FLOAT THE NEXT GENERATION HYDROFOIL

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FLOAT the next generation hydrofoil
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PRE FACE

Hi there!
You have made it so far! Cool! Let's keep on reading the graduation report.

In the last couple of months, I have been working on the final project of the master Integrated Product Design. This report will show the various steps I have been taking to complete this project.

During the project, a few new techniques were used to structure the design process. These supported me to approach the design process in a new and challenging way.

This crazy ride has been an eye-opener for me. Never before, I have been solely working on such a big project. The design project resulted in a lot of bumps along the ride, new personal principles for good design, new insights into the design process, and working with an actual client. However, I must say it was worth it!

Along the way, I have been helped by many people, and therefore I would like to mention a few of them. To begin with, my mentor from the TU Delft, Ehsan Baha. After this project, I could say that he is, by far, the best mentor I have ever had during a project on the TU Delft. Super friendly, supportive, and full of constructive criticism. Next to that, Peter Weitenberg for advising and helping during this project. Last but not least, I would like to thank Erik Tempelman for guiding me through the project in a more distant but concise way in comparison to Ehsan.

SUMMARY

Assignment

This project focusses on the creation of a hydrofoil specifically for the windsurfing market. The assigment was created for PWsurfsport. PWsurfsport is a windsurfing company based in Leiden. The company has two subsidiary companies called Tribal and KA. Sails. Tribal produces windsurfing fins and KA produces windsurf sails. Tribal wanted to add a new product to its product portfolio. In this case, the key objective for this project was to create a windsurfing hydrofoil, fitting the current product portfolio of the company and the future windsurfing market.

Approach

The research through design approach was used to reach the key objective. This approach is based on making prototypes. Further research was conducted based on the findings of the prototypes. Therefore, expert interviews, user research, market research, and calculations were used. Also, the 1-10-100 method was used to structure the design process. The method is used to create quick iterations that could be used as input for co-reflection sessions with the stakeholders. At last, a list of the designer 'good principles for good design' was created to validate design decisions throughout the project.

Research and findings

The 1-10-100 method ensured that through three design cycles, research was conducted and findings were presented. The result was a final design that could be presented to the stakeholders. After every cycle, a reflection about the cycle and a list of key takeaways were presented. These served as input for the next cycle. The first cycle was the exploring phase. This phase was intended to create a first rough prototype at the beginning of the project. The one day project resulted in a prototype based on market availability and history research. The second cycle, a ten-day cycle, was called the prototyping phase. During this phase, two hydrofoil experts were approached and asked for their opinion about the first concept.

Also, much more thorough research was conducted in the form of company research and material and production research.
This cycle resulted in a concept that was completer than the first concept and could serve as the final input for the last cycle. The final cycle, the detailing phase, served as a cycle were the last research was conducted, additional items were designed, and the final design was developed.

During the research phase, a few crucial steps were taken to ensure that the final design was adequately justified. Justifying the final design was done by approaching four different experts. These were a windsurfing fin expert, structure and optimization experts, a composite expert, and a marketing expert. The most important findings from this extensive research resulted in the final design vision:

'Creating the next generation free ride hydrofoil for the windsurfing and kitesurfing market. The product needs to be appealing to the user in terms of visual appearance, user experience, and quality.'

Float the next generation hydrofoil

The float is a product that enables the windsurfers and kitesurfer to buy a hydrofoil that is reliable, strong, and easy to use.
The following elements make the hydrofoil different from the current market:

- The hydrofoil consists of only three parts making the assembly and disassembly quick and easy.
- The foil has a combined mast and fuselage, making it stronger and therefore prevent cracks and defaults in the mast.
- The foil can be used for either wind or kitesurfing. The only thing that needs to be replaced is the front wing connection and the connection at the top.
- The foil has a convenient travel bag with safe storage compartments for the parts.
- The foil is supplied with a convenient tool that can be used to connect the parts and connect the hydrofoil to the board without applying too much force.

The final concept (figure 1) is an improved version of the current hydrofoil for the windsurfing and kitesurfing market. It is stronger, more accessible in use, and designed to use by a wide range of users. This product gives Tribal a new way of entering an emerging market with a product that fits the next generation hydrofoil user.

This product serves as a starting point for Tribal. The development of the hydrofoil is an ongoing design challenge, and further research and testing are recommended to improve the development of this hydrofoil.

Figure 1. Float, the next generation Hydrofoil

CONTENT

INTRODUCTION

The introduction paragraph explains the start of the project, the initial assignment, and the stakeholders.

1.1 How the project started

Before even thinking of graduating, I already knew that I wanted to do a project which involved water sports. Ever since I was eight years old, I performed different water sports such as kitesurfing, wakeboarding, and swimming. Previous projects were not related to watersports therefore the master thesis seemed like the perfect opportunity.

The first step I took was selecting a company. Therefore I needed to create a list of possible companies. These companies were ranging from kitesurfing companies such as NORTH to surf companies such as O'Neill.

Eventually, a company that builds windsurfing fins and sail called PWsurfsport was proposed.

Next, I called the CEO of the company, Peter Weitenberg, to arrange the first meeting. The first meeting was quick and concise. We created the assignment, made a time slot, and agreed on the coöperation. After finalizing the design brief/project with the client, the next step was to find a suitable chair and mentor.

Third, I reached out to different chairs and mentors form Industrial Design. Eventually, Erik Tempelman was contacted. He agreed to supervise during the project as a chair. He introduced Ehsan Baha as a possible mentor. After his agreement, the project started to take shape and a first meeting was planned with the chair, mentor, student, and company mentor.

During this meeting, we created the initial design brief. The agreement was to create a windsurfing hydrofoil.

Structure of the report

1. Chapter one will explain how the project got started, the context of the project and the initial design brief.
2. Chapter two will present the different approaches used throughout the project and the principles of the designer.
3. Chapter three present the findings of the exploration and presents the first design.
4. Chapter four will present the results of the concepting phase.
5. Chapter five presents the outcomes of the detailing phase and the final concept.
6. Chapter six finalizes the graduation report with an evaluation of the concept and a reflection on the designers' personal identity.

1.2 The assignment

1.2.1 Project context

Hydrofoils
A hydrofoil is becoming much more prevalent in board-related water sports. They are invented to create less resistant travel through water. A hydrofoil is a large fin attached to a mast that is screwed underneath a surfboard (figure 2).

Because of the lift created by the hydrofoil, the board gets out of the water, creating less resistance. The lift can be compared to an airplane wing. Therefore it is possible to travel through the water with less wind than typically needed creates a bigger window in wind ranges where a windsurfer can operate.

Client
PW surfsport is a company that produces windsurfing equipment. They are the market leader in high-end sails and fins. The subsidiary company for making the fins is Tribal and for sails KA.

The company is based in Leiden and has a workshop. They produce fins and small parts for the sails. This workshop also serves as an innovation center to create and optimize parts. Next to that, they have a factory in Sri Lanka that produces the sails.

Because of the relatively small windsurfing market size, companies tend to avoid making products overseas in foreign countries. Therefore, companies such as PWsurfsports are producing their products at the company. Small production sizes and smaller investments are used when creating new products. Therefore, new production techniques are developed in-house to keep costs low, helping to create products faster for smaller orders.

Figure 2. Windfoiler

1.2.2 Initial proposal

The project started with the creation of the assignment/Design brief. First, a draft was created by (figure 3). After that, a meeting was planned to reshape the draft with the client, chair, and mentor.

The assignment of this project was to deliver a working prototype and a final concept that could be used by the company as a starting point for its product portfolio.

The assignment consisted out of four iterations. The first one was comprehensive research on materials. The second one was a fluid-dynamics and strength/stiffness calculation. The third one were expert interviews. The expert interviews gave a lot more insight into hydrofoils and hydrodynamics. Lastly, the user experience was created by interviewing and recording a user.

The outcome of the assignment was a proposition of a product explicitly fitting the needs of the company and the windsurfing industry. In order to start the project, the initial design vision was:

'The project aims to create a new hydrofoil, especially for windsurfing. In order to create a viable product, in the end, research will be conducted through material research, fluid dynamics, and overall shape construction. In the end, a working prototype will be used to test the concept and show whether the concept works or not.'

Figure 3. Assignment preperation

APPROACH

The approach paragraph explains more about the research through design technique. It elaborates on the 1-10-100 method, co-reflection, and annotated portfolios.

2.1 Research through design

During this project, the research through design approach was used (figure 4).

In research through design, researchers develop and deploy novel artifacts, digital or physical, as a tactic to learn about specific aspects of the human experience (Dow *et al.*, 2013). They also function as a means of realizing a thing that has to be perceived, recognized, and conceived or understood (Mäkelä, 2007).

I am a designer who likes to build prototypes. I think one of the most critical steps in designing is the representation of a final design in real life. So instead of doing standard design research by reviewing scientific papers or user tests, research is conducted by making products/prototypes. Relevant outcomes of this design process were noted and used as input for the following steps in the design process.

This approach consisted of three methods; The 1-10-100 method, co-reflection, and annotated portfolios. The explanation of the three methods is in the following pages.

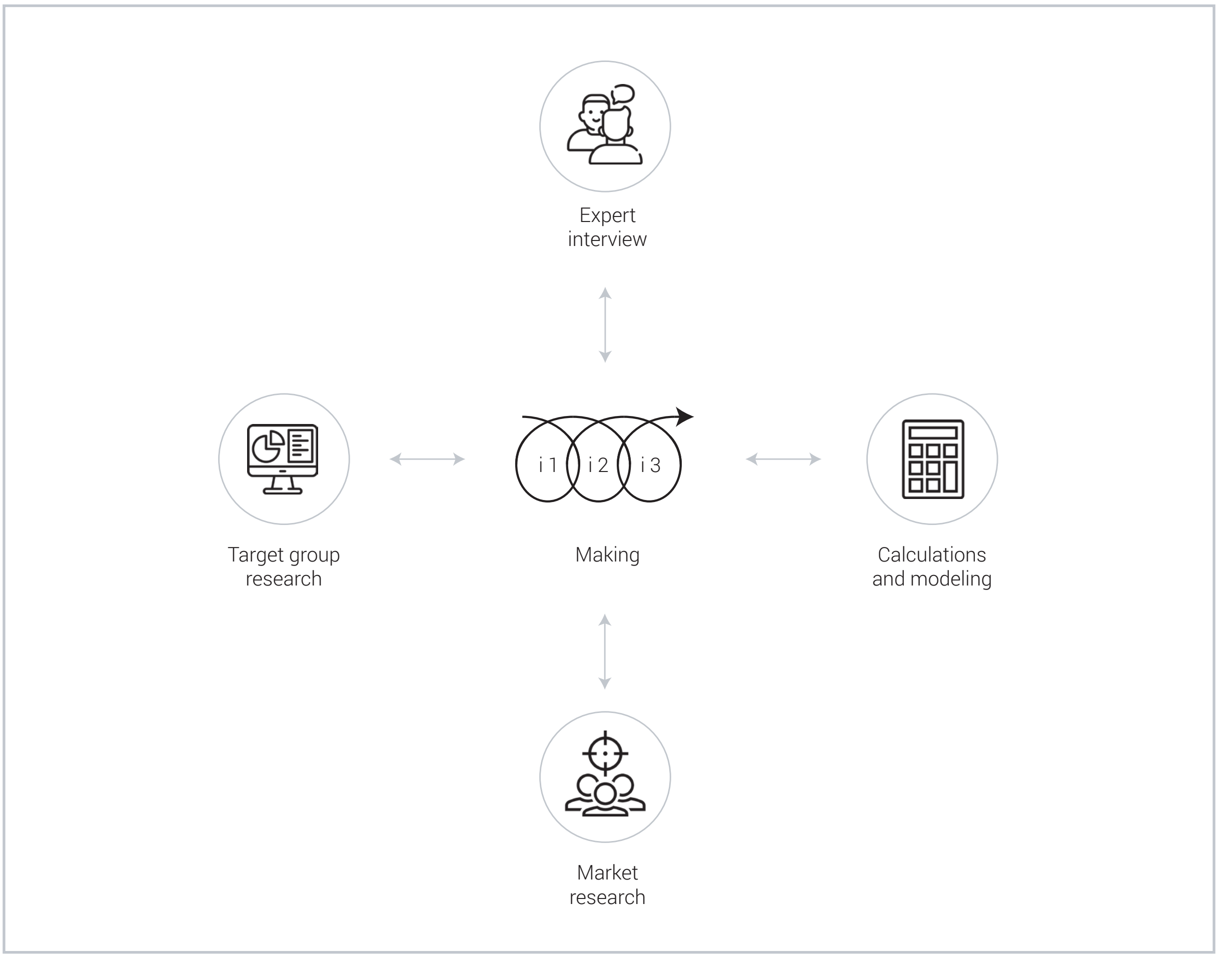


figure 4. Research through design approach

2.2 1-10-100 method

In order to organize the project, the 1-10-100 method was used.

The 1-10-100 method is a principle. The core idea is to go through a complete design cycle three times within a project, with different time frames (Turnhout *et al.*, 2013).

The 1-10-100 method is useful for encouraging discovery in a design project (Turnhout et al. 2013). Each cycle creates a new prototype or solution. In order to evaluate the solution, a prototype is shown to the stakeholders. This prototype will be evaluated and used as input for the next cycle.

Figure five shows a rough overview of the 1-10-100 method. The 1-10-100 method consists of a one-day iteration, a ten-day iteration, and an 88-day iteration. This method also represents the three main chapters in this report.

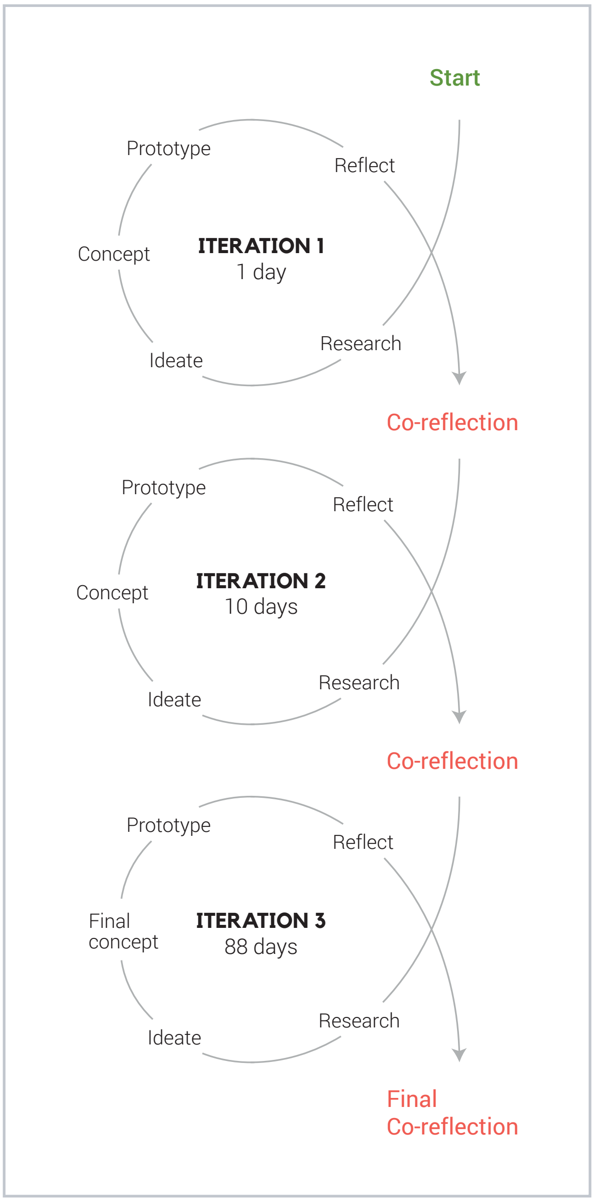


Figure 5. 1-10-100 visual

2.3 Annotated portfolios

The second method used during the project was annotated portfolios.

Annotated portfolios provide a way to present the fruits of design that simultaneously respect the particularity and multidimensionality of design work while meeting many of the demands of generalizable theory (Gaver & Bowers, 2012). In other words, it provides another way of doing research and progressing results.

Annotated portfolios are about making 3D or physical prototypes and showing them to the relevant stakeholders. After showing the prototypes to the stakeholders, annotations are made on paper and used as input for the project. Concluding, it serves as a reflection tool for the stakeholders to communicate their thoughts to the designer.

In this project, I used annotated portfolios in two different ways. The first one was that it helped with documenting the project progress and reporting the results.

Secondly, the method was used to involve the stakeholders. The stakeholders were able to give feedback by annotating the 3D prototypes. Figure 6 gives an example of an annotated portfolio created with a stakeholder.

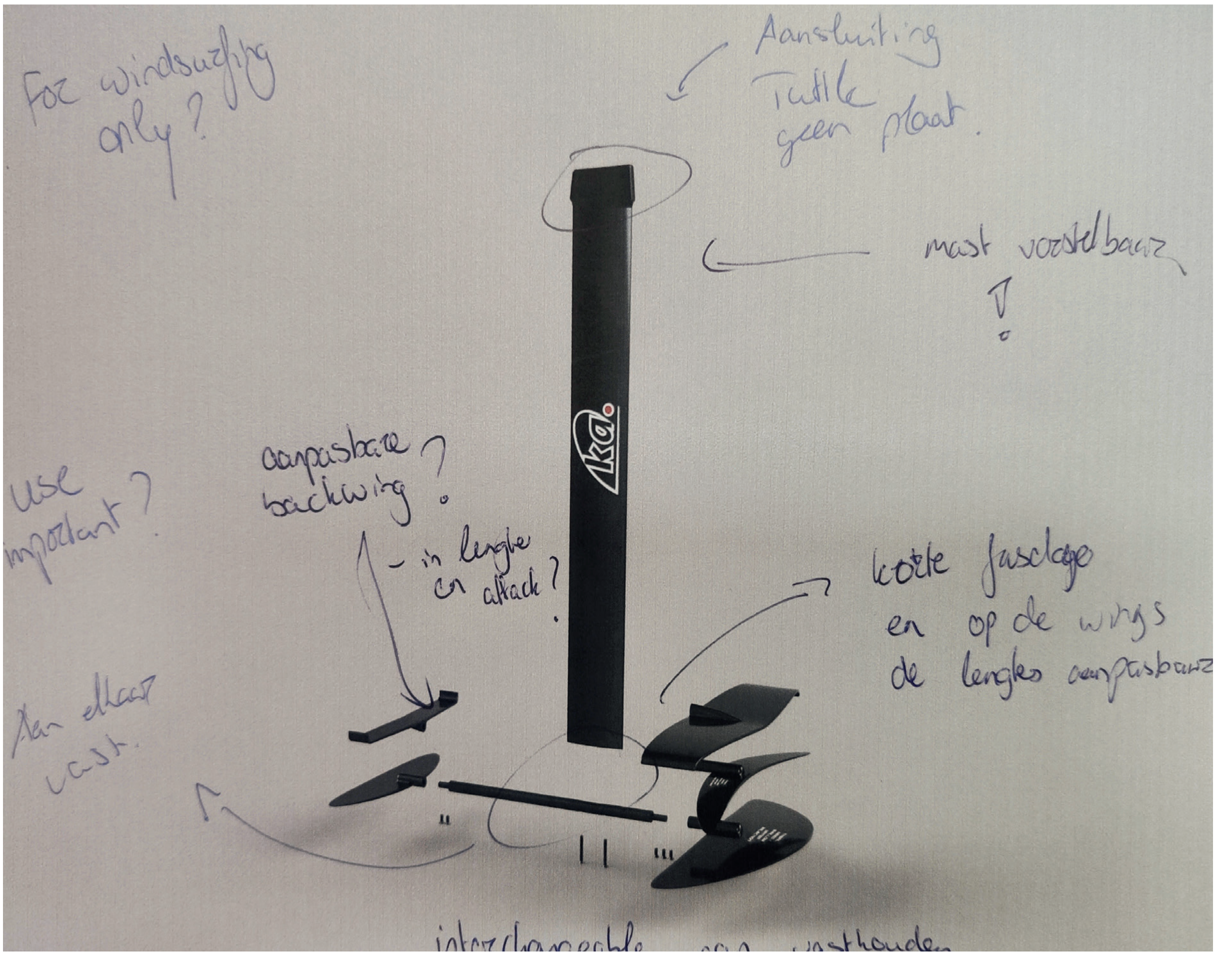


Figure 6. Annotated portfolio from project

2.4 Co-reflection

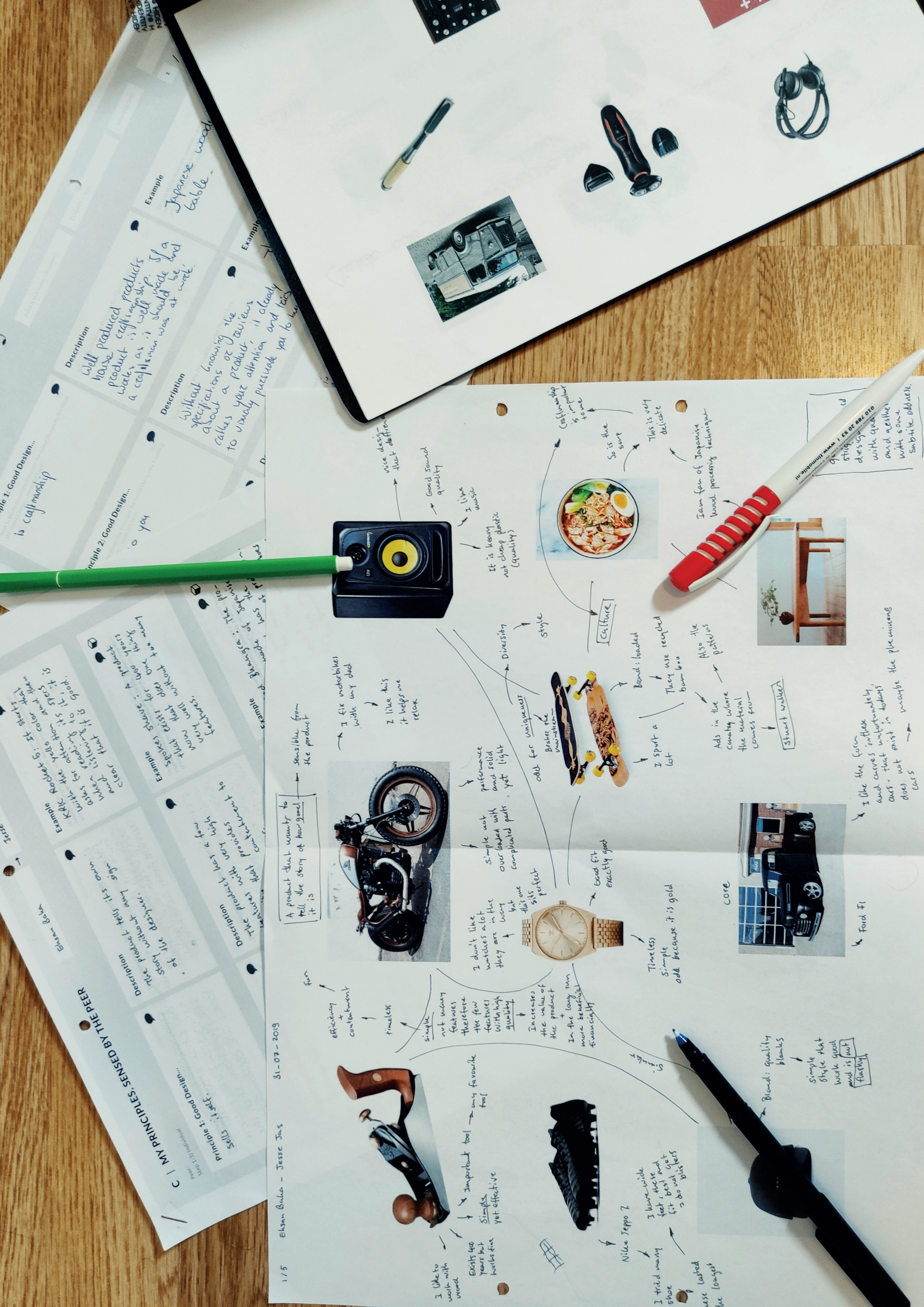
The last method used during the project was co-reflection.

In a design context, co- reflection can be defined as an inductive process, a dialogical inquiry between designers and users used to build upon their transformative vision (Tomico *et al.*, 2009).

By introducing several reflecting moments in the design process, created the opportunity for the stakeholders to give their opinion about the project. In the co-reflecting sessions (figure 7), which were frequently done using powerpoint presentations or by using prototypes, the stakeholders were forced to share their vision about the project. During these sessions, I could also share my vision on the project.

Fruitful sessions with shared views on the design project were outcomes of the co-reflecting technique. The sessions created a starting point before entering the next cycle.

Figure 7. Co-Reflection with several experts


MY PRINCIPLES, SENSED BY THE PEER
Principle 1: Good Design...
Description
Example

2.5 Principles for good design

2.5.1 Personal principles for good design

In order to create a product at the end of the design phase that represents not only the needs of the intended user and stakeholders but also houses an identity from the designer, a list of personal principles for good design is created (figure 8-12).

The awareness of a designer's personal understanding of good design nurtures creativity, decision making, process planning, and drive to design and promote the acceptance of a radical product concept inside of a corporate setting (Baha *et al.*, 2018).

During the industrial design study, I noticed that there was not a clear vision of the type of designer I represented. Therefore, an excellent way to explore this was the personal principles for good design method.

To find the personal principles for design, a workshop was conducted. The workshop started with making a 'good design' board. These were products I considered good design.

The second step was to use this design board as input for interviews with close friends and family. These interviews led to the generation of 5 essential design principles.

The results are stated on the next page in figure (8-12).

2.5.2 Closing remarks

During the workshop, a personal view on design was created. The workshop taught my personal principles for good design and how I can translate these to my projects.

Good design invloves craftmanship

Well-produced products house craftmanship. A product that is well made and works the way it is supposed to be is well crafted. An excellent example of this is Japanese woodworking. As seen in figure 8, the joints are made with the utmost precision.

Figure 8. Ishitani furniture table

Good design is timeless

The product is not bound to specific trends and can be used throughout a large timespan. An excellent example of a timeless piece is a classic watch such as the Daniel Wellington (figure 10). The clock has a simple and slick design fitting every occasion.

Figure 10. Daniel Wellington watch, Timeless design

Good design talks to you

Without knowing the specifications or reviews about a product, it already catches the attention of a user and tries to persuade him/her to buy it. An example of such a product is the KRK Rokit 5 (figure 9). It stands out by having the yellow cone.

Figure 9. KRK Rokit 5

Good design tells a story

The product is not only visually appealing but also tells a story by about how it is made. An example of this product is the loaded bhangra (figure 11). The graphics on the underside of the board represents the graphical art used by the indigenous people.

Figure 11. The loaded bhangra longboard

Good design is functional

The product does what it is supposed to do without being extraordinaire or special. The quality of the product is more important than visual design. An example of such a product is a planer (figure 12). It is robust, well crafted, and visually simple.

Figure 12 . Planer no.5

1ST ITERATION: EXPLORATION

The 1st iteration paragraph shows the first step in the 1-10-100 method, the exploration. First, the goal of the project is explained. After that, the ideation is shown leading up to the concept phase. The concept phase shows the first concept. The paragraph ends with a reflection and the next steps.

3.1 Goal/aim

The goal of the first iteration was to explore the project in one day and create the first prototype.

The 1-10-100 method started with a one day challenge. An eight-hour planning was created for this challenge (figure 13).

The advantage of doing the first iteration is the early development of a prototype. Instead of presenting much research to the stakeholders, a first impression can be presented.

The prototype could already provoke a discussion about what the stakeholders wanted and provide a good starting point for the second cycle of the 1-10-100 method.

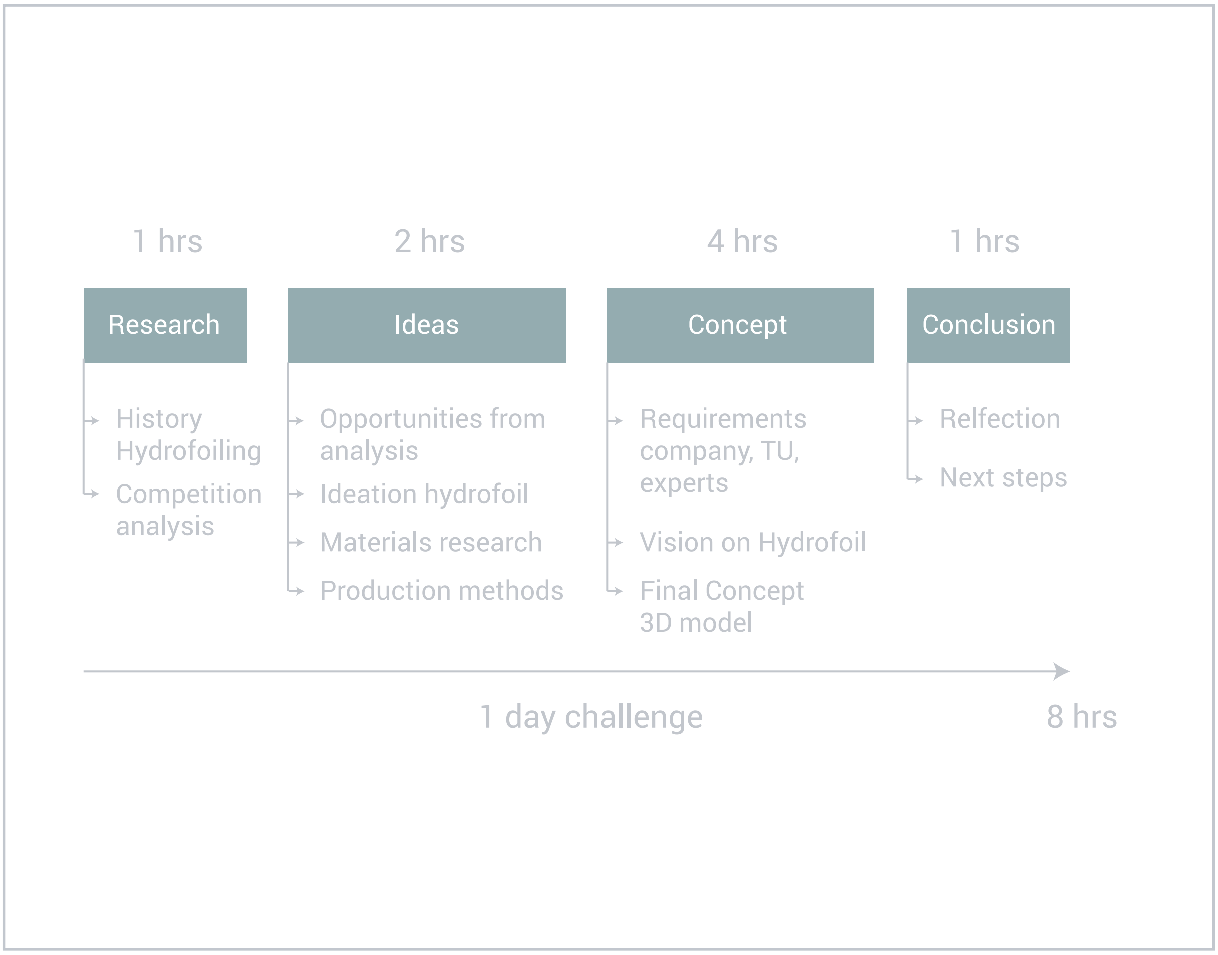


Figure 13. 1st cycle from the 1-10-100 method

3.2 Research

The first step of the one day challenge was the research part. Two subjects were chosen to research. The first one was the history of the hydrofoil, and the second one was the competition analysis.

3.2.1 History of the hydrofoil

The first hydrofoil vessels date around 1869. After that, in 1909, the first hydrofoil boat was built by Alexander Graham Bell with a single bow foil(figure 14). In 1971, Joop Nederpelt designed the first wind surfboard with a hydrofoil attachment. It resembled the foils used for boats (figure 14). The first real hydrofoils date back to the year 2000. (Rosado, 1999).

3.2.2 Competition analysis

The second research topic was the availability of the current market. What is out there, and what are the different options provided by the market leaders. Looking at the current market, three different models are the most common (figure 14). These are the wave foil, the race foil, and the freeride/ freestyle foil.

The other noticeable difference between the foils is that the wings of the companies vary in shape and size, which means that there is not one characteristic shape for a particular situation. Providing the best formula for a specific wing is still an ongoing design challenge, even for the market leaders.

Wavefoil
Starboard

Racefoil
Moses

Freeridefoil
Starboard

Figure 14. Top two; first windfoilboard and first hydrofoil boat, bottom different hydrofoil types

3.3 Ideation

The ideation chapter explains the most important findings during the benchmark sessions about the hydrofoil and shows the first idea sketching session.

3.3.1 Benchmark hydrofoil

To get a better understanding of the current market availability, a visual was created to highlight the most important features (figure 15). The following features are, for now, the most noticeable:

- Some companies use an angle of attack at the back or front wing that can be changed a few degrees to the desired attack.
- The wings of every company differ in shape and size.
- The two most common materials used for the hydrofoils are carbon and aluminum.
- The different parts of the hydrofoil are connected with stainless steel bolts
- The board connectors differ between companies meaning that there are many connection options such as deep tuttle, tuttle, and plate connectors.

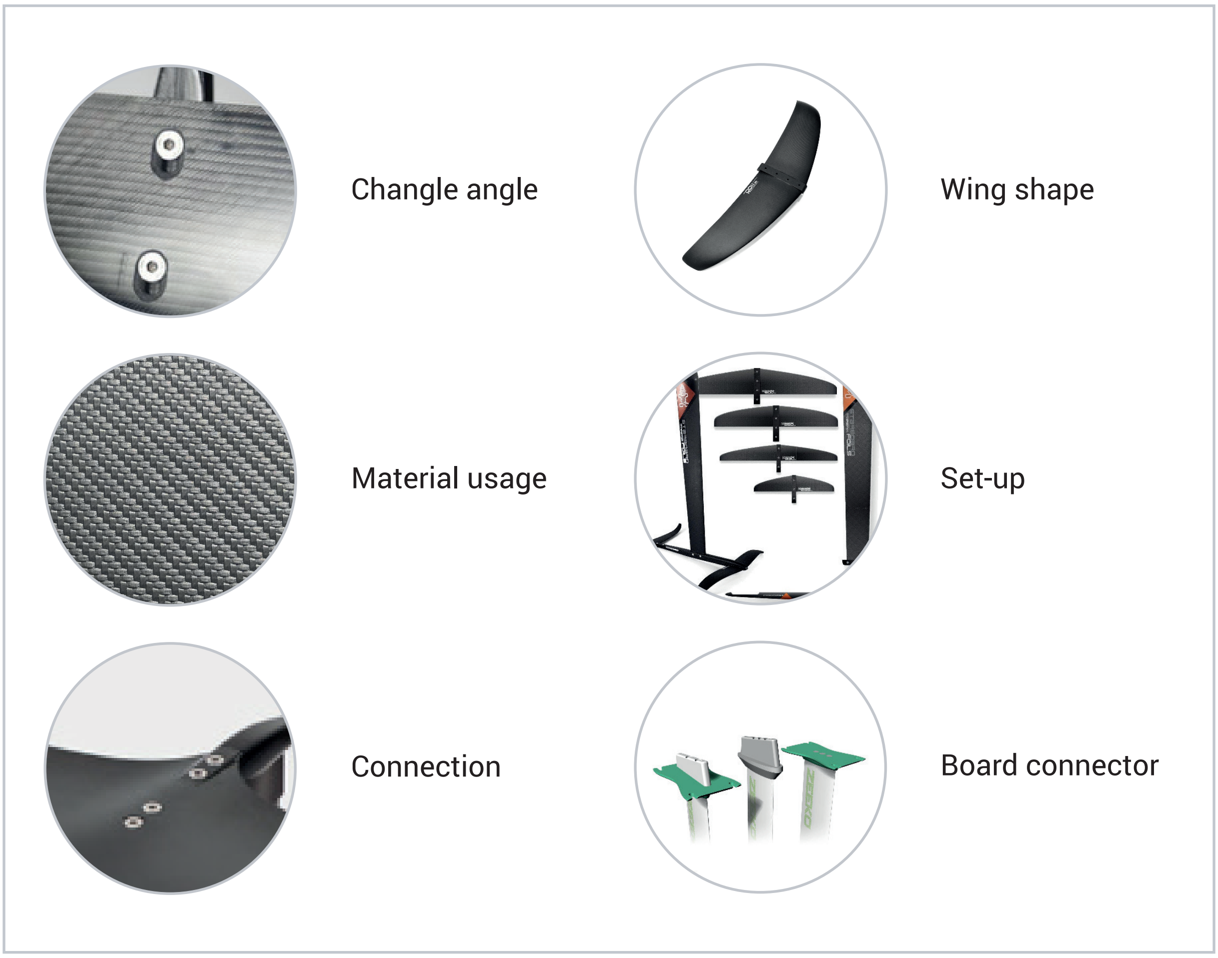


Figure 15. Benchmark by looking at competitors

3.3.2 Idea sketching

The outcomes of the benchmark session served as input for the ideation. Since the time for idea sketching was only one hour, a quick and rough ideation session was conducted on paper(figure 16). The main findings during this session were that the concept needed changeable wings. Also, a simple attaching system to the board was favorable.

The material chosen for the foils is carbon because the company uses this for their products. The production method was also chosen based on the experience of the company. High-pressure carbon fiber injection works best with carbon fiber.

Figure 16. Ideation session

3.4 First concept

3.4.1 Initial requirements

In order to create the concept, a requirement list was made. The list serves as a guideline for the concept. The list consisted of the requirements of the stakeholders and the designer. These where:

Company:

- Production product in-house
- For high end windsurfers
- Interchangeable wings/parts
- Fits product portfolio

TU Delft:

- Usage of new materials/material research
- Marketing of product
- Look into the use of recycled plastics
- New production techniques

Personal:

- Needs to be timeless
- It needs to be functional
- The product needs to be different than other hydrofoils

3.4.2 Initial design vision

Next to the requirements, a vision was created. The vision supports the outcome of the concept. It also explains what the concept needs to do/have. The initial design vision was:

'Creating a product that is different from what is currently out there by providing the user with a set up that can be used in different conditions. By having three front wings, the product is used in either low wind, waves, or as a racing set-up. With a quick connection system, the wings can be changed in record time.'

3.4.3 First concept

The following pictures in figure 17 visualize the concept. It consists of a mast, a fuselage, three changeable front wings, and two changeable back wings. The front wings have different shapes specifically for wave, race, and free ride.

The connection of the wings is via a circular connection, making it stronger than the more common 'screw-on top' connection. Next to that, a connection between the wings mast and fuselage is achieved with stainless steel bolts making the concept waterproof.

Figure 17. First concept after cycle 1

3.5 Reflection

The first cycle was a success (figure 18)....
The first cycle gives an excellent first impression of the total design challenge.

The first cycle resulted in a 3D concept that was shown to the stakeholders. Even by doing the steps quick and rough, an excellent result could be achieved. Also, the first cycle gave an excellent first impression of the total design challenge. Early on in the process, improvements could be analyzed and used as input for the second cycle.

In the next cycle, the following steps will be addressed to create the second iteration. The design now only focusses on the changeability of the wings. Still, a lot of other features need to be checked, such as the size of the fuselage and mast.

Second, only little market research was performed during this first cycle. More research needs to be conducted to create a product that is appealing to the target group and stand out from the competition. Therefore, a user group analysis will be made in one of the next two cycles.

Lastly, a more extensive Ideation and concept phase will be conducted. Exploring different setup options for the hydrofoil and an extensive material and production research will result in a second concept that is more substantiated.

Figure 18. Exploded view of concept after cycle 1

3.6 Next steps

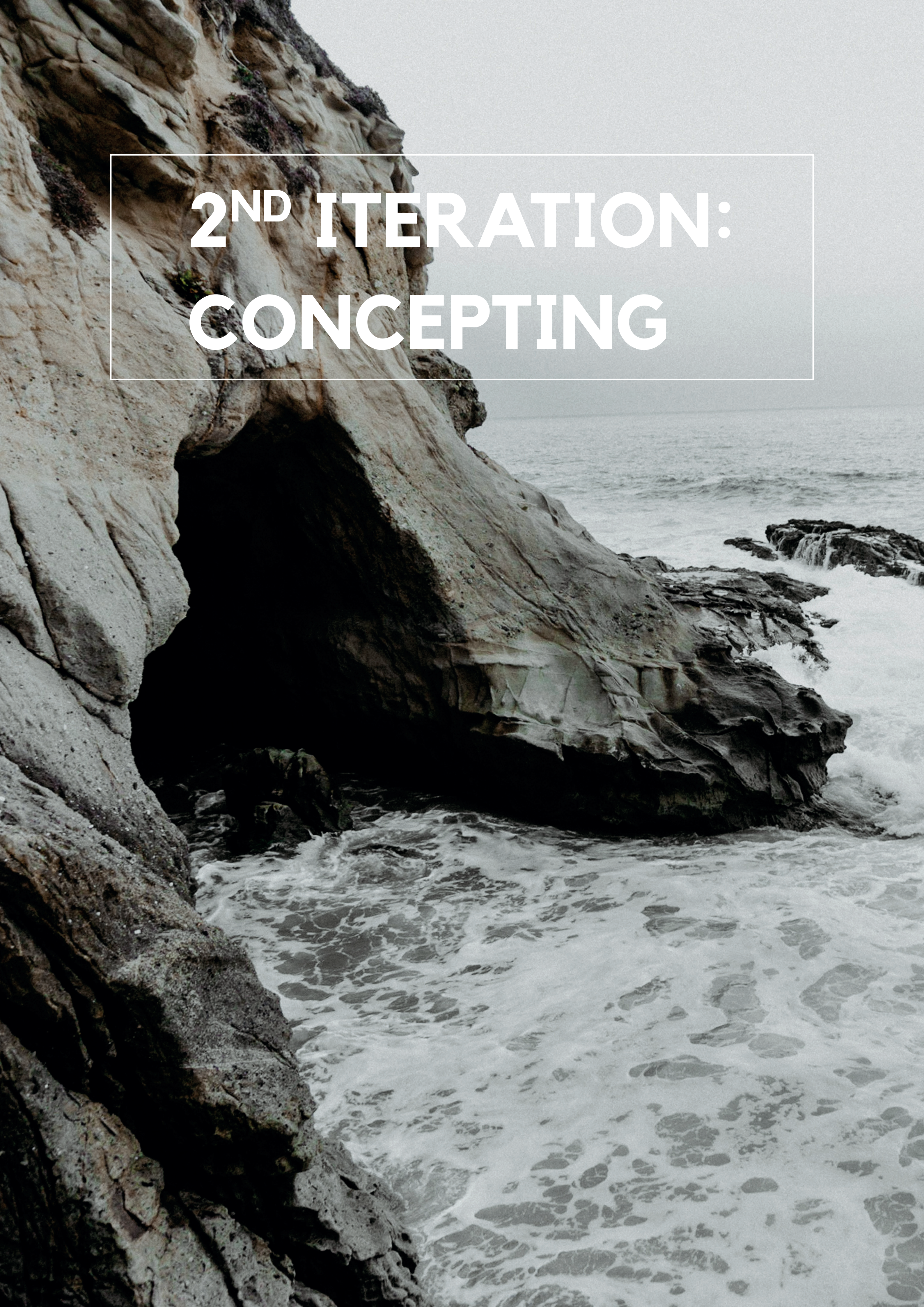
After doing this first one day cycle, it is clear that a lot of standard design steps are either done very rough or left out. These need to be improved in one of the following two cycles.

1. The first thing to do is user group research. Interviewing the user group and finding out what they want will be useful for the second phase. Also, market research needs to be conducted helping the product stand out in the current hydrofoil market.

2. Next to that, the shape of the wings has to be looked into. Therefore, a CFD analysis and an interview with a hydrofoil builder will be used. The materials and the production of the product are still in the development phase. New production techniques and sustainable materials could be used for the development of the hydrofoil.

3. Finally, prototypes need to be built. Next to doing computer simulations, physical prototypes are essential. With these prototypes, tests need to be performed with a prototype to see whether it works or not.

2ND ITERATION: CONCEPTING



The 2nd iteration paragraph shows the second cycle of the 1-10-100 method, concepting. First, the second goal/ aim is shown created with the input of the first cycle. Second, more extensive research was conducted. Third, the ideation is shown containing information gathered from the research. Next, the concept is presented, explaining the different parts. The paragraph ends with a reflection and the next steps.

4.1 Goal/aim

The second cycle aimed to create a concept based on the idea formed in the first cycle. Figure 19 shows the planning of the second cycle. The second cycle lasted ten days and consisted of four parts, the research, ideation, the second concept, and the conclusion.

During this cycle, the focus was on creating a concept that served as a starting point for the last cycle. In this design cycle, thorough research was conducted by consulting two hydrofoil experts, doing a materials and production technique research, and creating a company profile. The second concept served as the last iteration before entering the last design cycle

Again, a co-reflection session at the end with the stakeholder resulted in a starting point for the last cycle.

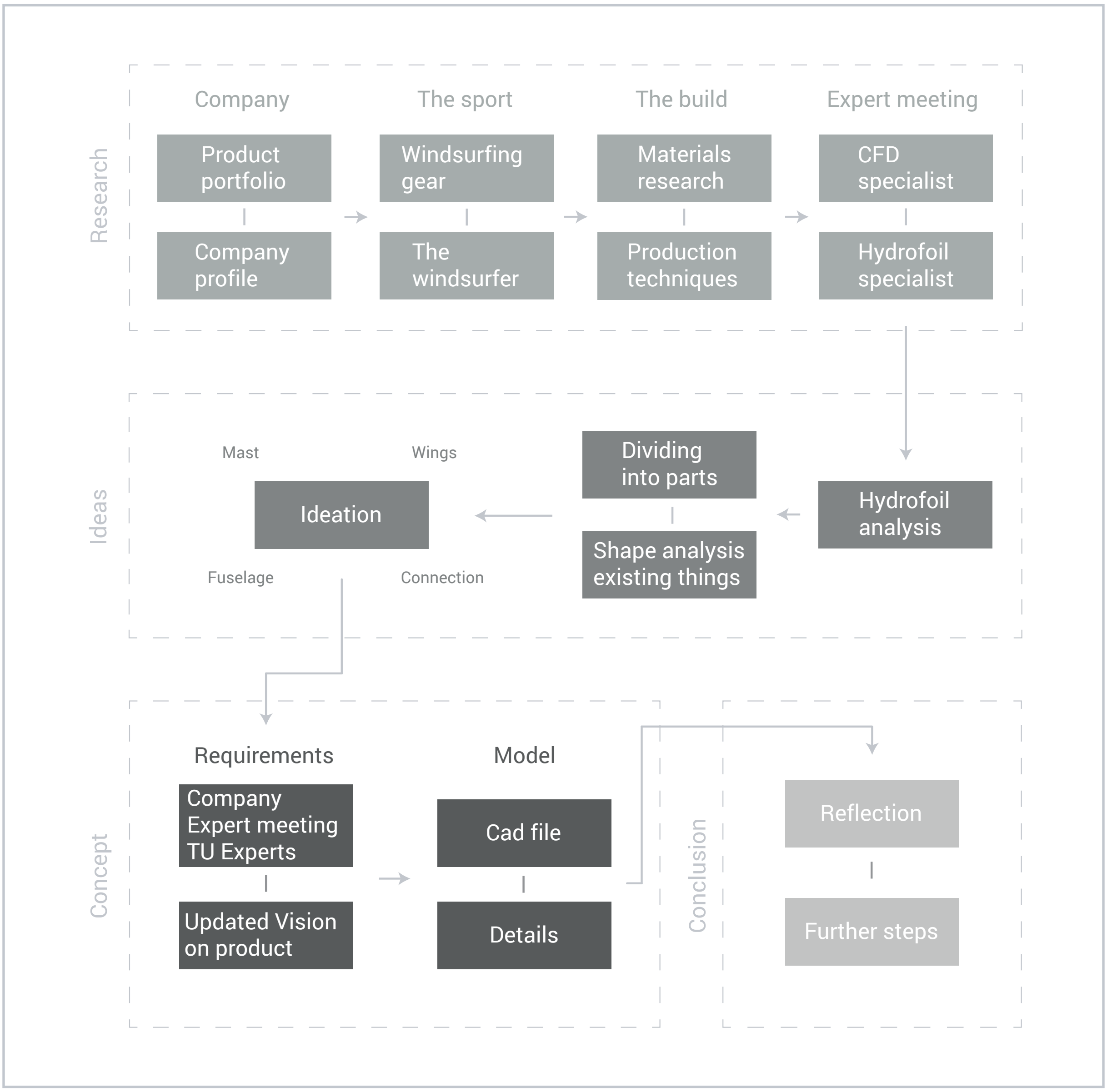


Figure 19. Overview second cycle

4.2 Research

4.2.1 Company profile

PWsurfsport is a windsurfing company based in Leiden. The company has two sister companies called Tribal and KA. Tribal sells windsurfing fins and KA sells windsurfing sails. The first step in the second research phase was to make a company profile and is visualized in two figures that explain the company (figure 20) and the product portfolio (figure 21).

The company consists of four employees. These employees ensure that the products are of high quality by making and finishing them by hand. Therefore, the company has a workshop with a dust-free room, a CNC router room, a carbon and epoxy mold room, and the main workshop containing sanders and several other tools.

The product portfolio of the company indicates what kind of products the company sells. They sell nine different types of fins ranging from carbon to G10 material, eight different sails, and three carbon masts. These products are sold by different distributors and through their website.

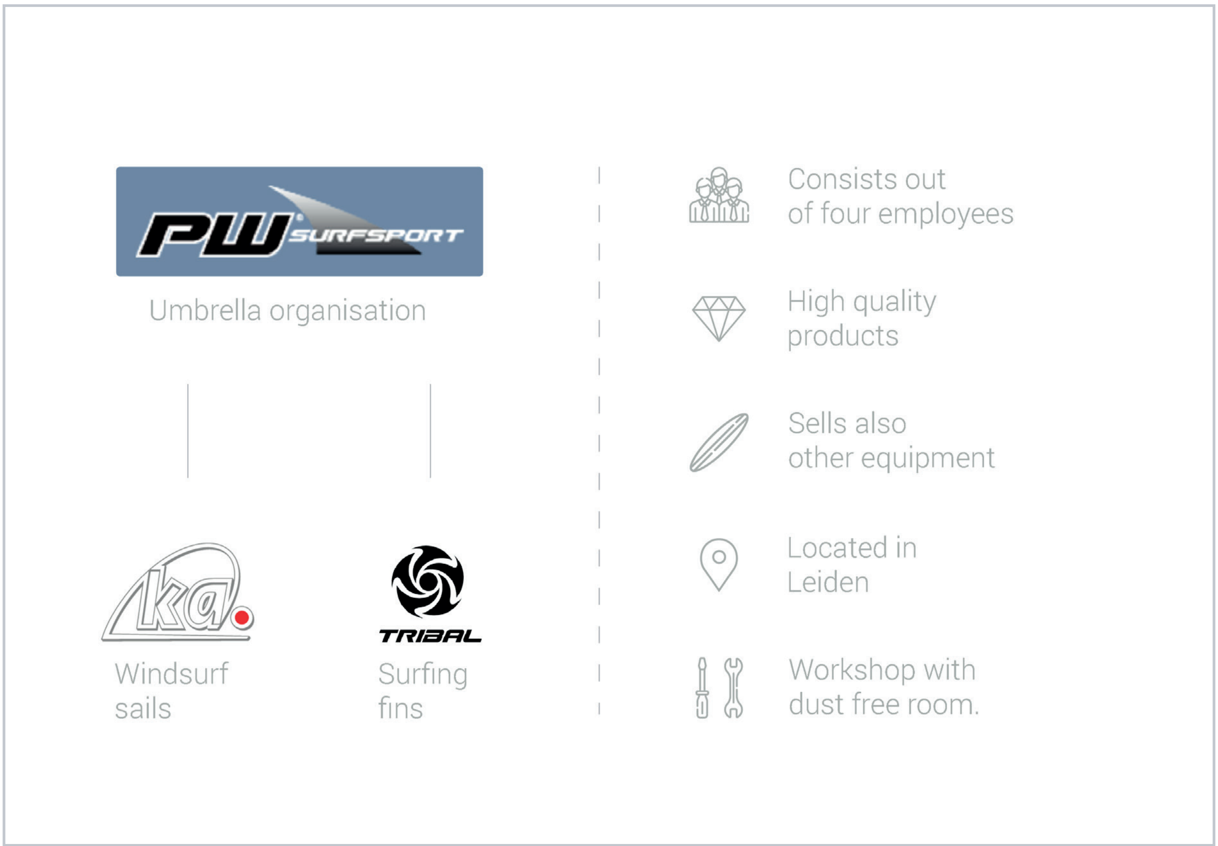


Figure 20. Company overview

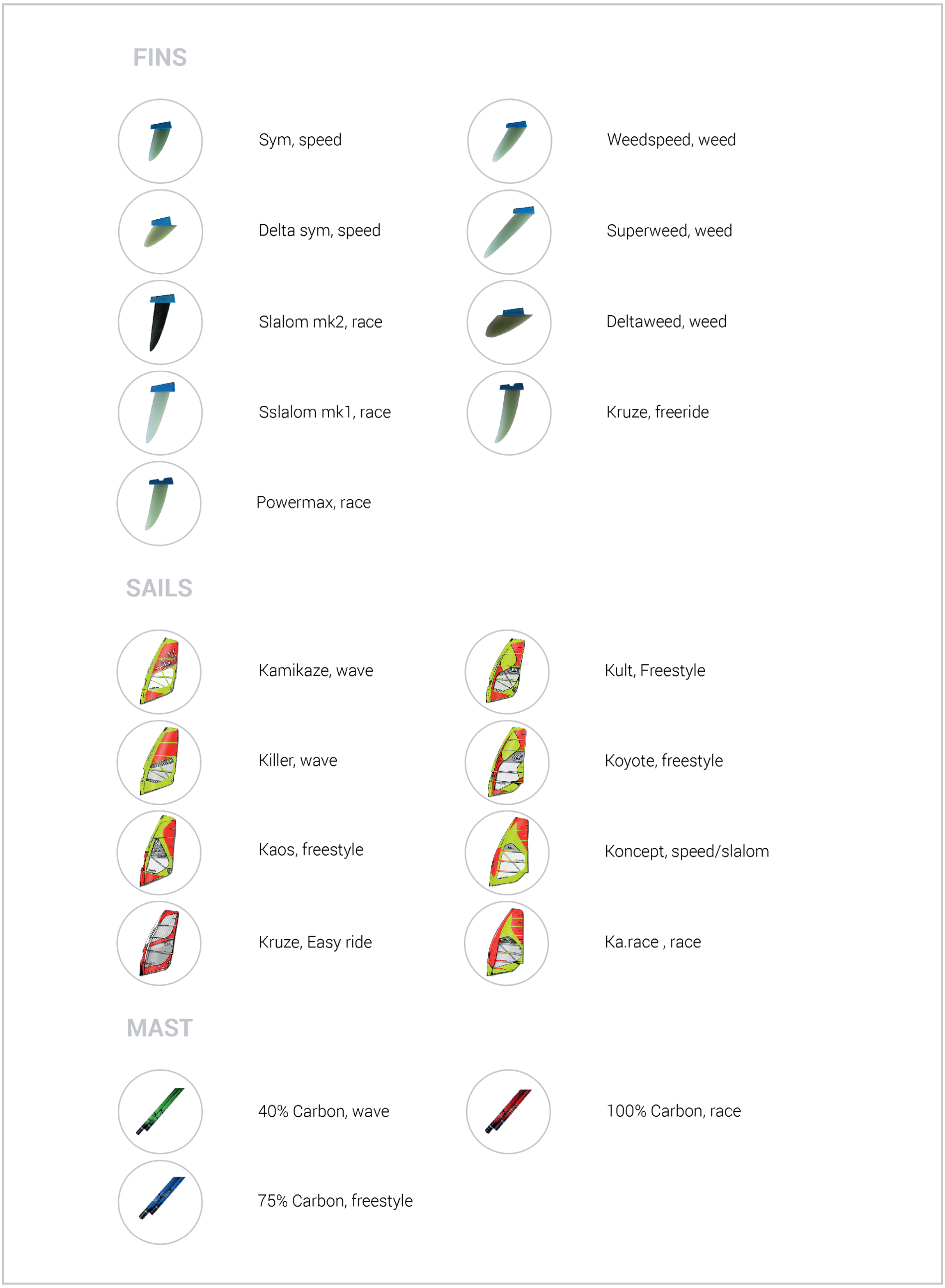


Figure 21. Product portfolio PWsurfsport

4.2.2 The equipment

In order to get a good understanding of the different equipment that is attached to the hydrofoil, figure 22 was made. The figure shows the windsurfing gear as it now used without a hydrofoil. It consists of a sail, board, and a fin.

The hydrofoil will be placed at the connection point of the fin/skeg. The fin is connected to the board via a deep Tuttle connection (figure 22). The connection ensures a rigid and robust bond between the board and the fin.

These connections are present on most of the windsurf boards. In order to make the hydrofoil fit on most of the boards, the hydrofoil will be equipped with a deep Tuttle connection.

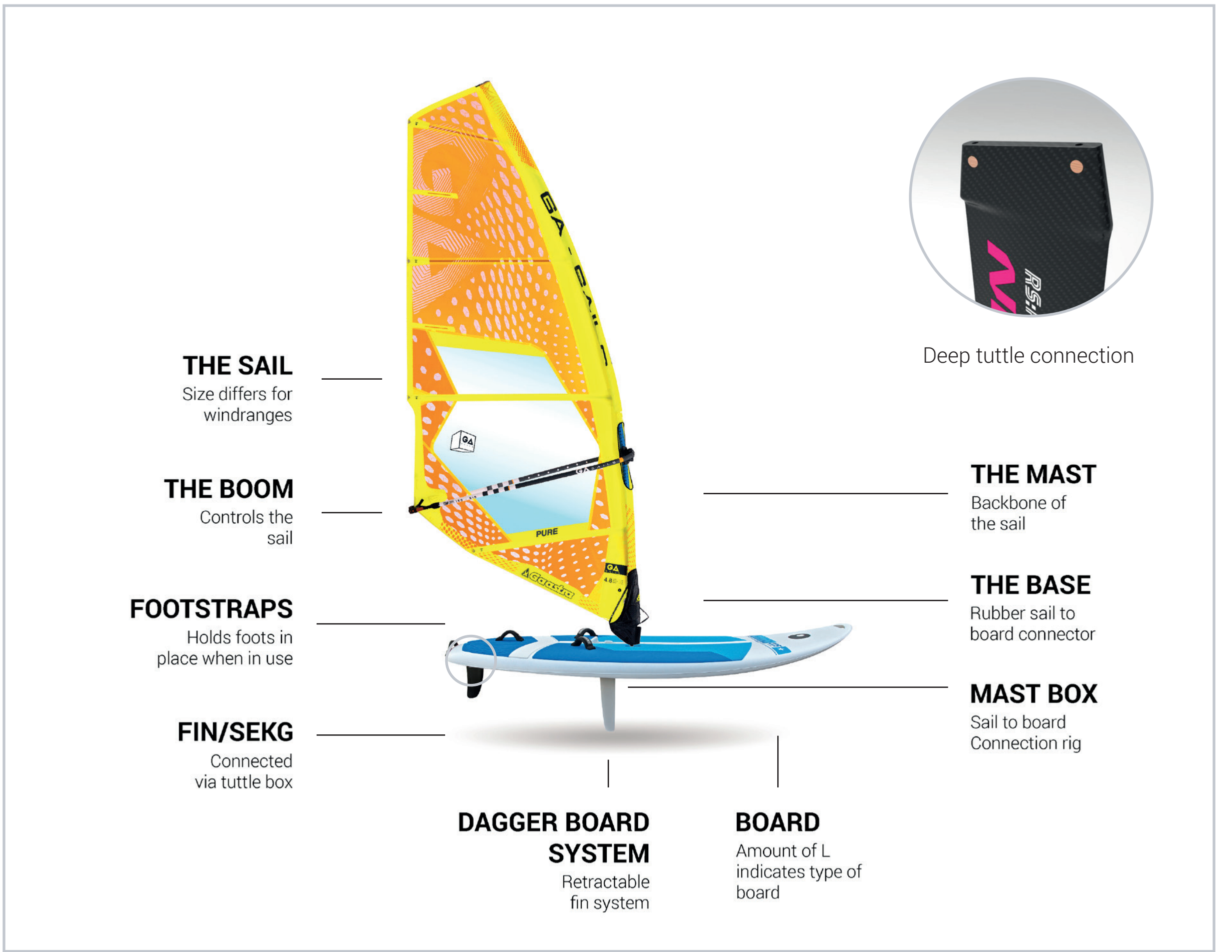


Figure 22. Windsurf equipment

4.2.3 Persona

A persona was created to get a better understanding of the user. Expert interviews and input of stakeholders formed the basis for developing a representative persona. The persona provides a good reflection of the intended user (figure 23). The aspects in the figure act as a guideline for the design proces in the idea and concept phase of the second cycle.

ASPECTS

- Has a high budget to buy gear
- Wants to Windsurfs whenever he or she can
- Gear needs to be intuative and easy to use.
- Wants high quality products
- Cares about the environment.

Figure 23. Persona

4.2.4 Material selection

Five materials were selected for the final concept (figure 24).

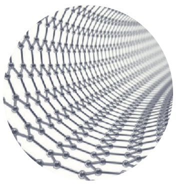
The first one was Carbon Nanotube. This material consists out of a two-dimensional hexagonal lattice of carbon atoms. It is shock-absorbing and stiff. The drawback is of the material is that it is flexible.Carbon Nanotube is used for electromagnetic devices.

The second material is Curran. Curran consists of cellulose nanofibers from vegetables such as carrots. These fibers are extracted from the food waste industry and, therefore, sustainable. The material is durable, stiff, and lightweight. The disadvantage of the material is that it is hard to finish. It is now mainly used for fishing rods.
The third material is Coyote. It consists of basalt braid. The material is very flexible, lightweight, resistant to cracking, and less expensive than carbon fiber. The drawback of the material is that it is only used as reinforcement for carbon fiber layups and prostheses.

The fourth material is Tegris. The material is made out of 100% polypropylene composite material. Tegris is recyclable, strong, stiff, and lightweight. The drawback of the material is that it is rough. It is mainly used for body armour.

The last material is Primetex. This carbon fiber material has a gap-free structure reducing the machining time. Also, it has excellent water resistance making it perfect for watersports equipment.

If we look at the specifications of the different materials, Primetex is the best suiting material for the hydrofoil.



Carbon nanotube

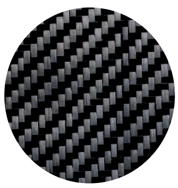
Strongest carbon material
Still in development
Very flexible and forgiving

Coyote

alternative for carbon fibre
Made from basalt rock
Cheap, durable and lightweight

Curran

Can be combined with epoxy's
Made from vegetable fibers.
Strong, stiff and light



Primetex

Excellent water tightness
Gap free structure
Lightweight, strong

Tegris

Polypropylene material
Lightweight, weather resitant,
poor uv resistance

Figure 24. Material selection for concept

4.2.5 Production technique

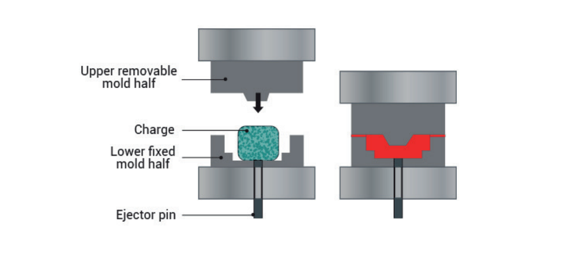
For the production method, three production techniques were selected (figure 25). These were based on the material selection and the techniques the company uses.

The first one was the vacuum infusion process. Vacuum infusion is a process where resin gets sucked through layers of material (such as carbon fiber) when vacuuming a plastic bag.

The second one was light Resin Transfer Molding. It is a two-part matching closed mold that is either made of metal or a composite. Resin and a harder are mixed and vacuum pumped under pressure through the mold. Sometimes, the mold is heated to help the process.

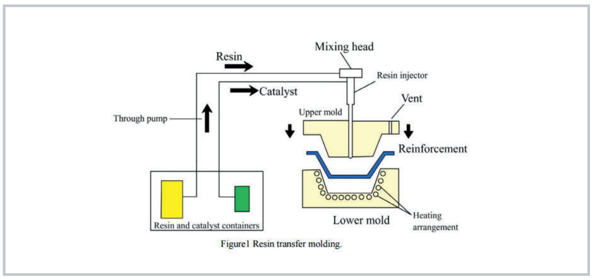
The last one is compression molding. The heated material is placed in an open cavity mold. After that, the mold is closed, applying pressure to the material, making it form into the shape of the mold.

For this cycle, light resin transfer molding will be used. It can form complex parts and is now already used by the company for fins.



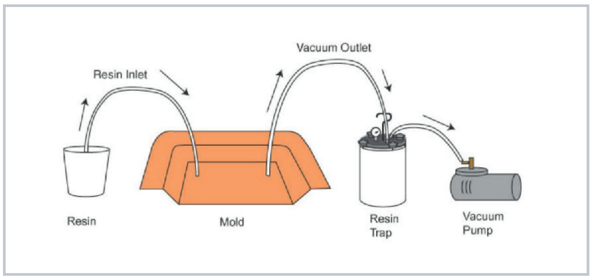
Compression molding

Pro: Easy to make big parts
Quick and easy
Con: Not to complex parts can be made



Light Resign transfer molding (RTM)

Pro: Very precise and clean forms
Perfect for making very complex forms
Con: Limited amount of finishing



Vaccum infusion

Pro; Perfect for carbon fiber materials
Con; Long process
Can easliy leed to leeks(plastic bag)

Figure 25. Different production techniques

4.2.6 Expert interviews

Expert interview Hydrofoil specialist

The first interview was with Bram Hoogendijk (figure 26 top). He was an early adopter in the kite and windsurfing hydrofoil production business. After Windsurfing for several years, he discovered kitesurfing and fell in love with it.

The main goal of the first interview was to gain as much information about hydrofoils as possible. Especially the use of materials and production techniques were essential.

Main insights interview 1:

- **Angle:** the importance of the angle of the front wing. The front wing needs an angle of attack between eleven and nine degrees.
- **Wing shape:** the shape of the front wing. The freeride wing has a reversible profile. The profile gives stability when riding and helps to lift the board out of the water.
- **Mast transition:** the transition between the mast and fuselage is essential. Creating a more significant transition area between the two makes the product more hydrodynamic.
- **Lightweight:** also, try to make the product as lightweight and robust as possible. Therefore the total weight of the gear needs to be as low as possible to increases the riding pleasure.

The first interview was very insightful. A lot of tips and tricks about hydrofoiling, building a hydrofoil, and shape definition were conducted.

Expert interview CFD specialist

The second interview was with CFD specialist Jan Willem Krijger (figure 26 bottom). He is a Naval architect specialized in computational fluid dynamics. He works as an expert engineer on hydrodynamic problems at GustoMSC.

The main goal of the second interview was to elaborate on the first design I made in the first cycle and discuss what profiles for the mast and wings would be beneficial.

Main insights interview 2:

- **Reverse profile:** a reversed profile is essential when designing the front wing. A reversed profile is the best shape for a freeride set up.
- **Size wing:** The weight of a person determines the size of the wing. The size of the wing also depends on the amount of wind.
- **Mast fuselage connection:** the mast and fuselage should be made into one part to make the whole product stronger and stiffer. In many situations, cracks and deformations develop during regular use. Therefore, a total mast and fuselage connection will be preferable.
- **Connection hydrofoil:** the Tuttle box will be eventually replaced in windsurfing. Many problems occur during windsurfing at the Tuttle box. However, if we look at the current market, it is clear that all the windsurfing boards have Tuttle boxes.

The second interview helped to start designing the front and back wings and provided useful information about the mast.

Figure 26. Top visual of first interview, bottom visual from second interview.

4.3 Ideation

4.3.1 Subdivision parts

The ideation phase of the second cycle is divided into four subsections (figure 27).

1. **Board connection:** the first subsection is the board connection. As earlier mentioned, this will be a deep Tuttle box connection. It needs to provide a rigid and robust connection between the board and the hydrofoil.
2. **Mast + Fuselage:** the second subsection is the combination of the mast and fuselage. These parts serve as the backbone of the product. The part connects the board and the wings to the hydrofoil.
3. **The wings:** the third subsection consists out of the front and back wing. These serve as the lifting and counter lifting parts of the product.
4. **Part connection:** the last subsection consists out of the two connection parts at the front and the back of the mast. These serve as the connection points of the front and back wing.

Figure 27. Hydrofoil subdivision

4.3.2 Idea sketching

The idea sketching session was used to create ideas for the four subsections. Figure 29 shows the exploration of ideas for different subsections.

For the first subsection, the board connection, inspiration was derived from existing windsurfing hydrofoils and the expert meetings. The most important finding during this session was the use of either a plate or a Tuttle box connection for the hydrofoil.

For the second subsection, the mast +fuselage, inspiration was used from the expert meetings and already existing hydrofoils. One of the main findings during the session was merging the mast and fuselage.

The third subsection, the wings, is inspired by forms and shapes found in nature. These were wings of birds, manta rays, and airplanes (figure 28). The most important finding during this session was the use of three front wings for different situations and only one stabilizing back wing.

The last subsection, the connection of the wings, are also inspired by the expert meetings. The main finding during this session was a squared connection pin for the back and front wing.

Figure 28. Moodboard idea sketching

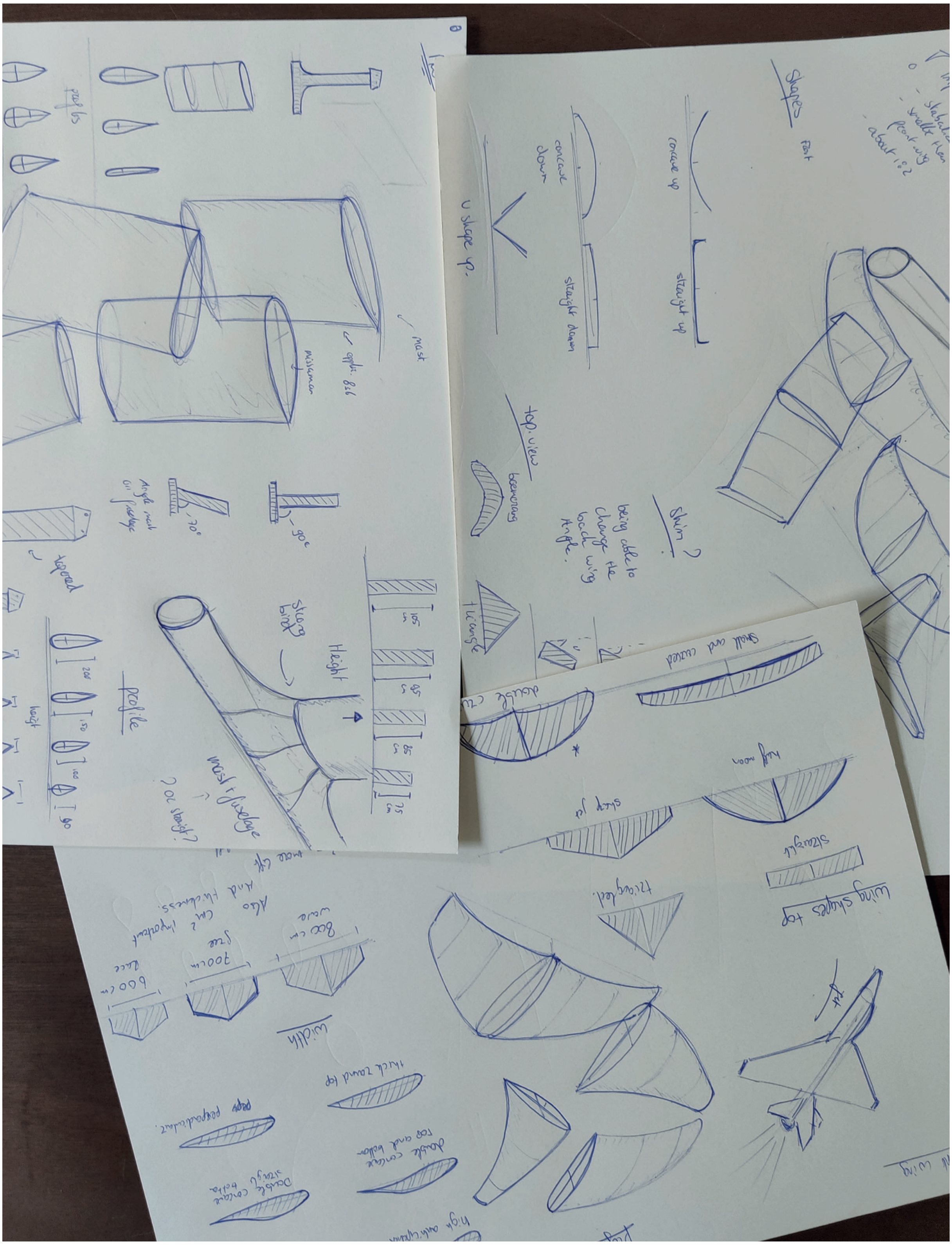


Figure 29. Ideation second cycle

4.4 Second Concept

4.4.1 Revised requirements
The conceptualization started with making a list of requirements. These requirements were found to be necessary during the expert interviews and the research chapter. The most important were:

- The wings need to be interchangeable so that the product can be used in various conditions.
- The concept needs to work for race, freeride and wave style.
- The product can be customized to fit the needs of every customer.
- The product needs to be as durable and lightweight as possible.
- The product is for the higher price segment of windsurfing.
- The product needs to be stiff and forgiving/flexible.
- The product can be made in-house at the company.
- The product needs to work with windsurfing and kitesurfing equipment.

4.4.2 Revised design vision
Next to the requirements, a vision was created to support the requirements. This vision is an improved version of the vision presented in the first step.

First cycle vision: 'Creating a product that is different from what is currently out there by providing the user with a set up that can be used in different conditions. By having three front wings, the product is used in either low wind, waves, or as a racing set-up. With a quick connection system, the wings can be changed in record time.'

New vision: 'Creating a hydrofoil that can be personalized for different wind ranges, setups such as kitesurfing or windsurfing, and the hight of the mast.'

4.4.3 The second concept
The concept is made to work with either a kite surfboard or a windsurf board. Therefore, the product can be used by multiple sports.

The concept consists of four parts (figure 30). The board connection, the mast+fuselage, the front wing, and the back wing. In order to explain the whole concept, each part and connection will be explained separately in the following pages.

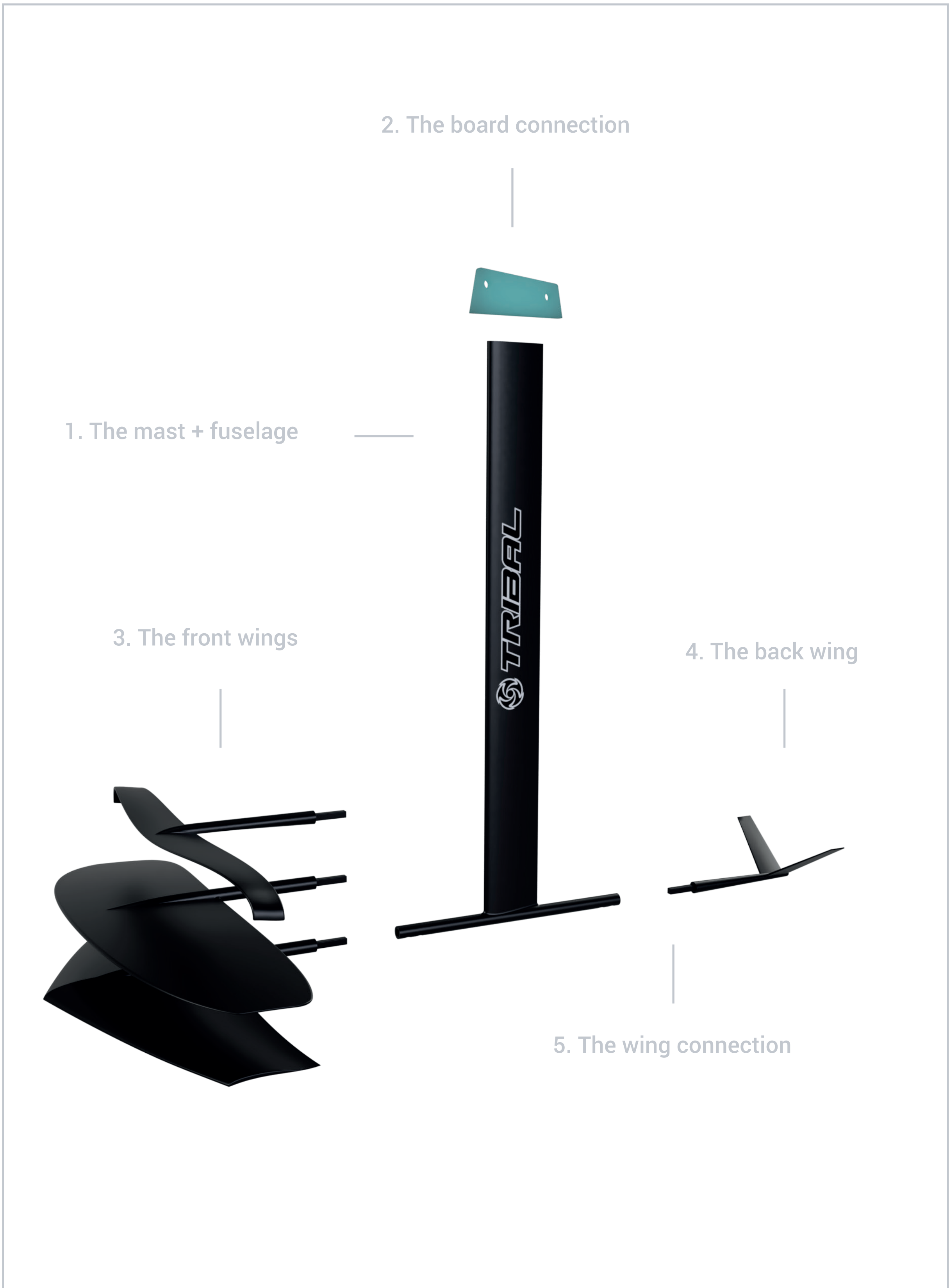


Figure 30. Concept after cycle 2

1. The mast+fuselage

One of the recommendations of the CFD specialist was to merge the mast and fuselage (Krijger, 2019). By merging the mast and fuselage, a stronger connection is achieved. In other cases, were the mast and fuselage are two separate parts, tears and ruptures frequently appeared.

Also, the mast and fuselage can be shortened into the preferred size. By making the fuselage and mast longer than the most extensive available size, the part can be cut into the preferred size for every situation. The combined mast and fuselage can, therefore, act as either a windsurfing mast or kitesurfing mast.

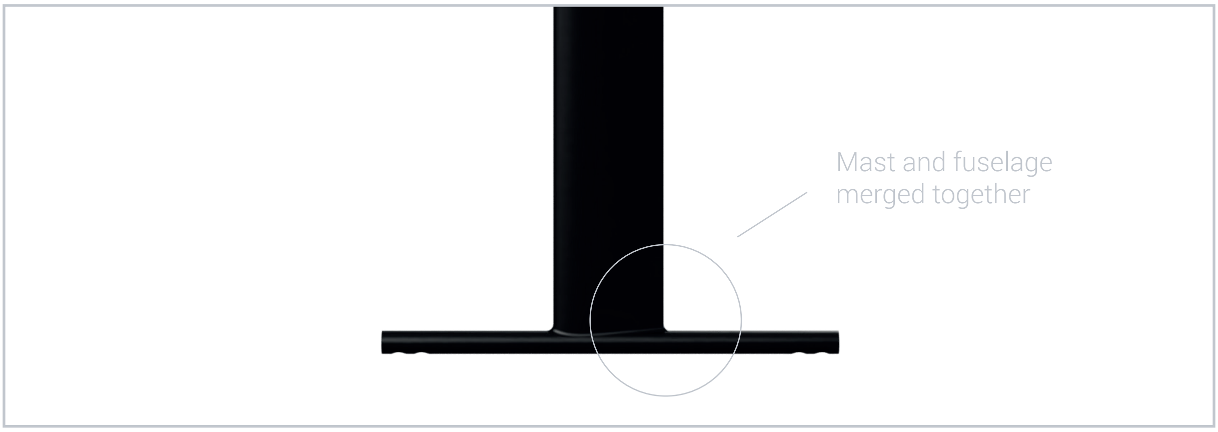


Figure 31. Top; diifferent mast sizes, below; merged result

2. The board connection

The connection from hydrofoil to board is one of the most critical design challenges (figure 32). The most critical problem is the connection of the hydrofoil to the board. Frequently the Tuttle box inside the board comes loose because of extreme forces created by the water (Hoogendijk, 2019).

A possibility to address this problem is to create a new connection between board and foil to make the connection stronger.

Therefore, a connection plate could be a solution. However, for this ten-day challenge, we assumed that the product needed to fit on existing windsurf boards. Thus, the only option was to use a deep Tuttle connection system.

Figure 32. Left tuttle box connection, right plate connection

3. The front wings
In order to work correctly, the hydrofoil needs to work in the three most common situations (race, freeride, wave). Therefore, the concept needed three different wings (figure 33).

The first wing, the free ride, is the most important one. This one is supposed to work in every situation. It has a reversible profile to ensure that it is stable at higher speeds and an easy start out of the water. Also, the slightly thick and full profile ensures that the wing can be used in low wind ranges and with heavier equipment such as a windsurf board.

The second wing, the race wing, is smaller and broader than the free ride wing. It has a slim shape and a reversible profile, ensuring that it provides stability when going fast. Also, the shape of the race wing ensures that when one side of the wing lifts out of the water, the other side compensates the forces and directs the foil back into the fully submerged position.

The third and last wing is the biggest of the three wings. It has a wide and thick profile to ensure that it can float in low wind conditions. The profile also ensures that the wing lifts quickly from the water.

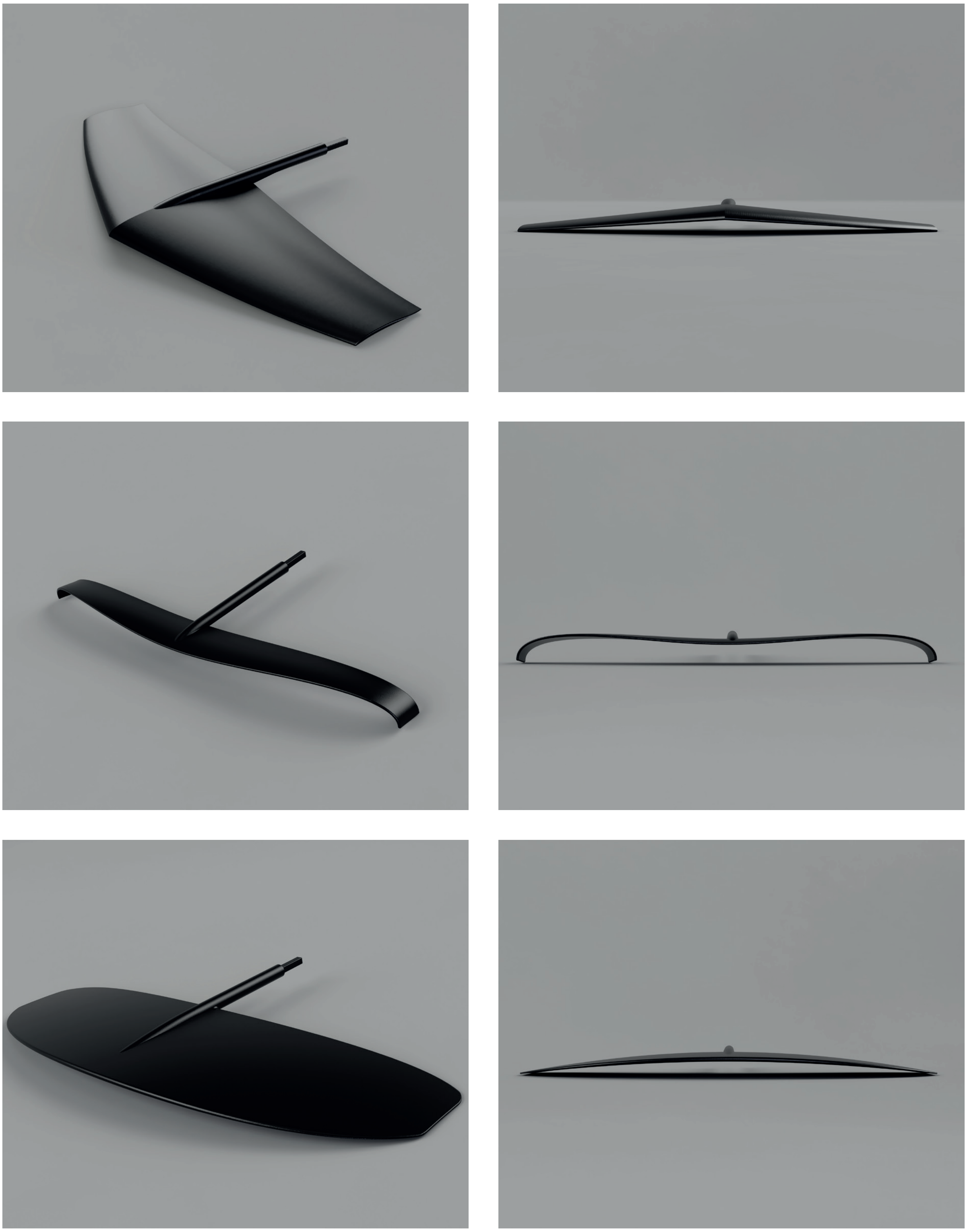


Figure 33. Front wings. top to bottom: Freeride, race, wave

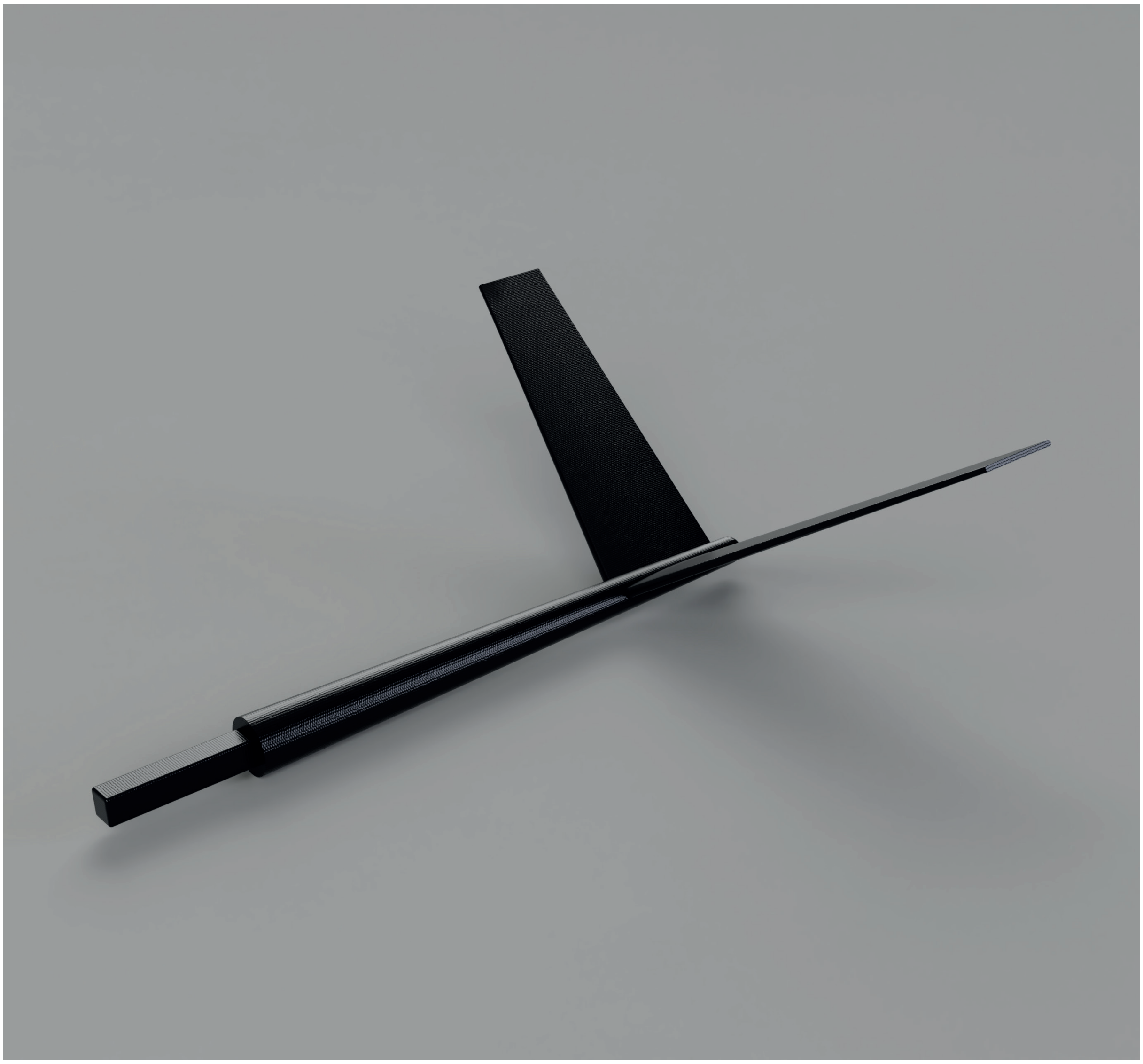


Figure 34. Back wing

4. The back wing

The back wing is the stabilizing factor of the hydrofoil (figure 34). It gives the rider stability, especially in turns and when riding at high speeds.

The shape of the back wing, with the wings facing upwards, is based on the stabilizing wing of an airplane. The shape also resembles the back wing of the hydrofoil designed by the hydrofoil expert (Hoogendijk, 2019).

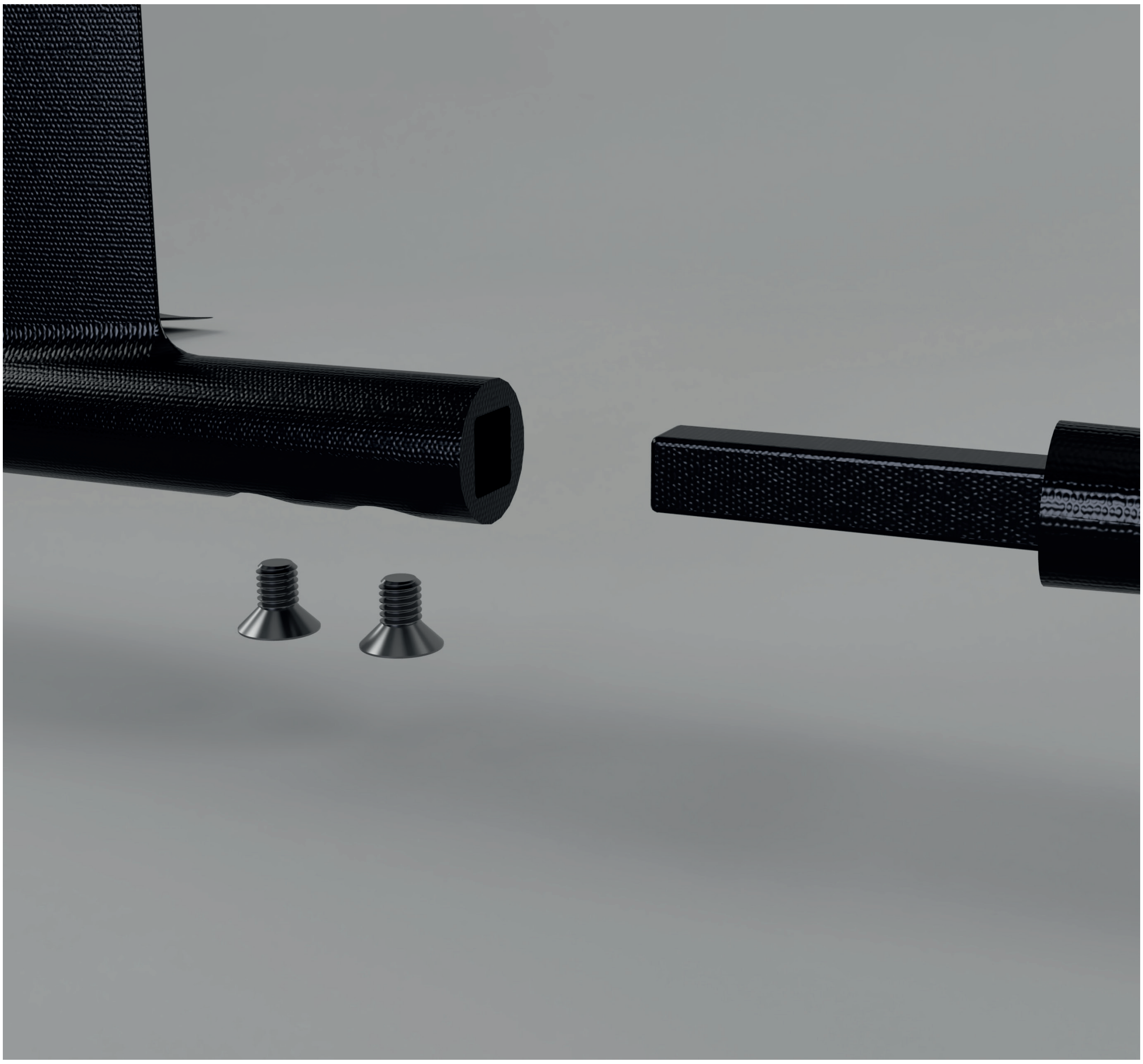


Figure 35. Connection between parts

5. The wing connection

The connections of the wings are essential. The connection shown in figure 35 is stronger than the connections available in the current market.

At the end of the wings, a square pin is present. This pin fits in the hole present in the fuselage. After putting the pin into the hole, the two are connected with two bolts. This connection ensures that the powers are not only transferred to the bolts, but also through the pins.

4.5 Reflection

The second cycle resulted in a more defined concept (figure 36). The concept was created using extensive research, detailed ideation, and interviews with hydrofoil specialists. The result will be used as a starting point for the third and last cycle, detailing.

The decision to make the combined mast and fuselage changeable, make the product useable for either windsurfing or kitesurfing. Also, personal preferences could be achieved by this feature. Personal preferences can make the concept more stable, maneuverable, and easy to ride for a beginner.

Next to that, the interchangeability of the wings is improved. The strength of the connection is increased, and it is easier to switch between wings. However, tests need to confirm whether the system works with sand, saltwater, and long-time use.

The next steps focus on improving this concept. For example, the material is based on the current material the company uses for fins. By using this material, the company can make the product in house. Next to that, other materials should be researched, leading to a more sustainable, cheaper, or even stronger material than currently used for the hydrofoils.

Also, the shape of the wings is now derived from existing designs and input from the experts. These shapes need to be tested and improved. The finalization of the wings will be the most challenging part of the detailing process.

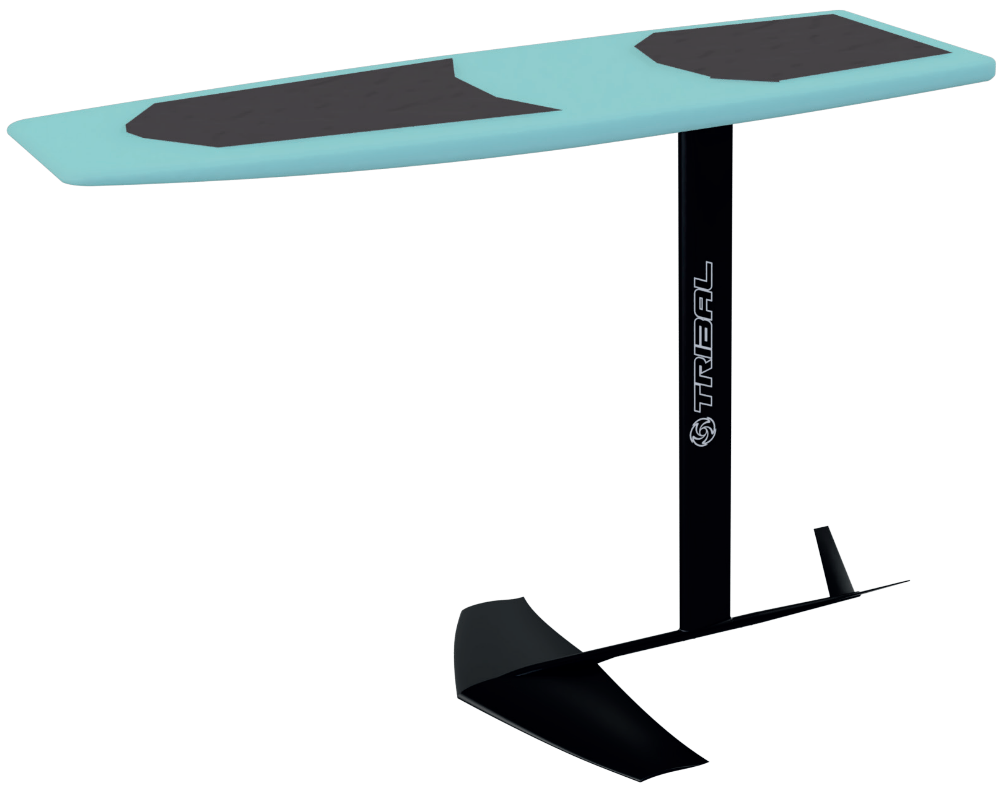


Figure 36. Second cycle hydrofoil with kitesurfboard

4.6 Key takeaways

In this second cycle, a solid starting point is created for the third and last cycle of the 1-10-100 method. Still, a few things need to be worked out more thoroughly:

- For instance, it would be a good idea to find a few early adopters in the wind foiling watersport who can help develop and test the hydrofoil creating a small test panel for the prototype.
- Also, extensive marketing research needs to be conducted, helping to place the product in the right market. Next to that, it will indicate how much the product will cost and what features it needs to have.
- The next step is to finalize the material choice and production technique for the concept. First, a calculation needs to made to find the internal powers in the concept. With this information, maximum stress and strain value can be determined. These represent the minimum values a material needs to have. With these values, a specialized composite material company could be approached for their professional opinion.
- At last, prototypes need to be made. These will serve as a consumer interaction tool to evaluate if the concept meets the demands of the intended user. Next to that, they will play an essential roll in the user test. The user test is one of the most critical testing tools for the concept.

3RD ITERATION: DETAILING

The 3rd iteration paragraph shows the third and last cycle of the 1-10-100 method, detailing. The concept created in the second cycle served as the starting point for the third cycle. The first step of the third cycle was extensive research on the user, production techniques, and materials. Also, different calculations were created, and experts were interviewed. Then, the concept was detailed by using the key takeaways of the second and first cycle. Lastly, a reflection and the next steps will end the paragraph.

5.1 Goal/aim

The last cycle aimed to create a final concept that could be tested with the intended user. In this stage, the fine details of the concept were developed. A much more thorough research and concept phase was conducted. Figure 37 shows an overview of the third cycle.

By the end of cycle two, an improved concept was created and shown to the stakeholders. After presenting the design to the stakeholders, a new plan was made, eventually leading to the result presented in the final concepting phase.

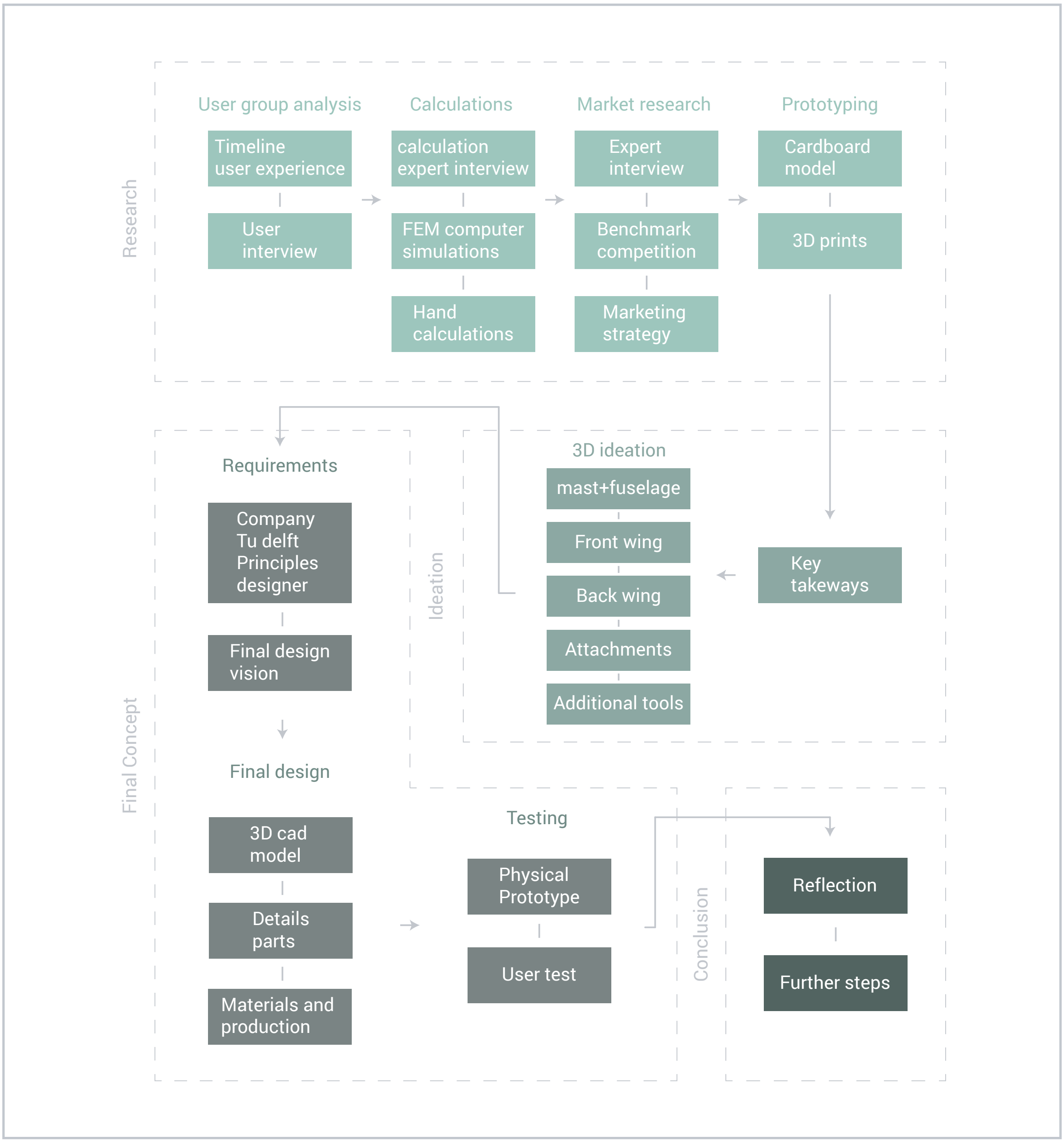


figure 37. Overview third cycle

5.2 Research

The research phase will show the user experience and the opportunities it presents, the calculations on the hydrofoil, a marketing analysis, a shape, construction analysis, and the physical and 3D prototyping.

5.2.1 User experience

An interview with a competitive windsurfing hydrofoiler was used to find relevant opportunities (Boon, 2019). The outcomes of the interview are visualized from pre-use until after use in figure 38. The entire extensive user scenario can be found in appendix A.

The experience of the user is divided into five scenarios; pre-use, assembly, use, disassembly, and after use. The most interesting opportunities and findings are explained in figure 39 to 43.

1 **Pre use**

The gear is carefully chosen according to the wind conditions.

2 **Assembly**

The different parts are connected and brought to the beach.

3 **Use**

The user uses the foil and hovers over the water in a playful and challenging way.

4 **Disassembly**

The parts need to be dissasembled and stored in their storagebags.

5 **After use**

The parts of the hydrofoil and windsurfboard need to be cleaned and dryed to prevent mold.

Figure 38. set-up user experience


H-FIRE-91

① Pre use

In the pre-use phase (figure 39), two opportunities were present in the last phase. The opportunities presented themself during the use of the travel bag.

The first opportunity was found when the user was carrying the gear. Already, much gear needs to be carried to the beach to be able to windsurf. Therefore, an easy to carry bag for the hydrofoil parts would be desirable.

The second opportunity concerned access to the parts inside the bag. The arrangement of the parts could be more convenient to enhance the user experience.

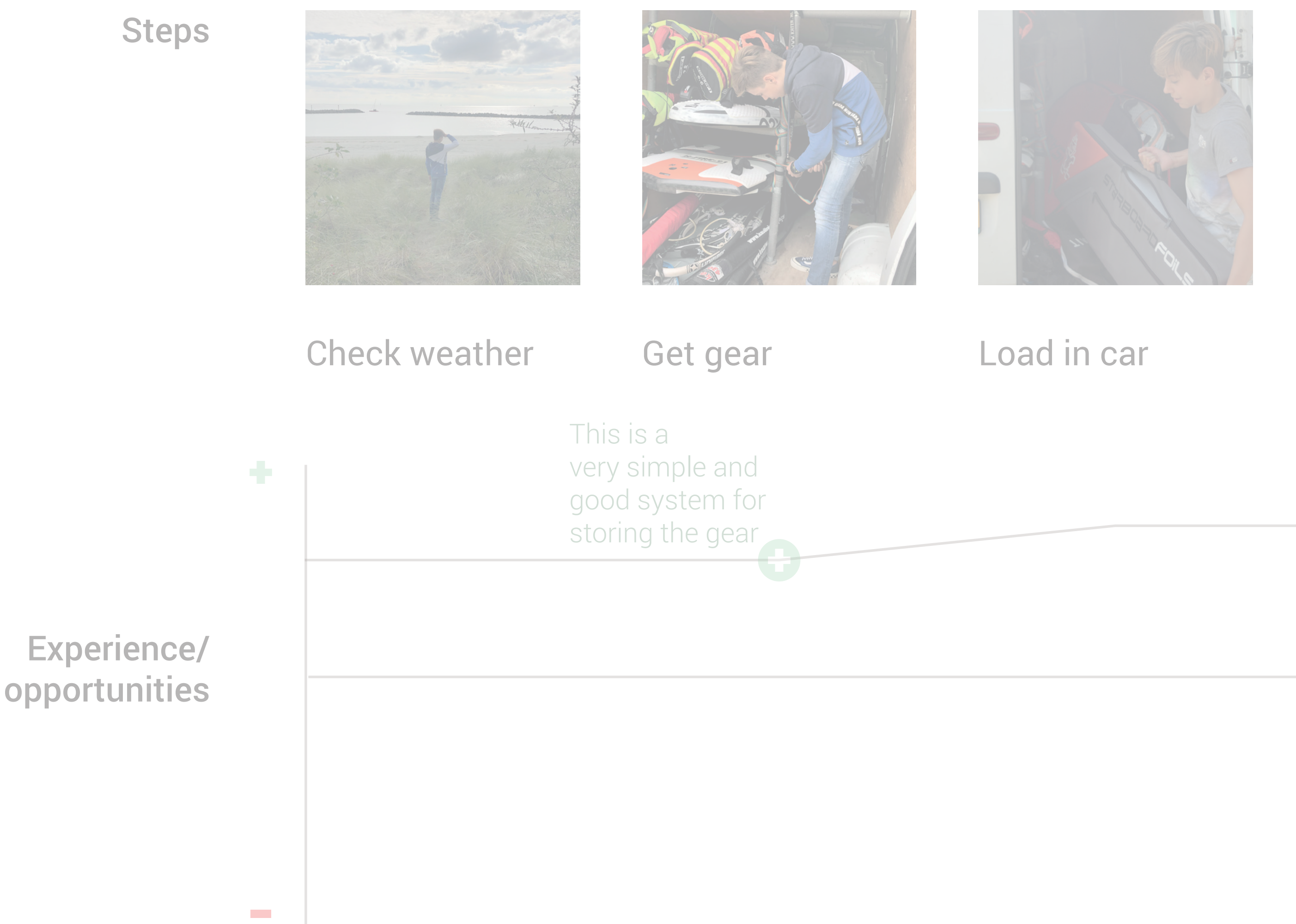


figure 39. Pre use visual

1

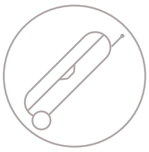
Grab from car

Lay-out gear

Grab from bag

Choose parts

A lot of gear!
Easy carrying
would be usefull



Better storage
bag for easy
acces to gear

2 Assembly

The second phase of the experience is the assembly. Figure 40 shows a disappointing user experience during every step of the assembly. Improvements could be made for this phase.

The first opportunity in the assembly is the lack of useful tools. Now, a small inconvenient tool is provided with the set. A more ergonomic and comfortable working tool would be an excellent addition to the set.

The second opportunity was found when the user told that he made his own wing protectors. These were needed to protect the wings when they were carried to the beach. Also, they protect the wings against the sand. Therefore, another opportunity presented itself, providing the set with wing protectors.

The last opportunity was the ability to carry the gear to the beach. Now, carrying the gear to the beach is performed in a rather unpleasant way without the hydrofoil. Adding

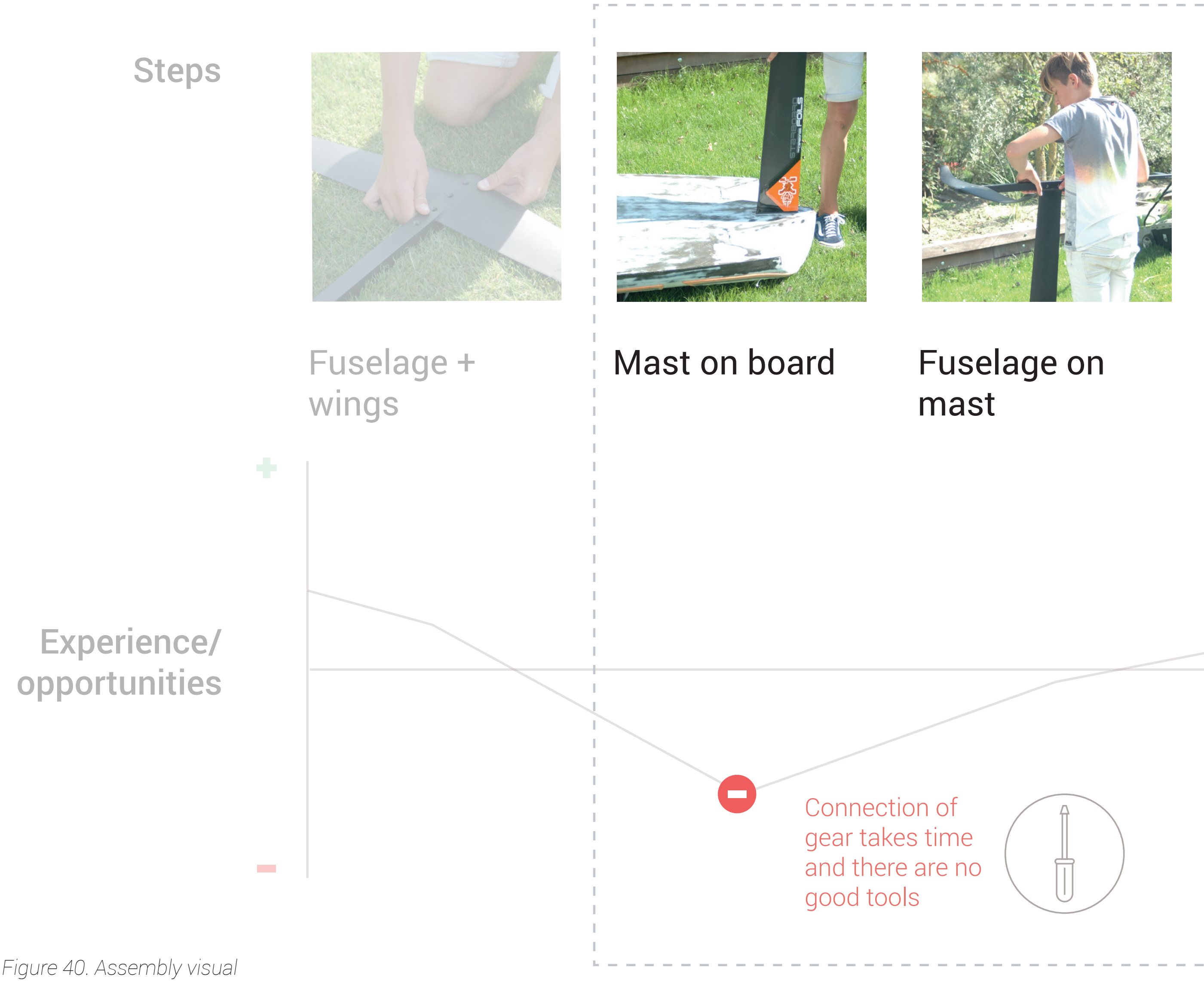


Figure 40. Assembly visual

the hydrofoil should not further reduce the carrying experience of the gear. A smart solution to carry the gear would be favorable.

2

Protectors on wings

Install other gear

Everything to beach

Connect other gear

Self made protectors. Deliver these with the set.

Not easy to carry everything to the beach

3 Use

The use phase is one of the most important ones (figure 41). During the use phase, we found the highest experience rate. In order to keep this as high as possible, the gear needs to be made from high-quality materials. Also, the gear needs to be as good, or even better, than the current hydrofoils from the competitors.

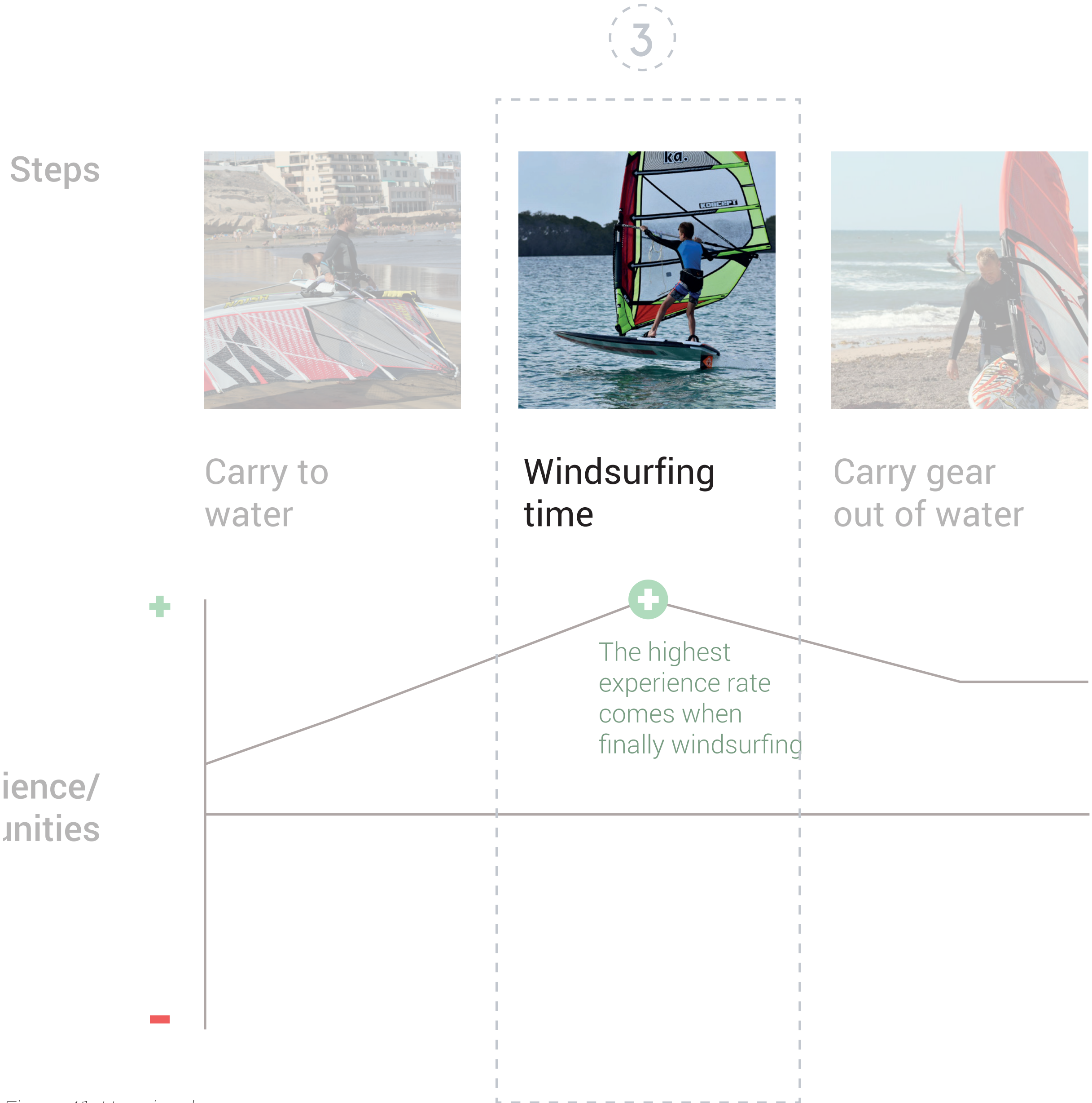


Figure 41. Use visual

4 Disassembly

After using the gear on the water and bringing it back to setup place, the disassembly begins (figure 42).

Again, the first bad experience begins when the gear is carried back to the setup place. Because this lousy experience happens twice, a proper solution should be presented for the final product.

The second irritation point is the lack of a proper storage box for screws and tools. Therefore a proper storage box should be provided.

The last noticeable lousy experience from the user is the storage of the different hydrofoil parts into the bag. A new, better storage system within the bag would be a welcome addition.

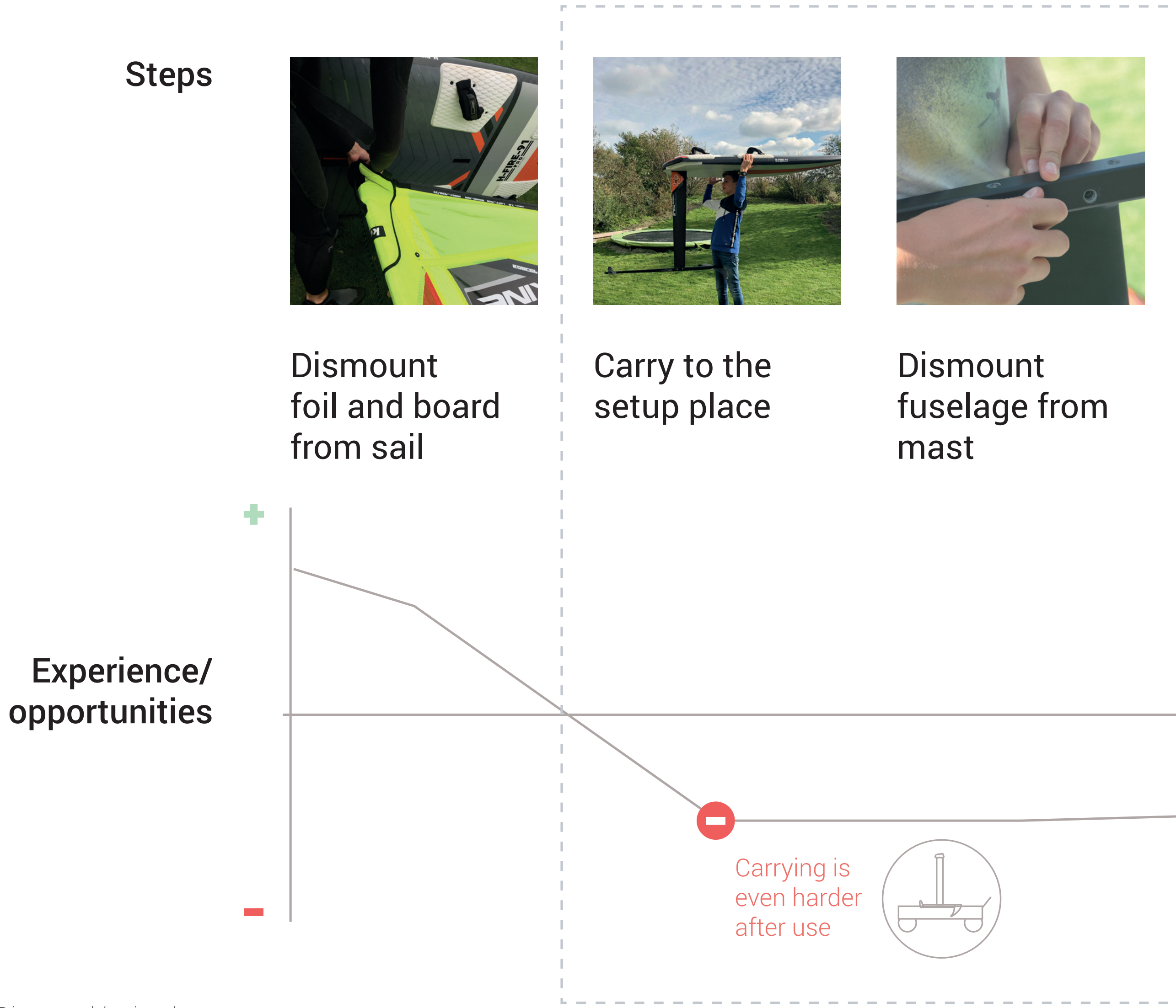


Figure 42. Disassembly visual

4

Dismount wings and fuselage

Dismount mast from board

Foil parts back in bag

Disassemble other windsurf gear

No storage box for the screws.

An easy storage system would me usefull

5 After use

After using the materials and bringing it back to the primary storage location, the parts need to be cleaned (figure 43).

Now, the hydrofoil set does not contain a cleaning set. Therefore, household cleaning items are used to clean the material. A convenient cleaning set that fits into the carrying bag would be a welcome addition.

At last, as earlier mentioned in the assembly and disassembly phase, the parts of the hydrofoil are not easy to store in the carrying bag. One of the significant opportunities for the hydrofoil is providing a better storage bag.

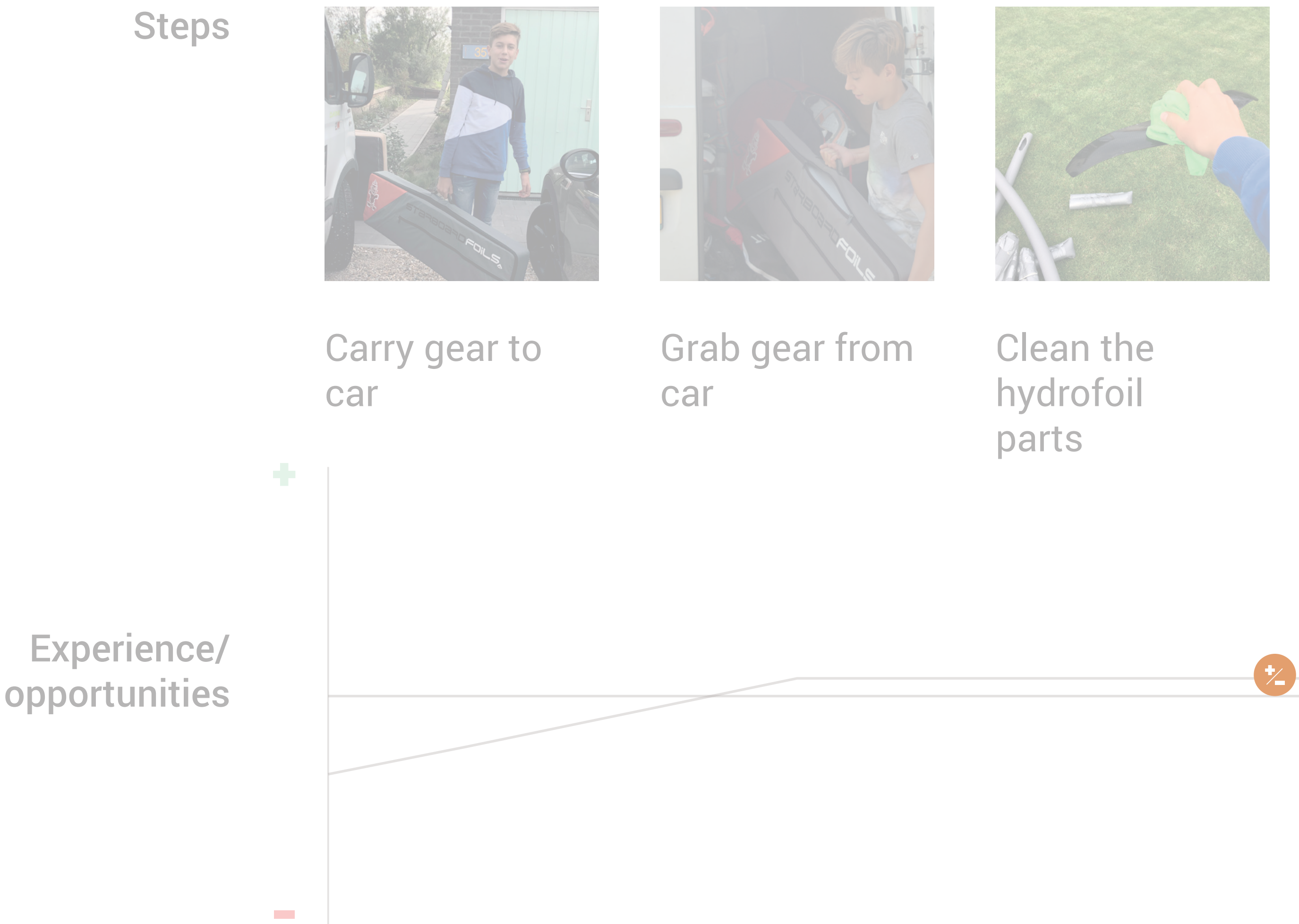


Figure 43. After use visual

5

Clean other windsurf gear

Dry with a towel

Foil parts back in bag

Store gear in shed or van

Create a cleaning set to come with the foil

Again no easy or convenient way to store the parts

Conclusion

The user scenario was a handy tool to find opportunities to enhance the user experience. Being able to talk with the user while using the hydrofoil, and observing every step, resulting in not only user experience opportunities but also preferred setups for the hydrofoil.

These are the main three insights of the user experience:

- The most desired setup for freeride is a 900cm2 front wing, an 85cm mast, and a 100cm fuselage.
- Next to that, the user stated that there should be a minimum amount of screws present on the hydrofoil. Having many screws means longer assembly time and a less streamlined product. The screw holes are now taped by the professional hydrofoilers to ensure a better water flow around the product.
- Finally, the additional items next to the hydrofoil itself are essential. A useful carrying bag and an assembly tool are just two of the many improvements that could be achieved.

5.2.2 Hydrofoil calculations

The second part of the research phase was calculations on the hydrofoil. The calculations aimed to find the powers present on the hydrofoil. In order to calculate these powers, four steps were taken. The first step was to approach experts in maritime technology. After that, calculations by hand were performed to create a first impression on the powers present on the hydrofoil. Next, computer FEA simulations were done to give a second impression on the forces present on the hydrofoil. These were conducted to have a comparison. Finally, a composite expert was interviewed to find out where the most important structural problems would occur during the use of the foil.

Expert meeting

In order to get a good understanding of the different technical challenges such as hydrodynamics, internal power distributions, and material and structural optimization, three experts from the TU Delft were approached (figure 44). They were approached by sending them an e-mail containing the concept of the second iteration, or by approaching them in real life with a physical prototype.

Also, two team members of the solar boat team of the TU Delft were asked to give their opinion on the hydrofoil and what they would do in terms of calculating internal powers.

The following points stood out during the expert meetings:

- Try to make the current situation not to complex. Use standard calculation rules to simplify the situation.
- Use a high safety factor when calculating the internal powers. Water, and especially seawater, is very unpredictable. Therefore, a high safety factor will prevent the concept of failing in an early stage.
- In this case, testing, checking the results, and doing it again will be needed. Simulations will not be good enough to test the concept.

Dirk Roekaerts
Fluid mechanics
Department of process and energy

'Don't make your calculations to complex. The problem is not easy. Try out some literature of the TU Delft repositiry.'

Fred van Keulen
Structual optimization
Department of precision and microsystems engineering

'Try to find the right specialists for the different problems you have. Don't make it to complex .'

Ido Akkerman
Ship hydrodynamics
Department of maritime technology

'Simualtions will lead to very complex calculations. In order to calculate the powers on the hydrofoil, try to use standard calculation rules.'

Solarboat team TU Delft
DREAMhal

'Use a simple beam calculation for the internal powers on the hydrofoil. Use a high safety factor to make the product safe for extreme situations.'

figure 44. Calculation experts TU Delft

Calculations by hand

The first calculations on the hydrofoil were done by hand. In order to do these calculations, two things were important. First, the situation was simplified. In figure 45, the hydrofoil is separated into four sections; the mast, the fuselage, and the front and back wing. Secondly, the powers present on the parts of the hydrofoil were calculated. The full calculations can be found in appendix B.

In order to start the calculations, a few assumptions were determined at the beginning. These were:

- The density of seawater at 20 degrees is 1027kg/m3.
- The mast size is 850 mm.
- The mast width and length are 13 mm and 100mm.
- The Fuselage size is 1000mm.
- The average Carbon fiber E-modulus is 100 GPa and tensile strength 1.25 GPa (CES Edupack).
- The fuselage width is 35mm, and the thickness is 3mm.
- A person of 100kg is standing on the windsurf gear, which represents a total weight of 120kg.
- The calculations were simplified to simple long beam calculations.
- An uncertainty factor of 8 is used to ensure material failure (solar team, 2019).

After that, the powers present from outside on the hydrofoil are calculated. In figure 46, a free body diagram of the hydrofoil with the predicted powers is shown. Significant is the drag and lift on the foil. The lift is calculated through the law of Archimedes (appendix B). The drag is calculated with the formula provided by the hydrodynamic expert (Akkerman, 2019). These were respectively for the lift 1.2KN and for the drag 668N.

With the external powers calculated, the internal powers could be determined. First, two assumptions regarding the mast were made before calculating the internal powers. These were; the lift on the mast is negligible, and the neutral force N is negligible.

Next, In order to calculate the powers, a free body diagram was made (figure 47). At the top, the mast is clamped in order to do a long beam calculation. With the free body diagram, four calculations were made regarding the maximum bending of the mast and the maximum angle of the mast. The outcomes of these were a maximum of 3,4 mm bending and a maximum 0,35 degree angle.

After that, the internal powers on the fuselage were calculated. Figure 48 shows the free body diagram of the fuselage. First, two assumptions were made. These were; the drag on the fuselage is negligible, and N is negligible. The maximum bending and the angle was calculated by clamping the fuselage at the beginning of the mast. With this free body diagram 4 calculations were made. These resulted in a maximum bending of 0,6mm and a maximum angle of 0,11 degrees.

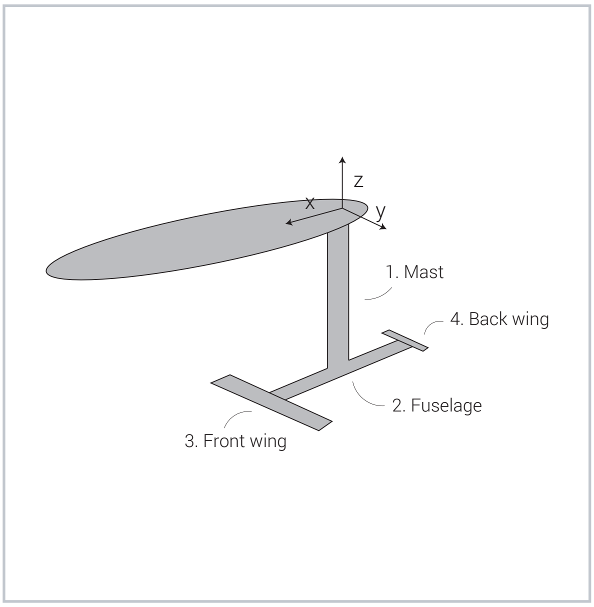


Figure 45. Simplification of hydrofoil

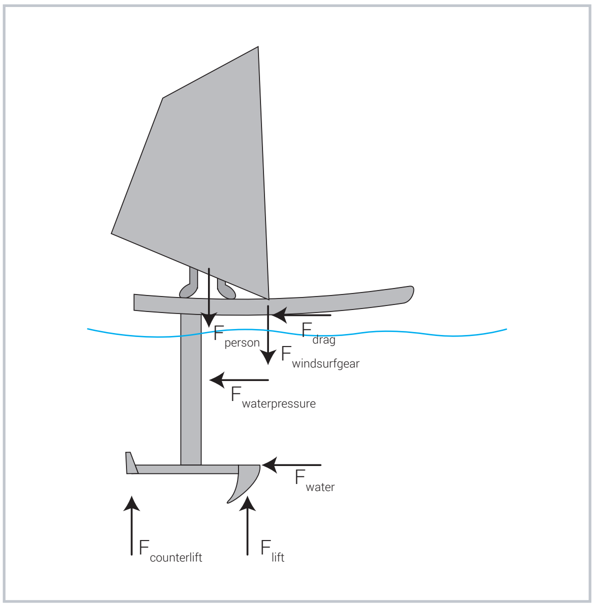


Figure 46. Free body diagram with present powers

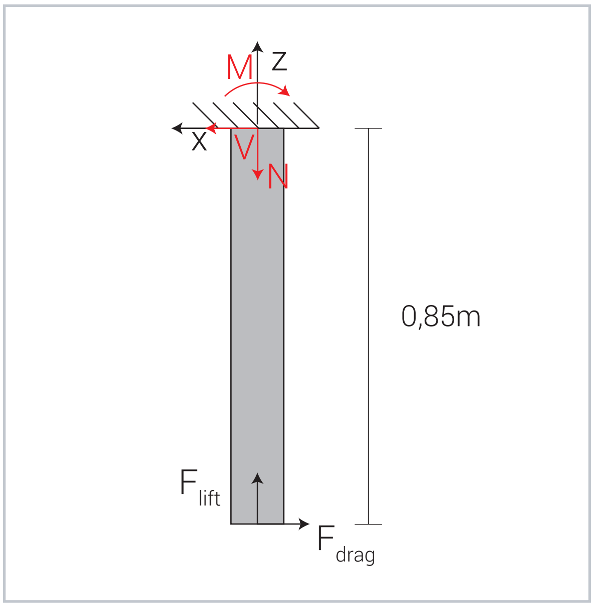


Figure 47. Free body diagram of the mast

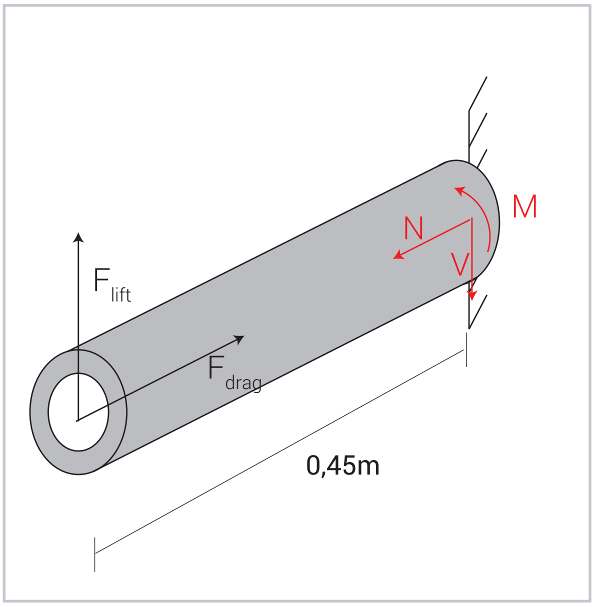
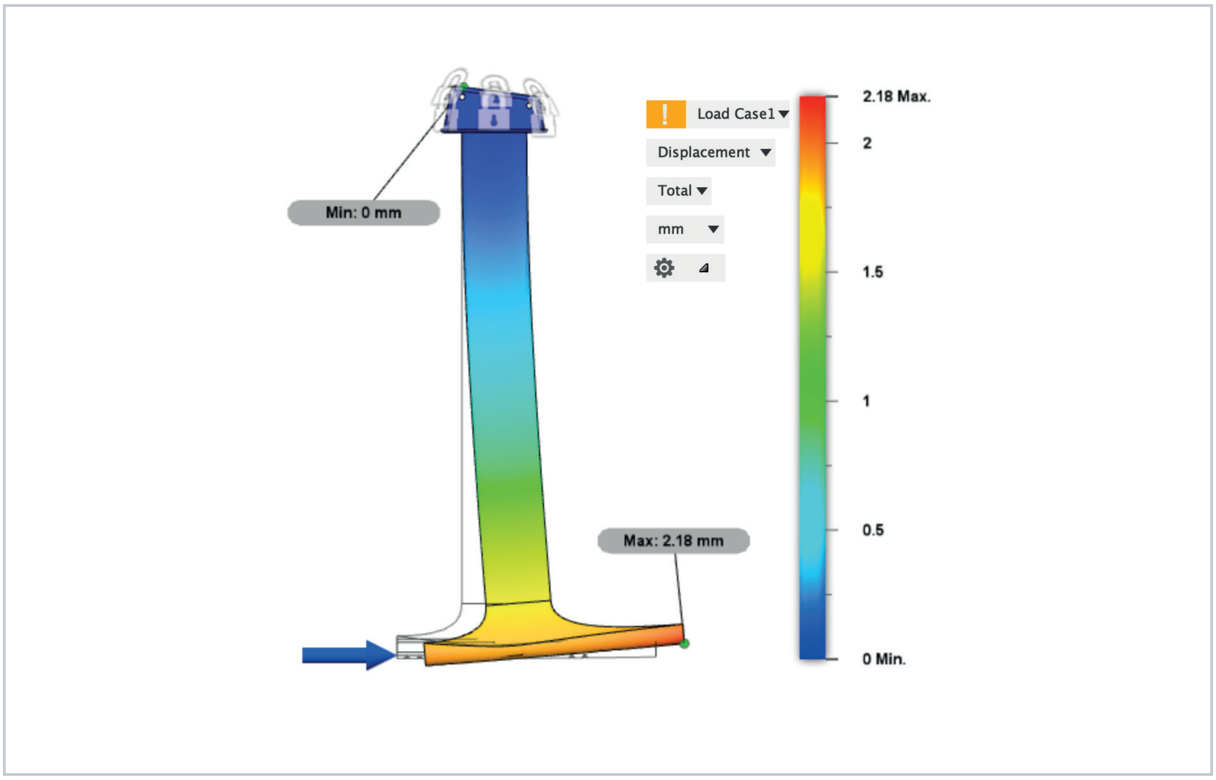


Figure 48. Free body diagram of the fuselage

Computer simulations
In order to check the hand calculations, an FEA analysis was conducted. The FEA analysis used a 3D cad model. With this cad model, the same situations presented in the hand calculations were used to calculate the internal forces. The maximum bending of the hydrofoil was 2.18mm (figure 49). The maximum stress was 211.6 MPa. If we multiply the maximum stress of 211.6MPa with the uncertainty factor of eight, we get total maximum stress of 1,7 GPa, which is higher than the average tensile strength of carbon fiber (1.25 Gpa). Still, the maximum stress stays within a reasonable factor of almost 6.



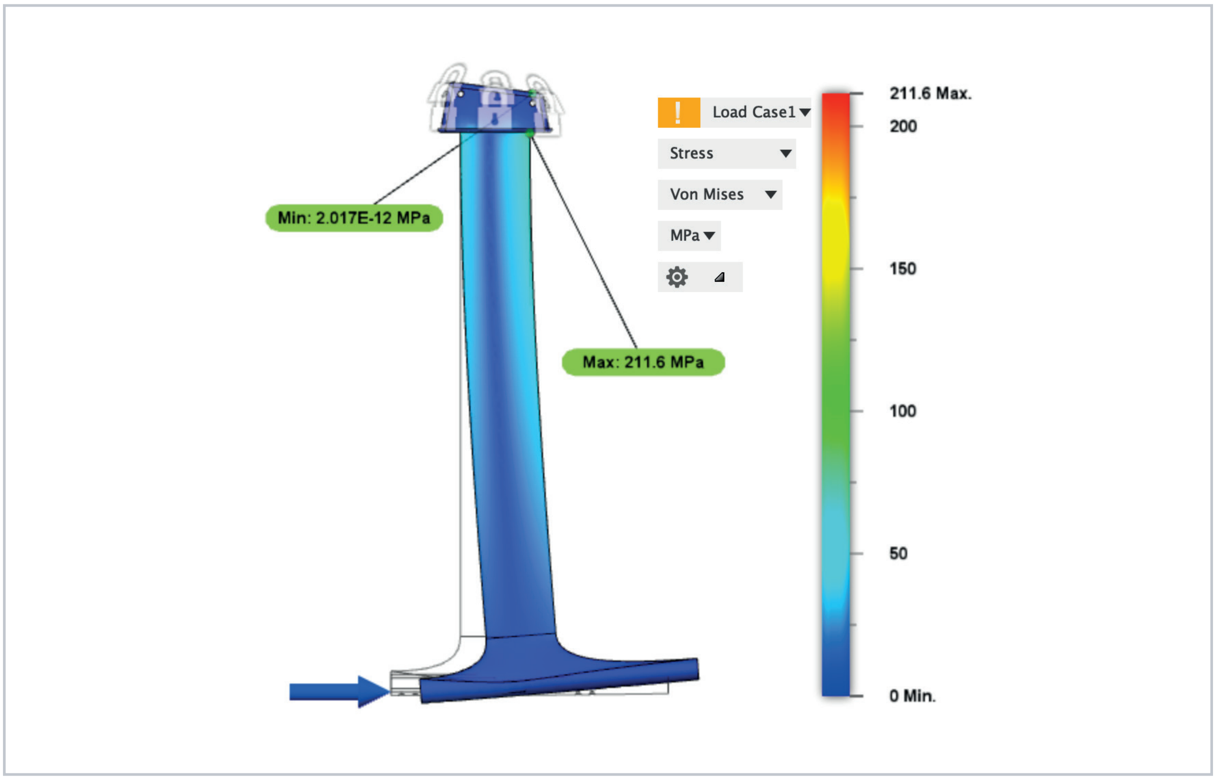


Figure 49. Computer simulations, right maximum bending left maximum stress

Product strength analysis

After calculating the internal and external powers present on the hydrofoil, another expert was approached (Bergsma, 2019). This expert is an assistant professor at the Aerospace faculty of the TU Delft and an expert in structural integrity and composites. A co-reflection session with the expert resulted in information about were the most important powers were present within the hydrofoil and how the total concept should have been built.

During the session, the internal powers were discussed. The expert pointed out that it was essential to look at the concept with surfer and other equipment (figure 51). Figure 51 shows attention points such as the Tuttle box, the transition of the mast and fuselage, and the placement of the front wing. The most important one of the three was the mast and fuselage transition.

In this transition, many shear powers are present (figure 50). In order to create a stiff and robust transition, it was advised to place the carbon layers in 0, 45, and 90 degrees (Bergsma,2019).

Next to the orientation of the carbon, the core of the mast and the wings were discussed. The idea was to create a foam core with a carbon layup around it. The recommendation was to use a PVC core, which is light, easy to manufacture, floats, is water-resistant, and safe to use with composites and epoxies. The expert finally recommended using a minimum of three millimeters thick carbon layup to ensure a robust, rigid, and stiff product.

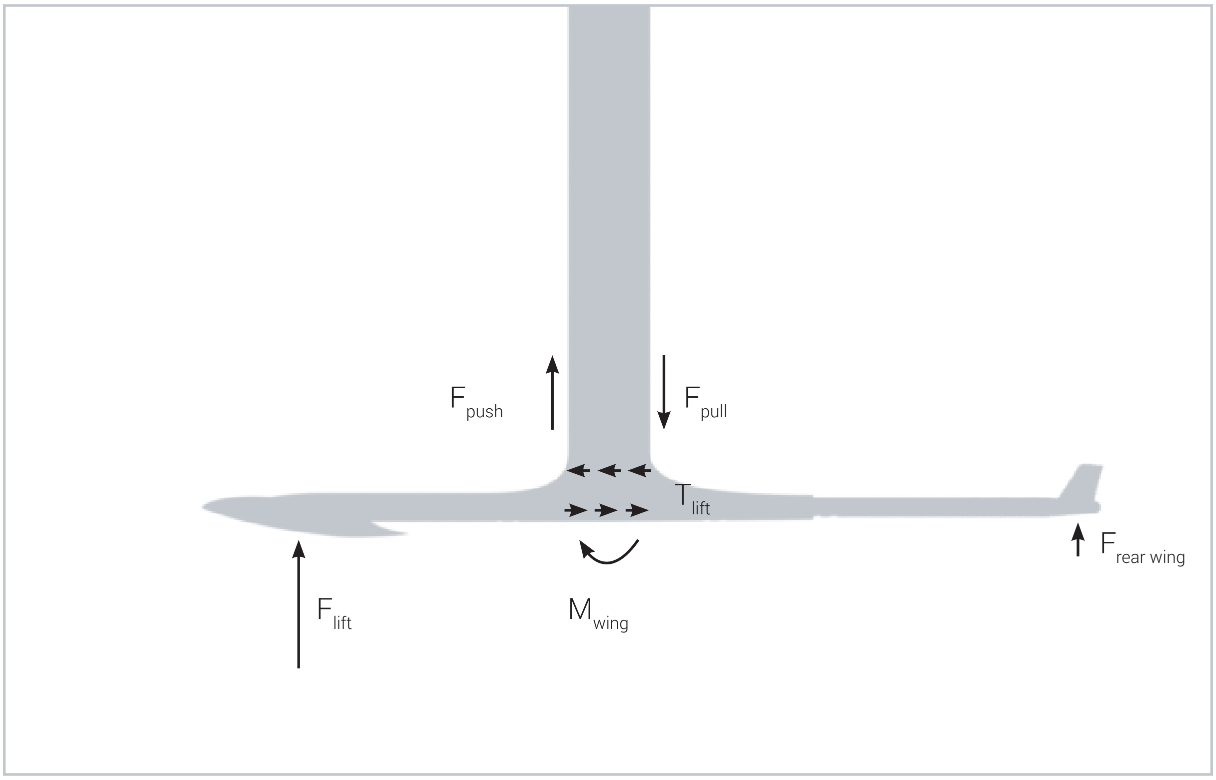


Figure 50. Shear powers present in the foil.

Figure 51. Total FBD windsurfer

5.2.3 Market research

In order to sell a product in the best possible way, a marketing strategy is needed. The entry strategy for a new product or service is a crucial decision area as it provides the platform from which competitive advantage must be gained and sustained throughout the product life cycle (Green and Ryans, 1990).

Before making the market and product research, A marketing expert was interviewed (Hultink, 2019). The expert is a professor of new product marketing at the Technical University of Delft. The interview resulted in the following three recommendations:

- It was essential to look at the current hydrofoil market, what kind of products are available, and what features do they have.
- Also, it was essential to create a marketing penetration strategy based on the company profile and competitors.
- Finally, new product marketing strategies combined with the AIDA model was made in order to trigger the right user in buying the product. Because of the relevant new market, this would be the best strategy to use.

With the advice of the expert, three marketing methods were used to define the strategy:

1. Placement of the brand in the current market.
2. The current hydrofoil consumer market.
3. Marketing analysis strategy.

Placement of brand in current market

The first step for making a market strategy decision was to look at the current market placement of the brand. Tribal is a brand that produces windsurfing fins. The current market consists of multiple brands. Figure 52 visualizes the current position of Tribal based on the quality and price of the products. The figure shows that Tribal is placed in the higher price and quality segment of the market. Therefore, the concept will need to be made out of high-quality materials.

Figure 53 complements the positioning of the brand. The four p’s (Needham, 1996) show where the brand is positioned, where it currently sells its products, what kind of price range it is located, how the current products are promoted, and where the products are sold. Tribal sells high quality products for the higher price segment of the market. The products are sold at different watersport shops and online on their website

Figure 52. Brand positioning in terms of quality and price

Figure 53. 4 p's model of Tribal

Current hydrofoil consumer market

Next, the current consumer market off hydrofoils for windsurfing was researched. Figure 54 shows the diffusion of innovation theory (Rogers, 2003). This model shows the consumer groups related to market share. Today, the hydrofoil is relatively new and used by the early adopters. The strategy for the new concept is to target the early majority.

Early majorities are pragmatists, comfortable with moderately progressive ideas, but will not act without substantial proof of benefits (Robinson, 2009). Therefore, they need to be triggered by proof of guaranteed performance, a strategic advertisement showing 'common' people using the product, and ease of use.

Market analysis strategy

For the last step, the Ansoff model was used to find the right marketing strategy (Ansoff, 1957). Figure 55 shows which marketing strategy should be used. The deliberate marketing strategy will be a combination of a market penetration strategy and a product development strategy. This strategy is chosen because the windsurfing equipment market is already existing, and the hydrofoil products are relatively new.

A second model, the AIDA, was introduced to help and form the final strategy. AIDA is short for attention, interest, desire, and action. The model represents the amount of time, energy, thought, and different resources used by people in the process of purchasing a product or service or devoted to obtaining a particular thing or result (Ghrivu, 2013).

This first step was of the AIDA was to define the intended user group. In the research phase of the second cycle, a persona was created. This persona was based on information gathered by the company mentor. In short, the persona represented a fanatic windsurfer or kitesurfer who tries to surf whenever he or she can. He/she has a high budget, is willing to pay a high price for quality products, and likes to have a product that is out of the box ready.

The second step was to define the four stages of the model. First, the product needs to trigger the intended user to buy the product and grabs its intention. This will be achieved by using a video commercial explaining the benefits of the product, contrary to the current market.

After that, the attention of the user will be trigged by showing them the unique features of the product.

Next, the desire needs to be created with the intended user group. This will be done by showing different professional en non-professional wind and kite surfers using the concept.

Finally, the action step will trigger the user to buy the product. With the combination of the market penetration and product penetration strategy and the first three steps, the user will be triggered to buy the product.

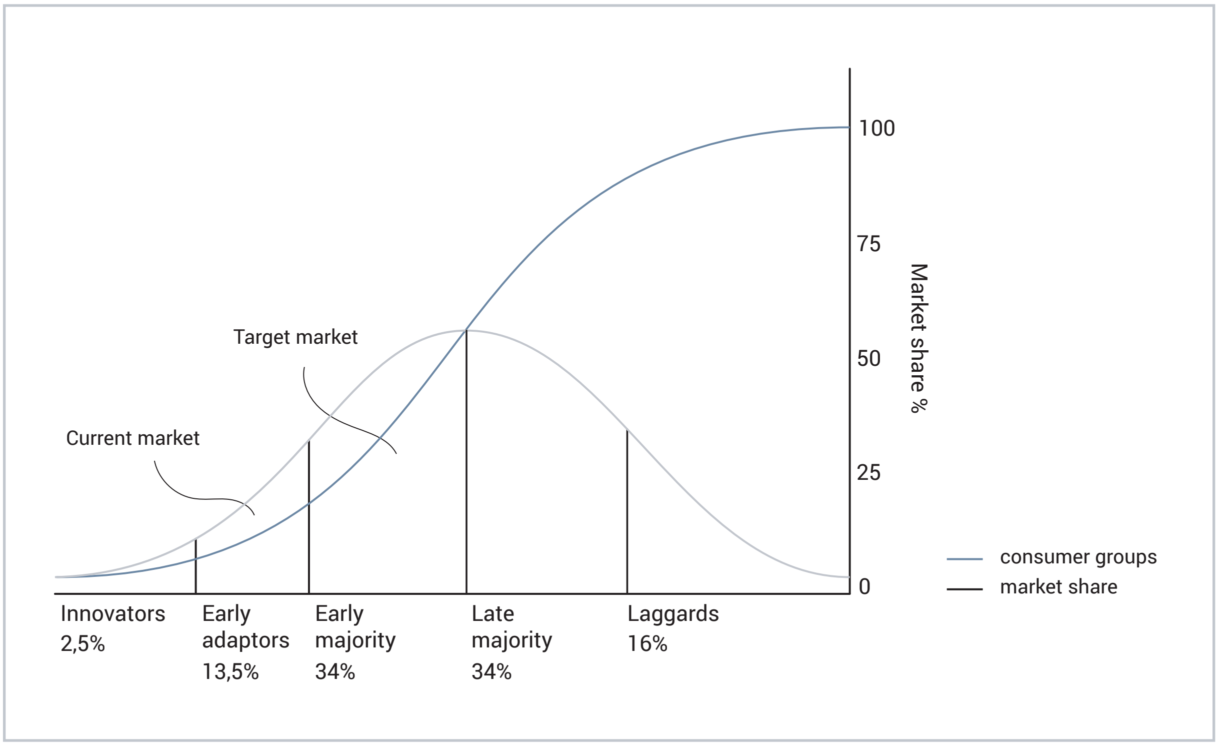


Figure 54. Diffusion innovation theory

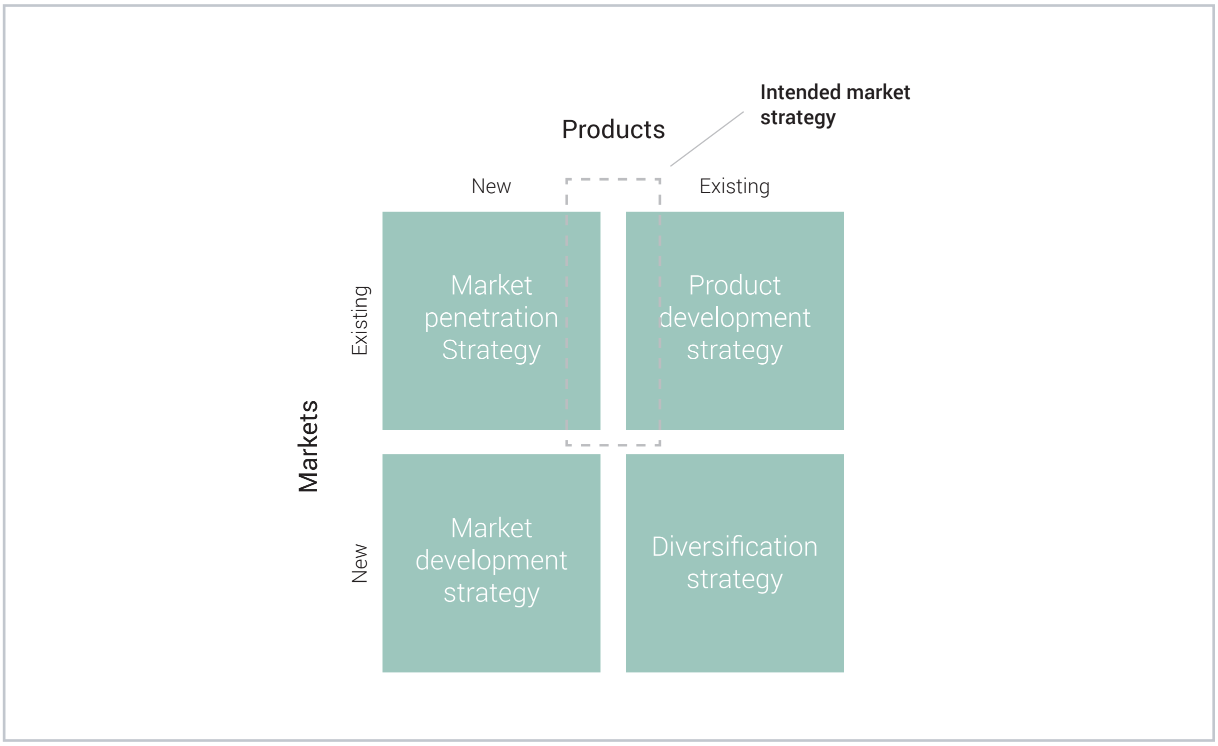


Figure 55. Ansoff marketing strategy model

5.2.4 Shape analysis

Being able to move through the water with little resistance requires an aerodynamic shape of the mast, front wing, and back wing. Next to that, the front wing needs to create a lift in order to raise the windsurf board above the water.

Nowadays, various companies aim to expand this market by offering several types of foils. However, the existing research on their design is limited and their development is based on experience of the riders and on simplified hydrodynamic theories, or both. (Ocaña-Blanco et al., 2017). Therefore, finding the right shape for the different parts is a challenge.

The mast

The shape for the mast was found by consulting a fin expert (Lockwood, 2019). The expert is the fin designer for Tribal and lives in Australia. For the mast, a symmetrical shape called the Eppler 836 is widely used for masts in the hydrofoil industry. After consulting the expert, he advised using his designed shape (figure 56), which could withstand higher powers from 10 knots (figure 59). This shape is stable, aerodynamic, and resistant to high powers.

The front and back wing

A different shape was used for the front and back wing, the Eppler 186 (figure 58). The right shape was found by using an airfoil datasheet (Selig, 2019). The shape needed to create a lift and a stable ride (freeride option). Therefore, it needed to have a nonsymmetrical shape, with a more extended upper surface and a shorter lower surface to ensure that the wing creates lift (figure 57). The Eppler 186 has a double concave upper surface, creating stability when going through the water.

It has also got a thin profile making the front and back wing aerodynamic.

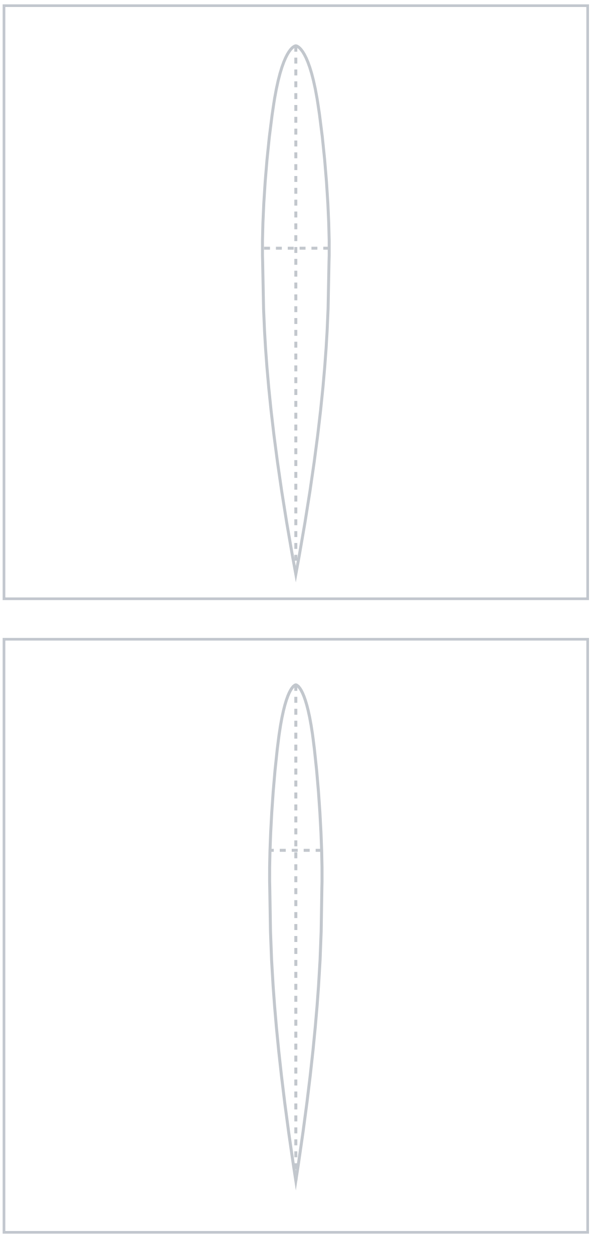


Figure 56. Eppler 836 above, Chris Lockwood below

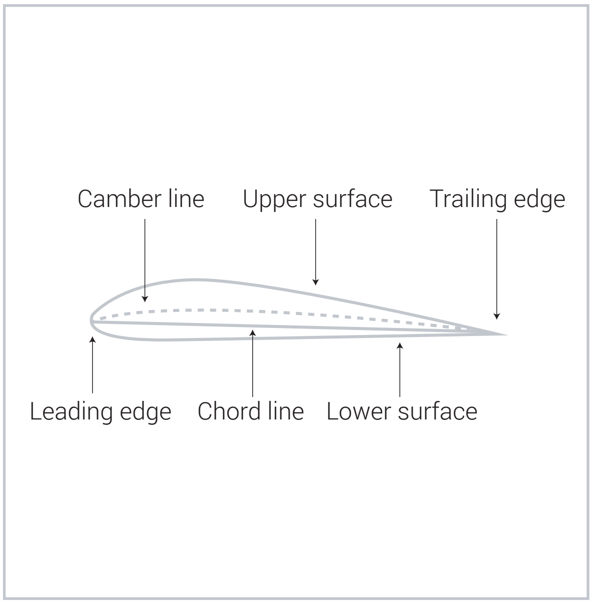


Figure 57. Shape of a hydrofoil

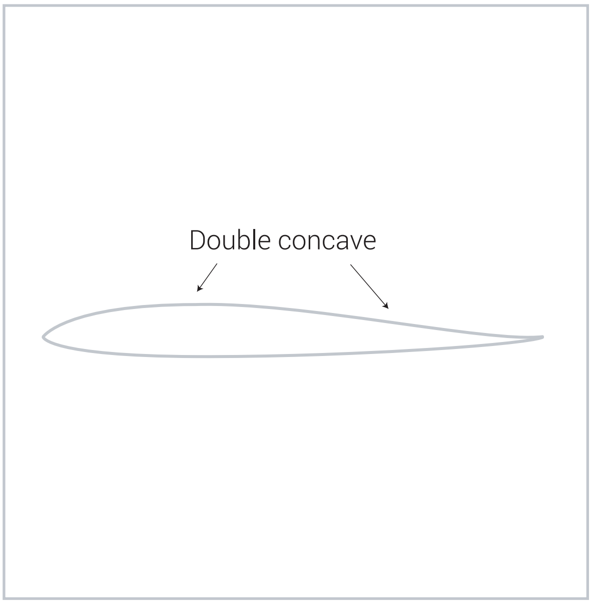


Figure 58. Eppler 186 shape windfoil

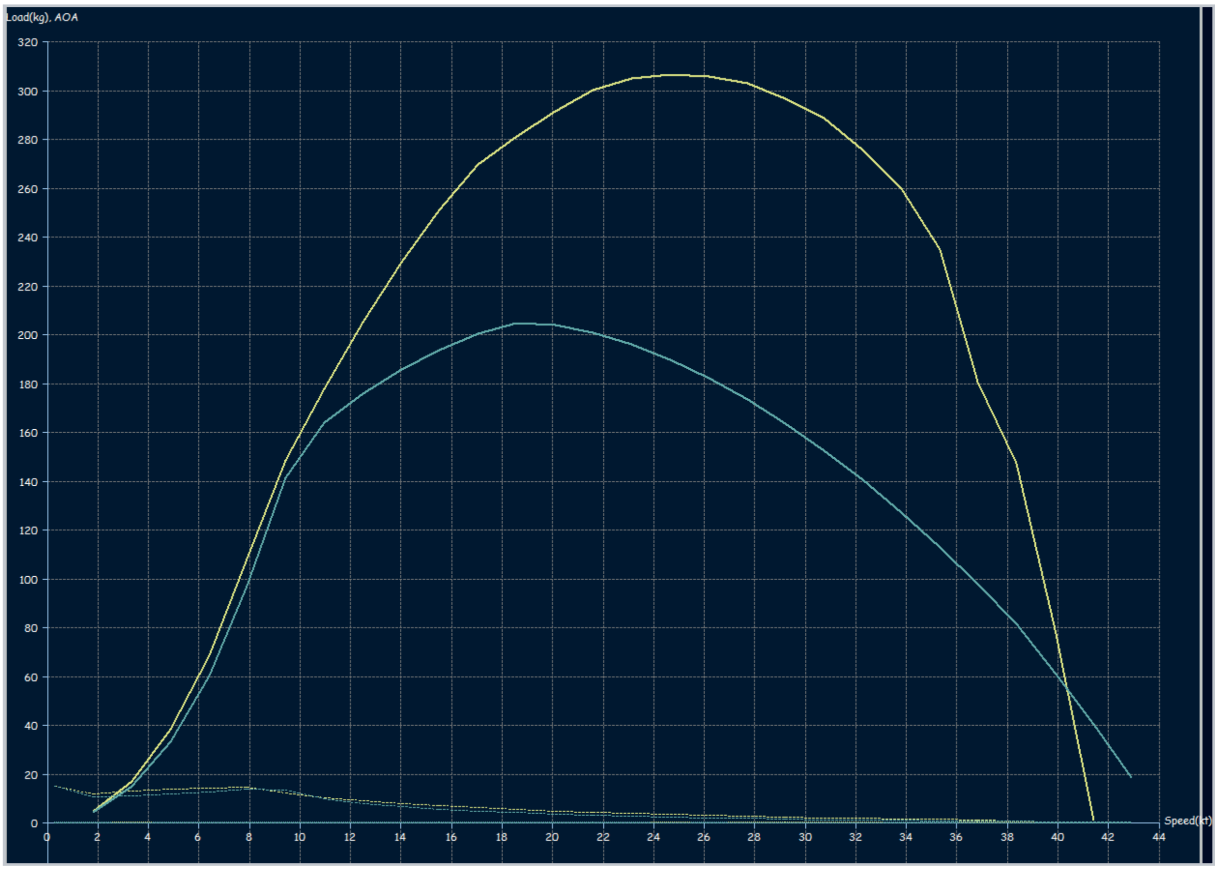


Figure 59. Difference in load for eppler 836 shape and shape deliverd found by Chris Lockwood at high speeds

5.2.5 Prototyping

The last step of the research chapter was the creation of prototypes. In order to co-reflect with the stakeholders, two types of prototypes were made during the last cycle. First, a physical prototype was made out of cardboard (figure 60). This prototype was made to get a sense of the size of the product. The parts were created according to the outcome of the second cycle.

Second, prototyping was done by making 3D models. Because of the size and complexity of the concept, rapid prototyping was conducted using 3D software. These prototypes were then discussed with the company and changed accordingly.

For the mast, this resulted in four different iterations (figure 61).

These two ways of prototyping helped to explore the real size of the product and create a sense of how the parts connect to each other.

Figure 60. Physical cartboard prototype

Figure 61. Different 3D iterations. Top left 1st iterations, top right second, bottom left third and bottom right fourth.

5.3 Ideation

In the ideation phase of the last cycle, the additional equipment was created. During the user research part in the previous chapter, a few opportunities presented themselves. In order to implement these into the final design, the last Ideation was conducted.

Figure 62 shows the ideation created on paper by hand. The ideation was conducted to find a suiting storage bag. The second Ideation was about creating a suitable tool to fasten the parts. The last Ideation was about creating a convenient storage box for storing the bolts used for fastening the parts.

3D models were also used to create new ideas. The combination of 3D sketching and hand sketching worked out to be a perfect combination for creating the last ideas for the additional equipment.

The last idea sketching phase resulted in a convenient traveling bag, a tool to fasten the parts, and a case to store the bolts. These will be explained in the final concept chapter.

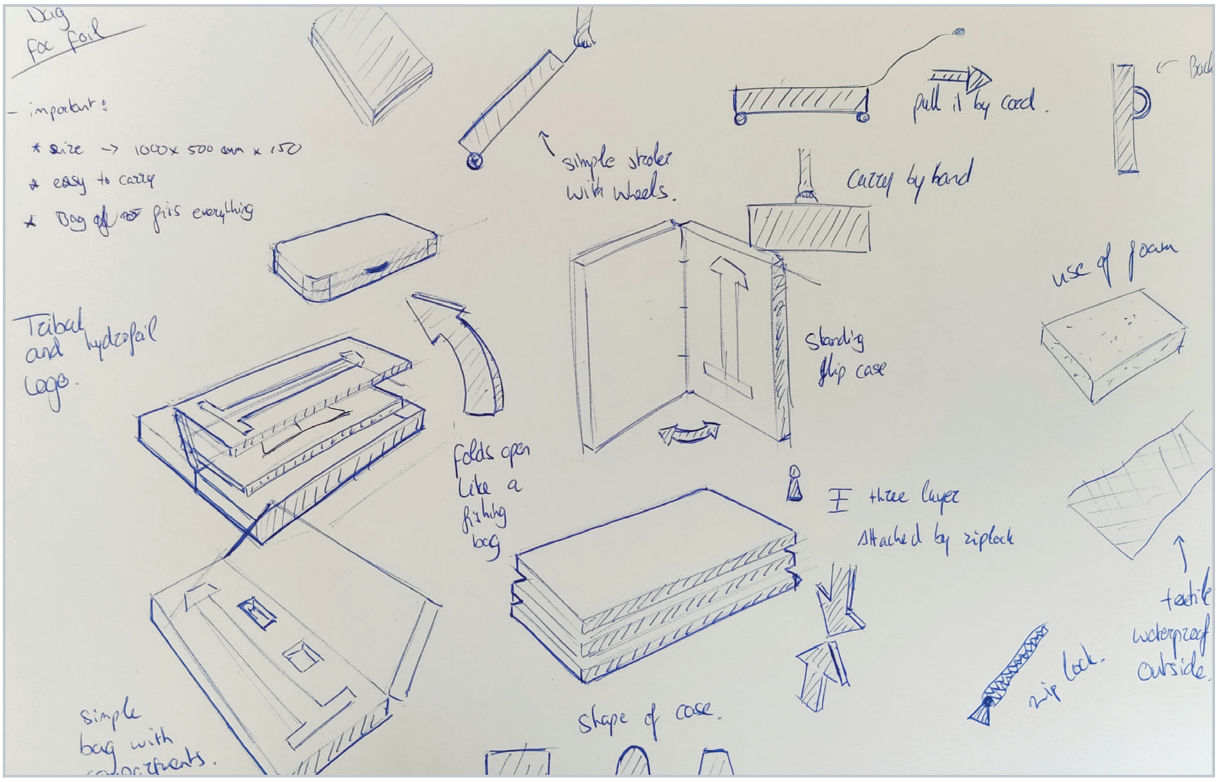


Figure 62. Idea sketching the carrying bag

5.4 Final concept

5.4.1 Final requirements
Before creating the final concept, a requirements list was made. This list combines the requirements found in the first, second, and third cycle. The most important requirements are listed below.

- The product can be used by windsurfers and kitesurfers
- The user experience of the product needs to be simple, intuitive and convenient
- The product needs to have functional additions such as a travel bag
- The product can be easily cleaned
- The product needs to stand out from the current hydrofoil market
- A suiting marketing plan needs to be created in order to sell the product
- The product needs to provide an option to adjust the size of the fuselage to create a product that can be used in multiple situations

5.4.2 Final design vision
Next to the requirements, the final design vision was created. This vision is a finalized vision derived from the vision from the first and second cycle. The final vision was:

Second cycle vision: *'Creating a hydrofoil that can be personalized for different wind ranges, setups such as kitesurfing or windsurfing, and the hight of the mast.'*

Final design vision: 'Creating the next generation free ride hydrofoil for the windsurfing and kitesurfing market. The product needs to be appealing to the user in terms of visual appearance, user experience, and quality.'


TRIBAL
Float
The next generation hydrofoil

5.4.3 The final concept

The final concept represents the end result of the research through design process. On the left, the final design is presented in a real-life situation.

Float is a new version of the already existing windfoil/kitefoil (figure 63 to 65). It has a couple of new features in contrary to the competition and can be used in two situations. It can be used as a hydrofoil for windsurfing and kitesurfing.

The float consists of three main parts, the mast, front wing, and the back wing. The hydrofoil has a custom made traveling bag, connection tool, and a convenient storage box for the screws.

The float is made out of 100% carbon fiber with a solid PVC foam core. Nine layers of carbon fiber ensure a stiff and robust product without making it heavy. Also, a specialized epoxy resin with a UV blocker ensures that the hydrofoil will not wear during use and is protected against yellow coloring.

The foil has the Float and company logo displayed on the mast. The rest of the foil has a clean black carbon look. The additional equipment has a black color, and the logo of the foil and Tribal are printed in white (good principles for design).

In the next subsections, the main features of the parts are explained.

Figure 63. Float when fully assembeld

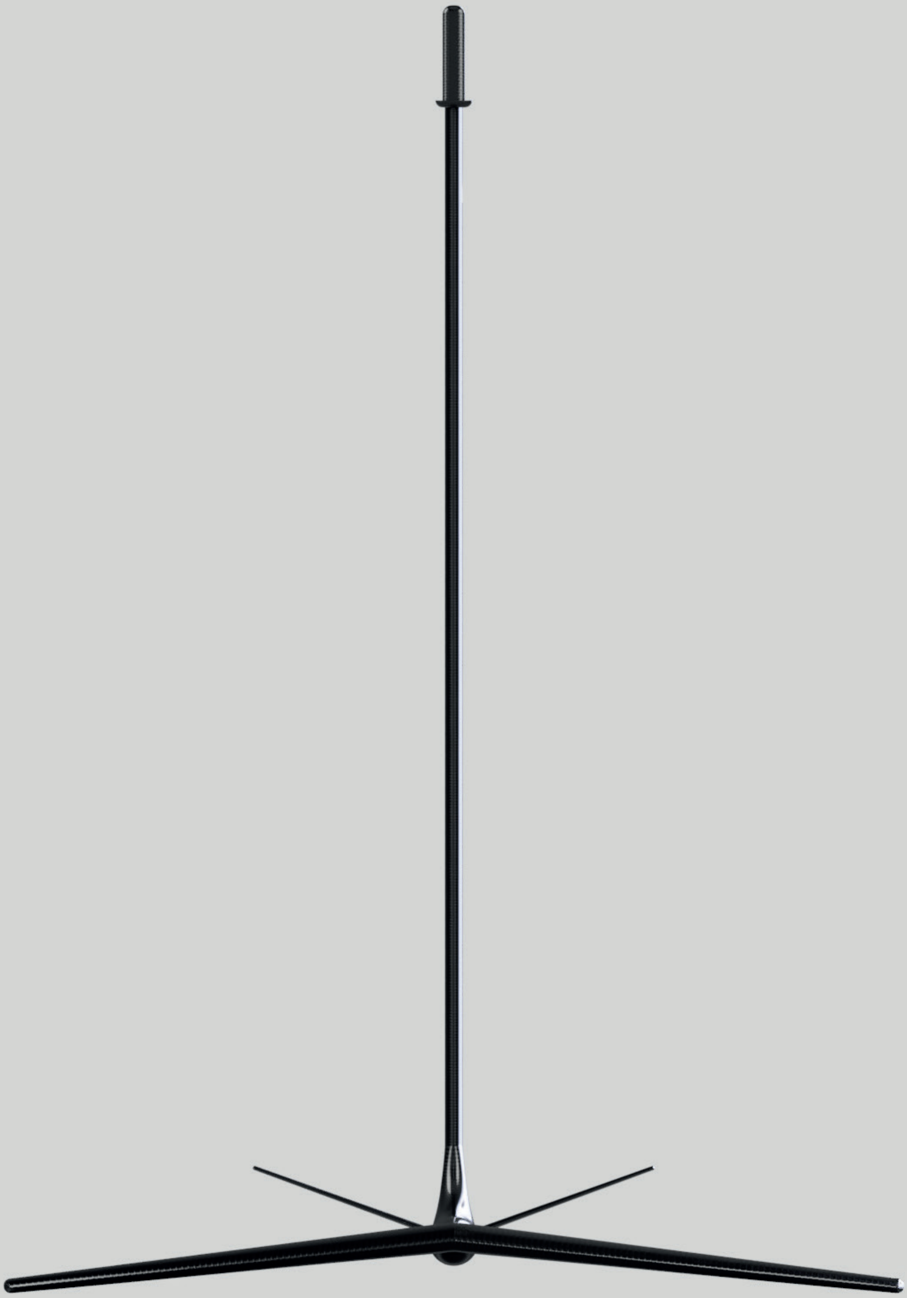


Figure 64. Front view Float

Figure 65. Side view float with windsrufboard and user

5.4.4 The set up

The Float is shown in figure 67. It consists of three main parts, the mast, the front wing, and the back wing. It is a free ride hydrofoil made explicitly for the windsurf and kitesurf industry. The main focus of the hydrofoil is the windsurfing market. However, because of the convenient design, only the front wing needs to be changed in order to create a kite surf setup.

Windsurf set up

The windsurf setup, shown in figure 66, consists out of a 900cm2 front wing, the changeable back wing, and the standard 85cm mast. The Float is not provided with a windsurf board and needs to fit on any board. The Float can be connected to any board because of the deep Tuttle box connection.

Kitesurf set up

The kitesurf setup consists out of a smaller front wing of 700cm2, the changeable back wing, and the 85cm mast. The front wing of the kitesurf setup is smaller than the windsurf set up because of the difference in lift. The total lift needed for the windsurf setup is higher than the kitesurf setup because the total weight of the windsurf gear is higher than the kitesurfing gear. In order to make the float fit on any kitesurf hydrofoil board, a plate connection is provided.

Figure 66. Windsurf setup (left), kitesurf setup (right)

Figure 67. Exploded view of the foil

5.4.5 The two connections

Between board and foil
The connection between the board and the foil creates the link between the lift power created by the foil and the propelling power of the sail.

The deep Tuttle box is the preferred connection for the windsurfing set up (figure 69). The Tuttle box ensures that the foil can be mounted to almost every wind surfboard. The Tuttle box has a tuffnol insert, which creates a strong bond for the dowel nuts (Godwin, 2002). Long hex screws connect the board with the foil. They go through the board into the dowels nuts located in the Tuttle box. The Tuttle connection has an edge around the bottom. The edge creates a new clamping face when the foil is connected to the board.

The second connection is the square plate (figure 70). The connection is used for kitesurfing boards. The connection can be used on kitesurfing hydrofoil board. The shape of the plate creates a strong bond between the board and the foil.

Both connections are entirely made out of carbon and formed with the mast in the mold, creating a secure connection.

Between parts of foil
Four bolts connect the wings of the hydrofoil. These bolts go through the mast and screw into the back and front wing (figure 71). The back and front wing also have a tuffnol insert. This insert is durable, easy to thread, and corrosion-proof (Godwin, 2002).

The bolts have a Torx head (figure 68). Standard Philips heads wear out very easy. After multiple uses, the heads eventually lose their shape. Torx heads are much stronger and better to use multiple times. Therefore, they were chosen for the final design.

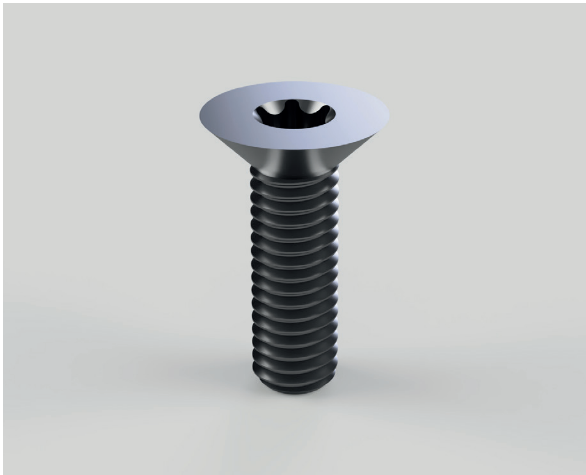


Figure 68. Torx bolt

Figure 69. Deep tuttle connection

Figure 70. plate connection

Figure 71. Connection of front and back wing

5.4.6 In depth explenation parts

The following subchapter will briefly explain the three parts that define the hydrofoil.

Mast

The final mast is a combination of the mast and fuselage (figure 74). This is different compared to the competitors. Currently, there is no company that uses combined mast and fuselage. The connection between the two was already used for the second cycle, and further worked out in the last cycle. The mast and fuselage are connected with a significant fillet transition (figure 72). This connection ensures a strong bond and reduces tears in the material. The profile of the mast has a shape provided the fin expert of Tribal (Lockwood, 2019). It has got a slender profile that can withstand more power than the standard Eppler 836 profile mainly used by other companies.

The mast is 850 mm long, the optimal length for free riding (Boon, 2019). The fuselage is 400 mm and has two different connection options for the front and back wing.

The front wing socket is a rounded square. The square enables a non-movable and robust fit and is fastened with two 6mm bolts. The back wing socket is round and provides the option to slide the back wing (figure 73). Sliding the back wing gives the user the opportunity to enlarge the total size of the fuselage. Enlarging the fuselage is used for a more stable ride when foiling. Also, the sliding option enables multiple users, in terms of weight, to use the foil. The back wing is also connected with two 6 mm bolts.

The board connection is either a deep Tuttle box connector or a plate connector depending on the use. Both can be connected to the board with standard connection bolts. For the deep Tuttle, these could be the standard 6mm bolts used for connecting fins. These go through the board into the Tuttle box connectors. The plate connecting used for kitesurfing uses four 6 mm bolts directly screwed into the kitesurf board.

Figure 72. Fillet transition

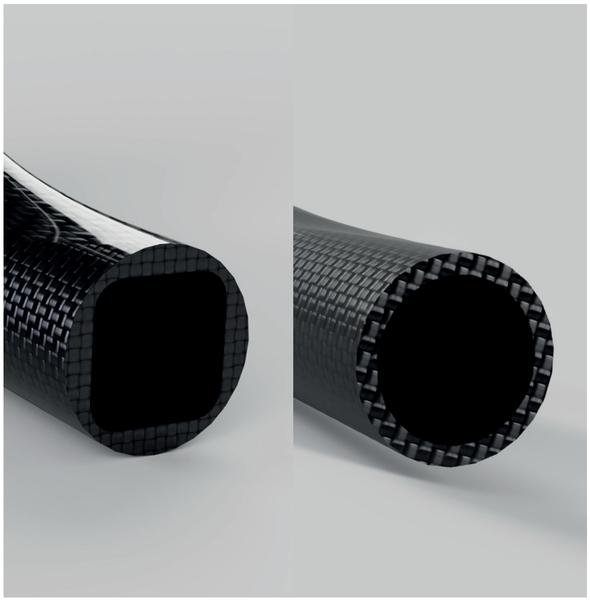


Figure 73. The front and back connection

Figure 74. Total mast

Front wing

The front wing determines the style of the foil. In order to create a foil that can be used by most of the users, a free ride front wing was created (figure 75). The front wing has a reversed profile (figure 76). The reversed profile gives the foil a stable feel and creates an easy start and lift-off (Hoogendijk, 2019). The profile of the wing is based on the Eppler E186 profile (shape analysis). This profile has a sturdy lift, is stable during fast speeds, and glides smoothly through the water.

The windsurfing front wing has a span width of 650 mm and a total surface area of 900cm2. The kitesurfing front wing has a width of 550mm and a total surface area off 700cm2. The size of the front wing is the most common and preferred size for free riding for windsurfing and kitesurfing (Boon, 2019).

The wing connector, behind the wing, has a round shape that seamlessly connects with the mast (figure 77). The squared end fits perfectly in the squared connector, ensuring a strong bond.

In the first two design cycles, three front wings were presented. After consulting the company, the decision was made only to create a free ride wing in the last cycle.

The intended user prefers a product that is out of the box ready (research). Therefore, having only one front wing eliminates the decision of choosing the desired front wing. In the future, upgrades will be available in the form of other front wings.

Figure 75. The freeride front wing

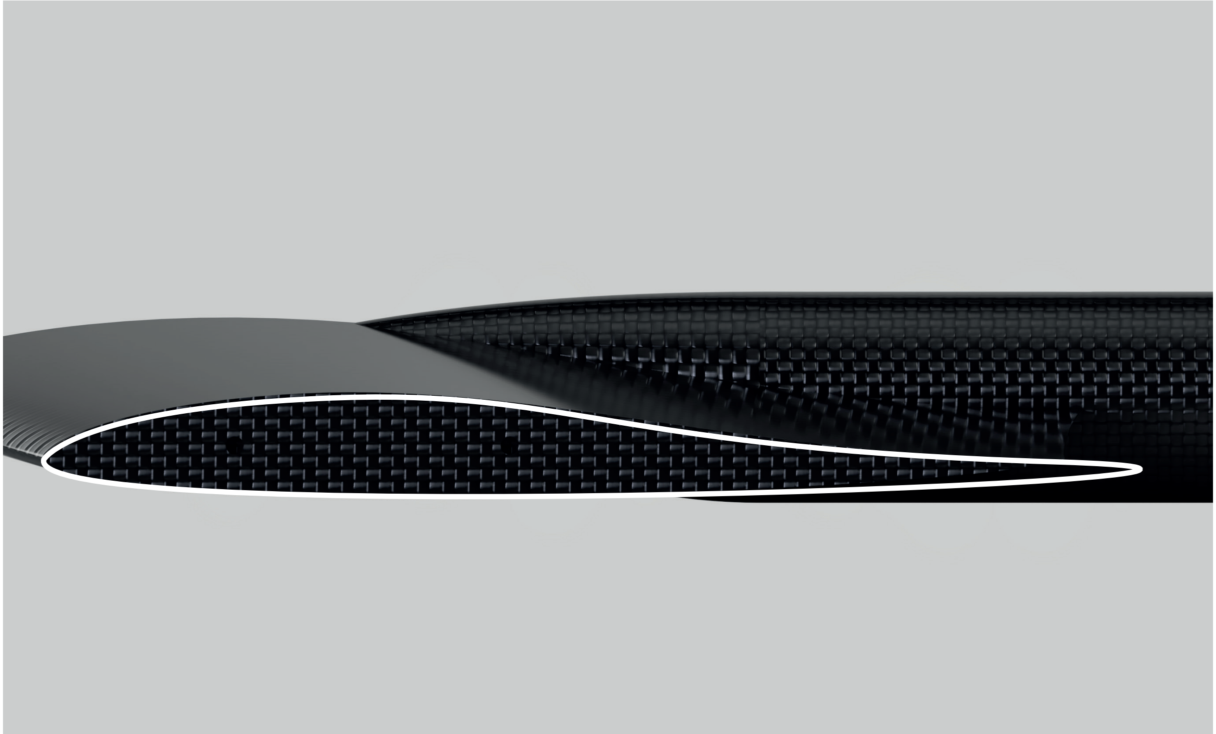


Figure 76. Reversed profile

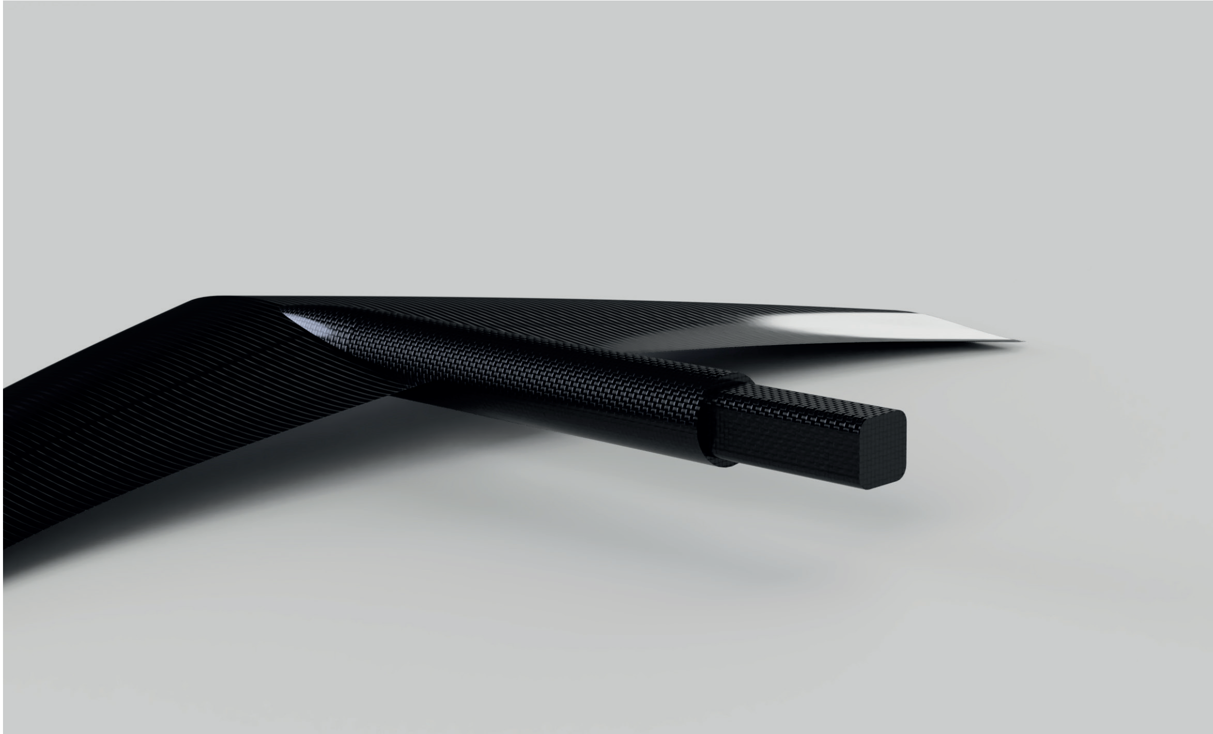


Figure 77. Front wing connection

Back wing

The back wing, also known as the stabilizer, is used to stabilize the hydrofoil. The wing (figure 78) has an upward v-shape and has a reversed profile. The shape of the back wing is derived from the hydrofoil expert interview (Krijger, 2019) and inspired by airplanes. The profile of the wing is the same as the front wing, an Eppler E186, which enables a smooth and stable ride.

The front tube of the wing has a circular shape (figure 79). The shape enables the user to slide the wing into different positions (figure 80). When fully extended, the wing creates a longer total fuselage length. This makes the hydrofoil more stable and also enables heavier users to use the foil. If the wing is fully retracted, it shortens the fuselage making the foil easy to maneuver and perform turns.

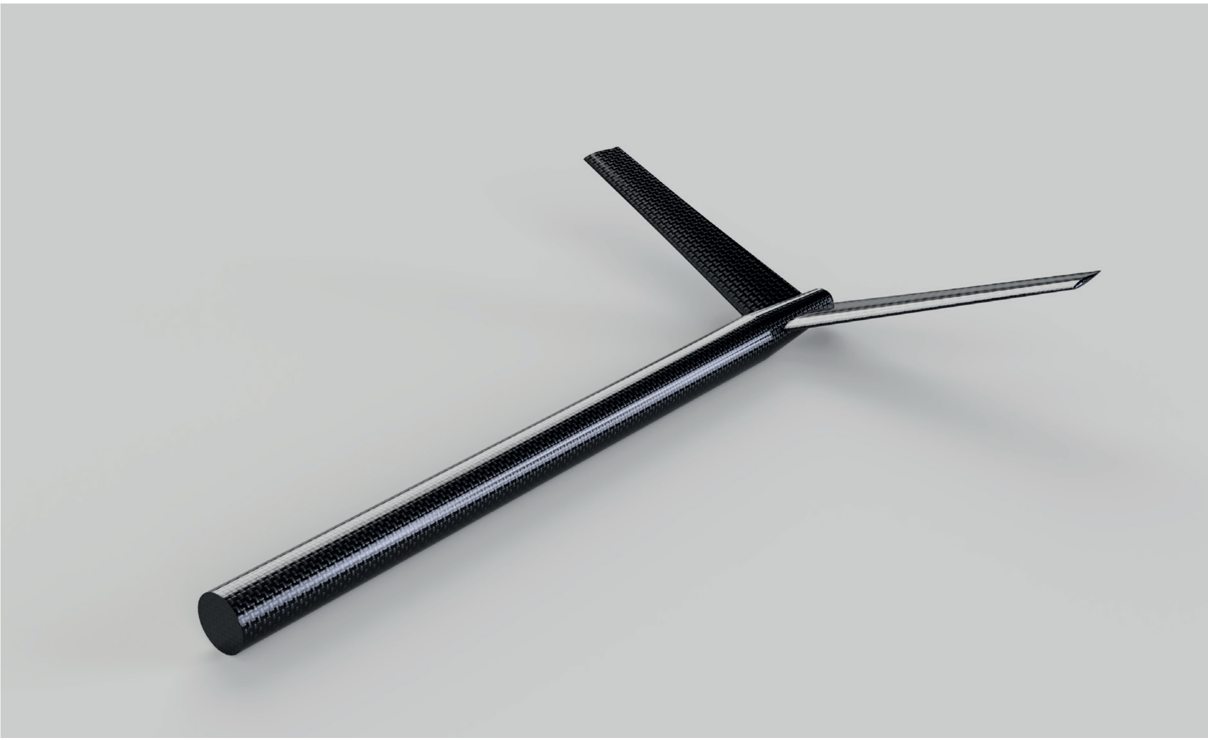


Figure 78. The back wing

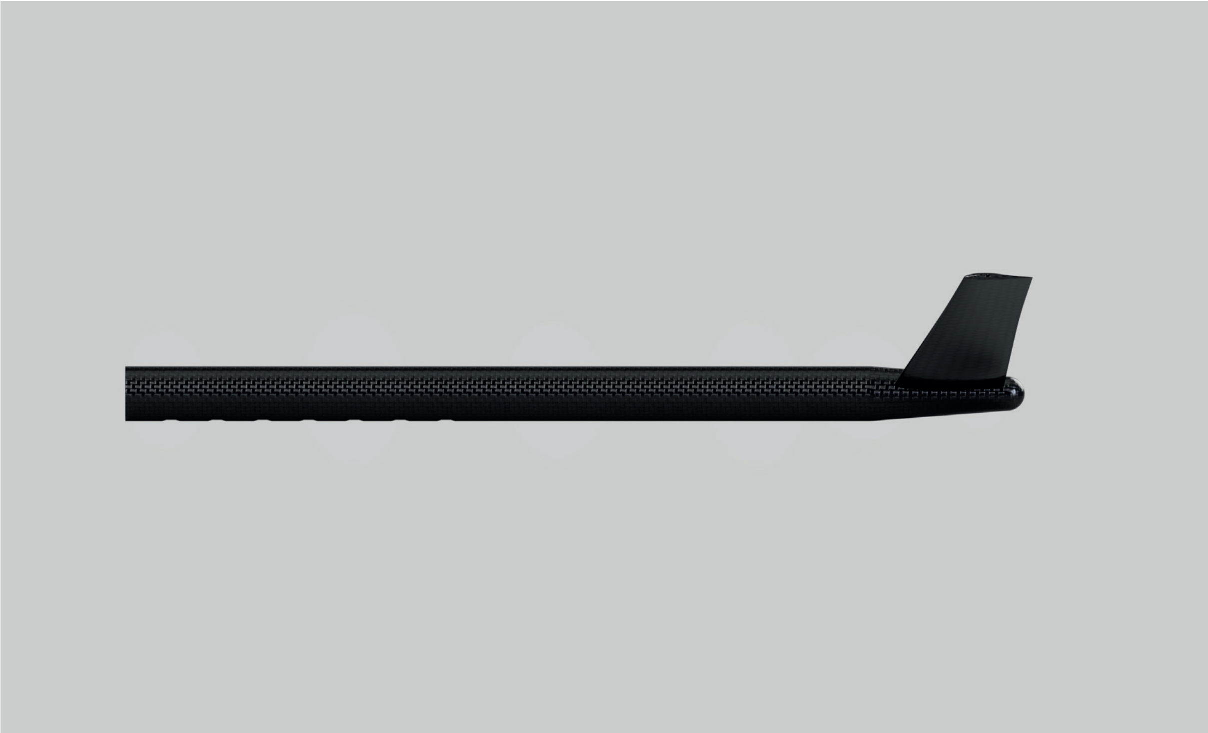


Figure 79. Shape of front tube

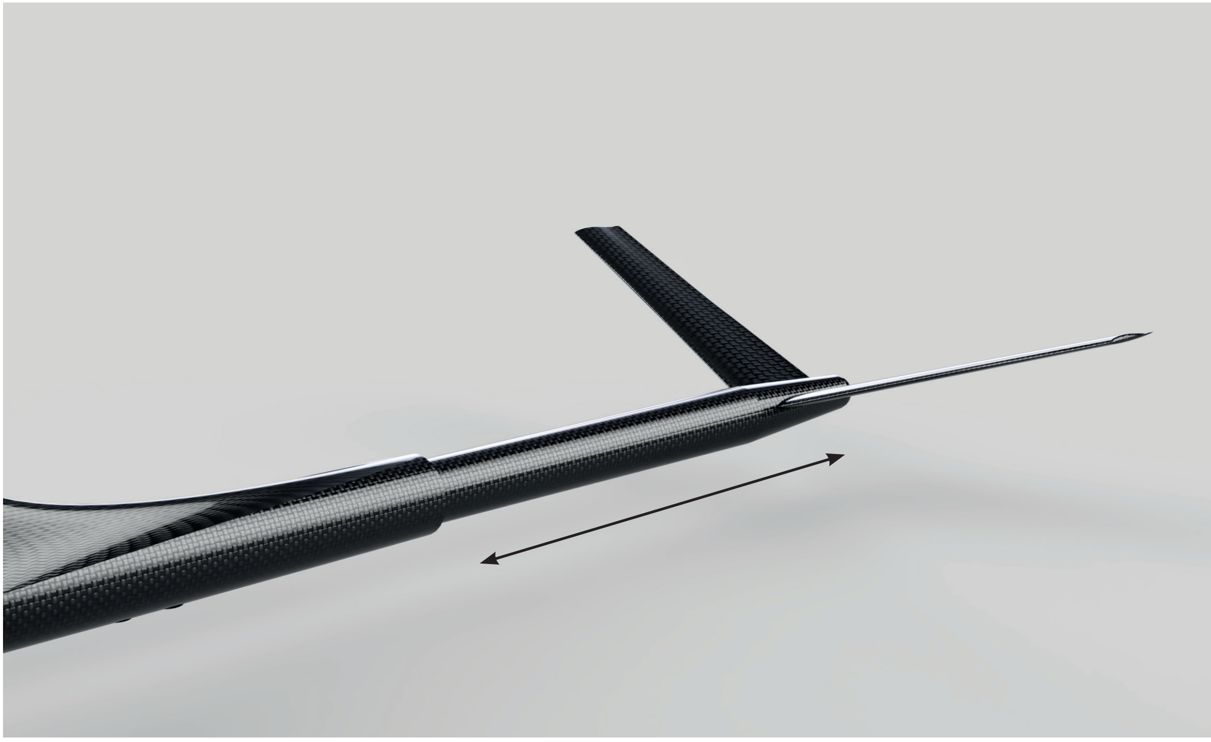


Figure 80. Sliding ability to create a longer or shorter fuselage

Materials

The mast, front wing, and back wing are al made of 100% carbon with an inner PVC foam core. The parts are constructed of a carbon composite, resin, and foam core sandwich (figure 82).

The carbon fiber used for this model is 200 grams Primetex carbon fiber. The material is very stiff because the fibers are spread in both the weft and warp direction (research cycle 2). The material is more tightly woven than standard carbon fiber, ensuring a better finish. For the parts, a combination of plain, twill, and unidirectional weave are used (figure 81). These types of weaves have different properties in terms of directional strength. Fort the parts a nine-layer carbon will be used. These will produce a 3 mm thick construction wall capable of protecting against deformations and ruptures.

The foam core used for the sandwich is cross-linked PVC foam. The material is stiff, durable, water-resistant, and resistant to styrene (Black, 2003).

An epoxy resin was used to ensure a strong bond between the carbon layers and foam core. The chosen epoxy resin for this product was R&G epoxy resign L together with R&G hardner GL 1. This epoxy is robust, durable, and water-resistant. The epoxy also has a low viscosity making it perfect for light resin transfer molding. The Hardner is infused with a UV blocker protection from turning yellow when exposed to sunlight.

At the top of the mast and the split section, two types of carbon are placed. Because of the acting shear powers in these two sections (Bergsma, 2019), the 0 degree, 90 degree and 45 degree angled carbin fiber layers will be used to compensate the powers (figure 83).

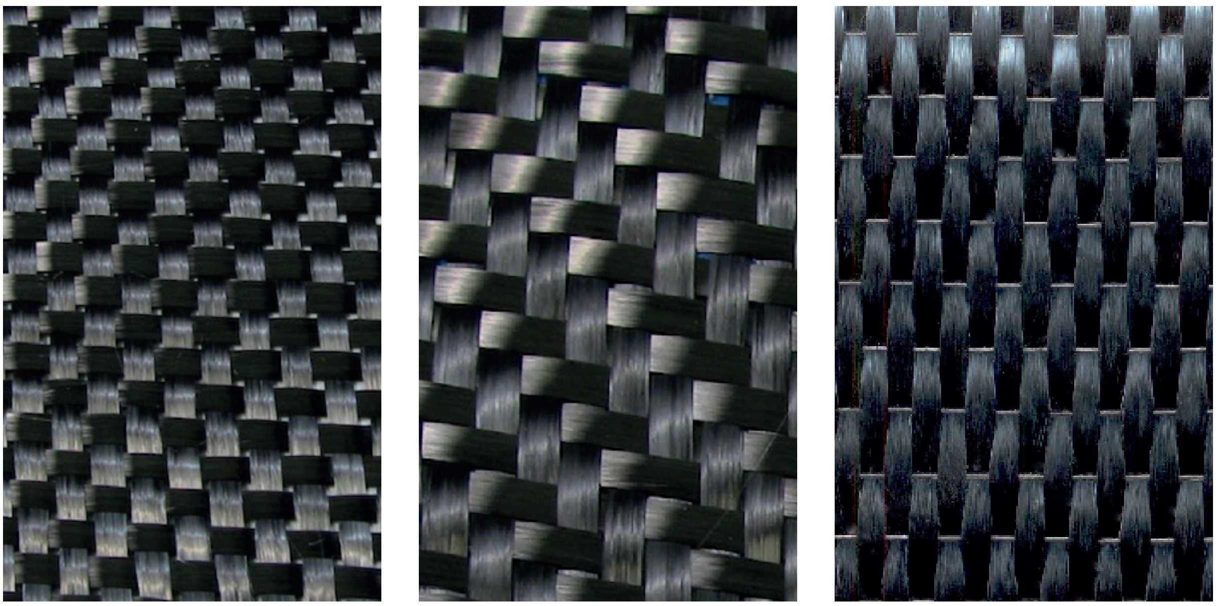


Figure 81. Plain, twill and unidirectional carbon weave

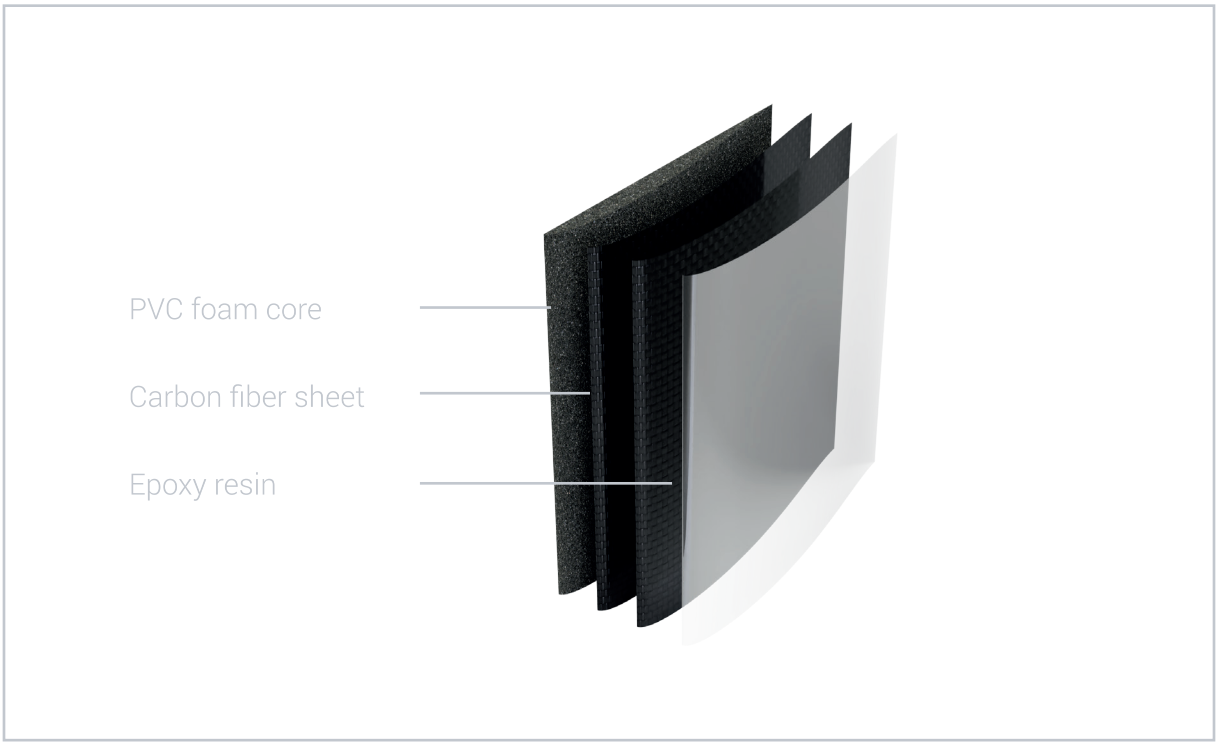


Figure 82. Lay up sandwich

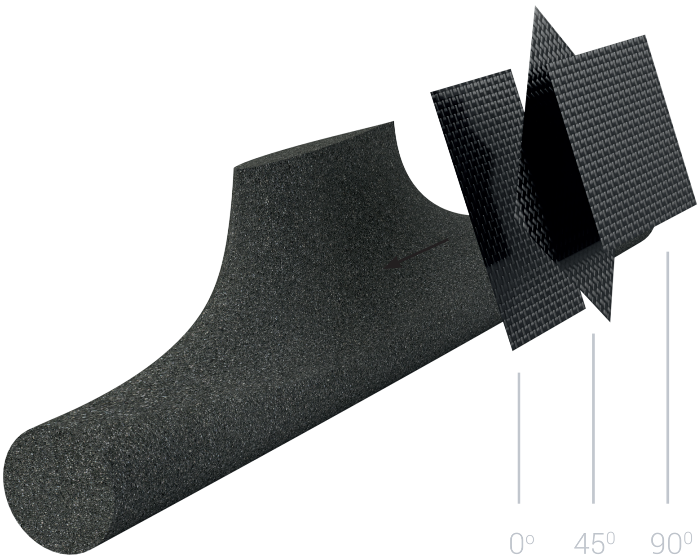


Figure 83. Three types of lay-up angles to ensure a strong connection at the transition

Production

The parts of the hydrofoil are produced using Light Resign transfer molding (research cycle 2). Light resign transfer molding is a production process where parts are produced using a negative mold. The mold is constructed of two parts. After the materials are placed in the mold, the mold is closed, heated, and pressurized. After reaching the desired heat, the resin is pushed through the mold by using a vacuum pump. After the curing time, the mold is opened and the final product is released.

For the parts of the foil, an aluminum mold is used (figure 84). The two-part mold has two negative CNC carved holes representing the outside of the part. Around the hole, a gate is present to hold a rubber seal. This seal prevents the resin coming out of the mold. Figure 85 shows the exploded view of the mold before going into production.

When the carbon sheets are placed in the mold, and the foam core is placed, the two molds are bolted together. The mold is then pressurized and heated. After the desired pressure and temperature is reached, the resin gets vacuum pumped through the mold. After curing, the part is released, and the product is ready for finishing.

Once out of the mold, the parts have some excess material around the edges. This material is cut off with a multitool. Next, the part is sanded, cleaned and coated with a last coat of epoxy to create a fault-free product.

Light resign transfer molding is a cost-effective and relatively quick process in contrary to other production methods (Lin et al., 2006). It also produces products that need a small amount of finishing. Another advantage of using the process is that the company already uses it.

Other companies produce additional equipment such as the bag, toolbox, and tool.

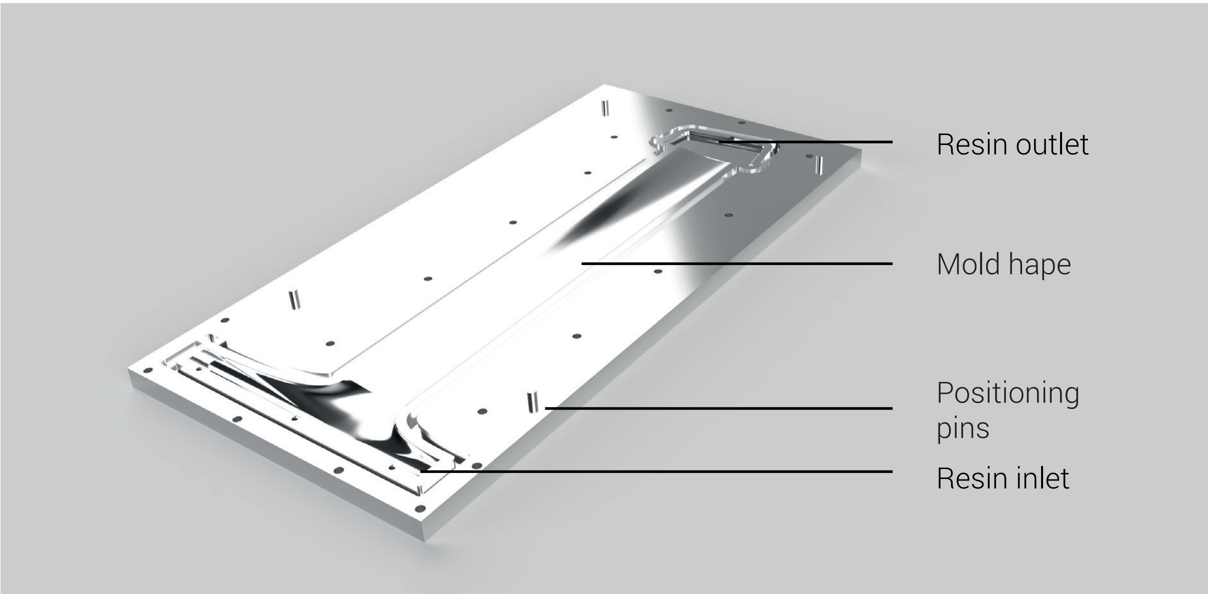


Figure 84. One side of the aluminium mold.

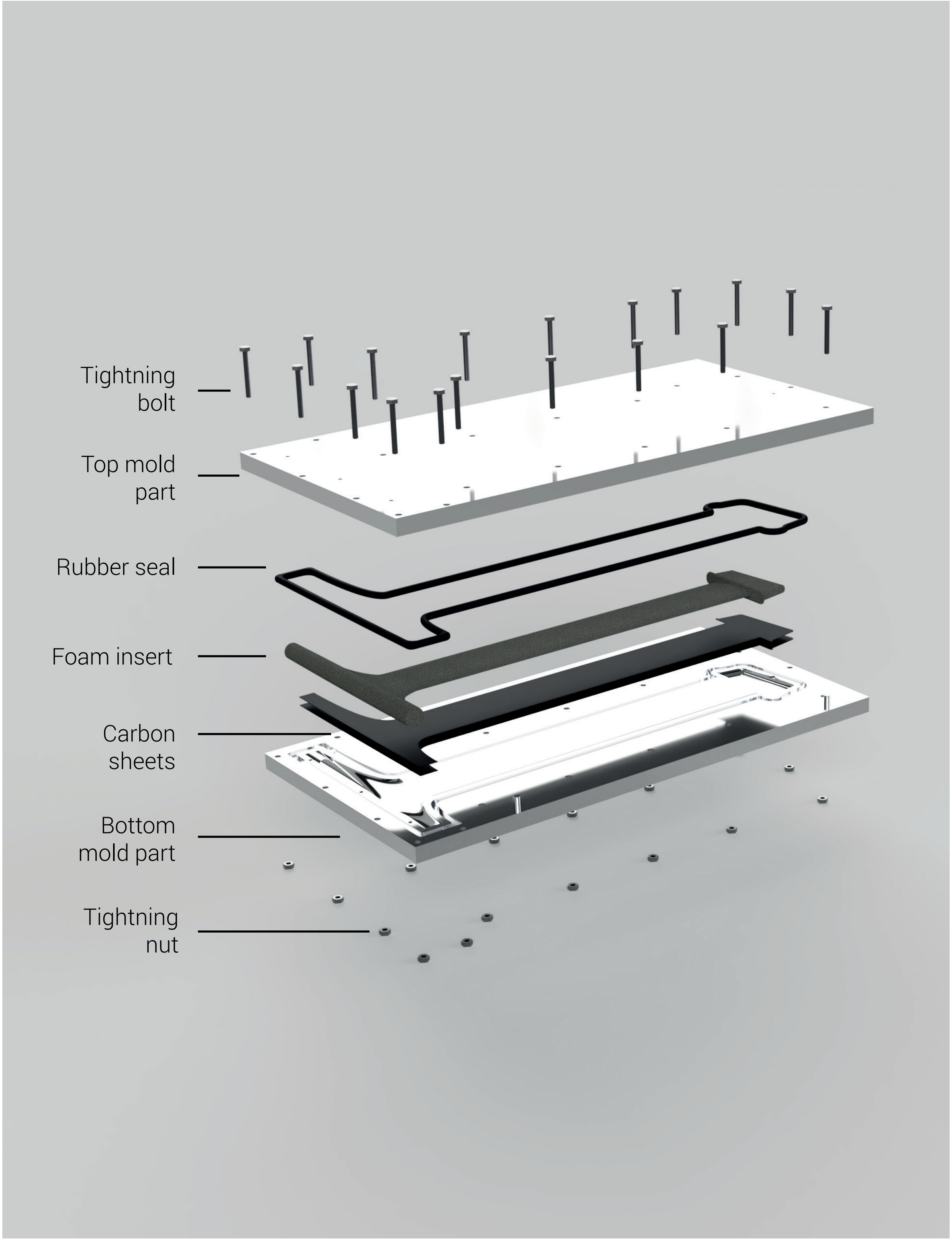


Figure 85. Mold creation of the mast

5.4.7 Additional equipment

Travel bag

In order to carry the foil around and store it properly after use, a convenient travel bag was created (figure 86).

The outside of the bag is made out of CORDURA Fabric (figure 87). The material is widely used in the backpack and luggage industry and is known for being waterproof and resistant to tears and scuffs.

The inside of the bag is made out of EVA foam (figure 88). The foam is water-resistant, hard but yet soft enough to ensure no damage is caused to the parts and shock absorbing.

The shapes of the parts, tool, and the bolt case are perfectly cut out of the foam to ensure that the parts can be stored properly inside the travel bag (figure 89).

A convenient zipper closes the top and bottom part of the bag and secures everything inside. In order to carry the bag, a handle is provided. This handle is placed on the side and also made out of the water repellent material.

Figure 86. Travel bag

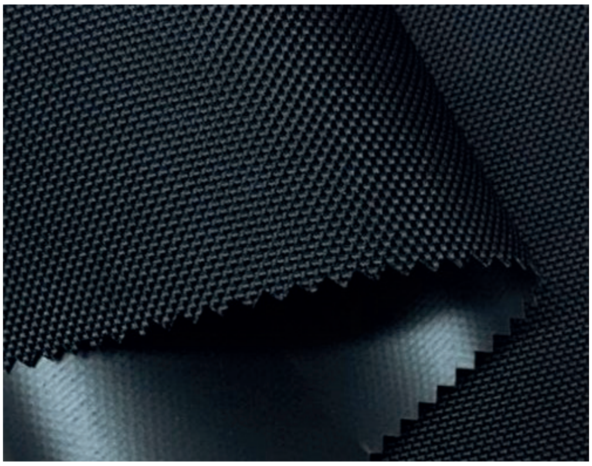


Figure 87. CORDURA fabric

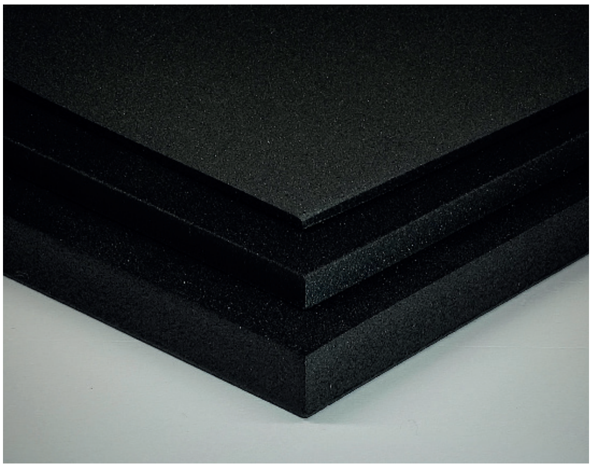


Figure 88. EVA Foam

Figure 89. Storage of parts in travel bag

Tool for tightening the bolts
Bolts achieve the connection between the parts. The bolts need to be tightened with a tool. If companies provide a tool, a simple l-shaped tool with a hexagon tip is provided. The float has a torque wrench making the connection easy, quick, and safe (figure 90). The torque wrench ensures that the bolts are tightened in the right way, not too tight and not too lose, helping to expand the lifetime of the screw holes and, therefore, the lifetime of the product.

The tool has a simple universal snap-on system (figure 91). Standard bits can be placed inside the snap-on system and used to tighten the bolts. The parts of the float are connected with Torx heads. Therefore, the tool will be provided with a Torx bit and a standard Philips bit.

bolt storage box
The last addition to the foil is a convenient storage box for the bolts (figure 92 and 93). It has a PLA eco-friendly outside shell and an EVA foam insert. This insert is big enough to hold six 6mm bolts and four 80mm Tuttle connection bolts. The box fits perfectly inside the travel bag and ensures that the bolts are stored when not in use.

Figure 90. Tool for tightening the bolts

Figure 91. Snap on system and torx bit

Figure 92. Exploded view bolt storage box

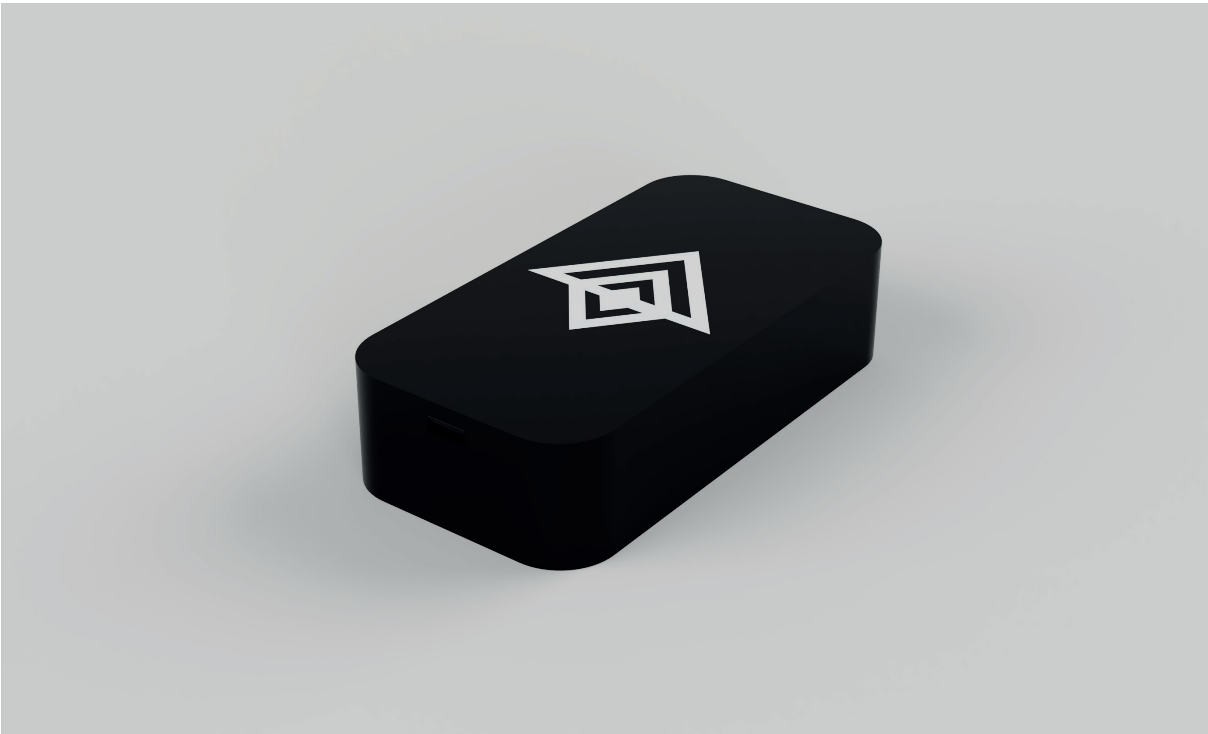


Figure 93. Bolt storage box

5.4.8 Marketing strategy

A well-established introduction strategy of a new product involves four essential steps; Identification of the intended targeting group, a marketing mix model of the company, predicting financial expenses, and controlling the total project (Hultink, 1998). Therefore a marketing and product strategy was created in the research part of this third cycle.

The outcome of the research chapter was to use a combination of market penetration and new product development strategy. Also, the research part indicated that the use of the AIDA model would help create a well-defined marketing strategy plan.

For the final marketing strategy, the AIDA model (Ghrivu, 2013) was used as a guideline. The steps of the AIDA model involved attention, interest, desire, and action (figure 94). The five steps of the AIDA model are explained are:

Intended user

The intended user of the product was defined in the research part of the second and third cycle as; the fanatic wind and kitesurfer who tries to surf whenever he or she can meaning that in whatever weather condition, the user will try to surf. Also, the user has a high budget, wants high-quality products, and would like a product that is out of the box ready.

AIDA

After defining the user of the product, the four steps were used as a guideline for the marketing strategy. Figure 95 shows the four steps. The first step is that the product needs to attract costumers' attention by using a short youtube video showing the new concept.

Second, the interest of the potential customer is picked by creating a detailed information page on the website of tribal. Also, a second video clip will explain the full details of the product.

Third, consumers desire to want the product will be triggered. The desire will be created by showing the advantages of the product in contrary to the current market. These advantages are; easy assembly and disassembly of the product, a seamless transition of the mast and fuselage making the product stronger, the product only exists out of three parts, and the product has a convenient travel bag and screw container box.

Lastly, after persuading the user to buy the product, a call to action needs to be created by giving the user a pleasant buying experience. After buying the product, there will be an email sent to the buyer with a personal thank you note. The box will contain a user guide with instructions on how to set up the foil and what can be modified.

Cost price

The final cost price for the foil was calculated using information from the company, the predicted sold products, and the cost price of the materials. The estimated calculation of the hydrofoil is presented in appendix C.

The total purchasing price was determined at 1200 euros.

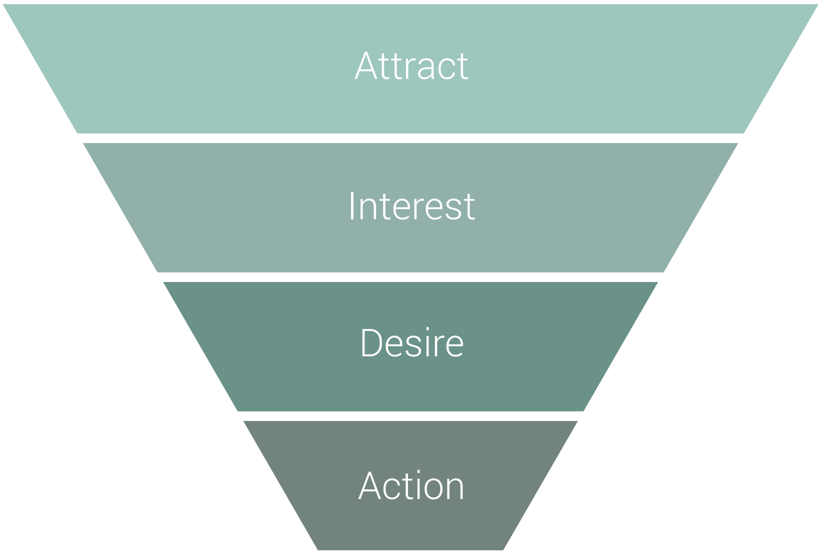


Figure 94. AIDA model

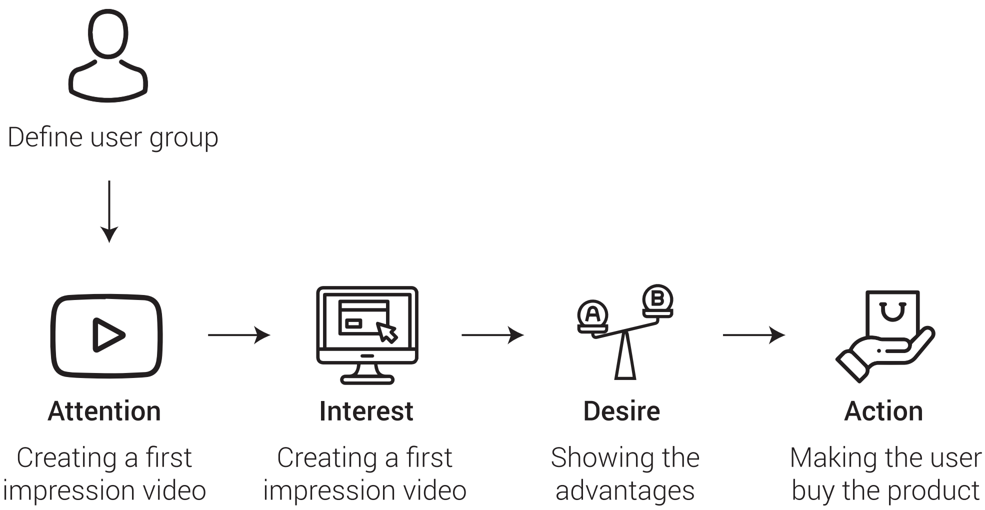


Figure 95. Three types of lay-up angles to ensure a strong connection at the transition

5.4.9 Final prototype

After creating the final concept, a 1:1 scale physical prototype was created (figure 98). This prototype was created to show the stakeholder the final result of the design process.

The build of the prototype began with a building plan. The prototype needed to physically and visually represent the final concept. Therefore, the prototype needed to be made at a 1:1 scale and hand laminated with carbon fiber and epoxy.

The firsts step was to create the model in a 3D modeling software called Fusion 360. After modeling the total concept, the parts were deconstructed into smaller parts. These smaller parts could then be printed with a 3D printer (figure 96). After printing every individual part of the front wing, back wing, and mast, the parts were glued together in order to create the three parts of the final concept. After gluing, the parts were primed with epoxy filler and sanded to make them ready for the carbon layup process.

The second step was the carbon layup (figure 97). The carbon layup was done in two steps in order to laminate both sides of the parts. The carbon layup started by cutting the carbon sheet into the right sizes. After that, the epoxy resin was prepared with the right amount of epoxy to harder ratio. Then, the cutout sheets were coated with the epoxy and carefully placed on top of the parts. This resulted in a combination of 3D printed part laminated with carbon fiber on one side. Before doing the other side, the first laminated side needed to cure. This was done using an oven preheated at 30 degrees.

After two days, the other side was laminated using the same steps as before. Eventually, after thoroughly drying, the finishing could start. Firstly the excess material was cut off. After that, the parts were sanded and finished with a second boat epoxy coat satin coat. After thoroughly drying, the prototype was polished and showed to the stakeholders.

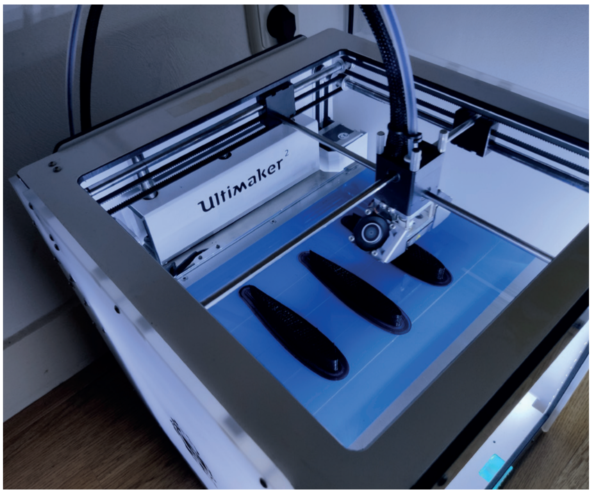


Figure 96. 3D printing the parts

Figure 97. Hand laminating carbonfiber

Figure 98. Final prototype

5.5 Reflection

The last design cycle focussed on extensive research and design improvement. Co-reflection sessions with multiple experts resulted in useful insights for the final design. The result, Float, resembles the wishes of the company, the TU Delft, and my personal principles for good design (figure 99).

The improvements, in comparison to the second concept created in the second cycle, were definitely noticeable.

First, the user group was researched, resulting in a list with requirements that were useful for the creation of the additional equipment. Next to that, it showed the pain points that occurred during the use of the current hydrofoil of the user.

Second, calculating the internal and external powers with tips and tricks of the experts resulted in a clear view of the total concept in terms of internal and external powers. With these findings, a suitable material could be chosen, and the right production technique could be selected.

Third, the profiles of the mast and wings were not easy to define. With the help of the fin expert of tribal, the right profile of the mast was defined. The profiles of the wings were found by consulting the expert in the first cycle and the use of the UIUC Airfoil DATA site website.

Lastly, to create a well-established marketing plan, a marketing expert was interviewed. This resulted in a well-established marketing plan that would ensure the first step in selling the product.

Still, the design cycle does not end here. The final design will serve as a starting point for Tribal.

The next step will be:

- Testing the final concept and optimizing the profile shapes of the front wings.
- Evaluating the marketing plan.
- Producing the final product.

Figure 99. Final Concept, Float

5.6 Key takeways

The focus in the last cycle was detailing. The product was worked out in terms of material, production, marketing, and structural optimization. A few essential key takeaways were derived from this last cycle:

- Prototyping is one of the most important steps in designing. Having the ability to test different ideas and concepts with the intended user and stakeholders, delivers valuable information.
- Using the expertise of experts provides valuable information for a project. Do not be afraid to fail and ask an expert.
- Instead of creating a product that can be used by all, create a well-designed product, especially for a specific user group.
- The wings are very complex. The shape, form, size, and thickness are all crucial factors for the performance. Physically testing different options is the only way of finding the perfect wing.
- A windsurf and kitesurfing hydrofoil is a complex product. The foils are still in the development phase. Therefore, there are a lot of different shapes and sizes among competitors.
- Now, the foils are only used by the early adopters. The intended user, the early majority and late majority, should be triggered to buy the hydrofoil by using the intended marketing strategy and using the AIDA model.

CONCLUSION

6.1 Final reflection

6.1.1 Final concept Float

In a relatively quick time of 20 weeks, I have been able to produce a final concept, a well-structured report, and a final prototype. This final concept, Float, represents the implementation of the findings during the several research phases, expert interviews, and my personal principles for good design.

The Float enables the user to buy a product that is reliable, strong, and easy to assemble. Also, the design of the Float enables multiple users to use the product.

However, there is also a downside to the project. The time frame of the project withheld me of building a functional prototype. Also, the final concept still needs to be validated with the intended user to show if the concept works and if the user likes the product.

6.1.2 Design Approach

In this project, I have been using a new design approach and four new design methods. In a former project, I used standard design techniques such as the double diamond. These methods withheld me from producing prototypes. By using the new design approach and the four new methods, a new way of designing was presented to me. These were the research through design approach, the 1-10-100 method, annotated portfolios, co-reflecting, and my personal principles for good design.

The research through design approach gave me the ability to do quality research by making prototypes. I would like to incorporate this design approach into my professional career.

1-10-100 method

The 1-10-100 method was used to structure the design process and complement the research through design approach. Instead of performing the standard design steps in a linear pattern, it resulted in three iterating design cycles. The first cycle resulted in a starting point for the project but also structured the whole design process. Reflecting on each cycle is part of the 1-10-100 method and served as the moment of involving the stakeholders in the design process, discussing and deciding on the next steps.

Annotated portfolios

The annotated portfolio method was used in two ways. The first one was the use of a notebook. The notebook was used to write down thoughts, reflective moments during the project and gather information from interviews and findings during the research phase. The notebook also helped me to make a to-do list. These lists created a structured day or week plan to help me achieve the predefined agenda points.

Second, the annotated portfolios were used during the expert meetings. By showing the 3D hydrofoil prototypes on paper, the experts were able to make annotations. Instead of interviewing an expert and making notes, the expert could write down his own notes. This valuable information could then be used as input for the design process.

Co-reflecting
The 1-10-100 method supports co-reflecting sessions after and during every design cycle. Involving stakeholders by co-reflecting had a very positive effect on mutual understanding with the client. Involving the client within the project ensures that the requirements and wishes of the company are incorporated into the design.

Personal principles for good design
The last method used during the design process was de personal principles for good design method. During previous projects, I was guided by the stakeholders of a project. Therefore, I created a product that resembled the vision of the stakeholder. By using the personal principled for good design method, I could take a step back from the project and reflect on what I wanted to incorporate. By incorporating your principles, the design is not only appealing to the stakeholder, but also to the designer. Concluding, incorporating my personal principles for good design improved the final design.

6.2 Recommendations

The last cycle of the 1-10-100 method resulted in the final design. The final design should be seen as a starting point. Further research and development are needed to finalize the design. Therefore, I would like to present three recommendations:

6.2.1 Testing

The first, and for me, one of the essential steps is testing the concept. Unfortunately, the production of the hydrofoil was delayed, which made it impossible to test the prototype. Testing is needed to ensure that the concept works, is appealing to the consumer, and can withstand the predicted forces in a real-life situation. Besides that, the new construction of the final design should be tested to ensure the functionality of the hydrofoil.

6.2.2 Materials

The selected materials for the concept need to be tested. It is essential to look at whether the composites sandwich of the predicted nine layers of carbon fiber would be enough to withstand the forces in real life. According to the testing results, a new lay-up of materials could be made. The new lay-up could improve the overall strength of the product and reduce material costs.

6.2.3 Co-reflecting with the intended user

One of the most important steps of designing is presenting the concept to the intended user and receiving their feedback. In the future, new prototypes should be shown to the intended user to receive valuable information from the user group.

6.3 Personal reflection

This personal reflection shows my final verdict of me as a designer. It concludes an overview of the things that went well during the design process, things that could be improved, and the things that I am proud of.

6.3.1 Reflecting on me as a designer

During this project, I have learned to use my strengths, I challenged my weaknesses and found my Personal principles for good design. For example, I have been using my strength of making prototypes in a prominent role during the project. This ensured that I kept my motivation to proceed with the design process. I have also been trying to improve my weaknesses by incorporating them from an early stage into the design process. A significant challenge for me was reporting and graphic design. My mentor supported me during this process. Co-reflecting with him resulted in my personal graphic style and a clean report.

Next to that, the personal principles for good design helped me in defining 'me' as a designer. During my bachelor and master, I have noticed that if you are outstanding in graphic design, sketching or presenting, the chances are that you will be characterized as a good designer. In my case, as someone who likes to create prototypes, this was not the case. With the principles of good design, I was able to present myself as the designer that I am today and see myself as a (good) designer.

6.3.2 Working relationship with a client

For this project, I decided to work with a company. In former projects, this resulted in good collaborations and fruitful outcomes. During this project, it went from a promising start to a less satisfactory collaboration towards the end. In the beginning, I was told that I was able to make a lot of prototypes at the company. During the project, I noticed that my client was not pleased with the results. This eventually resulted in only creating a visual concept and not a concept that could be tested.

From this experience, I have learned that it is important to communicate with the company regularly. Keeping the company involved, and making them excited about the project, helps retain the relationship between the designer and the company. Also, telling the company about the limitations of a project at the beginning will exclude unexpected situations and disagreements. Therefore, in future projects, I will be instructing the client with a more thorough and clear expectation plan.

6.3.3 Dealing with setbacks

During this project, there were a couple of setbacks. First, I tore my Achilles, which made it impossible to build a prototype in the early stages of the design process. Then, I got unexpected news from my client about building the prototype. These setbacks were unpleasant and made me think about the relevance of the project. Eventually, I turned these set back into positives and looked at the things I had achieved during this project. In every project, there will be setbacks and unexpected problems. The way to deal with this is thinking about everything that does work out. Whenever a door closes, another one opens. In a future project, I would like to incorporate this way of dealing with setbacks.

6.3.4 Closing thoughts

I have learned a lot of new things during this project. I can call myself a designer according to my personal principles, I have learned to deal with setbacks during an important project and learned to tackle my weaknesses in order to improve myself as a designer.

The lessons that I have learned during this master thesis will be a valuable input for the rest of my professional career as an industrial design engineer.

ADDITIONAL

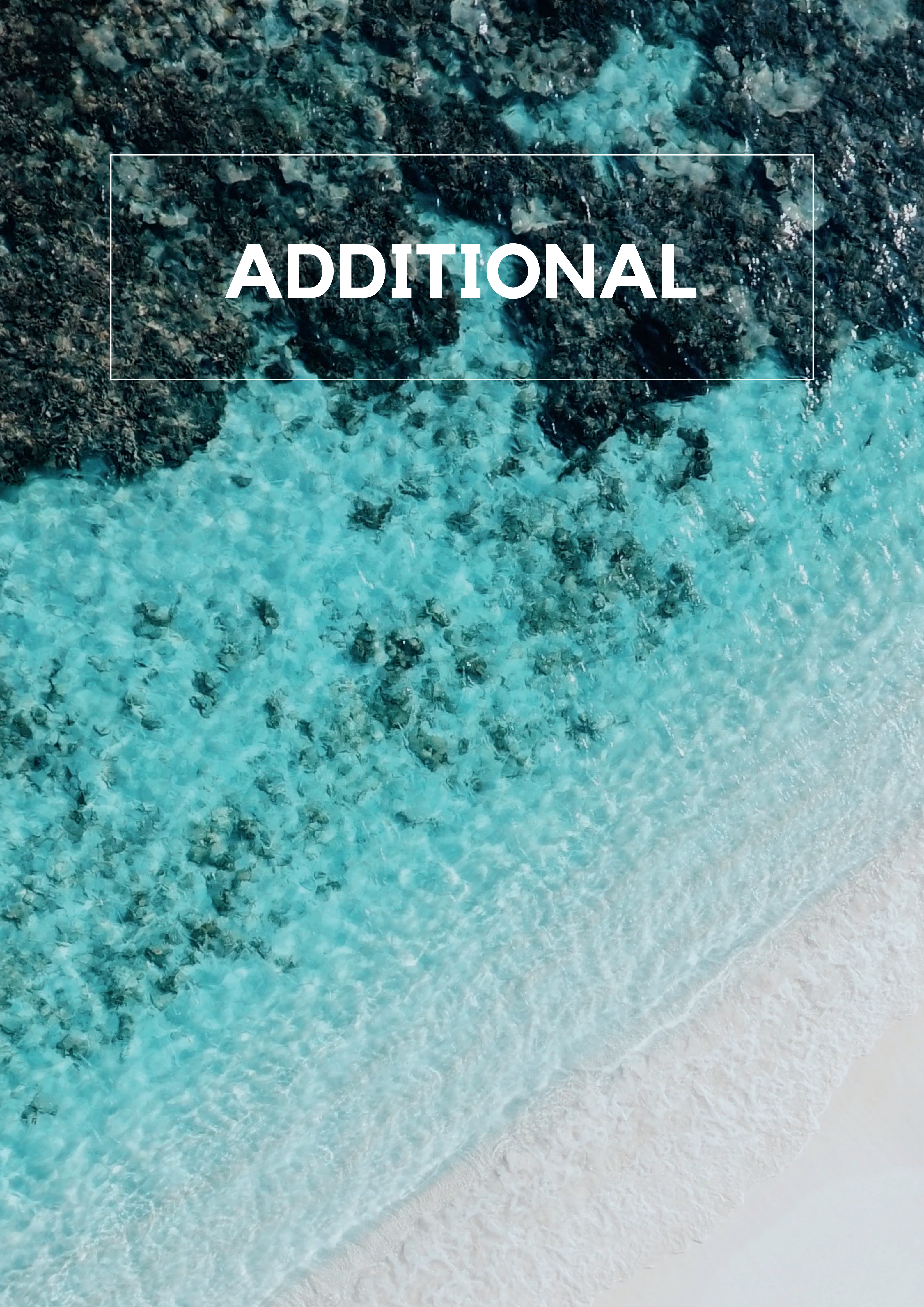


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Figure references

Figure 14:

- Left top picture first hydrofoiler Joop nederpelt: https://www.webstagramsite.com/tag/sardiniawindsurfingmuseum
- Right top picture first hydrofoil Boat : http://www.bluebird-electric.net/hydrofoils.htm
- Bottom picture three different types of hydrofoils: https://www.californiakiteboarding.com/product/2019-starboard-sup-wave-pro-foil/, https://www.kingofwatersports.com/product?productid=moses-vento-111-foil-2018&group=NL, https://www.kater.nl/windsurf/foilen/windsurffoils/starboard-freeride-alu-2020_diversen_24575.html?channable=e736.NDU4ODctOTktKw&utm_campaign=Starboard&utm_content=&utm_source=google&utm_medium=cpc&utm_term=&gclid=Cj0KCQiAiZPvBRDZARIsAORkq7c97u1lejLDb-yF1b_qtpkfBeaKeyKoYcHPA2yvqcyfvVCq1ix79k4aAuq-EALw_wcB

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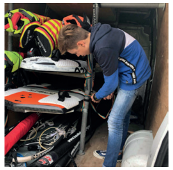
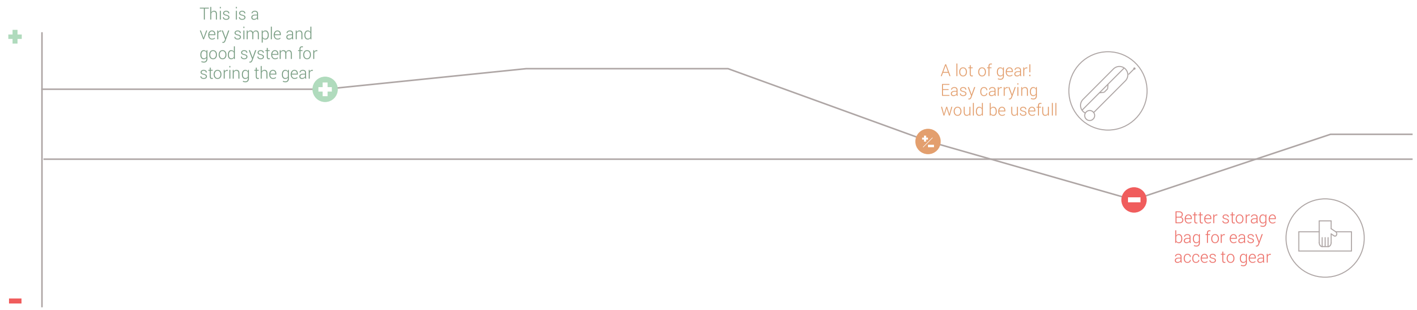
7.3 Appendix

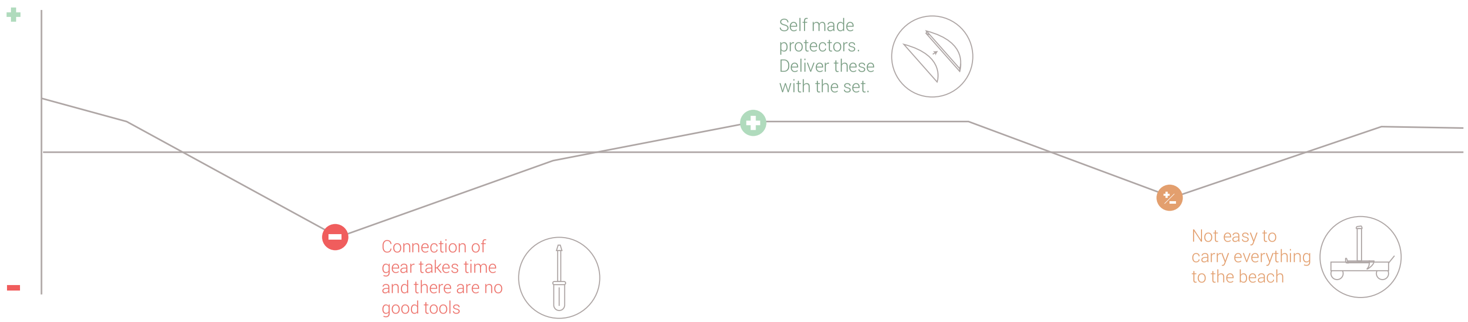
7.3.1 A. User experience

PRE USE

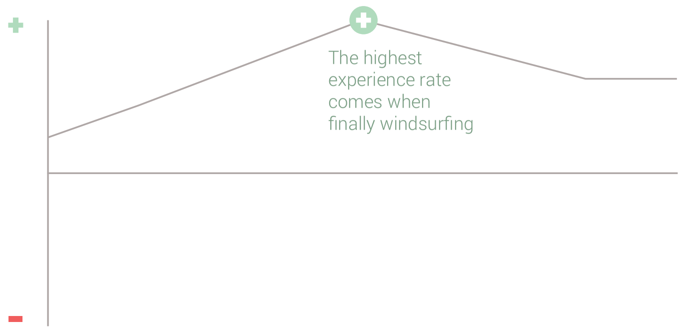
Steps	 Check weather	 Get gear	 Load in car	 Grab from car	 Lay-out gear	 Grab from bag	 Choose parts
Explanation	First step in the total process. Checking wether there is enough wind and the conditions are good enough.	After checking the conditions, the right gear is selected and grabbed from the shed.	The gear is than loaded into the car. With the gear loaded into the car he drives to the desired location.	When arrived at the desired location, the gear is grabbed from the car and carried to the beach or lake.	The first thing to do is lay-out al the gear. A decision is made based on the conditions present at the time.	Al the parts are grabbed from the hydrofoil bag, And layed out on the grass.	Based on the conditions(wind conditions, type of water, wave height) the proper parts are chosen.
Experience/ opportunities							
Reflection	Finding out if there is enough wind to foil is the first exciting step which lifts the mood of the windsurfer	The frist time seeing the gear excites the user even more.	Loading the gear in the car is always a big puzzle.	Pulling the gear out of the van some-times edns up in letting gear fall on the ground.	The bag is big and not easy to carry. A much more ergonomic and easy to carry bag would be better.	It is not easy to grab the parts from the bag, Foam spacers are added. These make grabbing the parts uneasy.	By having al the parts layed out, a good choise can be made.



ASSEMBLY

Steps							
	Fuselage + wings	Mast on board	Fuselage on mast	Protectors on wings	Install other gear	Everything to beach	Connect other gear
Explenation	After chosing the right gear, the first step is to connect the wings to the fuselage	Next, The mast is connected to the board with 2 screws going through the board into the mast	Following, the fuselage with wings is connected to the mast.	Before transportati-on to the beach, protectors are placed around the wings.	All the other gear, such as the sail, are prepared and installed.	First the board and hydrofoil are taken to the beach. After that all the other gear.	When all the gear is at the beach, the assembly begins. All the necessary parts are connected so that the can be used.
Experience/ opportunities							
Reflection	Sometimes the wings are croocked when connected. There are also a lot of screws that need to be tightened	The mast needs to be properly secured. Therefore, shaking the mast in place is important when tightning the screw	The connection pins jam from time to time. Therefore sometimes you need to do the connection twice.	These are home made. Carbon is very delicate, therefore these are needed. But the don't come with the total package.	Installing the other gear takes almost the same amount of time as installing the foil.	Carrying the gear is not convenient. Having a hyrdrofoil stikking under the board makes it even harder.	Also, by having the hydrofoil sticking underneath the board, connecting the other gear is even harder than normally.

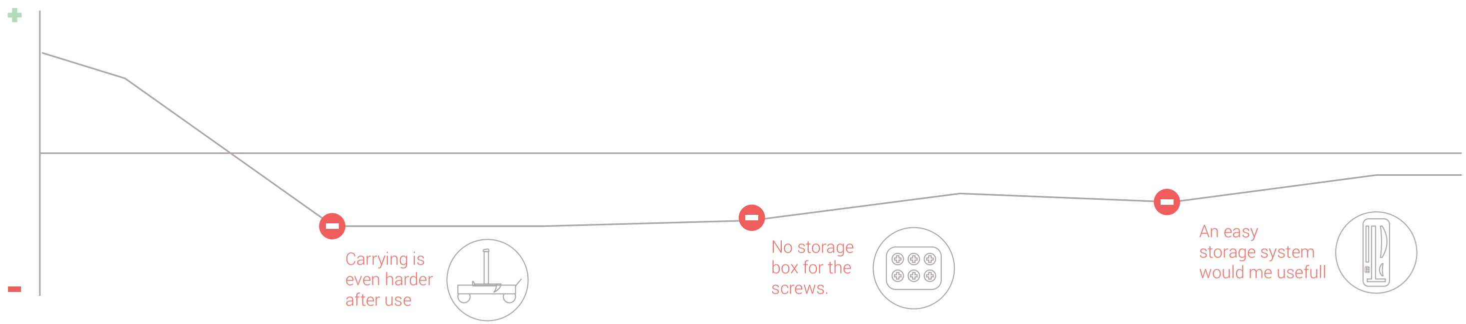
USE

Steps	 Carry to water	 Windsurfing time	 Carry gear out of water
Explenation	The use of the gear starts by tacking it to the water.	Finally! The moment the windsurfer is waiting for. The actual use!	After finishing up another great windsurfing session, the gear is carried out of the the water.
Experience/ opportunities			
Reflection	Carriying the gear to the water is not easy. Therefore, the gear is assembled right before entering the water	The most fun comes when riding the foil. Freedom, flying and going fast are the three main quotes from the windsurfer.	After the surfing session taking the gear back to shore can be exhausting.

DISASSEMBLY

Steps	 Dismount foil and board from sail	 Carry to the setup place	 Dismount fuselage from mast	 Dismount wings and fuselage	 Dismount mast from board	 Foil parts back in bag	 Disassemble other windsurf gear
Explenation	The first first step of the dissasembly is to dismount the foil and board from the sail.	Next, the board and foil are carried to the grass. There the dissambly of the foil can begin.	The first step is dismounting the fuselage from the board.	The second step is dismounting the wings from the fuselage.	The last step is disconnecting the mast from the board.	When everything is dismounted, the foil parts are placed back into the bag.	Then, the rest of the gear is dismounted and placed into their traveling bags.

Experience/ opportunities

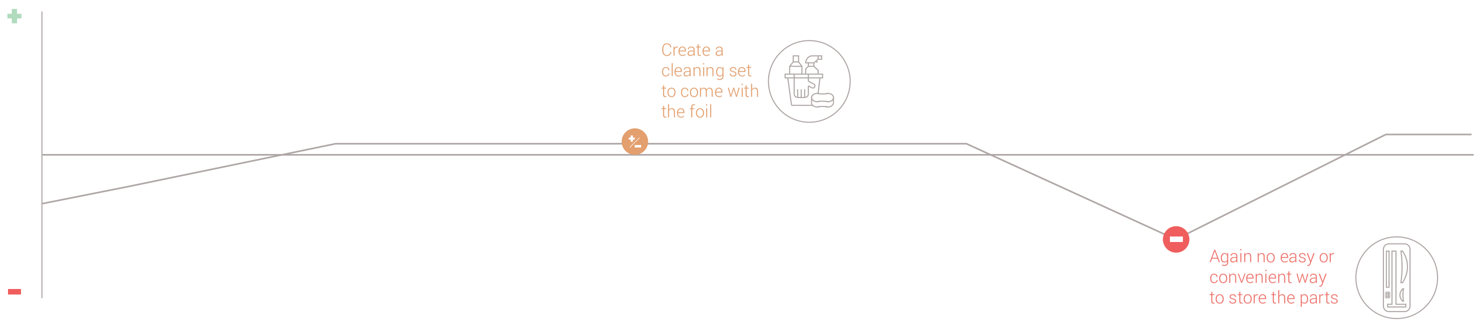


Reflection	Easy to do and is a common step when disassembling the windsurf gear.	Carrying the board is still very hard. Even more when exhausted from the session.	Hard sometimes to get the screws out of the holes. To tight when put on.	A lot of screws to screw out of the holes. A lot of times screws dissapear. And there are no spares.	A lot of force needed to wiggle out the mast after use.	The bag is not easy to handle. It is hard to place the products back in the bag.	Takes as long to disassemble al the other parts as the the foil.

AFTER USE

Steps	 Carry gear to car	 Grab gear from car	 Clean the hydrofoil parts	 Clean other windsurf gear	 Dry with a towel	 Foil parts back in bag	 Store gear in shed or van
Explanation	After everything is packed, the gear is taken to the car.	When arrived back home, the gear is either taken out of the car for storedge at home or left in the car.	But before storing the parts, the parts are frequently cleaned. In case of use in the sea they are cleaned everytime.	The other gear is also cleaned. Harness, wetsuit, etc. are cleaned with tap water.	To prevent mold and other wearing from happing on the gear, the parts are dried with a towel.	After drying the parts, the parts are placed back into the bag.	The last step is placing all of the parts into the shed for storage.

Experience/ opportunities



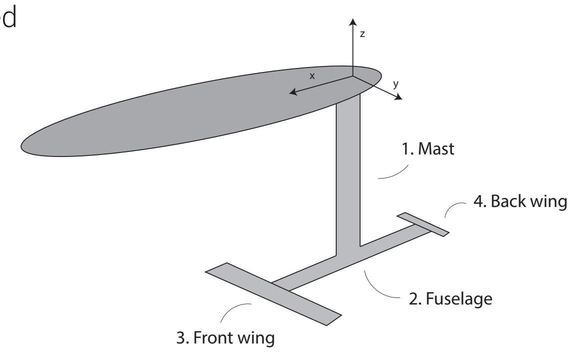
Reflection	-	-	Is ok to do, not super easy but that is with all the windsurfing gear	-	-	again, not easy to do. Could be made better.	-

7.3.2 B. Calculations

<u>Statics and dynamics for external forces:</u>

Specifications seawater:

The specifications of seawater are very unpredictable. In order to do calculations, two standard characteristics of seawater are chosen. These are the most common used ones for calculations. The following characteristics are used throughout the upcoming calculations:



Density at 20 degrees-> 1027 kg*m-3
Viscosity -> 1,1 M*Pa*s

In order to make a choice in what calculation method should be used, a list of different formulas is listed.

The law of Archimedes

“It is the uplifting force a body experiences in a fluid or gas.”

Fs = p x g x V

Fs = Lifting force (MPa)
p = mass density (kg*m-3)
g = gravitational constant, (9,81 m/s2)
V = Volume of displaced fluid (L)

Lifting power wing

“Lifting force created by a wing due to traveling at a certain speed through a gas.”

L = 0.5 x p x v^2 xCl

L = lifting force (MPa)
p = mass density air (kg*m-3)
v = air speed (m/s)
Cl = Lift-coefficient.

After consulting the TU Delft experts from Marine technology and the Solarboat team, it was obvious that a complete calculations of all the resulting powers within the materials would be too much. Therefore, a simplified calculation was advised using the long beam technique and simplified FBD's of the situation.

First, Five free body diagrams where made(figure..). From these, two where chosen to actually calculate by hand. The others and the chosen two where also simulated in a 3D software simulation(autodesk).

For the hand calculations it was important to calculate the maximum strength and stress value. In order to calculate these values, the powers on the hydrofoil were calculated.

Lift

Archimedes

We assume that the person with the gear represents a total volume of 20 + 100kg. But to be safe we will make the values a bit higher, so the gear ways 20 kg and the person 100 kg plus the hydrofoil. That makes a total of 120 kg.

Fs = rho x g x V

rho = 1.0
g = 9.81
V = 120*1.0 = 120

Fs = 1.024x9.81x120= 1,2 KN

lift for hydro wings

L = Cl x 0.5 x rho x v^2 x s
Cl = 0,5
rho = 1024,8 kg/m^3 (seawater)
v = 15 m/s -> 30 knots
s = 0,09 m^2

L = 0.5x0.5x1024.8x15^2x0.09 = 5184N

Drag

- Pressure of water on hydrofoil

The maximum pressure of the water on the hydrofoil under water, when we keep the maximum depth at 0.8 meters, is 1.1026kg/cm2. The total pressure is measured on the front surfaces on the hydrofoil since it is traveling in that direction. The total cm2 of the hydrofoil is

90x1,3 = 117cm2
wings = 14cm2
fuselage = 9.6cm2

Which is a total of 117+14 + 9.6 = 140.6cm2

The total pressure on the hydrofoil is -> 140.6x1.1026 = 155.03 kg
This means a total force of 155.03x9.81 = 1521N

- Drag of water on hydrofoil

D = Cd x 0.5 x rho x v^2 x s

with

Cd = Cd0 + (Cl^2/(e x pi x A x R))

and

A x R = b^2/S

Cd0 = 0.01
Cl = 0.5
b = width wing 0.8 m
S = surface area wing 0.09 m^2
e = 0.85 (1 for elliptic 0.7 for constant)
rho = 1024.8 kg/m^3 (seawater)
v = 25 m/s -> 50 knots (Extreme situation)
s = 0.09 m^2

Ar = 0.8^2/0.09 = 7.11

Cd = 0.01 + 0.5^2/(0.85xpix7.11) = 0.0232

D = 0.0232x0.5x1024.8x25^2x0.09 = 668,7N

In order to calculate the internal forces the most extreme drag and lift forces are used from the prior calculations. With these the following mathematical formulas can be used to calculate the maximum bending and angle. First the two different moment of inertia are calculated. After that the maximum bending for the different situations are calculated.

<u>Modulus of torsion calculation for mast</u>

For the modulus of torsion from the shape of the mast we will use a simplification. We will use the formula of an oval shape.

This is

$Io = (pi \times a \times b^3) / 4$

with a = 50 mm
and b = 6,5 mm

This results in:

Io = (pix100x13^3)/4 = 172552 mm4 = 172x10^-9 m4

For the fuselage the modulus is:

$Io = (pi\ (d1^4-d2^4)\ )/ 4$

With

d1 = 35 mm
d2 = 29 mm

This results in

Io = pi(35^4-29^4)/4 = 623090 mm4 = 623x10^-9 m4

The lift and drag is (from calculations):

FL = 1,2 KN
FD = 668,7N

Io mast = 172 x 10-9 m4
Io fuselage = 623 x 10-9 m4

We will need de following formulas to calculate the maximum bending moments and strengths.

Bending:

M = PL   Maximum moment

f = (PL^3)/(3EI)   Maximum bend from point force

0 = (FL^2)/(2EI)   Maximum angle from force

fm = (ML^2)/(2EI)   Maximum bend from moment

0m = (ML)/(EI)   Maximum angle from moment

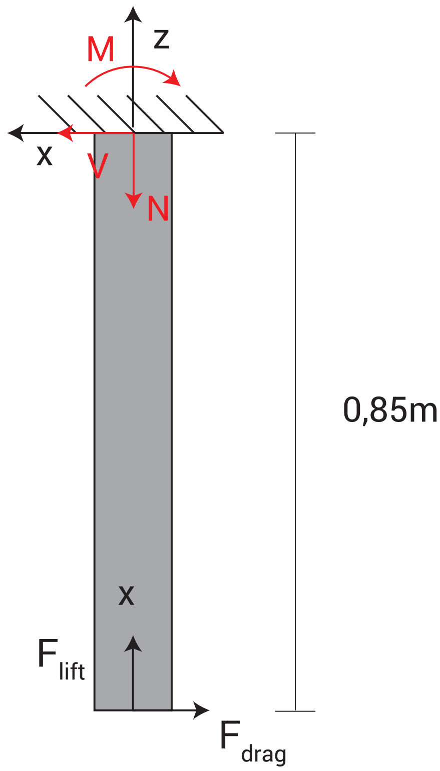
f = maximal amount of bending (mm)
P = force on point (N)
L = Length (mm)
E = E module (MPa)
I = modulus of torsion (mm^4)

Assumptions:

- drag on mast is <<
- N <<
- E carbon with epoxy = 100 GPa

First we will calculate the powers present on the mast.

FL = 1,2 KN
FD = 668,7N
I mast = 172 x 10-9 m4
L = 0,85m
Md = 0,6 x 0,85 = 0,51 kN/m
ML = 1,2 x 0,45 = 0,54 kN/m
E = 100 GPa

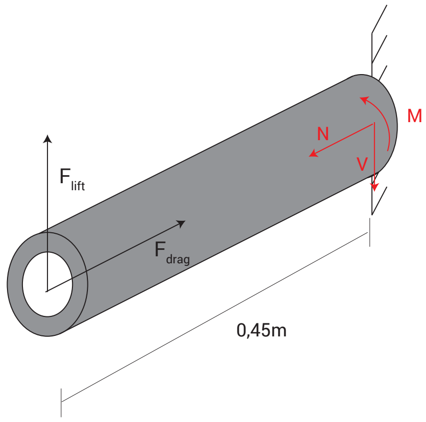


<u>Drag:</u>

fV = (PL^3)/(3EI) = (600 x 0,85^3)/3x100x638 = 0,0019 m = 1.9 mm

0 = (FL^2)/(2EI) = (600 x 0,85^2)/2x100x638 = 0,006 rad = 0,34 degrees

Moment:



fm = (ML^2)/(2EI) = (510 x 0,85^2)/2x100x638 = 0,0028 m = 2,8 mm

0m = (ML)/(EI) = (510 x 0,85)100x638 = 0.0068 rad = 0.39 degrees

Then secondly the powers present on the fuselage.

Lift:

f = (PL^3)/(3EI) = (1200 x 0,45^3)/3x100x638 = 0,0006 m = 0.6 mm

0 = (FL^2)/(2EI) = (1200 x 0,45^2)/2x100x638 = 0,002 rad = 0,11 degrees

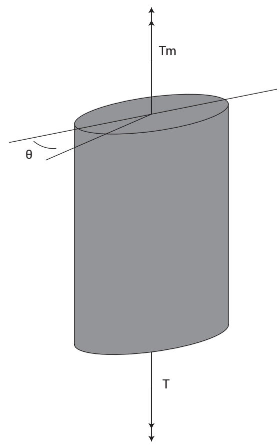
Moment:

fm = (ML^2)/(2EI = (540 x 0,45^2)/2x100x638 = 0,0009 m = 0,9 mm

0m = (ML)/(EI) = (540 x 0,45)100x638 = 0.0038 rad = 0.22 degrees

Then there is also a situation where twist can happen. When a windsurfer makes a turn, the mast will experience a force that makes it twist.

In this situation we clamp the bottom part of the mast and have the maximum shear moment on the top.



Assumptions beforehand:

- Board length is 2,3 m
- The windsurfer is traveling with a speed of 10 m/s
- G = 3/8 of E = 40
- T = 1,2 X 1,15 = 1,38 kN/m

J = (pi x a^3b^3)/(a^2+b^2) = (pi x 50^3 x 6,5^3)/50^2+6,5^2 = 43 x 10-9 m4

y = TL/GJ = (1380 x 0,85)/(43 x 40) = 0.68 rad = 38 degrees!!!

That is way too much.
But this is in a situation where the bottom is clamped. In the real life case the bottom also moves in the water. Therefore a real life test needs to be done in order to see if this calculation resembles the truth.

7.3.3 C. Cost price calculation

The final cost price for the foil was calculated using information from the company, the predicted sold products, and the cost price of the materials. The carbon fiber, epoxy resin, will be bought from a company called Fasrverbundwerkstoffe located in Germany. This company is used by PWsurfsport to buy everything they need for their carbon fiber products.

The material used for making the mast and wings is Primetex carbon fiber. The carbon fiber is priced at 15 euro per square meter. In total material used for the hydrofoil will be around 16 m2.

The amount of epoxy resin for the foil is estimated by Peter at 5 kg in total. The coast of the epoxy resin is called R&G and costs 19.09 euros per kg.

The PVC foam core will be bought at SFT Industrie CO. Ltd in China. The amount of foam needed for the mast and wings is 1.5 m2 of foam with a thickness of 40 mm. This is priced at 8 dollars per square meter. Which is approximately 0.9x8= 7.2 euros

The additional bought items from other companies such as the bolts, rivet nuts, the bag, and the toolbox are listed in the figure and estimated prices from similar products.

The marketing, servicing, aluminum mold, and other business cost are an estimation made by Peter. Next to that, the working hours per foil are also estimated.

Finally, a prediction of the amount of sold foils was made. If we look at the current market and the amount of work that goes into making one foil, we start out low with an estimated sales of 100 pieces if we divide that with the number of additional costs a total of 100 euros per foil is spent.

The figure shows that the predicted production cost of the foil will be 600 euros. The eventual cost of the product will be calculated with a profit margin. In the current market, the high-end hydrofoil prices range from 1000 euros to 1800 euros. By using a profit margin of 2, we get a total price of 1200 euros, which fits right in-between the competition.

Price estimation

	price per piece	amount	total			
Hexcel primetex	15	16	240			
Epoxy resin	19,09	5	95,45			
PVC foam core	7,20	1,5	10,8			
Protective coating	20	1	20			
bolts	0,10	6	0,6			
bolt inserts	0,20	11	2,2			
rivet nuts	0,50	2	1			
the bag	20	1	20			
the bolt box	4	1	4			
Total			**394,05**			
additional costs						
Marketing	500	1	500			
Servicing machines	1000	1	1000			
Other business costs	500	1	500			
Mold aluminium	8000	1	8000			
Total			10000	**Total price per Foil Additional costs**		
Predicted amount to sell	100			**100**		
Making molds						
working hours	1	1	1			
Making the parts	price	hours				
working hours	15	6	90			
Finishing	price	hours				
Working hours	15	6	15			
Total			**106**		**Total producing cost**	**With profit margin of 2**
					600,05	**1200**

1