Deliverable n°4.3.1

Technical report on the dimensioning of the sailboat structure

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Partners

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Work done

1) Objectives :

The aim of this report is to present the approach used to design the biocomposite components integrated into the foil sailboat.

This report presents the approach taken, the problems encountered and the solutions adopted. The constraints of the specifications and the criteria used to select the materials used are presented. The calculation notes and results obtained are also presented in tabular form. This report presents the optimisations carried out during the iterative stages of the design. It presents the subcontractors involved in the study and design of the yacht's components. This technical report is based on the deliverables of the MT 3 work module - Sewn and woven semi-finished products, made exclusively of fibres.

2) Approach

Selection of the foiling boat and the partner

To validate the use of the multiaxial preforms developed by Teillage Vandecandelaère (TVDC) in the MT 3 work module - Sewn and woven semi-finished products made exclusively from fibres, Kairos has selected the Birdy Fish sailboat (www.birdyfish.com). Current Birdy Fish sailboats (hereafter referred to as conventional Birdy Fish) are made from a composite of fibreglass, polyester resin, PVC foam and polyester non-woven (Soric).

Figure 1 : Conventional birdy fish sailing yacht

This yacht is unique in that it is a foiling yacht. The principle of foiling is not new. The first sailboats of this type date back to the middle of the 20th century (see figure 1).

Figure 2 : The Monitor designed in the 1950s by the American Gordon Baker

Foilers developed slowly throughout the second half of the 20th century, until the 2013 America's Cup, when two flying catamarans equipped with foils competed. Thereafter, development accelerated. The number of foil-equipped boats multiplied, and foils appeared on dinghies as small as a few metres, such as those in the Moth International class, right up to the giant trimarans in the Ultim class, which are 32 m long. Foils can also be found on surfboards, stand-up paddles and motorboats, etc.

To date, these flying boats are mainly made from high-performance composite materials incorporating carbon fibre and glass fibre.

The challenge of the WPT4 work module is to demonstrate that natural fibres, which have less impact on the environment, can also be used to make a foil sailboat.

Kairos carried out a comparative study of the various foiling yachts available on the market and contacted the companies concerned. The table below shows the sailboats and companies that were considered in the choice of partner for the foil sailboat.

Name of the boat	**Type of sailboat**	**Country of production**	**Nature of the exchanges with the boatbuilders**
BirdyFish	Monocoque	France	Boat selected
easy to fly	Catamaran	France	Out of budget
epoh	Monocoque	France	Integration of the foil to do
The foiling dinghy	Monocoque	Allemagne	Not interested
Befoil	Catamaran	France	Not interested
F101	Trimaran	UK	Not interested
Skeeta	Monocoque	Australie	Not reachable
waszp	Monocoque	Australie	Not reachable
UFO	Catamaran	USA	Not reachable
whisper	Catamaran	UK	Not reachable
Ifly 15	Catamaran	Allemagne	Not reachable

A shortlist of 3 candidates was drawn up to select the most appropriate company for the project. The three companies selected were Birdy Fish, Easy To Fly and EPOH. Birdy Fish was chosen because it came out on top of a ranking based on technical and cost criteria. Details of this study are available in the document analysing the offers foiler.

3) Specifications:

The specifications for the sizing of the Birdy Fish foiling sailboat are based on two aspects:

- The sizing standard ISO 12215-5-2008-Small craft, hull construction and sampling.
- Feedback from conventional Birdy Fish sailboats..

4) Dimensioning

Hull and deck

The hull and deck of the Birdy Fish sailboat are made in two different toolings (see below). Each of these two areas benefits from specific sampling.

Figure 3 : Hull tools

Figure 4 : Deck tools

These elements are subject to stress due to various phenomena:

- Hydrostatic pressure and hydrodynamics
- Global forces in the ship's beam
- Local forces due to the anchoring of chainplates, foils, rudder and crew displacement

The dimensioning approach consists of establishing samples and comparing them with the requirements of the ISO standard. To comply with the requirements of the standard, the samples must meet minimum values for flexural rigidity (EI) and flexural strength (σ). Other dimensioning approaches may also be considered by the standard. The existing fibreglass composite hull and deck specimens were evaluated against the standard during the initial design by the architect. Kairos then compared the flax fibre composite specimens of the new yacht with the fibreglass composites of the existing yacht.

The composite materials that make up the hull and deck are sandwich materials. They are the assembly of skins made of flax fibre and polyester resin with a core material of recycled PET foam (for the deck) and cork (for the hull).

The formulas recommended by the standard for the stiffness and strength criteria are presented below. These criteria involve different aspects of the zone under consideration: dimensions, curvature, hydrostatic pressure, pressure correction to take account of dynamic aspects, etc.

$$M_d = 83{,}33 \times k_c^{\ 2} \times 2k_2 \times P \times b^2 \times 10^{-6} \quad \text{Nmm/mm}$$

Figure 5 : Sandwich skin strength

$$EI \text{ par mm de largeur} = \frac{b^3 \times k_c^{\ 3} \times P \times k3}{12 \times 10^3 \times k_1} \text{ N·mm}^2\text{/mm}$$

Figure 6 : Rigidity of the sandwich material

In addition to the requirements of the standard, and in order to produce a high-performance sailboat, the design consists of keeping the weight of the composite as low as possible. Past experience has shown that a flax composite design results in a weight increase of between 10 and 15% compared to a glass composite, for equivalent mechanical properties.

The table below shows the sizing results for the initial fibreglass hull and the flax fibre hull. Two approaches are presented for the dimensioning of the flax fibre shell:

- Linen (Compocalc): this column presents the mechanical results (EI and σ) and the mass of the sample from the modelling. The mechanical property results from activity T4.1 are used to feed the mechanical property prediction models and the mass.
- Linen (Test): this column presents the results of mechanical testing and weighing carried out on test specimens manufactured using the selected sample.

Location	**Hull bottom**		
Version	**Glass**	**Flax (compocalc)**	**Flax(tests)**
Ext. skin	Verre LT + mat cousu 600/100 gr	2 x Flax - woven roving - 360 g/m²	2 x Flax - woven roving - 360 g/m²
Cork	2 x Soric LRC, 3 mm	2 x liège NL10 3mm	2 x liège NL10 3mm
Int. skin	Verre LT 600 gr	2 x Flax - woven roving - 360 g/m²	2 x Flax - woven roving - 360 g/m²
TOT weight (kg/m2)	4.83	5.4	5.51
Comparison with reference	0.00%	11.80%	14.08%
Mx max (σ)	458	221	261
Comparison with refrrence	0.00%	-51.75%	-43.01%
EI (Nm2/m)	270	457	382
Comparison with reference	0.00%	69.17%	41.37%

Tableau 1 : Dimensioning hull

The differences between the linen sample and the glass sample are as follows:

- 14% greater mass
- 43% lower flexural strength
- 41% greater flexural rigidity

Flax offers good stiffness properties, enabling a higher EI value to be obtained than glass. On the other hand, flax has poor strength properties, particularly in compression. This results in a flexural strength that is 58% lower than that of glass.

The proposed design is a compromise between weight gain and mechanical properties. Thanks to Kairos' experience with natural fibre composites and Birdy Fish's feedback on conventional sailing yachts, the weight gain of the hull has been contained to +14%, as in this area of the vessel the predominant dimensioning element is the EI flexural rigidity criterion.

The differences between the modelling and the test results are acceptable.

The deck of the Birdy Fish in linen is designed according to the same criteria as the hull.

Location	**Deck**		
Version	**Glass**	**Flax (compocalc)**	**Flax (test)**
Ext. skin	Sergé Verre 400 gr , 0/90°	1 x Flax - woven roving - 360 g/m²	1 x Flax - woven roving - 360 g/m²
Cork	Corecell M80/ 12 mm PH	1x PET T92.80 15mm SX P30	1x PET T92.80 15mm SX P30
Int. skin	Sergé Verre 400 gr , 0/90°	1 x Flax - woven roving - 360 g/m²	1 x Flax - woven roving - 360 g/m²
TOT weight (kg/m2)	2.97	3.705	3.24
Comparison with refrrence	0.00%	24.75%	9.09%
Mx max	831	520	442
"Mxmax design"	374	260	221
Comparison with refrrence	0.00%	-30.48%	-40.81%
EI (Nm2/m)	561.26	1046	849
Comparison with reference	0.00%	86.37%	51.27%

Tableau 2 : Echantillonnage pont

The differences between the linen sample and the glass sample are as follows:

- 9% higher mass
- 41% lower flexural strength
- 51% greater flexural rigidity

Internal structure

The internal structural elements are largely made up of the multiaxials developed in the MT3 work module. The BX 312 multiaxial is used to distribute local and global stresses (see the 3 types of stress mentioned above) to the largest possible areas of the ship.

For example, a pressure peak due to slamming in the forward area of the hull must be distributed via the forward longi (c.f. Deliverable T4.3.2 - sailboat manufacturing plan). The BX 312 used in this forward spar allows the slamming stresses to be transferred from the hull to the deck. This minimises the local peak stress on the hull and distributes it over a larger surface area.

The same approach is used in all the internal structural elements (mast bulkheads, bench bulkheads, etc.), in areas requiring local reinforcement (livewell reinforcement, chainplate reinforcement, foil well reinforcement, etc.), and in the connections between the different areas of the yacht (planking/table, hull plate/deck connection, etc.).

The sizing principle used for areas requiring fibres at +/- 45 via BX 312 lin is based on a sampling equivalent to the planar shear strength (τ12) of BX glass. The formula used to ensure this correspondence is:

$$\tau_{12} = \frac{F}{S}$$

The shear stress (τ12) is a function of the force applied (F) and the surface to which this force is applied (S). This formula can be expressed as follows:

$$F = \tau_{12} * S$$

The flax BX are sized so that they can withstand the same stresses as the glass BX. The design is therefore carried out in such a way that the product (τ_12* S) is similar for the flax and glass zones. In this specific case, the comparison is made for a composite of identical width in linen and glass. The surface area (S) can therefore be reduced to the thickness of the composite (Ep). The formula is therefore expressed as:

$$F = \tau_{12} * Ep$$

Table 3 below shows that the breaking strength of a ply of 312 g/m² BX linen is equivalent to that of a ply of 400 g/m² BX glass. The samples presented in Deliverable T4.3.2 - sailboat manufacturing plan were therefore established by replacing 1 BX glass 400 g/m² with 1 BX linen 312 g/m².

Tissus	**T12 (Mpa)**	**Épaisseur du pli (mm)**	**F=TxS (N/m)**
BX verre 400 g/m²	39.6	1.69	67
BX lin 312 g/m²	27.1	2.4	65

Tableau 3 : Dimensioning BX in shear

5) Production

The recommendations for production are given in the process section of Deliverable T4.3.2 - Sailboat production plan. Details of the manufacturing process will be presented in Deliverable T4.4.1 - Sailboat manufacturing report.

Conclusion

This report presents a summary of the work carried out to design the sailboat. It is based on the results obtained during the work carried out on the WPT3 and WPT4 modules. The multiaxials developed in the WPT3 work module are technically suitable for ship production. Minor optimisations, in particular the possibility of obtaining multiaxials in narrow widths, are underway with Teillage Vandecandelaère to facilitate their use in certain circumstances.