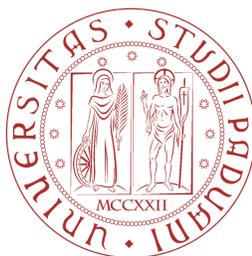


FOILING SuMoth CHALLENGE



UNIVERSITÀ
DEGLI STUDI
DI PADOVA

Foiling SuMoth Challenge Stage 1 - 2024 DESIGN, MANUFACTURING & SUSTAINABILITY

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ABSTRACT

This report revolves around the thought and design process behind the future creation of the first foiling vessel produced by Métis Vela UniPD, *Atlas*.

The project born in 2016, called *Banfi*, was abandoned due to COVID-19 and brought back to life by the post-pandemic generation of the team.

Even though *Atlas* has almost nothing to do with *Banfi*, it carries its will and here is presented from the ground up.

Starting from the core ideas, through the development of every part of the boat as well as the manufacturing process for every part that we have the possibility to produce in house.

Close to nothing, as of the day of writing this report, has been manufactured due to various inconveniences, but the hopes are high while looking forward to participating in the 2025 edition of the Foiling SuMoth Challenge with a flying *Atlas*.



INTRODUCTION

Given our long history as a sailing team that has been trying to build more sustainable alternatives for the sailing panorama, the SuMoth Challenge presented itself as the next step in our development, combining our core principle of sustainability and building eco-friendly boats with the cutting edge technology of the hydrofoils.

This year everyone pulled together and made a push to participate in the competition, and while *Atlas* is still in the works due to mishaps along the way, *Métis* finds itself breathing fresh air in the SuMoth Challenge. For that we have to deeply thank the SuMoth Association, starting with Bruno Giuntoli, for allowing us to participate.

Special thanks goes to the University of Padua, who sustains us through our endeavors, especially to professor Andrea Lazzaretto, our Team Manager, who helps out and encourages us to pursue our objectives.

One more acknowledgement goes to each and every member of the team, as without each other this wouldn't be possible, and especially to Marco Pitteri, our Team Captain, who led the way up to here.



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NOMENCLATURE

Lift distribution to be intended **Main/Elevator** in percentile

AOA = Angle of Attack

CL = Lift Coefficient

TE = Trailing Edge

LE = Leading Edge

RTM = Resin Transfer Molding

VARTM = Vacuum Assisted Resin Transfer Molding

FEM = Finite Element Method

LCA = Life Cycle Assessment

SuMoth = Sustainable Moth

COG = Center of Gravity

UD = Unidirectional

FCS = Flight Control System

VOC = Volatile Organic Compounds



1. ENGINEERING AND DESIGN

1.1. State of the art

The idea of building a foiling vessel has been lingering in the minds of the team for a few years now, but it was during the spring of 2023 that it was decided that the next sailboat would have been a Moth dinghy. Through observation of last year's edition of the Foiling SuMoth Challenge and of the Moth Class regattas taking place during the Foiling Week we understood that, while complying to regulations, the sailboats differed a lot between each other. We had an older Moth project which dated back to 2016, but due to the ever changing state of the art with this kind of sailboats, we found ourselves starting anew. Thus project *Atlas* started from the ground up.

1.2. Preliminary design

At first we started by trying to define an as accurate as possible physical system for the Moth. Given our limited knowledge on foiling vessels we started from a basilar system of forces, finely tuning it through thought out hypotheses on the boat behavior and looking at footage of other Moths. We gave particular attention to the three main stages of the navigation: the starting Archimedean state, the Lift Off procedure and the Cruising motion. The Touch Down motion was neglected and given only a thought for a worst case scenario, as we decided to concentrate on making an impact resistant boat.

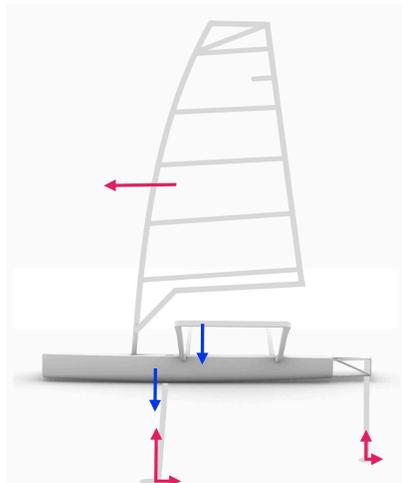


Figure 1: A simple schematics of the forces



1.3. Hull

The hull design was a big challenge at first as we never tried to build a boat of this size. Our design philosophy was based on three principles: simplicity, renewability and avoidance of extremisms.

Simplicity: both from a manufacturing, designing and usability perspective.

Renewability: as we can utilize the same hull and mould again while at the same time improve on them.

Avoidance of extremisms: we wanted to avoid extreme choices to ensure a safer and more viable life expectancy for the Moth

With these starting points we started to work on the shape of the hull.

1.3.1. Looking for inspirations

As we had no experience with Moths or any other foiling sailboats we started looking around, both in person at events and online, at other Moths.

We looked at various boats and decided to keep as our references three models: The Swift, the Bieker and the Exocet (see Figure A1 of the [Appendix](#)).

We chose these ones in the vast choice pool because they exhibited good all around performance and were the ones that came closer to what our building skills could produce.

1.3.2. Designing the hull

Given those three references we started to sketch a hull using Rhinoceros7.

Every time the design department met we would exchange ideas and doubts, especially around the topic of the most important features of the hull. The team was divided between a more draggy concept that would be more stable in the Archimedean state and a slimmer one that presented itself with narrower sections.

While working on the hull we sketched every new iteration by hand, but after a while we realized that the process was too time consuming.

We therefore developed a Grasshopper program for Rhinoceros7 to parametrize our concept through certain key features. By doing so we eased our designing process, producing many variants a week.



Figure 2: A couple of early iterations of the hull.



We had a breakthrough thanks to one of our key designers, Alberto Abiti, who came up with an idea for the water lines which became the definitive baseline for our final design iterations.

From this iteration the design team took two paths, one with a higher prismatic coefficient and one with a lower one. Through further experimentation we ended up with two models.

In the end we opted for the model with a higher prismatic coefficient that we thinned down near the bow and straightened out the deck.

We didn't run any CFD until the very end as we decided to concentrate on designing a boat whose lines varied gradually and whose hydrostatic analysis gave a stable Archimedean state. The graduality of the waterlines, now that the entire design process is complete, translated in a low drag hull through the CFD analysis (see Figure A2 at the end).



Figure 3: Atlas' actual hull.

The main measures of the final hull are as follows:

Length	3355 mm		
Stern width	370 mm		
Stern height	307 mm		
Max width	423 mm		
Max height	342 mm		
Bow height	238 mm		

Table 1: Dimensions of the Atlas' hull.

1.3.3. Hull materials

Last year we built a skiff, *Aletheia*, with flax prepreg and learned a lot from such experience. Given the mistakes that we made along the way, we decided to keep going and build *Atlas* with the same material, trying to improve on the previous project.



Once finished shaping the hull we started looking for the critical points that would need strengthening, such as the supports for the wings, the stump's hole or the attach points for the gantry.

The hull will be made of a multilayered sandwich structure composed of flax prepreg with an aluminum honeycomb in between. While the thickness of the flax will be determined by the number of skins, the thickness of the honeycomb will vary depending on the local structural needs.

For the deck we opted to go back to an earlier solution that was utilized on the *Athena* skiff of our production, a sandwich structure that layered PET foam with flax, this time utilizing flax prepreg. The matrix for the sandwich is an epoxy resin.

1.3.4. Structures

Next up was strengthening the hull, especially in critical points, like the slots for the wings, and ensuring general stiffness.

At first we decided to go with a classic scheme of bulkheads and a full length arbor, but utilizing this kind of setup increased the total weight of the system and also, given that we wanted to create a monocoque-ish hull, wasn't viable for construction.

After many iterations the structures will be composed of a hull-long beam, a bulkhead on the sides of the support for the stump and a rod that pushes from the bottom of the bow to the part of the deck right in front of the stump.

Because we decided to build a monocoque hull, with the deck and the bottom of the boat fused together, we can't place structure near the wings, as to create this sort of hull we would need to put a peculiar vacuum bag inside and outside of it, and having more structures would mean a more complex bag.

The detailed manufacturing process is detailed in the latter section [2.2.3. The hull](#).

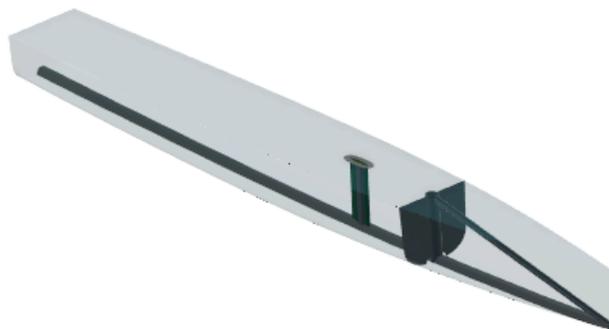


Figure 4: Internal structures of the Atlas.



1.4. Foils

Considering this would be the first time the Métis design team had to deal with foils on this level, we put a lot of thought on every step of the process and followed the same principles that were applied to the hull designing process.

1.4.1. Conceptualization of the problem

To ease the job we looked at the physical problem and studied every possible combination sailor-boat to understand the range of performance we needed.

We opted for a configuration of foils that, between main and rudder foil, produced a total of 1400N of lift, but still we had to decide the distribution between the two wings, as such would influence the sailing.

The target lift was calculated by placing a few constraints on the masses at play and on the expected performance we hoped to achieve.

These parameters are of the essence for two of the three stages described beforehand: Lift Off and Cruising Motion.

While in the Archimedean State and during the Touch Down maneuver these parameters are of far less importance.

	Lift Off	Cruising Motion
Total mass (Sailor+Boat)	120 kg	120 kg
Total lift	1400 N	1400 N
Sailing speed	5 kn (2.6 m/s)	15 kn (7.7 m/s)
Heel angle	0°	0°

Table 2: Constraints used for the design of the foils.

1.4.2. Design

The lift distribution was as much of a problem as designing the foils in itself.

Through speaking with experienced engineers and sailors we came to the conclusion that while a 60/40 would be best for a more stable approach, we could push ourselves up to a 80/20 distribution for peak performance.

This problem wasn't as straightforward as it seemed, as a different distribution would mean different designs, and in all of this we still had to consider a crew that wasn't experienced.

A disadvantage of having a high delta in the distribution would be that eventual pitching movements would be accentuated.



Some of us started to delve in the literature to look for inspiration and asked about for insights, while others tried their best to sketch from the ground up a set of foils.

This process took months, and through what would be around 20 complete sets of foils we varied both in planform and profile.

After fixing a lift objective we started to look through the extensive catalog of hydrofoil profiles that are the most frequently used and analyzed in literature.

Some of the profiles initially analyzed were:

NACA 63412	MH42
AG 24 Bubbledancer	RG14
GOE 565-il	S2048

Table 3: Profiles taken in consideration at first.

As read left to right, the profiles can be seen in the [Appendix](#).

Thanks to the knowledge from our courseworks and a bit of analysis with XFLR5 we narrowed down the work to a NACA 63xyy, whose numbers signify different characteristics of the wing.

The first single digit represents the optimal lift coefficient at an ideal AOA, calculated through theory.

The “3” indicates the placement of the maximum camber in percentile, calculated as a fraction of the chord

The “x” is the distance in tenths of the cord from the LE to the maximum camber point.

The last two numbers represent the thickness over chord ratio in percentile.

One of the main points of discussion was the camber on the main foil, as having more of it would mean an assured higher CL, leading to more lift force generation, and letting us use a smaller wing, which would lead to less materials used. The other choice was to go the opposite way, with less camber, a safer option as eventual incidents would be easier to control.

After extensive discussions with some of our professors and industry experts we decided to go for less camber to minimize the possibility of stalling.

Using XFLR5 we analyzed the various profiles, ending on the NACA 63412 as a starting point. From then on through trial and error we worked with the *INVERTED DESIGN* function of the software. Thus we developed a profile whose polars graphs satisfied us, keeping in mind that we couldn’t design something that would render the water flow laminar for the whole length of the profile as in case of a stall would bring us to a catastrophic end.

Through various iterations we ended on our final version that let us work on the shape of the foil.



Given that we had no prior experience in the field we looked around and thanks to sailors and ex-team members we could get a few measurements of their setups. Once we obtained those measurements we started to experiment with shapes and sizes.

Every time we modeled a new foil we would change our profile and adapt it to the various sections, as at the tip the foil works in different conditions than the ones at the root of the foil.

At first we started from the textbook examples of a planform, given a certain wingspan and chord, we opted for a trapezoidal and elliptic shape and worked on those.

To ensure a balanced performance from the entirety of the foil we opted to maintain an elliptical distribution of the lift over the wings.

After various iterations we opted for a double elliptical planform with trimmed tips as with it we could hope to guarantee a good overall performance, minimize the drag from the vortices at the tips and a viable form for manufacturing.

A member of the hydrodynamics team, Marco Salvato, together with our Team Captain, Marco Pitteri, built a script for MatLab and a Grasshopper extension for Rhinoceros7 to ease the work, as through MatLab we could create the dat files of the wings we studied, described in every characteristic, while the Grasshopper script helped us create the 3D models from those files. The CAD models were built keeping in mind that with our building skills we had to keep a TE gap of a few tenths of a millimeter, as building a razor sharp exit tip would be nigh-impossible.

These CAD models have then been utilized for complete fluid dynamics and structural analysis.

One of the main focuses of these two analyses has been the central bulge, as it had to be structurally sound and not compromise the performance of the foil in any meaningful way.

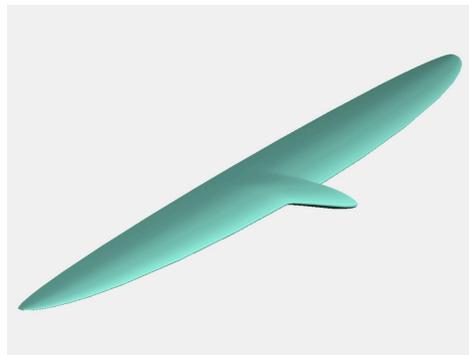


Figure 5: The latest main foil

Given the multiple functions of the rudder foil, as it is needed for lift generation, for maneuvers and trim control, we decided to use a symmetrical airfoil. While this choice lowers the system's efficiency, it allows effectiveness for both negative and positive AOA of the wing, which is a desirable feature for a control device.



The optimization process of the appendages will go on throughout the summer, even after the 2024 SuMoth Challenge, given that we only participate in the S1 phase and we are still far from the production of the foils.

1.4.3. Verticals

The vertical is the part of the Moth that sustains about all weight load during the fly and it must maintain the foil in the design position to let it work properly. For this reason, we take care about the design process of this part with the objective of reducing weight and maximizing stiffness.

First, we made an estimation about the forces acting on this part and we noticed that the most critical conditions occur when half foil is ventilating. For this reason, we decided to study the structure in the design condition (when the boat is flying) and in this critical condition. During the nominal conditions there are only two forces: Drag and Lift. At this point of the design process we didn't know exactly the magnitude of these forces so we estimated them considering other boats.

We started the design process dividing the vertical in two parts: a straight one and the connection part between the vertical and the foil.

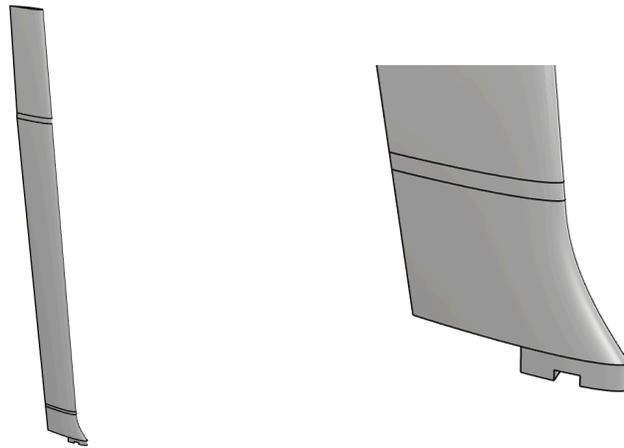


Figure 6: The complete vertical (left) and the joint for the main foil (right).

Our efforts have focused on the first one because it is the most stressed. We started to evaluate the shape and we chose a symmetrical profile due to the reduced drag. We discussed using an aluminum shaped tube in the center with the aim to improve the stiffness, but we decided to use UD carbon fiber as reinforcement and that allows us to reduce the weight.

It has been decided to develop a Finite Element Analysis on the transom with the purpose of estimating the behavior of this component.

FEA results concerning stresses and displacements in the design condition are reported below in the [Appendix](#).



The given results are borderline acceptable; going forward we are going to further develop the internal structures and make tests to see the actual strength of the finished piece to ensure safety for our sailors and structural resistance.

1.5. Wings and Rig

1.5.1. Wings

For many meetings we discussed the wings and after various ideas were thrown around, such as mono-curve wings or straight tubes bent at certain angles, the chosen design is a double S with 25 degrees inclination to avoid immersing during manoeuver, connected to the hull through recesses on hull and deck.

Once we defined the first design the main issue was the choice of the materials: at first we thought of building a wood frame with rigid composite panels in flax and aluminum honeycomb.

Opinions were sought out on various types of wood, and ash was the best alternative, although after many iterations of profile section even with PET core and fiberglass reinforced there was a stiffness problem and the weight to avoid excessive deformation was too high. In the end we opted to build an aluminum, squared section frame and the fabric of a decommissioned sail instead of panels, kept in place by a sliding cord for awning and some elastic ropes.

We opted for a squared section as it has the best resistance to flexing, especially when compared to a circular one.



Figure 7: Wings of the Atlas.

Wings length and width overall	1100 x 2249 mm
Wings inclination	25°
Wings height over deck	405 mm
Wingbars section	50 x 50 mm

Table 5: Wingbars dimensions.



1.5.2. Gantry

We first discussed the feasibility of various designs, shapes and materials. We previously experienced the design and construction of a gantry for a 1001 VelaCup skiff, consisting of an aluminum tubular frame, which led to a simple, solid and proven structure. Despite its simplicity, we decided that aluminum tubes were too heavy for this new application, so we considered either carbon tubes in a frame or a carbon monocoque design. We thought that monocoque design would have led to better performance, but we decided to discard this solution due to lack of time, need of lower production costs and construction simplicity in our first attempt.

We finally focused on the tubes, trying to design a simple but effective way to align them and solve inaccuracies of our first tubular frame. Second, we spent time thinking about attachment points, ending with ballpoint joints and clevises: this solution ensures simplicity and flexibility to the frame, in order to have the ability of trimming simply by regulating the threads. A key point of this configuration is the ability to quickly adapt a possible evolution of this gantry for the next edition of SuMoth or a spare one in case of damage. We are currently discussing a way to integrate rudder mounting points, in order to withstand lift forces coming from foil wing: these forces, coupled with others, will also add strain to the gantry mounting points located on the stern. We are finding the best solution to strengthen the area without compromising our challenging manufacturing plan.



Figure 8: The gantry of the Atlas.

1.6. Electronics and flight control systems

1.6.1. The stability problem

Concerning the stability of the boat, we mainly focused on the longitudinal stability during the cruising phase. We decided that the structural aspect of the design had priority on the distribution of mass and on the position of the various elements of the boat. For this reason we decided to give us the possibility to change some parameters of the boat that have influence on the matter.



These parameters include the incidence of the main wing, the position of the sailor along the wings and possibly the addition of weights to achieve better stability.

We developed a flight simulator and thanks to it we could analyze the cruise phase for different wind conditions, different ride heights and different positions of the sailor. We found some different configurations in which static stability is reached.

The main problem was modeling the transient phase at lift off, especially while the hull was still in the water. This phase of the flight will need more study and a more refined system of equations that describes it and is of the essence to create a FCS that works.

1.6.2. The flight control system

The control system on foiling vessels dictates whether or not these boats perform to the full extent of their capabilities.

To solve this problem the main option is to utilize a sensor wand, as it hits the water below the boat it regulates the flight height by adjusting the flap of the main foil.

One may regulate the sensitivity of the wand thanks to built-in adjustments in accordance with parameters such as the optimal AOA for the main foil and depending on the external conditions.

The mechanical system is a thoroughly studied and understood mechanism, with its strong points and problems caused by changes in the surface of the water, such as waves.

These events may cause the sensor wand to fully extend or to rapidly vary its angle, causing the flap on the main foil to move at a similar speed, bringing a sudden change in performance and causing crashes.

As a way to lessen the probability of these events to occur we decide to opt for a short term solution and a more complex one for the future.

The first choice is to place an electronic filter between the spar that carries the motion from the wand to the staff that moves the flap, while the more complex one is the development of a fully electronic flight control system by our electronics department, SailTrack.

After observing closely the moth structure, to understand how it works and how to apply our knowledge at its best, we decided to create a digital representation of the mechanical system by sampling the wand movements and the consequent flap adaptation. The data acquisition process and framework developed by the SailTrack for our skiffs has been adapted to the purpose of flight control for the Moth. As said earlier, we opted for the mechanical system as we considered it a time-saving approach.

More specifically, we chose the mechanical controlling model to regulate and avoid common problems, as already mentioned, such as drag and regulation.



In the takeoff phase, the position of the flap increases the drag, because of the max lift angle. The digital controller will allow us to create presets for the foil angle during the lift off phase and, therefore, to decrease the drag.

Hence, every single regulation of the mechanical system being digitized makes it easier to manage the settings for the foil, in order to save time and increase efficiency.

Pragmatically speaking, the mechanical system replica was created using two main components: a rotary encoder placed on the wand pivot point, in order to keep track of the wand angular motion, as the process input; while another sensor correlates the acquired data to the main foil position. This procedure has the purpose of determining the link between both the wand and foil position, that then will be codified in a controller that pilots a servo motor and will, finally, actuate the main foil pushrod.

The long-term solution we are planning to develop is way more interesting from our point of view and requires more digging, since it needs a deeper mathematical understanding.

We chose a model-based approach, using to good advantage a Simulink model, created by our team member Marco Salvato, to design a reliable controller for the moth.

We will put it to use as soon as we have completed building our moth, since we prefer to study the process using exact data and, most importantly, focus on the efficiency of the whole system.

This is further complicated by the lack of experience, hence we decided to go with a reliable system for the time. It will help the system of working sensors created for the other boats, that permits us to track in real time many parameters, such as the COG, the wind intensity and direction, the boat speed and many more.



2. MANUFACTURING AND COST ANALYSIS

2.1. General description

As of the writing of this report close to nothing has been manufactured due to lack of materials and general delivery problems, probably by June we will have the master mould completed and hopefully will be working on the female mould.

2.2. Hull

We decided that the hull would be built in a three step process: first would come the master mould, then the female one and inside of it we would create the hull.

2.2.1. The master mould

While working on the hull we kept in mind that we had to create a geometry that could be built at our building skill level. The *Banfi* had a symmetrical mould already built, completely made out of plywood, which we will partially utilize to create the new master mould.

The bigger planks of plywood will be cut to shape and shaped to match the tangency to the CAD surface. Together with the Head of Construction we opted for the strip-planking method. This method is our safest choice to create a 1:1 replica of the hull's CAD, keeping in mind that time will be of the essence and a job done better early on would mean less sanding down the line, resulting in less waste produced.

While the ribs will be built with plywood, the strips will be made out of Yellow Pine, which is tender and easy to work with. With a jigsaw we will route the planks to ensure a snug fit. The method utilized for the routing is that of the “bead and cove”, which ensures high precision.

Once the master is finished we will try to smooth out the imperfections and fill the gaps with putty and then sand it down.

To end the job we decided to 3D print the last two centimeters of the bow as the geometry would have been complex to make with wood.

This will also help detach the female mould once it's completed.

2.2.2. The female mould

The next step is the manufacturing of the female mould.

For the SuMoth we decided to opt for a dry flax infused mould, keeping the use of the flax prepreg only for the actual hull.



We decided to go back to infusing the mould as the process that we utilized for the previous boat, *Aletheia*, of laminating glass fiber with gelcoat gave us a few problems that should be prevented this way.

One of the main concerns is the integrity of the die as well as the internal finish, which will dictate the outer surface smoothness of the hull. The latter will impact both the period of construction and the materials used, as eventual corrections and repairs would lengthen the process and increase waste production.

As for the integrity of the die, if the process is not conducted with precision and with everything under control, points of weakness could present themselves and impact negatively on the hull structure.



Figure 9: The female mould

2.2.3. The hull

After the female mould is done we can finally start to layer the hull's materials together with the internal structures.

Everything has been studied to lower the weight while maintaining a sound structure both for an increased performance and to utilize less materials.

The various layers will have between 1 to 2 cm of overlay to ensure security and connection.

The carbon fiber used in the structure will be all upcycled from previous works that we made.

The vacuum bag needed to bond the deck to the rest of the hull is placed inside and comes out through a hole between the mast and the daggerboard trunk. Such a place will result in the most stress and will be reinforced with the carbon fiber. The permitted quota of carbon fiber will mainly be used to fix the deck to the hull.

This procedure, while complex and with a few downsides, will result in continuity between the deck and the hull, which should grant great structural benefits by following the results of the various FEM analysis. The union of the two parts will be granted once the entirety is processed in an autoclave.



2.3. Foils

Once we finish working on the wings, we will design the moulds for them with extreme care as we planned to manufacture the foils utilizing the VARTM method.

To ensure a safe and long life expectancy to our wings we opted to build them with carbon fiber and epoxy resin.

We opted for Vacuum Assisted RTM as it has two main benefits compared to infusion and the normal RTM: it spreads the resin equally throughout the various layers of fibers and it reduces the consumption of it. The resin reduction can be up to 30% compared to the standard RTM. In fact, while the RTM process has a percentage of fibers equal to approximately 30% by weight and a percentage of resin equal to 70%, the VARTM process has of a percentage of fiber load that increases up to 60% by weight of the laminate with the remaining 40% of resin.



Figure 10: Sample of a foil tip made trough VARTM

Given that we are getting close to finishing the designing of the foils and lack the materials we have yet to create them, the main option is to make the dies out of wood and treat the surface with a lacquer of some sort to have a great surface finish.

It goes without saying that doing so isn't comparable to a die made out of machined aluminum in terms of smoothness, but the upside is in the modifiability at low expenses and recycling of the wood.

While in other parts of the project we have decided to have a bigger ecological footprint with certain processes or materials, with the foils' moulds we decided to make something that could be modified easily as we are no experts in terms of foil making and everything we are making could result in a failure.

2.4. Verticals



Once the shape was selected, we started talking about the manufacturing process. We chose to use two different processes to produce the vertical parts: a RTM process for the connection part and a lamination process for the straight part. About the lay-up, we agreed to use two carbon woven layers as skins and four UD carbon fibers as stiffener core in the largest section.

2.5. Wings

To build the wings we plan to rely on an external company specialized in tube bending, especially with square section tubes, since achieving the necessary tolerances we need machinery that we do not possess. For the fabric on which the crew sits and moves, the aim is to find a decommissioned sail and cut it to the right shape using templates, then thread the rope that will support it through appropriate eyelets. On the edge closest to the hull, we plan to attach it using a C-profile with a rubber core sewn directly onto the fabric, which will slide inside.

2.6. Rig

Regarding the rig, our initial plan was to use an old mast and an old sail, bought new in 2016, that were gifted to us by an ex-team member who has a Moth and replaced it a couple of years ago.

Subsequently we also explored the possibility of purchasing a complete used setup (mast, sail and boom) because this was the easiest and the cheapest way to have a certain starting point and we were sure the whole rig would fit perfectly. Furthermore this approach allowed us to optimize both costs and sustainability.

Similarly we will do with the wand system, which will be bought once we have the hull completed.



Figure 11: The current mast

2.7. Gantry



Considering our previous experience in building a tubular frame, we focused on more efficient ways to cut tubes and prevent alignment issues.

We are currently set on the idea to use more templates in the first phase of the assembly, trying to replicate the transom with its mounting points using a wooden board and clevises. Then position another template halfway and ending with the vertical tube. In order to properly cut tubes, we think that should be easier to print templates in common paper, made on CAD software simply by unrolling the surfaces of the tubes including the cuts.

In a similar way to our first experience, we will wrap carbon cloths at intersections to ensure connection between tubes of the frame.

2.8. Materials

The main materials that will be used for the production of the *Atlas* are:

Wood

Mainly used for the construction of the master mould due to being easily available, does not need special treatments to be used and is the eco-friendliest choice for this type of work.

Dry Flux

Our preferred choice for the creation of female moulds, optimal substitute in place of carbon fiber, especially for this use since it has similar properties to its prepreg counterpart.

Carbon Fiber

Kept to the quota that can be utilized in the build, is used for the main stress points, given that we have no experience with this kind of vessel and we want to make a safe structure while abiding by the ecological standard of the competition.

Aluminum Honeycomb

The choice for the core given its great properties, especially its flexibility that permits us to use it for the whole length of the hull. For these qualities we have chosen it over the PET foam that we used on previous projects.

Flux Prepreg

As the main material used for the hull will permit us to build and manufacture the *Atlas* without many concerns regarding the hardships that it's going to endure.

PET foam



To calculate the environmental impact and the lifecycle plans of materials, we decided to take into consideration the main parts of the elements of the boat with their secondary parts: hull, hull moulds, foils and wings.

Hull

The hull will be made of a multilayered sandwich structure composed of flax prepreg with an aluminum honeycomb. Flax fiber is very interesting from the ecological point of view, so for this reason it is taken into consideration by the team as it is renewable and recyclable, and it is obtained from natural sources. This translates into a reduction in dependence on non-renewable resources, as well as contributing to environmental sustainability. The use of these natural fibers also offers great advantages in terms of the lightness of the final product due to their low density. Otherwise, the aluminum honeycomb structure is light and characterized by high mechanical properties, such as resistance to compression and shear, and also has great advantages in terms of sustainability. In fact, aluminum is 100% recyclable; it is an infinitely reusable material to create new products every time and the recycling process requires only 5% of the electricity needed to produce primary aluminum.

Hull Moulds

While the female mould will be consisted in a dry flax infused mould, whose characteristics have been explained previously being flax also used for the hull, also the master mould will be manufactured in materials environmentally friendly: Yellow Pine that will be utilized to make the strips that compose all the surface of the mould and poplar plywood panels to make the ribs. Furthermore, the last two centimeters of the master mold will be made by 3D printing, using polylactic acid (PLA), a bio-based thermoplastic that can be recycled. To make the female mold, the resin used to infuse the flax fibers is the SX38 HT epoxy resin for high temperatures, which unfortunately is a material that cannot be recycled.

Foils

Foils will be made with carbon fiber and epoxy resin SX8 EVO through Vacuum Assisted Resin Transfer Molding (VARTM), a manufacturing process that is also a relatively cost-effective solution compared to normal RTM due to lower tooling and processing costs. RTM and VARTM are also very clean processes with low volatile organic compounds (VOCs). Because of the carbon fiber, the foils can't be recycled.

Wings



Differently from the more sustainable initial idea, which involved the construction of a wooden frame with rigid composite panels in flax and aluminum honeycomb, due to mechanical resistance problems, we chose to use an aluminum frame and instead of the panels, the fabric of a decommissioned sail. However, this new choice has allowed us to use a metal that is always highly recyclable, aluminum, and to reuse parts of old boats, thus allowing the recycling of materials.

3.3. Actions for a sustainable future

With a view to increasing the performance of boats, the choice and research of increasingly high-performance and at the same time “green” materials realized with eco-friendly processes, are one of the objectives of our team. Today, fiber-reinforced composites are difficult to recycle and require high energy to be produced, so to make more sustainable composites, different considerations must be taken into account to achieve this objective. Surely the use of natural fibers, such as flax fibers, is a way to reduce material impact, which are also characterized by high specific properties. One of our issues is also to find valid alternatives, from a mechanical and performance point of view, to carbon fibers that in our case are used in the foils. In fact, carbon fiber can't be recycled and its production requires high energy consumption and high CO₂ releases. Added to this, important is also the possibility to replace thermoset matrix materials, such as epoxy resins, used in our case for the construction of the foils and of the hull moulds, by using thermoplastic resins, that are recyclable. Also, the incorporation of recycled/recyclable materials, such as in our case the reuse and the arrangement of recycled parts from old boats, can lead to a more eco-friendly solution.

Taking all of this into consideration when we were designing we optimized in a way to make the parts renewable and improvable, especially the hull part, on which we spent a lot of time to have a product that is solid and whose form won't lose in performance in the future. In the same vein is our approach for the rigging and the wings, as buying or building lasting items, that will need little maintenance, will lead to a lower footprint over the years.

4. TEAM & RELATED



4.1 TEAM OFFICERS

- A.1.1. Marco Pitteri
Team Captain
- A.1.2. Leonardo Rensi
Team Co-Captain and Chief Designer
- A.1.3. Leone Tuci
Communication Officer and Sailing Crew Captain
- A.1.4. Luigi Giacomelli
Head of Construction
- A.1.5. Pietro Salata
Head of Marketing
- A.1.6. Andrea Dragonetti
Head of the Finance Department

4.2 SPONSORS



SVILAPP
Sviluppiamo Applicazioni







4.3 ACKNOWLEDGEMENTS

A special thanks goes to these companies and the people that make them, as with their active financial investments and their availability to teach us and share their know-how they helped us reach success. Thanks to them we can experiment and try out new solutions for our boats, giving Métis Vela UniPD a stable platform from which we can further our work.

5. MARINESHIFT 360 LCA

5.1. General results

We carried out the life cycle assessment (LCA) considering only the materials used to create the master mould.

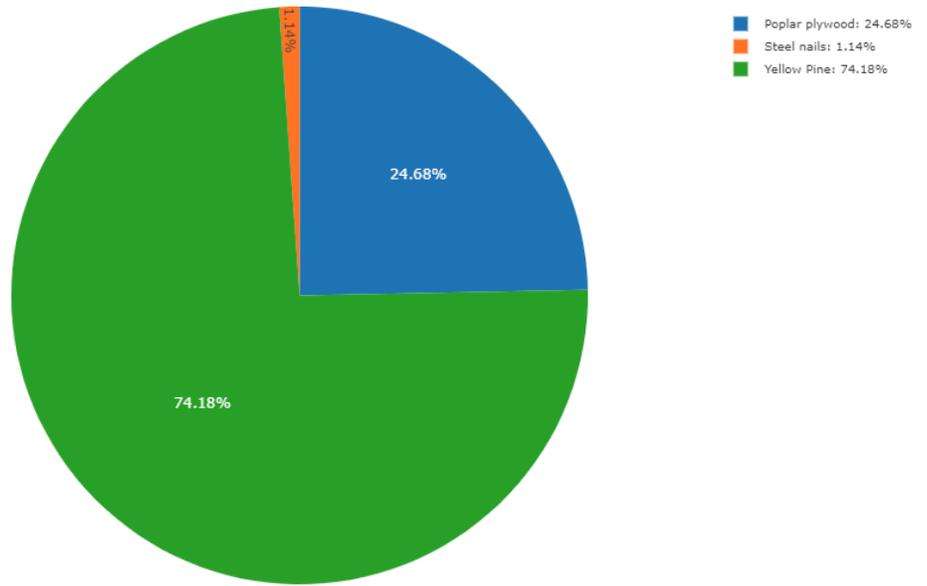


Figure 12: Energy consumption - renewable

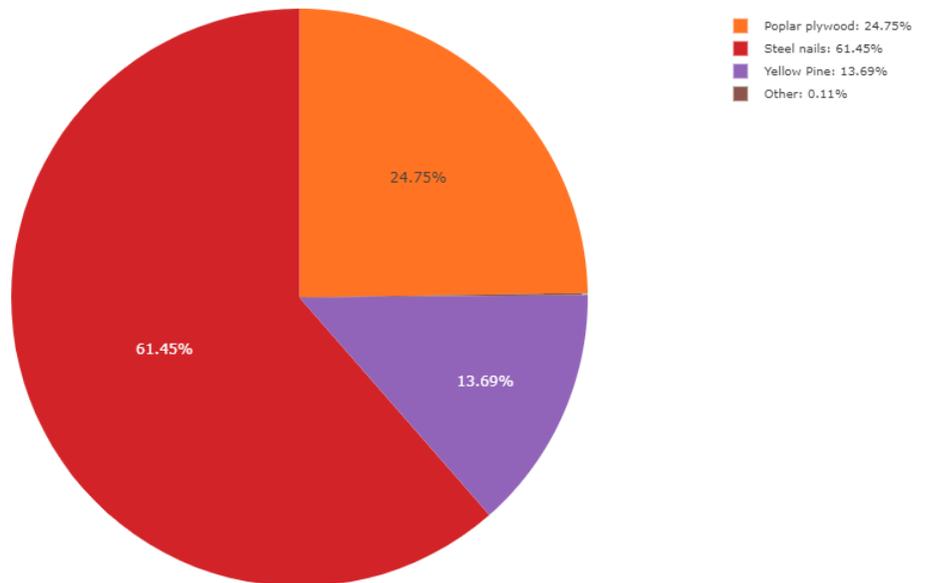


Figure 13: Global warming - fossil

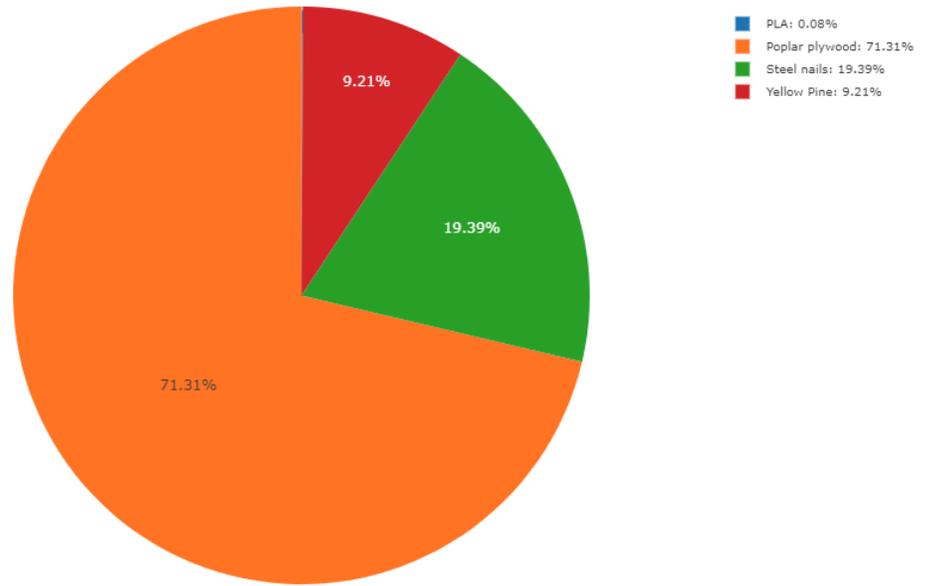


Figure 14: Water consumption

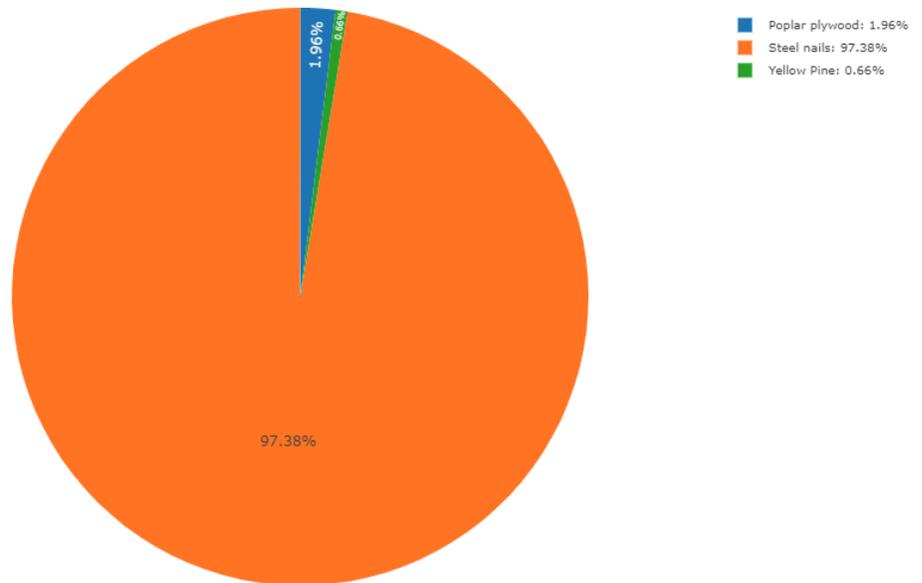


Figure 15: Mineral resource scarcity

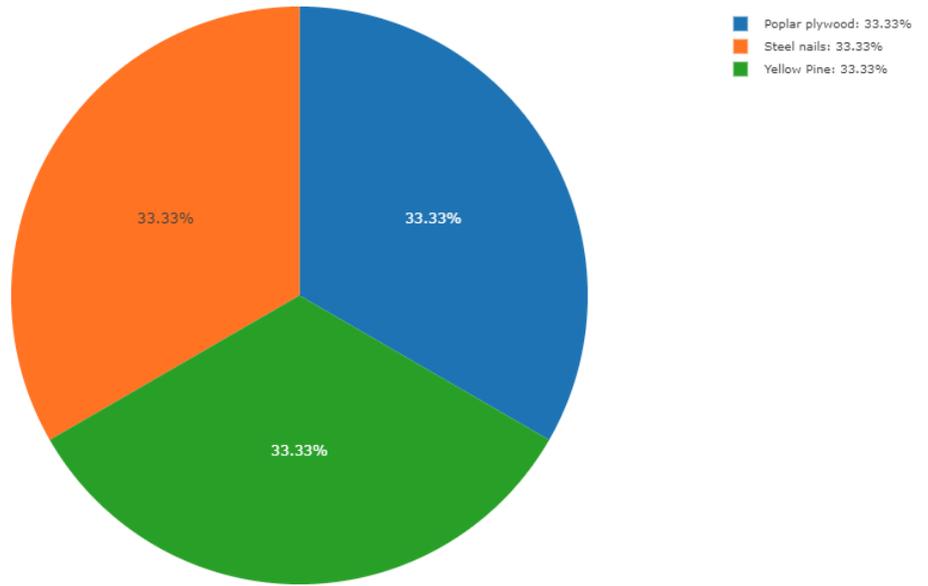


Figure 16: Marine eutrophication

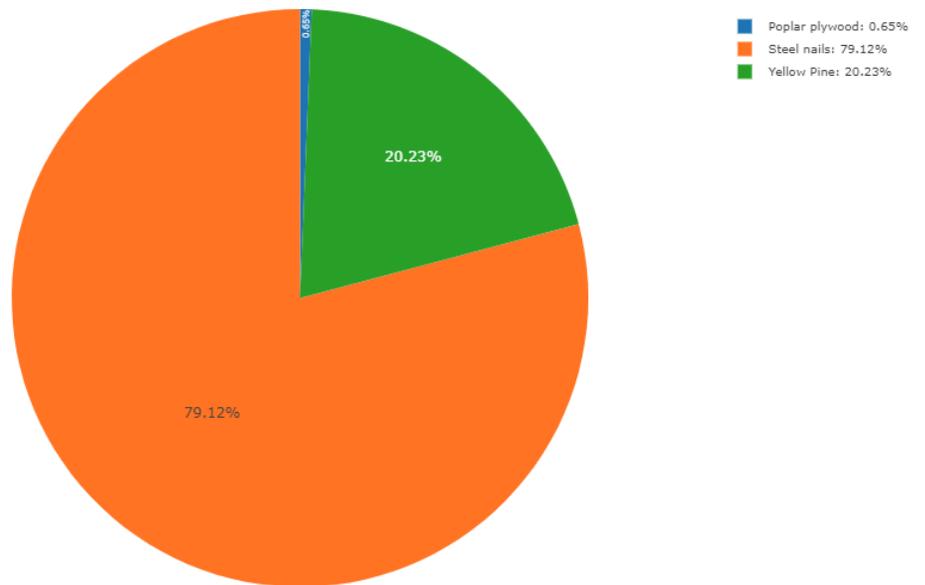


Figure 17: Waste factor



6. BIBLIOGRAPHY

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Fabio Eggert - "Flight Dynamics and Stability of a Hydrofoiling International Moth with a Dynamic Velocity Prediction Program (DVPP)" - thesis

Mike Drela - [Airfoil Tools](#)

IMCA (2017), International Moth Class Rules, International Sailing Federation

SailTrack - [GitHub - metisvela/sailtrack: Performance Tracker for Racing Sailboats](#) - website

MarineShift360 - [MarineShift360](#)

A. APPENDIX A - MS360 LCA

Boat life cycle assessment discussion

Despite the limited life cycle assessment that we were able to carry out, considering the only part actually built, i.e. the master mold of the hull, we can in any case make some considerations on the main materials and processes that we will use. Our forecast analysis shows that the gantry and foils will represent some of the biggest environmental impacts of the boat because they will be made respectively of carbon tubes, carbon fiber and epoxy resin, which have excellent mechanical properties, but cannot be recycled. Despite our difficulty in finding alternative solutions to carbon, the creation of carbon foils will be carried out using Vacuum Assisted Resin Transfer Molding (VARTM), a clean process with low VOCs, which also involves a more limited use of epoxy resin compared to normal RTM. For the rest, most of the efforts from a sustainability point of view will be made on the hull of the boat and its moulds.

In fact, this choice led us mainly to consider renewable and recyclable flax fibers for the construction of the hull and wood for the creation of the master mold.

Overall results & CO2 equivalent impact

The overall results and the CO2 equivalent impact for the manufacturing can't be shared yet given the state of the project.

Predictions in this early stage would be misleading and going forward we can't know if they will be respected.

We will keep writing down each and every procedure to make a correct assessment for next year's SuMoth Challenge.



APPENDIX

Figures, tables and calculations the likes of CFD and FEM analysis cited throughout the report are found here as per instructions.



Figure A1: The Swift Moth by Damic Design (top left), the Bieker Moth by Mackay Boats (top right) and the Excet Moth by Maguire Boats (bottom).

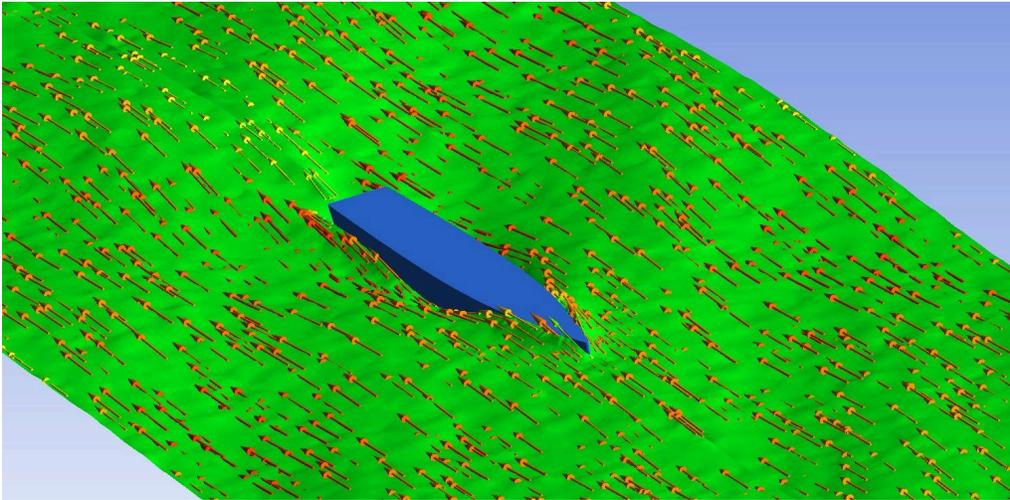


Figure A2: CFD of the hull in the Archimedean State.

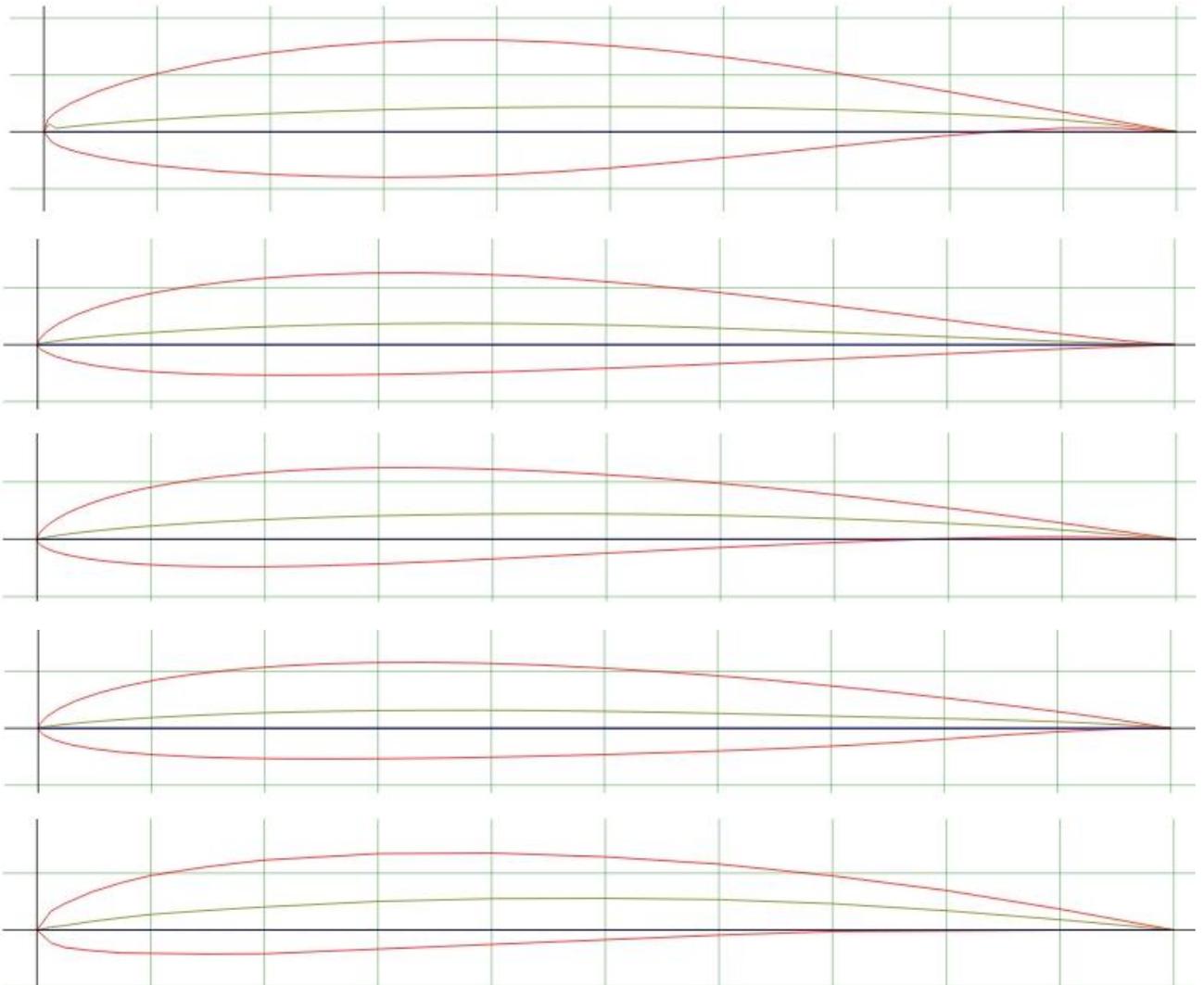




Figure A3: From the top: NACA 63412, MH42, AG-24 Bubbledancer, RG14, GOA-565-il, S2048.

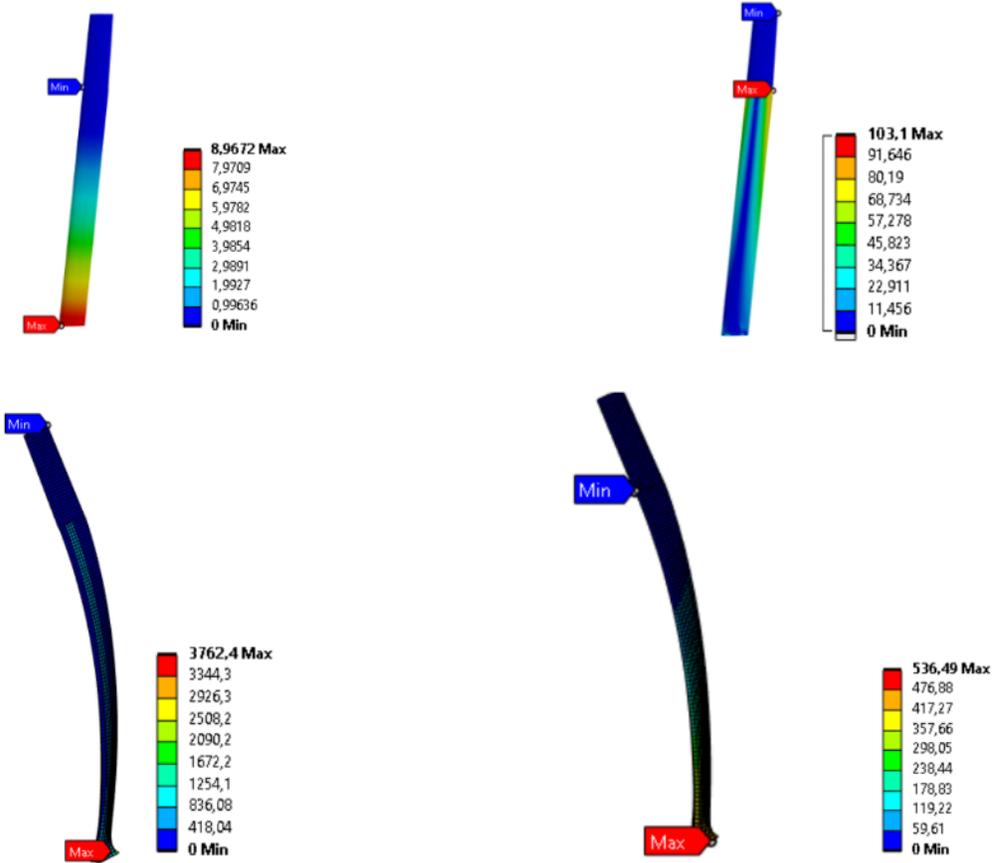


Figure A4: FEA results concerning stresses and displacements on the verticals.