Design of a 23 m modern-classic wooden sailing yacht with timber investigation

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Szczecin, February 2018

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ABSTRACT

Interest in to classic sailing yachts has been rising lately. Still, these kind of vessels are primarily reserved for small group of people, because of the high cost, demanding maintenance and big crew that is necessary for operating vessel.

Because of these drawbacks, new type of sailing yacht emerged, they are called modern-classic yachts. These yachts look as traditional ones above the water, but under the water they have modern hull and appendages. They are much more reliable, affordable and easier to sail.

Yacht that is presented in this Thesis, aims to place itself in this category. So it will use traditional materials, mostly wood, with some improvement of modern technology. It is common for this kind of vessels to unquestionably copy appearance of classic yachts, when it comes to part of the hull above water line and deck design. In this project author will question that idea and try not to mimic old designs, but instead try to design sailing yacht in a way that designers from classic era would, if they would design it today.

Design will be kept very clean and minimalistic. Volumes mostly shaped by aero and hydrodynamics, with no unnecessary details. Hull will be black, with one line to define physiognomy, on contrary, deck will be bright, in order to contrast hull and to make sailors job easier. Pure space with no obstacles, light so visibility is good and it doesn't heat up by sun.

In order to improve construction methods and materials used to construct modern-classics, two kinds of studies were conducted, both of them analyzing wood based construction materials.

First study was a series of destructive tests that were conducted on wooden samples with different scarf ratios. All of samples had scarf joints, but with different ratios. Test was conducted in order to determent how strong is each of these joints. This way results could be compared with empirical values used in ship construction.

In second study author was concern about longevity. It is possible to test samples of laminated wood in laboratories and determent their strength precisely, but it is unknown how will they behave in 50 years. Every day new, improved types of glue, get invented, but it is hard to predict their behavior on the long run. That is why part of this thesis was focused on discovering test method that will artificially age wood. So when artificially aged specimens are produced, it is possible to test them for strength as they were decades old.

Figure 1 – 3D visualisation of the vessel

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1. INTRODUCTION

The preliminary title of this Thesis was:

"Design of a 23m modern-classic wooden yacht

with

Comparative, destructive, structural testing of timber beams

and

Development of artificial aging method for timber-epoxy longevity"

This title was too long because the university regulations, but from it is possible to see that goal of this research is to find better methods for constructing wooden vessels in modern time. This being said, it doesn't mean that yacht design is just a model that was used to apply these techniques, because this vessels design is experiment itself, especially when it comes to space organization and visual features. Nevertheless it did enforce techniques that were tested in structural experiments.

Yacht is intended for a families with quests or companies who would rent it to different customers, luxury cursing ship that would go around Mediterranean sea, but could also cross Atlantic and visit Caribbean if necessary. With speed being welcomed but second to comfort.

Focusing on different aspects of ship design at the same time enabled author to look his work from different perspective, expanded his naval knowledge and it set a path for new ideas and solutions to be found.

Additionally, two kinds of structural experiments were conducted. First one was comparing different kind of scarf joints to each other. And second one, was validating new concept of sample production for artificial ageing of laminates.

2. DESIGN BRIEF

Since author has affection towards wooden yacht and wanted to do study wooden structures, modern-classic seemed like good choice (example in figure 2).

When it comes to size, multiple factors were analyzed. First of all, it was crucial to satisfy ISO standards, so standards for vessels from 2.5 to 24 m was chosen [13]. It is also known that more and more often yachts are purchased by companies and not private owners, so in order to be more competitive on the market it would be good if it had cabin for crew. Boat should be luxurious, so it need to fit all commodities.

Because of all these things previously stated, certain guidelines appeared:

- length should be somewhere between 22 and 24 m,
- wood as building material,
- modern-classic look,
- 6 passengers and 2 crew members,
- commodity has slight primate over speed and performance,
- appearance above waterline should be classical, but with conscience that vessel is from modern era,
- capable of category A certificate – RCD II ISO 12215/12217.

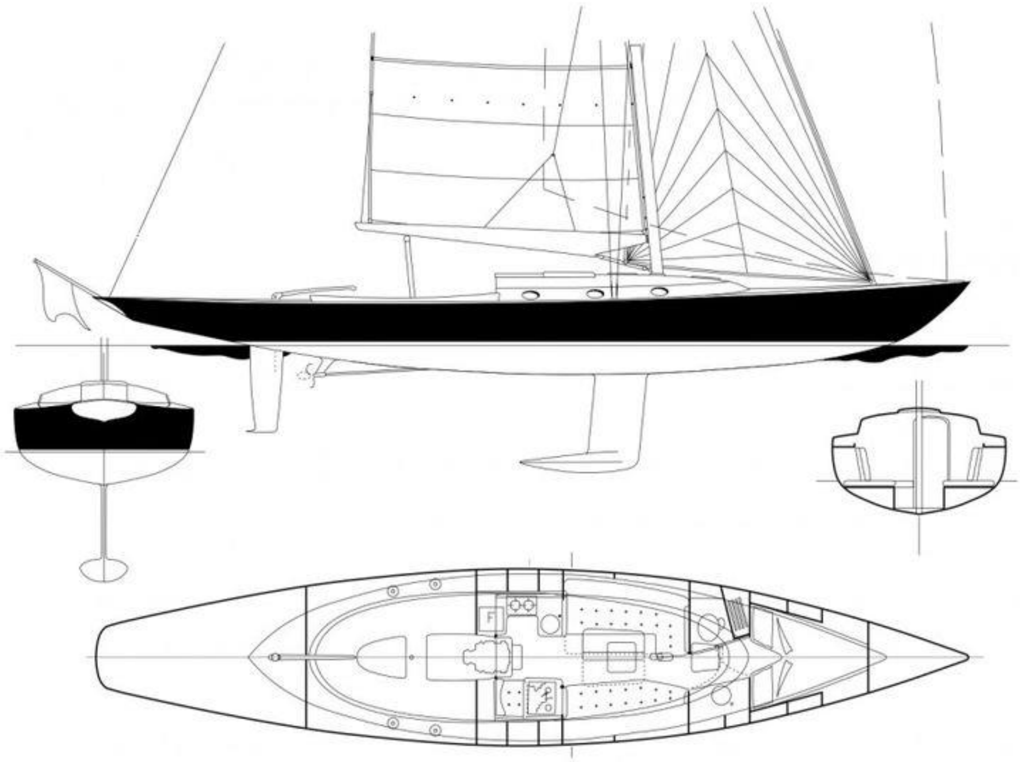


Figure 2- One of vessels designed by "Spirit Yachts", example of modern-classic concept

[https://spirityachts.com/sailing-yachts/the-classic/spirit-46/]

3. YACHT DESIGN

In this chapter, logic behind design choices will be presented and explained.

3.1 Concept

Idea was to create truly wooden boat, using traditional approach, with introduction of modern techniques up to certain level. Same goes for looks, traditional design was emulated, but with introduction of some modern technology, like laminated wood, it was possible to push design further. Finally, when it comes to performance, hull under the water is completely modern. So it's possible to spot common teem when looked on to structure, looks and performance. Author tried to design vessel in a same manner like designers from classical era would if they had our tools, methods and technology.

3.2 Parametric research

Modern-classic is a relatively new kind of vessel. There are many shipyards that try to emulate looks of classical boats, but often they don't use wood as construction material. Instead of that they use aluminum, fiberglass or even carbon.

That is why it was quite hard to find examples for case study. However, there are two shipyards in United Kingdom that specialize in this kind of crafts. First one is Spirit Yachts from Ipswich [www.spirityachts.com] and second one is Fairlie in Hamble [www.fairlieyachts.com]. Yachts from this two shipyards make list for parametric study with addition of "Wild horses", yacht designed by Joel White. Data was gathered from public domain, it was possible to find drawings, measurements and other information for every sample.

Author manage to find more examples, but even dough they were true modern-classics, because of different building philosophies, they would step away from parametric curve too far. On the other hand, some of boats that didn't get in to parametric study end up effecting design in some other way. For example, German Frers's Tulip (one of the vessels from parametric study) had a great influence when it comes to hull shape, but it could be used just as wage inspiration, since boat is made in aluminum and it's significantly larger.

All of vessels in this study had high chain spoon bow, but in order of getting cleaner design, author decided to go for straight bow. This wouldn't create big effect on displacement, since bow extension has low volume, but it change waterline length significantly (see figure 3). This is why when using parametric study, waterline length was rigged, so it correspond with vessel of same displacement but with spoon bow. This adjustment provided more relevant results, but also it created a safety margin which could be used if some other factors demand slightly different ratio.

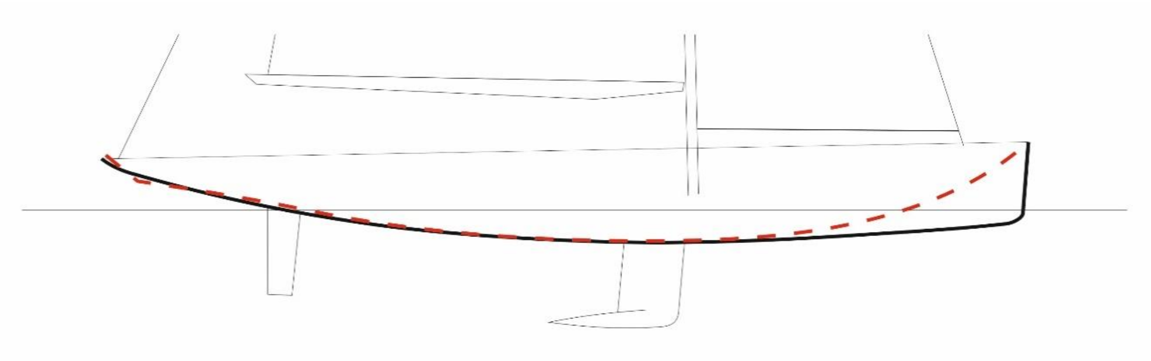


Figure 3 – Two boats with almost same displacement have different waterline because of different bow shape

This research provided all of basic ratios needed to start with design process, like Length to Beam ratio, Slenderness ratio, Ballast ratio, Sail Area to Displacement ratio and Length to Draft ratio. Process of design is a spiral, so all of these dimensions will be corrected during the process, case study gives information necessary for the first loop, in this case they are:

- LOA: 23.00 m,
- LWL: 18.00 m,
- BOA: 4.85 m,
- BWL: 4.30 m,
- Canoe draft: 0.80 m,
- Keel draft: 3.00 m,
- Displacement: 28.00 t,
- Ballast ratio: 0.39 %,
- Sail Area: 232.00 m^2.

See appendix A1 for ratio diagrams and yachts measurements.

3.3 Craft requirements and regulations

In order to be able to enter the market vessel needs to comply with certain regulations. Yacht is shorter than 24 meters and it's meant to be recreational vessel, apropos she will be verified using the recreational craft directive. In order to verify structure ISO 12215 [15,14,13] will be used. During the design phase, software HullScant [1] was used. This program is based on an ISO rules, but never the less elements were checked later, also some of elements program couldn't generate, such as floors, main girder and keel, so they were calculated directly from the rules (ISO 12215).

When it comes to stability, ISO 12217 [17] was used, but in first stages of designing Maxsurf Stability was in use Maxsurf. Since Maxsurf [2] still rely on old version of ISO standard, manual check with new version was necessary.

When designing rig construction, it was done following GL's Guidelines for Design and Construction of Large Modern Yacht Rigs [3]. This was necessary since there is still no ISO standard considering rig design.

3.4 Hull design

Main mission of any modern-classic design is to capture the spirit of the classic era, but with performance abilities of modern time.

Base for hull design was parametric study, this is what provided starting outline that was later shaped in to final hull. Aesthetics played major role, since it was important to emulate appearance of classical vessel. Straight bow was chosen in order to get clean design without superfluous details and shapes. For same reason aft without any transom was chosen, to create a feeling that hull is graceful shape that could be generate with little struggle, buy curving materials in hydrodynamic form (figures 4 and 5).

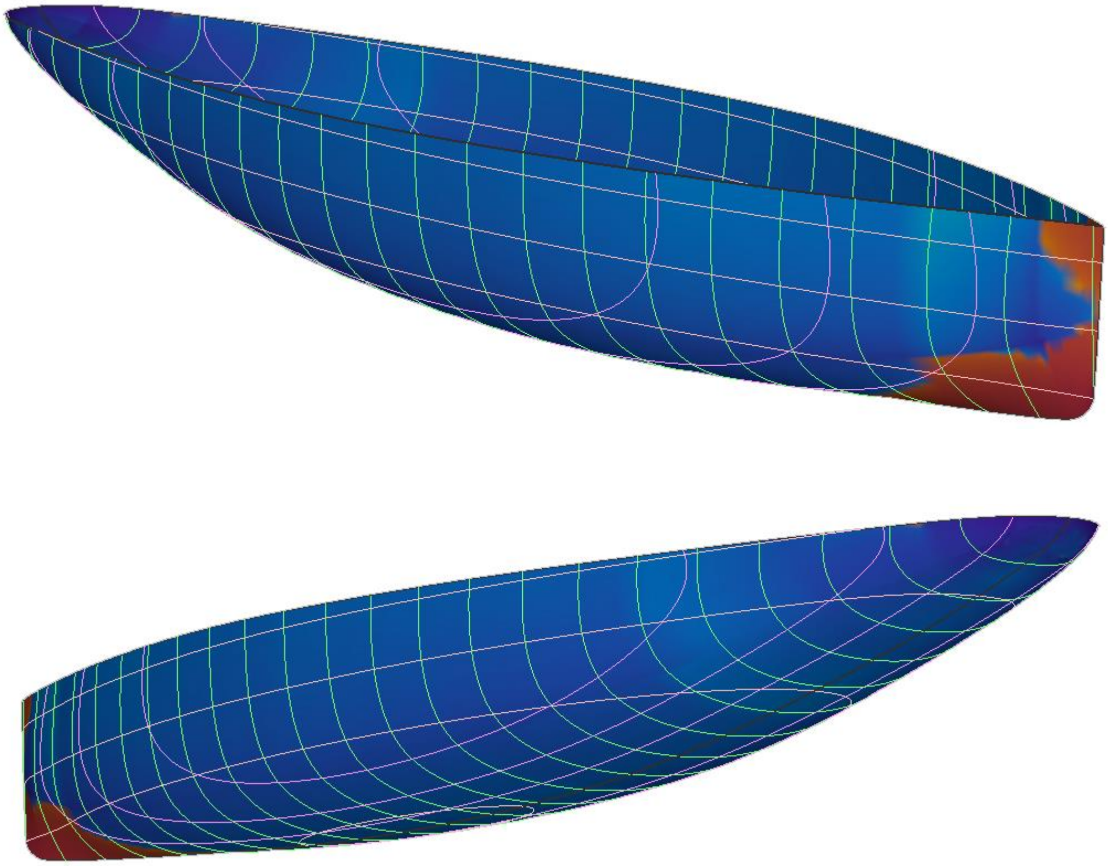


Figure 4– Back/Port view of hull

Looking at model, it is noticeable that is quite smooth, blue area is convex and red are is concave.

At midship we can see that hull has “U” shape, this makes C_M quite high and directly affects resistance. Certainly shape that is more close to “V” shape will produce less resistance and make vessel more efficient, but this would be achieved by hurting transversal stability. If this was racing hull this would be small cost to pay, but since hull designed here is for cruising yacht, comfort of passengers comes first. “U” shape will provide extra stability and more space inside, which is crucial for comfortable voyage (figure 5).

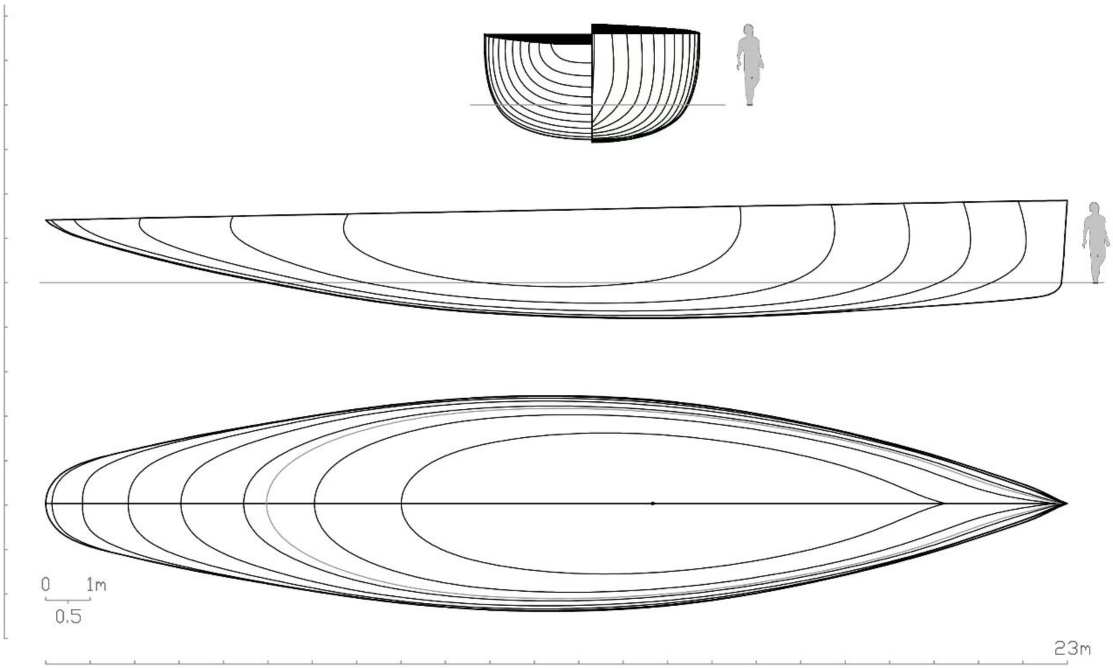


Figure 5 – Hull lines – produced using FormSys MaxSurf – More detailed lines plan is in appendix

Nevertheless, effort to reduce resistance was made. MaxSurf [2] was used to achieve high fairness of the hull. Also, canoe draft is made to be very low, which helped with resistance.

3.5 Deck design

Same principle of smooth and clear design was applied on to deck. Ideally deck would be completely flat. This would make sailors happy as well, since they would gain clean podium to perform during sailing, without any obstacles. That is the cleanest and minimalistic it could go, but this was not possible since space inside would be limited.

Classical approach is to make superstructure, deck house, this way more internal space is gained. This is very practical solution, provides needed space and light, but when it

comes to design aspect, this solution creates two separate entities, hull and superstructure are not the one anymore. Definitely, there is many good looking boats that went for this solution, but too many times deck looks like plate with piece of wedding cake on it (deck house would be the desert in this allegory).
Solution was needed, one parameter that must be satisfied was clean deck with no obstacles. So author tried to "inflate" deck at place where extra space was needed. Bubble was created in the middle of deck, this way disturbance of deck was minimised. It's basically still flat deck that was just lightly "pushed up" at place where this was necessary (figure 6).

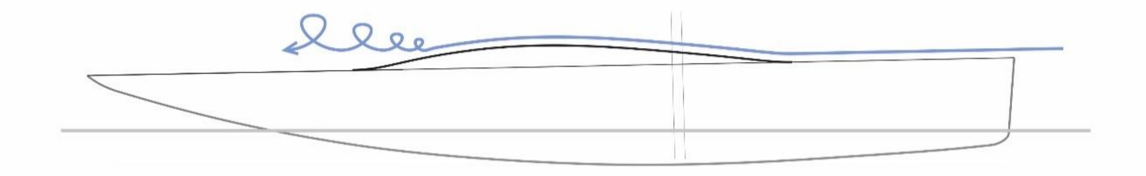


Figure 6 – Aerodynamic shape of superstructure

One more thing that was concerned was aerodynamic of this new volume, but since it was bubble, it was not hard job shaping it in aerodynamically friendly shape.
During sailing guest are supposed to stay in cockpit, while crew does the sailing. There is a rail connecting cockpit and main entrance so guests can climb in safely. Also, there is second entrance, from owner's cabin directly to cockpit.
This shape is also not demanding when it comes to production, after all it follows the same principles of geometry as some parts of hull. Frames will be made out of laminated wood, so it will be easy to model described volume.

3.6 System engendering

Since this is preliminary design, not all the systems will be presented to the same level of detail, but all mediums available will be used in order to achieve feasible design.

3.6.1 Powering

Once hull was designed resistance was calculated using MaxSurf [2], yachts hull complies with Delft Systematic yacht hull series [4], so analysis could be considered quite precise. Firs weight estimation was done using parametric study, and later it was updated after every loop passing on the design spiral.

Since this is preliminary design, for sailing vessel where engine will be mostly used in marina and as a generator, MaxSurf [2] analysis and parametric study were considered as exact enough tools for this task.

After conducting resistance analysis it was noticed that engines from parametric study wouldn't have problem satisfying necessary power expectations. Most of yacht from parametric study used Yanmar engines, so Yanmar (*4JH4-HTE Series*) [www.yanmar.com/media/global/com/product/marinepleasure/sailBoatPropulsion/catalog/Yanmar-4JH4-HTE.pdf] was suggested for this vessel as well.

Analysis showed that chosen engine, could bring boat up to 10.5 knots, what is much more than needed to go around the marina. Only reason size of engine wasn't reduced is because engine will be used as electric generator as well.

The Specific Fuel Consumption (SFC) was computed using engines brochure, theoretically if vessels goes maximum speed, it would have range bigger than 370 nautical miles, which is more than enough for this kind of vessel.

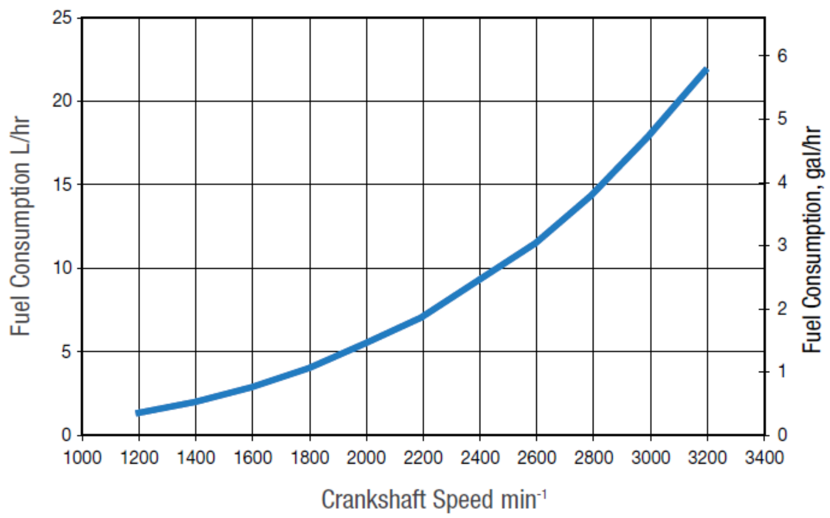


Figure 7 – Fuel Consumption curve – Yanmar brochure
[www.yanmar.com/media/global/com/product/marinepleasure/sailBoatPropulsion/catalog/Yanmar-4JH4-HTE.pdf]

To find propeller diameter *Propeller Handbook by Gerr* [5] was used. In this book there are two ways to estimate propeller diameter, but one that is based on HP and RPM was used. Method is valid for three blade propellers that have oval (flat-face) section and blades widths that are close to 0.33 mean-width ratio:

$$D = \frac{632.7 \times SHP^{0.2}}{RPM^{0.6}} \quad \text{Eq. 1}$$

Where:

D – Propeller diameter in inches

SHP – Shaft horse power at the propeller

RPM – Shaft RPM at the propeller

This is an empirical equation that has been proven to give good initial estimation, values that could be used in order to continue with design spiral. After running numbers trough this engineering tool it was calculated that propeller for this vessel should have 32.45 cm diameter, what is in a range of expected diameters for vessels of similar size.

When selecting gear box (Yanmar - KM35A/35A-2), one with 2.64 reduction ratio was find to fit engine.

3.6.2 Other Systems

Author didn't go into small details when it comes to rest of the systems, but all of them were considered during designing and developed to the general level. This is a preliminary design, so this details were not crucial. On the other hand, weight estimation was done precisely in order to have clear picture of boat performance. That is why all systems were considered and all the items are listed in weight estimation table. Also, size of all the tanks (fuel, fresh water, grey water and black water) was calculated since this is something that effects stability quite a bit (figure 9). Fuel tanks are made narrow in order to fit space as close to center of gravity as possible, this way fuel amount won't affect trim, there was simply no space under the floor of saloon, due to structure elements. Another factor that has to be considered are batteries, so consumption of electricity was estimated, in order to find exact weight of batteries. When selecting equipment, author mainly relied on supplier's catalogues [6] and recommendations.

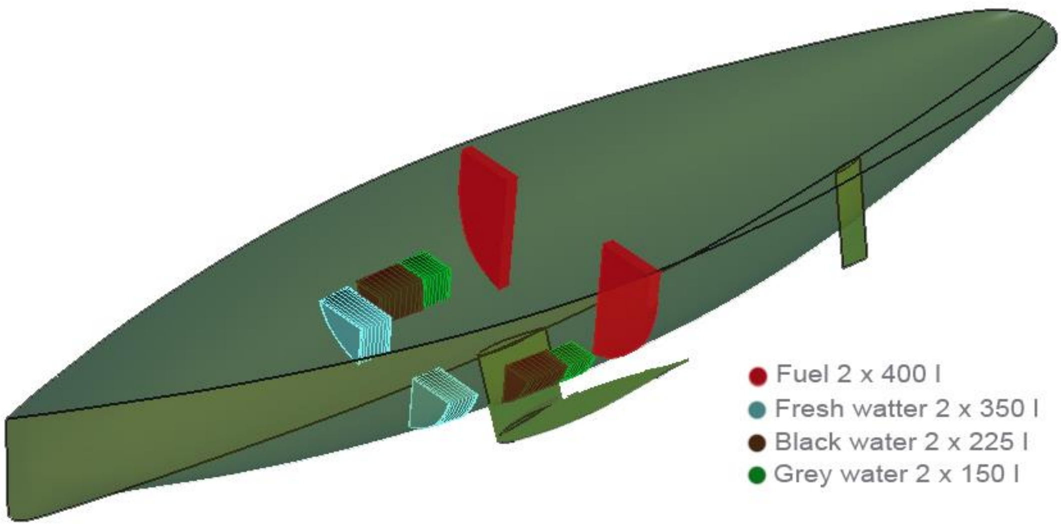


Figure 8 – Positioning of tanks – produced in order to calculate stability

In order to predict AC/DC consumption, table containing all electrical loads of the vessel was developed. Few assumptions were made when it comes to time running per day for each item and loads were gathered from manufacturers.

After analyzing data it was confirmed that chosen engine could be used as generator as well. Spreadsheet with all electrical loads is in appendix A2.

3.7 Sail Plan, Appendages and Rig Design

3.7.1 Sail Plan

Starting point for design of sails plan was sail area, this information was gained from parametric study, conclusion was that sail area should be somewhere around 233 m^2. Author chose standard Bermudian Rig, starting ratio between main sail and jib was 65 to 35 percent, but after some adjusting, mostly due mast positioning, ratio was changed to 32 to 68 percent.

After finishing drawing, guided by previous stated rules, main dimensions were gained. Height of the mast is 28.3 meters, area of main sail is 157.3 square meters and jib is 75.74 square meters, so 232.7 square meters in total. When standing in cockpit, boom is at 2.2 meters height, which makes possible for people to stand up.

3.7.2 Keel and Rudder Design

Keel and rudder are in direct correlation with sail area. If keel area is too small, boat would start moving sideways and it would heel too much, but if it was too big it would generate extra weight and yacht would be slow. So it’s crucial to design it wright size.

First thing to calculate is SFF, Sails Side Force, since this is the force keel is fitting in order to put boat in balance. To get this value sail lift and sail drag are necessary.

Sail Drag force [39]:

$$D = 0.5 \ x \ \rho_{air} \ x \ A \ x \ V^2 \ x \ C_D \qquad Eq. 2$$

Where:

ρ – *density of air (kg/m³)*

A – *sail area (m³)*

V – *speed (m/s)*

C_D – *the drag coefficient*

Drag coefficient (C_D) [39]:

$$C_D = \frac{C_{Dp\ main} \ x \ A_{N\ main} + C_{Dp\ jib} \ x \ A_{jib}}{A_{N\ main} + A_{N\ jib}} \qquad Eq. 3$$

Where C_{Dp} is parasitic drag coefficient, which was obtained using diagram presented on Figure 9.

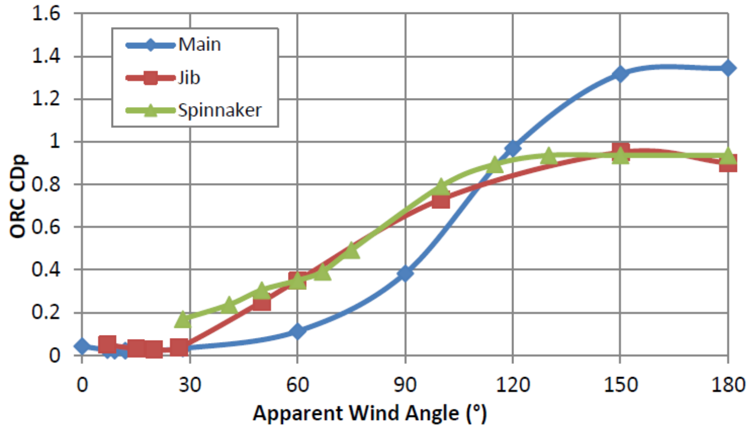


Figure 9 – Parasitic drag coefficient - Offshore Racing Congress (2013). ORC VPP Documentation.

Once drag is sail drag is obtained, next value needed is lift.

Sail Lift force [39]:

Eq. 4

$$L = 0.5 \text{ x } \rho_{air} \text{ x } A \text{ x } Va^2 \text{ x } C_L$$

Where:

ρ – *density of air - 1.225(kg/m³)*

A – *sail area (m³)*

Va – *Apparent wind speed (m/s)*

C_L – *the lift coefficient*

For this occasion apparent wind speed was taken to be 16 kts (8.23 m/s)

Where lift coefficient was computed using same principle as drag coefficient.

Lift coefficient:

$$C_L = \frac{C_{L\,main} \times A_{N\,main} + C_{L\,jib} \times A_{jib}}{A_{N\,main} + A_{N\,jib}} \qquad \textit{Eq. 5}$$

Where $C_{L\ main}$ and $C_{L\ jib}$ was taken from graph below.

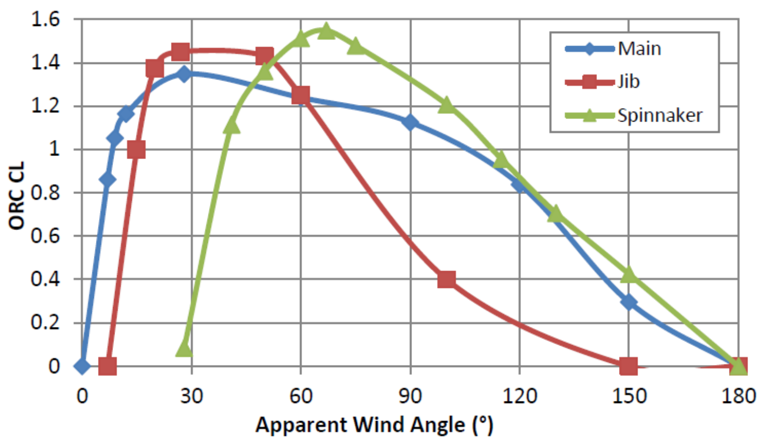


Figure 10 – Lift coefficient - Offshore Racing Congress (2013). ORC VPP Documentation.

When drag and lift are obtained everything necessary to obtain sails side force is known.SFF (Sail Side Force) [39]:

Eq. 6

$$SFF = L \cos \beta_A + D \sin \beta_A \text{ (kN)}$$

Where:

β_A – Angle between Apparent wind speed and yacht heeling (in this case it was 30°)

Now when sail side force is known, keel side force needs to be created to match it. In theory these two forces should be equal and they are, but not hundred percent of side force is provided by keel and rudder. Some of side force comes from canoe body of the yacht, modern-classic hulls have shallow draft, so estimation will be made that canoe body crates only ten percent of side force. That is why [39]:

$KSF = 0.9 \times SSF$ *Eq. 7*

Next step is to calculate area of keel. Formula that computes lift of the keel is using area of the foil. So, if estimation is made that L is equal to 0.9 of SSF, all factors necessary to calculate area are known.

Eq. 8

$$A = \frac{0.9 \times SSF}{0.5 \times \rho \times V^2 \times C_L}$$

Where:

A – *Area of keel and rudder combined*

ρ – *Water density*

V – *Speed of the vessel is correlation with speed of the wind*

C_L – *Keel lift coefficient*

C_L was obtained from NACA 65 0012 lift coefficient graph, estimated leeway angle was 3° (figure 12).

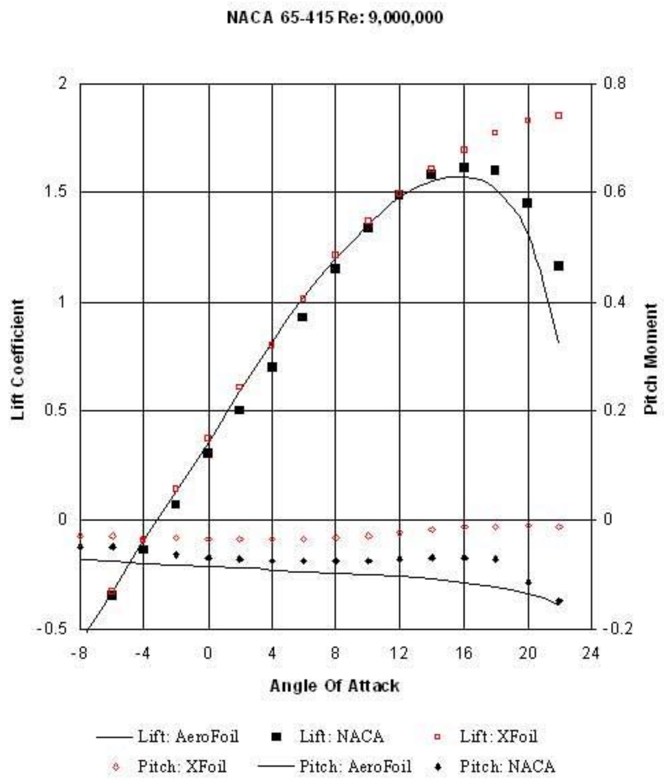


Figure 11 – Lift coefficient diagram for NACA 65 0012 foil section [https://www.google.pl/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&ved=&url=http%3A%2F%2Fslideplayer.com%2Fslide%2F3520095%2F&psig=AOvVaw3vUaFDRO-_Xm2zQ4mYi1OC&ust=1512844955311551]

Now that combined area of keel and rudder is known it is necessary to divide it among these two foils. Examples from parametric study were examined and it was decided that 70 percent of area should go to keel and 30 percent to rudder.

Shape of keel was inspired by drawings from case studies, with slope designed to respect Taper ratio. According to this ratio, tip and root should have 0.45 ratio, first this kind (trapezoid) keel was drawn, but then (in order to satisfy parametric study) trailing edge was pushed so it creates rhomboid shape of keel.

When it comes to rudder design, it was noticed that Jafa rudder [35], model: RUD48R, with 16% of core to thickness ratio, satisfied both size requirements from previous computation and shape requirements by parametric study. That is why it was chosen for vessel.

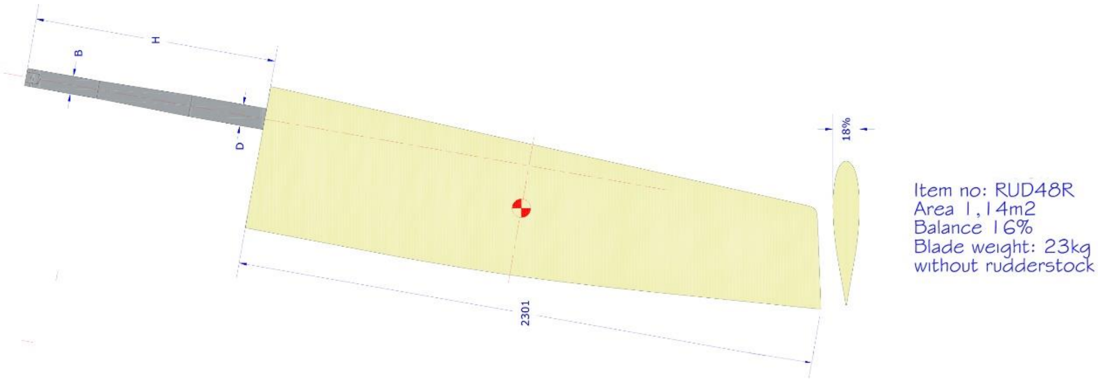


Figure12 – Rudder design chosen for yacht – from Jafa Rudder Systems [http://www.jefa.com/rudder.htm]

Exact position of KSF center was needed, this was solved geometrically. It was assumed that lays somewhere on a line (orange) between center of are of the rudder and center of keel. So two lines (blue and green), perpendicular to this imaginary line, were drawn. Each going in opposite direction, with length proportional to area of each foil, length of line representing area of rudder (starting from center or keel area) was drawn up till 40 percent, since that was estimated contribution to lift by rudder. When two tips of these lines were connected, new line (red) emerged, this line is sharing intersection with imaginary line (orange) connecting two centers of area of the foils, at this intersection center of KSF lies (Figure 14).

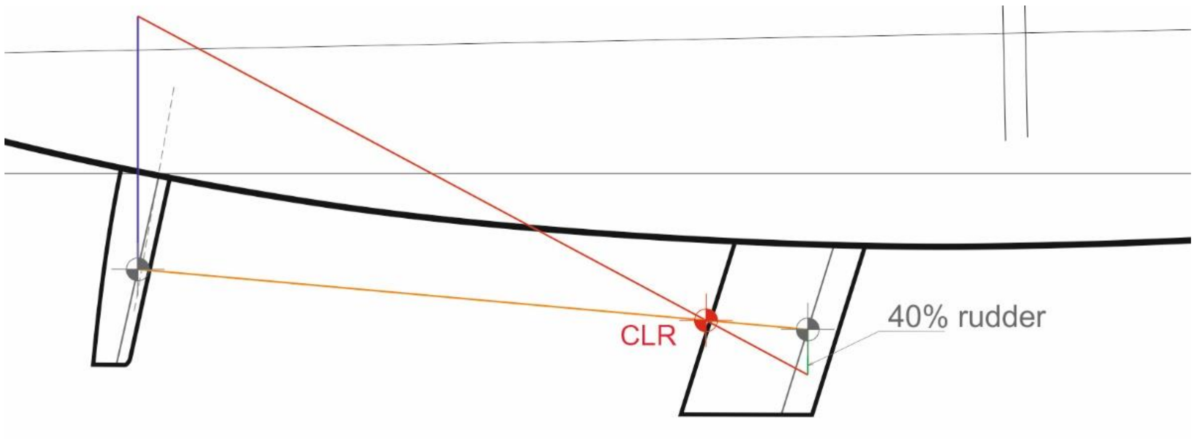


Figure 13– CLR positioning

3.7.3 Bulb design

In order to place center of gravity as low as possible, the bulb was needed. Many criteria were considered when designing bulb. First of all which profile would have best hydrodynamic performance. For this reason, article from Professional Boat Builder [7] was considered.

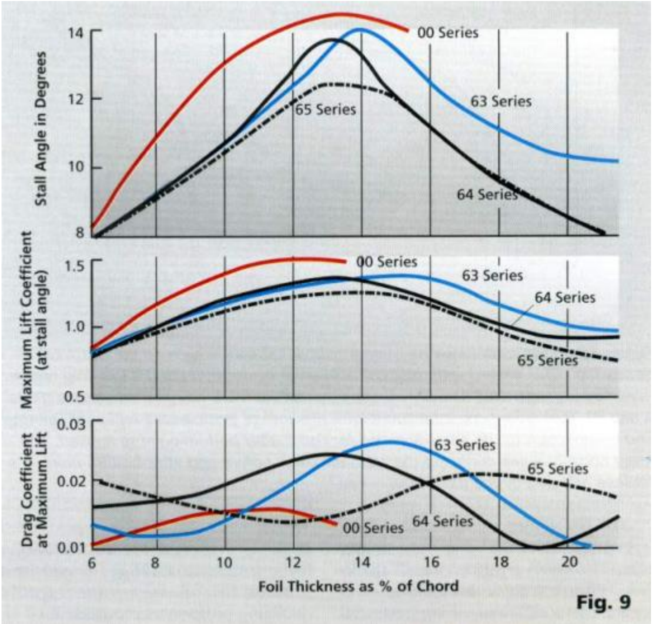


Figure 14 – Comparison of different NACA section for bulbs – from Professional Boat Builder magazine

Second criteria was ballast ratio, since yacht should have 35% - 40% ballast ratio it was necessary for bulb to obtain certain volume.

Also, since it was crucial to bring center of gravity as low as possible it was decided to use two different NACA sections for bulb, so bulb has wider beam than depth, with length of 4.35 m.

After all these concerns bulb shape was defined:

Bulb water plane section: NACA 65 0017

Bulb buttocks section: NACA 65 0012

Keel fin: NACA 65 0012

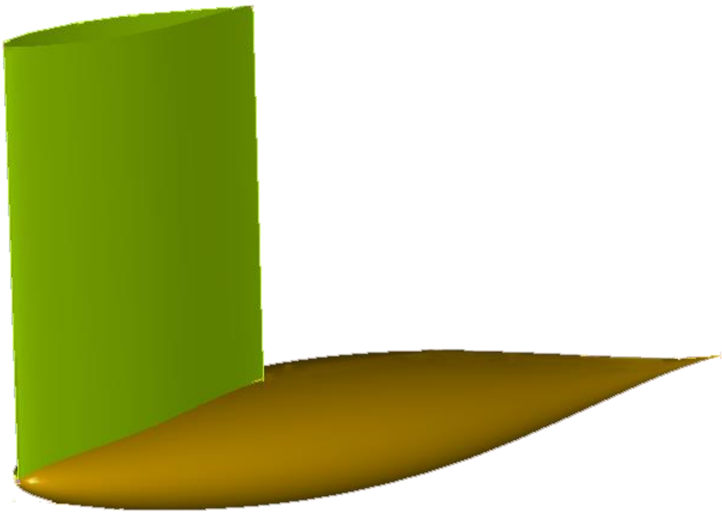


Figure 15 – Bulb with keel fin

This shape of keel and bulb does five great performance when it comes to stability, but this is geometrical shape that will produce a lot of stress at joint of bulb and fin. Since bulb is made out of lead and keel fin is made of cast iron, steel reinforcement will be necessary.

3.7.4. Bulb and Keel Structure

Keel structure, as many features of the keels, is something that many designers and builders like to keep for them self. This is one of those hidden elements that can improve general performance of the vessel a lot.

Many times reinforcement of the keel is not even necessary, or it can be accomplished with some simple elements as bars or plates. Also, since keel is often made out of lead, steel mold can became casing that is also reinforcement for the element.

But in this case, keel has challenging shape, it looks like fin with large console, made of lead, this can potentially cause many problems, especially it could produce afflux of stress at corner where foil meets the bulb and lead is very ductile material.

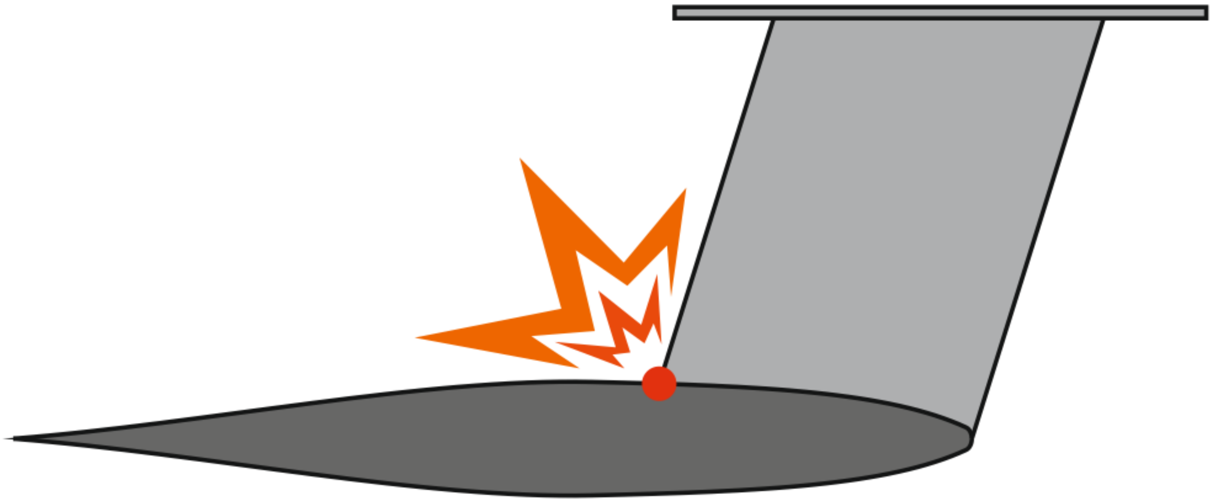


Figure16– Potentially problematic spot for the keel

In order to solve these problems, author reached for structural solutions usually used in different industry. His suggestion would be to use steel reinforcement or steel cables that were prestresed, like those used for bridge constructions.

3.7.4 Lead

As previously discussed, CE and CLR should be in balance. Modern-classic yachts from the parametric study have lead between 6% and 10%, which is considered not unusual for yachts with similar hulls [8]. On the drawing below, both 6% (blue) and 10% (red) lead is annotated and its noticeable that lead of this vessel is located wright in between those two values (closer to 10%), what was the goal of the design.

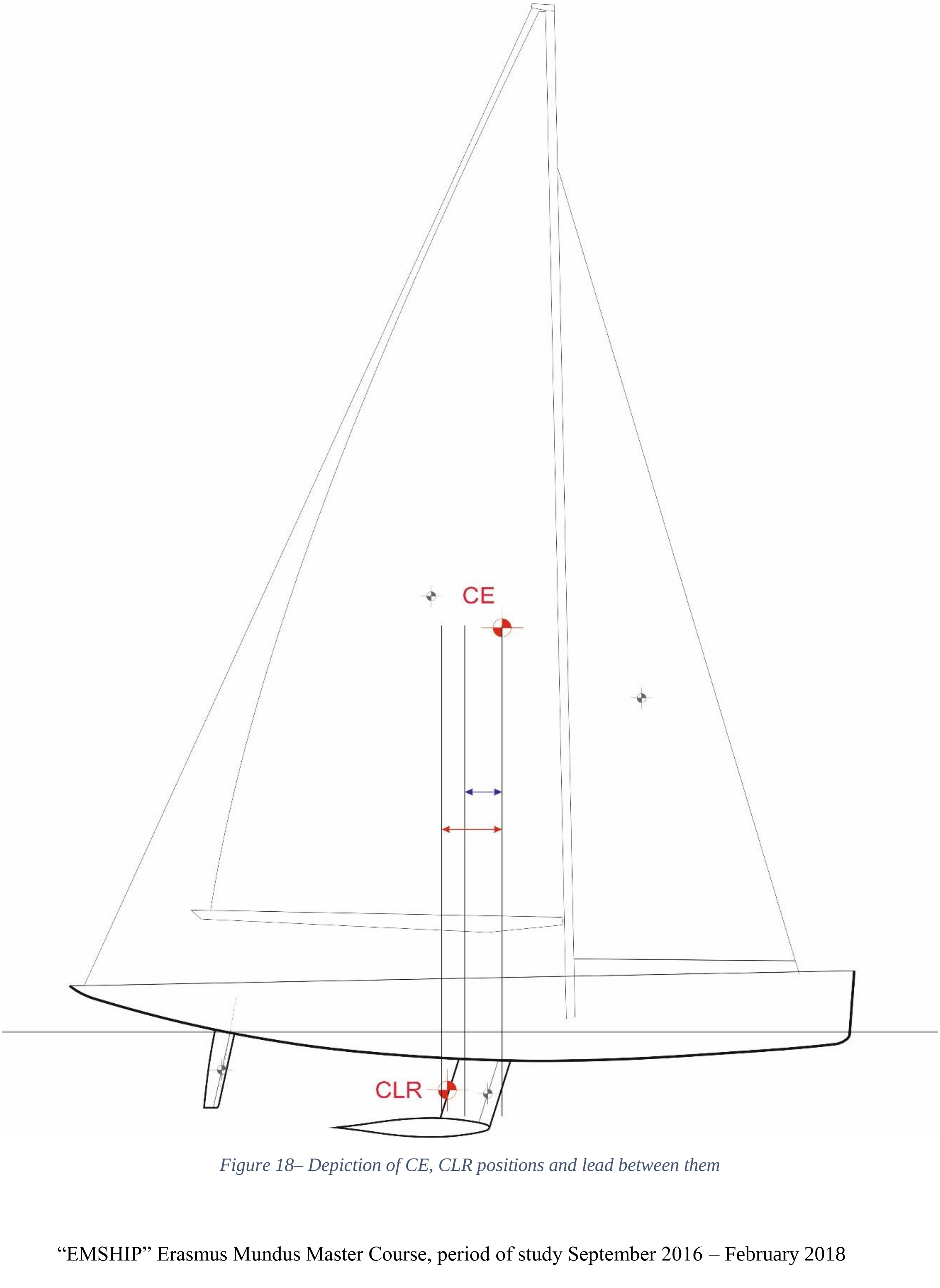
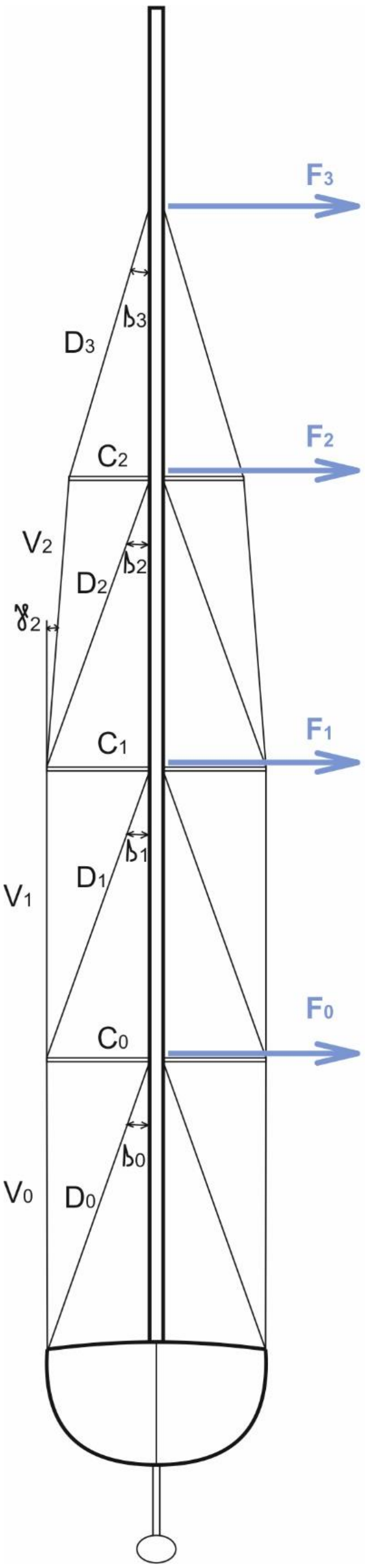


Figure 18– Depiction of CE, CLR positions and lead between them

3.7.5 Rig design

Now that sails are defined geometrically, rig construction should be computed. Rig should be able to stand forces that are coming from pressure wind applies to sails. When this force is applied we are considering that boat is heeling 30^o, what is standard in industry. It was decided to go for mast with three spreaders, since mast is relatively long, this way mast will be stiffer and it will have smaller section. On the other hand, this decision excluded using some of commonly used standards. Rig design was verified using GL standards [3], Nordic Boat standards [9] and ISO standards [10].



3.7.5.1 Shrouds and stays

In order to calculate forces in shrouds and stays it was necessary to calculate transverse forces in main sail (Ftm), jib (Ftf) and spinnaker (Fts). This was done using Germanischer Lloyd [3] standard, this can be further exanimated in appendix.

According to GL:

$F_0 = 0.05 \times Ftm$ [Eq.9]

$F_1 = 0.15 \times Ftm$ [Eq.10]

$F2 = 0.25 \times Ftm$ [Eq.11]

$F3 = 0.3 \times Ftm + 0.4 \times Ftf + 0.4 \times Fts$ [Eq.12]

According to ISO 12215 – 10:

$D_3 = F_3 / \sin\beta_3$ [Eq.13]

$V_2 = F3 / (\cos\gamma_2 \times \tan\beta_3)$ [Eq.14]

$C_2 = F_3 - V_2 \times \sin\gamma_2$ [Eq.15]

$D_2 = (F_2 + C_2) / \sin\beta_2$ [Eq.16]

$V_1 = (F_2 + C_2) / (\cos\gamma_1 \times \tan\beta_2) + V_2 \times \cos\gamma_1 / \cos\gamma_2$ [Eq.17]

$C_1 = F_2 + C_2 + V_2 \times \sin\gamma_2 - V_1 \times \sin\gamma_1$ [Eq.18]

$D_1 = (F_1 + C_1) / \sin\beta_1$ [Eq.19]

$V_0 = (F_1 + C_1) / (\cos\gamma_0 \times \tan\beta_0) + V_1 \times \cos\gamma_0 / \cos\gamma_1$ [Eq.20]

$C_0 = F_1 + C_1 + V_1 \times \sin\gamma_1 - V_0 \times \sin\gamma_1$ [Eq.21]

$D_0 = (F_0 + C_0) / \sin\beta_0$ [Eq.22]

Using this formulas it was possible to calculate all forces in shrouds and stays.

Figure 19– Forces in Shrouds and stays

Using GL standards it was possible to calculate Halyards, standard uses pressure from sails and amount of aloud sagging in cable.

After examining loads and applying safety factors, it was decided that all shrouds should have same thickness, since if it was done other ways diameters wouldn’t wary negligible. Alloy chosen for the wire is Nitronic 50 Coil, with diameter of 9.5 mm and minimum breaking load of 10200 kg.

3.7.5.2 Mast

Carbon mast would be the best choice for this type of vessel, never the less, since is more feasible and closer to practical conditions, author decided to design aluminum mast.

To calculate stresses in mast, one of crucial information is righting moment at 30^o, this information is obtained from MaxSurf [2], but also checked according to Nordic Boat standards [10].

$$RM_{30} = GM \times D \times \sin 30^o \times \cos 30^o \times g \qquad \text{Eq. 23}$$

Where:

RM_{30} – *Righting moment at 30^o*

D – *Displacement*

g – *Gravitation acceleration*

With known RM, it is possible to calculate design load (PL) for each panel, highest load was in first panel:

$$PL = (1.5 \times RM_{30}) / b \qquad \text{Eq. 24}$$

Where:

b – *Shroud base (m), distance from mast to point where shroud is attached to deck*

Next step is calculating of transverse second moment of area (Ixx), since, potentially this could be done with could be done with Nordic Boat standards, but since design has three spreaders (Nordic Boat Standard can deal with one or two) *Buckling theory Masting and Rigging Notes*[11] by Stephen Wallis will be used.

$$I = \frac{P \times L^2}{n \times \pi^2 \times E} \qquad \text{Eq. 25}$$

Where:

L – *Length of panel*

n – *Safety factor, in this case 2.05*

Same principle, with different load is used to check longitudinal section moment of area (Iyy).

Each panel of the mast has different loads, but it was decided to use uniform section for entire length of mast, therefore the panel with most load dictates section size for the rest. Mast section was chosen from Selden catalogue (section C285) was chosen. Dimensions of section are 285/147 mm, with Ixx = 1127 cm^4 and Iyy 3508 cm^4.

3.7.5.3 Boom

There is simple way to calculate boom size using Nordic Boat standard [10], it depends on to righting moment of vessel, same as for the mast.

Section modulus:

$$SM = 600 \times RM\ (E - d1) / (\sigma 0.2 \times HA) \qquad \text{Eq. 26}$$

Where:

HA – distance from waterline to center of effort (m)

E – Length of the boom (m)

d1 – Distance between boom and gooseneck (m)

In this case obtained section modulus was enormous, Nordic boat standard is in practice used for boats up to 24 meters, but originally was written for vessels up to 15 meters, therefore it can make mistakes when pushed to the limits.

In this case boom manufacturer (Selden) was considered, in catalogue there is table, which helps chose boom section according to features of the yacht. Most conservative measurements were put in table and section recommended is B380. Dimensions of section are 380/186 mm, with I_{xx} = 3283 cm^4 and I_{yy} 12030 cm^4. Proper depiction is in appendix, rig drawings.

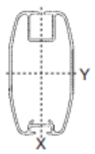
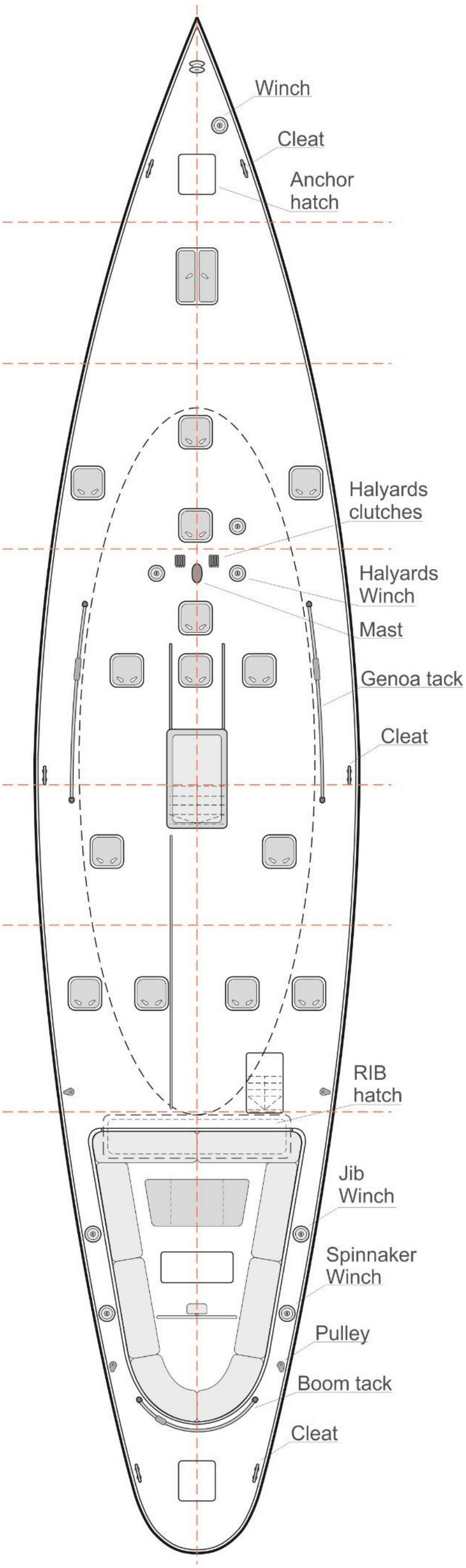
	Boom section	Dim., mm height/widht	I_y cm⁴	I_x cm⁴	Wall thickness mm	Weight kg/m	W_y^{min} cm³	W_x^{min} cm³	Sail groove mm
	B087	87/60	60.2	27.7	2.0	1.70	13.4	9.3	4.5
	B104	104/60	97.5	33.6	2.0	1.90	18.5	11.2	4.5
	B120	120/62	155	42.5	1.8	2.12	24.8	13.7	5.5 ± 0.75
	B135	135/71	265	70	2.0-2.8	2.66	39	19.5	5.8 ± 0.75
	B152	152/82	433	126	2.5-2.9	3.59	54.2	30.4	5.8 ± 0.75
	B171	171/94	726	189	2.3-3.2	4.66	80.6	41.2	5.5 ± 0.75
	B200	200/117	1280	343	3.1	5.88	121.5	61.3	6.25 ± 0.75
	B250	250/140	2706	692	3.2	7.95	200.1	101.3	6.25 ± 0.75
	B290	290/155	5209	1524	4.1	11.50	339	196	10.25 ± 0.75
	B380	380/186	12030	3283	4.5-9.0	17.80	586	353	No groove

Figure 20– Boom section – from Selden catalogue

[http://www.seldenmast.com/files/1322118734/595-808-E.pdf]



3.8 Deck Layout

Since this is cruising yacht, chosen deck plan is ferly simple, designed in a way where most of activity will be done around the mast, so guests can enjoy in the cockpit.

Although, main sail can be controlled from cockpit. Jib and spinnaker can be controlled with winches that are reachable from cockpit too.

Jib is attached to furler that is positioned in far front of the deck.

Halyards are guided at the mast, there are halyard clutches and three winches.

Wright behind furler is chain locker, which has enough space for anchor and sails.

There is technical hatch in cockpit, with life raft, but spare parts, gear as well and steering system.

Beneath the front cockpit seats is a long hatch. This hatch is for three meters long dingy, as well as for fenders and water toys. To store dingy, boom can be used as a crane.

Figure 21 – Deck plan

3.9 Structure

As most of modern-classics this yacht will have wooden structure. First ideas for structure were driven from parametric study [Apendix A1], most of examined vessels have hull made of planks that are covered with few layers of veneer and then whole volume is coated with sheet or two of fiberglass, just for water tightness.

To get first idea about structure Gerr [12] method was consulted. This is simple empirical method that will provide quick results, but not very precise ones. Usually elements are over-dimensioned, comparing to ISO or some other rules [14].

3.9.1 Gerr method

This method gets its name from its author, naval architect who developed it in order to get preliminary dimensions fast. Method could be compared to be precise as some rules of thumb, so it’s not tool for final results, but its perfect place to start.

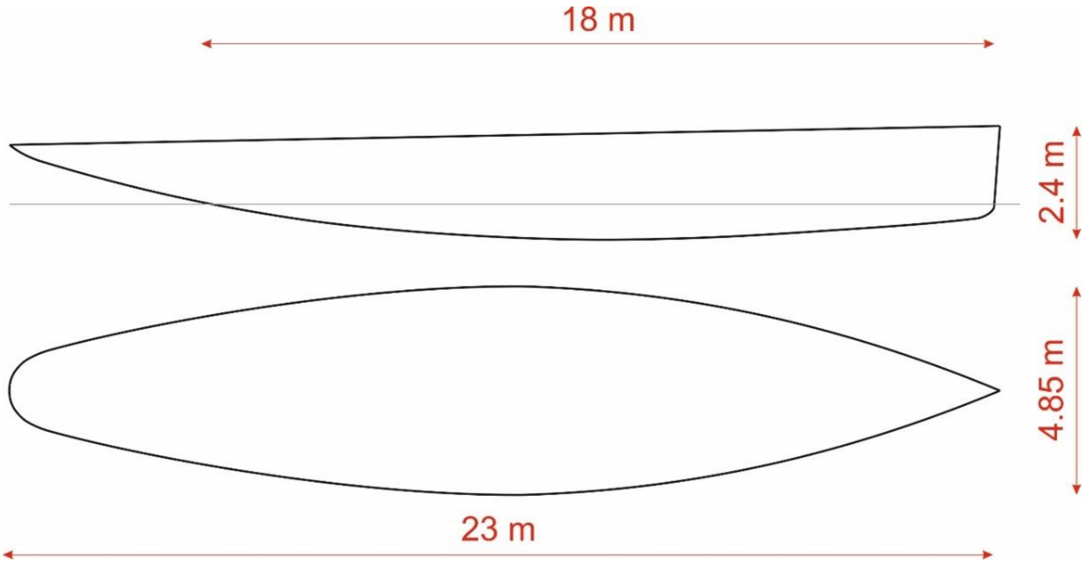


Figure 22- Hull with dimensions necessary to do the Gerr calculation [12]

LOA: 23m

B: 4.85 m

Depth of hull: 2.4 m

LWL: 18

SN = LOA x B x Doh : 28.32

SN = 9.5

SN is coefficient that is unique for each vessel and its used trough method to obtain dimensions of structural elements.

Plank thickness:

$0.74 \times SN^{0.4} = 1.82$ inc = 46 mm

This dimension is for strip plank construction, with no veneer and fiberglass.

Frame dimensions (Gerr see frame as square section, so this is dimension of one side):

$34.79 \times SN^{0.36} = 78.24$ mm

Method suggested that dimensions of frame sections of frames immediately ahead and aft of the partners should be increased by 20%.

Frame spacing:

$257.5 \times SN^{0.27} = 452.06$ mm

Strip – plank frame spacing:

4 x bent-frame spacing (but no more than 900 mm)

4 x 452.6 = 1891.5 -> 900 mm

Modern wood epoxy construction:

Reduction of planks:

$16.52 \times SN^{0.3} = 32.43$ mm

Double diagonal exterior wood veneer:

$(10.92 \times SN^{0.2}) - 8.13 = 9$ mm (two layers)

Hull sheeting fabric weight:

$1044 + (281.4 \times SN) = 3717.3$ g/m^2

Biaxial glass laminate:

(Weight of dry glass – 9.7) : 813 = 4.5 mm

Reducing of planking:

32 mm plank + 4.5 mm sheeting = 36.5 mm

36.5 – 9 mm veneer = 27.5 mm planking

Therefore, according to Gerr [12], hull structure would look as on figure 23.

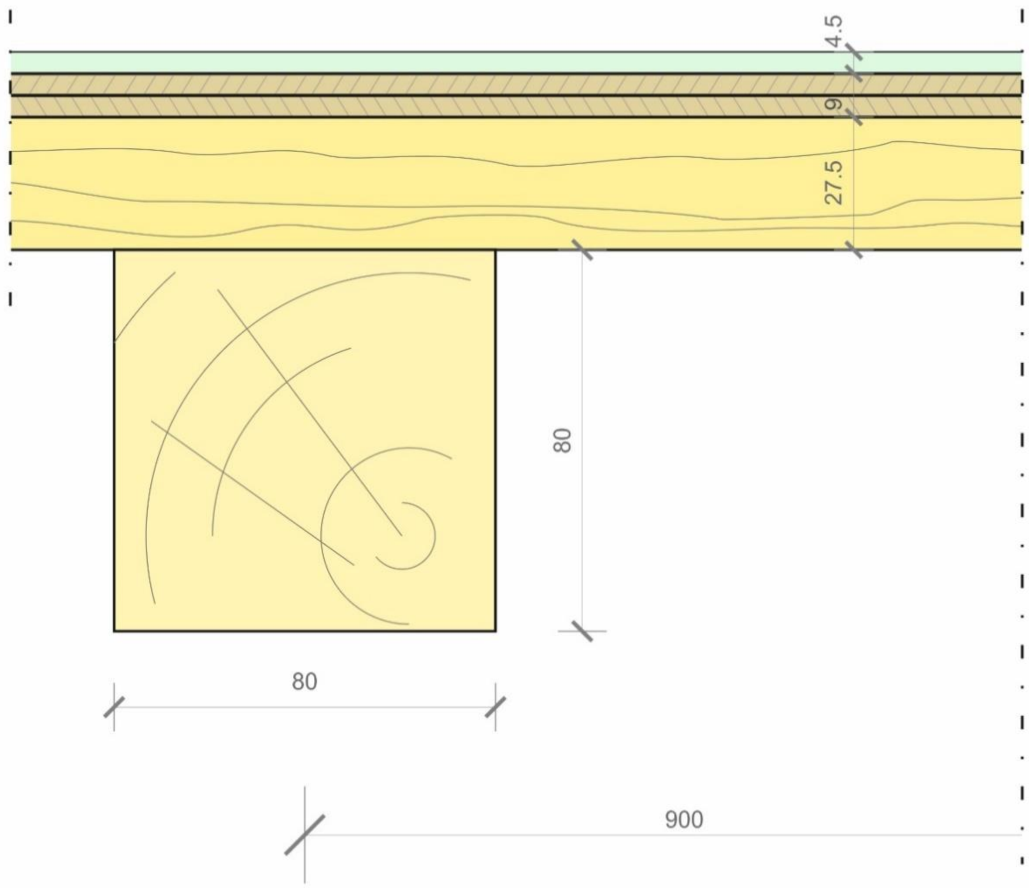


Figure 23 – structure elements according to Gerr

3.9.2 ISO Standard

To verify structural strength of the vessel, ISO 12215-5 [13] was considered. This standard covers vessels with length from 2.5 to 24 meters. Standard recognized four different categories of vessels: ocean, offshore, inshore and sheltered waters. This vessel was calculated with in the terms of ocean category (A). This is the category with highest requirements, since ocean has harshest condition, for example, standard predicts that yacht might encounter waves up to 4 m height. To be even more conservative, height of 7 m was chosen, by standard.

For any structure material is one of crucial factors. It was already been said that this yacht will be made out of wood, but not much about wood was said. Generally speaking, wooden boats have two main parts of construction, support made of frames and stringers and skin (hull) made of planks (or more layers, like veneer and fiberglass).

On figure below, this division is easily spotted, since empty hull is depicted, with no furniture, instruments, engine or tanks inside. On the photo elements of skeleton are shown (frames, keelson, flours and sprits) as well as planks that makes skin (hull).

Figure 24 – Example of modern – classic structure – Spirit yachts (Yacht 56)

[https://spirityachts.com/sailing-yachts/the-classic/spirit-56/]

Vessel presented in this theses will have same type of construction (figure 24), strip-plank plus cold molded veneers (wood epoxy). Skeleton and skin will both be made out of wood, but since these two elements have different roles, different kind of wood will be used.

Frames will be made out of oak. Oak is easy available almost everywhere, and traditionally was proven to be good wood for structural elements. Frames have to be made from hardwood and oak is hard wood, very strong. Oak is very dense wood, which is why it’s capable of bearing stresses, but because of this it’s quite heavy. There are some types of wood that are quite strong, but also light, like mahogany, but they are much more expensive. That is why oak was chosen, with the best characteristics when big picture is examined.

Traditionally, frames for wooden boats are made using steamed wood. Since different wooden glues are around since Second World War and new glues are invented every day, this project will use frames composed out of laminated wood. Laminate frame is easier to produce, especially if it's big frame (like in this project), dimensions of frame sections are much less restrictive as well as overall shape of the frame.

When it comes to planks, read cedar was chosen. This wood is most used wood for planks, it's very light, but still very strong. All of the examples from case study used this material for hull.

3.9.2.1 Structural calculations – Frames and plating

To obtain main structural elements, frames and plating, a software called "Hullscant" [1] was used. This software uses ISO 12215 [13] as its base.

Hull can have very few big frames and thick plating over it, or a lot of small section frames with very thin plating on top. Those are two extremes, best solution (when it comes to cost and weight) is somewhere in between. Author used Hullscant [1] to run many possible structure designs on this scale, until optimum was find.

Software need to be provided with basic information and measurements of the yacht, from there it can calculate different levels of pressure at different points of the hull. Usually, highest pressure is at front part of the bottom. This is the part of boat that is deep in the water and gets all the slamming.

For frames spacing is most important factor (transversal structural system), because of general arrangement, spacing was fixed to 700 mm. This way good usage of space inside was possible. Figure below shows positions of frames. Frames have same spacing, butt different dimensions of frame sections. Since frames in the middle are longer (red), their section is bigger, frames at aft and fore (blue) part of vessel are shorter, so they have reduced size of section.

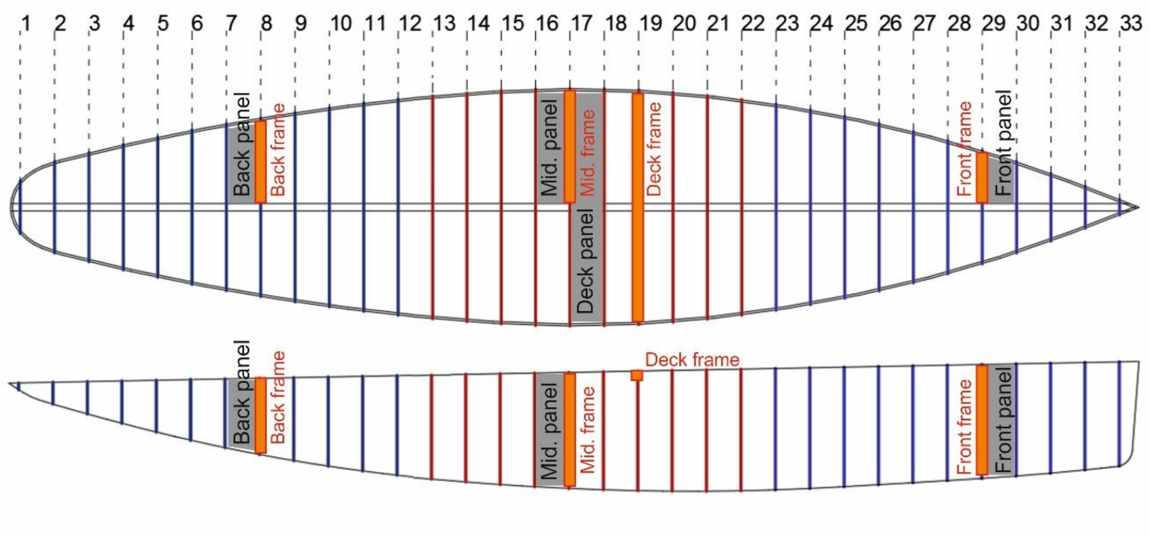


Figure 25– Frame positions

To calculate plating, four panels were created. Three at the bottom (aft, middle and front) and one at the deck.

Label	Requirements		Offered		Results		
	t mm	t_{min}	Label	t mm	t Ratio	t_{min} Ratio	Plating Comply?
PanelA1 - front	23.45	10.80	Cedar, Western Red - strip planking, 45 degree veneers	25.00	1.066	2.314	yes
PanelA2 - midsection	21.93	10.80	Cedar, Western Red - strip planking, 45 degree veneers	25.00	1.140	2.314	yes
PanelA3 - back	19.47	10.80	Cedar, Western Red - strip planking, 45 degree veneers	25.00	1.284	2.314	yes
Deck ply	14.13	6.80	Plywood, 500kg/m³, 11 plies, perpendicular to face grain	18.00	1.273	2.645	yes

Figure 26 – Panel results – Hullscant [1]

After calculations, it was decided to use panels of 25 mm for hull and 18 mm panels for deck. These dimensions were chosen since materials used here can be easily find pre-cute and produced to this thickness. It is much cheaper to use "of the shelf" products, than to custom make everything.

Material chosen for the deck is plywood, with 5 mm of teak strips on top. Since deck has convex shape, plywood will have to be cut in to strips as well and then arranged on the frames, same way strip-planking is done on the hull. Plywood was chosen because deck doesn't need to hold so much pressure, comparing to hull, and plywood is strong enough, but cheaper than cedar.

ISO [13] rules recognize veneers as factor that improves construction, but it factor that is introduced for veneers does not consider thickness, so parametric study will be considered in order to get exact thickness.

When calculating frames, same logic was used as for panels. There are four different kinds of frames.

Label	Dimensions and Location						Calculations to ISO Standard					Requirements			Offered				Results			
	Length mm	Spacing mm	Longitudinal Position metres	Location	z metres	Curvature mm	k_L	k_{AR}	z	k_z	Design Pressure kN/m²	SM cm³	A_W cm²	t_w mm	Label	SM cm³	A_W cm²	t_w mm	SM Ratio	A_W Ratio	t_w Ratio	Comply?
Stiff mid	4500	700	12.000	Bottom	--	1000.000	1.000	0.250	--	--	34.7	665.173	124.215	10.0	Frame oak mid	743.067	208.000	160.0	1.117	1.675	15.927	yes
Stiff front	3000	700	17.000	Bottom	--	850.000	1.000	0.250	--	--	34.7	295.633	82.810	9.1	Frame oak front	327.561	100.000	100.0	1.108	1.208	10.989	yes
Stiff back	3000	700	4.000	Bottom	--	850.000	0.689	0.250	--	--	34.7	295.633	82.810	9.1	Frame oak back	327.561	100.000	100.0	1.108	1.208	10.989	yes
stiff deck	4850	700	16.000	Deck	--	150.000	1.000	0.250	--	--	6.6	291.120	25.296	5.3	Frame oak deck	321.279	110.000	100.0	1.104	4.348	18.957	yes

Figure 27 – Frame results – Hullscant [1]

The entire Hullscant report is in the appendix. So, after computing structure by using Hullscant, final dimensions are presented on figures 26 and 27.

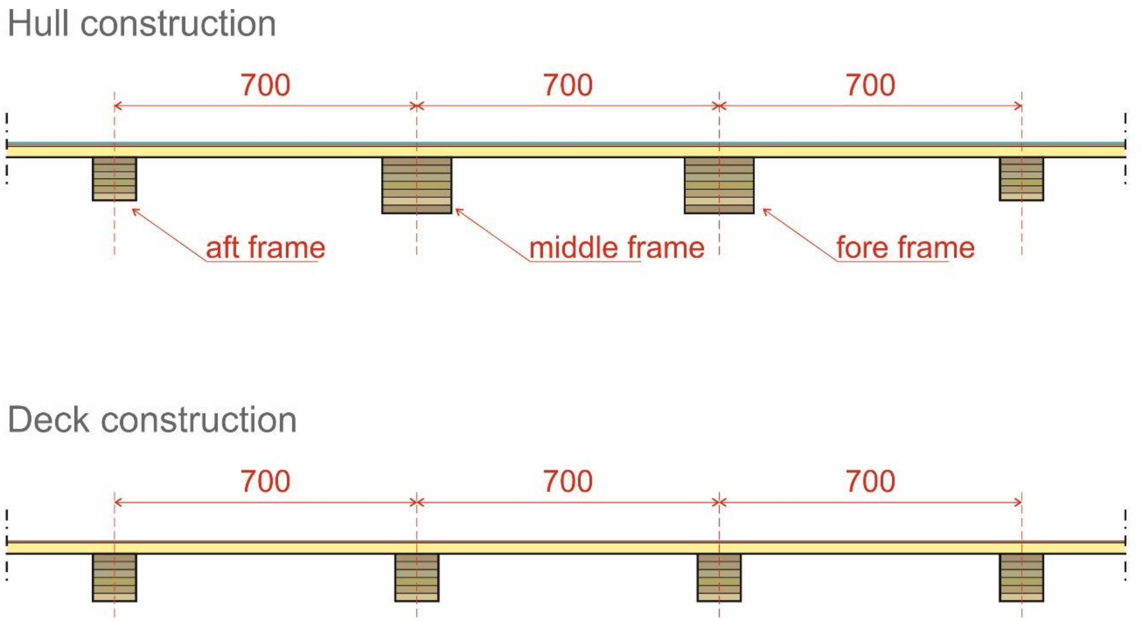


Figure 28– Hull and deck construction raster

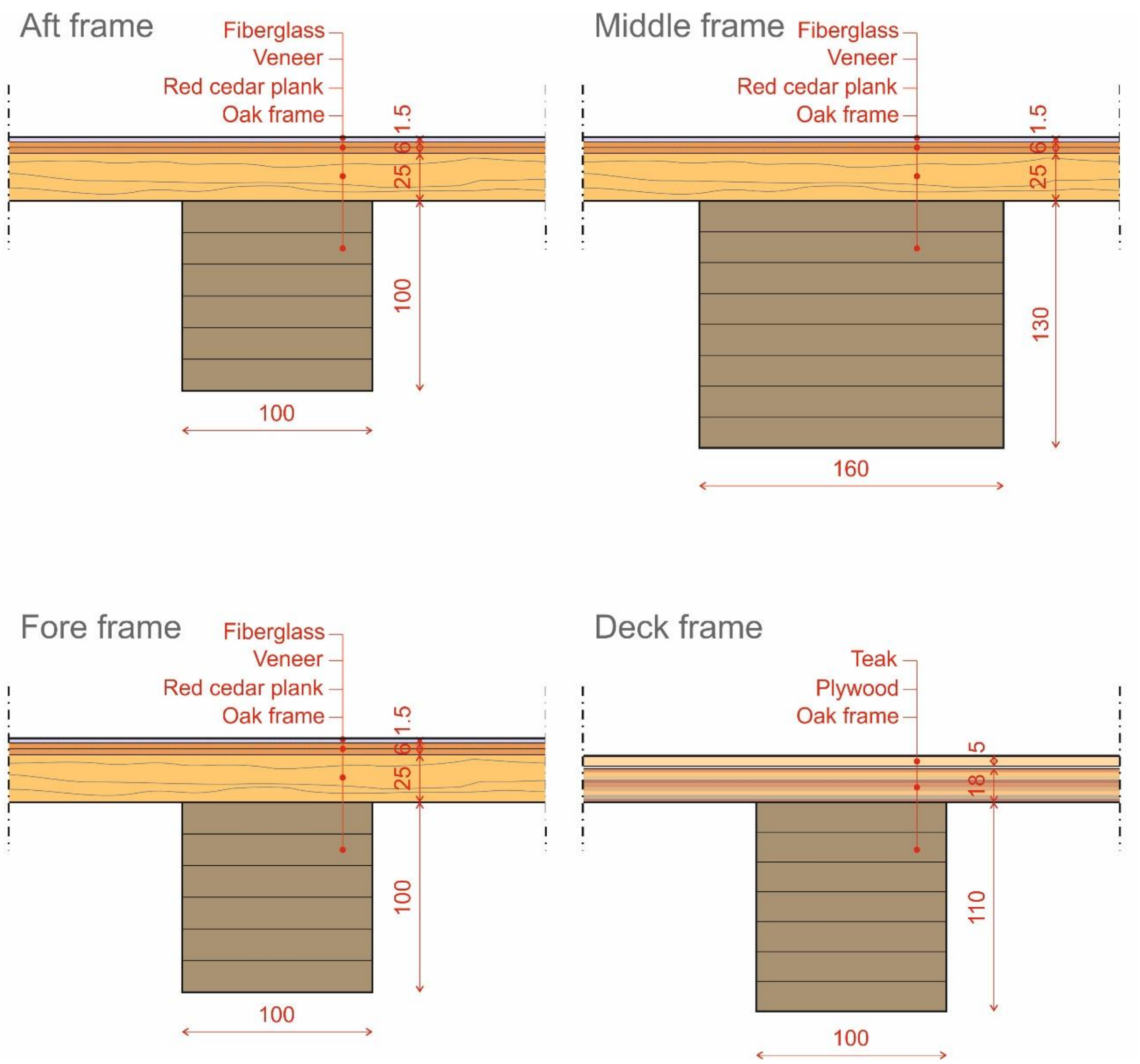


Figure 29 – Hull and deck construction details

3.9.2.2 Keel bolts

Keel is attached to hull by using bolts, calculating these bolts was done by using ISO 12215 – 9 [14]. There are two ways of attaching keel to hull (to keelson), first is keel directly bolted without top flange and the other is with using top flange. Since keel section used here (NACA 0065 12) is quite narrow, not all of necessary bolts could fit inside the keel section. That is why top flange is used.

Two load cases were used to calculate bolts. First load case occurs when boat heels for 90°. Second load case is keelboat longitudinal impact, in this situation keel hits the ground.

When calculating, second load case provided bigger bolt section, 28 mm comparing to 22 mm provided by first load case. To be on the safe side, it was decided to adopt M30 bolts.

In total 18 bolts was necessary, in the area that keel flange covers, only three frames existed, this means that additional construction elements need to be inserted, flours (figure 30).

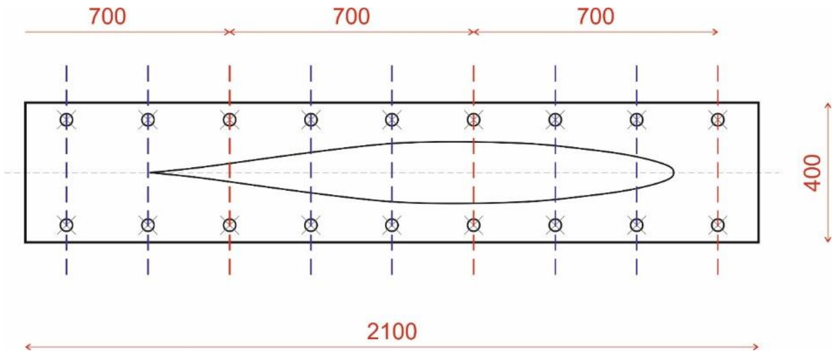


Figure 30 – Keel flange

On figure above, positions of bolts are depicted as well as axes of frames and floors that will take the load. Red lines are for frames and blue are there for floors.

Spreadsheet used for calculation of bolts can be find in appendix.

3.9.2.3 Floors and girder

Floors are transversal elements that get stress from keel through the bolts and then they dispense that stress evenly through the rest of hull construction. Girder is longitudinal element that connect floors and frames.

To calculate these elements ISO 12215 – 9 [14] was used once again. As seen from previous chapter, nine floors are needed (to simplify, frames will be considered as floors in this chapter). Never the less, standard has minimum spacing allowed between floors, when this was computed, it was realized that only seven floors can fit this keel. Calculation was continued as if there was seven floors, this way construction is more conservative. Calculation will be done for seven frames, but in reality, nine of them will be installed, because they are needed for bolts. This will make yacht stronger.

Standard recognized four types of floors, since frames are considered floors here, they would be in category of fully fixed floors. On the other hand, floors in between would fit category of floors with simply supported ends. To be on the safe side again, all of the floors were treated the same, as simply supported.

Three load cases were used to calculate floors and girder. First load case was already described in previous chapter, boat heeling for 90^{o}. Second load case was keelboat vertical pounding, situation where boat goes through heave motion and on her way hits the ground. The third load case was keelboat longitudinal impact again, this is situation where vessel on her way hits ground longitudinally. Again, this last load case was determine dimensions of floors and girder. It is also only load case that does not affect all flours in the same way. Biggest stress was recorded at first and seventh flour (first and last) since they had the biggest leaver effect from the hit.

After calculations it was determine that floors should be 260 mm high and wide as much as frames in that area, 160 mm. This dimension is adopted with high safety factor, this high safety factor was chosen in order to be close to dimension of floors of vessels from parametric study. Same logic was used to calculate girder. Girder had to be at last 400 mm wide, since this is dimension of the flange, so 460 mm was adopted and height of the girder is 280 mm (figure 31). Girder has these dimensions only above keel, in order to absorb and distribute stress from that area, in the rest of the hull, girder (keelson) has smaller section, since its calculated to satisfy global strength.

Spreadsheet used for calculation of floors and girders can be find in appendix.

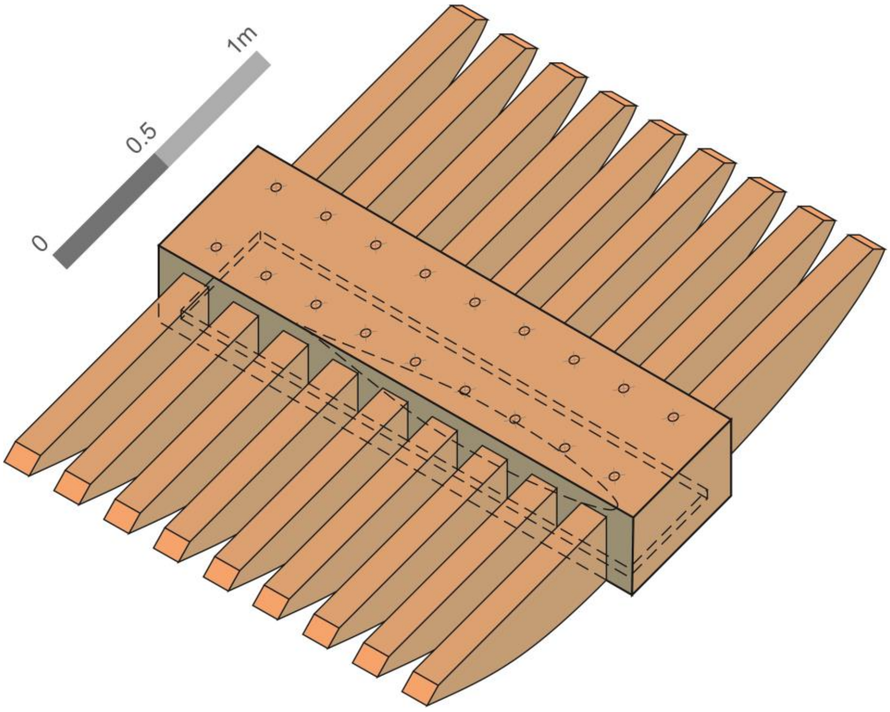


Figure 31 – Floors and girder

3.9.2.4 Global strength

To calculate global, longitudinal strength, ISO 12215-6 [15] was used. Boats under 24 m could actually be calculated only for local loads and it would be assumed that they are strong enough for global loads as well, but standard has some exceptions, one of them are “transversely framed sail boat experiencing large rig loads”, this vessel has standard size rig, but it was decided to do the check in order to be more conservative.

Standard provides formulas for calculating maximum bending moment and deck compressive stress, this was used to calculate load on to structure.

Maximum bending moment:

$$\boldsymbol{M_{VHULL} = k_{GLOB} \times m_{LDC} \times L_H} \qquad \textit{Eq. 27}$$

Where:

$\boldsymbol{M_{VHULL}}$ - Hull bending moment (kN.m)

$\boldsymbol{k_{GLOB}}$ - Load coefficient for sailing yachts (2.7)

$\boldsymbol{m_{LDC}}$ - Displacement (kg)

$\boldsymbol{L_H}$ - Hull length (m)

Next thing to check is deck compressive stress, since vessels often fail in deck area.

Deck compressive stress:

$$\sigma_{DK} = M_{VHULL} \times Z_{DK} \times E_{DK} / EI_{NA}$$ *Eq. 28*

Where:

Z_{DK} – Vertical distance from the deck to the neutral axis of the hull (mm)

E_{DK} – Elastic modulus of the deck (Nmm^2)

EI_{NA} – Flexural rigidity of the hull girder at the mid-section (Nmm^2)

After calculating maximum moment and compressive stress, it was necessary to check does midsection comply with it. Larsson [8], in his book [figure 12.5] suggest a way, how to convert standard yacht mid-section in to a box shape, so moment of inertia is easier to calculate. This procedure was followed in this case (figure 32). But there was another problem, three different kinds of materials can be find in the mid-section, therefore there is three kinds of elastic modulus. That was next thing to be fixed.

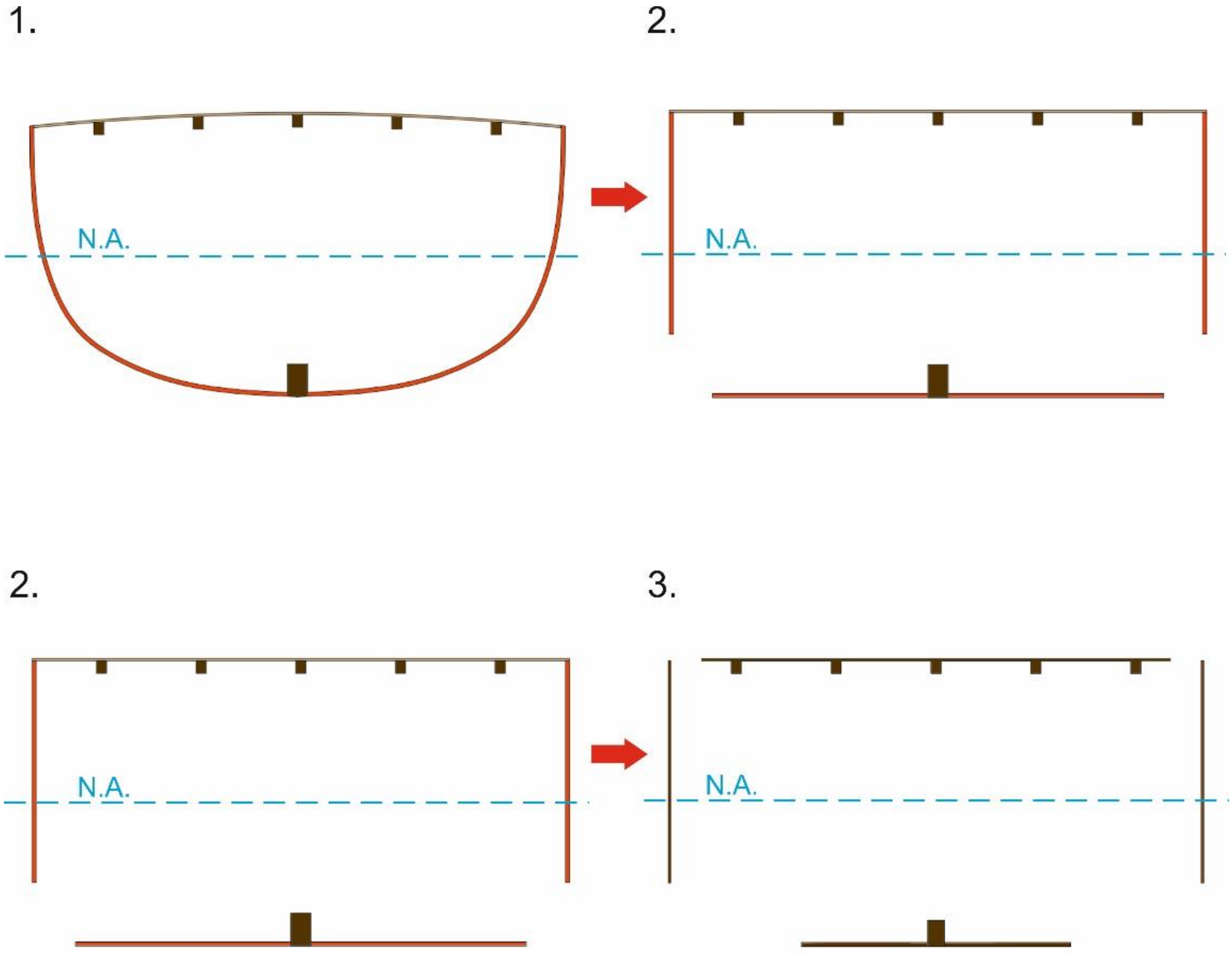


Figure 32 – Transformation of midsection in order to calculate global strength

It was decided to use oak as a reference, since this is the strongest material, and then by changing geometry all other materials were “converted” to oak. It was decided not to change heights of elements, but only breadth. So first yang modulus of material to be converted was divided by oaks yang modulus, which gave us number smaller than one, and then breadth of element was multiplied with this number. This way elements that were made out of weaker material, lost section area to the point where they could be considered to be oak [16].

$$Effective\ Breadth = \frac{E_{Laminae}}{E_{Ref}} \times Breadth$$

Eq. 29 [16]

When looked upon the original midsection it is possible to notice that most curved part is positioned close to neutral axis, this area does not contribute much to strength anyhow, so reducing section to flat elements is justified, since in the real section, pieces that carry most of the load are almost flat anyhow. Those parts are very bottom and deck area of the section.

In the end, dimensions of keelson are to be 240 x 150 mm, which still leaves plenty of room for safety factor.

To calculate global strength, some assumptions were made, for example, superstructure was ignored, this actually makes calculation more conservative. On the other hand, openings in the deck were ignored too, this does not help, but theoretically, if hatches opening were reinforced with same amount of material that was removed (or more) there should be no problems.

3.10 General arrangement

It was already been stated that this vessel is cruising yacht more than anything else, so certain level of luxury has to be obtained. On board there is main cabin for two people, two guest rooms both for two (one small and one big) and crew area for two people as well, so eight people in total.

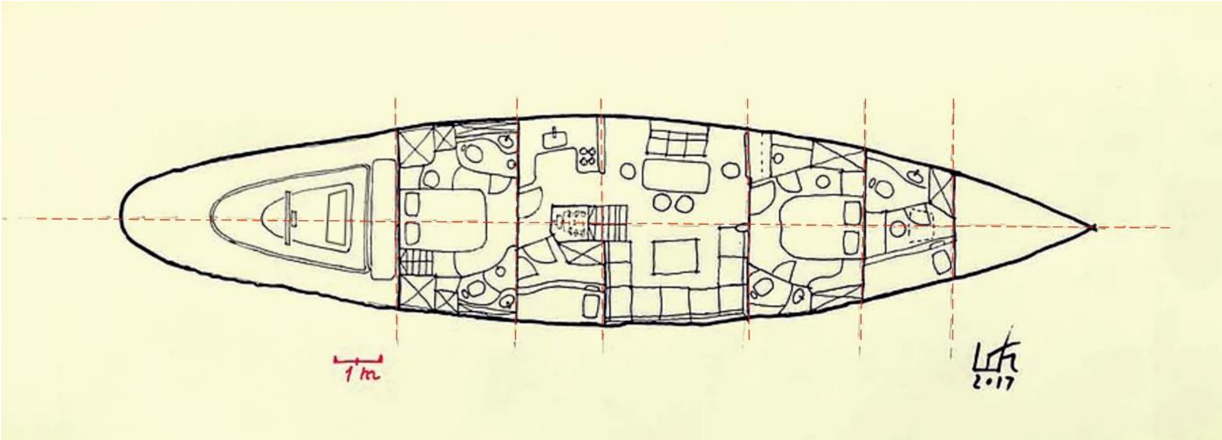


Figure 33 – Sketch of general arrangement

Technical drawing of general arrangement can be found at the end of the theses, for this paragraph sketch will be used (figure33).

Layout will be explained from left to right. First area is cockpit (this area is actually on the upper deck, but it was placed here so concept of GA could be explained on to one level) this area made for one person from crew to navigate the vessel, rest of the siting space is for guests. Cockpit is actually only safe area for guests during the voyage, they can go around the deck only when yacht is moored. This is why rail was build, from entrance to cockpit, so guests can move safely and quickly. Also, owner cabin has direct access to cockpit trough separate entrance. This division of deck space was made so crew can do their job efficiently, with nobody distracting them and guests can still get part of experience by comfortably sitting in cockpit. Also, deck is built to make things easier for people managing the vessel, rather than luxury purposes, what can't be said for any other space on board. Under the cockpit lays storage area, better presented in section in drawings appendix. In front of cockpit, there is short, but quite wide hatch, this is a place for dinghy. Dinghy will be stored in this slot with other inflatable equipment and toys, boom will act as a crane, to get equipment in and out.

Progressing to the next area to the right, there is owner's cabin, this area and rest of the layout is at the lower deck. This is the biggest and most luxuries cabin on board. Central place in the room is reserved for big queen size bed, room has separate bathroom as well. There is a study/makeup table wright next to the bed, room has plenty of storage space. Room can be accessed from two entrances, there is one from corridor that connects it with rest of interior, but there is direct way to upper deck and cockpit.

Going out from owner's cabin, on the right, there is a small guest room. This cabin has bunk beds and shared wardrobe, but it still have separate bathroom. It is not the most luxuries cabin at the vessel and it's more appropriate for kids or young people.

Right next to the small guest cabin is engine room, with proper sound and heat insolation. Room is small, but spacey enough to fit all of the needed equipment.

Across small guest room, at the port side, is the kitchen. Kitchen is equipped with all necessities needed to provide food for eight people for fifteen days, or theoretically, even more.

Central space and the biggest area are occupied by saloon. This place is meant for socialization, it's the place where guests and owners can spend their time together during the voyage. Author wanted to emphasize this space, make it big and make it to seem even bigger. So people would get out their cabins and spend time together, in wide and light space. There is dining area at the port side, light chairs are used, in order to make space look bigger and more transformable. Only at one side of the table sofa is to be found, this is because water tanks needed to be hidden beneath. If attention is paid at up/right corner of the room, it will be possible to see that captain table is hidden in the niche. This way, when niche is closed, equipment can be hidden, so it doesn't pollute the visual notion of the saloon. On the starboard side is the lounge area. This elements look robust in layout, but they will be quite low (standard dictate for sofa to be 35-45 cm high, this one will be 35cm), in order to make effect of high sailings above them.

Next room on the right of the saloon is big guest room. This room is slightly smaller than owner's cabin, but it can be easily be compared to in when it comes to commodities. It has even separation of shower and toilet. Only big advantage that owner's room has over this one is direct access to deck, which this room doesn't have. Possibility of direct access to deck was considered, but it was rejected upon realization that position of the room is far from cockpit, the safe area for guests.

On the far right, last cabin, is crew area. This is micro universe inside the yacht, one completely self-efficient unit that doesn't depend much on the rest of spaces. There is space for two crew members that has everything they need to have a comfortable trip. There are bunk beds, bathroom, table and even a small stove.

In the far fore of the vessel is storage compartment. In this compartment anchor, sails and other equipment could be found.

3.11 Stability

One of the most crucial parts of designing the yacht, but it couldn't be done before other stages are defined, one last thing to do before checking stability is weight estimation.

3.11.1 Weight estimation

In order to be able to claim that he knows exactly how his vessel is going to behave, designer must do weight estimation as precise as possible. This is only preliminary design, never the less, author tried to push this part of report as far as possible. First preliminary weight estimation was produced, based on estimations and parametric study, later item by item was designed or selected, so actual weight was known. Excel spreadsheet was created, in order to notify exact position and weight of each item. Like it was explained in Larsson's book [8]. Nevertheless, this spreadsheet will need to be changed and updated when vessel goes from preliminary project stage to next stage.

Here is summary of the weight estimation (full spreadsheet is in appendix A6). Also, if appendix A1 is checked, it is possible to see that vessel fits trends of parametric study.

	Mass	LCG	Moment X	TCG	Moment Y	VCG	Moment Z
	kg	m	kg.m	m	kg.m	m	kg.m
Total chain locker	350	20,65	41166,1	0	0	1,09	380
Total engine and tanks	3225	12,76	41166,1	-0,03	-82,5	0,99	3178,5
Total rig	1009,3	11,87	11983,15	0	0	7,71	7776,86
Total deck	709	11,97	8489,8	0	0	1,34	946,9
Total furniture	2161	11,57	24992,8	-0,09	-203,1	0,93	2014,82
Total structure	9497,6	12,49	118580,26	0,00	-8,81	1,21	11484,617
Total appendages	9359	10,88	101831,17	0	0	-1,63	-15275,45
Total	**26310.9**	**13.23**	348209	**-0.01**	-294	**0.40**	10506

Figure 34 – Weight estimation results

Information presented in the table above are for hundred percent loaded load case.

If results from figure 34 are observed, it's possible to detect three coordinates of center of gravity. In order to use this information, zero point of coordinate system must be known, this point is shown at following depiction:

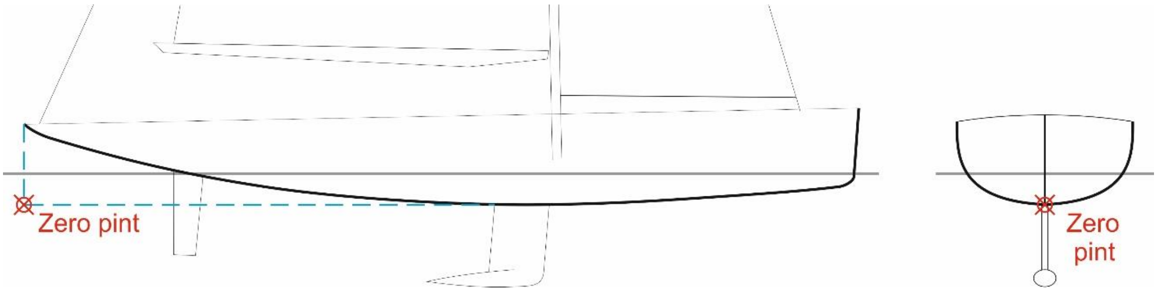


Figure 35 – zero point of coordinate system that was used for weight estimation

Ten percent of margin was added in to weight estimation. That is there to compensate if one or two layers of hull are changed, if owner decide to add some more equipment, or in similar situation.

3.11.2 Compliance with ISO 12217-2 [17]

Now that all variables are there, stability can be checked. Stability is evaluated by righting moment. To obtain GZ curve, Maxsurf [2] was used again. In total five different load cases were created (10%, 50%, 100%, loaded arrival and operating minimum), but on the figure below only two are presented. Two presented are two extremes, one is when the vessel is absolutely loaded, to the maximum and other one is when vessel is empty. In theory when vessel is loaded it should be more stable, this is true in this case as well. Nevertheless, difference between two extremes, when it comes to GZ, is just one degree. This is due the fact that loading capacity is quite small when comparing to the size of the vessel. Upon closer inspection, it's possible to see that difference between GZ max values for two extreme cases is just one degree.

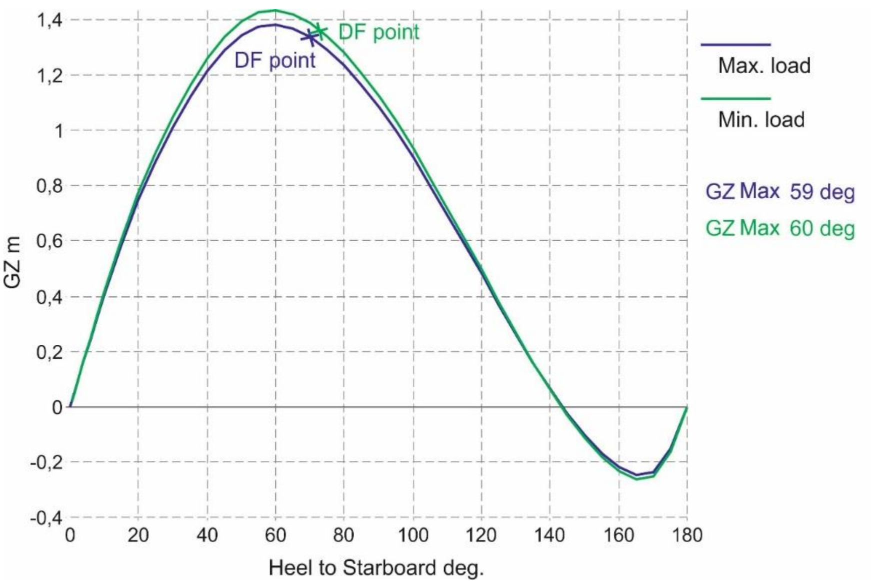


Figure 36 – GZ curve of the vessel

It was already stated many times, this vessel is luxury yacht, so stability was considered from beginning. Hull was designed to be wide and center of gravity was kept as low as possible. That is why load cases have small role in overall stability.

3.11.2.1 STIX

Vessel was designed to satisfy ISO rules [17], when it comes to stability, ISO rules uses the stability index (STIX factor). Minimum that any A category mono-hull, that respect rest of ISO rules, must to score on the STIX scale is 32. This is simply value stated by ISO rules.

This vessel managed to score more than minimum without any problems. There was two ways to check. First Maxsurf [2] was used, because this software use ISO as its foundations it also has to calculate STIX. When using Maxsurf, STIX score was 61,3. Nevertheless, this software still uses old version of ISO rules, meanwhile rules have been updated.

That is why a spreadsheet, look at appendix, was created to check STIX again. This spreadsheet was created based on the updated ISO rules. When using this new method, STIX factor was calculated to be 44.7. This value is lower, but it still passes regulations with high margin. Reason that value is lower is probably because rules are stricter in the new version, but also because was always using conservative values, so design would be on the safe side of the scale.

Upon closer inspection, it was realized that biggest difference between two methods comes from angle of vanishing stability. Maxsurf, which is based on old standard, has calculated angle of vanishing stability of 144.4^{o}, which is great, but it is a bit too much to expect.

On the other hand, spreadsheet that was based on updated version of standard, set angle of vanishing stability to 100^{o}, which is bare minimum to pass. New standard is simply more conservative, but anyhow, vessel passes both versions of standards without any problems (figure 37).

Assessment	Requirements	Conditions
Decking and covering	fully decked	Yes
Down flooding openings	6,2,1	comply
Down flooding height test	> 1,41 m	1,52 m
Down flooding angle	> 40°	77°
Angle of vanishing stability	> 100°	100°
Stability index	> 32	44,68
Compliance		Yes

Table Figure 37 - ISO 12217-2 – STIX requirements

Considering everything presented here it is safe to say that this is the vessel that is going to be safe for usage, not only that, it will provide comfortable rides with luxury experience to hers future owners.

3.12 Velocity prediction

In order to predict the behavior of the yacht with in different wind conditions, Win VPP software [36] was used to make a simulation of these conditions.
To get information about performance, hydrodynamic forces of the hull and appendages were used. When figure below is inspected, it's possible to find speeds of boat based on the wind direction and wind angle. This diagram is used to help crew better navigate and use boat to its full potential.

Black lines represent situations in which boat would use main sail and spinnaker and red lines are for main sail and jib scenario. It is possible to see that in ideal conditions, broad reach, yacht could go up to 16 knots.

VPP prediction provides more information, detailed report is in the appendix.

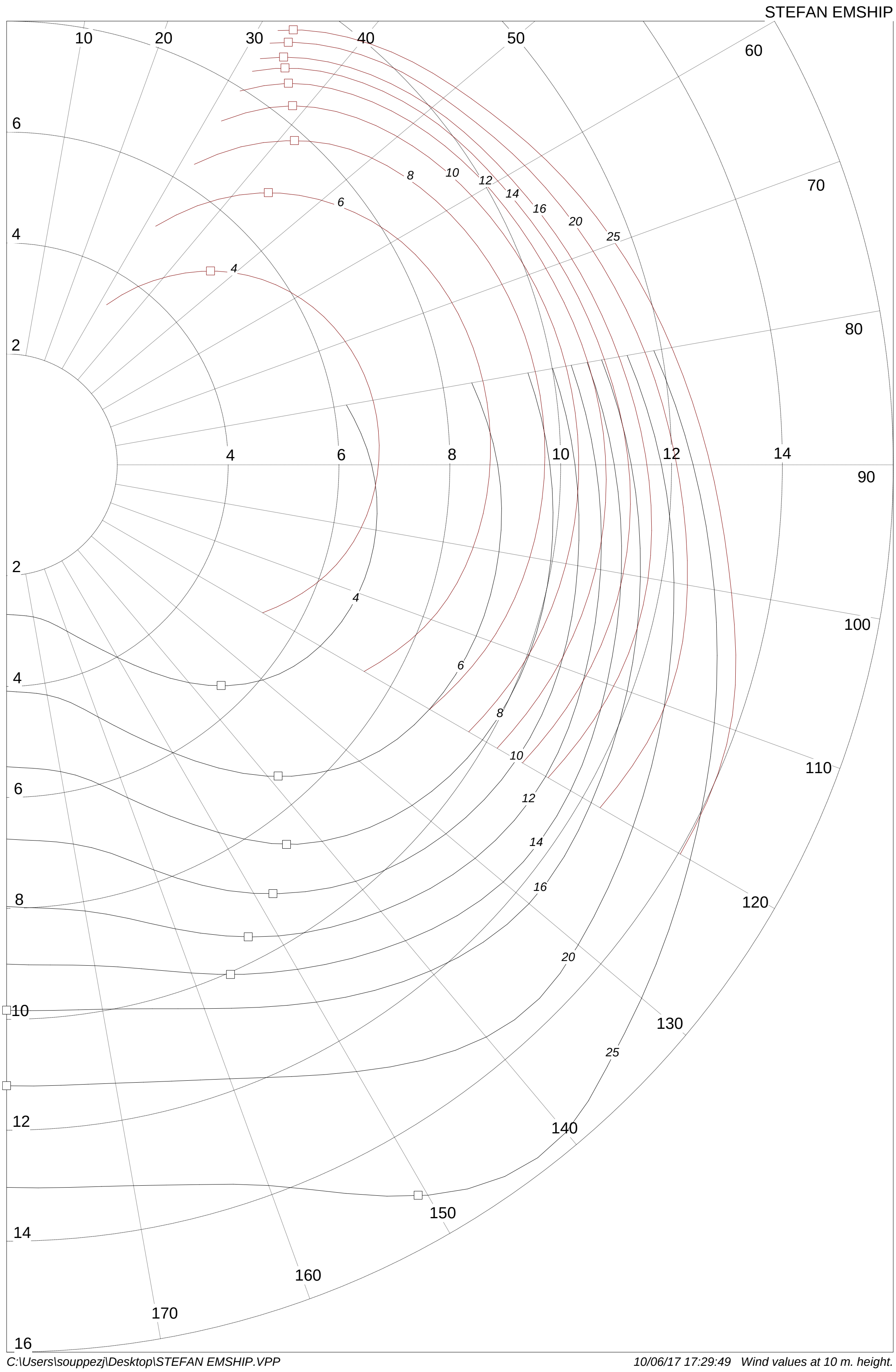


Figure 38 – VPP prediction [18]

3.13 Conclusion

Yacht was chosen by the author since he is deeply interested in wood structure vessels, especially sailing vessels that could be considered as crown joule of naval architecture.

In other spheres of human work and creation, people who do calculations and people who design appearance of items are usually divided in two teams. Naval architect should, ideally, have both of these roles and affection to each. This way ideas that support construction and ideas that support design don't conflict, they come from one source and instead of confronting they help each other to achieve good design. This is why it's very important not to undermine any aspect of production process.

Nevertheless, this was not just the aesthetically oriented design project. Idea was to provide efficient and comfortable vessel for small group of people to enjoy outdoors with some sailing experience. This provide opportunity for author to go through all the aspects of sailing life and sailing yacht design.

This was also perfect polygon for conducting structural resources, this aspect will be deeply explored in further chapters. Structure of this vessel is not something that needs to be hidden, necessary evil, it is part of the organism that play along in order to deliver fully enlightened vessel to the people onboard.

In the future, next step for this project would be to go one more loop on design spiral, this time determining attention to smaller systems inside the system as a whole. Now that general parameters are set, it is important solve out practicalities.

3.14. Technical description

After all of calculations and observations that were done in order to finish this vessel many information is gathered, all of which will be summarized in this chapter.

This vessel is wooden sailing yacht, when it comes to style, it could be defined as modern-classic. Wessel can hold six passengers and two members of the crew. Ship is intended for light cruising, with accent on comfortable voyage, not speed. Interior is spacy with a lot of open space. Deck is mostly kept flat, in order to give easy to use space for small crew to manage the yacht. Cockpit has comfortable seating area, for guests to enjoy the outdoors.

Key features:

- Comfortable and luxury cabins,
- Clean and spacy deck,
- Fully autonyms crew area,
- Big saloon,
- Separate access to deck for owner and guests,

Specifications:

- LOA: 23.00 m,
- LWL: 17.50 m,
- BOA: 4.85 m,
- BWL: 4.30 m,
- Canoe draft: 0.77 m,
- Keel draft: 3.00 m,
- Mast height: 28,50 m,
- Displacement: 25.50 t,
- Ballast ratio: 0.39 %,
- Sail Area: 232.00 m^2.

4. SCARF JOINT TEST

4.1 Introduction

Scarf joint is one of oldest and simples ways to join two pieces of wood. Two pieces of wood are cut at the same angle and joined together. In beginning two pieces of wood would be joined with wooden pins, later it would be metal connections and most presently, various types of glues.

Figure 39 – Early example of scarf joint – roof construction [https://i.pinimg.com/originals/79/8a/a9/798aa93fef2570235ea03234853ce3d2.jpg]

Main focus of this research will be kept on to plain scarf joints that use glue as medium of connection, more specific, epoxy resin. Obviously joints are not good things for construction, but they are inevitable, simply there won't always be piece of wood that is long enough. When it comes to scarf joints it is not a secret that the length of joint is in direct proportion of its strength. Nevertheless, with long joints problems appear as well, the longer the joint is the bigger is the waste. For example, if there are two piece of wood to be joined. For example, if two slates (20 x 20 x 400 mm) are to be joined, when 1:4 ratio joint is used waste is 10 percent, but if this ratio is 1:20, waste percentage 50 percent.

This is why it is very important to know how much of strength is lost with each scarf ratio. Since not every element in construction needs 100 percent of structural strength it is possible to use lower ratio joints, but some elements are crucial and they could bare only the long ratio joint. If exact strength of joint is known it easy to decide which scarf ratio is proper for each position in construction. Determining exact values of this estimations is main topic of this section of thesis.

There are already some values used in practice, for example Birmingham [19] writes about strength of different joints, but he doesn't give his sources, so it's unknown did he gain them empirically or experimentally. Results are not necessarily wrong, but here they will be tested scientifically.

4.1 Materials used in research

Materials chosen for this experiments are those that are regularly used in boat building, since goal of this research was to help real-life boat building, practical situations.

4.2.1 Epoxy resin

Epoxy is one of most commonly used polymers for wood joints, there are other kinds of glues, some of them stronger, but epoxy is easy to work with and it's been around long enough to be trust with.

Also, for most of other glues used in industry, conditions have to be perfect, when it comes to epoxy it would work in real life conditions of constructing site [20]. For example, it can deal with high moisture, epoxy does not require pressure during curing, and there is almost no shrinkage, range of curing temperatures is wide and it's easy to work with.

When preparing glue, epoxy resin is mixed with hardener which will start process of curing, some glass powder is added as well. Glass powder makes mix a bit more thick, this make it easier to use, since resin gets viscosity similar to ice-cream, and more important, it controls the level of soakage by wood. If resin was too thin, wood would soaked it in quick, and there possibility of gapes creation would appear.

In this research epoxy Ampreg 22 has been used. As most of epoxy resins this one is very user friendly, there is no fumes and curing temperature is low.

Components of adhesive used for experiment:

- Epoxy resin: Ampreg 22 – Epoxy laminating system,
- Hardener: Ampreg 22 - Epoxy laminating system,
- Microfiber: SP microballoons.

4.2.3 Wood

Wood is one of the oldest materials used in constructions, for this research, oak is material of choice.

In recent years, eco footprint of material becomes more and more important and wood is one of ecofriendly materials. If sources of wood are managed correctly, wood becomes ultimate renewable source.

Never the less, ecological aspects are not only benefit of timber as construction material, as Spirit Yachts CEO and head designer Sean McMillan would say [37]:

“There are many misconceptions surrounding boat building with wood. When used in combination with epoxy resin saturation it is in fact a far superior material to the modern composites used across our industry today. Wood is the only natural boat building material offering beauty, strength to weight ratio, flexibility and durability.”

Basic types of stress in wood [21]

Wood is not homogeneous material, it has different characteristics if observed in different directions.

Also, according to stress treatment, there is more than one type:

Strength in the fibers direction – Stress tries to elongate the element, depending on the strength level of wood, rupture can be fibriform (stronger wood) or stairform (weaker wood). Percentage of moisture is opposite proportional to strength of element.

Strength by the compressive force acting along the fibers – Element is shortened by stress. Density is crucial for this kind of stress.

Strength by transversal bending - This is kind of stress that will be explored by the details in this research, for this kind of stress, adhesion forces between fibers are most important.

These characteristics of wood are very well known, and it’s something that is taken into account when calculating and building construction. In ISO standards [14], strength of wood is characterized according to type of stress. In table below strength of different wood species according to different stresses is given, standard suggested that when calculating structure, maximum stresses should be up to 50% of these values, number is low because wood can be quite unpredictable material with a lot of flaws. There are other kinds of strengths and stresses, but they are not relevant for this research.

Hardwood		Density	$\sigma_{uf\,//}$ grain	$\sigma_{cu\,//}$ grain	$\tau_{u\,//}$ grain
Common name	Scientific name	ρ N/mm²	N/mm²	N/mm²	N/mm²
Aspen, European	*Populus tremula*	460	55	34	6
Afrormosia	*Pericopsis elata*	737	108	57	13
Afzelia	*Afzelia* sp.	817	100	63	13
Agba	*Gossweilerodendron balsamiferum*	497	65	35	9
Ekki (azobe)	*Lophira alata*	1 037	142	72	19
Iroko	*Chlorophora excelsa*	657	72	44	11
Jarrah	*Eucalptus marginata*	865	94	51	13
Kapur	*Dryobalanops beccarii*	705	93	53	10
Karri	*Eucalyptus diversicolor*	913	111	60	13
Keruing	*Dipterocarpus caudiferus*	641	88	48	10
Mahogany, African	*Khaya anthotheca*	513	67	36	10
Mahogany, American	*Swietenia marcrophylla*	497	67	36	10
Makore	*Tieghemella heckelii*	609	81	43	11
Meranti, light red	*Shorea dasyphylla*	481	70	40	8
Oak, European	*Quercus* spp.	689	77	41	11
Opepe	*Nauclea diderrichii*	753	96	58	14
Sapele	*Entandrophragma cylindricum*	673	89	47	14
Teak	*Tectona grandis*	641	84	48	12
Utile (Sipo)	*Entandrophragma utile*	641	83	48	14
Other woods		ρ	0,130 ρ	0,071 ρ	0,018 ρ
Hardwood – Elastic modulus // grain		E (N/mm²) = 17,5 ρ			

Table 40 – Part of table describing characteristics of hardwood – ISO 12215-5

4.3 Testing

As mentioned before, goal of this research is to compare different scarf joint ratios to each other. Different groups of wooden samples will be manufactured, each group of specimens will have same characteristics, when it comes to dimensions and material used, only difference will be scarf ratio. There will be control group as well, pieces of solid wood that don’t have joints.

To test this samples BS EN 408:2010+A1:2012 standard will be used (Timber structures — Structural timber and glued laminated timber — Determination of some physical and mechanical properties). This standard is predominantly used for laminated samples, but since no standard for scarf samples of same quality was excessive to author, this standard was chosen. Also, it could be argued that scarf is just one type of laminate. Test is four point, destructive, flexural type (figure 41).

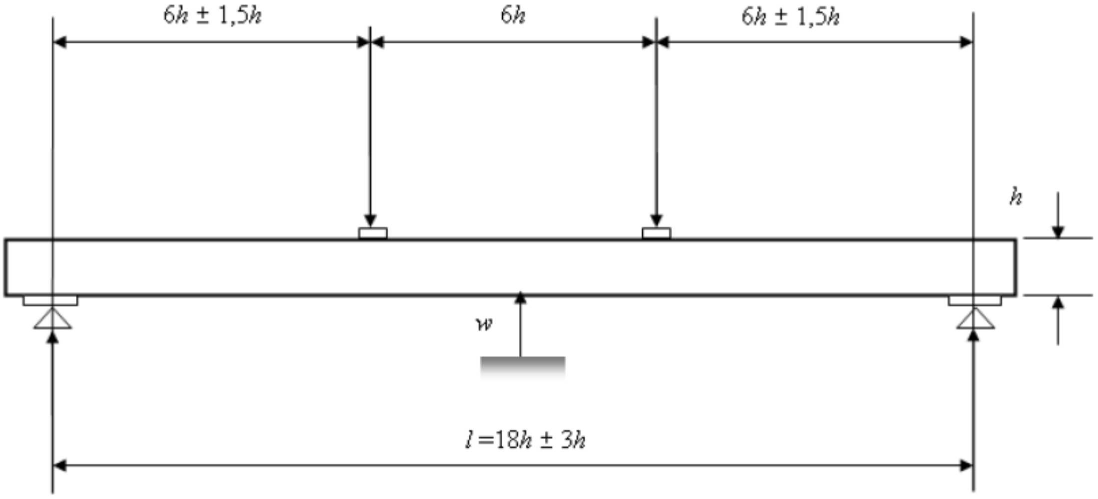


Figure 41– dimensioning of sample for test - BS EN 408:2010+A1:2012

4.4 Materials and production of samples

As stated before, main goal of experiment was to determent effect of scarf ratio in to scarf joint. To isolate this characteristic, all samples were wade to be as similar as possible, except the ratio, all other characteristics are to be same. Ideally, all samples were to be made from one piece of wood, this was not possible duo to lack of funds, density was measured for each sample and this characteristic was used to fix handicap. Whit this being stated, all samples were produced to resemble each other, with same dimensions (figures 42 and 43).

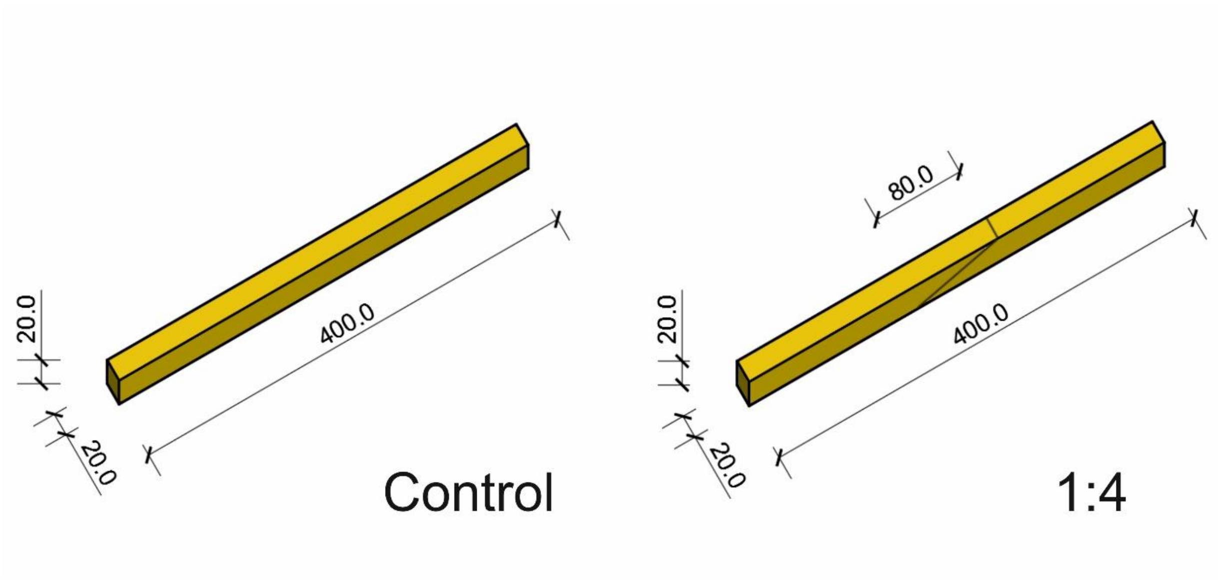


Figure 42– sample dimensions

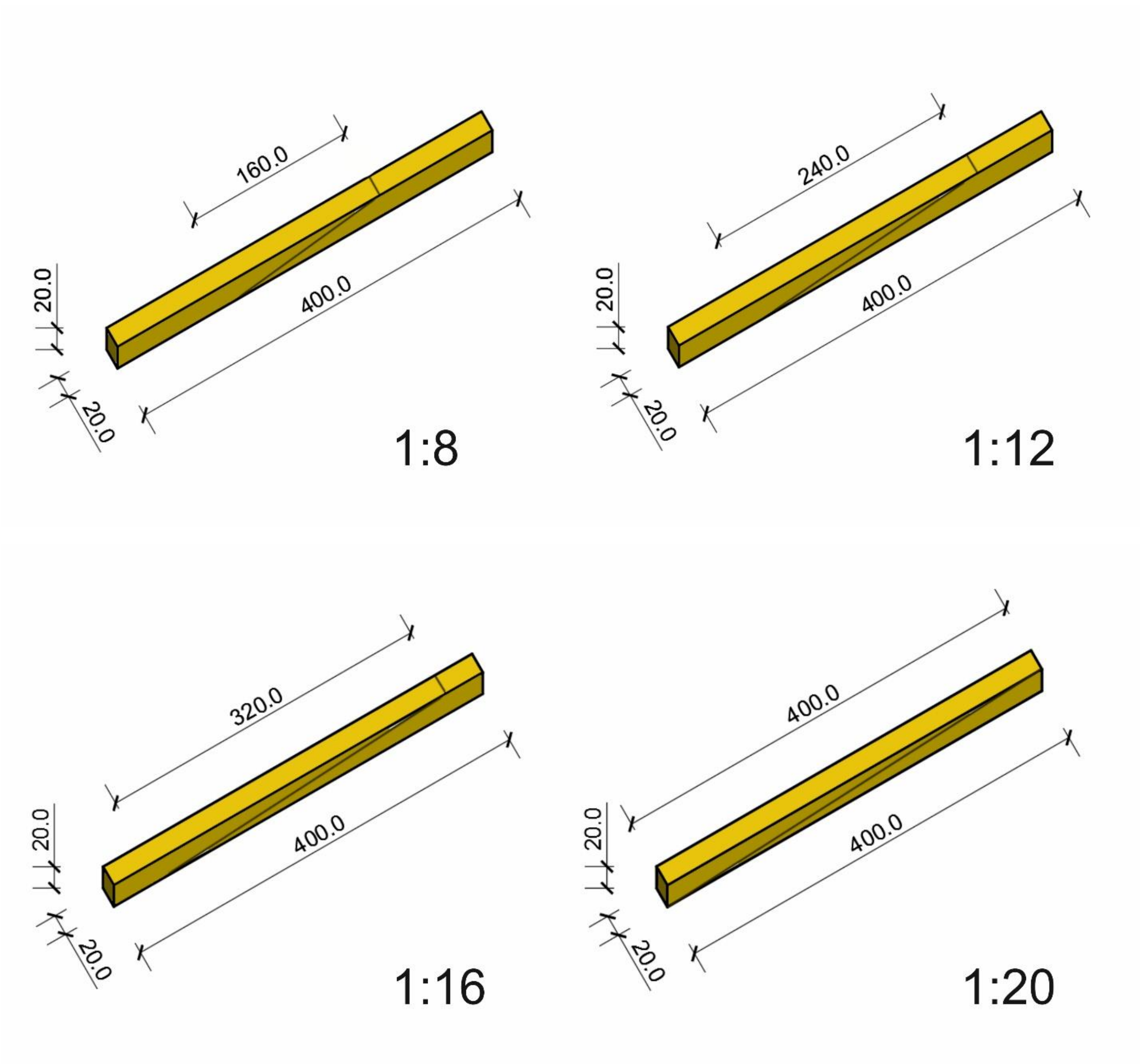


Figure 43– Sample dimensions

Wood used for production was European oak. When preparing samples, it was important to match wood fibers. Best solution was to make specimen from single piece of wood, which was cut, cleaned and then glued back together. This way fibbers would be able to transfer stress continuously, without mismatching. Also, center of scarf should match the center of sample (figure 44).

Figure 44 – Production logic of samples

Samples were made out of oak slats, there was 9 of them, with length variation between 1.5 – 2.6 m. Also section dimensions were different, so first thing to do was plaining them all to 20 x 20 mm section dimensions.

Figure 53 – Plaining of slats – by author

Next step was cutting slats in to sample sizes and then cutting samples in half according to wright ratio. For this purpose bandsaw was used (figure 45).

Figure 45– Samples production – bandsaw

Figure 46 – Samples cut in wright dimension with proper scarf ratio.

For samples to be as similar as possible, it was not enough to match type of wood and geometry of sample. Resin characteristics should match as well. As stated, glue was composed out of epoxy resin (75%), hardener (21%) and microfibers (4%), where percentage is referring to weight. Since there was too many variables, like exact ratio, room temperature, humidity and so on, it was decided to make all the samples on the same day with same batch of resin mixture. Since there was at least five samples per group, that meant that there was around thirty samples to produce. This required production of presses which were able to take 15 samples at the time. This way all the samples have glue that was produced, applied and cured at identical conditions (figure 47).

Figure 47 – Loading press with samples

During production, samples were on purpose produced slightly longer, this way there was margin safety factor, since there were effects hard to predict, like how much wood will bandsaw cut off for different ratio, also possible mistakes in measurement were easy to correct. Only after gluing all samples were finally cut to same size. This meant that not all of samples were same size before gluing, therefore set of bolts was set in order secure exact position of wooden parts. In transvers direction this was accomplished using same size wooden plugs. Between samples plastic film was applied, so samples wouldn't stick to each other. On top of samples foam was placed and then pressure was applied. Samples spend two days under pressure, after that they were stored for curing, two weeks in total.

Figure 48 – Samples curing

Figure 49– Sample before breaking test

4.5 Bonding of wood

When gluing two pieces of wood together, woods characteristics must be taken in to account when choosing adhesive and curing conditions. Soft wood requires elastic glue, but for hard wood more stiff glue can be used. Also, when curing, outside pressure can be used for soft wood in order to compensate for uneven surface of joint, if this logic is used for hard wood it can press out glue from joint [Loading capacity determination of the wooden scarf joint].

In order to achieve successful bonding of wood surface, preparation is needed [22]:

- Uniformity of surface – surface of joint must be plain and smooth, without defections. This way maximum contact area is guaranteed.
- Resin, wax and impregnation removal – This needs to be dome mechanically, no foreign objects should find their place in between two joint surfaces, especially not those that could chemically react with glue.
- Improvement of water content – Wood glued must be dry, there are excepted maximum values of humidity in timber, but joints are get better if wood is dryer, so sometimes parts of wood that are soon to be joint are treated locally against humidity.

4.10 Flexural test

Testing was done in the Mechanical testing laboratory Solent Southampton University during the internship period, test was four points flexural type, with machine produced by Llyod instrument with a capacity of 5 kN, with four-point load as shown in figure 50.

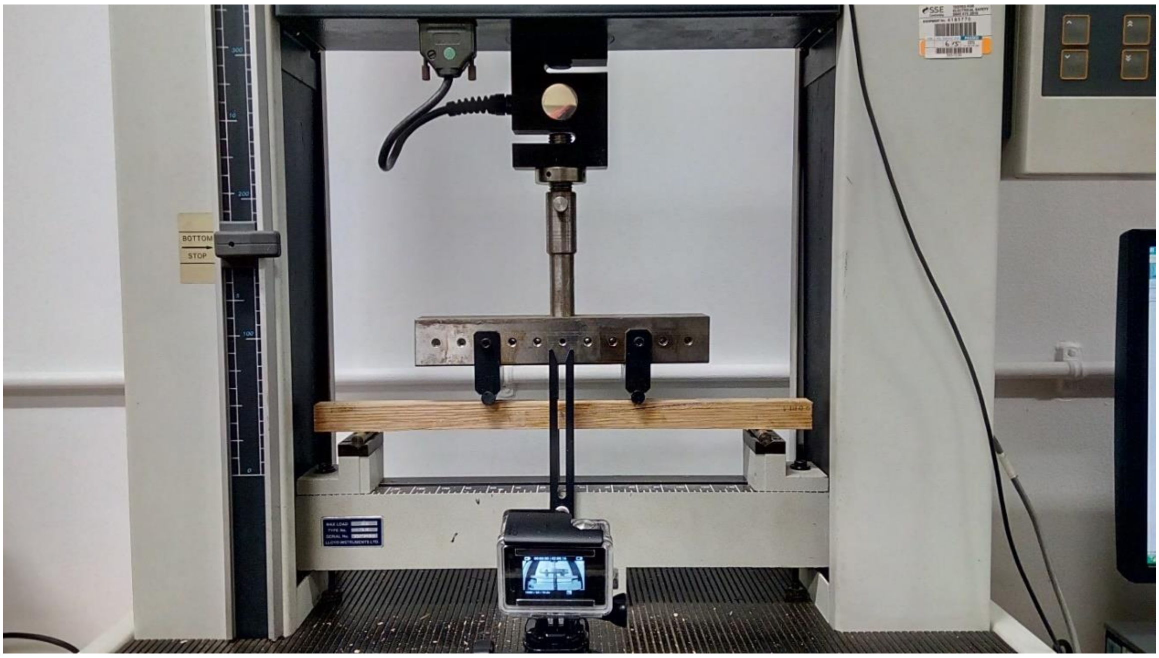


Figure 50 – experiment setup – starting position - the Mechanical testing laboratory Solent Southampton University

Testing was done using BS EN 408:2010+A1:2012 standard (Timber structures — Structural timber and glued laminated timber — Determination of some physical and mechanical properties) [40]. Under this standard, speed of crushing head was calculated to be 0.06 mm/s.

There was six different types of samples, each group had at least five samples, in order to confirm results. Each sample was set under constantly raising pressure until failing. Failure was defined as lost of 50% or more out of initial strength.

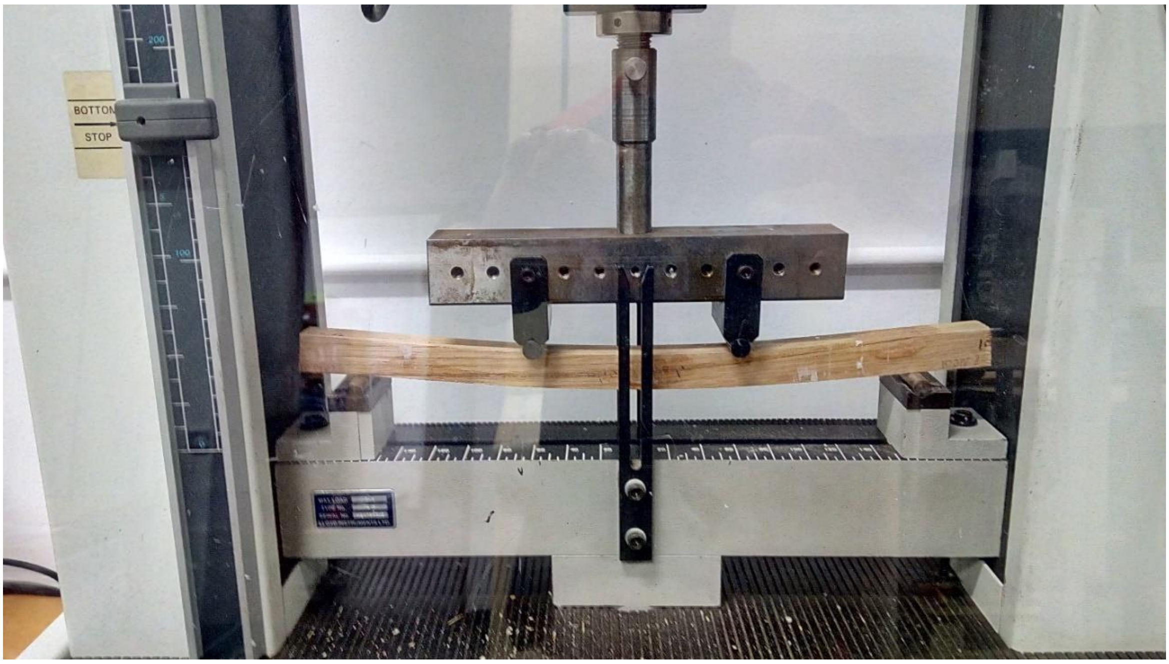


Figure 51 - experiment setup – element start to bend

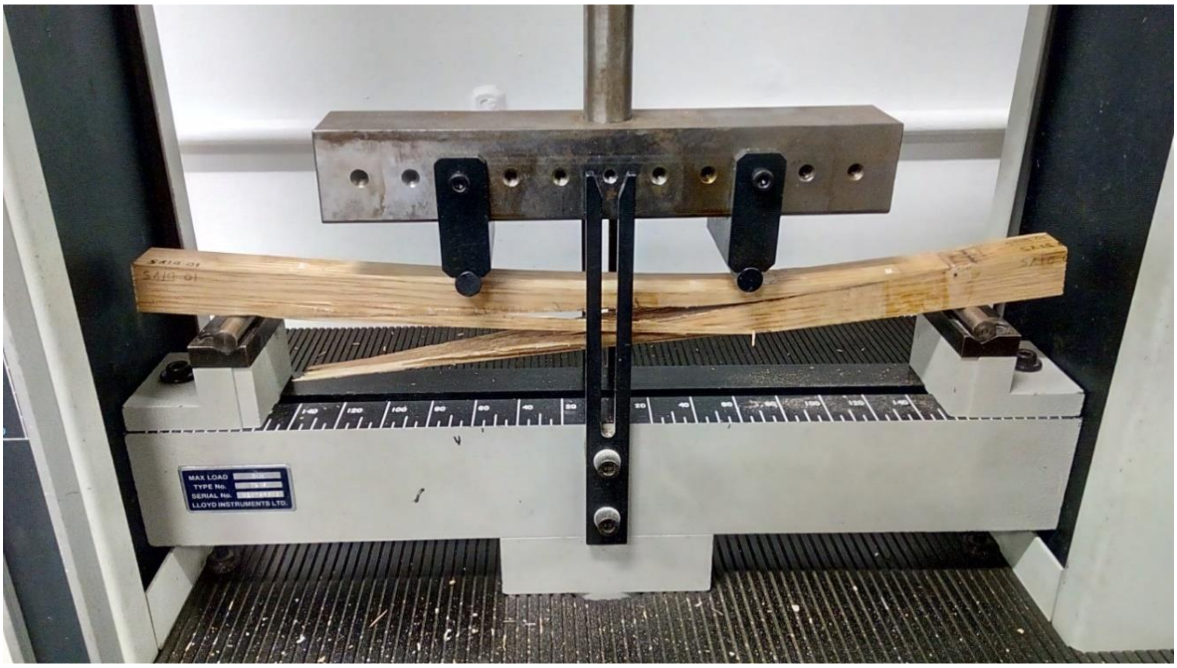


Figure 52- experiment setup – failure of sample

4.11 Results and discussions

Results for each scarf ratio are average value among all samples for that exact ratio. Furthermore, since samples had different density, maximum stress was adjusted for each section using density as handicap.

4.7.1 Control group

First sample to be tested was solid piece of timber, this was control group. After all joints should be strong as much as rest of the construction element. Therefore it is only logical to use untreated part of construction as a referent point.

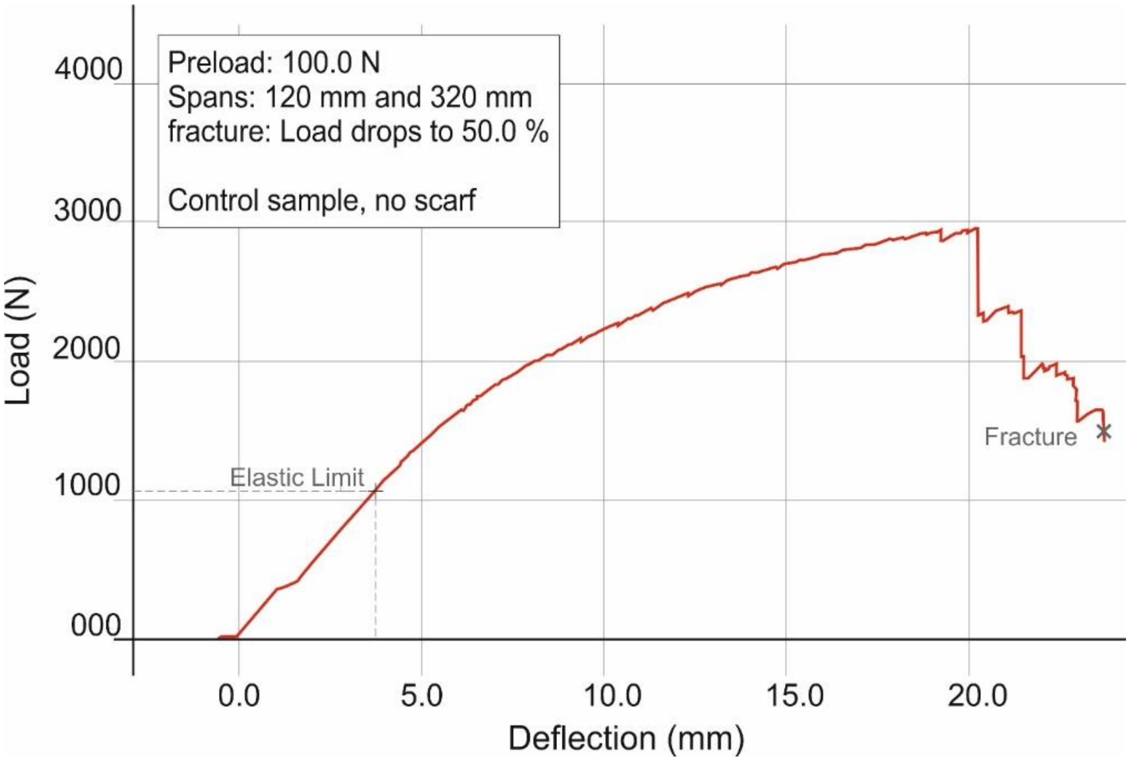


Figure 53- Load/Deflection diagram – control group

According Figure Maximum load that this element supported was close to 3000 N, which is close to expected value when ISO standards are concerned. Although, this value is few percent lower than expected. This could be easily explained with imperfections of the gran. Elements tested are only 20 mm wide, so if grain is not absolutely parallel to edge of sample a lot of strength is lost. Some of elements had some deviations of grain to the edge of element.

Figure 54 – Samples from control group

On figure 54, two samples from control group are depicted. If first (unbroken) sample is observed, it is quite easy to spot deviations in grain, grain is not near parallel to the edge of element. Second sample has much better grain orientation, which is why it was much more durable during breaking test.

4.7.2 Group of samples with scarf ratio of 1:4

This is the steepest ratio used in marine construction. It is well known as the weakest one, so it's mostly used in areas with low stress and risk.

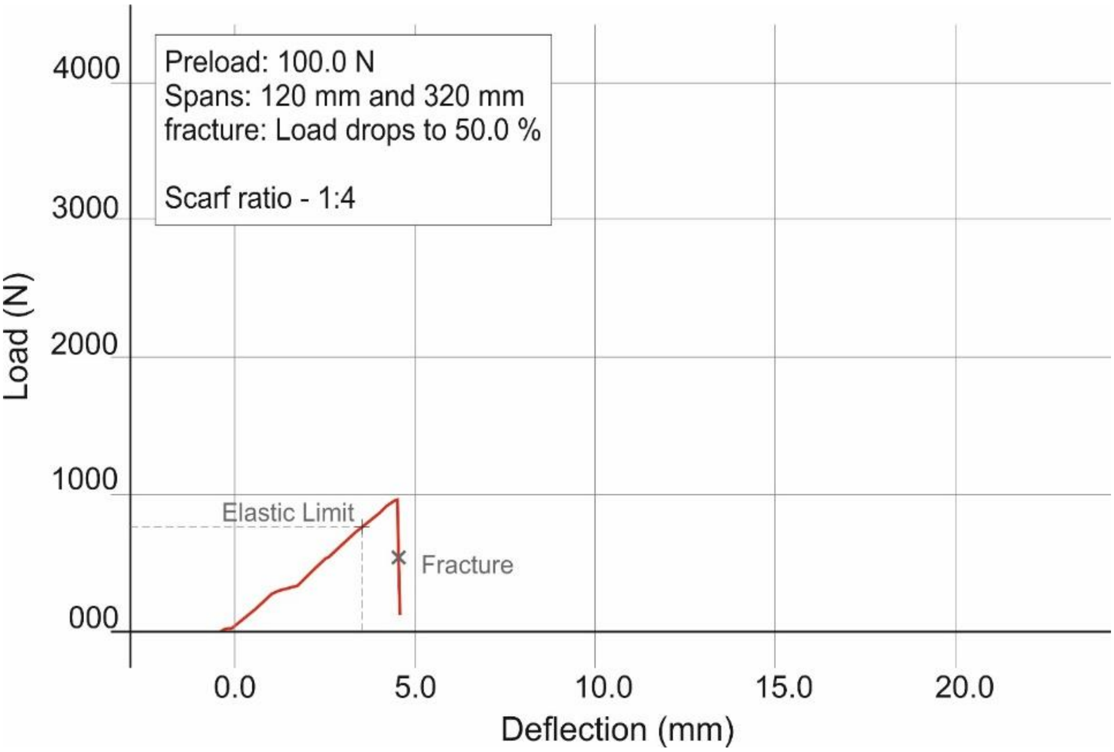


Figure 55 - Load/Deflection diagram – 1:4 ratio group

It is more than obvious, just from looking graphs that this scarf ratio sample group can't compete with control group when it comes to maximum stress. This scarf ratio group has less than 30 percent of strength comparing to control group. Nevertheless, construction elements are never designed according to maximum stress. Value that is considered is elastic limit, and even that limit is not used without safety factor. In ISO rules that factor is 0.5. So when elastic limits of two samples are compared, it turns out that scarfed element has value that is 76 percent of value of control element. This is still not enough, but it’s certainly good enough for some parts of construction, especially when 0.5 safety factor is considered.

Figure 56 - Samples from 1:4 scarf ratio group

In this group of samples wood failure was 0 percent. Simply all of samples cracked at the joint, as shown at figure above. Nevertheless, up on closer inspection of joints, it was noticed that there are some micro wood failures. This micro wood failures would appear only at annual grain rings, these grains are wider than rest of them, so resin could achieve better adhesion.

Figure 57– Micro wood failures that match annual ring grains

As shown in figure 57 before, all of samples were made out of single piece of wood, in order to match grain perfectly. Back than effect of annual rings wasn’t known to author, still, by chance, one sample was made from spear materials, and this sample was made out of two different pieces of wood. This sample was significantly stronger. When its joint was inspected, it had noticeable higher percentage of micro wood failure, this is due mismatch of annual rings, therefore there was more area covered by annual rings. This is certainly good news for builders, since in practice, joints are always made out two different pieces of wood.

4.7.3 Group of samples with scarf ratio of 1:8

This group have double the size of adhesive surface comparing to previous batch, so all characteristics of joint did improve, but overall characteristics of stress resistance and failure logic didn’t change.

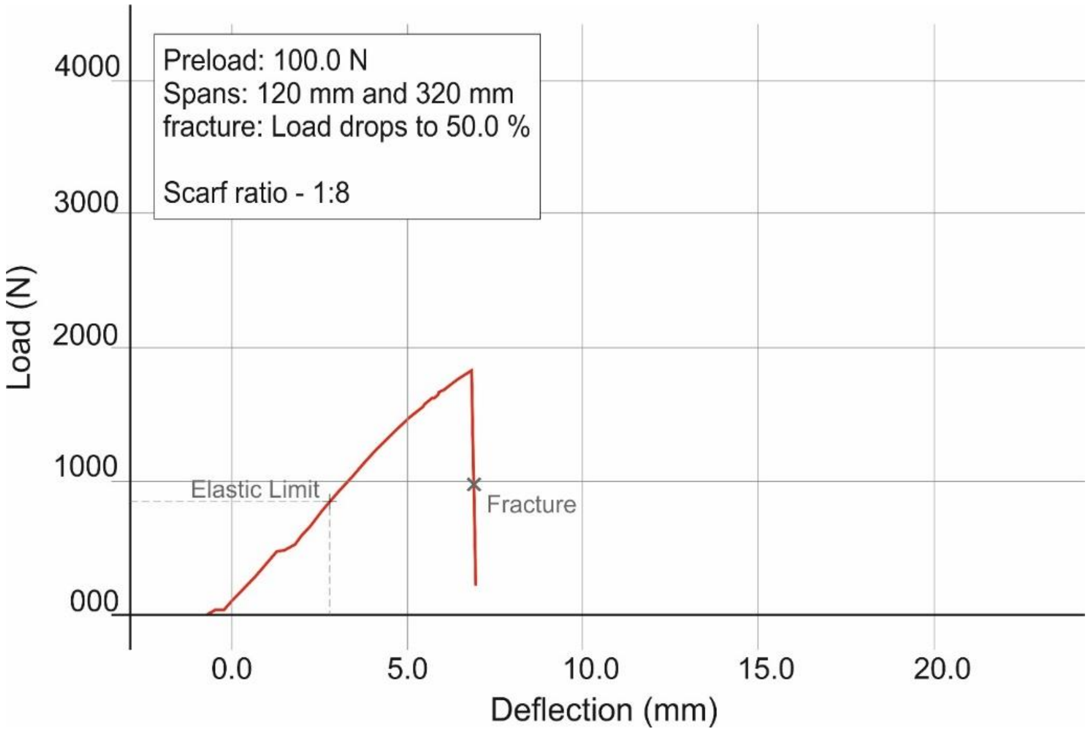


Figure 58 - Load/Deflection diagram – 1:8 ratio group (average graph of all the cases from one group)

Again there was no wood failure, except localized wood failure around annual grain rings, same as in previous group. Biggest difference was rise of strength, 1:8 ratio scarf could stand more than 50% of maximum stress that control group resist.

Same trend was noticed in rise of elastic limit. This time samples had, on average, 15 percent lover point of elastic limit, comparing to control group.

4.7.4 Group of samples with scarf ratio of 1:12

This is the first group of samples where wood failure start to appear, results are different from sample to sample, but all of them are close to results of control group, and more important, on average, this group was stronger than control group.

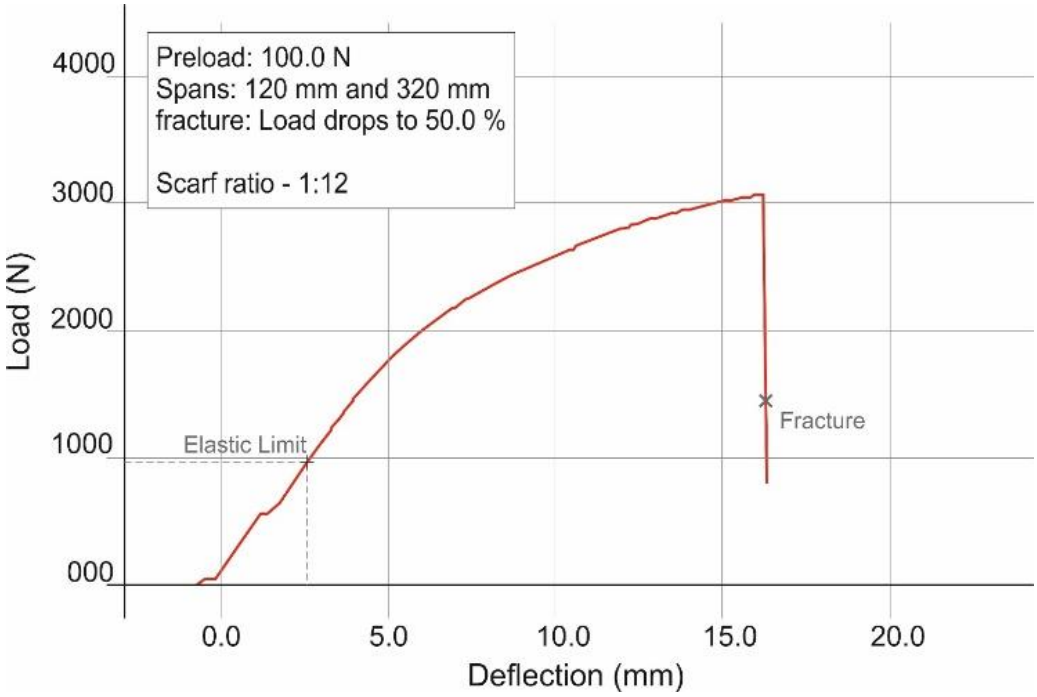


Figure 59- Load/Deflection diagram – 1:12 ratio group

On average maximum stress taken by average sample in this group is 2% higher than control group. There could be many reasons why this is the case, first of all, joint brings more stiffness to element. Joint is made using epoxy resin, material that is more stiff than wood. Since joint is in the middle of element, same as maximum moment, long, stiff reinforcement actually helps. Second, epoxy layer divides samples section in two parts. Therefore, if crack appears and starts to propagate, it will stop as soon as it hit epoxy layer.

Figure 60 - Samples from 1:12 scarf ratio group – wood failure

And crucially, when joints become more and more flat, sample start to resemble laminate wood more and more. When joint is very long, piece of wood is almost split longitudinally, comparing to first scarf group where this division was almost transversal. This could be seen as laminated wood element. It will be shown in rest of this research, that all of the trends that start to emerge slowly in this group of samples, only continues to grow in rest of the groups.

Interesting enough, point of elastic limit was actually 3.3% lower than control group. Probably, same stiffens that helped element to resist more force, did opposite for elasticity of element.

4.7.5 Group of samples with scarf ratio of 1:16

In this group 5 out of 6 samples had wood failure.

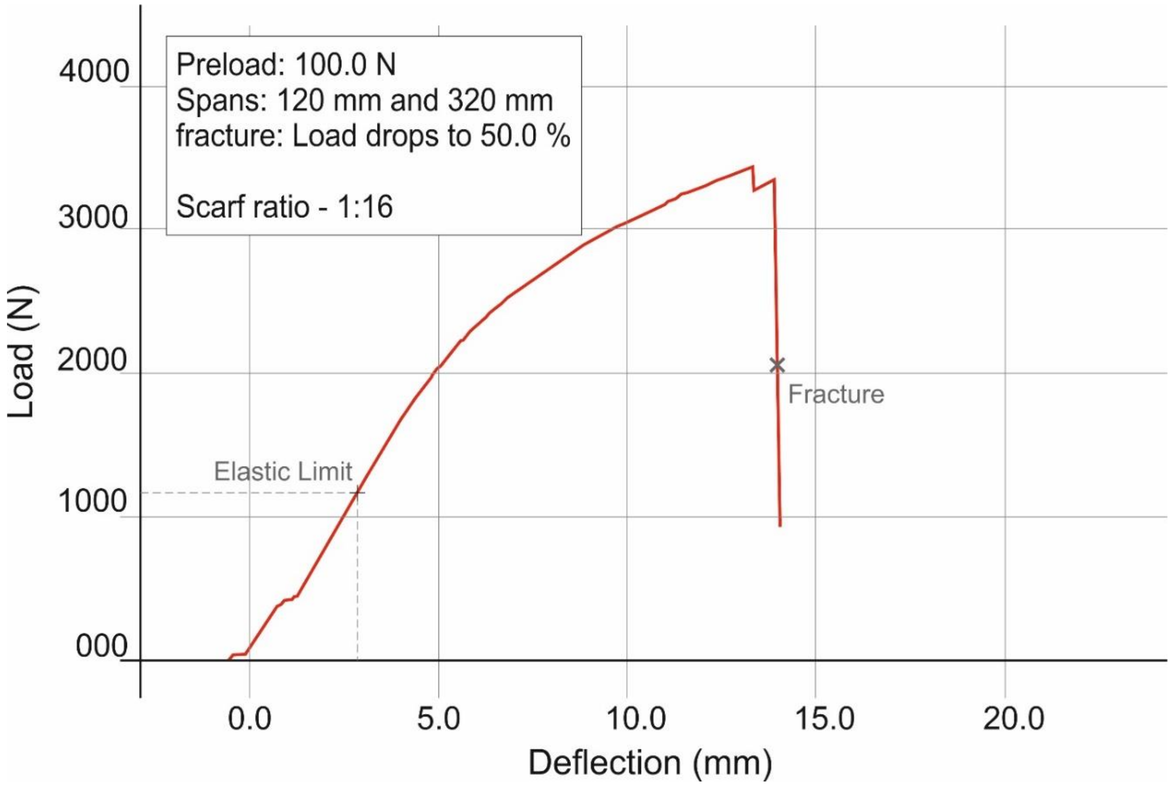


Figure 61 - Load/Deflection diagram – 1:16 ratio group

This sample, with scarf ratio of 1:16, is on average 15% stronger than control group, and elastic limit point is 17% higher than same control group. Therefore it is obvious that this ratio would be safe choice in any part of construction. Nevertheless, when scarf ratio start to rise, waste of wood follows along, therefore extreme scarf ratios should be used only when it’s absolutely necessary.

4.7.6 Group of samples with scarf ratio of 1:20

This is one of the most extreme scarf ratio used in ship construction, even there it's used quite rarely.

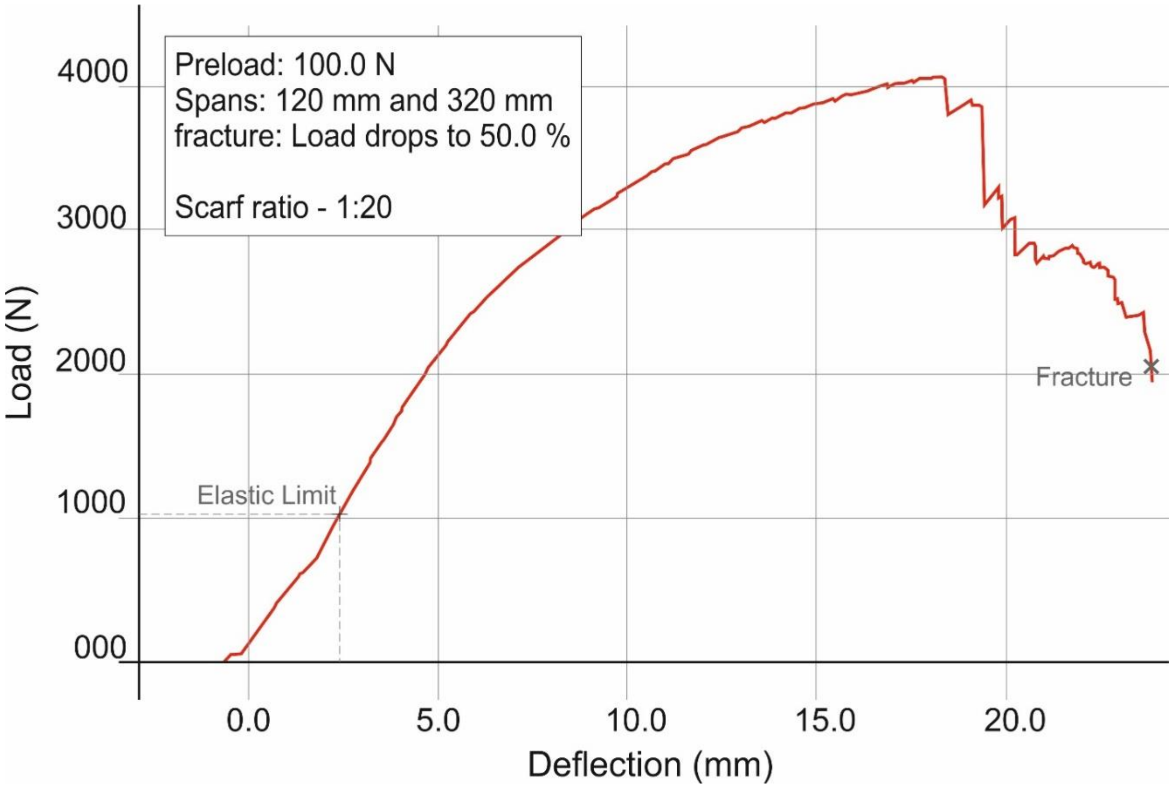


Figure 62 - Load/Deflection diagram – 1:20 ratio group

In this batch, on average, samples were 25% stronger than control group, elastic limit was higher as well. Which is not surprise if results from previous groups are looked on. One thing that is different this time is the shape of the graph, this time, not only that element is strong enough, but shape of graph starts to resemble control group. Wood failure was 100%. All this is ultimate proof that that this joint is a proper replacement for structural element.

Theory that joints start to behave al laminated wood with joint being elongated was already mentioned, but here it was confirmed. In this case scarf was as long as specimen, this is practically example of laminate. There was many studies comparing laminated wood to regular timber, like one done by Nan Guo [38], where similar results were gained (figure 63).

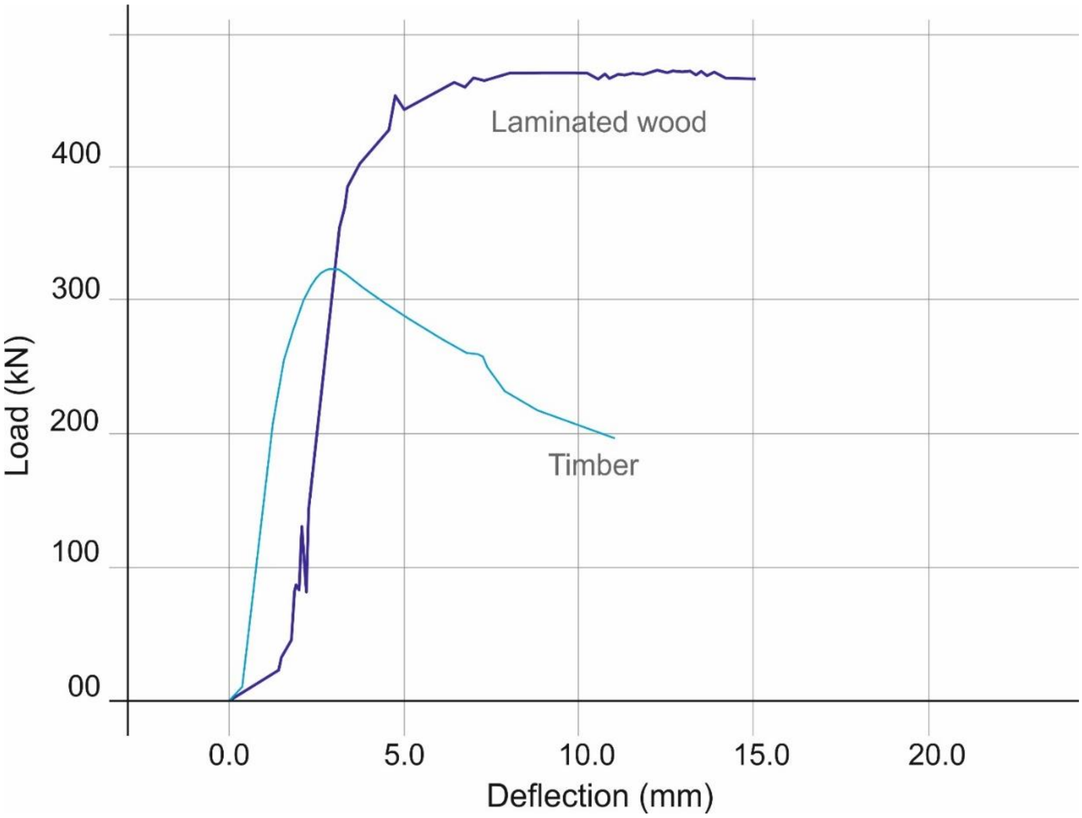


Figure 63 – Strength of laminated wood comparing to non-laminated wood by Nan Guo [38]

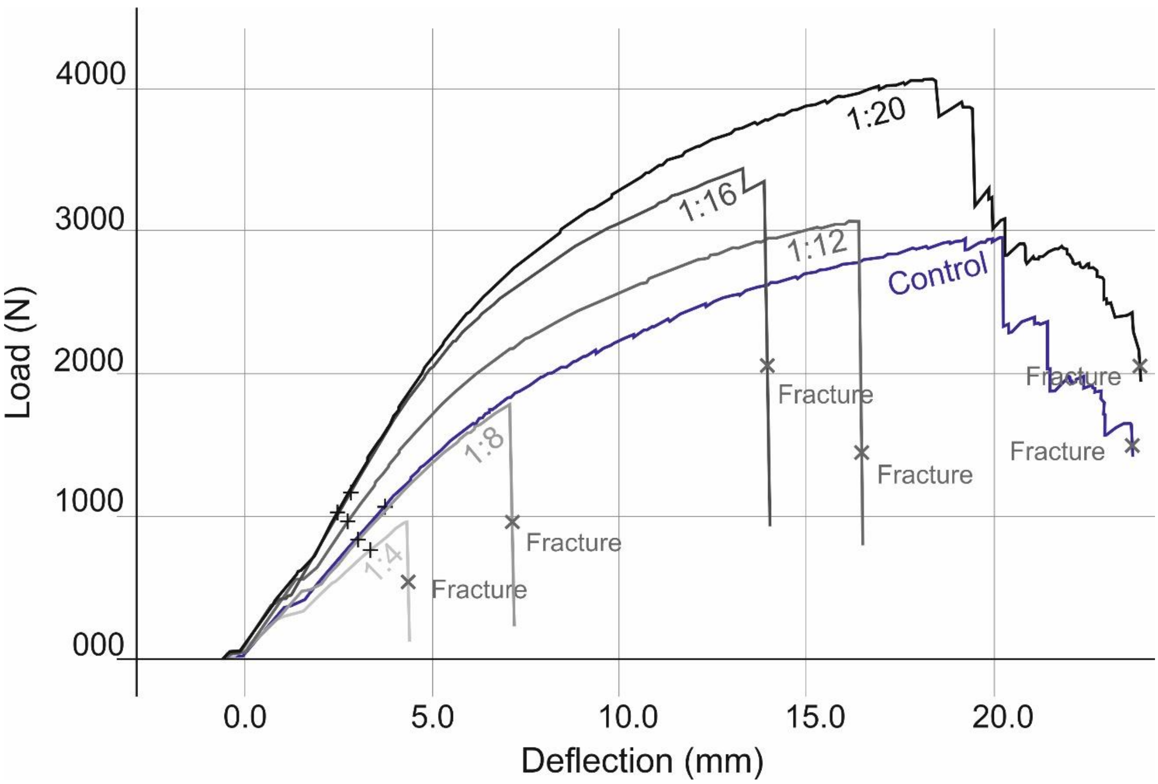


Figure 64– Comparing of all results at one place (average graph for each sample group)

On the figure 64 it is visible that comparing results can be drawn by two criteria, maximum load and elastic limit. Both criteria will be analyzed and two charts will be shown in next chapter.

4.12 Comparison with values used in practice

As mentioned before, this is not the first time somebody tried to define exact reliability of scarf joint. There is source that was used in practice for a long time, which is book about wooden boats written by Birmingham [19]. In his book Birmingham states that a 4:1 ratio joint is about 65% percent as strong as solid wood, he gives climes for other joints as well, therefore 8:1 is 85% strong, 1:12 is 90% and finally 1:20 is 95% as strong as solid wood of the same section. This values are put at the same graph with values gained in this research, figure below (figure 65):

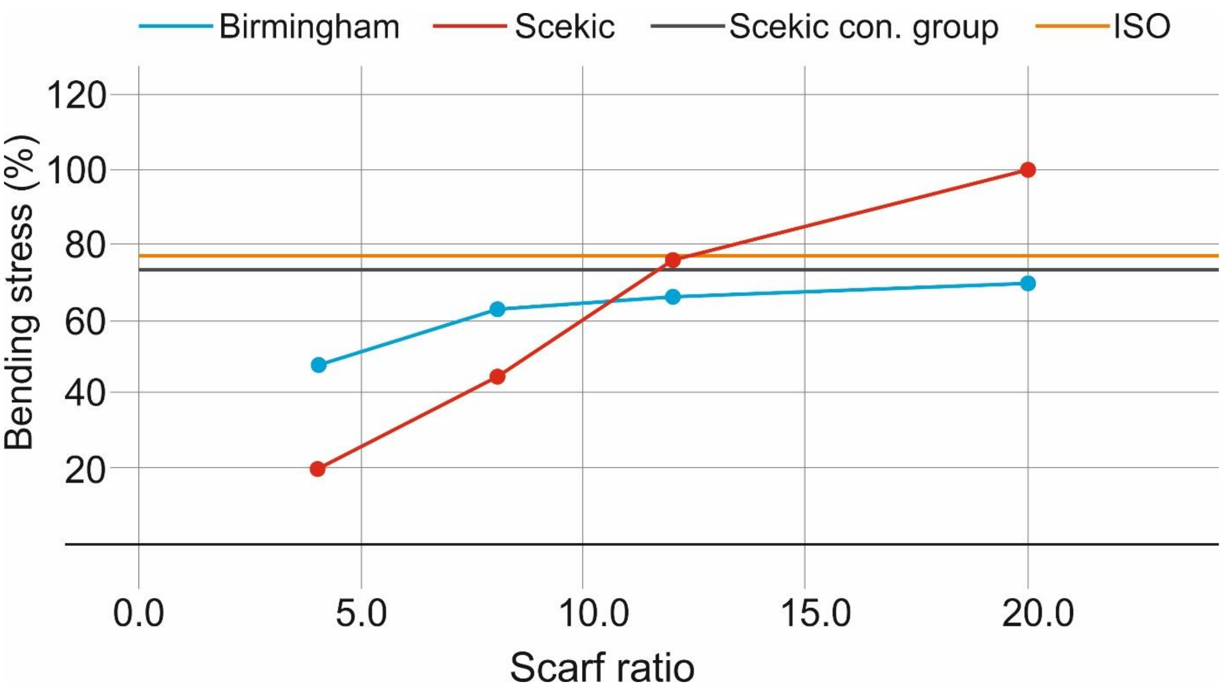


Figure 65 – Comparison of strength values experimentally gained with empirical values

It is not clear how did Birmingham gained values he presented in his book. Maybe he did perform some experiments, but knowing how big role empirical knowledge has in traditional boat building, these could also be some numbers that he put together from years of experience. One clue that supports this theory is fact that he never gives exact value, he always uses word “around” before stating value.

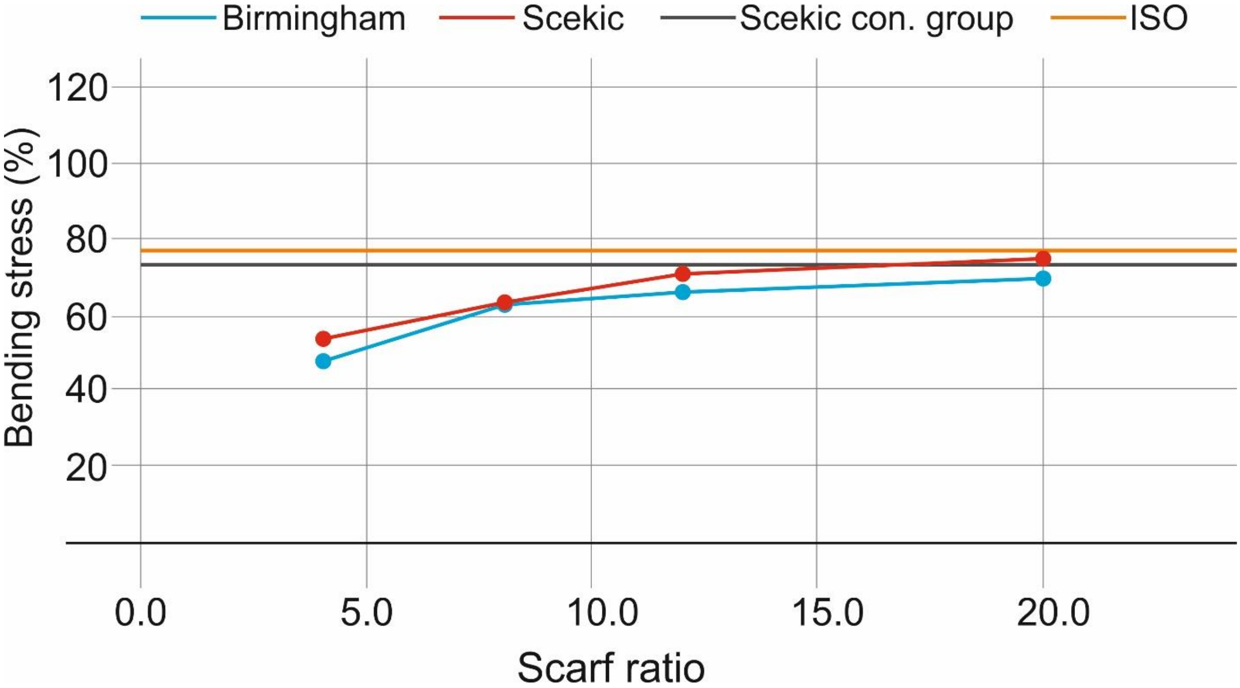


Figure 66 - Comparison of values experimentally gained with empirical values – Position of elastic limit point

Another clue to support this, is elastic limit point diagram. If elastic point position is examined, values are much closer to Birmingham results. What would be expected to gain if using equipment that was available in workshop, since it's harder to define failure in those conditions. Since lack of elasticity can be taken as a fail, same as actual rupture.

As shown here, when elastic limit is considered as wood failure, differences between two approaches are minimal. Values gained in this experiment have same trend, but a bit higher values. This could be explained by type of resin used, epoxy resins are improving every year, so even samples created same way will be stronger if resin is modern.

Elastic limit, even it is not the breaking point of construction, is not something that should be crossed when calculating stress in construction, therefore this could be taken as a confirmation of Birmingham's work.

4.13 Conclusion

First of all, research managed to prove concepts that were used in practice for a long time, with giving them exact values. It was proven that using scarf joints still is simple, but valid solution on the shops flour.

Larger joints, with larger glue surface start to behave like laminate wood, this makes them definitely stronger, but brings up the costs. There is more waist of material, sharp angles are more difficult to produce so more working hours is needed and finally consumption of resin is bigger.

Epoxy resin brings more stiffness in to structural element. This makes it more resistant to stress, but in the same way it brings elasticity point down. For the future experiments, it would be interesting to use longer samples, or three points test, just to see how big role this phenomena has.

Another unexpected fact was role of annual ring grains. Certainly this is the factor that brings more strength in to joints. That means that types of wood that have more annual rings per surface are stronger. For future experiments, it would be interesting to use samples with different amount of annual rings per surface of joint, so comparison could be made. Also, future researcher should compare samples made out of single piece of wood to samples made out of different planks.

5. DEVELOPMENT OF ARTIFICIAL AGING METHOD FOR TIMBER-EPOXY LAMINATES LONGEVITY

5.1 Introduction

There is growing need for use of laminated structures. Timber is renewable resource, but depending on the species it can take decades or even a century to grow trees ready for harvest. Laminated wood is more eco-friendly, because instead of requiring large sections of timber, it can be laminated using smaller pieces into size needed, thus resulting in a more affordable cost. Moreover, laminated wood is desirable for marine applications.

Depending on method of lamination, type of glue and wood, laminated elements can be significantly stronger than same size elements made of pure timber [23]. Nevertheless, there is a problem of longevity.

Wood is one of oldest building materials used by Mankind. Consequently, its characteristics are well known and it is possible to predict its longevity, with a small margin of error. Nevertheless, it is very complex to quantitatively predict its behavior correctly because wood is natural material and every piece of it is unique. Even if only one species of wood is examined, its characteristics will not be uniform. Many factors dictate those, for example [41]:

- geographical origin of trees,
- micro-climatic circumstances (did tree get enough sun etc.),
- which part of tree are we examining (trunk, branches…),
- Is there any imperfections in specimen (nodes, voids…),
- Moisture content,
- Grain orientation,
- Drying technique (quick drying can lead to build-in stress).

Whit all this difficulties in mind, wood is still one of most used construction materials. And when those previous factors are kept in mind it is possible to make some fact based estimations, with some safety margin. For building application, the life expectancy of wooden components can be predicted based on its position and exposure to the elements, as presented in [24]. So, despite the complications and singularities of each situation, the life span of wooden structural components can be predicted.

As a result, the main unknown for laminated constructions is the adhesive. Despite better adhesives being developed every year, with measured enhanced mechanical properties, the actual longevity remains a mystery.

Because of this, in practice, new materials are not used, since it is unknown how will they behave in few decades, instead quite often, ones that are used are glues that have been around since WWII , even they are worse than modern ones, at least it is well known what to expect from them [25].

To solve this problem, we would need to come up with accelerated aging method. This is been discussed in [25]: *The absence of such tests is the largest impediment to the introduction of new adhesives types and is the reason why the current adhesives are the same ones that have been used since the end of World War 2.*

5.2History of accelerated, artificial ageing of laminates

Because of problems explained in introduction many people tried to find reliable way to artificially age laminated specimens.

Group with most success was *Steering Committee for Accelerated Testing of Adhesives* (SCATA), they manage to develop machine that was capable of imitating ageing effects on wood, rapidly [25].

Test procedure is standardized in ASTM 3434 standard [26a]. Basically machine is boiling group of samples and then drying them, this is one cycle. Machine is automated so its able to repeat cycles up to 1600 times. There is only one of these machines in the world and its still in position of the group.

This method is great for comparing two kinds of adhesives, since it can clearly show which one can handle more cycles. So what is usually done is following, new product would be tested comparing to product of well know features and then it would be possible to conclude is new one better or not. Without guaranty that one cycle ages both material for same amount of real time.

Another thing that machine couldn’t sort out is how many cycles correspond with certain time of natural ageing. So in 1984, D. Caster try to compare samples treated in boiling machine with samples that were naturally ageing [27]. He had samples that were exposed to the elements up to 16 years, made with different kinds of adhesives and aged in four different locations in US. After testing and comparing natural aging to artificial, he concluded that 11 years of exposure to the elements could be equal to 800 cycles in boiling machine.

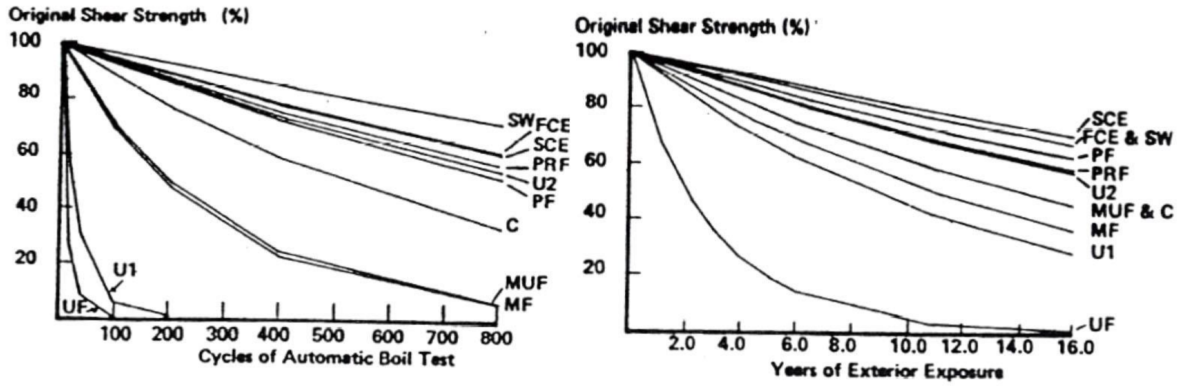


Figure 67– The correlation between the results from the 16 year exterior trial (left) and the ABT (right) [27].

The adhesives studied were phenol-resorcinol-formaldehyde (PRF), phenol-formaldehyde (PF), melamine-formaldehyde (MF), melamine-urea-formaldehyde (MUF), casein ©, urea-formaldehyde (UF), slow cure epoxy (SCE), fast cure epoxy (FCE), urethanes (U1 and U2) and solid wood (SW).

5.3 Epoxy adhesives

Epoxy adhesives are one of most used on the market, since they are easy available and easy to use, but they do have some drawbacks.

It is well known that water effects epoxy laminates much more than laminates with some other adhesives. So maybe boiling tests wouldn’t be the best way to test them after all.

Another problem is that epoxy adhesives have low percentage of wood failure,15-30% [25]. But this can depend on few factors, Jan Vanerek did some testing and notices that wood failure increase in samples where glue is applied on early wood of annual rings, where better penetration in cell wood structure is possible [28].

According to Charles R. Frihart epoxy has low wood failure index because it is tough adhesive and it fail to follow dimensional changes that wood makes with changes in ambient conditions [29].

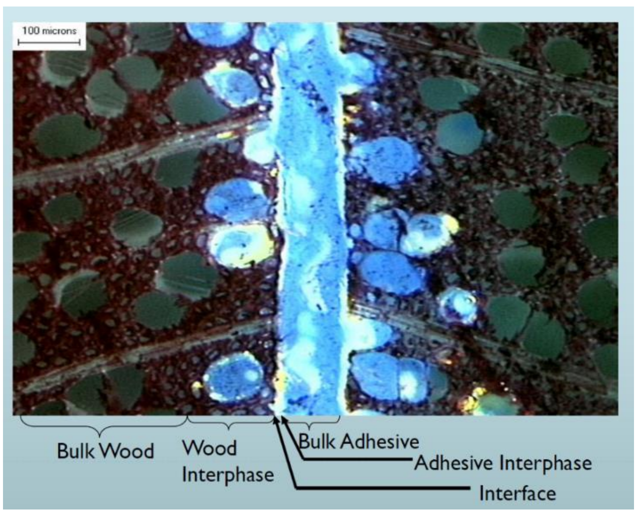


Figure 68 – Epoxy/Wood bound domain, with all zones of bound named and pointed [7]

From *Factors that Lead to Failure with Wood Adhesive Bonds* [30]:

‘From all the available evidence, the failure of the epoxy bonded wood laminates seems to be in the epoxy interphase. Epoxies have less delamination to wood that swells less.’

This is due the polarity of epoxy, which is present, but still it’s less than cell walls, so epoxy fails to penetrate through the wall. For reaction to be achieved, epoxy would need to meet amine with in the cell wall, which is not the case with un-modified epoxy resins [30].

The hydroxymethyl or HMR when used as a primer is capable to improve connection between wood and epoxy, it has been theorised that HMR actually stabilize the wood surface. When it comes to HMR, it has been proven that he is excellent primer for several types of adhesives and a number of wood species, but despite that this phenomena is not understood good enough, so exact method for HMR is not defined [30,31].

5.4 Influence of UV light

It is well known that UV light is one of biggest enemies of polymers, so it would be unappropriated not to mention it. There are tests for polymer samples with influence of UV light and depended which source of light is used, different standards are applied (ASTM D 4329, ASTM D 1499)[26a][26b].

But effects of UV light are not biggest problem of glues used for wood lamination. Simply because wood protects glue from direct exposure to light. Since UV beams can’t get through cardboard, there is no worry when it comes to any type of wood.

When creating method to accelerated ageing of laminate it would be logical to include factors and circumstances that will surround specimen in real life. It’s already mentioned that sun light doesn’t play a major role, but temperature certainly does, if we look at NLP Report [32], we can see:

Thermal degradation refers to the chemical and physical processes in polymers that occur at elevated temperatures. Increased temperature accelerates most of the degradation processes that occur in polymers such as oxidation, chemical attack and mechanical creep. Oxidation is generally considered to be the most serious problem when using polymers at elevated temperatures.

This leads to next standard.

5.5 Standard guide for accelerated aging of sterile medical device packages

When looked at certain features of epoxy, that were previously shown, and method of boiling machine, it can be seen that it is not certain is this method suitable for this material, it is not known do cycles effect wood and epoxy on same rate and there is no way to pinpoint correlation of number of cycles to actual, natural ageing. That's why author started looking into other standards.

ASTM F 1980 is used to test medical device packages [33]. This is artificial method that is capable of claiming longevity of polymer materials by changing the surrounding temperature. Basically, standard is there to make sure that the packaging holding medical equipment has expiration date at least as long as equipment itself.

This method raise interest, because epoxy is a polymer.

Standard provides detailed guidance how to do the testing, but basically: Samples of packaging are placed in an oven with constant humidity and temperature. Temperature shouldn't be higher than 60 degree Celsius. Samples are left there for weeks and with some simple calculations it is possible to calculate how many weeks in oven are equal to real life ageing conditions.

For example, in the figure below it could be seen that 3.7 weeks in the oven with temperature of 60 degree is equal to one year in real life.

In the table it can be seen that this depends on to Q_{10} value, this value can be calculated for every material, but standard also acknowledges that this is too complicate so it suggested to use value of 2 for materials that are unknown, since this is most conservative option.

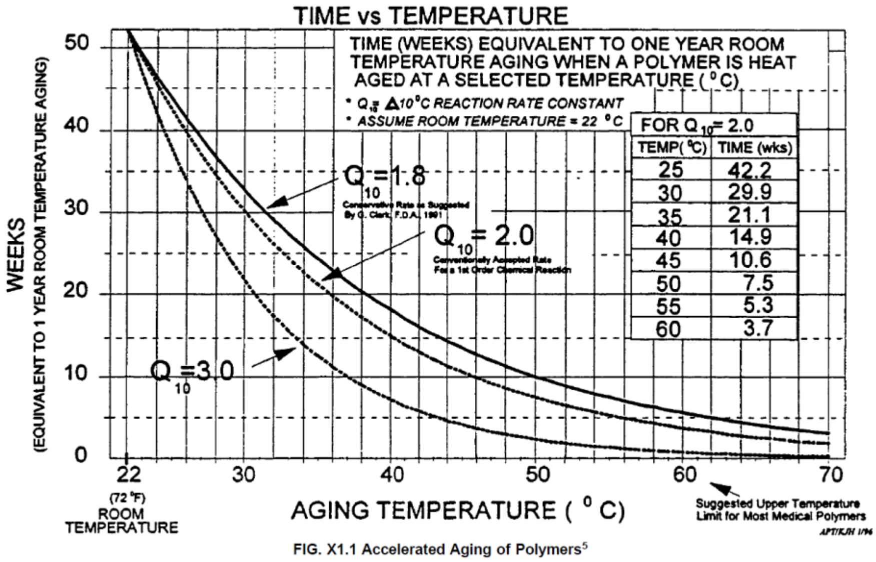


Figure 69 – Time vs Temperature diagram, ASTM F 1980 – 2 (Standard guide for accelerated aging of sterile medical device packages) [33]

From ASTM F 1980 – 2 standard: *Accelerated aging techniques are based on the assumption that the chemical reactions involved in the deterioration of materials follow the Arrhenius reaction rate function. This function states that a 10°C increase or decrease in temperature of a homogeneous process results in approximately, a two times or 1/2-time change in the rate of a chemical reaction (Q10)*[5].

5.6 Suggestions for the new test

Based on previously presented facts, custom test that is suitable for epoxy laminates could be proposed.

Some characteristics of epoxy adhesives were already discussed, so specimens should be designed according to those. Since perfect conditions for epoxy to bond should be required.

Test sample should be able to simulate forces and factors that occurs in reality. Since laminated wood is object of this study, most simple and effective solution would be to produce sample from one piece of wood, that is sliced in half, longitudinally, and then joined back in one laminate (Figure 79). This way layer of glue would experience almost no bending force, but maximum shear force.

In some cases wood type will be defined, but if it is not, it would be good to use soft wood with large porosity, this would increase wood failure in experiments. Hence the choice of pine for this experiment.

Before laying down epoxy layer, hydroxymethyl resorcinol primer should be applied. Since it was showed how much it helps bonding.

It can be seen that ASTW F1980 is much simpler and energy les demanding than ASTM 3434, but also it can be seen it is designed for polymer only, so it's unknown how it would influence wood. So solution might be in ageing glue separately.

Thin, cured film of epoxy should be used for ageing in oven, following procedure of ASTM F1980. After that, that film, should be glued between two pieces of non-aged wood. Wood needs to be treated with primer first and then epoxy glue should be added so sample of laminate could be formed. When applying epoxy glue to join film and wood, minimum of glue should be used, since layers that are over 1 mm thick can be bad influence on creep performance [25]. Now this method can be used to make artificially aged samples. Idea is to make groups of samples that have different age. It could start with control group that didn't age, so it could be used as a reference. After that it should be continued with making samples and each group should be older for a certain period of time (a year for example). When testing and comparing different groups to each other, degradation of epoxy adhesive over time should be visible.
Wood inside of the laminate wouldn't be aged. It has already been discussed that it is impossible to make procedure for aging wood up to specific age, since each piece of wood ages different (that is internal factor) and same piece of wood wouldn't age same way exposed to different elements (external factor). So for expected lifetime of wood, one would rely on same assumptions that is used when using pure wood constructions, which are not very exact, they are mostly empirical, but they are well proven in practice. But when it comes to layer of adhesive, it could be aged to exact point in the time needed, so when testing this kind of sample, focus would be on the part of laminate that is new and has unknown characteristics.
One could think of certain kind of test where wood is not even involved, one could test film only, but wood help us get more realistic results. First of all it distribute stress through the film realistically. Second, it was already discussed how does epoxy bond with wood, so the type of wood used in test will play a role in strength of that bond.

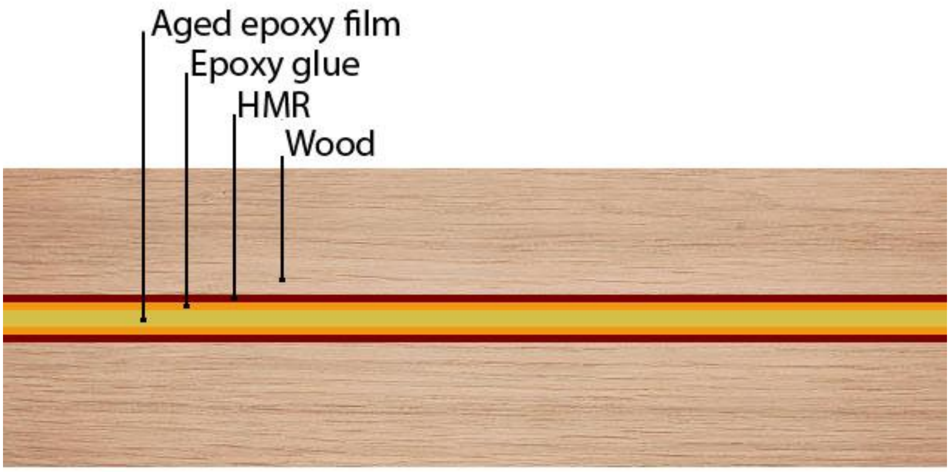


Figure 70 – Final layer assembly of test specimen

Whit this alignment of wood and other layers, percentage of wood failure could be increased in un-aged specimens. It would be interesting to see if un-aged specimens have high level of wood failure and then after testing group by group of aged samples, in one group of aged specimen wood failure would fall. This would provide the point in time (M2) where glue starts to be wicker than wood. Since un-aged wood is used for all specimens, this point would be higher than in real life (M1), since in realistic conditions wood ages as well, but it would provide us with safety margin (d1) (figure 71).

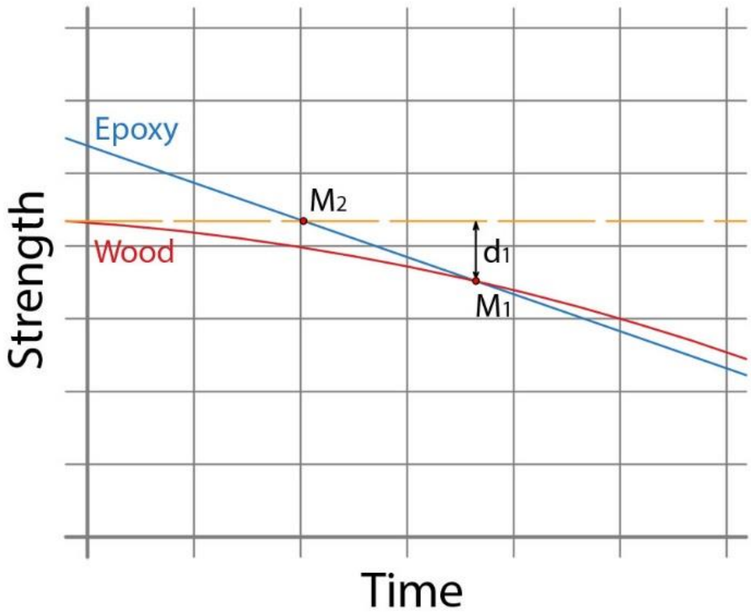


Figure 71 – Estimation of Strength over time diagram for wood and epoxy

Since it is important in which layer failure occurs, it would be good idea to pigment layers with different colors.

When it comes to size of specimen and test procedure, existing standards could be used, like BS EN 408 (Timber structures — Structural timber and glued laminated timber — Determination of some physical and mechanical properties). Also, size of specimen is dictated by actual available spacing on labs machinery.

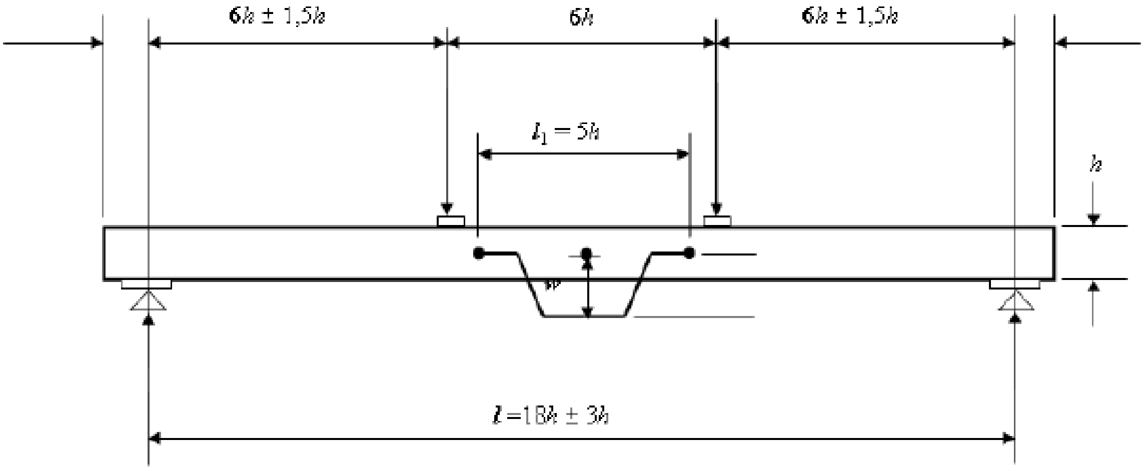


Figure 72– Test arrangement from BS EN 408 [12]

5.7 Proof of concept

Samples that are presented here are not manufactured in a usual way, usually resin cures inside the joint and it this case, resin cures elsewhere and only for purposes or testing is placed between planks. Because of these different production methods, some uncertainties occurred. So in order to proof that method is valid, tests needed to be conducted.

Two groups of samples were produced. First group was produced the same way it was described before (figure 79) with resin film. The other, control, group was constructed using absolutely same materials, but with resin applied uncured on to the wood, traditional way. These two groups of samples were used.

To test this samples BS EN 408:2010+A1:2012 standard will be used (Timber structures — Structural timber and glued laminated timber — Determination of some physical and mechanical properties).

Unfortunately, there was no enough time to age films of resins, but that is not crucial when proving concept of sample production. Main thing to prove here is that this kind of sample will give constant results that are possible to be analyzed in conventional way. Nevertheless, in future researcher it would be desirable to create samples with resin films of different age, so the aging concept could be proven as well.

5.7.1 Materials used research

Epoxy resin was used as adhesive, same type of resin as for previous experiment.

Components of adhesive used for experiment:

- Epoxy resin: Ampreg 22 – Epoxy laminating system (75%)
- Hardener: Ampreg 22 - Epoxy laminating system (21%)
- Microfiber: SP microballoons (4%)

Where percentage is the percentage of weight of mixture.

While for previous experiment oak was used, wood chosen for this test was pine. Since this test is conducted in order to examine characteristics of resin, where wood is just used as a medium to delivered stress, wood choice wasn’t crucial.

And if soft wood as pine is used, it can be almost guaranteed that there will be high rate of wood failure in un-aged group of samples. This means that if wood failure starts to wane in aged sample groups it is due to chemical changes in resin. Therefore, it would be direct visual proof of damage that was done by ageing. Finally, pine is quite cheaper, and available almost anywhere.

5.7.2 Production of samples

In previous experiment not all the samples were made from same piece of wood, therefore problem of density emerged. Since pine is much cheaper and less samples was needed it was possible to make all samples from single piece of wood. This way all samples were made with using same materials and under same conditions, so it was easy to compare them to each other.

There were two groups of samples, with only difference being usage of resin film. One group was made by using film and other by raw resin (figure 73).

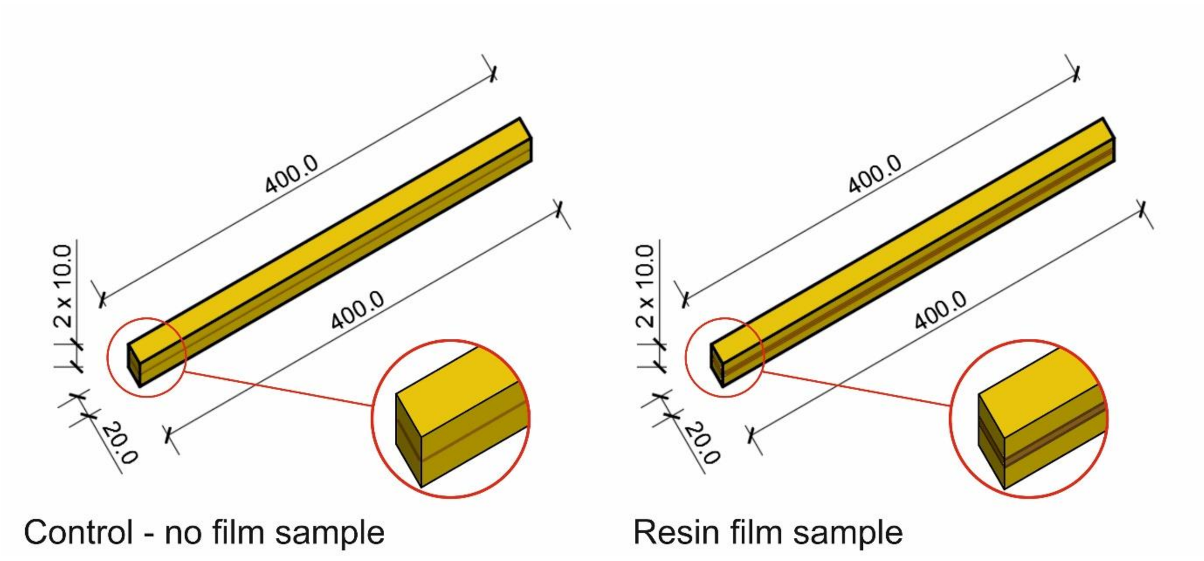


Figure 73– Sample dimensions and characteristics

As mentioned, all of the samples were made from single plank of pine wood. Plank was cute id smaller pieces (10 x 20 x 400 mm), using bandsaw.
After that, primer was applied, for the reasons already stated in the text. Primer was curing for two days before gluing.

Figure 74– Samples with layer of primer applied

When producing the control group, pieces with cured layer were glued using raw resin, whit characteristics already mentioned. Samples were under pressure for two days and then they would cure for two weeks.

When it comes to the other group, film was still needed to be produced. Resin with same characteristics was used, after mixing resin it was spread across waxed surface in to thin film (figure 75). Spreading was done using spatula.

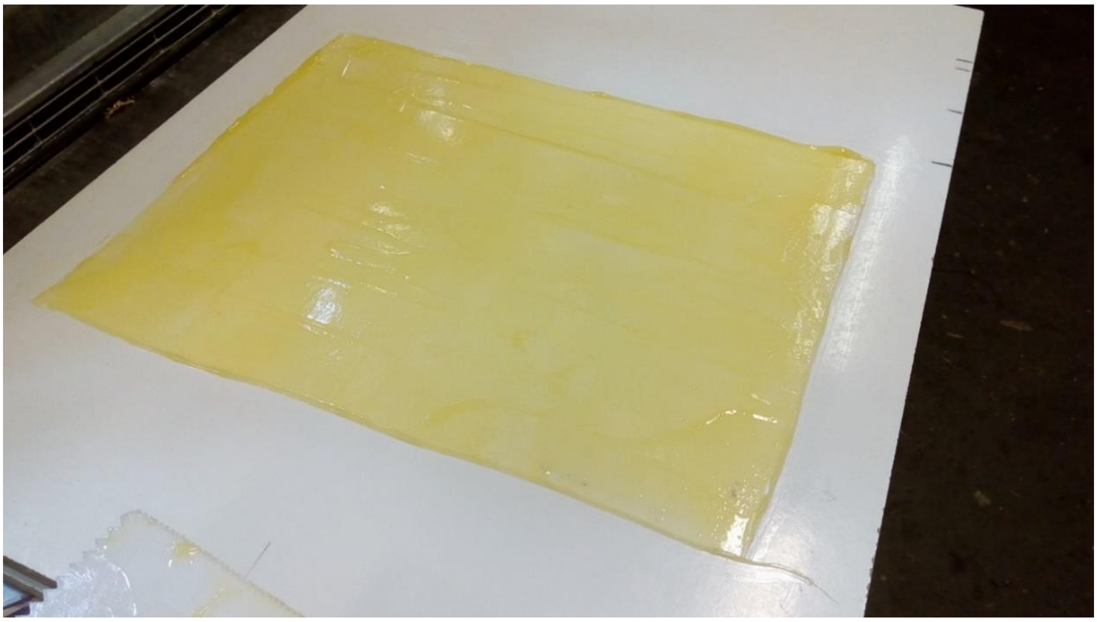


Figure 75 – Resin film, left to cure

After 24 hours, film was cut in to strips that were ready to glue between two pieces of wood.

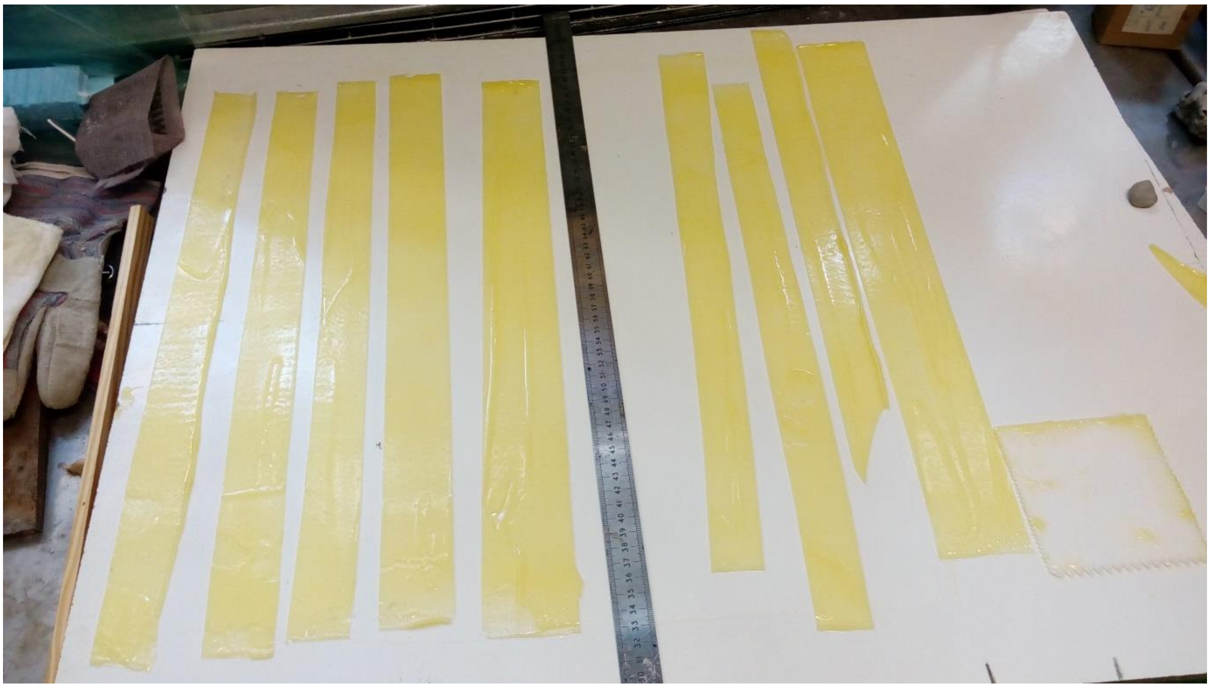


Figure 76- Strips of resin film

Next step was to assemble films and planks in to samples. So, between two pieces of wood (with cured primer) single piece of film was placed. In order to achieve attachment, thin layer of uncured resin was applied between film and each piece of wood.

After that samples were placed under pressure for two days and curing of two weeks with no pressure, before the test.

Figure 77 – Sample curing under pressure

It was already mentioned that epoxy resin doesn’t need pressure, but pressure in this case wasn’t great and it was used just to keep all of the parts in wright place. Before testing, any extra film sticking outside the wood was removed.

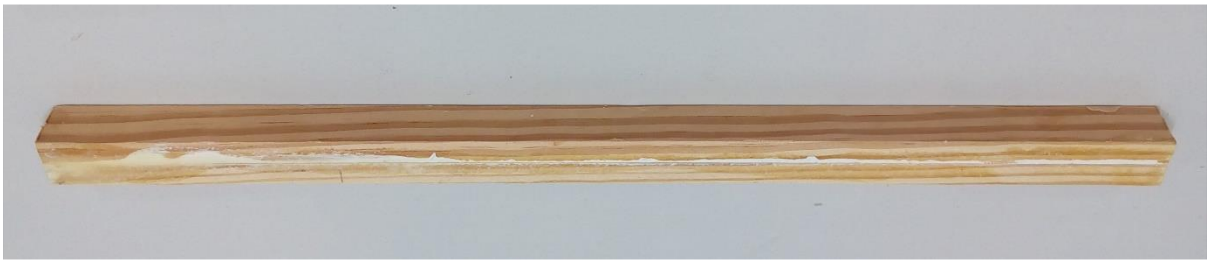


Figure 78 – Sample before testing

5.7.3 Flexural test

This test was done in same facilities and under same condition as previous one, at Solent University, Southampton.

Figure 79 - experiment setup – starting position - the Mechanical testing laboratory Solent Southampton University

Testing was done using BS EN 408:2010+A1:2012 standard (Timber structures — Structural timber and glued laminated timber — Determination of some physical and mechanical properties). Under this standard, speed of crushing head was calculated to be 0.06 mm/s. There was two groups of samples, each group had five samples.

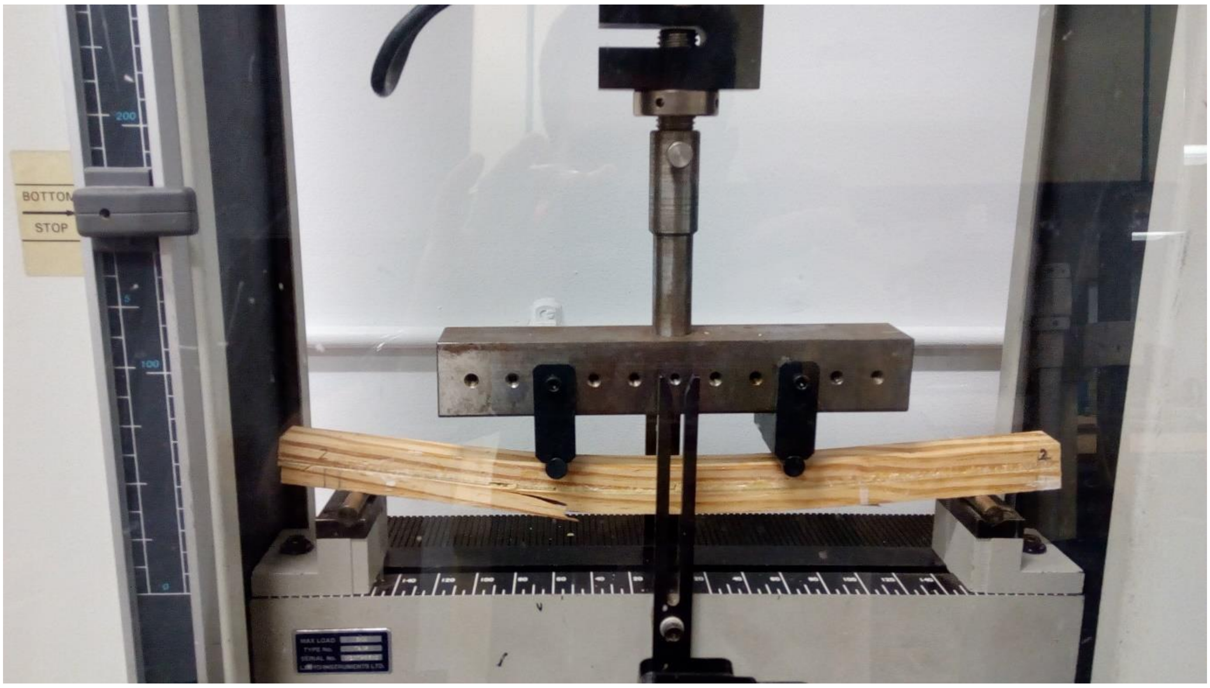


Figure 80 - experiment setup – failure of sample

Wood failure was high in both groups, actually only two samples didn't have wood failure, this is rate that could be neglected.

5.11 Results and discussions

The exact results of each test can be seen in appendix. Two groups of samples, that were build using same materials, but different techniques, were tested and compared.

5.11.1 Control group

First samples to be tested were laminated samples constructed in traditional way, with no resin film. They are used as a role model, referent point, since new type of samples should behave more or less similar to them.

Figure 81– Two samples from control group – wood failure

On previous figure wood failure is obvious. It was already been explained why wood failure is so rare with epoxy, but in this group there was high rate of wood failure. Primer helped a lot definitely, since it is obvious from previous experiment, that type of wood doesn’t not dictate much when it comes to wood failure. When using oak in combination with long scarfs, wood failure is almost 100 percent.

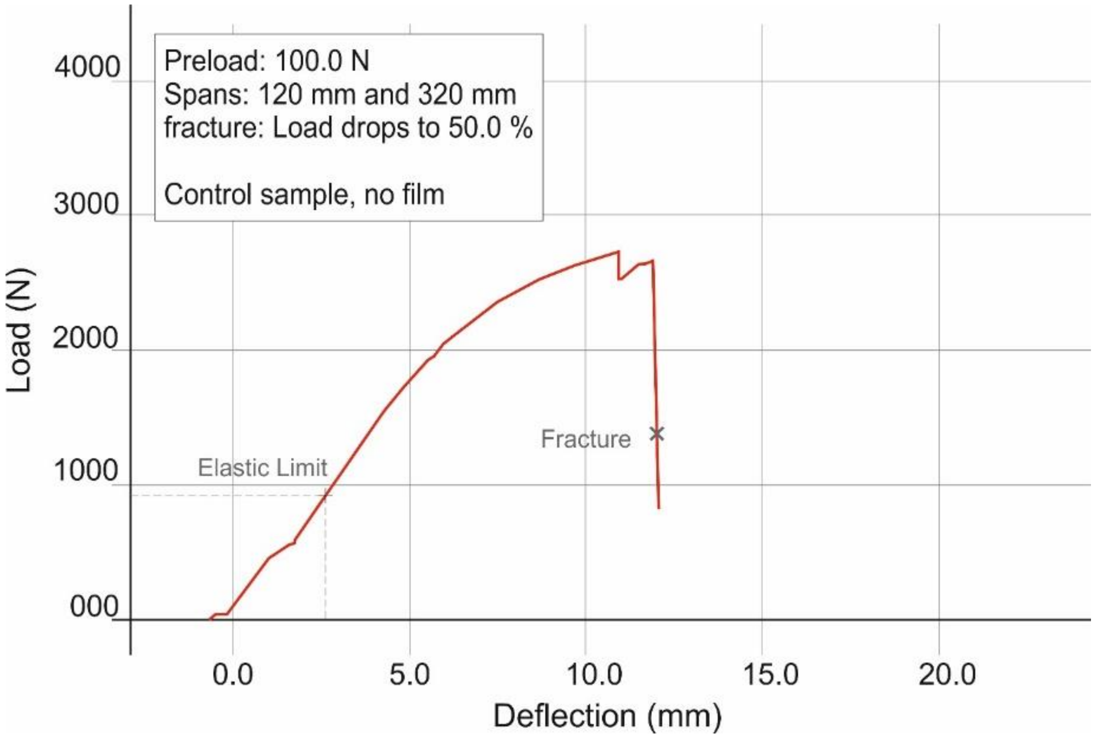


Figure 82 - Load/Deflection diagram – control group (average curve from the group)

On average, samples were able to stand loads close to 3000 N, this is not surprising and it was something expected.

5.11.2 Group of samples produced using resin film

Only difference between previous batch is fact that resin film was used instead or raw resin.

Figure 83– Samples from group with resin film – wood failure

Percent of wood failure is the same as for last group, only one sample didn't have wood failure. It is already noticeable that samples are comparable.

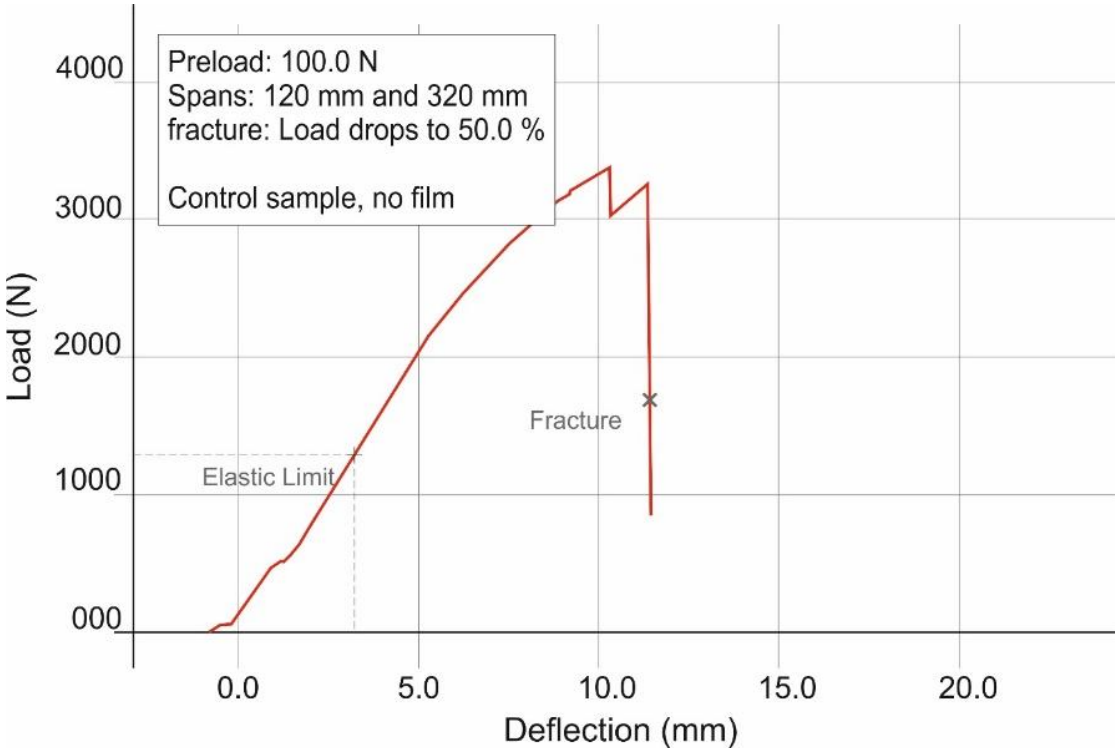


Figure 84 - Load/Deflection diagram – Group with resin film

When looking at diagram, it is noticeable that shape is visually similar, but load that sample tuck is a bit higher. This can be explained by difference of cross section. Both samples were produced by using wood of same size, but second group of samples, that has film, has section higher for 1 mm, since this is film thickness, which significantly impacts on the section modulus, and consequently the ability to withstand stress. That is why maximum load for second group is higher. Never the less, when maximum bending stress is computed, it is shown that first group of samples is actually the strongest one. When average maximum bending stress for first group (no film) is computed, value of 96 MPa is obtained, for second group (with film) this value is 89 MPa. When Young modulus is considered, values become even more similar, so close actually, that more samples would need to be tested in order to draw conclusions.

This is because wood is much more flexible than resin, so if higher percent of section is made of resin, element becomes less flexible, ergo sum weaker.

This proves that there is some differences between two groups of samples, but it also shows that this differences are small and predictable, since all the samples, in each group, do take same patterns of behavior.

5.12 Conclusion

The best way to confirm success of test procedure would be to test it with real time aged specimens. This will be time costly. In the meantime, user of standard could rely on work of D. Caster and replicate the part of his experiment which included artificial ageing. After that those results could be compared with results that were gained from testing specimens in a way described in previous chapter.

There would be some limitations. Carters testing is valid up to 11 years, which is not very significant part of expected life of many constructions. Also, he aged wood at same time with polymers, so adjustments would need to be done when comparing.

One solution of this problem would be to use boiling cycles machine to age films of epoxy only and then compare it with films of epoxy aged using ASTM F1980. This would be good way to compare effects of two methods. Since ASTM F1980 has method to determine exact age of material and it's used in production of medical equipment, it could be taken as test reference for ASTM 3434.

When it comes to proof of concept, it is obvious that it is valid. There are differences between samples, but they are less than 10 percent and they do follow predictable pattern. Proving that concept could be used for real-life testing.

5.10 Further work

Work doesn't end here, there is still some things to prove, lack of time and resources unable author to proceed, but some conclusions in order to give quinces could be drawn.

This research already proved that resin film can be produced in laboratory and furthermore, that is possible to build samples using it. Next stage would be to age film. ASTM F 1980 already gives guidance how to do it, there are conditions to be reached (temperature and humidity) and there is time intervals that need to be respected.

It will be necessary to build few groups of samples. This samples would have same geometry and they would be made in the same way, using same materials, only difference would be film. Each group would have film that aged for different time.

There is no need to go for less than 10 years, since most of known glues can resist this much time without significant structural loss. So, if first group (7 samples) is 10 years old (artificially aged) each next group should be 10 years older. This way, there would be groups that are 10, 20, 30, 40, 50, 60 and even more years old. Off course, as it was explained, only film would be aged, not the wood.

It is of extreme importance, that all the samples are made from same wood and same glue. When making film, all the films for all ages should be prepared from same batch at same day. It is very important to make samples identical as much as possible, this way only variation would be amount of time that film spend in aging oven.

This way, hopefully, experiment would prove that resin lose strength over time. Each older batch of samples would break with less pressure needed.

6. CONCLUSION

One of purposes of this document is to guide author and rider trough designing process of wooden sailing yacht, with strong dedication to structure design as well as logic of sailing yacht structure. Goal was to analyze a bit of all stages of design and not to focus on design stages as in depended. That is why some stages were not completely finalized, but all of them were discussed. Good preliminary project is like a good foundations of the project, which means that general characteristic have to be well defined, but not all of sub details are necessary settled.

Added to design process were two kind of structural and longevity studies, these were important since they remove some of unknown effects of usage of epoxy adhesives in constructions. Epoxy is one of most used adhesives for vessel constructions, but when it comes to wood structure, most of the time it was used according to experience and empirical knowledge, these tests tried to support these assumptions.

Of course, there is more than enough of place for improvement, author even gives advices to people that will succeed his work. This is important, since this kind of work shouldn't be capped in small isolated units, but quite the opposite, it should be made out of many researches that can be connected together like a puzzle.

Whit all this, stated above, it is possible to say that this document could be seen as manual, document that can introduce reader to design process, step by step.

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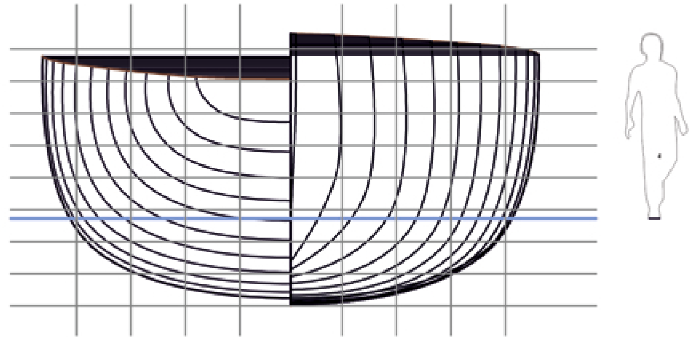
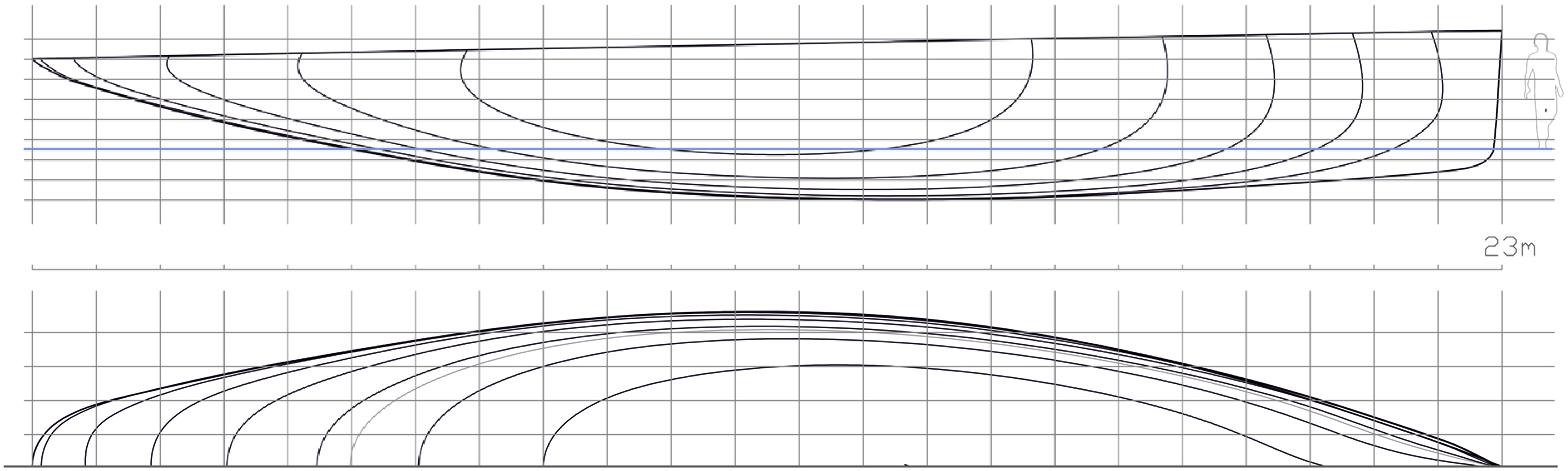
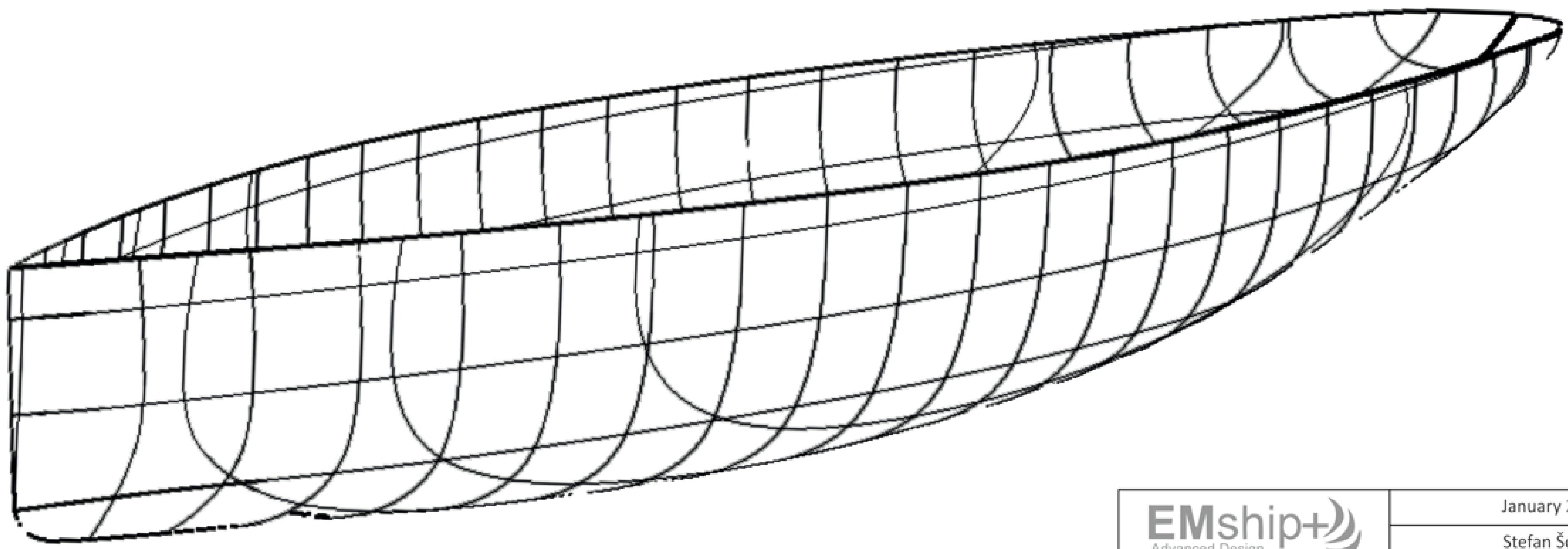
HULL LINES

Hull particulars

LOA	23	m
LWL	17, 7	m
BOA	4,85	m
BWL	4,25	m
Draft	3,00	m
Tc	0,77	m
Displ.	25,6	t
Cp	0,508	
Cb	0,417	







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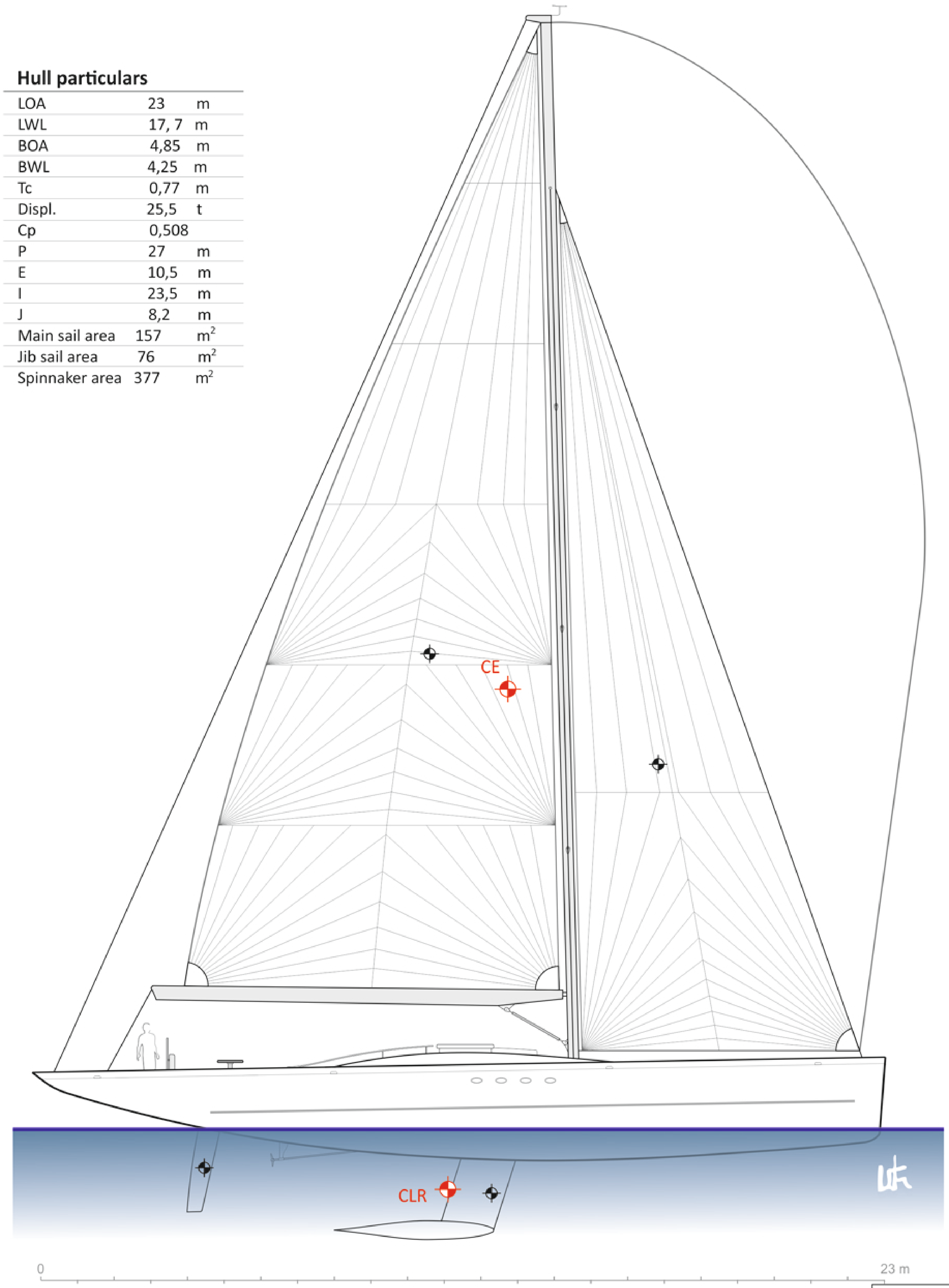
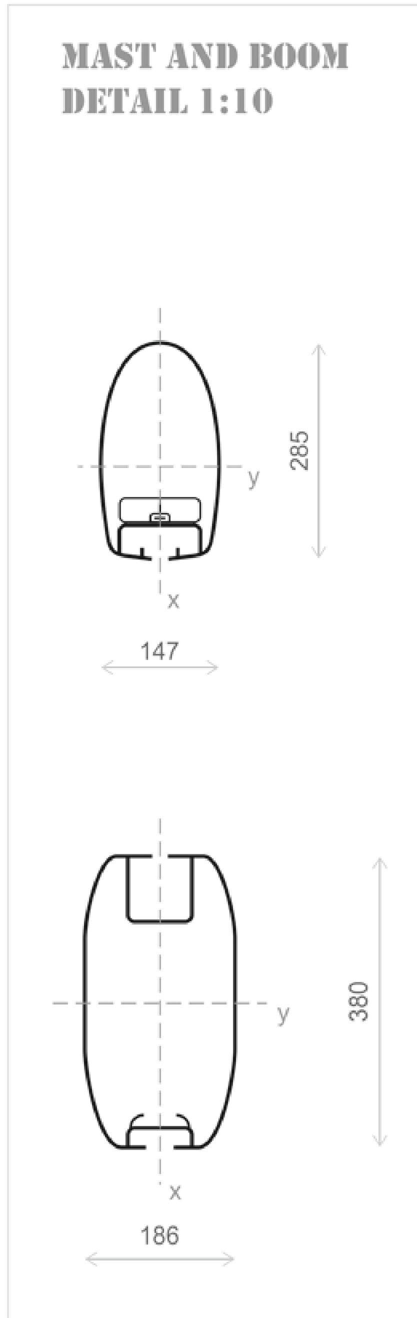
	A3 landscape	1:75	

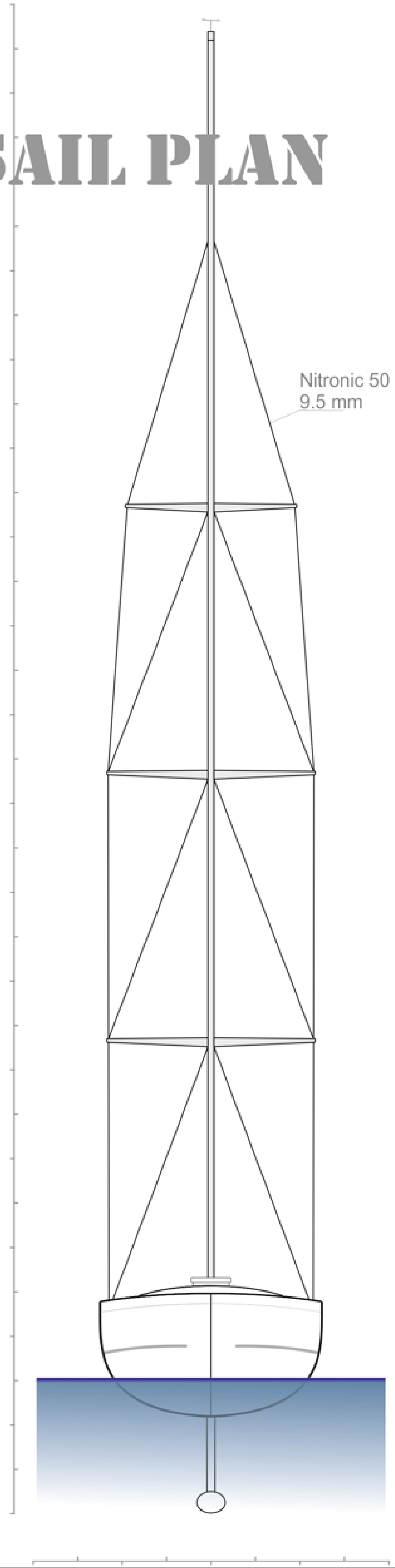
RIG AND SAIL PLAN

Hull particulars

LOA	23	m
LWL	17, 7	m
BOA	4,85	m
BWL	4,25	m
Tc	0,77	m
Displ.	25,5	t
Cp	0,508	
P	27	m
E	10,5	m
I	23,5	m
J	8,2	m
Main sail area	157	m^2
Jib sail area	76	m^2
Spinnaker area	377	m^2







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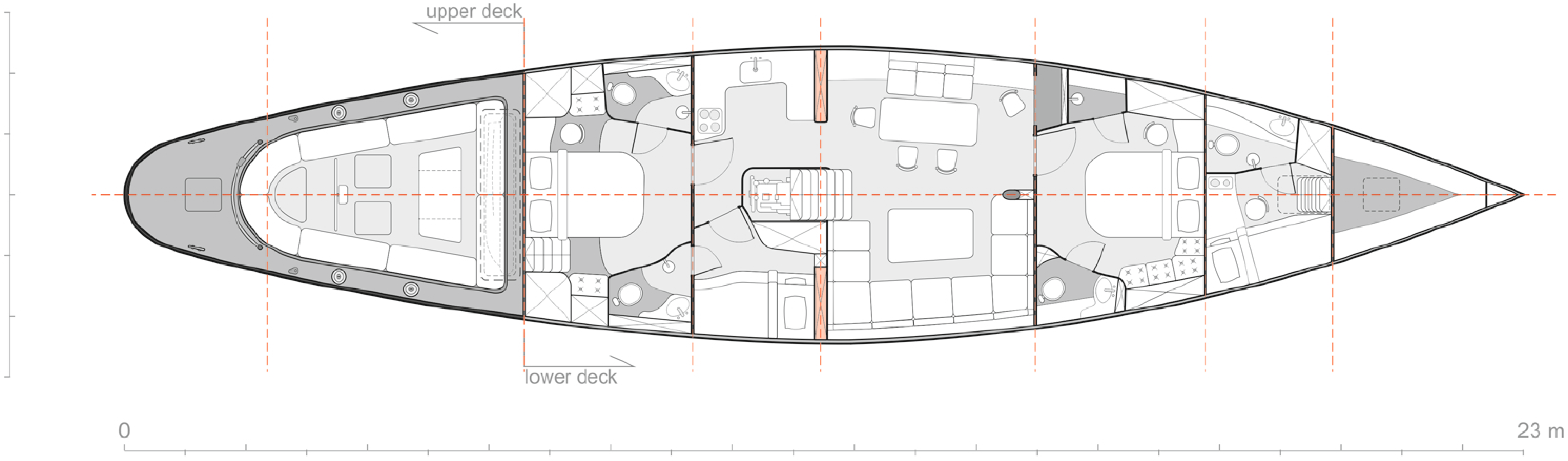
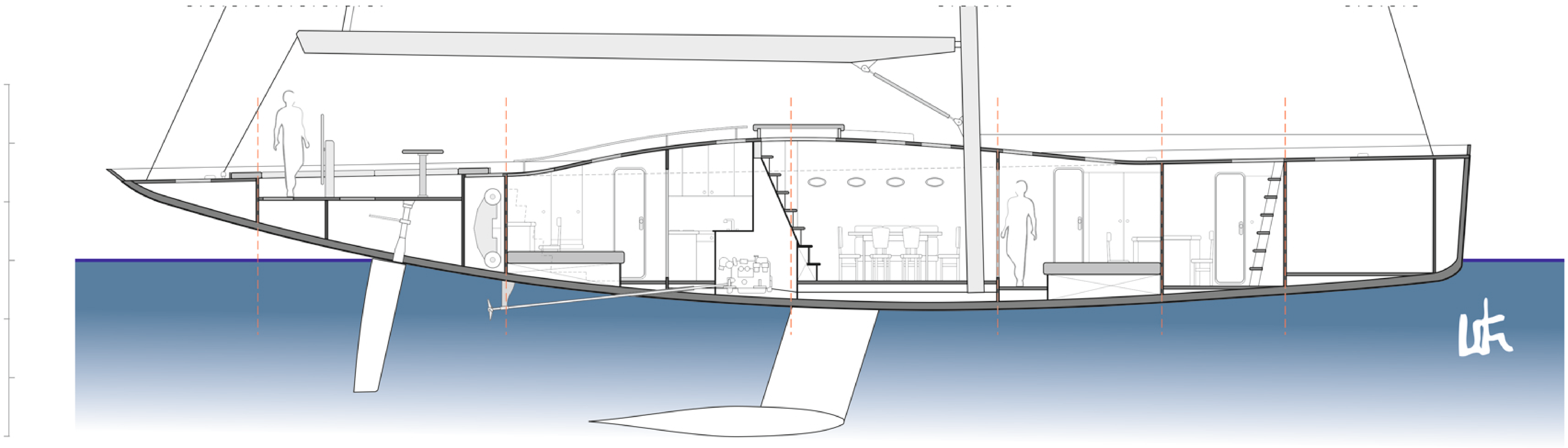
GENERAL ARRANGEMENT





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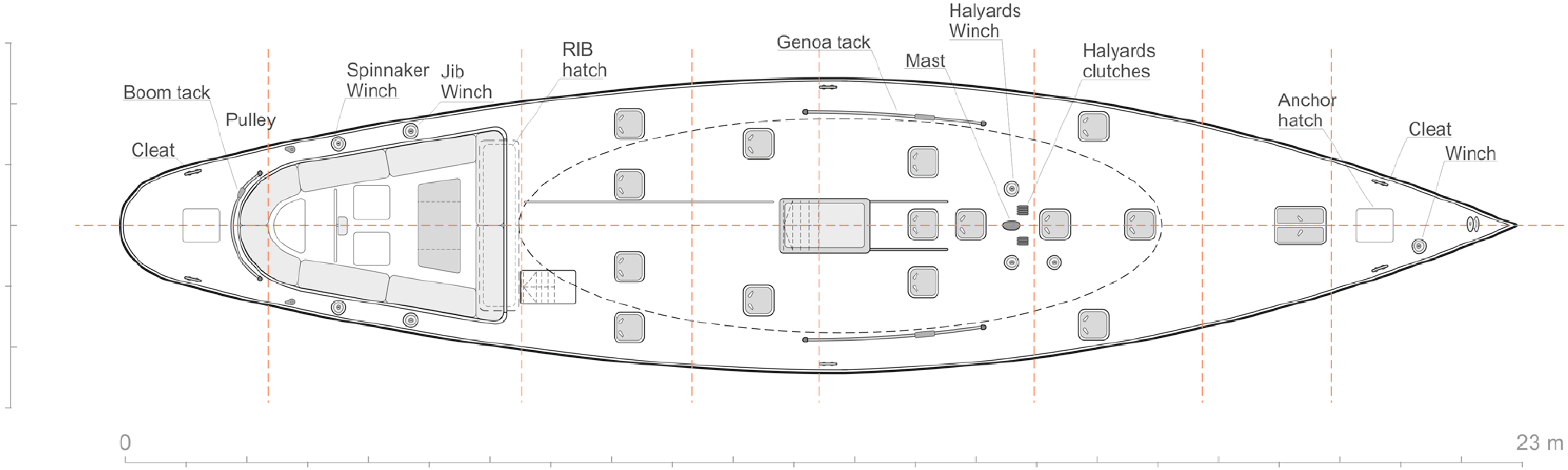
DECK ARRANGEMENT



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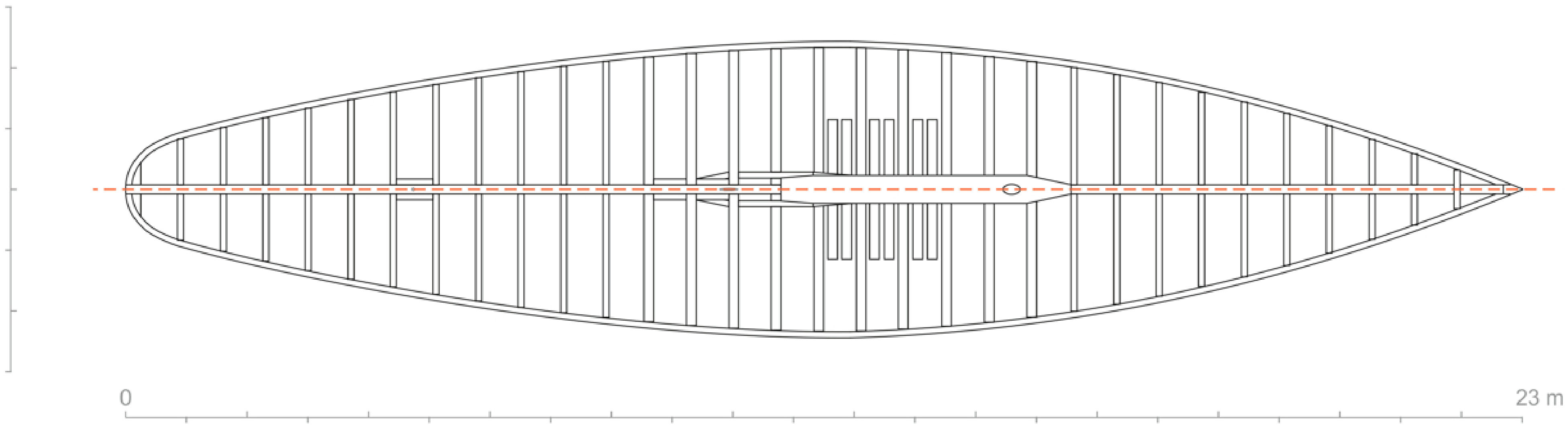
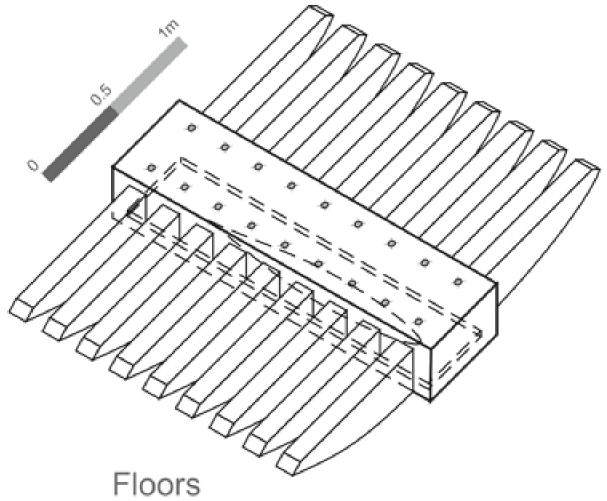
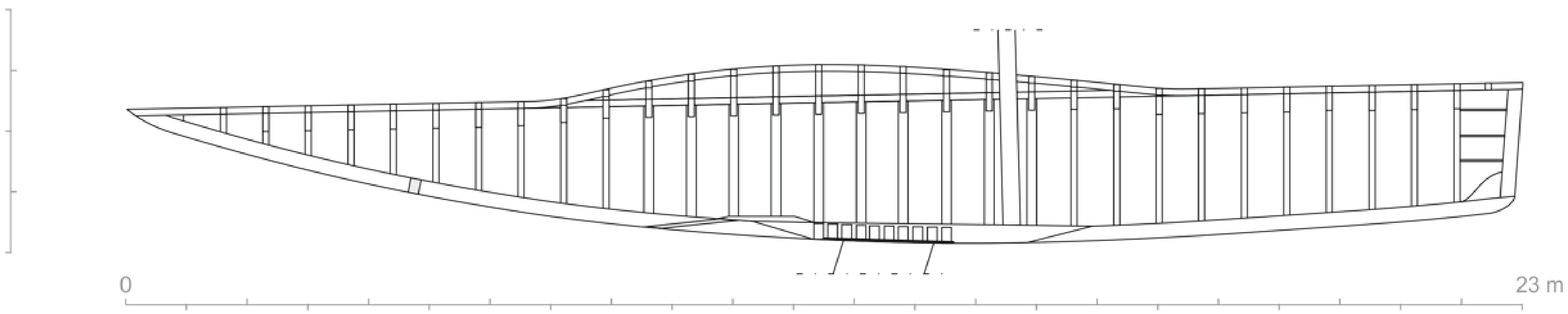
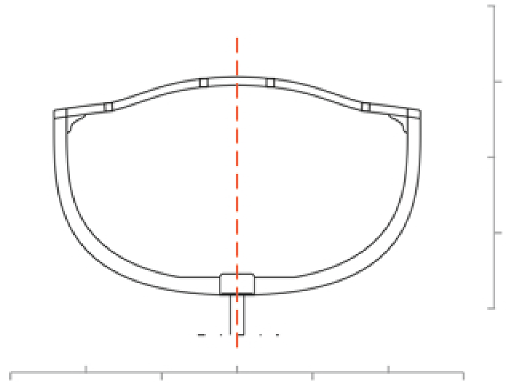
STRUCTURE



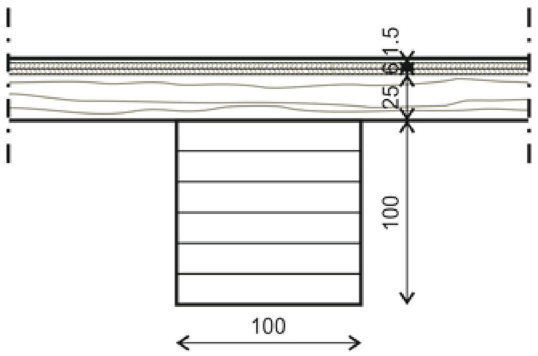


Floors

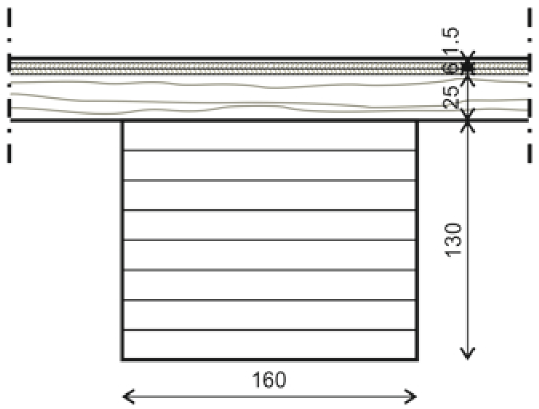




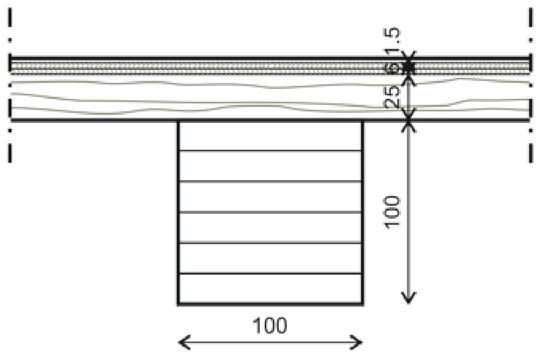
Aft frame



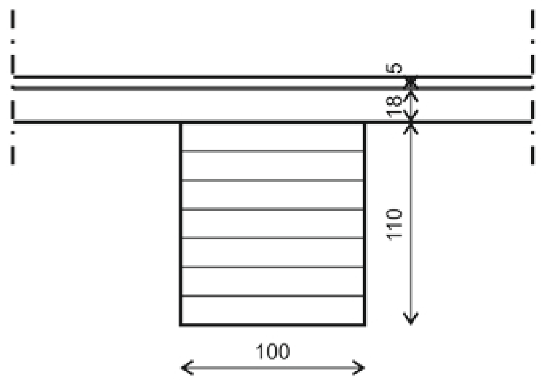
Middle frame



Fore frame



Deck frame



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3D VISUALISATION

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	A3 landscape	Visual	

3D VISUALISATION

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	A3 landscape	Visual	

3D VISUALISATION

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3D VISUALISATION

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3D VISUALISATION

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PHOTOMONTAGE

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	A3 landscape / Photomontage	

PHOTOMONTAGE

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	A3 landscape	Photomontage	

Appendix A1

A. Appendix to Parametric research

Yacht	Design	LOA [m]	LWL [m]	Beam [m]	Tc [m]	Tk [m]	Disp. [t]	Ballast [t]	Sail are [m^2]	Mast Height [m]
Fairlie 66	Fairlie	20,1	13,8	4,1	3,1	0,75	18	7,2	192	24,7
Spirit 74	Spirit Yachts	22,7	15,6	4,8	3	0,86	22	8,8	222	
Nazgul 76	Spirit Yachts	23,6	17,5	5	3	0,88	28	11,2	233	29,8
Spirit 100	Spirit Yachts	30,6	21,6	5	3,7		48	16,8	424,2	
DH60	Spirit Yachts	18,5	13	4,3	2,8	0,8	14,7	5,6	139	24
Wild horses	Joel White	23,3	16,4	4,9	3,35		24	9,6	208	

In graphs below all vessels from parametric study can be find, with the addition of vessel designed for this theses. Vessel designed here is represented by red dot.

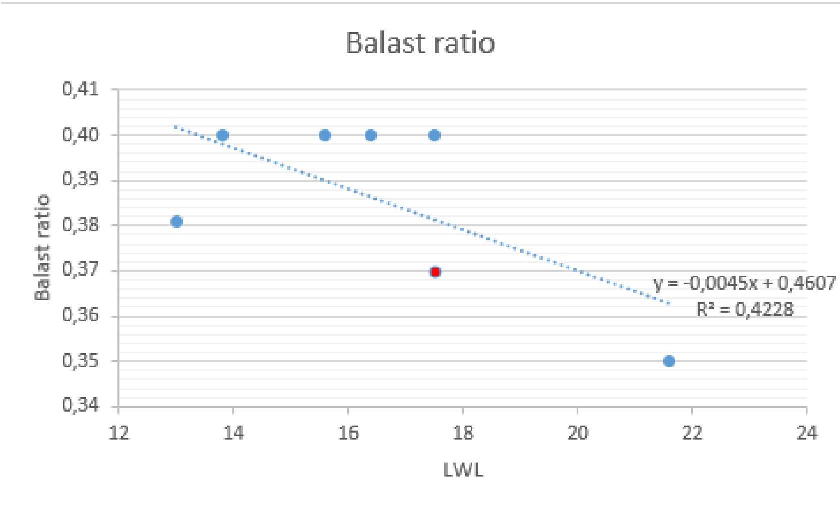

Figure 1- Ballast ratio

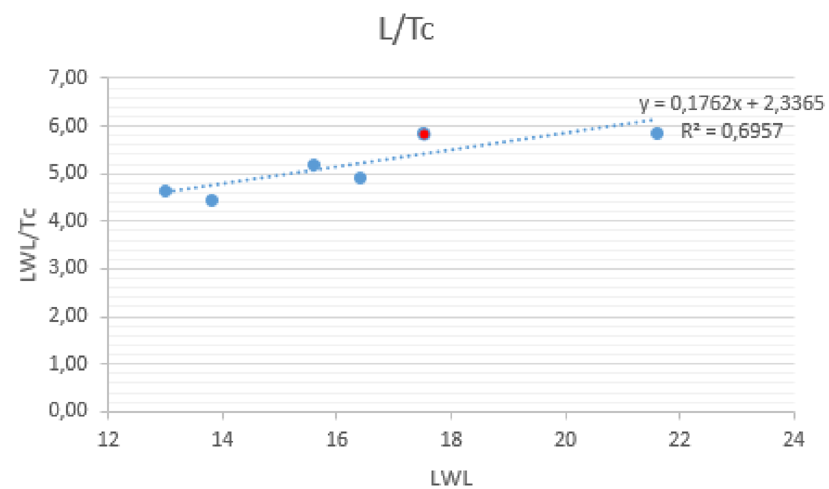

Figure 2 – Length to Draft ratio

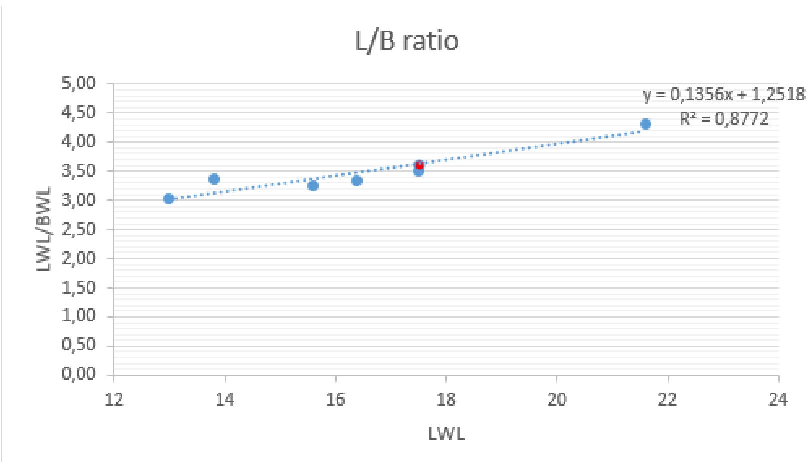

Figure 3 – Length to Beam ratio

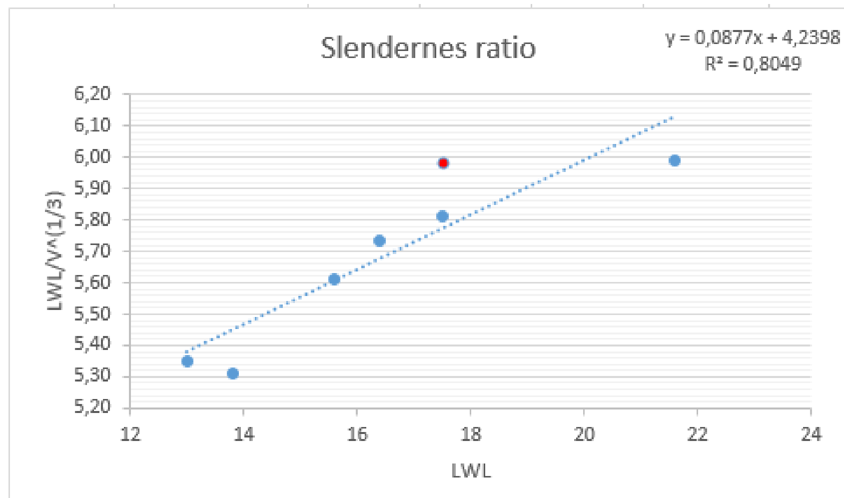

Figure 4 – Slenderness ratio

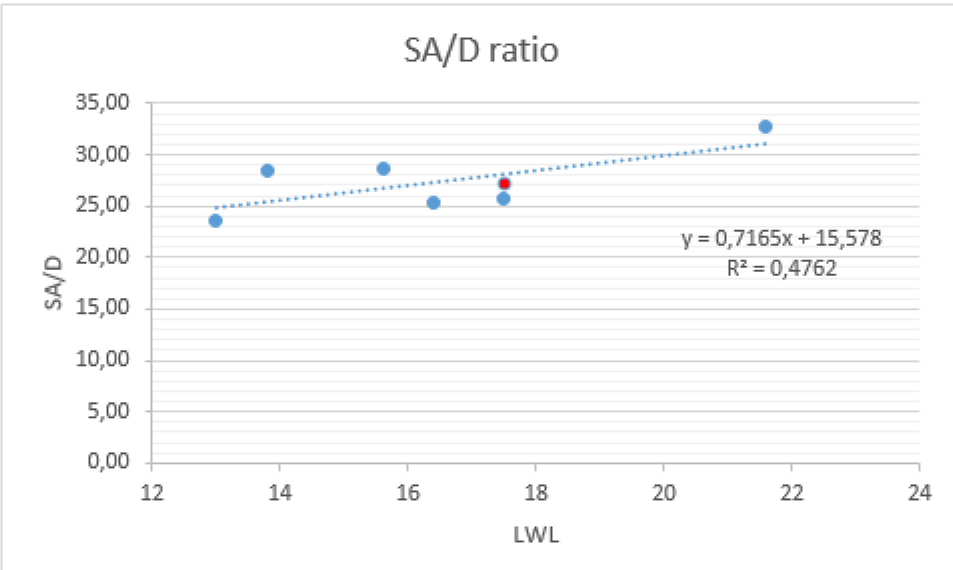

Figure 5 – Sail Area to Displacement ratio

Appendix A2

Electrical loads

item	no	Amps	H/D	total	
VHF/AIS/GPS loud	1	3	1	3	
VHF/AIS/GPS stby	1	0,42	23	9,66	
Chart plotter display	1	2,3	12	27,6	
Chart ploter stdb	1	0,8	12	9,6	
PC- working	1	8	5	40	
PC- stby	1	1	19	19	
Autopilot	1	8	5	40	
Radar	1	7	5	35	
Compass light	1	1	10	10	
Chain windlass	1	80	0,5	40	
Nav- lights	1	3,7	10	37	
Deck lights	6	1,7	6	61,2	
Interior lights	24	0,5	6	72	
bilge pump	6	9	1	54	
water maker	1	48	4	192	
fridge	1	4	24	96	
freezer	1	4	24	96	
battery charger	3	15	2	90	
Wash-machine	1	4	1	4	
charging devices	6	2	8	96	
water pumps	5	4	5	100	
toilets	4	15	0,3	18	
			sum	1150,06	
			margin	1,1	
			total E	1265,07	A/h per day
			Battery	215	A/h
			no	5,884028	

Appendix A3
Structure

ISO Scantling Report

Filename: E:\RAD\HullScan\Stefan.bst
Date : 20/10/2017
Time :14:54:23

Contents

Boat Particulars

Craft Type	Sailing
Design Category	A, Ocean
Composite Evaluation Level	EL-c, default data with 0.8 factor, ISO fibre content by mass
Displacement, m_{LDC}	25500.0 kg
Length of Hull, L_H	23.000 metres
Waterline Length, L_{WL}	17.673 metres
Waterline Beam, B_{WL}	4.250 metres
Canoe Body Depth, T_C	0.770 metres

General Calculations

Design Category Factor, k_{DC}	1.000
Base Bottom Pressure, $P_{BS\ BASE}$	91.052 kN/m^2
Base Deck Pressure, $P_{DS\ BASE}$	26.227 kN/m^2

Panel Geometry and Calculations

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
PanelA1 - front	2200	600	3.667	16.000	Bottom	--	400	1.000	0.624	0.500	0.000	--	56.8
PanelA2 - midsection	4500	540	8.333	12.000	Bottom	--	1000	1.000	0.674	0.500	0.000	--	61.4
PanelA3 - back	3600	600	6.000	4.000	Bottom	--	650	0.689	0.624	0.500	0.000	--	39.2
Deck ply	900	600	1.500	16.000	Deck	--	20	1.000	0.728	0.500	0.000	--	19.1

Panel Results

Label	Requirements		Offered		Results		
	t mm	t_{min}	Label	t mm	t Ratio	t_{min} Ratio	Plating Comply?
PanelA1 - front	23.45	10.80	Cedar, Western Red - strip planking, 45 degree veneers	25.00	1.066	2.314	yes
PanelA2 - midsection	21.93	10.80	Cedar, Western Red - strip planking, 45 degree veneers	25.00	1.140	2.314	yes
PanelA3 - back	19.47	10.80	Cedar, Western Red - strip planking, 45 degree veneers	25.00	1.284	2.314	yes
Deck ply	14.13	6.80	Plywood, 500kg/m³, 11 plies, perpendicular to face grain	18.00	1.273	2.645	yes

Stiffeners

Label	Dimensions and Location						Calculations to ISO Standard					Requirements			Offered				Results			
	Length mm	Spacing mm	Longitudinal Position metres	Location	z metres	Curvature mm	k_L	k_{AR}	z	k_z	Design Pressure kN/m^2	SM cm^3	A_W cm^2	t_w mm	Label	SM cm^3	A_W cm^2	t_w mm	SM Ratio	A_W Ratio	t_w Ratio	Comply?
Stiff mid	4500	700	12.000	Bottom	--	1000.000	1.000	0.250	--	--	34.7	665.173	124.215	10.0	Frame oak mid	743.067	208.000	160.0	1.117	1.675	15.927	yes
Stiff front	3000	700	17.000	Bottom	--	850.000	1.000	0.250	--	--	34.7	295.633	82.810	9.1	Frame oak front	327.561	100.000	100.0	1.108	1.208	10.989	yes
Stiff back	3000	700	4.000	Bottom	--	850.000	0.689	0.250	--	--	34.7	295.633	82.810	9.1	Frame oak back	327.561	100.000	100.0	1.108	1.208	10.989	yes
stiff deck	4850	700	16.000	Deck	--	150.000	1.000	0.250	--	--	6.6	291.120	25.296	5.3	Frame oak deck	321.279	110.000	100.0	1.104	4.348	18.957	yes

Report produced using Wolfson Unit M.T.I.A. HullScant - Hull Scantlings 12215.

Incorporating: International Standard - Hull construction - Scantlings - Part 5: Design pressures for monohulls, design stresses, scantling determination. ISO 12215-5:2008/Amd 1:2014 2014-09-30

Appendix A4

Keel bolts

Bolt diamether LC 1		
bi1	16,4	mm
bi2	319,6	mm
bi max	319,6	mm
Σbi^2	716891,84	
σdbolt	98	
d neck	21,69	mm

Bolt diamether LC 4		
Lk	2,1	m
Lk2	1,05	m
M 4.1.T	223775,1252	Nm
lri max	933	mm
lri 1	233	mm
lri 2	466	mm
lri 3	700	mm
lri 4	933	mm
Σlri^2	3263868	
σd bolt	98	
d neck	28,83	mm

Appendix A5

Floors and girders

Boat Partiulars		
M keel	8719	kg
Lwl	18,3	m
h k		m
Lf	2,8	m
a	0,95	m
c	0,193	m
M ldc	26000	kg
bi	0,34	m
βi=bi/Lf	0,12	-
n f	6	pc

Loadcase 1		
F1	85533,39	N
M 1.1	81256,7205	Nm
M 1.2	97764,66477	Nm

Loadcase 3		

F3	169526,61	N

Loadcase 4		
F4	203431,932	N
H f4 (L keel)	2,2	m
M 4.1	447550,2504	Nm
M 4.2	486812,6133	Nm

Floor 1 and 7		
L f1	2,32	m
bi	0,34	m
I	234346666,7	mm4
E	10679,5	N/mm2
EI	2,50271E+12	Nmm2
k ef	1	
k floor	2,00422E+11	
Mi (LC1)	16294,11	Nm
X 1		m
X r		m
li	0,82	
F vi (LC3)	28254,435	N
F vf4i	173861,65	N
F cvf4i (LC 4)	20488,72	N
		N
Loadcase 1		
f a/d	7023,32	N
f b/c	-51504,37	N
m a/d	0	Nm
m b/c	7169,41	Nm
Loadcase 3		
f a/d	14127,22	N
f b/c	14127,22	N
m a/d	0	Nm
m b/c	14421,06	Nm
Loadcase 4		
f a/d	10244,36	N
f b/c	10244,36	N
m a/d	0,000	Nm
m b/c	10457,44	Nm

Girder		
Lg1	2,33	m
E	10679,5	N/mm2
I	841493333,3	mm4
EI	8,98673E+12	Nmm2
k EF	1	
k girder	7,10451E+11	
K gfsr	0,59	>0.5
x	-0,2286	
Pg	0,8822	
Fcvg4j	153372,92	N

Floor		
h	260	mm
t	160	mm
section modul.	1802666,667	mm3
M	14421063,62	Nmm
Area	41600	mm2
Sigma	8,00	N/mm2
Shear	-1,24	N/mm2
sigma	4,75	koef
shear	-4,44	koef

Girder		
h	280	mm
t	460	mm
Section modul.	6010666,667	mm3
F	153372,92	N
Area	128800,00	mm2
Sigma	7,43	N/mm2
Shear	1,191	N/mm2
Sigma	5,11	koef
Shear	4,62	koef

Keelson

displacement	26000	kg		Mvhull	1614600000	Nmm
k glob	2,7					
L hull	23	m		σdk	4,00	N/mm^2
Zdk	1169,66	mm		safety	5,50	
Edk	10500	N/mm^2				
E	12057,5	N/mm^2				
I	4,11E+11	mm^4				
EI	4,96E+15	N*mm^2				

Appendix A6

Weight estimation

Structure

	Mass/pc	Mass	LCG	Moment X	TCG	Moment Y	VCG	Moment Z
	kg	kg	m	kg.m	m	kg.m	m	kg.m
Strusture								
Planking 143m2		1970,5	13,16	25931,78	0	0	0,82	1615,81
glue pl		50	13,16	658	0	0	0,82	41
Veener 6mm		591,2	13,16	7780,192	0	0	0,82	484,784
glue ve		178,7	13,16	2351,692	0	0	0,82	146,534
Fiberglass		228,8	13,16	3011,008	0	0	0,82	187,616
Deck ply 79m2		753,2	11,5	8661,8	0	0	2,38	1792,616
Deck fiberglass		121,6	11,5	1398,4	0	0	2,4	291,84
Deck teak		253,2	11,5	2911,8		0	2,41	610,212
Frame 1		16,1	0,35	5,635	0	0	2,1	33,81
Frame 2		13,8	0,9	12,42	0	0	1,92	26,496
Frame 3		16,2	1,6	25,92	0	0	1,81	29,322
Frame 4		18,7	2,3	43,01	0	0	1,7	31,79
Frame 5		21,1	3	63,3	0	0	1,59	33,549
Frame 6		23,5	3,7	86,95	0	0	1,48	34,78
Frame 7		26,0	4,4	114,4	0	0	1,38	35,88
Frame 8		28,4	5,1	144,84	0	0	1,29	36,636
Frame 9		30,9	5,8	179,22	0	0	1,2	37,08
Frame 10		33,3	6,5	216,45	0	0	1,06	35,298
Frame 11		35,7	7,2	257,04	0	0	1	35,7
Frame 12		38,2	7,9	301,78	0	0	0,95	36,29
Frame 13		40,6	8,6	349,16	0	0	0,91	36,946
Frame 14		105,1	9,3	977,43	0	0	0,88	92,488
Frame 15		108,5	10	1085	0	0	0,86	93,31
Frame 16		110,9	10,7	1186,63	0	0	0,85	94,265
Frame 17		112,4	11,4	1281,36	0	0	0,83	93,292
Frame 18		112,9	12,1	1366,09	0	0	0,82	92,578
Frame 19		112,4	12,8	1438,72	0	0	0,82	92,168
Frame 20		111	13,5	1498,5	0	0	0,82	91,02
Frame 21		108,6	14,2	1542,12	0	0	0,82	89,052
Frame 22		105,2	14,9	1567,48	0	0	0,82	86,264
Frame 23		48,2	15,6	751,92	0	0	0,83	40,006
Frame 24		46,2	16,3	753,06	0	0	0,85	39,27
Frame 25		44,2	17	751,4	0	0	0,87	38,454

Frame 26		42,3	17,7	748,71	0	0	0,9	38,07
Frame 27		40,3	18,4	741,52	0	0	0,94	37,882
Frame 28		38,3	19,1	731,53	0	0	0,98	37,534
Frame 29		36,3	19,8	718,74	0	0	1,03	37,389
Frame 30		34,4	20,5	705,2	0	0	1,07	36,808
Frame 31		32,4	21,2	686,88	0	0	1,12	36,288
Frame 32		30,4	21,9	665,76	0	0	1,17	35,568
Frame 33		24,4	22,6	551,44	0	0	1,22	29,768
Bow plank		12	22,76	273,12	0	0	1,7	20,4
Deck stiff 1		0	0	0	0	0	0	0
Deck stiff 2		11,2	0,9	10,08	0	0	2,22	24,864
Deck stiff 3		14,4	1,6	23,04	0	0	2,24	32,256
Deck stiff 4		17,3	2,3	39,79	0	0	2,25	38,925
Deck stiff 5		20,1	3	60,3	0	0	2,26	45,426
Deck stiff 6		22,6	3,7	83,62	0	0	2,28	51,528
Deck stiff 7		24,8	4,4	109,12	0	0	2,29	56,792
Deck stiff 8		26,8	5,1	136,68	0	0	2,3	61,64
Deck stiff 9		28,6	5,8	165,88	0	0	2,32	66,352
Deck stiff 10		30,1	6,5	195,65	0	0	2,33	70,133
Deck stiff 11		31,5	7,2	226,8	0	0	2,34	73,71
Deck stiff 12		32,5	7,9	256,75	0	0	2,36	76,7
Deck stiff 13		33,4	8,6	287,24	0	0	2,37	79,158
Deck stiff 14		34	9,3	316,2	0	0	2,38	80,92
Deck stiff 15		34,4	10	344	0	0	2,4	82,56
Deck stiff 16		34,5	10,7	369,15	0	0	2,41	83,145
Deck stiff 17		34,4	11,4	392,16	0	0	2,42	83,248
Deck stiff 18		34,1	12,1	412,61	0	0	2,44	83,204
Deck stiff 19		33,5	12,8	428,8	0	0	2,45	82,075
Deck stiff 20		32,7	13,5	441,45	0	0	2,46	80,442
Deck stiff 21		31,7	14,2	450,14	0	0	2,48	78,616
Deck stiff 22		30,4	14,9	452,96	0	0	2,49	75,696
Deck stiff 23		28,9	15,6	450,84	0	0	2,5	72,25
Deck stiff 24		27,2	16,3	443,36	0	0	2,52	68,544
Deck stiff 25		25,2	17	428,4	0	0	2,53	63,756
Deck stiff 26		23	17,7	407,1	0	0	2,54	58,42
Deck stiff 27		20,5	18,4	377,2	0	0	2,56	52,48
Deck stiff 28		17,9	19,1	341,89	0	0	2,57	46,003
Deck stiff 29		14,9	19,8	295,02	0	0	2,58	38,442
Deck stiff 30		11,8	20,5	241,9	0	0	2,6	30,68
Deck stiff 31		8,4	21,2	178,08	0	0	2,61	21,924
Deck stiff 32		4,8	21,9	105,12	0	0	2,62	12,576

Deck stiff 33		0	0	0	0	0	0	0
Floor stiffners		320	12,2	3904	0	0	0,35	112
Stringer deck 0		98	11,5	1127	0	0	2,42	237,16
Stringer deck 1		84	10,7	898,8	-90	-7560	2,41	202,44
Stringer deck 2		84	10,7	898,8	90	7560	2,41	202,44
Stringer deck 3		50	11	550	-180	-9000	2,42	121
Stringer deck 4		50	11	550	180	9000	2,42	121
Floors 8 pcs		346	12,2	4221,2	0	0	0,2	69,2
Keelson abv lead		206,7	12,8	2645,76	0	0	0,1	20,67
keel beam		481,6	14,7	7079,52	0	0	0,75	361,2
Bulkhead 1		72	6,5	468	0	0	1,5	108
Bulkhead 2		99	9,3	920,7	0	0	1,06	104,94
Bulkhead 3		101	14,9	1504,9	0	0	0,95	95,95
Bulkhead 4		71	17,7	1256,7	0	0	1,35	95,85
Bulkhead 5		42	19,8	831,6	0	0	1,52	63,84
Engine bed		60	10,9	654	0	0	0,32	19,2
paint		275,6	12,46	3433,976	0	0	1,19	327,964
				0		0		0
Wall 1		37,5	8,34	312,75	-1,2	-45	1,31	49,125
Wall 2		44	8,3	365,2	1,1	48,4	1,3	57,2
Wall 1		38	11,4	433,2	1,34	50,92	1,24	47,12
Wall 2		21	9,72	204,12	0,38	7,98	1,24	26,04
Wall 1		89	10,9	970,1	0	0	1,3	115,7
Wall 1		46	15,9	731,4	-1,26	-57,96	1,26	57,96
Wall 2		38	16,3	619,4	1,24	47,12	1,26	47,88
Wall 1		41	18,7	766,7	-0,62	-25,42	1,39	56,99
1		20,5	11,4	233,7	-1,7	-34,85	1,24	25,42
				0		0		0
total structure		9497,6	12,49	118580,26	-0,00093	-8,81	1,21	11484,617

Furniture

		Mass/pc	Mass	LCG	Moment X	TCG	Moment Y	VCG	Moment Z
	Furniture								
		kg	kg	m	kg.m	m	kg.m	m	kg.m
main cabin									
	Bed		12	7,5	90	0	0	1,3	15,6

	bed construction		32	7,5	240	0	0	0,75	24
	Wardrobe 1		43	6,8	292,4	-1,68	-72,24	1,4	60,2
	Wardrobe 2		44	6,8	299,2	1,67	73,48	1,4	61,6
	Stairs		28	6,7	187,6	1,1	30,8	1,57	43,96
	Table		14	6,6	92,4	0,9	12,6	1	14
	Chair		4	6,8	27,2	0,9	3,6	1	4
	Seats		16	7,4	118,4	0	0	1,1	17,6
	wc		15	8,1	121,5	-1,58	-23,7	0,6	9
	Vanity		5	8,3	41,5	-1,7	-8,5	1,1	5,5
	Vanity top		8	8,2	65,6	-1,75	-14	1,2	9,6
	shelf		9	8,4	75,6	-1,8	-16,2	1,5	13,5
	door1		5	8,3	41,5	-1,05	-5,25	1,2	6
	door2		6	8,8	52,8	-0,55	-3,3	1,2	7,2
	floor		190	7,2	1368	0	0	0,54	102,6
Kitchen					0		0		0
	kitc. Top		12	10,1	121,2	-1,88	-22,56	1,4	16,8
	cabinets		52	10,1	525,2	-1,88	-97,76	1,4	72,8
	washing machine		36	9,4	338,4	-1,2	-43,2	1	36
	Sink		2	10,1	20,2	-1,98	-3,96	1,3	2,6
	fridge		27	10,1	272,7	-1,9	-51,3	1	27
	freezer		27	10,6	286,2	-1,9	-51,3	1	27
	floor		104	10,3	1071,2	-0,9	-93,6	0,45	46,8
	Stowe		12	11	132	-1,5	-18	1	12
	Equipmant		50	10,7	535	-1,8	-90	0,8	40
Small room					0		0		0
	Beds		42	10	420	1,78	74,76	1,3	54,6
	Wardrobe		17	10,7	181,9	0,67	11,39	1,3	22,1
	Door1		5	9,1	45,5	1	5	1,2	6
	Door2		6	9,5	57	0,4	2,4	1,2	7,2
	wc		15	8,1	121,5	1,58	23,7	0,6	9
	Vanity		5	8,7	43,5	1,7	8,5	1,1	5,5
	Vanity top		6	8,2	49,2	1,75	10,5	1,2	7,2
	shelf		12	8,2	98,4	1,8	21,6	1,5	18
	floor		98	10,2	999,6	0,9	88,2	0,45	44,1
saloon					0		0		0
	Sofa		110	13	1430	1,13	124,3	0,75	82,5
	Small table		12	13	156	0,74	8,88	0,75	9
	Small sofa		20	12,8	256	-1,9	-38	0,8	16
	big table		12	12,8	153,6	-1,2	-14,4	0,9	10,8

	Chairs		16	12,8	204,8	-1,2	-19,2	0,8	12,8
	stairs		31	11,1	344,1	0	0	1,8	55,8
	Floor		280	12,8	3584	0	0	0,45	126
gest room					0		0		0
	bed		41	16,3	668,3	0	0	0,66	27,06
	door1		6	15	90	-0,7	-4,2	1,4	8,4
	door2		5	15,8	79	-1,2	-6	1,4	7
	door3		5	15,8	79	1,2	6	1,4	7
	Wardrobe 1		60	17	1020	-1,54	-92,4	1,5	90
	Wardrobe 2		40	17	680	1,6	64	1,5	60
	Table		8	17,3	138,4	-1	-8	1,1	8,8
	Chair		4	15,8	63,2	-1	-4	1	4
	Seat		9	16,9	152,1	1,1	9,9	1	9
	wc		15	15	225	1,4	21	1,2	18
	Vanity		5	15,9	79,5	1,42	7,1	1,4	7
	Vanity top		8	15,8	126,4	1,44	11,52	1,45	11,6
	shelf		9	16,4	147,6	1,46	13,14	1,7	15,3
	floor		130	16	2080	0	0	0,4	52
crew					0		0		0
	beds		44	18,6	818,4	1	44	1,4	61,6
	door		6	19	114	-0,45	-2,7	1,4	8,4
	table		18	17,8	320,4	0,2	3,6	1,1	19,8
	chair		4	18,1	72,4	0	0	1	4
	Wardrobe		30	19,2	576	-0,9	-27	1,5	45
	wc		15	18,1	271,5	-1	-15	1	15
	vanity		5	19	95	-1,3	-6,5	1,1	5,5
	vanity top		8	19	152	-1,4	-11,2	1,2	9,6
	shelf		14	18,4	257,6	-1,4	-19,6	1	14
	floor		78	18	1404	0	0	0,4	31,2
deck					0		0		0
	seats		90	4,2	378	0	0	2,1	189
	weal		22	3,9	85,8	0	0	2,8	61,6
	dinghy		42	6,15	258,3	0	0	1,5	63
					0		0		0
					0		0		0
	total furniture		2161	11,57	24992,8	-0,09398	-203,1	0,932355	2014,82

Deck

	Mass/pc	Mass	LCG	Moment X	TCG	Moment Y	VCG	Moment Z
Deck								
	kg	kg	m	kg.m	m	kg.m	m	kg.m
1		8	8,5	68	-0,8	-6,4	2,6	20,8
2		8	8,5	68	0,8	6,4	2,6	20,8
3		8	11	88	-1,5	-12	2,9	23,2
4		8	11	88	1,5	12	2,9	23,2
5		8	13,5	108	-1,1	-8,8	2,8	22,4
6		8	13,5	108	0	0	2,8	22,4
7		8	13,5	108	1,1	8,8	2,8	22,4
8		8	14	112	0	0	2,75	22
9		8	15,4	123,2	0	0	2,6	20,8
10		8	16,2	129,6	0	0	2,5	20
1a		5	11	55	-1,5	-7,5	2,3	11,5
2a		5	11	55	1,5	7,5	2,3	11,5
3a		5	15,7	78,5	-1,4	-7	2,4	12
4a		5	15,7	78,5	1,4	7	2,4	12
5a		5	17,8	89	0	0	2,5	12,5
6a		5	17,8	89	-1,3	-6,5	2,5	12,5
7a		5	17,8	89	1,3	6,5	2,5	12,5
Hatch - crew		10	19,1	191	0	0	2,6	26
People	75	600	11,5	6900	0	0	1,1	660
				0		0		0
Total deck		709	11,97	8489,8	0	0	1,34	946,9

Appendages

	Mass/pc	Mass	LCG	Moment X	TCG	Moment Y	VCG	Moment Z
	kg	kg	m	kg.m	m	kg.m	m	kg.m
Appendages								
Rudder		180	4,4	792	0	0	-0,53	-95,4
keel		2379	12,23	29095,17	0	0	-0,95	-2260,05
bulb		6800	10,58	71944	0	0	-1,9	-12920

total appendages		9359	10,88	101831,2	0	0	-1,63	-15275,5

Rig

	Mass/pc	Mass	LCG	Moment X	TCG	Moment Y	VCG	Moment Z
	kg	kg	m	kg.m	m	kg.m	m	kg.m
Rig								
mast		258,7	14,1	3647,67	0	0	12,8	3311,36
boom		185	9,8	1813	0	0	4,1	758,5
rigging		75,6	13,3	1005,48	0	0	12,5	945
main sail		100	10,5	1050	0	0	13,7	1370
genoa		70	16,7	1169	0	0	10,7	749
pedestal		60	14,8	888	0	0	0,1	6
spinnaker winches		100	7,5	750	0	0	2,45	245
Genoa winches		40	8,5	340	0	0	2,45	98
Halyard winch		60	10,5	630	0	0	2,45	147
Block		60	11,5	690	0	0	2,45	147
total rig		1009,3	11,87	11983,15	0	0	7,71	7776,86

Engine and tanks

	Mass/pc	Mass	LCG	Moment X	TCG	Moment Y	VCG	Moment Z
	kg	kg	m	kg.m	m	kg.m	m	kg.m
Engine and tanks								
Engine		217	10,9	2365,3	0	0	0,3	65,1
Geer box		40	10,4	416	0	0	0,3	12
Water maker		38	11,6	440,8	1,45	55,1	0,7	26,6
Starting batteries		42	11,5	483	0	0	0,6	25,2
ship service batteries		220	13,3	2926	0	0	0,2	44
radio batteries		148	13,5	1998	0	0	0,2	29,6
navigation		60	15	900	-1,76	-105,6	1,4	84
tools		30	5,4	162	0	0	2	60
piping		80	12	960	-0,4	-32	0,9	72
wires		100	12	1200	0	0	0,9	90
fresh water		700	14,9	10430	0	0	0,9	630
Fuel		800	11,4	9120	0	0	1,8	1440
Black water		450	13,3	5985	0	0	0,8	360

grey water		300	12,6	3780	0	0	0,8	240
total engine and		3225	12,76	41166,1	- 0,02558	-82,5	0,99	3178,5

Chain locker

	Mass/pc	Mass	LCG	Moment X	TCG	Moment Y	VCG	Moment Z
Chain locker								
	kg	kg	m	kg.m	m	kg.m	m	kg.m
Anchor		60	20,6	1236	0	0	2	120
chain		250	20,8	5200	0	0	0,8	200
winch		40	19,8	792	0	0	1,5	60
Total chain locker		350	20,65	7228	0	0	1,09	380

Total

	Mass/pc	Mass	LCG	Moment X	TCG	Moment Y	VCG	Moment Z
	kg	kg	m	kg.m	m	kg.m	m	kg.m
Total chain locker		350	20,65	41166,1	0	0	1,09	380
total engine and		3225	12,76	41166,1	-0,03	-82,5	0,99	3178,5
total rig		1009,3	11,87	11983,15	0	0	7,71	7776,86
Total deck		709	11,97	8489,8	0	0	1,34	946,9
total furniture		2161	11,57	24992,8	-0,09	-203,1	0,93	2014,82
total stucture		9497,6	12,49	118580,26	0,00	-8,81	1,21	11484,617
total appendiges		9359	10,88	101831,17	0	0	-1,63	-15275,45
Total		26310,9	13,23	348209,38	-0,01	-294,41	0,40	10506,247

Appendix A7

Stability - STIX

A gz	78	m*deg
Lh	23	m
m	23567	kg
Φv	77	deg
GZ90	1,111	m
h CE	12	m
As	232	m
Lwl	17,8	m
BH	4,85	m
Bwl	4,21	m
GZd	1,298	m
hce+hlp	11,13	m

FDS	1,03	0.5-1.5		FDL	0,95	0.75-1.25		FDF	0,86	0.5-1
FIR	0,70	0.4-1.5		FBD	1,04	0.75-1.25				
FKR	1,27	0.5-1.5		FWM	1,93	0.5-1				

	Value	Actual	
Downflooding openings			
Downflooding height test			
Downflooding angle	40	77	pass
Recess size			
Minimum Righting energy	172000	1838226	pass
Angle of vanishing stability	100	82,866	100 to be used
Stability index	32	44,68	pass
Detection and removal of water			

Appendix A8

VPP

STEFAN EMSHIP

Best Boatspeeds (kt)

	4	6	8	10	12	14	16	20	25
32.0	3.41	5.07	6.39	7.31	7.95	8.37	8.64	8.97	9.24
36.0	3.94	5.74	7.07	7.95	8.50	8.84	9.07	9.39	9.65
40.0	4.41	6.32	7.62	8.44	8.90	9.20	9.41	9.72	9.97
45.0	4.94	6.93	8.19	8.87	9.28	9.55	9.75	10.04	10.31
52.0	5.54	7.59	8.74	9.32	9.68	9.93	10.12	10.38	10.68
60.0	6.07	8.15	9.17	9.70	10.03	10.24	10.45	10.80	11.15
70.0	6.51	8.55	9.51	10.03	10.36	10.62	10.86	11.26	11.69
75.0	6.64	8.66	9.62	10.16	10.51	10.79	11.04	11.48	11.94
80.0	6.71	8.73	9.69	10.25	10.65	10.95	11.22	11.70	12.19
90.0	6.71	8.86	9.80	10.32	10.81	11.22	11.55	12.09	12.70
100.0	6.77	9.02	9.97	10.46	10.88	11.30	11.75	12.47	13.28
110.0	6.76	9.02	10.03	10.63	11.10	11.53	11.92	12.65	13.89
120.0	6.53	8.81	9.91	10.62	11.23	11.75	12.18	13.05	14.24
130.0	6.03	8.31	9.55	10.35	11.03	11.70	12.31	13.46	14.96
135.0	5.63	7.87	9.25	10.11	10.80	11.49	12.17	13.60	15.33
140.0	5.13	7.33	8.86	9.80	10.51	11.20	11.90	13.46	15.70
150.0	4.01	5.99	7.65	8.92	9.80	10.50	11.18	12.63	15.20
160.0	3.19	4.84	6.38	7.77	8.90	9.75	10.43	11.78	13.82
165.0	2.93	4.43	5.89	7.25	8.46	9.40	10.15	11.50	13.43
170.0	2.78	4.21	5.61	6.94	8.17	9.17	9.96	11.32	13.19
180.0	2.70	4.08	5.44	6.74	7.96	9.00	9.83	11.19	13.02
Up.Vs	5.08	6.81	7.82	8.28	8.56	8.74	8.89	9.16	9.40
Up.Bt	46.5	43.9	41.6	38.6	36.5	35.1	34.2	33.7	33.4
Up.Vmg	3.50	4.91	5.85	6.48	6.88	7.16	7.35	7.62	7.84
Dn.Vs	5.55	7.45	8.51	9.10	9.56	10.04	9.83	11.19	15.12
Dn.Bt	135.8	138.9	143.6	148.1	152.9	156.2	180.0	180.0	150.6
Dn.Vmg	3.98	5.61	6.84	7.73	8.51	9.19	9.83	11.19	13.17

Best Heel Angles (deg)

	4	6	8	10	12	14	16	20	25
32.0	3.46	7.43	11.70	15.37	18.19	20.30	21.96	22.85	23.01

36.0	3.94	8.80	13.34	16.92	19.51	21.51	23.10	23.20	23.37
40.0	4.37	10.05	14.67	18.06	20.53	22.41	23.33	23.46	23.61
45.0	5.21	11.00	15.99	19.16	21.45	23.23	23.55	23.63	23.71
52.0	5.69	11.66	17.24	20.15	22.29	23.72	23.68	22.86	22.90
60.0	5.96	11.82	17.72	20.79	22.79	22.95	22.85	22.95	23.15
70.0	5.88	11.15	16.02	20.91	23.11	23.14	23.15	23.21	23.41
75.0	5.68	10.55	14.91	19.22	23.26	23.24	23.23	23.29	23.52
80.0	5.40	9.84	13.69	17.46	21.50	23.33	23.30	23.38	23.57
90.0	4.26	13.06	21.98	13.95	16.99	20.31	23.42	23.51	23.51
100.0	5.75	12.70	20.59	22.66	22.44	15.19	17.84	23.53	23.56
110.0	5.28	11.29	16.79	21.27	22.65	22.65	22.73	16.80	23.23
120.0	4.15	8.93	12.32	15.34	18.72	22.47	23.00	22.99	23.19
130.0	2.93	6.05	8.14	9.99	12.14	14.73	17.71	23.39	23.63
135.0	2.19	4.27	6.26	7.69	9.33	11.39	13.84	19.93	24.00
140.0	1.46	2.95	4.28	5.68	6.94	8.55	10.51	15.45	23.27
150.0	0.47	1.06	1.74	2.46	3.24	4.18	5.65	8.55	13.22
160.0	0.15	0.34	0.61	0.95	1.37	1.90	2.57	4.32	7.46
165.0	0.10	0.21	0.38	0.61	0.90	1.30	1.80	3.12	5.51
170.0	0.06	0.14	0.24	0.39	0.58	0.83	1.16	2.04	3.42
180.0	0.00	0.01	0.01	0.02	0.03	0.04	0.06	0.12	0.21
Up	5.33	10.84	15.14	17.69	19.65	21.26	22.65	22.99	23.15
Dn	2.29	3.49	3.51	3.14	2.81	2.82	7.06	7.12	12.75

Best Flat

	4	6	8	10	12	14	16	20	25
32.0	1.000	0.891	0.820	0.726	0.633	0.550	0.482	0.460	0.473
36.0	1.000	0.944	0.851	0.742	0.642	0.560	0.491	0.512	0.529
40.0	1.000	0.987	0.877	0.757	0.657	0.572	0.538	0.563	0.585
45.0	1.000	1.000	0.904	0.782	0.679	0.594	0.597	0.629	0.658
52.0	1.000	1.000	0.950	0.826	0.722	0.657	0.683	0.910	0.965
60.0	1.000	1.000	1.000	0.893	0.788	0.942	0.990	1.000	1.000
70.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
75.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
80.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
90.0	1.000	1.000	0.983	1.000	1.000	1.000	1.000	1.000	1.000
100.0	1.000	1.000	1.000	0.937	0.997	1.000	1.000	1.000	1.000
110.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

120.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
130.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
135.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
140.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
150.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
160.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
165.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
170.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
180.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Up	1.000	1.000	0.886	0.751	0.644	0.557	0.487	0.482	0.493
Dn	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Best Reef or Twist

	4	6	8	10	12	14	16	20	25
32.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.917	0.810
36.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.884	0.782
40.0	1.000	1.000	1.000	1.000	1.000	1.000	0.971	0.859	0.760
45.0	1.000	1.000	1.000	1.000	1.000	1.000	0.943	0.836	0.738
52.0	1.000	1.000	1.000	1.000	1.000	0.986	0.918	0.742	0.653
60.0	1.000	1.000	1.000	1.000	1.000	0.885	0.821	0.742	0.669
70.0	1.000	1.000	1.000	1.000	0.965	0.910	0.863	0.785	0.708
75.0	1.000	1.000	1.000	1.000	0.993	0.938	0.890	0.810	0.733
80.0	1.000	1.000	1.000	1.000	1.000	0.969	0.920	0.839	0.759
90.0	1.000	1.000	1.000	1.000	1.000	1.000	0.994	0.910	0.822
100.0	1.000	1.000	1.000	0.965	0.878	1.000	1.000	0.999	0.903
110.0	1.000	1.000	1.000	1.000	0.956	0.901	0.853	1.000	1.000
120.0	1.000	1.000	1.000	1.000	1.000	1.000	0.954	0.858	0.763
130.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.980	0.867
135.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.935
140.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
150.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
160.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
165.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
170.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
180.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Up	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.902	0.799
Dn	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Best Leeway

	4	6	8	10	12	14	16	20	25
32.0	5.05	4.48	4.37	4.28	4.20	4.17	4.20	4.33	4.56
36.0	4.28	4.13	4.02	3.92	3.88	3.91	3.95	4.09	4.31
40.0	3.79	3.86	3.75	3.67	3.68	3.72	3.77	3.92	4.13
45.0	3.33	3.47	3.48	3.47	3.49	3.53	3.59	3.74	3.93
52.0	2.87	3.03	3.25	3.26	3.29	3.33	3.39	3.71	3.86
60.0	2.49	2.63	2.99	3.07	3.09	3.30	3.35	3.39	3.45
70.0	2.13	2.24	2.50	2.85	3.00	2.98	2.96	2.95	2.96
75.0	1.97	2.06	2.27	2.55	2.84	2.80	2.78	2.75	2.74
80.0	1.83	1.89	2.06	2.28	2.54	2.64	2.60	2.55	2.53
90.0	1.56	2.05	2.64	1.81	1.96	2.12	2.27	2.20	2.11
100.0	1.64	1.90	2.36	2.37	2.32	1.58	1.67	1.87	1.73
110.0	1.49	1.68	1.91	2.08	2.06	1.98	1.91	1.31	1.37
120.0	1.33	1.39	1.45	1.52	1.60	1.69	1.65	1.51	1.32
130.0	1.10	1.07	1.05	1.06	1.10	1.14	1.19	1.24	1.04
135.0	0.95	0.90	0.87	0.86	0.89	0.93	0.97	1.02	0.91
140.0	0.77	0.73	0.69	0.68	0.71	0.75	0.78	0.82	0.77
150.0	0.41	0.40	0.39	0.39	0.41	0.45	0.49	0.55	0.50
160.0	0.21	0.20	0.20	0.21	0.22	0.25	0.29	0.35	0.37
165.0	0.16	0.15	0.15	0.15	0.16	0.18	0.21	0.27	0.30
170.0	0.11	0.11	0.11	0.11	0.11	0.13	0.14	0.19	0.21
180.0	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Up	3.22	3.56	3.66	3.75	3.85	3.96	4.05	4.22	4.46
Dn	0.92	0.77	0.58	0.44	0.35	0.31	0.01	0.01	0.49

Best Apparent Wind Speed

	4	6	8	10	12	14	16	20	25
32.0	7.1	10.6	13.8	16.6	19.0	21.3	23.4	27.6	32.6
36.0	7.6	11.1	14.3	17.0	19.3	21.5	23.5	27.6	32.6
40.0	7.9	11.6	14.6	17.2	19.4	21.5	23.5	27.5	32.4
45.0	8.3	11.9	14.9	17.2	19.4	21.4	23.4	27.3	32.1
52.0	8.6	12.2	14.9	17.1	19.1	21.0	22.9	26.8	31.6
60.0	8.8	12.2	14.7	16.7	18.6	20.4	22.3	26.1	30.7
70.0	8.7	12.0	14.2	16.0	17.7	19.5	21.3	24.9	29.4

75.0	8.6	11.7	13.9	15.6	17.2	18.9	20.7	24.2	28.6
80.0	8.4	11.4	13.4	15.2	16.8	18.3	20.0	23.5	27.8
90.0	7.8	10.6	12.3	14.2	15.7	17.2	18.6	21.8	26.0
100.0	7.2	9.8	11.3	12.6	14.0	16.0	17.4	20.1	24.1
110.0	6.6	8.9	10.2	11.3	12.5	13.8	15.2	18.8	22.1
120.0	5.7	7.8	9.0	10.1	11.1	12.1	13.3	16.1	19.8
130.0	4.6	6.4	7.5	8.5	9.6	10.7	11.8	14.0	17.4
135.0	4.0	5.6	6.7	7.6	8.7	9.8	11.0	13.2	16.2
140.0	3.3	4.7	5.8	6.7	7.8	8.9	10.1	12.5	15.0
150.0	2.1	3.1	4.1	5.0	6.0	7.2	8.4	10.9	13.7
160.0	1.5	2.2	3.0	3.8	4.7	5.9	7.2	9.8	12.8
165.0	1.4	2.1	2.8	3.5	4.4	5.5	6.7	9.4	12.5
170.0	1.3	2.0	2.7	3.4	4.2	5.2	6.4	9.1	12.2
180.0	1.3	1.9	2.6	3.3	4.0	5.0	6.2	8.8	12.0
Up	8.3	11.9	14.7	17.1	19.3	21.5	23.5	27.6	32.6
Dn	3.9	4.9	5.2	5.3	5.6	6.3	6.2	8.8	13.7

Best Apparent Wind Angle

	4	6	8	10	12	14	16	20	25
32.0	17.3	17.2	17.5	17.9	18.4	18.9	19.4	20.6	21.8
36.0	18.1	18.2	18.6	19.3	20.0	20.7	21.4	22.8	24.2
40.0	18.9	19.2	19.9	20.7	21.7	22.6	23.5	25.1	26.8
45.0	19.9	20.4	21.4	22.7	23.9	25.0	26.1	28.1	30.0
52.0	21.4	22.3	23.7	25.5	27.0	28.5	29.9	32.5	34.7
60.0	23.1	24.5	26.5	28.7	30.7	32.8	34.6	37.4	40.0
70.0	25.4	27.5	30.5	33.0	35.5	38.0	40.1	43.5	46.7
75.0	26.6	29.1	32.5	35.5	37.8	40.6	42.9	46.6	50.1
80.0	27.9	30.8	34.6	38.0	40.6	43.2	45.8	49.8	53.6
90.0	30.7	33.3	36.9	43.1	46.6	49.3	51.6	56.4	60.8
100.0	32.8	35.8	40.5	45.9	50.9	56.2	58.9	63.2	68.1
110.0	34.8	38.4	44.4	50.2	55.8	60.6	64.7	71.9	75.8
120.0	37.3	41.4	48.7	55.9	61.7	66.6	71.4	78.8	84.7
130.0	41.5	45.7	53.9	62.5	69.6	75.2	79.9	87.0	93.2
135.0	45.3	49.4	57.4	66.5	74.4	80.5	85.4	92.0	97.8
140.0	51.3	54.7	62.0	71.5	80.2	86.9	91.9	98.3	102.6
150.0	74.8	75.2	79.8	87.0	95.6	103.1	108.5	115.3	117.8
160.0	112.4	111.3	112.5	115.4	120.1	125.4	130.1	135.8	138.7

165.0	132.1	131.3	131.6	133.0	135.2	138.7	142.0	146.5	149.0
170.0	149.0	148.4	148.5	149.2	150.3	152.3	154.4	157.5	159.2
180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0
Up	20.2	20.1	20.3	20.2	20.2	20.3	20.5	21.6	22.6
Dn	46.1	53.4	66.4	83.4	101.5	116.2	180.0	180.0	118.9

Resistance, Total (kg)

	4	6	8	10	12	14	16	20	25
32.0	47.1	98.4	161.9	225.3	282.0	330.6	372.0	436.8	503.6
36.0	58.2	123.7	199.9	273.1	337.9	394.4	442.2	519.2	601.7
40.0	69.2	149.8	237.9	320.6	394.6	458.2	511.3	602.8	701.4
45.0	83.3	180.2	284.7	380.3	464.7	537.6	598.6	708.3	827.0
52.0	102.3	219.3	348.8	461.5	561.4	647.7	721.6	843.8	992.9
60.0	121.2	257.5	414.9	550.4	669.3	761.6	852.9	1020.1	1204.1
70.0	138.4	291.1	467.8	651.8	799.0	917.2	1028.8	1235.1	1466.9
75.0	143.6	300.7	483.1	677.2	862.3	991.2	1113.6	1341.4	1599.6
80.0	146.3	305.3	490.3	691.1	897.3	1063.0	1196.6	1447.2	1731.8
90.0	144.1	330.4	571.8	684.4	907.0	1138.1	1356.8	1656.0	1991.3
100.0	147.7	351.5	610.7	817.6	1006.2	1093.2	1347.3	1857.9	2247.4
110.0	146.0	344.9	599.0	869.0	1103.5	1317.1	1526.5	1770.2	2477.6
120.0	133.8	308.2	533.4	801.0	1103.3	1421.5	1670.8	2113.2	2603.7
130.0	110.7	246.5	428.3	659.2	938.7	1260.2	1614.1	2298.0	2842.2
135.0	94.7	210.1	367.7	571.6	825.3	1127.5	1473.4	2236.2	2966.8
140.0	77.5	173.7	306.0	480.3	704.3	980.8	1305.9	2060.8	3040.0
150.0	47.5	107.0	193.1	312.9	479.3	696.9	964.4	1624.8	2546.5
160.0	30.8	68.3	123.3	200.6	309.8	464.2	670.3	1215.1	2063.0
165.0	26.2	57.6	103.1	167.3	256.7	390.5	576.9	1092.7	1914.8
170.0	23.8	52.1	92.8	150.1	229.6	349.4	520.9	1014.7	1819.1
180.0	22.5	49.0	86.8	140.0	213.8	323.5	484.6	963.2	1755.6
Up	87.4	173.8	253.2	303.5	344.7	379.6	410.9	471.8	538.0
Dn	91.9	181.4	262.7	340.4	422.9	542.6	486.3	969.5	2514.0

Heel Force (mast plane) kg.

	4	6	8	10	12	14	16	20	25
32.0	289	573	890	1145	1330	1461	1560	1743	1959
36.0	330	678	1008	1250	1415	1536	1628	1826	2049

40.0	365	772	1102	1326	1480	1591	1688	1892	2118
45.0	403	843	1192	1397	1536	1640	1747	1951	2180
52.0	441	894	1277	1460	1587	1689	1800	2106	2353
60.0	463	907	1310	1500	1617	1813	1931	2118	2332
70.0	458	860	1201	1510	1690	1784	1874	2045	2250
75.0	443	816	1128	1410	1658	1747	1832	1998	2200
80.0	420	764	1045	1301	1551	1704	1785	1947	2141
90.0	359	849	1315	1069	1277	1488	1678	1827	2001
100.0	383	819	1238	1375	1485	1162	1340	1684	1850
110.0	348	728	1037	1263	1381	1458	1537	1277	1672
120.0	289	578	782	954	1134	1316	1399	1540	1725
130.0	204	391	524	640	768	918	1079	1382	1559
135.0	151	293	404	495	598	723	867	1193	1472
140.0	101	203	293	366	447	549	670	958	1351
150.0	33	73	120	169	223	287	364	550	834
160.0	11	24	42	65	94	131	178	298	483
165.0	7	15	26	42	62	90	125	216	357
170.0	4	10	17	27	40	58	81	141	237
180.0	0	0	1	1	2	3	4	8	15
Up	412	832	1135	1302	1424	1521	1601	1780	1993
Dn	143	222	223	198	177	177	4	8	807

Lead-ce ahead of clr (m)

	4	6	8	10	12	14	16	20	25
32.0	0.000	0.164	0.297	0.457	0.622	0.775	0.908	0.929	0.849
36.0	0.000	0.230	0.411	0.618	0.821	1.006	1.168	1.101	1.020
40.0	0.126	0.302	0.531	0.782	1.021	1.237	1.335	1.268	1.185
45.0	0.181	0.399	0.686	0.987	1.270	1.526	1.543	1.473	1.382
52.0	0.241	0.531	0.899	1.269	1.615	1.870	1.835	1.440	1.360
60.0	0.303	0.663	1.126	1.579	1.998	1.817	1.786	1.802	1.790
70.0	0.363	0.783	1.314	1.926	2.282	2.376	2.431	2.478	2.477
75.0	0.383	0.820	1.366	1.997	2.631	2.740	2.809	2.874	2.888
80.0	0.396	0.841	1.390	2.025	2.744	3.146	3.232	3.324	3.350
90.0	0.369	1.276	2.476	1.973	2.680	3.477	4.258	4.433	4.456
100.0	0.559	1.405	2.694	3.543	3.696	3.192	4.027	5.920	5.974
110.0	0.571	1.407	2.612	4.023	4.829	5.195	5.471	5.240	7.929
120.0	0.505	1.274	2.286	3.543	5.069	6.849	7.444	7.787	7.816

130.0	0.000	1.036	1.824	2.843	4.108	5.632	7.426	10.935	10.898
135.0	0.000	0.840	1.573	2.457	3.569	4.929	6.555	10.596	13.166
140.0	0.000	0.000	1.238	2.072	3.037	4.239	5.687	9.314	15.153
150.0	0.000	0.000	0.000	0.000	0.000	2.825	4.151	6.978	11.287
160.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.842	8.759
165.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	8.112
170.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
180.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Up	0.194	0.377	0.581	0.723	0.845	0.952	1.052	1.003	0.910
Dn	0.402	0.785	1.149	1.503	1.877	2.396	239.453	240.425	11.093

Times for 1 nm (secs)

	4	6	8	10	12	14	16	20	25
32.0	1057.2	709.4	563.2	492.3	452.9	430.2	416.8	401.4	389.8
36.0	912.6	626.9	509.5	452.9	423.4	407.2	396.9	383.5	373.0
40.0	816.6	569.3	472.5	426.7	404.6	391.4	382.5	370.5	361.0
45.0	729.4	519.3	439.4	405.7	388.0	376.9	369.2	358.5	349.3
52.0	649.4	474.1	411.9	386.2	371.7	362.6	355.8	346.7	336.9
60.0	593.0	441.6	392.7	371.3	359.0	351.6	344.6	333.5	322.9
70.0	553.4	420.9	378.4	358.8	347.6	338.9	331.6	319.6	308.0
75.0	542.5	415.6	374.2	354.4	342.4	333.6	326.0	313.5	301.5
80.0	536.3	412.6	371.6	351.2	338.0	328.7	320.8	307.8	295.4
90.0	536.5	406.2	367.3	348.7	332.9	320.8	311.6	297.7	283.5
100.0	531.8	399.0	361.1	344.0	330.8	318.6	306.3	288.6	271.1
110.0	532.7	399.2	358.9	338.6	324.3	312.3	302.1	284.5	259.1
120.0	551.0	408.6	363.2	338.9	320.5	306.4	295.5	275.9	252.8
130.0	596.7	433.5	377.0	347.9	326.3	307.7	292.5	267.4	240.7
135.0	639.7	457.6	389.3	356.2	333.3	313.2	295.9	264.7	234.8
140.0	702.2	491.4	406.4	367.4	342.6	321.5	302.4	267.4	229.2
150.0	898.1	601.3	470.5	403.6	367.2	342.9	321.9	285.1	236.8
160.0	1127.3	744.3	563.9	463.4	404.4	369.3	345.2	305.7	260.4
165.0	1229.8	812.2	611.0	496.8	425.4	382.9	354.7	313.0	268.0
170.0	1293.7	854.7	641.3	518.7	440.9	392.8	361.3	318.1	272.9
180.0	1335.7	882.7	661.6	533.8	452.2	400.0	366.2	321.6	276.4
Up	1029.7	733.7	615.7	556.0	523.2	503.0	489.6	472.4	459.0
Dn	905.1	641.8	526.1	465.7	423.1	391.9	366.2	321.6	273.4