	0.326	138.2	258.0	59.5	455.7	34.3	65.8	4.46586
10.00	0.343	185.7	283.8	65.3	534.7	41.6	85.8	5.24006
10.50	0.360	255.5	310.7	71.3	637.5	51.9	114.9	6.2475
11.00	0.377	373.9	338.7	77.6	790.2	69.2	163.4	7.74396
11.50	0.394	546.9	367.8	84.1	998.9	92.6	233.9	9.78922
12.00	0.411	754.0	398.1	90.9	1242.9	117.2	318.2	12.18042
12.50	0.428	972.0	429.4	97.9	1499.3	139.3	406.9	14.19314
13.00	0.446	1220.6	461.9	105.1	1787.5	161.7	507.9	15.5175
13.50	0.463	1475.4	495.4	112.6	2083.4	181.2	611.5	17.41732
14.00	0.480	1694.7	530.0	120.3	2345.0	193.6	700.9	19.481
14.50	0.497	1897.4	565.8	128.2	2591.4	202.0	783.6	21.39572
15.00	0.514	2078.6	602.6	136.4	2817.5	206.8	857.8	23.1115
15.50	0.531	2230.4	640.5	144.8	3015.6	207.8	920.3	24.55288

16.00	0.548	2360.5	679.4	153.4	3193.3	206.4	974.1	25.79434
16.50	0.566	2482.2	719.4	162.2	3363.9	204.1	1024.5	26.96622
17.00	0.583	2600.1	760.5	171.3	3531.9	201.4	1073.4	28.11262
17.50	0.600	2713.4	802.7	180.6	3696.7	198.4	1120.6	29.72766
18.00	0.617	2823.6	845.9	190.1	3859.6	195.1	1166.6	30.82408
18.50	0.634	2914.9	890.1	199.9	4004.9	190.7	1205.0	31.74802

STABILITY CRITERIA			100%		50%		10%	
6.2.1 Downflooding openings								
no hatches or opening less than (<) above loaded waterline	0.2	m	1	pass	1	pass	1	pass
6.2.2 Downflooding height at equilibrium				pass		pass		pass
the min. freeboard of the	DownfloodingPoints							
shall be greater than (>)	1.42	m	1.9	pass	1.9	pass	1.9	pass
6.4 Minimum righting energy				Pass		Pass		Pass
AGZ		m.deg	194.6771		193.0237		192.5174	
mmo		kg	31102		31102		31102	
not less than (<)	172000	kg.m.deg	6054847	pass	6003423	pass	5987676	pass
6.5 Angle of vanishing stability				Pass		Pass		Pass
shall be greater than (>)	130	deg	136.6	Pass	136.4	Pass	135.9	Pass
6.2.3 Downflooding angle				Pass		Pass		Pass
shall be greater than (>)	40	deg	136.6	Pass	136.4	Pass	135.9	Pass

6.6 STIX				Pass		Pass		Pass
delta	0	See ISO 12217-2						
AS, sail area ISO 8666	72	m^2						
height of centroid of AS	9.18	m						
LH, Stability calculated	23	m						
BH, Stability calculated	6.1	m						
LWL, Stability calculated	22.971	m						
BWL, Stability calculated	5.554	m						
height of immersed profile area centroid, Stability calculated	2.552	m						
STIX value shall be greater than (>)	32	See ISO 12217-2	112.6	Pass	110.5	Pass	109.5	Pass
Intermediate values								
m, mass of boat in current loading condition		tonne	32.628		29.958		29	
height of waterline in current loading condition		m	3.84		3.918		3.843	
phiD, actual downflooding angle		deg	135.7		138.9		140.3	
PhiV, actual angle of vanishing stability		deg	136.6		136.4		135.9	
AGZ, area under righting lever curve, from -0.1 to 132.2 deg.		m.deg	194.67		193.0237		200.03	
GZ90, righting lever at 90 deg		m	1.654		1.696		1.695	
GZD, righting lever at downflooding angle		m	0.034		-0.093		-0.157	
FR		See ISO 12217-2	70.2		66.075		63.97	
LBS, weighted average length		See ISO 12217-2	22.978		22.93		22.954	
FL, length factor		See ISO 12217-2	1.159		1.159		1.158	
FB, beam factor		See ISO 12217-2	2.027		2.086		2.109	
VAW, steady apparent wind speed		m/s	n/a		n/a		n/a	
FDS, dynamic stability factor	2.568	See ISO 12217-2	1.5		1.5		1.5	

FIR, inversion recovery factor	1.306	See ISO 12217-2	1.306		1.283		1.272	
FKR, knockdown recovery factor	6.723	See ISO 12217-2	1.5		1.5		1.5	
FDL, displacement-length factor	0.956	See ISO 12217-2	0.956		0.942		0.938	
FBD, beam-displacement factor	1.049	See ISO 12217-2	1.049		1.042		1.04	
FWM, wind moment factor	1	See ISO 12217-2	1		1		1	
FDF, downflooding factor	1.507	See ISO 12217-2	1.25		1.25		1.25	
6.7 Knockdown-recovery test (angle of vanishing stability in flooded condition)				Pass		Pass		Pass
shall be greater than (>)	90	deg	136.6	Pass	136.4	Pass	135.9	Pass
6.8 Wind stiffness test (angle of equilbrium with heel arm less than specified value)				Pass		Pass		Pass
Heeling arm = A cos^n(phi)								
A =	1.2	m						
n =	1.3							
shall be less than (<)	45	deg	13.4	Pass	12.9	Pass	12.7	Pass
11.8.2 Range of positive stability				Pass		Pass		Pass
from the greater of								
angle of equilibrium	-0.2	deg	-0.2		-0.2		-0.2	
to the lesser of								
first downflooding angle	136.6	deg	136.6					
angle of vanishing stability	136.6	deg			136.4		135.9	
shall be greater than (>)	90	deg	136.6	Pass	136.4	Pass	135.9	Pass

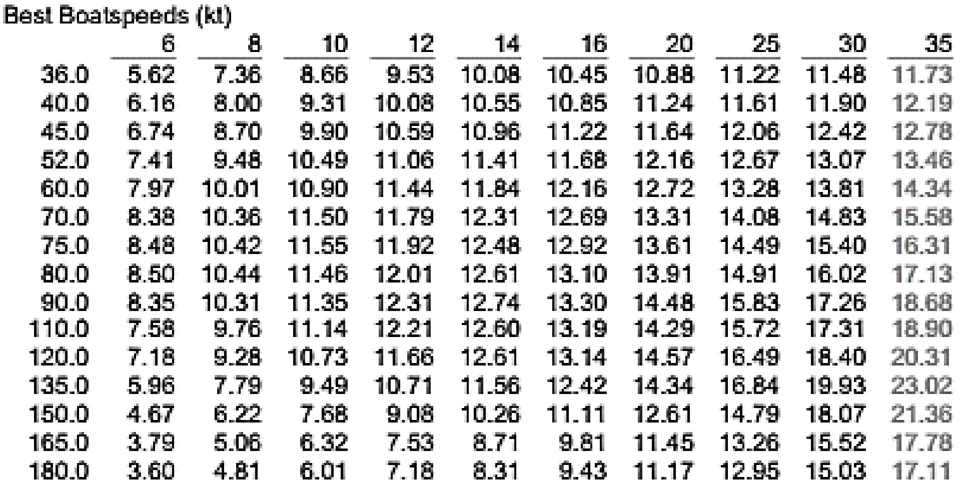
11.8.3 Angle of downflooding				Pass		Pass		Pass
shall not be less than (>=)	40	deg	136.6	Pass	136.4	Pass	135.9	Pass
11.8.3 Angle of equilibrium - derived wind heeling arm				Pass		Pass		Pass
Heeling arm = A cos^n(phi)								
n =	1.3							
gust ratio	2							
Smallest heeling arm derived from GZ at								
spec. heel angle	60	deg	60		60		60	
first downflooding angle	135.7	deg						
shall be greater than (>)	15	deg	36.4	Pass	36.4	Pass	36.3	Pass
Intermediate values								
Amplitude of gust heel arm		m	5.258		5.385		5.402	
Amplitude of steady heel arm		m	2.629		2.693		2.701	
Amplitude of heel arm from GZ at spec. heel angle		m	5.258		5.385		5.402	
11.9.2.2 Range of positive stability				Pass		Pass		Pass
from the greater of								
angle of equilibrium	-0.2	deg	-0.1		-0.1		-0.1	
to the lesser of								
first downflooding angle	135.7	deg	135.7					
angle of vanishing stability	136.6	deg			136.4		135.9	
shall be greater than (>)	90	deg	136.6	Pass	136.4	Pass	135.9	Pass

Appendages

C	0.02	cruising yacht
KA	7.868147	m^2
CL,2D,1	0.1	-
α	5	deg
AR	3.04684	-
sail CL	1.2	
Vb	4	knot
Vt	16	knot
TWA	60	deg
Va	12.493	m/s
Pair	1.225	kg/m^3
L	902.606	N
Heel angle	21	deg

SSF	842.66	N
GM	5.98	m
DISP	26	kg
g	9.8	m/s^2
HA	1.196	m
KSF	842.66	N
Te	3.17	m
Fn	0.30	-
Ae	2.56	-
dα keel	4.67	deg
keel Cl	0.756	-
KA	3.31	m^2
KA/SA	1.104	

WIN VPP

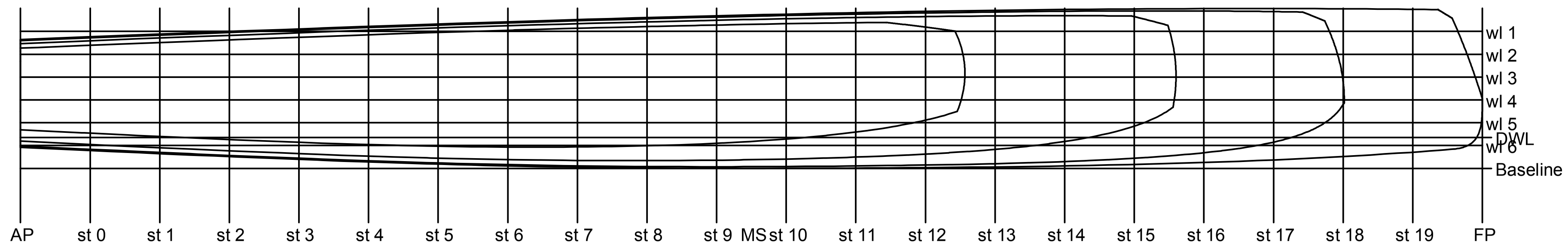


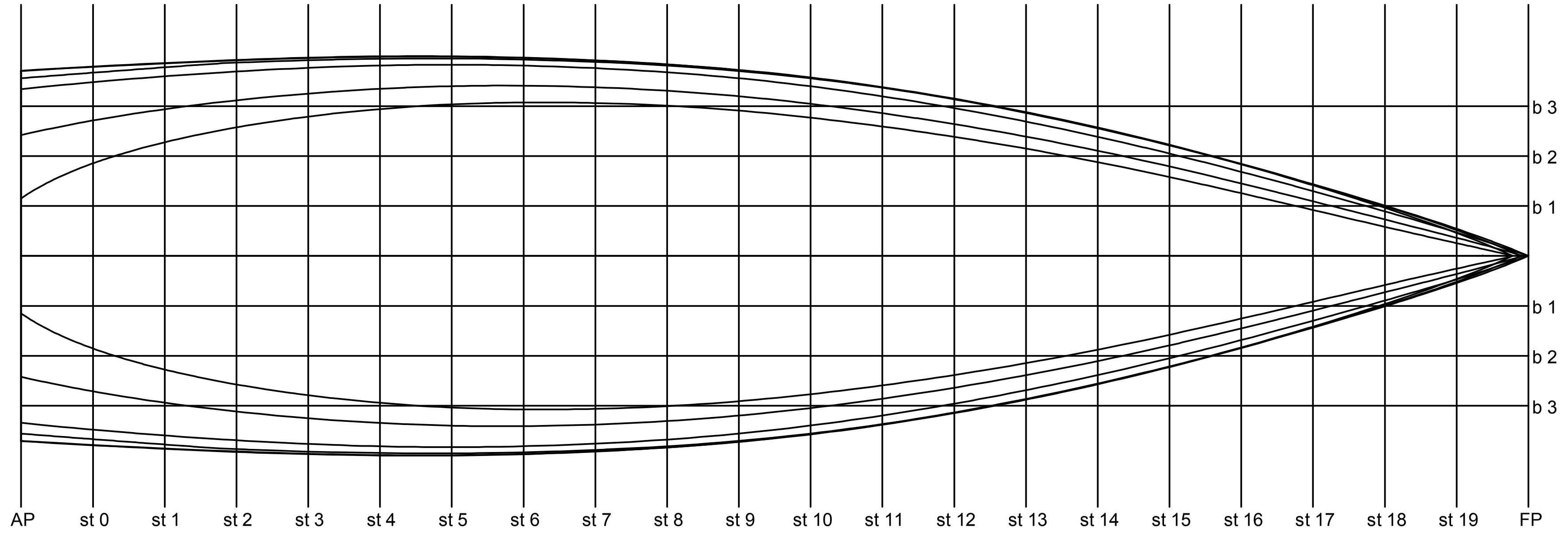
Best Boatspeeds (kt)

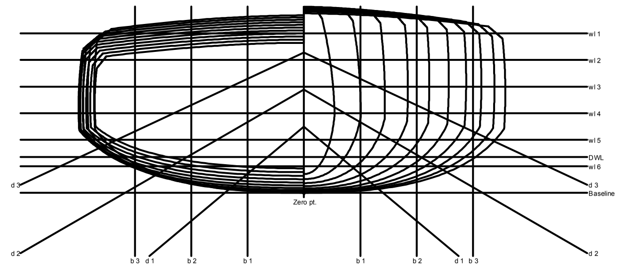
	6	8	10	12	14	16	20	25	30	35
36.0	5.62	7.36	8.66	9.53	10.08	10.45	10.88	11.22	11.48	11.73
40.0	6.16	8.00	9.31	10.08	10.55	10.85	11.24	11.61	11.90	12.19
45.0	6.74	8.70	9.90	10.59	10.96	11.22	11.64	12.06	12.42	12.78
52.0	7.41	9.48	10.49	11.06	11.41	11.68	12.16	12.67	13.07	13.46
60.0	7.97	10.01	10.90	11.44	11.84	12.16	12.72	13.28	13.81	14.34
70.0	8.38	10.36	11.50	11.79	12.31	12.69	13.31	14.08	14.83	15.58
75.0	8.48	10.42	11.55	11.92	12.48	12.92	13.61	14.49	15.40	16.31
80.0	8.50	10.44	11.46	12.01	12.61	13.10	13.91	14.91	16.02	17.13
90.0	8.35	10.31	11.35	12.31	12.74	13.30	14.48	15.83	17.26	18.68
110.0	7.58	9.76	11.14	12.21	12.60	13.19	14.29	15.72	17.31	18.90
120.0	7.18	9.28	10.73	11.66	12.61	13.14	14.57	16.49	18.40	20.31
135.0	5.96	7.79	9.49	10.71	11.56	12.42	14.34	16.84	19.93	23.02
150.0	4.67	6.22	7.68	9.08	10.26	11.11	12.61	14.79	18.07	21.36
165.0	3.79	5.06	6.32	7.53	8.71	9.81	11.45	13.26	15.52	17.78
180.0	3.60	4.81	6.01	7.18	8.31	9.43	11.17	12.95	15.03	17.11

PRINCIPAL PARTICULARS

L.O.A	23.00 M
L.P.P.	22.96 M
BEAM MLD.	6.100 M
DESIGN DRAFT	4.115 M
Displacement	32.63 ton
Tc	0.439 m
Cp	0.54







REV	DATE	REVISIONS	BY

DRAWN BY: MLS 27 July 16
CHECKED BY:
APPROVED BY:
DRAWN BY:
SRI LESTARI MAHARANI

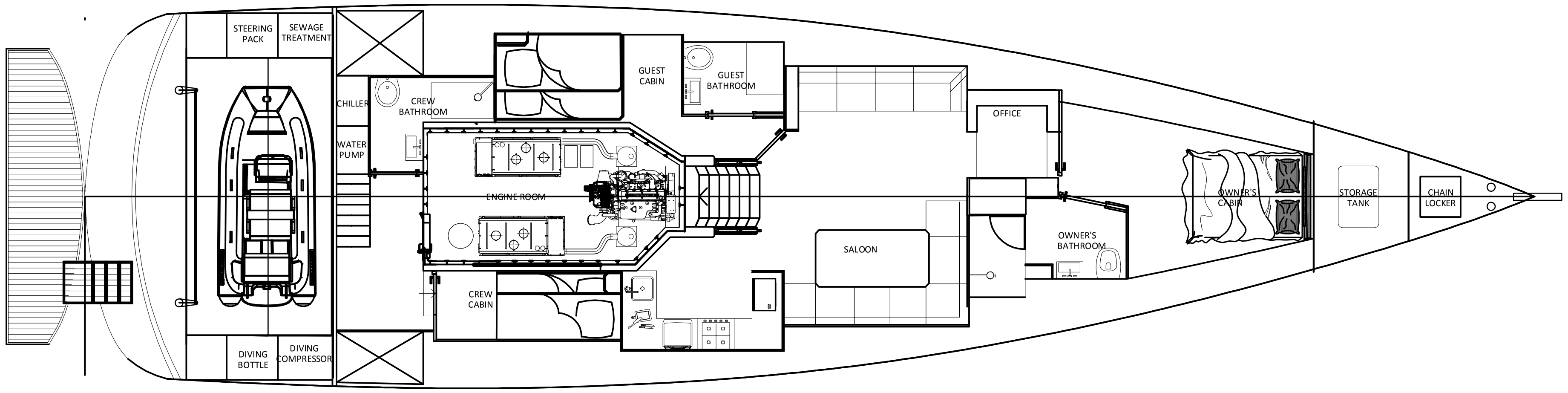
TITLE:
HULL
LINES PLAN

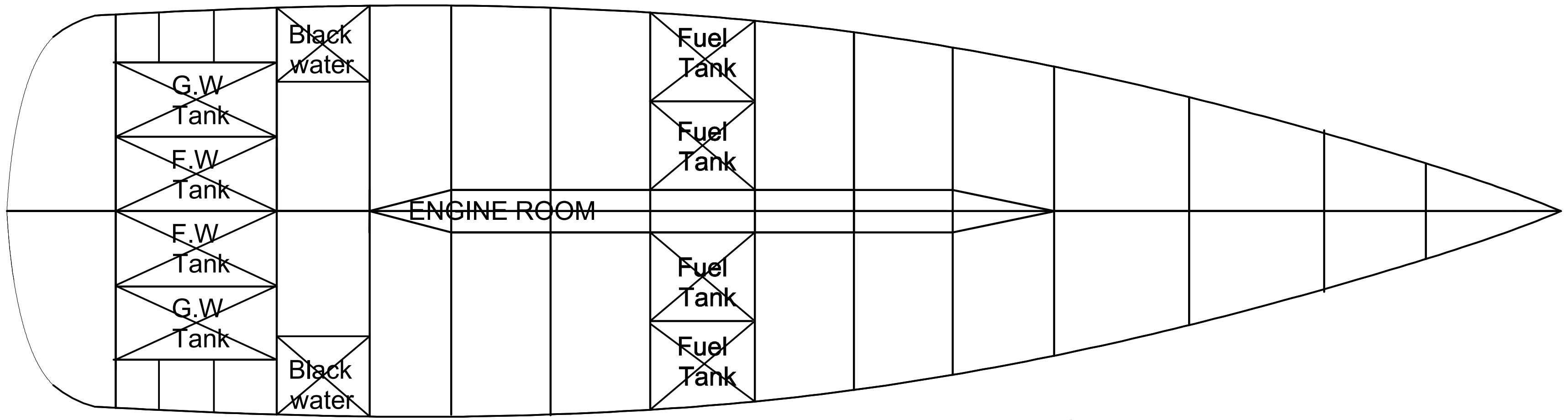
SHIP NAME:
ANT-ARCTIC-LAB 75'

Units	mm	SCALE	1 : 155 (A3)
DRW NO.	G-000	SHEET	1 OF 1

PRINCIPAL PARTICULARS

L.O.A	23.00 M
L.P.P.	22.96 M
BEAM MLD.	6.100 M
DESIGN DRAFT	4.115 M
Displacement	32.63 ton
Tc	0.439 m
Cp	0.54





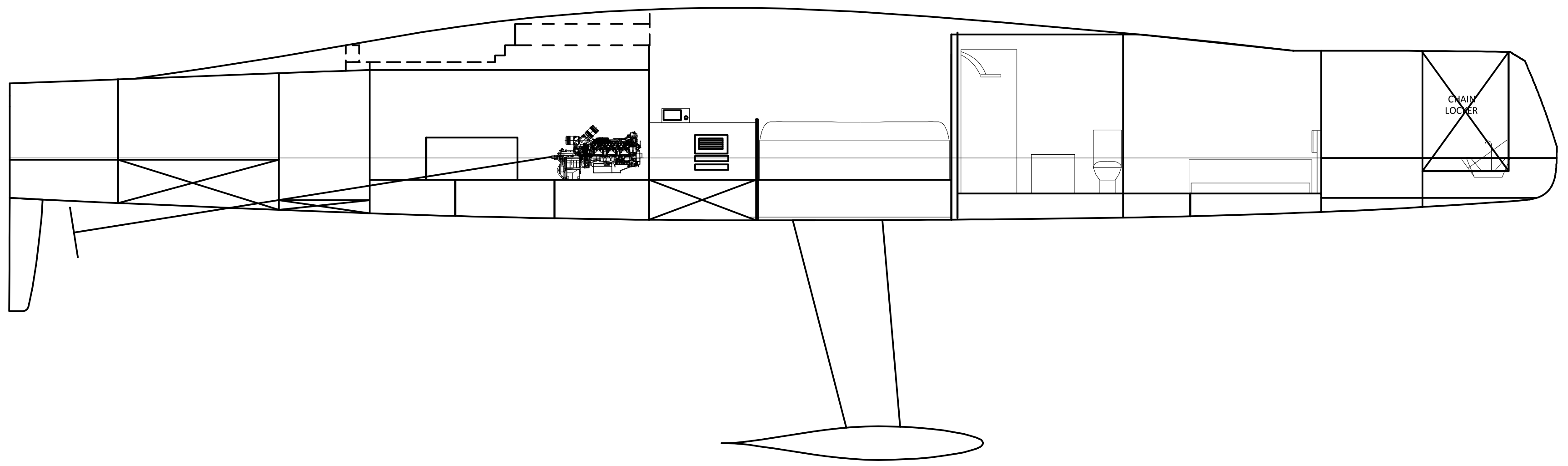
@below lower deck

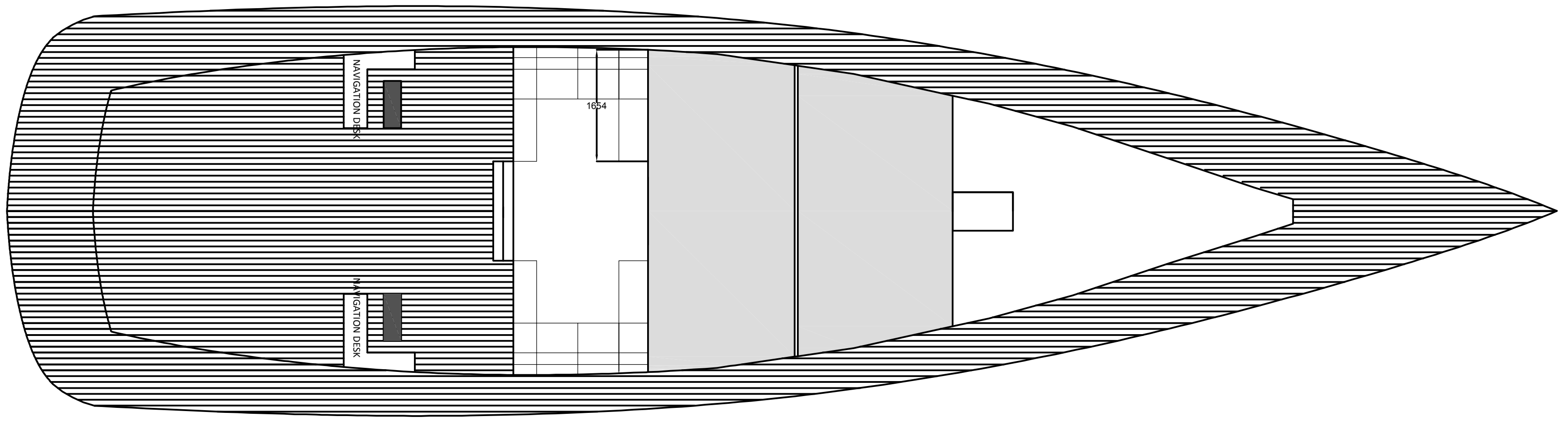
REV	DATE	REVISIONS	BY

DRAWN BY: MLS	27 July 16	TITLE: GENERAL ARRANGMENT	SHIP NAME: ANT-ARCTIC-LAB 75'
CHECKED BY:			
APPROVED BY:			
DRAWN BY: SRI LESTARI MAHARANI			
Units	mm	SCALE	1 : 155 (A3)
DRW NO.	G-000	SHEET	1 OF 2

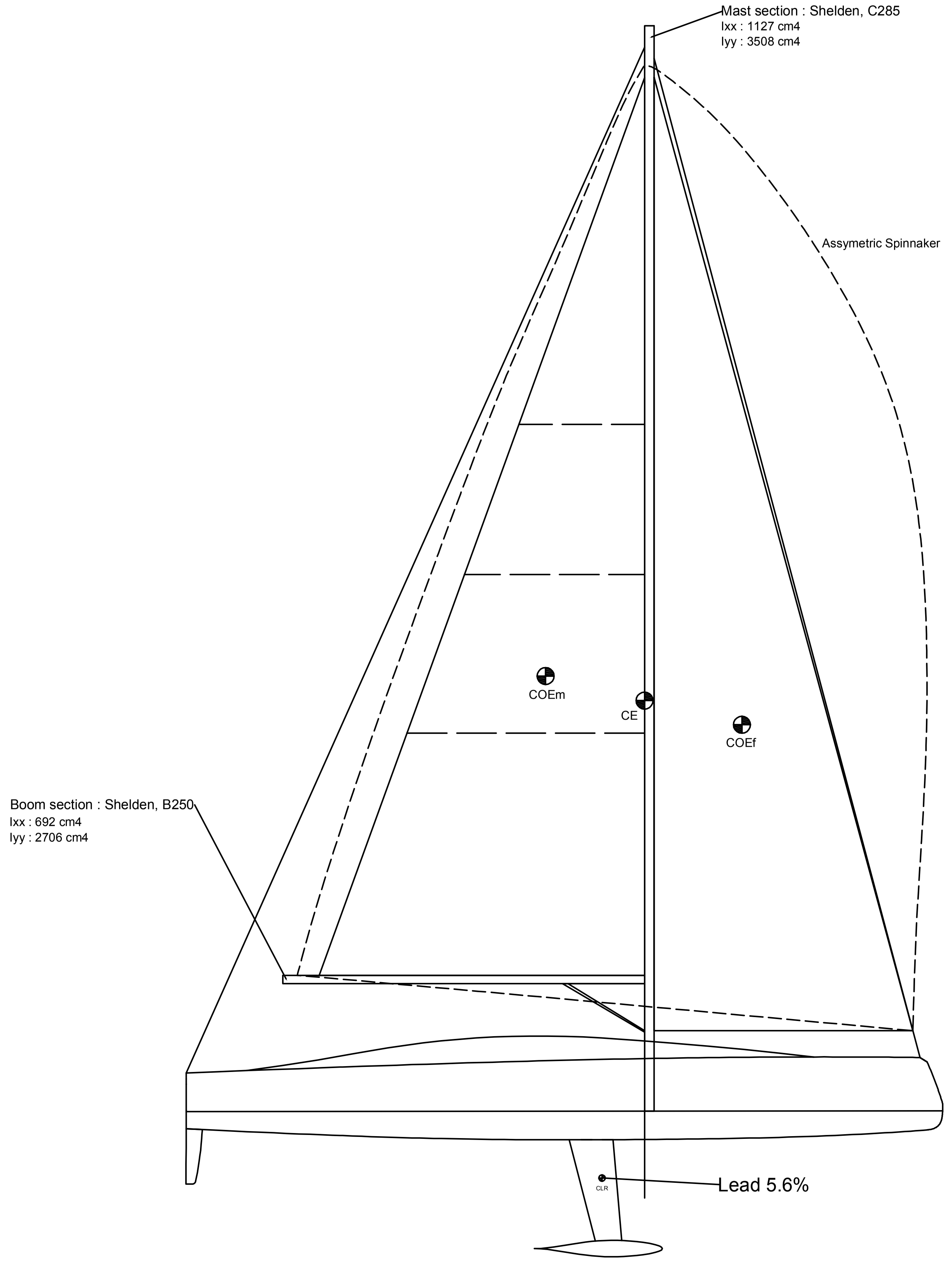
PRINCIPAL PARTICULARS

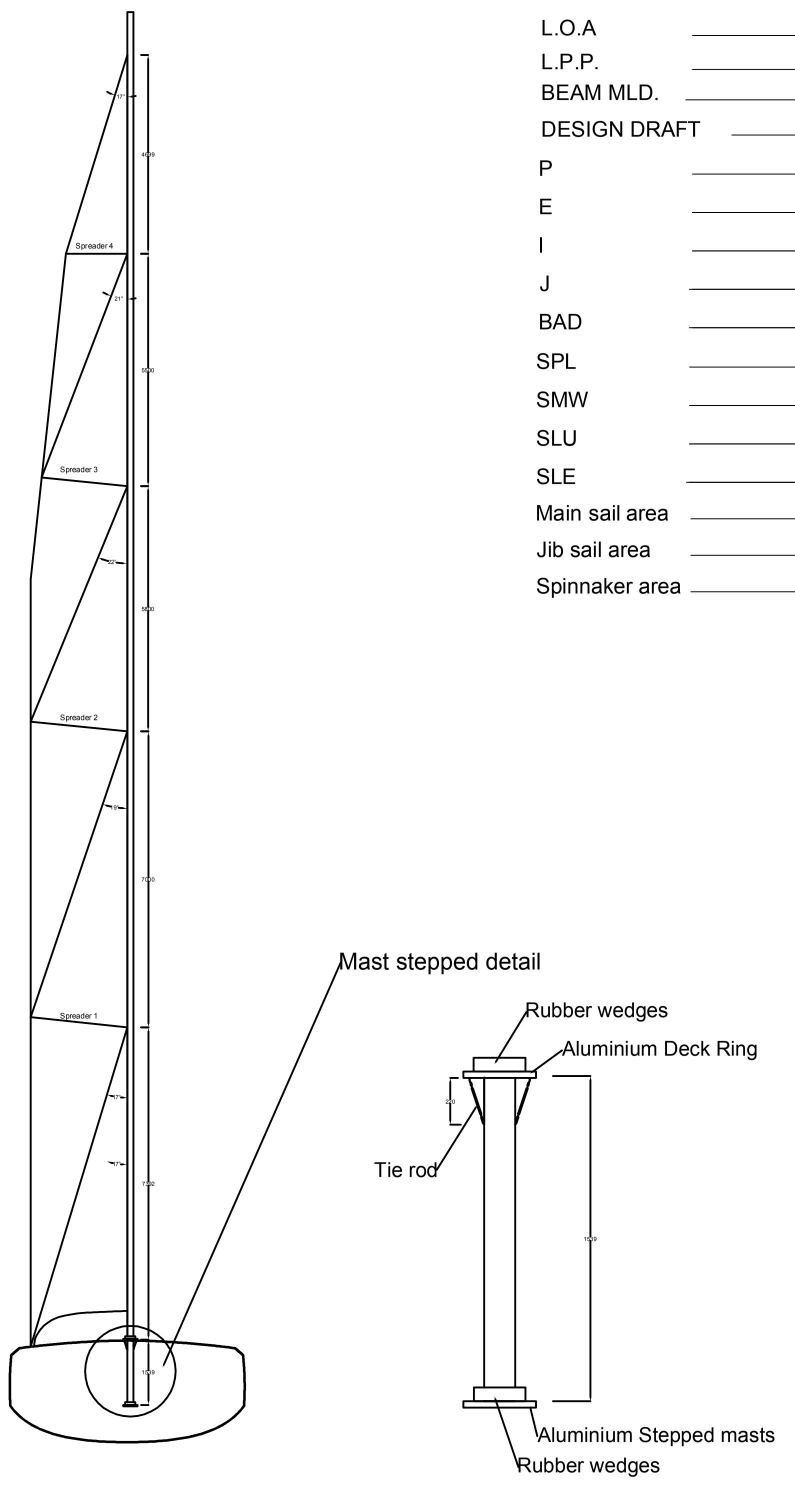
L.O.A	23.00 M
L.P.P.	22.96 M
BEAM MLD.	6.100 M
DESIGN DRAFT	4.115 M
Displacement	32.63 ton
Tc	0.439 m
Cp	0.54





REV	DATE	REVISIONS		BY
DRAWN BY: MLS	27 July 16	TITLE: GENERAL ARRANGMENT	SHIP NAME: ANT-ARCTIC-LAB 75'	
CHECKED BY:				
APPROVED BY:				
DRAWN BY: SRI LESTARI MAHARANI		Units: mm	SCALE: 1 : 155 (A3)	
		DRW NO.: G-000	SHEET: 2 OF 2	





PRINCIPAL PARTICULARS

L.O.A	23.00 M
L.P.P.	22.93 M
BEAM MLD.	6.100 M
DESIGN DRAFT	4.100 M
P	27.30 M
E	9.900 M
I	29.50 M
J	8.900 M
BAD	2.000 M
SPL	8.900 M
SMW	11.28 M
SLU	29.62 M
SLE	30.47 M
Main sail area	135.08 M2
Jib sail area	237.61 M2
Spinnaker area	301.50 M2

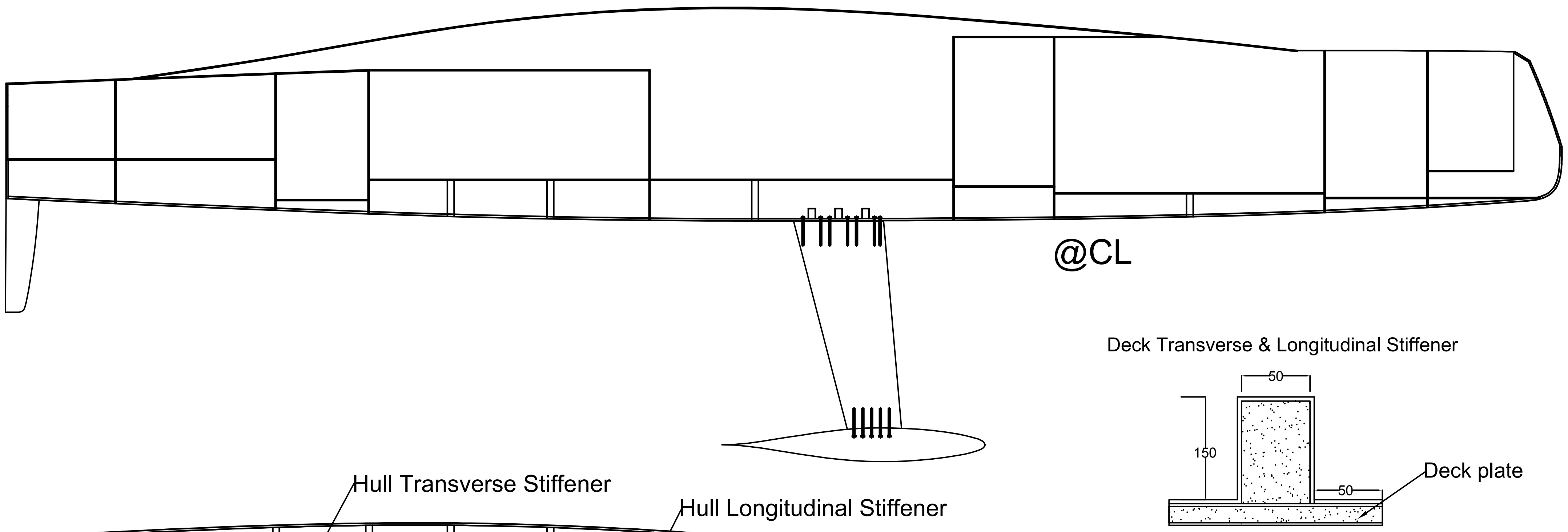
REV	DATE	REVISIONS	BY

DRAWN BY: MLS 10 June 16
CHECKED BY:
APPROVED BY:
DRAWN BY:
SRI LESTARI MAHARANI

TITLE:
RIG & SAIL PLAN

SHIP NAME:
ANT-ARCTIC-LAB 75'

PROJ. NO.
DRW NO. G-000
SCALE 1 : 175 (A3)
SHEET 1 OF 1

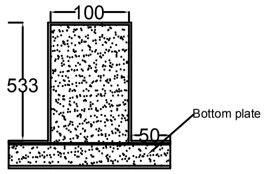


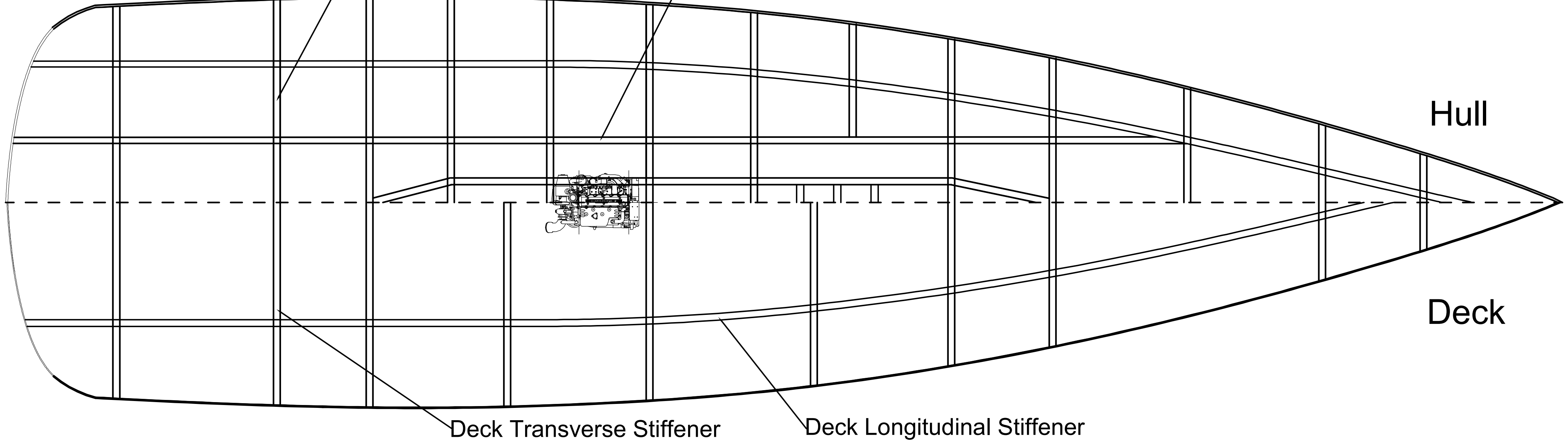
PRINCIPAL PARTICULARS

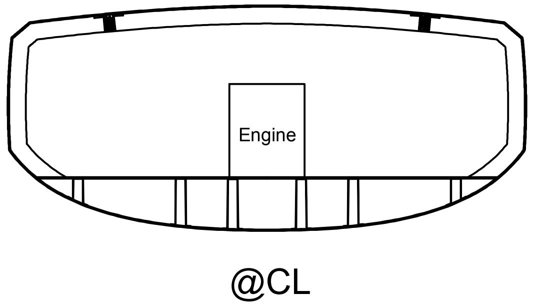
L.O.A	23.00 M
L.P.P.	22.93 M
BEAM MLD.	6.100 M
DESIGN DRAFT	4.163 M
Displacement	25.37 ton
Tc	0.487 m
Cp	0.54
LCB %	43.03
LCF %	40.42

Deck Transverse & Longitudinal Stiffener

Hull Transverse & Longitudinal Stiffener







Part	GFRP(A) & BFRP(B)	BFRP(C)
Bottom plating	$[0^{0}_{4}, \pm 45^{0}, 90^{0}, 0^{0}_{4}]_{outer}$ $[balsa, 27mm]_{core}$ $[\pm 45^{0}, 0^{0}, \pm 45^{0}, 0^{0}, WR, CSM]_{inner}$	$[0^{0}_{2}, \pm 45^{0}, 90^{0}, 0^{0}_{2}]_{outer}$ $[balsa, 27mm]_{core}$ $[\pm 45^{0}, 0^{0}, \pm 45^{0}, 0^{0}, WR, CSM]_{inner}$
Side plating	$[0^{0}_{2}, \pm 45^{0}, 90^{0}, \pm 45^{0}, 0^{0}_{2}]_{outer}$ $[balsa, 20mm]_{core}$ $[0^{0}, \pm 45^{0}, 0^{0}, WR, CSM]_{inner}$	$[0^{0}, \pm 45^{0}, 90^{0}, \pm 45^{0}, 0^{0}]_{outer}$ $[balsa, 20mm]_{core}$ $[0^{0}, \pm 45^{0}, 0^{0}, WR, CSM]_{inner}$
Deck plating	$[0^{0}, \pm 45^{0}, 0^{0}, 90^{0}, 0^{0}]_{outer}$ $[balsa, 12mm]_{core}$ $[0^{0}, \pm 45^{0}, 0^{0}, WR, CSM]_{inner}$	$[0^{0}, \pm 45^{0}, 0^{0}]_{outer}$ $[balsa, 12mm]_{core}$ $[0^{0}, \pm 45^{0}, 0^{0}, WR, CSM]_{inner}$

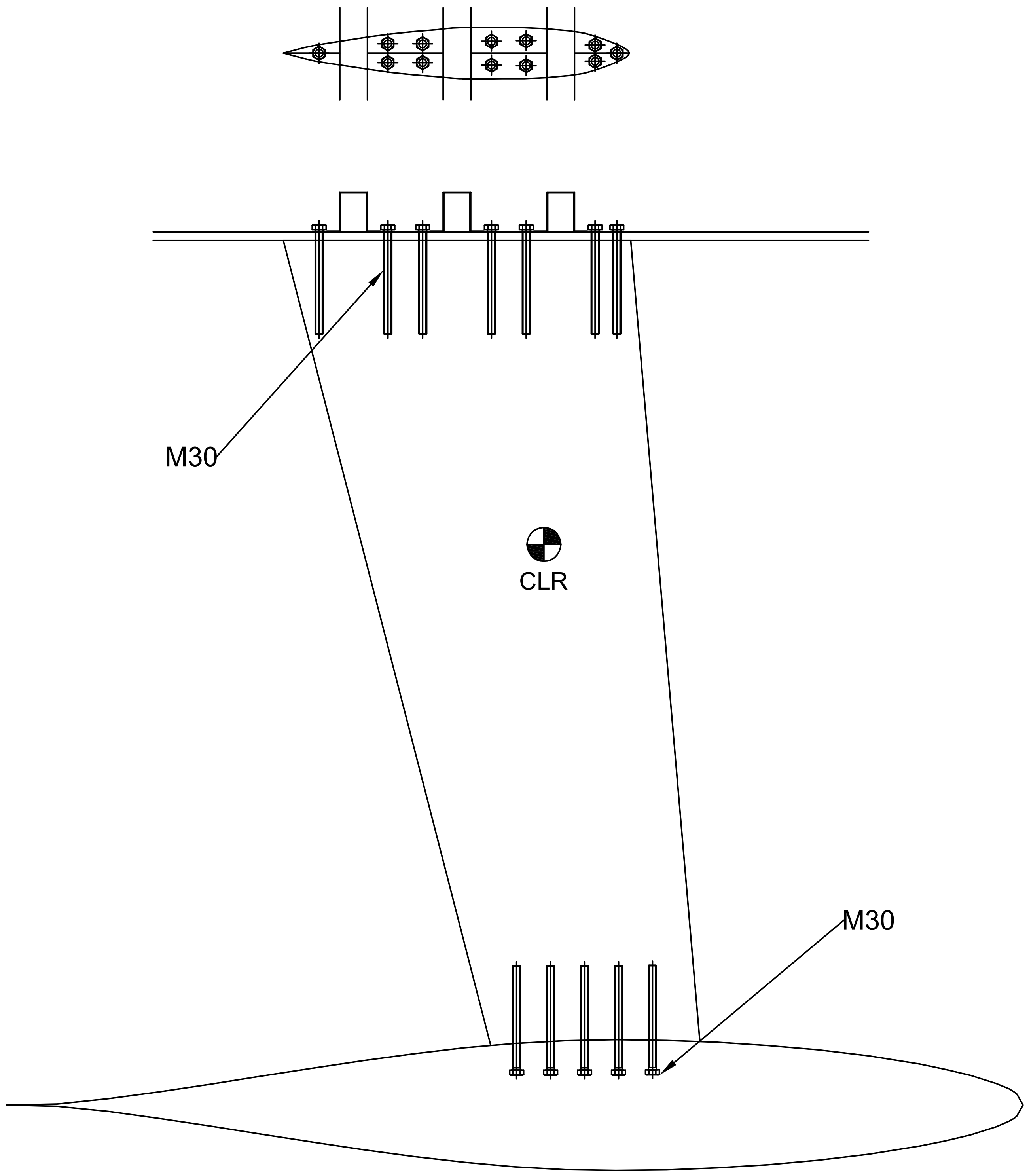
REV	DATE	REVISIONS	BY

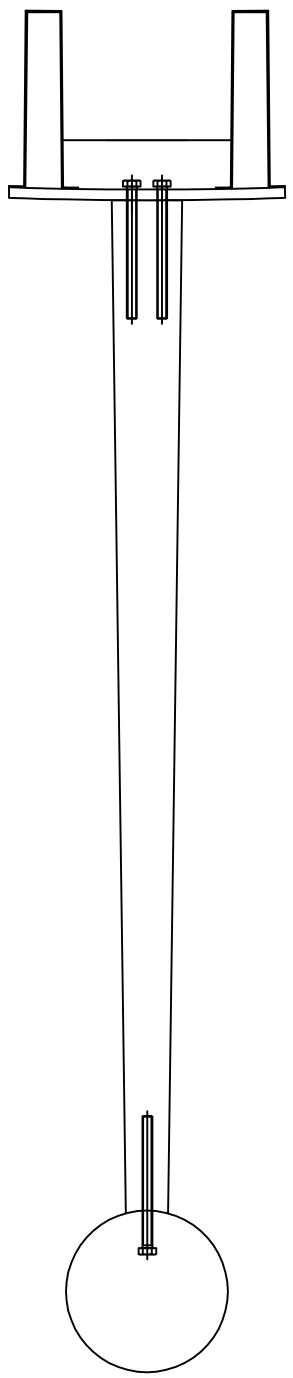
DRAWN BY: MLS 27 July 16
CHECKED BY:
APPROVED BY:
DRAWN BY:
SRI LESTARI MAHARANI

TITLE:
PROFILE & DECK PLAN

SHIP NAME:
ANT-ARCTIC-LAB 75'

Units	mm	SCALE	1 : 120 (A3)
DRW NO.	G-000	SHEET	1 OF 1





PRINCIPAL PARTICULARS

L.O.A	23.00 M
L.P.P.	22.93 M
BEAM MLD.	6.100 M
DESIGN DRAFT	4.163 M
Displacement	25.37 ton
Tc	0.487 m
Cp	0.54
LCB %	43.03
LCF %	40.42

Materials : Keel,cast iron with density 7800 kg/m3
Bulb,lead with density 11000 kg/m3

	M30	
pitch	2	mm
diameter	30.49	mm
Washer ID	33	mm
washer OD	58	mm
washer thickness	4	mm
nut	M30-3.5	
nut thickness	24	mm

REV	DATE	REVISIONS	BY

DRAWN BY: MLS	28 Sept 16	TITLE: KEEL AND BULB CONSTRUCTION	SHIP NAME: ANT-ARCTIC-LAB 75'
CHECKED BY:			
APPROVED BY:			
DRAWN BY: SRI LESTARI MAHARANI			
Units	mm	SCALE	1 : 50 (A3)
DRW NO.	G-006	SHEET	1 OF 1