FOILING SuMoth CHALLENGE

POLITO SAILING TEAM

Politecnico di Torino

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

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Contents

ABSTRACT

This report aims to describe the design, manufacturing and sustainable aspects of the development of a modified moth prototype concept; firstly, the conceptual phase is described, explaining the choices made throughout the project starting from the description of the new structural design of the vertical of the foils, followed by the design of a new gantry, concluding with the new electronic flight control system and the telemetry system. In this report, there is no reference to the hull, deck and deckhouse because no new additionsor changes have been made concerning these parts. After the design section, this report briefly explains the manufacturing aspects even though the previously mentioned elements are still in the making. The last section regards the sustainability aspects highlighting the differences between the old concept and the modified one in terms of the environmental impacts of the choices made.

INTRODUCTION

This year, the Polito Sailing Team decided to compete at the SuMoth Challenge with 2 moths, a new one and Sula, the one we used at the previous two editions. We value thework done in previous years and we wanted to refit our boat again to allow it to competeat Lake Garda another time. The refit project started in the autumn of 2023, analyzing all the problems and weaknesses found during the SuMoth Challenge 23 and before, and at the same time pointing out the strengths and results obtained.

Once the research phase ended, we developed the action plan to refit the moth and match the performances wanted. The boat underwent several upgrades, including the design of a new gantry for improved stability, a complete refit and new paint for the hull, and a changing control line setup for better performance. Our project also concerns the design and integration of a wireless electronic control system. Our system is designed to elevate the performance, stability, and maneuverability of foiling boats, opening new innovative frontiers for sailors in the world of sailing.

We would like to thank our sponsors, our professors and our former team members who were always willing to answer our every question and to help us bring new ideas to improve the work done and encourage team spirit. After this year's work, we are happyto say that the result we achieved is both innovative and revolutionary at the same time even with the boat going into its third year of development; we can still research and bring improvements in every area without building a new boat, but rather by exploiting the work already done.

LIST OF TABLES

LIST OF FIGURES

1. ENGINEERING AND DESIGN

1.1. Rudder

1.1.1 Structural Design

Last year, CFRP (Carbon Fiber Reinforced Polymer) was selected to achieve the highest structural resistance, along with GFRP (Glass Fiber Reinforced Polymer). The combination of these two materials offers excellent mechanical properties and a better sustainability solution compared to using pure CFRP alone.

	Rudder
Navigation Speed	$3 m/s$
Incidence	$4.5°$
Leeway Angle	$3°$
Heel Angle	$0°$
Navigation Speed	$4 m/s$
Incidence	$-4.6°$
Leeway Angle	$3°$
Heel Angle	$15°$

Table 1: Operative conditions used for structural design (In order, nominal and critical ones)

The mass percentages of the two materials are both roughly 50% and fully respect the constraints imposed by FSMC's rules. The materials' mechanical properties obtained from an in-house testing campaign are listed in Table 1 below.

Mechanical property	Symbol	Magnitude $[MPa]$ UD CFRP 400 g/sqm	Magnitude $[MPa]$ Biaxial CFRP 200 g/sqm	Magnitude $[MPa]$ UD GFRP 160 g/sqm	Magnitude $[MPa]$ Biaxial GFRP 300 g/sqm
Young Modulus	E1	163480	15520	57200	23750
$90°$ Young Modulus	E2	8190	15520	N/a	23750

Shear Modulus	G12	4830	26348	19450	14230
Tensile Strength	Xt	1890	139	1200	425
Compressive strength	Xc	1200*	N/a	450*	N/a
90° Tensile Strength	Yt	20	139	N/a	425
90° Compressive Strength	Yc	70*	N/a	N/a	N/a
In-plane shear strength	S	50	320	43	196

Table 2: CRFP and GRFP mechanical properties obtained from the in-house testing campaign (**: data obtained from literature, N/a: data not available*)

Linear static analyses were conducted on the rudder assemblies to study maximum stresses and determine the layering to be used for component manufacturing. These analyses led to the subdivision of the appendage structure into main plies and smaller reinforcement plies to optimize material contribution and distribution. In fact, there are several plies where stresses are more intense compared to others; furthermore, CFRP is utilized where the risk of fracture is greatest. Additionally, there are many unidirectional (UD) plies on both the foils and vertical components. These enhance bending behavior, while 45° biaxial plies were added to resist stresses resulting from torque application. Furthermore, a spar was introduced into the rudder vertical to ensure greater stiffness and reduce its displacements. A detailed table with the new ply lay-up for rudder and rudder foil can be found inAppendix B.1

All analyses were conducted using *Altair OptiStruct solver*. Results of the simulations show that the most stressed part are foils' fuselage (bulb) sides and the verticals' joint areas. This is because of the bending moment and its course along the wingspan. Contact forces and locations are in expected ranges and show the expected behavior. Stress concentrations can be observed in n areas where there are geometrical variations, and in proximity of ply stack changes due to the presence of local reinforcements. Displacements show a relatively rigid behavior of the entire appendage, in line with the objective of having high stiffness for boats' stability. In fact, displacements are designed to be less than 10 percent of the longitudinal dimension of the component, so that the approximation of small deformations and pseudo-line behavior is valid. Moreover, this range of values ensures that the desired fluid-dynamic performance is achieved.

1.1.2 Changes Made in Stratification

This year we revised the structural design of the vertical component of the rudder, applying the same design philosophy used for the centerboard in order to prevent it from breaking and prolong its life. We optimized the distribution of carbon fiber composite (CFC) material within the structure to enhance its resistance under load.

In the previous design, one ply of CFC extended throughout the entire length of the vertical component. However, in the revised design, we strategically removed this continuous plie and replaced it with two plies that only extend to 50% of the length of the vertical component. This adjustment is based on the understanding that a better material distribution can be achieved by concentrating more CFC near the constraint zone, where the bending moment intensity is higher.

By reallocating the CFC from the less stressed regions (first half of the length) to the more critical areas (second half of the length), We have effectively increased the structural efficiency. In practical terms, this means that the carbon fiber, which waspreviously positioned in areas experiencing low bending moments, is now utilized inregions with high bending moments. This targeted reinforcement ensures that the vertical component of the rudder is better equipped to handle the stresses encountered during operation, resulting in a sturdier and more reliable structure.

1.2. Flight Control System

1.2.1 Electronic Control System

Commercial moths depend on a variety of mechanical components to regulate the riding height of the boat. Even though this has become the industry standard, this system can exhibit various flaws. The mechanical control system is intricate and clustered, as every aspect, from the riding height to the wand's elastic tension, is adjusted with a sailing rope. These factors add to the already complex controls of the moth. Another significant issue can be found in the mechanical slope, which can produce an inaccurate and imprecise actuator response on the push rod.

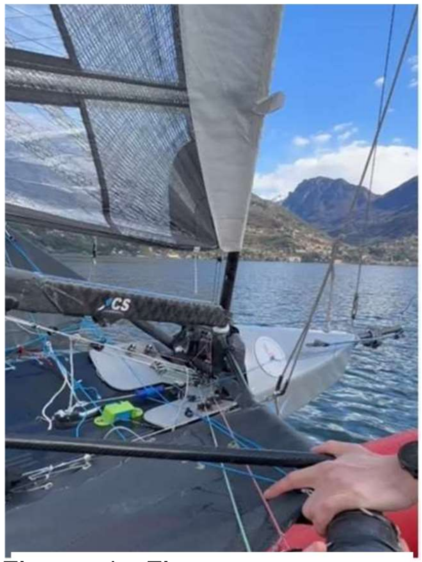

Figure 1: First test on water

1.2.2 Introduction

To address the previously said issues the electronic control system has been design withsome guiding points to address those flaws:

- Enhancing the overall stability and maneuverability of foiling boats, ensuringsmooth transitions between foiling and non-foiling states.
- Developing an intuitive user interface for boat operators, allowing them to easily adapt, fine tune and monitor the foiling system, providing real-time feedback on the remote.
- Improving performances by exploiting the possibility to set the foil at the minimum drag configuration, just before the take-off phase (ETO Enhanced TakeOff).

The electronic control system utilizes a servo motor to actuate the flap control surface ofthe main foil. A target ride height is initially chosen by the sailor, whom it is given the possibility to adjust it in a second moment. The system uses the feedback from the heightsensor and from the IMU to feed the controller which aim for the given target. The electronic controller surpasses the mechanical system in terms of performance by incorporating a GPS. This addition enables the system to improve the aerodynamic efficiency of the main foil, thereby enhancing its capabilities.

1.2.3 System Components

Ultrasonic Waterproof Sensor (JSN-srt04)

The ultrasonic sensor uses sonar impulse to determine the distance of an object, in thiscase the height of the boat from the water surface, this module has a sensitive range from

20cm up to 600cm with a tested measurement rate of 100 ~ 200ms. The sensor works bysending a high frequency sound, with the ultrasonic transmitter, when signaled by the *trigger pin.* Then, if the sound bounces on an object the wave is reflected and come backto the module. The sensor "listens" for the ultrasonic sound with the ultrasonic receiverand then sends data via the *echo pin.* Since the speed of sound in the air is known andthe sensor collected the time between *trig and echo,* it is possible to compute the distance of the object.

Servo Motor Hitec D845WP IP67

A servo motor is a rotary actuator that allows for precise control of angular position, velocity and acceleration in a mechanical system. The motor is coupled witha sensor for position feedback to control its motion and final position. The motor model has been chosen for its capabilities of providing strength, speed and precision.

Voltage [V]	Torque [kg/cm]	Speed [Sec/60grd]
4.8	32,5	0.26
6.0	40,5	0.21
7.4	50,0	0.17

Table 3: Servo Motor Characteristics

The servo motor is the only moving element of the system, through a single lever theservo-arm is connected to the flap rode and this allows the motor to operate directly onthe flap's angle on the main foil.

Esp32 D1 Mini

ESP32 is a series of low-cost, low-power system on a chip microcontroller with integratedWi-Fi and dual-mode Bluetooth. The mini version suits perfectly with our needs: it allows to have the same performances as the normal size one but in a smaller scale with less GPIO pins. This model is indeed necessary to elaborate the data coming from the ultrasonic sensor.

Battery Shield V1.2.0 for D1 Mini

This battery shield allows the Esp32 D1 mini to be powered by a mobile power supply. Thischip also enables short charging times with a maximum charging current of 1000 mA. Thanks to the integrated charge control, with automatic switch-off, your battery is alwaysprotected against overcharging.

ElioIOT

ElioIOT is a complete development board equipped with built-indifferent kind of sensors and features, such as Light Sensor, Pressure and Altitude, Laser Distance, Accelerometer and Gyro,
MicroSD Slot, charging support and more. The board is poweredby a more powerful version of the Esp32 series, the Esp32-S3 one. This module has also various GPIO pins that allows it to control different elements.

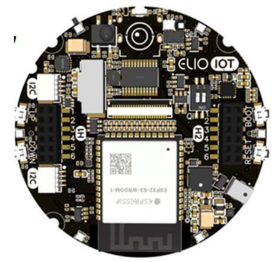

Figure 2: ElioIOT

Neo-6m Gps module

The NEO-6M GPS module is a well-performing complete GPS receiver with a built-in which provides a strong satellite search capability. With the powerand signal indicators, it is possible to monitor the status of the module. Thanks to the databackup battery, the module can save the data when the main power is shut down accidentally.

LCD Module 2004 20x4 i2c interface

This Lcd module communicate useful information to the users and enables the possibility to change the system settings to fine tuning end to visualize some parameters.

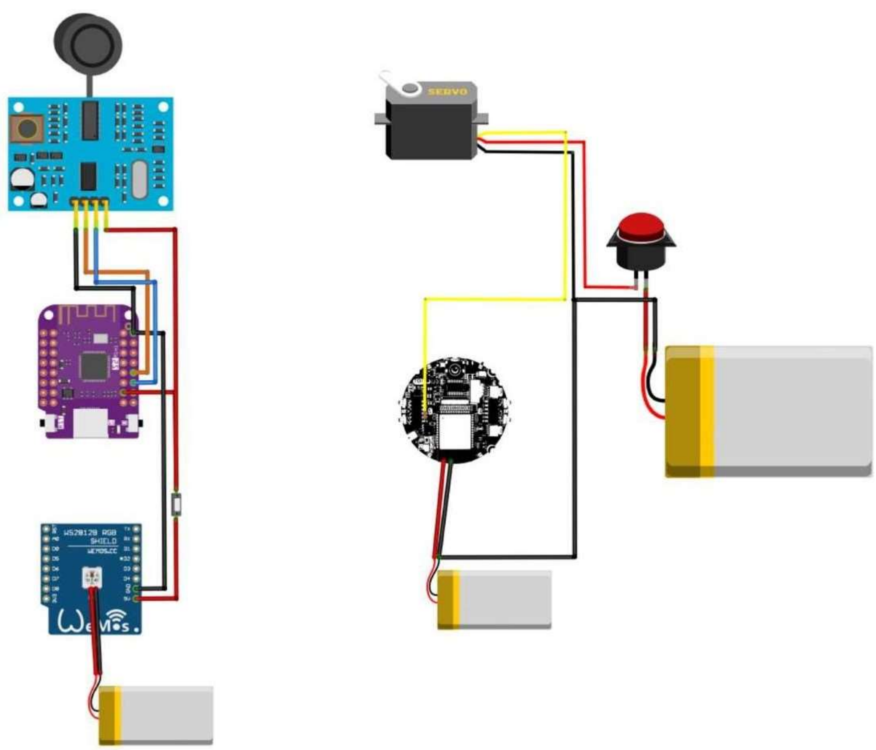

Figure 3: Circuit Diagram

1.2.4 Additional Components

3D printer

The system relies on 3D printing for the encapsulation of all the sensors, the cases are printed and the openings are waterproofed with a ring of silica and a sets of screws. The servo motor case is also 3D printed, allowing protection and an easy mounting point on the boat.

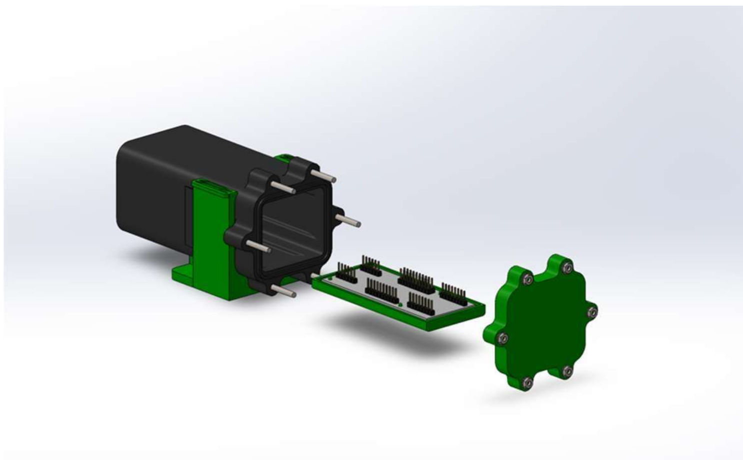

Figure 4: 3D printed waterproof box

Batteries

All the microcontrollers are powered by a LiPO rechargeable battery 3.7 V 2000mAh 1S. The servo motor is instead powered with a LiPO rechargeable battery 7.4 V 4500mAh 2S 25c.

Waterproof On/Off Switch

A waterproof self-lock switch is added to power off and power on the servo motor only when needed.

1.2.5 System Composition Overview

The control system operates on a two-tier architecture, consisting of a central hub and multiple independent sensor nodes. This is thought to improve the robustness to failure due to the harsh working environment on which the system operates. By making each module independent, it is possible to avoid at least one possible single point of failure and thus making the system safer. Communications between nodes happens on WIFI IEEE 802.11, with a costume packet system built specifically for this purpose. This ensures less cable work on both the boat and the modules, making maintenance easier and faster.

Distance nodes

Each sensor node is equipped with an ESP32 Mini D1, a LiPo battery, a battery shield, anda JSN-srt04, it operates as a self-contained unit, encapsuled in a waterproof box, responsible for computing the height.

Distance nodes position

Since the modules needs to have the ultrasonic transmitter and ultrasonic receiver exposed to measure the distance, the designated position is attached on the bowsprit, facing down.

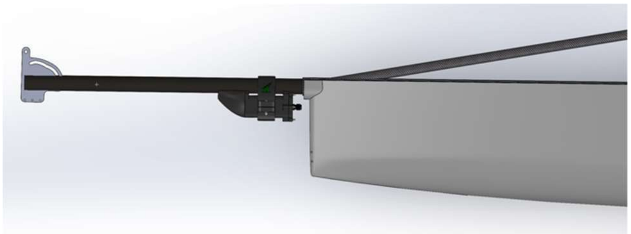

Figure 5: Height module position

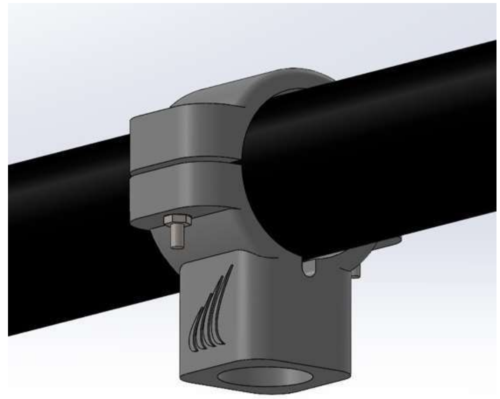

Figure 6: Ultrasonic sensor position

Hub

The central hub is equipped with a ElioIOT module, LiPo battery and the neo-6m gps module. It plays a pivotal role in collecting, processing, and storing data from distributed sensor nodes. It acts as the brain of the system and thanks to the real-time distance data computes the correct flap angle. The hub exploits the two cores CPU architecture of the Esp32-s3 provided by the ElioIOT board, one core is designated to handle all the communications coming from the distance modules, the gps module and the remote while the other core is assigned to the control task. This enables the hub to perform both tasks at maximum performances reducing the latency. Inside the hub waterproof box, the is also the battery that powers the servo motor.

Hub Position

The designated hub position is behind the deckhouse, this allows the safety of the components and an easy point access.

Remote

The remote is equipped with an ESP32 Mini D1, a LiPo battery, a battery shield, an LCD module end a rotary encoder. The receive the speed and the current distance from the hub and displays them together with the gps status on the LCD screen to allow the see the system data in real time.

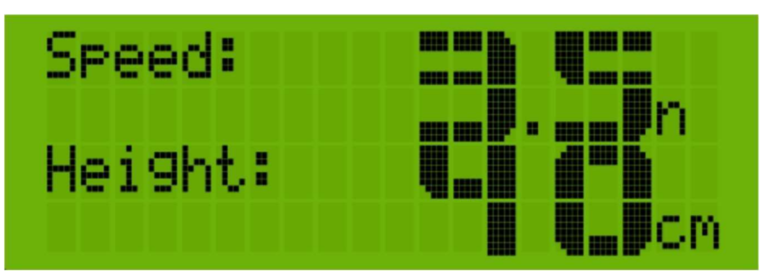

Figure 7: Remote LCD - Speed and Height Screen

The Remote is also capable of sending different settings to the Hub, this improves the versatility because is possible to try different configuration while on water.

The configurable parameters are:

- Target flying height
- Enhanced Take Off
- Max Flap Angle
- Min Flap Angle
- Neutral Flap Angle

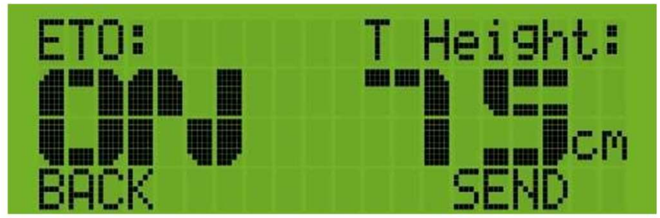

Figure 8: Remote LCD - Enhanced Take Off and Target height settings

1.2.6 Flight Control

The flight control flow starts in the distance node where the water distance is computed every 100 ~ 200ms, this bottle neck depends only on the ultrasonic sensor type. After the computation the data is sent to the hub where some pre-processing happens, outliers are removed with a median filter, this ensures more safety if the received distance is not in the expected range, more over a correction on the measured height is performed by applying trigonometric to account for roll and pitch conditions. The angle of corrections is retrieved from the built-in IMU (Inertial measurement Unit) of the ElioIOT, hence a more accurate distance value is used in the control operations.

The flight control relies on the proportional–integral–derivative controller (PID), this controller is suitable for this use case since a dynamic modeling of the boat sailor system is extremely non-linear and can be a trivial task.

PID Controller

A proportional–integral–derivative controller (PID) is control loop mechanism employing feedback. A PID controller continuously computes the error between a target point (r(t) – target height) and a measured variable(y(t) – current height) and applies corrections based on three parameters: Proportional (Kp), Integrative (Ki), Derivative (Kd).

The controller tries to minimize the error by constantly regulating the control variable. Those adjustment are computed as a weighted sum of the control terms.

$$wd_c = K_P * e(t) + K_I \int e(t) + K_D \frac{de(t)}{dt}$$

$$e(t) = r(t) - y(t)$$

Figure 9: PID Equations

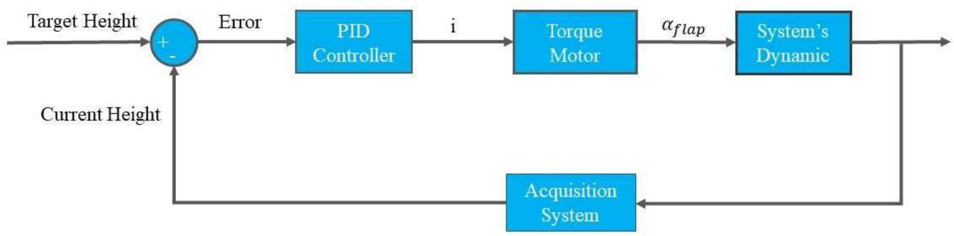

Figure 10: Eletronic System Control Model

Parameters tuning

Each of the tree PID parameters accounts for a different behavior:

- The Kp term sets how proportionally large the control output should be withrespect to the error. Using only the proportional term will result in an error between the target point and the processed value since the proportional dependson the error itself.
- The Ki term accounts for the past values, it tries to eliminate the residual error by adding a control effect due to the historic cumulative value of the error. When the error disappears the integral also stop to grow, this reduce the effect of the proportional since the error is going down.
- The Kd term is the estimate for the future term, it tries to reduce the future error based on the current error rate trend, so bigger changes produce greater control effects.

Based on the previous assumptions we studied the case of a PI controller by setting Kp = 0.8, Ki = 0.5 and Kd = 0.0. The choise to set the derivative to zero is determined by the factthat a derivative action on the control could interfere with the overall stability of the flight, without appropriate filtering.

Adaptive Parameters

The system's output is the angle of the flap that the controller computes to reach and maintain the chosen height. To further improve the controller performances a technique of adaptive parameters is exploited. This trick allows the system to change autonomously the configuration of the PI, thus changing its behaviors. The starting parameters are set as said in the previous paragraph, then as the boat come closer to the target height those coefficients are slowly changed, until saturation, to reach a configuration more conservative that can maintain the target height more smoothly improving stability.

Enhanced Take Off (ETO)

One of the main purposes of the electronic system is to improve the performances of the mechanical one, this led to the development of a new way of taking off. The boat is designed to start rising at a specific speed, to make easier reaching the foiling speed this new feature sets the flap of the main foil in a neutral position where it produces the lowest amount of drag possible. By doing that, the boat can start foiling before the conventional one and since that it is the configuration on which it is designed to have the best performances, this system is able to improve the boat's efficiency.

1.2.7 Telemetry System - Lily

Introduction

The project has been designed with three main objectives:

- Developing a modular telemetry system that can be reused on many different boats enabling the user to collect the data from different boats.
- Allowing the support boat to be aware of both the system status and the boat performances via an intuitive user interface.
- Collecting and storing data on an SD to access the training information on a second moment, this is a crucial part to be able to validate the boat's numerical dynamic model.

System Components

Some components are the same used in the control system, we will report the same description below.

Ultrasonic Waterproof Sensor (JSN-srt04)

The ultrasonic sensor uses sonar impulse to determine the distance of an object, in this case the height of the boat from the water surface, this module has a sensitive range from 20cm up to 600cm with a tested measurement rate of 100 ~ 200ms. The sensor works by sending a high frequency sound, with the ultrasonic transmitter, when signaled by the *trigger pin.* Then, if the sound bounces on an object the wave is reflected and come back to the module. The sensor "listens" for the ultrasonic sound with the ultrasonic receiver and then sends data via the *echo pin.* Since the speed of sound in the air is known and the sensor collected the time between *trig and echo,* it is possible to compute the distance of the object.

Esp32 D1 Mini

ESP32 is a series of low-cost, low-power system on a chip microcontroller with integrated Wi-Fi and dual-mode Bluetooth. The mini version suits perfectly with our needs: it allows to have the same performances as the normal size one but in a smaller scale with less GPIO pins. This model is indeed necessary to elaborate the data coming the different sensor attached on the boat.

Battery Shield V1.2.0 for D1 Mini

This battery shield allows the Esp32 D1 mini to be powered by a mobile power supply. This chip also enables short charging times with a maximum charging current of 1000 mA. Thanks to the integrated charge control, with automatic switch-off, your battery is always protected against overcharging.

LILYGO® LoRa32 V2.1

An Esp32 development board with integrated Wi-Fi and dual-mode Bluetooth also equipped with 0.96-inch display, a LoRa SX1278 /SX1276 module which allows low frequency radio communication and an built in SD card writer/reader

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9-DoF Orientation IMUs – BNO085
An Inertial Measurement Unit (IMU) which consists of gyroscopes to measure and report angular rate, accelerometers to measure and report specific force and magnetometer to measure the surrounding magnetic field.

GPS Breakout - Chip Antenna, SAM-M8Q
The SAM-M8Q GPS Breakout is a high quality, GPS board with equally impressive configuration options. The SAM-M8Q is a 72-channel GNSS receiver, meaning it can receive signals from the GPS, GLONASS, and Galileo constellations. Thanks to the data backup battery, the module can save the data when the main power is shut down accidentally.

Batteries
All the microcontrollers are powered by a LiPO rechargeable battery 3.7 V 2000mAh 1S.

3D printer
The system relies on 3D printing for the encapsulation of all the sensors, the cases are printed and the openings are waterproofed with a ring of silica and a sets of screws. The servo motor case is also 3D printed, allowing protection and an easy mounting point on the boat.

3.5-Inch TFT LCD Screen

A 3.5-inch color screen with 480X320 resolution which supports 65K color display withtouch functionalities. Uses the SPI serial bus to comunicate with micro-controllers.

System Composition Overview
The wireless telemetry system operates on a two-tier architecture, consisting of a central hub and multiple sensor modules. This choice is justified by the harsh condition of the working environment, which heavy test the system robustness. By making each module independent the system is able to keep working although one of the modules fails. Communications between nodes happens on WIFI IEEE 802.11, with a costume packet system built specifically for this purpose. This ensures less cable work on both the boat and the modules, making maintenance easier and faster.
Distance node
The sensor node is equipped with an ESP32 Mini D1, a LiPo battery, a battery shield, and a JSN-srt04, it operates as a self-contained unit, encapsuled in a waterproof box, responsible for computing the height.

Distance nodes position

Since the module needs to have the ultrasonic transmitter and ultrasonic receiver exposed to measure the distance, the designated position is attached on the bowsprit, facing down.

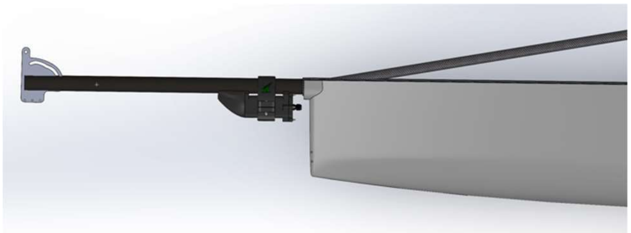

Figure 11: Height module position

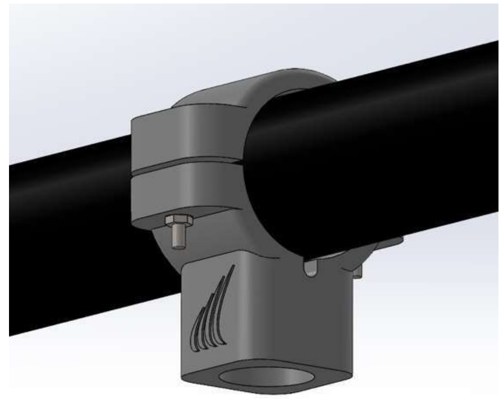

Figure 12: Ultrasonic sensor position

IMU node

The sensor node is equipped with an ESP32 Mini D1, a LiPo battery, a battery shield and the BNO085 IMU, it operates as a self-contained unit, encapsuled in a waterproof box, responsible for computing the roll, pitch and yaw angles.

IMU node position

The designated position of the IMU node is inside the deckhouse, this allows to have a fix position reference to compute di angles and to preserve the module from unexpected hits.

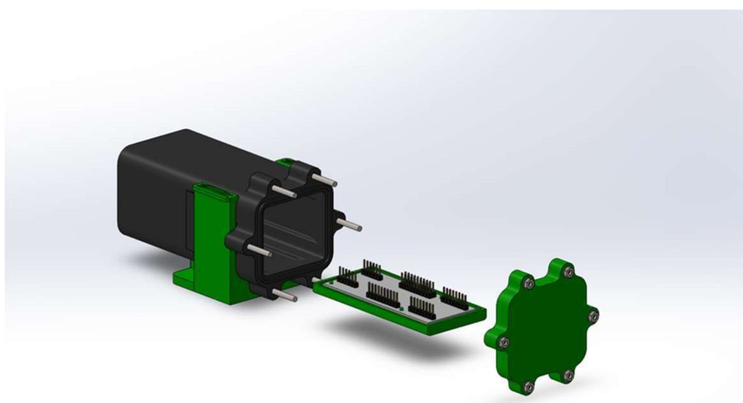

Figure 13: 3D printed waterproof box

Hub

The central hub, equipped with a LoRa32 module, GPS, battery, battery shield and an SD card, plays a pivotal role in collecting, processing, and storing data from distributed nodes.The Hub work can be divided in different bullet points:

- Data Collection and Formatting: The hub is responsible for receiving data from various sensors distributed on the sailing boat Upon receiving data from the sensor modules, the hub process and aggregates the information and creates a formatted in a CSV line that encapsulates all relevant data points such as position,speed, distance from water, roll, pitch and yaw.

- Data Storage: The formatted data is then stored in an SD card.

- Sensor Status Monitoring: Simultaneously, the hub monitors the status of each sensor module. It regularly checks if the sensor nodes are "alive" by sending a query at predefined intervals.
  The hub maintains a data structure that records the status of each sensor modulebased on their responsiveness. If a sensor fails to respond the status in the structure isupdated accordingly.

- Periodic Sensor Status Update: At predefined intervals, the remote initiates a request for status updates via the LoRa or WIFI module. The response includes the value of status structure and sensor readings, enabling the remote to presenta complete view over the system.

- Start/Stop Data Recording:
  The hub is designed to listen for remote commands via the LoRa communicationsystem. It
  checks for specific signals indicating whether to start or stop the data recordingprocess.
  If a "start recording" command is received, the hub initiates or resumes the data recording
  process, appending new data to the existing record. If a "stop recording" command is
  received, the hub concludes the recording process, finalizing the current session’sdata.

Remote

The remote control is composed by Lora32 module and the TFT screen it serves as a userinterface for interacting with the central hub, providing the capability to initiate and terminate the data recording process remotely. It also allows to have a real-time data visualization to see theboat’s performances during test, trainings and races.

Figure 14: Remote User Interface

1.3. Gantry

The gantry was elongated to maximum length, while complying with the SM Competition rules, to achieve better dynamic flight stability. To do this we changed the lengths and the angles of the tubes while re-using the existing mounting points. During the design process, we explored the idea of making a gantry almost as a continuation of the shapeof the hull but we couldn't manage to find a way that applies with Moth class rules.

The design process for Sula's attachment system began with a focus on creating a robust internal structure capable of withstanding various mechanical stresses encountered during operation.

The design starts as a continuation of Sula's rear section and gradually converges towards the point where the rudder is attached. This combination ensures the attachment system is both robust and lightweight, contributing to the vessel's stability and efficiency.

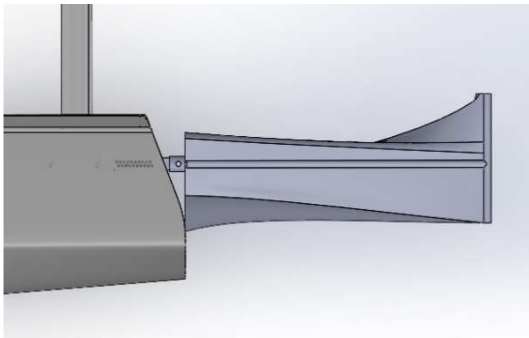

Figure 15: New Design of Gantry

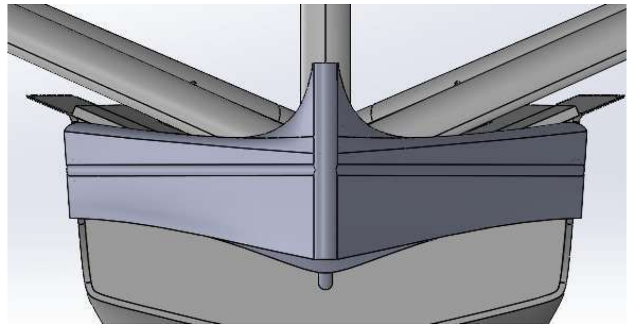

Figure 16: View of the gantry showing the 3-point attachment

Three-point Attachment

The design incorporates a three-point attachment connected with tubes at the rear of the boat. This already existing configuration provides a stable and balanced connection, crucial for maintaining structural integrity.

Tubular Connections

The attachment system consists of two types of tubes; side tubes and central tubes. Each type of tube plays a role in managing the stresses encountered:

Side Tubes: There are two side tubes, one on each side of the structure. These tubes are responsible for absorbing and managing lateral tensions that arise from the sides of the vessel. To handle these forces effectively, the side tubes are designed to be thicker, providing additional strength and rigidity.

Central Tubes: The central section of the attachment features two tubes aligned vertically. These tubes are tasked with managing vertical tensions. Given the different nature of these forces, the central tubes are designed to be thinner than the side tubes, optimizing the material use while ensuring sufficient strength to withstand vertical stresses.

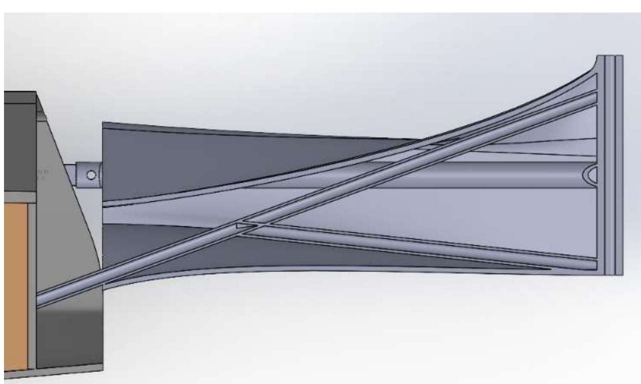

Figure 17: Cross section view of Gantry

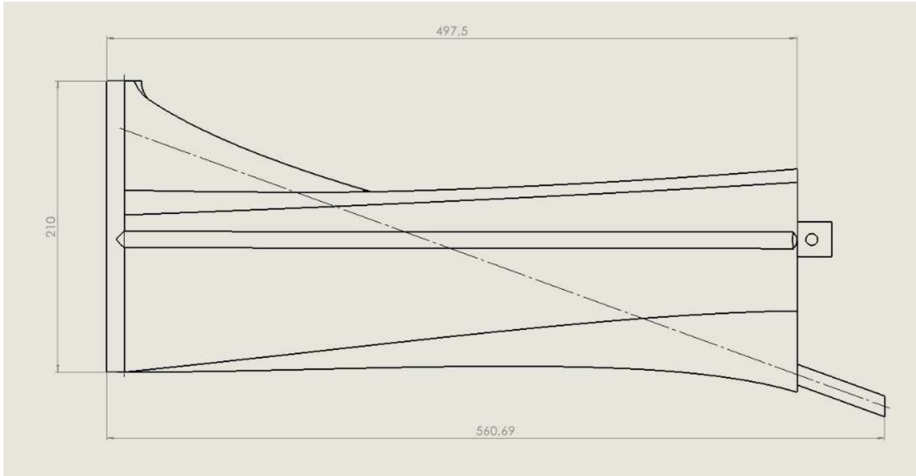

Figure 18: Dimensions of the Gantry

Based on the dynamic analysis, we identified the most stressed planes, areas, and directions within the attachment system. This load analysis revealed critical regions where the component experiences different types of stress: traction and compression. The analysis indicated that the bottom part of the structure predominantly undergoes traction, while the upper part, which completes the shape, primarily experiences compression. Given that the stiffness of this component is directly related to the overall rigidity of the boat during sailing, this piece must demonstrate minimal deformation and high stiffness.

The gantry's design incorporates manufacturability ideas aimed at facilitating future lamination procedures. By simplifying the lamination process, we ensure that the production is efficient and the quality of the lamination is consistently high. This approach minimizes potential errors and reduces the time required for each lamination cycle.

The bottom part is subjected to significant traction forces. To address this, we are implementing a sandwich lamination approach in these areas. Sandwich lamination involves placing a core material between two layers of CFC, providing additional strength and rigidity to withstand traction forces effectively.

The workflow continues with a Fem analysis on the piece, which is currently in process to have a definitive decision on the stratification.

1.4 Wand Length Control

We changed the wand the length control line which was a placed on the deck and metal wire passes through the front of the boat and connected to tip of the wand . Instead we use a rope circuits which is starting from the tip of the wand and passes from outside of the hull from the blocks and goes to the wings. In this way we made it easier for the sailor to change the sensitivity of the wand depending on the conditions on water .

2. MANUFACTURING AND COST ANALYSIS.

2.1. Rudder

2.1.1 Mold Preparation

The molds were cleaned, sanded, resin-coated, and filled (where necessary), then proceeded with finishing and polishing.

HORIZONTAL MOLD: We reused the molds used for the previous laminations. Only one was reshaped because the MDF was damaged in an area corresponding to the trailing edge, and filling the defect would have compromised the line.

At the baseboard of the upper valve of the horizontal, a 3D printed insert was placed. This was designed because this is the area that breaks most frequently when the valve detaches from the mold. The modification thus allows the mold to be reused for multiple laminations as the printed part is more resistant. The insert also allows for less interference during the coupling of the mold and the pre-laminated baseboard. Due to a CAD design issue, the insert was smaller than the host hole, so before lamination, we filled the gap with putty so that resin would not accumulate in the area.

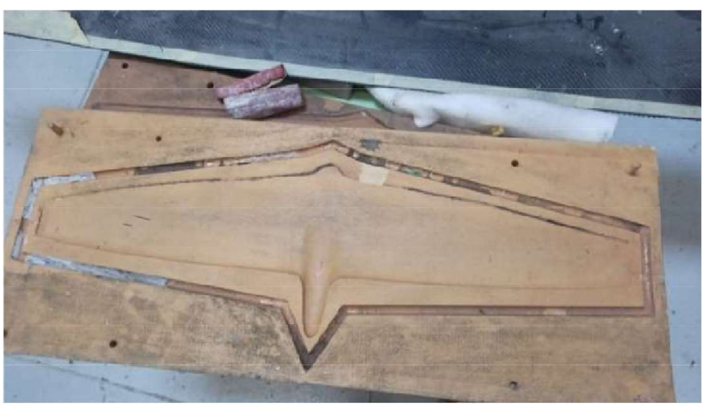

Figure 19: Rudder Foil Mold

Figure 20: 3D printed Insert

2.1.2 Fiber Cutting

We designed the templates from the mold and then proceeded to fiber cutting. Despite the upper valve of the horizontal having the baseboard, the skins were cut with the same template because when inserting the pre-laminated baseboard, it has rounded edges and therefore does not require an excess of fiber.

2.1.3 Valve Lamination

Horizontal Baseboard Lamination:

To achieve greater precision of the joint, we laminated the baseboard a couple of days before laminating the valves using the Teflon mold. For this lamination, we used two bi-axial carbon skins and fiber straps (UD).

Figure 21: Laminated Baseboard

The valves were then hand-laminated onto the molds. As we learned last year the wasteof consumables and the resin is much less this way we completed the lamination by impregnation of the fibers directly in the molds. First, we inserted the pre-laminated baseboard. In the horizontal lamination, the fit was not perfect, probably because the Teflon mold on which the baseboard was laminated was warped.

After many fit checks between each pair of valves, the laminates were glued together using loaded bio-based resin. Expanding epoxy foam was used as a filler. The moldswere clamped together tightly and left to cure

Figure 22: Rudder Lamination Process

Valve Finishing:
We finished the laminated valves by sanding the excess fibers along the edges so that the molds would fit together.

2.1.4 Molding Closure

Vertical Closure:
Before closing the vertical molds, we fixed the threaded insert required for the horizontal to vertical joint with loaded resin. We inserted a threaded rod inside to maintain alignment with the appropriate groove.

Mold Opening and Rudder
FinishingTube Lamination for tiller
We wrapped a carbon tube on the top of the verticals. We used 3 biaxial carbon fibers and one UD fiber. Additionally, we placed another fiber transversely to secure those placed axially. The second time we did the process, we wrapped a carbon tube where the hole for the pin had already been made.

Figure 23: Finished Rudder

2.2. Gantry

The gantry has not been manufactured yet. Once this has been completed, this section will describe the production's steps in detail.

2.3. Cost Analysis

This section includes all costs in SM$ for this year's project.
In tables 4,5,6 all costs for the appendages (laminates) are listed.

In table 8 we have listed all electronics purchased this year. As per the SMC rules, theSM$ equivalent of all electronics purchased for data acquisition and EFSC were considered as equivalent to their purchase price in Euros.

Rudder Molds				
	Description	Unit Quantity	SM$/Unit	Total Cost(SM$)
Vertical	MDF [kg] Machining(CNC)[h]	12.6 2	10 40	126 80
Vertical	Total Vertical Mold			206
Foil	MDF [kg] Machining(CNC)[h]	14 3	10 40	140 120
Foil	Total Rudder Foil Mold			260
Total				466

Table 4: Rudder Mold Costs

Rudder				
Description		Weight [kg]	SM$/kg	Total Cost (SM$)
Vertical	Std.Epoxy Resin	1.14	25	28.5
	CF T700	0.465	150	69.75
	GF-E	0.172	25	4.3
	GF-S	0.308	75	23.1
	Epoxy Foam	0.161	25	4.025
	Insert(stainless steel)	0.02	30	0.6
	Total Vertical			130.275
Foil	Epoxy Bio-Based Resin	0.403	15	6.045
	CF T700	0.177	150	26.55
	GF-E	0.095	25	2.375
	GF-S	0.107	75	8.025
	Epoxy Foam	0.135	25	3.375
	Total Rudder Foil			46.37
Total				176,645

Table 5: Rudder Costs

Hand Lay-Up Lamination Consumables			
Description	Unit Quantity	SM$/Unit	Total Cost(SM$)
Vacuum Bag[m^2]	2.8	2	5.6
Breather[m^2]	2.09	3	6.27
Peel Ply [m^2]	2.09	5	10.45
Spiral Tube[m]	3	1	3
Tacky Tape[15mroll]	0,47	8	3 .76
WAX Release Agent[kg]	0.045	5	2.25
PVA Release Agent[L]	0.072	2	1.44
Total			32.77

Table 6: Hand Lay-Up Lamination Consumables Costs

3D Printed Components				
Description		Unit Quantity	SM$/Unit	Total Cost(SM$)
IMU Box Closure	PLA[kg] 3D Printing	0.040 0.087	10 20	0.4 1.74
IMU Box	PLA[kg] 3D Printing[h]	0.102 3.25	10 20	1.02 65
IMU Support	PLA-CF 3D Printing	0.030 1.02	10 20	0.3 20.4
GPS Box	PLA[kg] 3D Printing[h]	0.144 3.97	10 20	1.44 79.4
Sensor Supports	PLA-CF[kg] 3D Printing[h]	0.036 1.50	10 20	0.36 30
GPS Supports	PLA[kg] 3D Printing[h]	0.006 0.27	10 20	0.06 5.4
Box Closure for the Height Sensor	PLA[kg] 3D Printing[h]	0.019 0.93	10 20	0.19 18.6
Height Sensor Supports	PLA-CF[kg] 3D Printing[h]	0.122 3.49	10 20	1.22 69.8
GPS Box Closure	PLA[kg] 3D Printing[h]	0.028 1.22	10 20	0.28 24.4
IMU Slider	PLA[kg] 3D Printing[h]	0.011 0.30	10 20	0.11 6
Height Sensor Box	PLA[kg] 3D Printing[h]	0.111 3.60	10 20	1.11 72
Battery Box	PLA[kg] 3D Printing[h]	0.025 0.67	10 20	0.25 13.4
Battery Box Closure	PLA[kg] 3D Printing[h]	0.175 1.17	10 20	1.75 23.4
Test Box	PLA[kg] 3D Printing[h]	0.067 2.30	10 20	0.67 46
Total				484,7

Table 7: 3D Part Costs

Electronics			
Description	Unit Quantity	€/Unit	Total Cost (€ = SM$)
Height Sensor GPS Batteries GPS for Telemetry Height Microcontroller IMU Screen Battery shield	1 1 6 1 1 1 1 3	14.99 16 8 50 12 50 24 3	14.99 16 48 50 12 50 24 9
Total			223.99

Table 8: Electronics Cost

Description	Total Cost(SM$)
Rudder Molds	466
Rudder Laminates	209.415
All 3D Printed Components	484,7
Electronics	223.99
Grand Total	1384.105

Table 9: Total Cost Breakdown

3. SUSTAINABILITY ANALYSIS

3.1. General description

The improvement in Sula's design is mainly of a structural and functional nature, with no changes in terms of sustainability, neither for materials nor for processes.

3.2. Boat and elements lifecycle

3.2.1 Rudder

For the construction of the new rudder, it was necessary to mill again still using MDF, one valve of the vertical and one valve of the horizontal sections. For the latter, we started from the old mold, to which a 3D-printed insert was added. This insert facilitates the extraction of the rudder from the mold, preventing damage and allowing its reuse for future laminations.

3.2.2 Electronic Control System

As for the new electronic control system, the focus was on designing a modular system that could be used in the future on new moths, thus extending its lifecycle.

3.3. Actions for a sustainable future

The naval industry is facing a profound reflection on its responsibility towards the marine environment, as the impact of the industry on the delicate ecosystem is now widely recognized. It is therefore crucial to adopt sustainable solutions to mitigate this impact.Amongst all these options, bio-based composite materials stand out as one of the most promising choices as they represent an eco-friendly alternative to traditional materials. Natural fibers, such as those derived from sources like flax and hemp, require fewer resources compared to synthetic fibers for their production. Vegetable-based resins, derived from vegetable oils or starches, can effectively replace traditional petroleum- based resins, thus reducing greenhouse gas emissions associated with their production.The biodegradable or recyclable aspect of bio-composite materials also promotes better waste management, reducing the accumulation of non-biodegradable materials innatural environments and landfills.

In some specific applications, bio-based composites may not offer the same mechanical performance as traditional materials, but new technologies and production processes are being developed to pave the way for increasingly high-performing and sustainable materials. However, there are challenges to overcome, such as the limited availability of plant biomass, which requires the development of strategies to address them. Nonetheless, bio-based composites represent one of the most promising options for promoting sustainability in the naval industry.

It is essential to adopt an integrated approach that also considers the optimization of production processes, sustainable design, proper waste disposal, and the implementation of specific policies/regulations.

In our student team, we focus heavily on the importance of designing efficient boats both hydrodynamically and structurally. Additionally, we have recently conducted studies on these materials to explore how to incorporate them into our production processes to create increasingly eco-friendly products.

4. TEAM

4.1 TEAM MEMBER

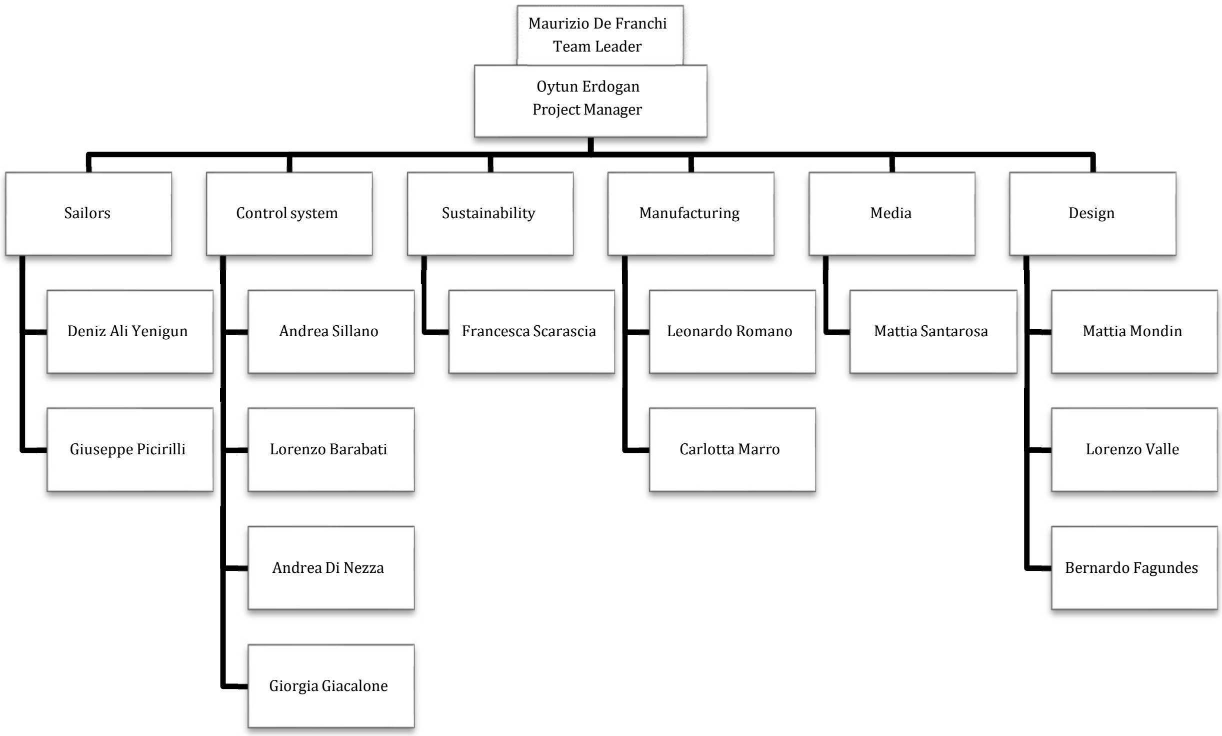

Table 10: Team Members

A. APPENDIX A – Rudder Stratifications

A.1 Valve stratification Rudder Vertical

	Geometric Form	Material
Ply 1	Mold	Carbon Biax 200g/mq
Ply 2	WHOLE PART	CarbonUD 400g/mq
Ply 3	Vertical REINFORCEMENT LARGE	Carbon UD 400g/mq
Ply 4	Mold	Glass Biax 300g/mq
Ply 5	JOINT REINFORCEMENT	Carbon UD 400g/mq
Ply 6	JOINT REINFORCEMENT	Carbon Biax 200g/mq
Ply 7	PIN REINFORCEMENT	Carbon Biax 200g/mq
Ply 8	SMALL PIN REINFORCEMENT	Carbon Biax 200g/mq
Ply 9	FOIL JOINT REINFORCEMENT	Carbon Biax 200g/mq
Ply 10	FOIL JOINT REINFORCEMENT	Carbon Biax 200g/mq
Ply 11	WHOLE PART	Glass UD 160g/mq
Ply 12	WHOLE PART	Glass UD 160g/mq
Ply 13	Vertical REINFORCEMENT LARGE	Glass UD 160g/mq
Ply 14	Vertical REINFORCEMENT LARGE	Glass UD 160g/mq
Ply 15	Vertical REINFORCEMENT LARGE	GlassUD 160g/mq
Ply 16	Vertical REINFORCEMENT NARROW	GlassUD 160g/mq
Ply 17	Vertical REINFORCEMENT NARROW	GlassUD 160g/mq

Table 11: Rudder Vertical Stratification

A.2 Upper valve stratification FOIL

LEGEND TO FIBER TYPES AND WEIGHT (g/m²)	FOIL (Upper Valve)	POSITION
BIAX GLASS 300		MOLD
BIAX CARBON 200		WHOLE PART
UD CARBON 400		WHOLE PART
		REINFORCEMENT B (narrow)
UD GLASS 160		WHOLE PART
		REINFORCEMENT A (large)
		REINFORCEMENT A (large)
		REINFORCEMENT B (narrow)
		REINFORCEMENT B (narrow)
		REINFORCEMENT C (central)
		REINFORCEMENT C (central)
UD CARBON 400 (90°)		REINFORCEMENT D (central 90°)

Table 12: Upper Foil Stratification

A.3 Inferior valve stratification FOIL

LEGEND TO FIBER TYPES AND WEIGHT (g/m²)	FOIL (Inferior Valve)	POSIZIONE
BIAX GLASS 300		MOLD
BIAX CARBON 200		WHOLE PART
UD CARBON 400		WHOLE PART
		REINFORCEMENT B (narrow)
UD GLASS 160		WHOLE PART
		REINFORCEMENT A (large)
		REINFORCEMENT A (large)
		REINFORCEMENT B (narrow)
		REINFORCEMENT B (narrow)
UD CARBON 400 (90°)		REINFORCEMENT D (central 90°)

Table 13: Inferior Foil Stratification