AirCargoChallenge 2022

Technical Report

Team #01

Trencalòs Team

Acknowledgements

The Air Cargo Challenge competition provides the members of the Team the opportunity to expand and apply the knowledge on aircraft design and manufacturing but also project management skills such as organization, communication and team working. This however, could not be achieved without the support of many people and entities that had helped this project become a reality. Foremost, we want to thank the Universitat Politècnica de Catalunya and specially our school Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa for the unconditional support both in economic and academic means. We also want to thank our Professor in Charge Martí Coma Company for keeping an eye on the project. Former Trenaclòs Team members' work and experience has been very much useful and welcomed. We thank our friends and families for the constant support, encouragement and patience.

Last but not least, without the support of the sponsors, the project couldn't have become a reality:

Abstract

The Air Cargo Challenge (ACC) provides the opportunity to engineering and science students from all over the world to meet and test their skills in designing, building and flying an RC plane in a challenging competition consisting on getting the maximum possible score on a prescribed flying mission.

This document presents the methodology and tools adopted by Trencalòs team to develop the ACC22 aircraft design, the results obtained after the design process, the knowledge and experience gained through all steps and the conclusions extracted at the final design stages. The analytic and iterative methods required to obtain an optimal configuration in order to achieve the maximum competition score are presented.

Finally, the design drawings with the most relevant data are attached to the report.

Contents

1 Introduction

Trencalòs Team, from Universitat Politècnica de Catalunya (UPC) faces its eighth participation in the Air Cargo Challenge with an almost completely renewed membership: students coming from different years of studies and different backgrounds as well. The aircraft for this edition will be named *Rovelló*, named after a famous Catalan cartoon, with the spirit of joining folklore and culture with technology.

1.1 Aim of the project

The aim of the current project is to design, build and fly a radio-controlled aircraft within the regulations for the Air Cargo Challenge 2022 to be held in Munich.

1.2 Justification

Trencalòs Team was born in 2006 at *Escola Superior d'Engnyeries Industrial, Aeroespacial i Audiovisual de Terrassa* (ESEIAAT) with the objective of competing in the Air Cargo Challenge 2007, which took place in Lisbon. The Team has participated in all the previous ACC editions, since its first international appearance in 2007. With all this experience carried, the Team aims to finally win the Air Cargo Challenge in its eighth participation. As students, it is a great opportunity to learn new engineering skills and to take the challenge of completing this international project with the highest succeeding possibilities.

2 Project Management

In this section the project is going to be defined, all the necessary tasks that will be carried out for the successful development of the project but also the organization and planning to respect all the deadlines.

2.1 Scope

This project will include:

- Aerodynamic design of wing and tail.
- Stability analysis.
- Structural analysis of wing, fuselage and tail.
- Mechanical design and manufacturing of wing, fuselage, tail and cargo bay.

- Propulsion and electronics systems selection.

2.2 Requirements

According to the regulation for the Air Cargo Challenge 2022, there are some imposed requirements that must be accomplished. Nevertheless, due to the wide span of choices for the aircraft design, there are also some self-imposed requirements in order to obtain the best aircraft design and manufacturing process the team can afford. All these requirements are listed below:

- Aerodynamics
  - The maximum take-off distance will not exceed 40 m.
  - At 60 s after take-off, the aircraft may reach an optimal altitude of 100 m.
  - The aircraft must be able to travel the maximum distance possible.
  - The aircraft must grant stability and controllability for all extreme CG positions.
- Structure
  - The size of the assembled aircraft must fit into an imaginary rhombus-shaped box with an edge length of 1.5 m each, but the angles between the edges are free to choose, and also with a maximum height of 0.5 m.
  - The transportation box for the aircraft must not exceed 1100 x 400 x 250 mm^3, where all the parts of the aircraft will fit at one time.
  - The aircraft must be able to carry the highest possible payload, but the maximum take-off mass will never exceed 20 kg.
  - The automated measuring equipment must be placed in the aircraft with an unobstructed view of the sky.
- Systems (propulsion & electronics)
  - The electric motor must be an unmodified *AXI 2826/10 GOLD LINE V2.*
  - The propeller will be an *APC-E 10x6E.*
  - May be used up to 3 cells of batteries that have a maximum voltage of 12.6 V and a maximum continuous discharge of at least 30 A for cell.

2.3 Organization and planning

Once the project is defined as a whole, it's time to split the work into more specific tasks that will be defined and scheduled.

First, the tasks are going to be defined in the list below, split in different sections.

- Deliveries and payments
  - First payment: Make the first payment before 01/02/2022.
  - Preliminary report: Deliver the preliminary report, developed as requested by the regulation, before 01/03/2022.
  - Second payment: Make the second payment before 01/04/2022.
  - Technical report and drawings: Deliver the technical report, developed as requested by the regulation, before 01/03/2022.
  - Video presentation and proof of flight: Deliver the video presentation and proof of flight, developed as requested by the regulation, before 20/06/2022.
  - Poster: Develop and print the poster as requested by the regulation before 01/07/2022.
- Aerodynamics
  - Preliminary wing design: decide the first aerodynamic wing design approach and obtention of aerodynamic coefficients using XFLR5.
  - UAV stability analysis: study of the wing-tail stability using XFLR5.
  - Payload prediction: calculation of the theoretical maximum payload using an own software called MAGAPP.
  - Flaps and ailerons design: decide the size and position of flaps and ailerons to get the desired level of controllability.
- Cargo Bay
  - Preliminary design: decide the first Cargo Bay approach to fit approximately the payload calculated.
  - CFD analysis: study of the Cargo Bay aerodynamics using Computational Fluid Dynamics methods.
  - Blueprints: creation of the Cargo Bay blueprints using SolidWorks.
  - Final Cargo Bay: manufacture of the Cargo Bay.
- Mechanical design
  - Wing mechanical design: Selection of the wing structure and manufacturing process.
  - Fuselage mechanical design: Selection of the fuselage structure and manufacturing process.
  - Tail mechanical design: Selection of the tail structure and manufacturing process.
  - Final blueprints: creation of the aircraft final blueprints using SolidWorks.
- Structures
  - Wing structural analysis: Study of the wing structure.
  - Fuselage structural analysis: Study of the fuselage structure.
  - Tail structural analysis: Study of the tail structure.

- Propulsion and electronics
  - Systems selection: select the electronic and propulsive systems.
  - Wiring: create the electrical scheme of the aircraft.
- Manufacturing
  - Wing manufacture: manufacture of the final wing.
  - Fuselage manufacture: manufacture of the final fuselage.
  - Tail manufacture: manufacture of the final tail.
  - Assembly: junction of all the parts to get the final aircraft assembled.

Second, these listed tasks have to be scheduled in order to keep the project evolution organized and optimize the work time. It will be done using a Gantt diagram, which represents the tasks against time. To see the diagram, go to section 8.

2.4 Budget

The detailed budget for the project is defined as a table, which includes all the expenses and incomes that will be needed for a successful development of the project. To see the table, go to section 8.

3 Aerodynamic design

The purpose of the current section is to present the methodology followed to design the main aerodynamic surfaces of the wing and its results. First, a description of the digital tools used throughout the processes is presented. It is followed by an explanation of the steps carried out to evaluate the flight performance and theoretical points in the competition of each candidate. Afterwards, a summary of the results of the analysis is shown and finally the analysis and results of the final design are presented.

3.1 Software used

For the aerodynamic analysis, 2 tools have been used:

- **XFLR5** is an open source software developed by André Deperrois used for aerodynamic analysis of the wing and the empennage. It contains a two-dimensional airfoil analysis module (Mark Drela's XFOIL) with both direct and inverse design as well some three-dimensional procedures based on potential flow such as an analytical lifting line method (LLM) and 3 numeric methods: a horseshoe vortex lattice method (VLM1), a ring vortex lattice method (VLM2) and a 3D panels method. Moreover, it can calculate the dynamic stability of the aeroplane.

It has been used to obtain the main aerodynamic coefficients and their derivatives of the aircraft. the two-dimensional module has also been used to analyse airfoils.

- **MAGAPP** is an in-house C++ library first developed for the ACC09 and further improved over the years that computes the main flight capabilities of an electrically propelled UAV. It uses the propeller and electric motor parameters alongside the main aerodynamic coefficients to estimate some performances of the UAV such as:

  - Maximum takeoff weight (MTOW).
  - Maximum level flight speed.
  - Maximum climb angle.
  - Maximum climb rate.
  - Range and endurance capabilities.

  All capabilities can be used either separately or sequentially, which makes it a key tool for the design process. All these 5 capabilities have been used as they are crucial for a good estimation of the competition performance.

  The input values that this library needs are the following:

  - The characterization of the propeller via the physical dimensions and the thrust and power coefficients in terms of the advance ratio ($C_T(J)$, $C_P(J)$).
  - The constants of the motor or a first-order method (K_v, K_q, I_0, R_{int}).
  - The parameters of the battery pack (voltage, capacity, discharge rate).
  - A polar at a fixed angle of attack used to analyse the takeoff run ($C_L(U_\infty)$, $C_D(U_\infty)$).
  - The maximum lift coefficient at takeoff C_{Lmax}.
  - An equilibrated polar where $L = W$ during the cruise stages.

  The methods used in MAGAPP present some limitations due to the formulation used, but it has been proved by the team over the years that the results are in accordance to real performance of the aircraft built.

3.2 Methodology

The aerodynamic design process is separated in 3 main blocks: conceptual design, preliminary design and detailed design.

In the conceptual design phase, the general configuration of the aircraft is chosen, this is much needed for the design of all parts of the aircraft. Decisions such as the number of wings, type of stabilizer and landing gear have to be taken.

The preliminary design is more laborious and requires both numerical and manual analysis. Therefore, this phase has been separated in two blocks.

- In the first block, the airfoil and the optimal wing surface are selected.
- In the second one, the chord distribution along the span is selected alongside other geometrical values.

Both blocks consist of an iteration of analyses of multiple geometrical configurations (candidates). In order to compare the performances of all candidates evenly, the density of the analysis has been set at the standard value of $\rho = 1.225 kg/m^3$, but this will be further analysed in the payload prediction estimation (see section 7). Each analysis is depicted in figure 1 and consists of :

- A fixed angle of attack aerodynamic analysis in XFLR5 to obtain $C_L(U_\infty)$ and $C_D(U_\infty)$ during takeoff.
- An estimation of C_{Lmax} without flaps in XLFR5.
- MTOW computation using the previous values in MAGAPP.
- Obtention of an equilibrated polar for the previous MTOW in XFLR5. .
- Obtention of maximum level speed and climbing rate in MAGAPP.
- Estimation of ACC score using equation 1.

$$ACC_{score} = \left[\frac{MTOW}{MTOW_{max}} \cdot \frac{v_{max}}{v_{max_{max}}} \cdot \frac{Palt}{1200}\right] \frac{10}{3} \tag{1}$$

Where:

$$Palt = -3.92 \cdot 10^{-5} h_{60}^4 + 1.08 \cdot 10^{-4} h_{60}^3 - 1152 h_{60}^2 + 64.2 h_{60} - 537 \tag{2}$$

And h_{60} has been considered $(\text{MIN}(v_v \cdot 60, 100))$ where v_v is the climbing rate in m/s.

3.3 Conceptual design

Multiple configurations have been studied and analysed are both throughout history and in the literature. In table 1 a comparison of the benefits and disadvantages of each configuration is included.

Table 1: Overview of aircraft configurations

Configuration	**Benefits**	**Disadvantages**
Conventional	High reliability	Limited innovation
Biplane	High structural strength	High interference between wings
Canard	No deep stall	Low stability
Tandem	High lift generation	High interference between wing
Flying wing	High aerodynamic efficiency	Low stability

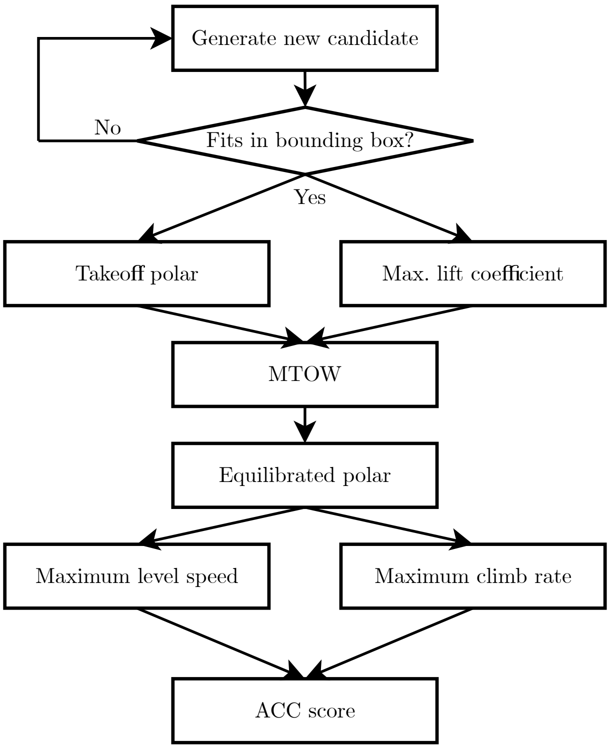

Figure 1: Flowchart for the aerodynamic analysis of a candidate

For this project, simplicity and ease of construction have been taken into account in all steps of the design to ensure a reliable outcome. For this purpose, the team has selected a conventional configuration due to the construction simplicity and good stability indexes known from previous projects. The chosen configuration consists of high wing, conventional empennage and pushed engine. A tricycle landing gear has been chosen in order to facilitate the control of the aeroplane in the ground during takeoff and landing.

3.4 Preliminary aerodynamic design

As commented before, during the preliminary design, 2 iterations have been performed. The main size restriction of the aircraft is given by the bounding box of 1500x1500x500 mm in which the aircraft has to fit in ready to fly. After a first topology analysis in has been decided to set the wingspan at 2 m for the first block.

Regarding the airfoil to be used, 3 alternatives have been considered based on experience of the team in previous competitions: S1210, S1221 and S1223. For each one of this airfoil, 4 different rectangular wings have been analysed with 0.17, 0.19, 0.21 and 0.23 cm chord. The results for these 12 configurations can be observed in figure 3.

This first iteration has provided us with crucial information for the design. As it can be seen in figure 3, the best score is obtained for a wing with around 0.5 m^2 of surface in all airfoils, and the best performance is provided by the S1221 airfoil.

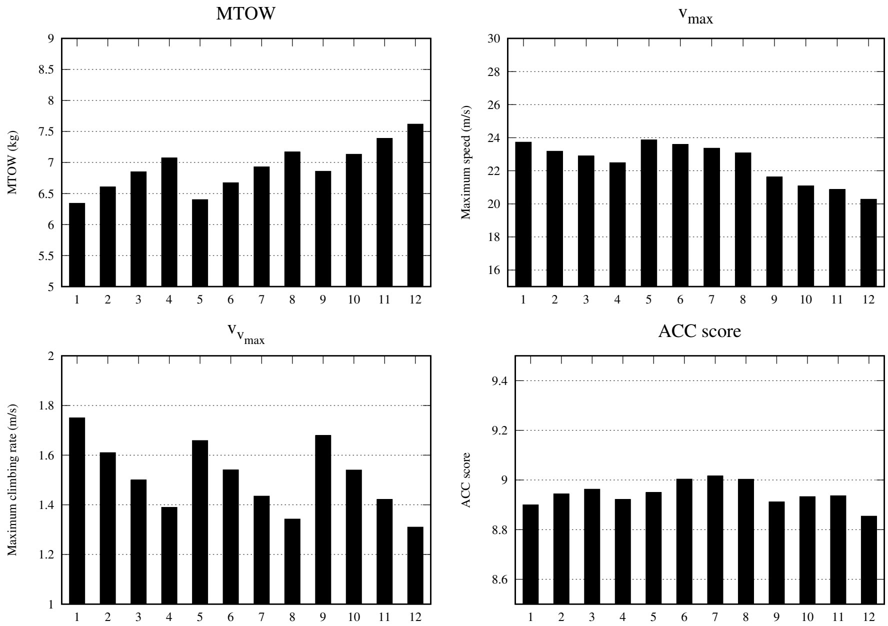

Figure 2: Results of the first iteration

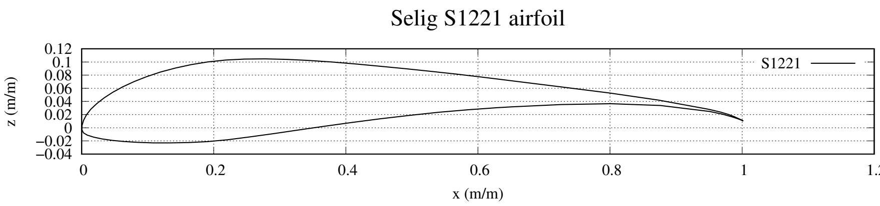

Figure 3: Geometry of the airfoil chosen

The second iteration has been started with the previous knowledge of the first one, that is, a S1221 as airfoil and a surface close to 0.5 m^2.

The wing has been divided into 3 segments. With the idea of preserving ease of construction and simplicity, the central segment has been decided to be rectangular and to add taper on the outer segments. This 3 segment configuration avoids joins at the wing's root, where the highest loads exist. Furthermore, they fit well inside the transportation box and still leave enough space for the rest of the aircraft.

Multiple candidates were generated by modifying the root chord and taper ratio, while still following the previous decision. In figure 4 the results for 12 of the candidates with a better score are depicted. It can be observed that the results are very even between all candidates, so any of these results would have decent results in the competition. However, candidate 'L' has been selected for the final results. Table 2 shows the dimensions in the different sections of the semi-wing. Linear distribution is assumed between these.

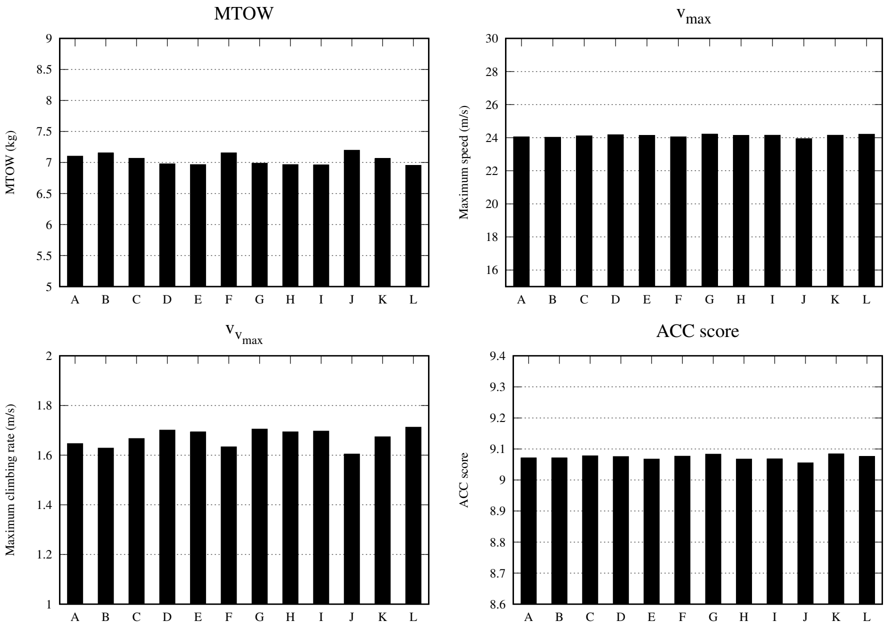

Figure 4: Results of the second iteration

Table 2: Dimensions of the final wing

y (m)	offset (m)	Chord (m)
0.0	0.00	0.28
0.3	0.00	0.28
1.0	0.04	0.20

3.5 Detailed design

Tail design

In the conceptual design, a conventional tail has already been chosen. Regarding the cross-section of the 2 surfaces, a symmetrical NACA 0009 airfoil has been selected for the vertical stabilizer, as it has been observed that it provides enough housing to accommodate the servo in the fin. For the horizontal stabilizer, 3 different airfoils have been considered: NACA 0009, NACA 0012 and an inverted Eppler E205. The latter has been observed to offer a higher efficiency and thus lower drag in relation to the other NACA airfoils. For this reason, it has been chosen.

The dimensioning of the horizontal and vertical tail have followed an iterative process, where span, chord and offset have been modified in different candidates to fulfil the constraints of the bounding box both in height and width. The bounding box restriction has been a major headache in this step of the design. A low lever arm than the desired one for the stabilizers has had to be chosen. For each candidate, low stability behaviour has been analysed. Table 3 shows the dimensions of both stabilizers. No dihedral or twist has been applied.

Table 3: Dimensions of the tail

	VTP		HTP	
	Root	**Tip**	**Root**	**Tip**
Chord (m)	0.175	0.175	0.19	0.13
x (m)	0.72	0.72	0.72	0.735
y (m)	0	0	0	0.3
z (m)	0	0.25	0	0

Control surfaces design

Control surfaces have been designed following the experience of the Team in previous competitions. From previous experience of the Team Selig airfoils are prone to stalling when flaps are implemented. For this reason, no flaps will be added. In their place, flaperons will be used in the 2 outer sections of the wing (this means a 70% of the span). The hinge will be located at $x_h = 0.7c$ for the ailerons.

The tail control surfaces will be extended all along the span of the 2 stabilizers and the hing will also be located at $x_h = 0.7c$

Final design

In figure 5 the drag polar and other relevant aerodynamic curves are represented. In table 4 the main parameters of the wing are shown.

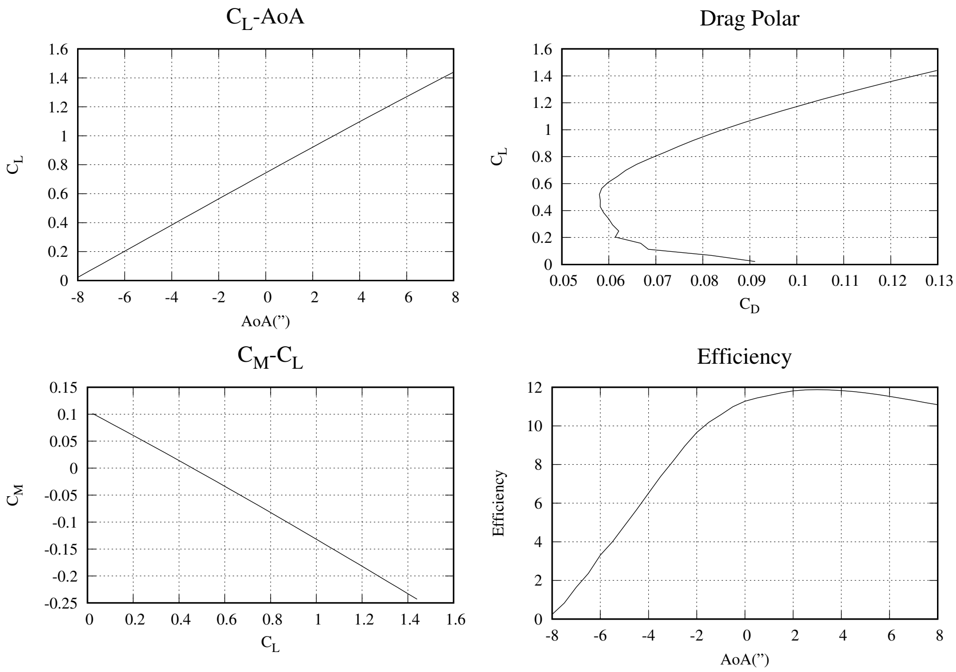

Figure 5: Final's design polar

Table 4: Dimensions of the final wing

S (m^2)	**b** (m)	**MAC** (m)	**AR**	**TR**	**Incidence** (^{o})	**Dihedreal** (^{o})
0.504	2	0.255	7.94	0.714	0	0

Weight distribution and centre of gravity

The following table shows the weight estimation for the different parts of the aircraft, as well as the desired centre of gravity.

Table 5: Mass prediction and centre of gravity calculation

	Mass (kg)	$x_{cg}(m)$ **from LE**
Wing	1.10	0.084
HTP	0.10	0.8
VTP	0.10	0.8
Engine	0.18	-0.34
Tail boom	0.05	0.5
Electronics	0.50	-0.15
Landing gear	0.20	0.07
Cargo bay	0.25	0.07
Payload	PL	0.07
TOTAL	**2.48 + PL**	**0.07**

The mass distribution has been thought so that the centre of gravity is at 7 cm from the root chord leading edge. To prevent displacements of the centre of gravity due to the payload, the cargo bay together with the payload and the landing gear have been located at the aircraft's centre of gravity.

Stability analysis

The analysis have shown appropriate stability for this configuration with a moment coefficient slope

$$\frac{\partial C_M}{\partial C_L} = \frac{\frac{\partial C_M}{\partial \alpha}}{\frac{\partial C_L}{\partial \alpha}} = -0.24 \tag{3}$$

This value has been proven enough in the previous designs of the Team. However, once the aircraft is built and tested, any modification needed will be added to the aircraft in order to ensure proper stable behaviour. At this point, it is important to remember that this slope value is equal to the static margin nondimensionalised with the MAC.

Although the payload will be located at the centre of gravity longitudinally, displacement of 1 cm of the centre of gravity have been considered as extreme CG positions. These 2 extreme cases lead to static margins of 29% of the MAC for the forwardmost case and 21 for the least stable CG position.

$$\frac{\partial C_M}{\partial \alpha} = \frac{\partial C_{Lw}}{\partial \alpha}(\hat{x}_{cg} - \hat{x}_{acw}) - \frac{\partial C_{Lt}}{\partial \alpha}\eta_t \hat{V}_t(1 - \frac{\partial \epsilon}{\partial \alpha_w}) \tag{4}$$

Equation 4 has been evaluated with the following values: $\frac{\partial C_{Lw}}{\partial \alpha} = 4.7$, $\hat{x}_{cg} = 0.27$, $\hat{x}_{acw} = 0.29$, $\frac{\partial C_{Lt}}{\partial \alpha} = 3.66$ $\eta_t = 0.9$, $\hat{V}_t = 0.54$ and $\frac{\partial \epsilon}{\partial \alpha_w} = \frac{2C_{L\alpha}}{\pi AR} = 0.377$.Which results in a static margin of 23.7%, which is the same value obtained numerically via XLFR5.

Due to time constraints, lateral stability and dynamic phenomena such as the phugoid mode could not be studied.

4 Structural Design

4.1 State of the Art

Throughout the different editions of this competition, Trencalòs Team has developed several configurations to tackle the problem that is the structural design. These solutions include balsawood designs, D-Box or conventional structures. During the last competition held in Stuttgart the Team focused on building a structural skin sandwich design.

The skin sandwich made with composite materials has some advantages in front of conventional *semimonocoque* structures.

- **Good surface finishing:** Composite and laminate materials can achieve very smooth surfaces without post-treatment if the molds and the techniques are applied properly. This finishing can be better than the ones achieved with balsa and Oracover, or a foam surface. Laminate composites, adopt the surface finishing directly from the mould.
- **Use of the maximum inertia:** The structural skin sandwich concept positions the spar caps right into the aerodynamic skin of the airplane.
- **Maximum torsional strength:** The skin sandwich withstands the torsional stresses in the wing.

This concept also involves some difficulties that need to be solved for the proper functioning of the structural design.

- **Non-continuous wing:** Since the airplane has to fit in a transportation box the wing needs to be divided into different segments.
- **Slow first stages of construction:** The making of the moulds is a slow process that could delay the start of the construction of the airplane.

Nevertheless, because of the positive results the structural skin provided during the last edition of the competition, it is also going to be the method used this year.

4.2 Wing design and manufacture

This section explains the mechanical design of the wing and its structure. For this, all its components and its usefulness are detailed.

4.2.1 Main beam

The main beam consists of a carbon fiber and ROHACELL sandwich structure with a rectangular cross-section. Due to the shape of the wing the beam is going to be located at the thickest part of the tips airfoils, and because we want it to be as straight and continuous as possible when it comes to the central airfoils it won't pass through the thickest part of these.

A series of carbon layers will be stacked on the top and bottom of a ROHACELL core, but the layers will be embedded in the wing's skin to ensure the best distribution of stresses from the skins to the spar and cargo bay. This concept design will also allow the Team to study the spar as the only structural element.

Figure 6: Main beam concept

4.2.2 Joiners

The joiners will be the main change from the 2019 edition airplane. For the Stuttgart competition the Team decided to build the joiners using moulds, and although in theory the idea was good, in practice it was a lot more difficult to make work. For that reason, this year, the joiners used will be carbon fiber tubs. Part of a tub will be imbedded into the beam structure, while a smaller tub snugly fitted to the imbedded one will work as the actual joiner.

4.2.3 Ribs

The ribs that the wing needs are to close the different sections, since having a structural skin it is not necessary to use reinforcement ribs. Therefore, one rib should be designed for the central section and another for the final part of the wing. An additional rib is also designed with flaps at the bottom to be able to join the cargo bay and the wing.

Two units must be made of the central rib and these must have a space to allow the passage of cables, the main beam and wing joiners and the torsion pins and tubes.

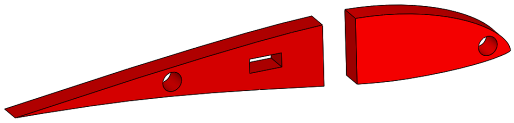

Figure 7: Central rib

Two units of the final ribs will also be necessary. These must be closed as they serve to finish the wing.

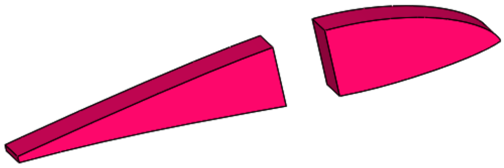

Figure 8: Final rib

The rib designed to join the wing and cargo bay is shown below. Two must also be manufactured.

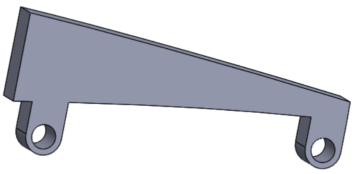

Figure 9: Cargo bay rib

4.2.4 Skin

The main function of the skin is to form the outer aerodynamic geometry of the wing, withstand the bending moment and withstand the torsion moment.

The structural skin is going to consist of a carbon fiber and ROHACELL sandwich, the fiber used in this case will be one already woven at 45º.

Below are the elaborate CAD models of the skin.

It is observed that in the lateral section, figure 10, a gap has been left where the flaps will be located and a hole has been made at the point where the servo will be placed.

The central section, figure 11, is constant, it has 4 holes through which the flaps of the ribs of the wing and the cargo bay will come out.

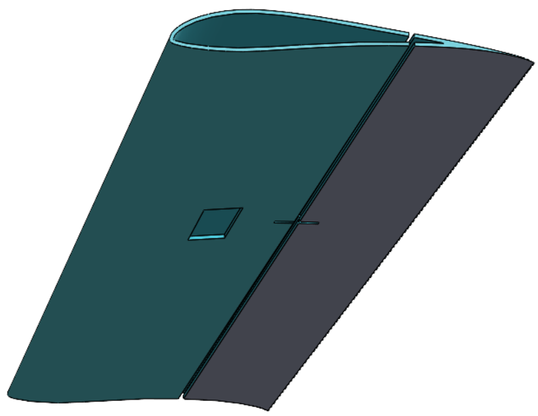

Figure 10: Left section of the wing skin

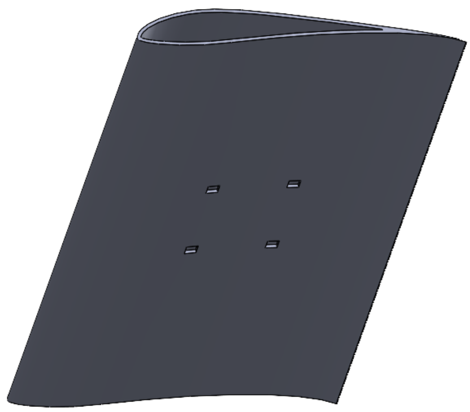

Figure 11: Central section of the wing skin

4.2.5 Moulds

In order to build the structural skin of the wing we will use moulds. Our wing is composed of 3 sections, the central and two lateral. For each section we will require 2 moulds: one for the upper side of the wing and one for the lower side. For this reason we need to design 6 moulds.

There are mainly two ways to build the moulds. The first is to build a master pattern or plug, that is, to build the final piece in order to use it later in the manufacture of the mould. The second is to build the mould directly, usually by milling a block of the material from which you want to make it.

In 2017 the team conducted a comparative study of 4 mould construction methods to decide which was the most optimal construction method. This year we have recovered this study, adapting it to the current circumstances and requirements and modifying certain variables to decide how we are going to manufacture this item. Below are explained the 4 design and manufacturing methods studied and shows the OWA analysis performed to decide which is the most optimal.

Option 1: Directly milled high density polyurethane moulds with fiberglass

This option consisted in milling high density polyurethane and then applying a fiberglass coat and gel-coat that needed to be sanded. The gel-coat has to be applied. This method is developed to leave a high quality surface after milling. The high density polyurethane is strong enough not to compress in the process and not to deform the wing shape on the mould.

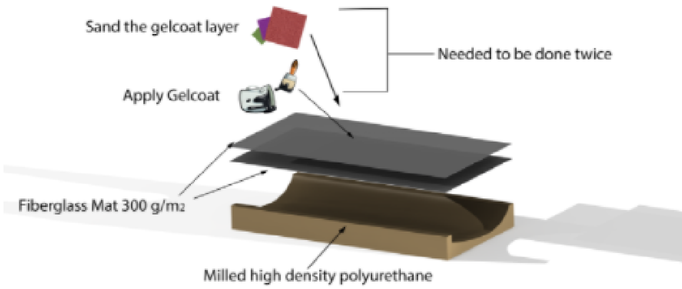

Figure 12: Directly milled high density polyurethane moulds with fiberglass

Option 2: Directly milled wood moulds with polypropylene

The second method consists on manufacturing a mould core with high density polyurethane or wood. After that, a polypropylene sheet deformed with a heat gun has to be applied. This is one of the simplest methods. The polypropylene layer was chosen because this material does not stick to the epoxy, so it helps us when building the wing.

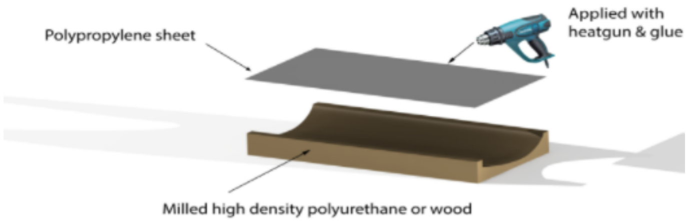

Figure 13: Directly milled wood moulds with polypropylene

Option 3: Interlocked slices of wood with polypropylene

To reduce costs, another mould construction process was taken into account. This consisted in creating an interlocked slices structure of MD wood of to replace the core, as it can be seen in figure 14. After that, a polypropylene sheet deformed with a heat gun was also applied.

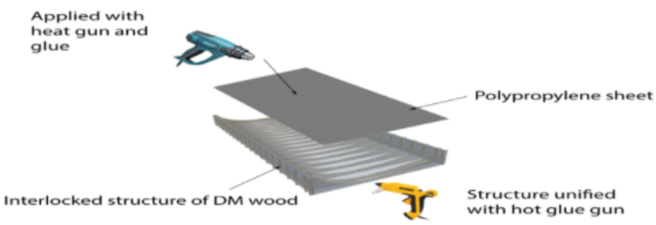

Figure 14: Interlocked wood slices and polypropylene

Option 4: High density polyurethane plug/master pattern

For this type of mould making, a master pattern is required. This pattern is of the shape of the final product and, from it, the moulds are built. This process is usually used when the ultimate goal is to make moulds from composite materials. Although this master pattern can be made of various materials, the one that will be taken into account is high-density polyurethane because it is cheaper than the rest of the options. Other materials that can be used are epoxy, like EB700 and EB6200 and urethane. This process is not difficult nor expensive. However, it requires more time than the others. It was the method used in 2019.

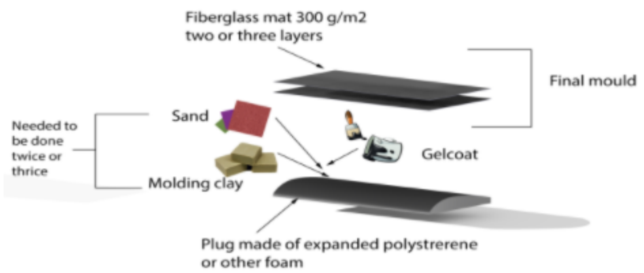

Figure 15: High density polyurethane plug/master pattern

To select the best option, the OWA selection method has been used. This process consists on selecting the variables that are more important to the analysis and give them a weight. The ones with a higher weight must be the most important. After that, all the options are ordered from worse to better for each variable. Finally, you sum up all the scores and re-range the sum from 0 to 1. The option with the higher score is considered the best. The variables selected are the cost of the material, the time required, the complexity, the surface finish and production life. We have not taken into account the cost of the machinery necessary for construction, since our sponsors provide it to us.

Table 6: OWA selection method

	Weight	Option 1 Milled PUR		Option 2 Milled wood		Option 3 Wood slices		Option 4 Milled plug	
Criteria	g	p	$p \cdot g$	p	$p \cdot g$	p	$p \cdot g$	p	$p \cdot g$
Material cost	70	1	70	2	140	4	280	3	210
Time required	30	2	60	3	90	4	120	1	30
Complexity	70	3	210	4	280	1	70	2	140
Surface finish	50	1	50	4	200	3	150	2	100
Production life	20	3	60	1	20	2	40	4	80
TOTAL	240	-	450	-	730	-	660	-	560
OWA	-	0,47		0,76		0,69		0,58	

From this table we choose the option with the highest score: the construction of the moulds milling medium density wood.

Once the type of moulds has been decided, it is possible to proceed with their design and manufacturing. To do that, the process is divided in 4 main steps. The first step is to develop the CAD models of the moulds using *SolidWorks*. Then, the specific material is selected and prepared for further milling, which is the third step. Finally, subsequent processes are applied to add the thermoplastic layer.

Of these steps, the only one currently performed is the CAD design of the moulds, shown below.

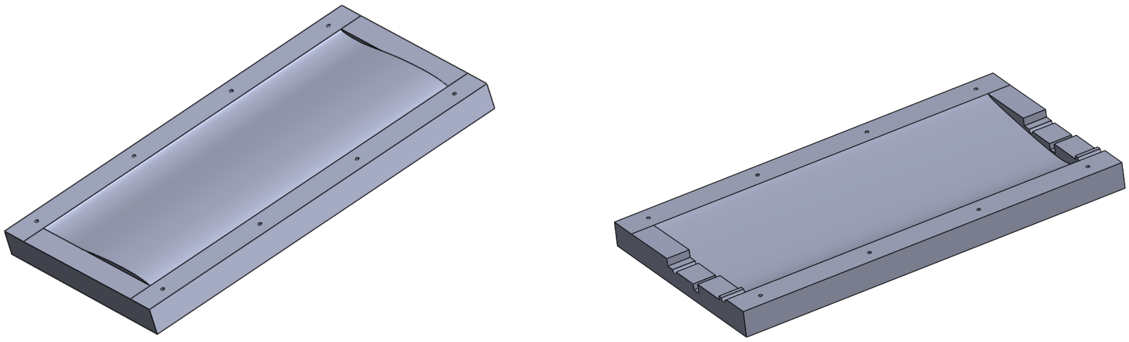

Figure 16: Upper and lower central mould CADs

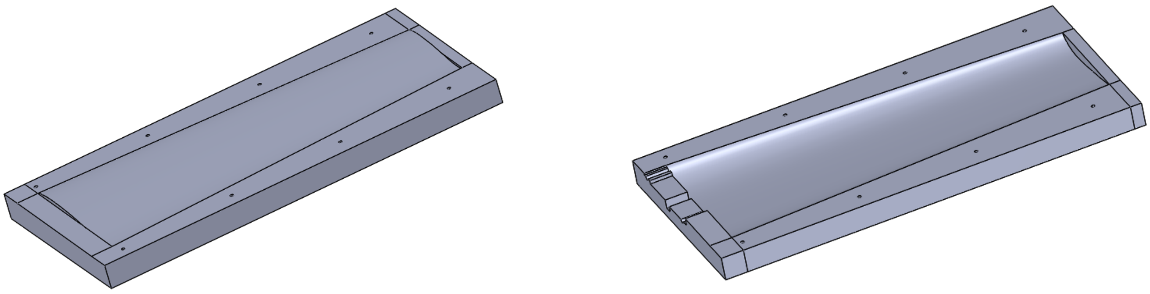

Figure 17: Upper and lower right mould CADs

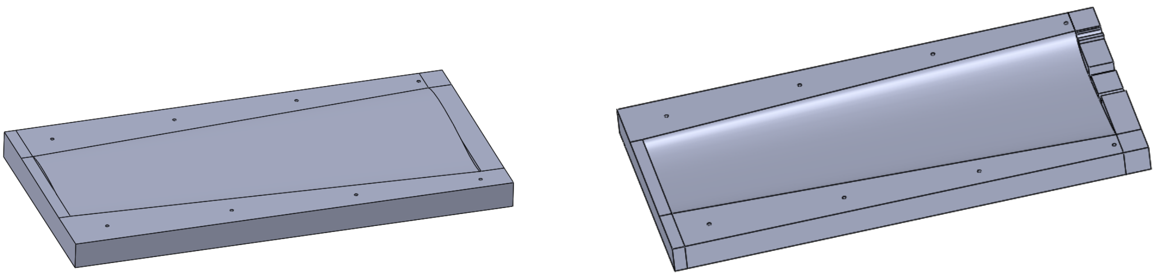

Figure 18: Upper and lower left mould CADs

4.2.6 Final design

The final wing design is the following one:

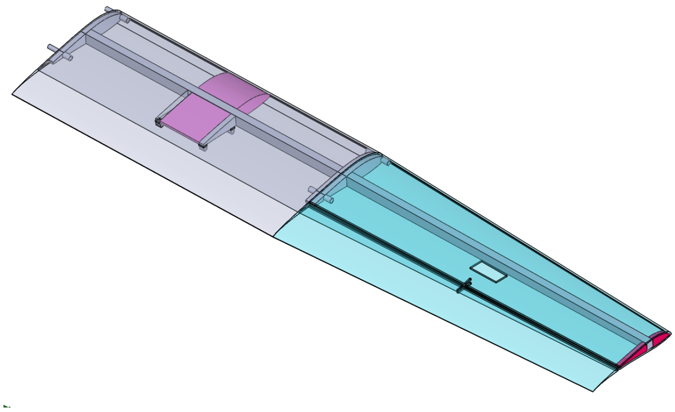

Figure 19: Total wing CAD

4.3 Materials Choice

The following materials have been chosen to build the structure and wings of the aircraft, this selection is made taking into account the performance, the availability and price of the materials.

- Spar caps fiber reinforcement: TENAX UMS 40 800 tex roving.
- Spar core: ROHACELL IG-F 31.
- Wing skin fiber reinforcement: Carboweave CW29.
- Skin sandwich core: ROHACELL IG-F 71.

4.4 Final Design

For the final structural design sizing some key parameters have been set, some of these are brought by the competition's regulations while others by aerodynamic or other design restrictions.

- The structure will be sized for a MTOW of 10 kg.
- The structure will be divided into 3 segments, the middle one will be 600 mm and the other two will be 700 mm, constituting a wingspan of 2 m.
- The maximum height of the spar is set at 21.89 mm as it is the airfoil's thickness at the position where the main spar is being located.
- The number of layers on top and bottom of the spar will be sized with different criteria: the top layers to prevent local buckling and the bottom layers to hold traction and stresses.
- The wing's sandwich skin is composed by two layers of Carboweave CW29 separated by a 1.2 mm ROHACELL IG-F71 sheet.

The sizing of the different structural components is currently still on the works. At the moment a Matlab code is being worked on to help the Team determine the amount of carbon fibre layers that will need to go on top and bottom of the main beam structure to be able to support all the loads applied to it during take-off, climb, cruise and landing.

The wing joiners are sized using the main beam nucleus geometry. For that reason, they will consist of a carbon tub of 16 mm of external diameter and 14 mm of internal, as well as a carbon tub of 14 mm of external diameter.

5 Propulsion and electronics

5.1 Propulsion

An APC 10x6E propeller has been selected for powering the flight. It will be coupled to the AXI 2826/10 v2 engine set by the regulations. These 2 elements will be attached using the screw nut provided with the motor. The propeller-motor group will be attached to the airframe using 4 screws provided with the motor and also epoxy. These attachments can be observed in figure 20.

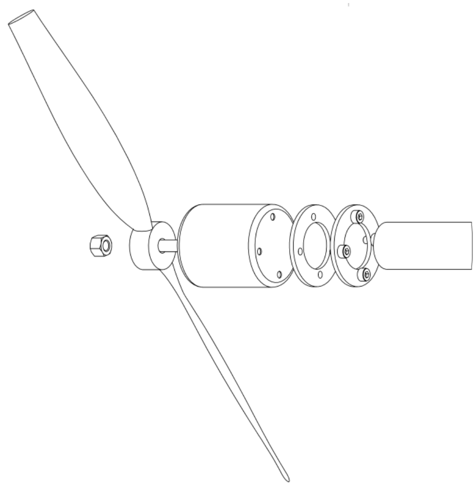

Figure 20: Fixing system of the drivetrain

This fixing system ensures easy assemble and disassemble of the main parts, both for transport and inspection.

With data for current consumption over a range of speeds calculated by self developed software MAGAPP, battery capacity can be calculated. To simplify, only motor consumption is considered, and flight time is divided in three segments: takeoff, climbing, where max. current is considered, and free flight time, where max. speed is considered. As regulation sheet specifies, the plane must take off within 40 m runway, reaching in our case a speed of 12 m/s in approximately 10s. Climb time is considered to be 60 s consuming 30.35 A, and free flight time is considered to be 120 s at max. speed (23 m/s). Therefore, battery capacity needed for those operations is:

$$MotorConsumption = 10 \cdot 30.35 + 60 \cdot 30.35 + 120 \cdot 26.4 =$$
$$= 5292.5As \cdot \frac{1000mA}{1A} \cdot \frac{1h}{3600s} = 1470.14mAh \tag{5}$$

This would leave the battery with a voltage lower than desired, so to keep voltage over test voltage throughout the flight, battery capacity has to be increased by a minimum factor of +50 %, giving a minimum necessary capacity of around 2200mAh. Next battery to size is the independent battery. Servos consume has to be taken into account. Maximum current for each servo is 1A.

$$ServoConsumption = Nservos \cdot I_{max} \cdot FlightTime =$$
$$= 5 \cdot 1 \cdot (10 + 60 + 120) \cdot \frac{1000mA}{1A} \cdot \frac{1h}{3600s} = 264mAh \tag{6}$$

Finally, receiver system is estimated to consume around 100mAh during this period of time, demanding a total capacity of approximately 1500mAh for primary battery and 400mAh for secondary battery. This would empty the batteries at the end of the flight, leaving no power for unforeseen events. To prevent that and ensure the aircraft's returns to the ground safely, battery capacity is doubled to 2 · 1500 mAh and 1 · 800 mAh.

5.2 Electronic Requirements

As the regulations specify, all lithium based batteries can be used and teams can use packs with up to 3 cells in series. A set of two 3 cell LiPo batteries will be used, which will enable the team to change batteries between flights and confer the power system with redundancy in case a battery fails or gets damaged.

It is worth noticing that an Electronic Speed Controler (ESC) with an integrated battery eliminator circuit (BEC) is used. ESC's without this technology have been considered, but none of them had the desired features. Those type of ESC without BEC (normally named OPTO ESC's) have been chosen because of regulations the specifying: "An independent RX battery pack is mandatory, with a minimum capacity of 600 mAh". From this regulation, the team has concluded that an independent BEC must be used for a lower and stable independent battery voltage. Therefore, the BEC from the ESC is not going to be used.

The chosen ESC is a Hobbywing platinum pro V3 50 A ESC, with integrated 7V BEC as mentioned before, and a programming card associated allowing for some parameters to be tweaked slightly improving propulsion performance. It is capable of working within 2S-6S voltage range and capable of sustaining 70 A for 10 s. A 50 A ESC has been chosen to avoid overheating in ESC, as the competition is held in July and the motor is intended to work at maximum performance all flight.

The chosen BEC is a TurnigyR8-15A BEC, capable of working from 2S to 3S voltage range, with 8 A maximum continuous current and 15 A peak current. This intensity range has been chosen for similar reasons as used in the choosing ESC.

To sum up, in the field of electronics:

- Performance of the propulsion system has been computed via in-house developed software MAGAPP (see in section *3.1 Software used*).
- An RC system (receiver, servos, ESC, etc) has been searched to control the different control surfaces present in the aircraft, using available components.
- Sizing of the batteries has been carried out in order to achieve adequate weight and autonomy.
- Temperature test on power cables reaching servo terminals has been carried out to ensure that those cables will withstand highest intensities required by servos.

Finally, an electric scheme (see Appendix Section C Electronic Design) with all the electronic and propulsion components of the plane has been developed to rightfully assemble the system.

6 Cargo Bay design

In this Air Cargo Challenge edition, some changes have been made in terms of what is the payload that will be load in the plane. This year, the plane has to load blood bags. So, a few changes had been made in the cargo bay design comparing with other year's design, especially in the size of the cargo bay,

6.1 Preliminary Design

The principal requirements of the cargo bay design needs to follow the following requirements:

- **Good charge-discharge** of the payload ratio, in order to maximize the punctuation of the competition in terms of time of charge-discharge. To ensure this point, a preliminary cargo bad been built in order to try different configurations of the blood bags. These will be fitted in horizontally.
- **Stability of the bags inside the cargo during flight disturbances** because the relative movement of the bags inside the cargo could interfere in the stability of the plane, in terms of the movement of the gravity centre. To ensure this, pre-inflated air bags will be inside the cargo in order to fill the empty space. In the event that the cargo is not filled, some pressure will be applied over the bags, so, these will not move.

- **Aerodynamic and structural design**, these two parts doesn't need from additional, or specific design. In this case, just an optimization of both aspects is needed. Both aspect will be seen in the following sections.

6.2 Structural design

The main part of the cargo bay, as it can be seen at the next figure, consists of a rectangular box, where it's base is made of sandwich structure with balsa wood and carbon fibre, and it's sides, made of birchwood. In order to minimize the weight, the laterals had been designed with some specific holes, because this part of the structure is not designed to support the biggest loads.

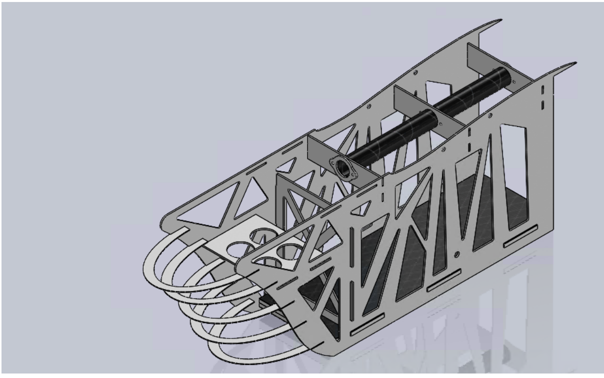

Figure 21: Cargo Bay 3D model

6.3 Aerodynamic design

The main objective of the aerodynamic design of the cargo bay, is to minimize the impact of it in terms of aerodynamic resistance. No more requirements are needed in this aspect. To achieve it, some ribs had been added to the frontal part(as it can be seen in the previous figure), that will be covered with some film in order to improve the aerodynamic performance.

6.4 Final Design

The final design of the Cargo Bay has been designed to carry 10 blood bags of 300g, so, should be able to carry 3 kg of payload (although the analyses have shown that the aircraft is capable of lifting more cargo, a conservative design had been made, instead of a risky one).

7 Payload prediction

With the final aerodynamic design (see section 3) an in-depth analysis of the possible payload to be lifted has been carried out using XFLR5 and MAGAPP for multiple densities. To decide at which densities, the analyses shall be performed, the average density in Munich during July has been studied. Values of pressure and density over the last 13 years ([10]) have been used to calculate the average density, which has resulted in $\rho = 1.20\ kg/m^3$.

For this reason, the payload has been predicted for several values of air density between 1 and 1.4. An OEW of the aircraft of 1.9 kg has been considered according to the results obtained previously. In this study, a takeoff distance of 40 meters has been considered. In figure 22 the outcome of this analysis is presented.

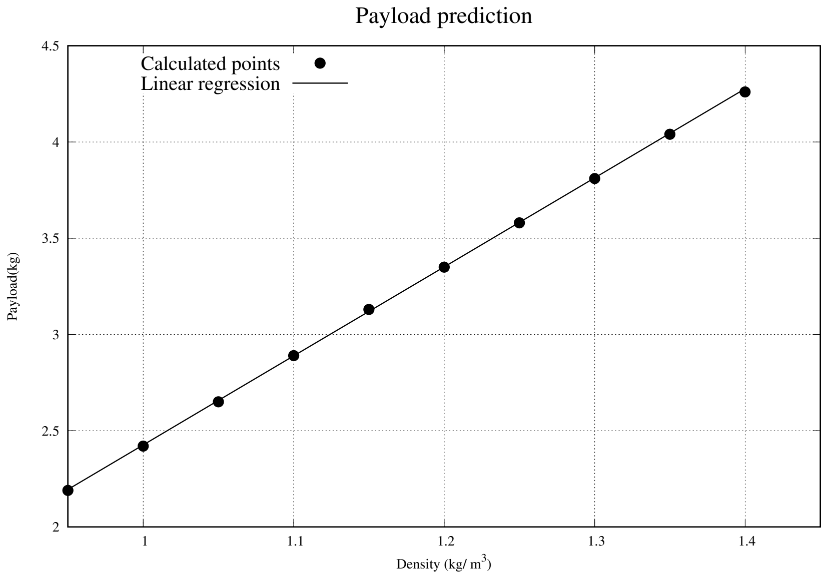

Figure 22: Payload prediction in terms of air density

Thanks to the linear regression, the payload can be expressed in terms of the density (in SI units) as:

$$PL = -2.204 + \rho \cdot 4.626 \tag{7}$$

for the range where the density effect has been analysed.

8 Outlook

After finishing the design process, many tasks are to be done within the following weeks.

When possible, experimental analysis of the motor-propeller performance will be done to double-check the theoretical results.

These tasks include the construction of the different parts of the aircraft, starting with the milling of the moulds, as it is a long process and prone to delays. The construction of the rest of the aircraft is the main task to be done.

The Team is currently assembling the tail. Several tests are being performed at the moment.

These include wing joiners testing, main spar testing and fuselage build-up feasibility. As soon as the aircraft is completely built, moulds and flight tests will be carried out in order to assess both aerodynamic and structural calculations. If any minor changes are considered opportune, they will be implemented.

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Appendix

A Gantt diagram

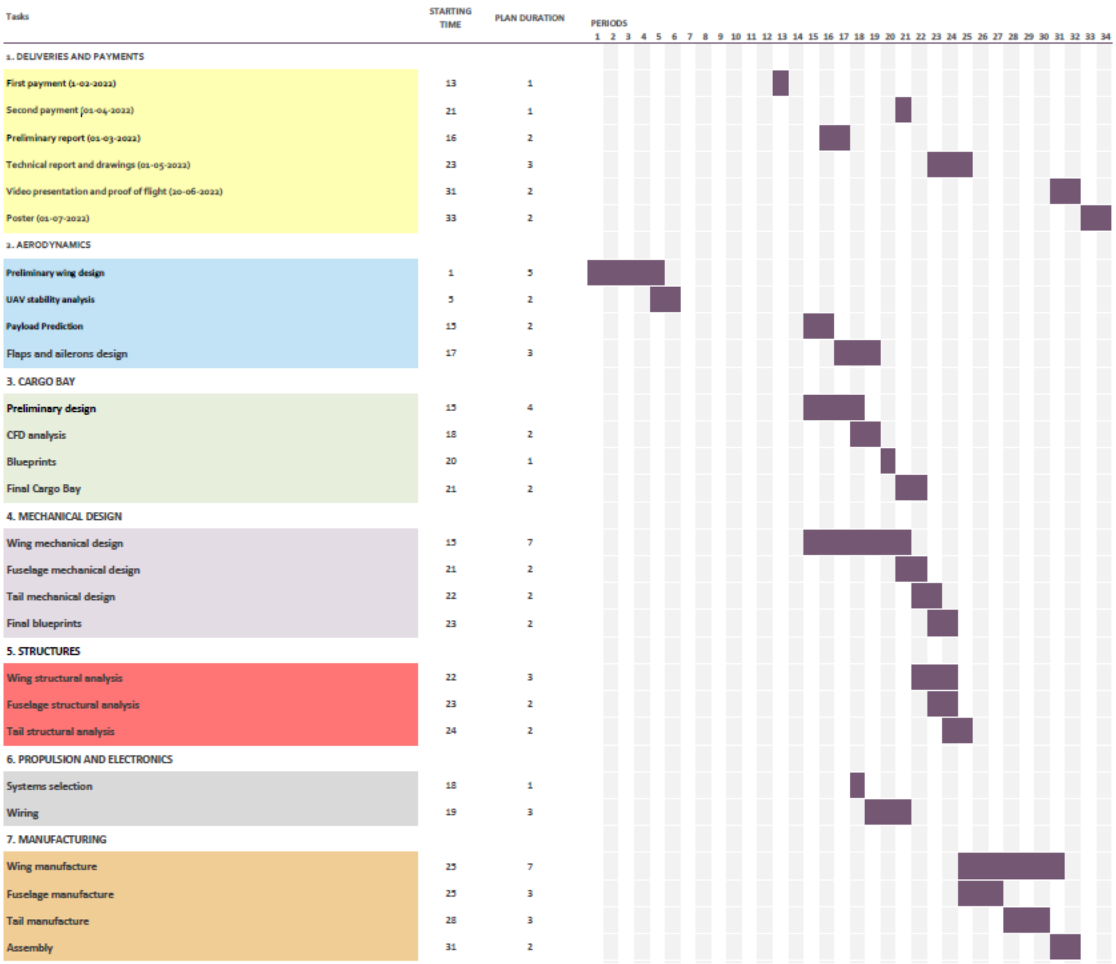


Figure 23: Gantt diagram

Table 7: Periods definition

Period	Days	Month	Period	Days	Month
1	8-14	November 18	7-13	March	
2	15-21	November	19	14-20	March
3	22-28	November	20	21-27	March
4	29-5	November/December	21	28-3	March/April
5	6-12	December	22	4-10	April
6	13-19	December	23	11-17	April
7	20-26	December	24	18-24	April
8	27-2	December/January	25	25-1	April/May
9	3-9	January	26	2-8	May
10	10-16	January	27	9-15	May

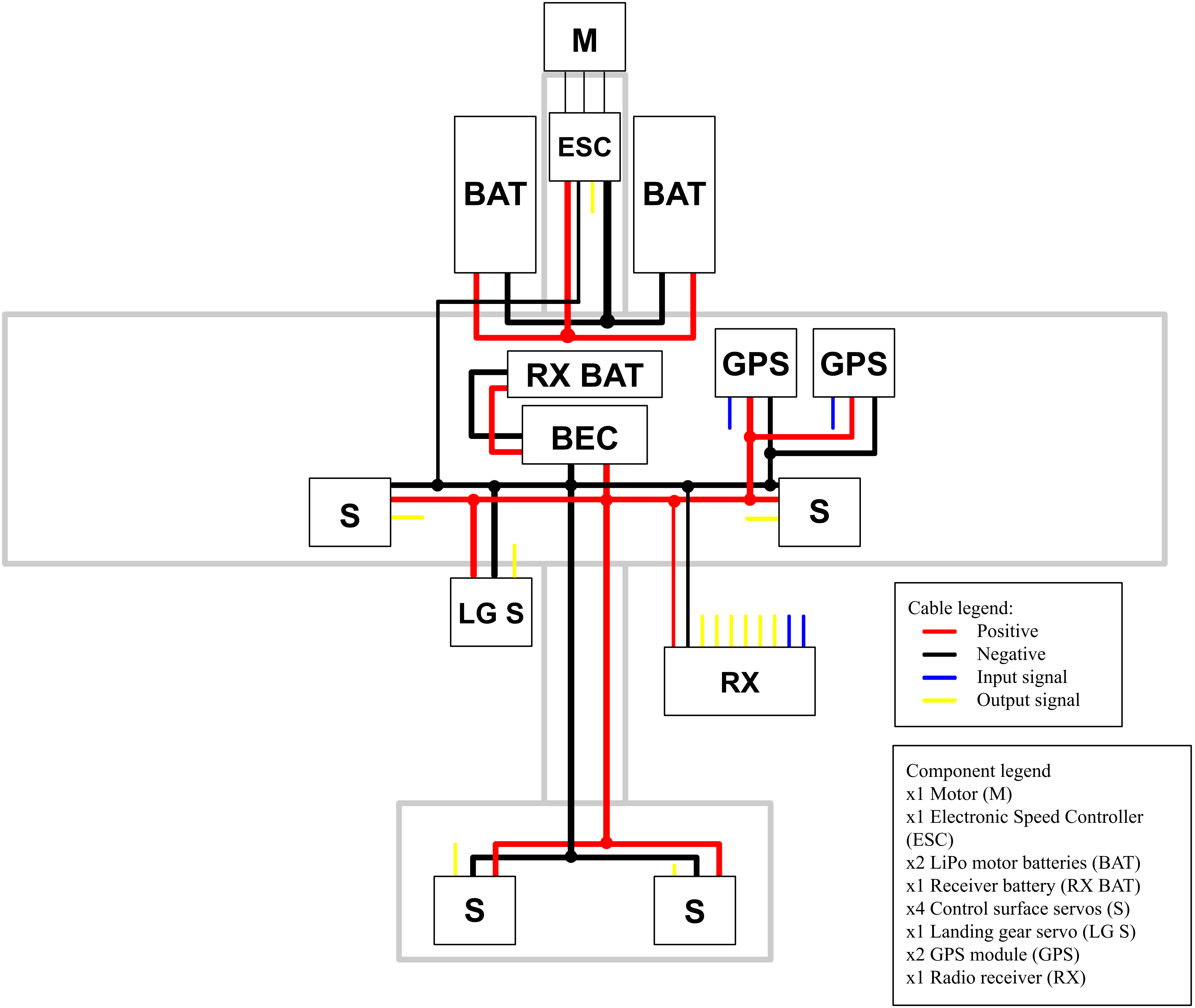
Period	Days	Month	Period	Days	Month
11	17-23	January	28	16-22	May
12	24-30	January	29	23-29	May
13	31-6	January/February	30	30-5	May/June
14	7-13	February	31	6-12	June
15	14-20	February	32	13-19	June
16	21-27	February	33	20-26	June
17	28-6	February/March	34	27-3	June/July

B Budget

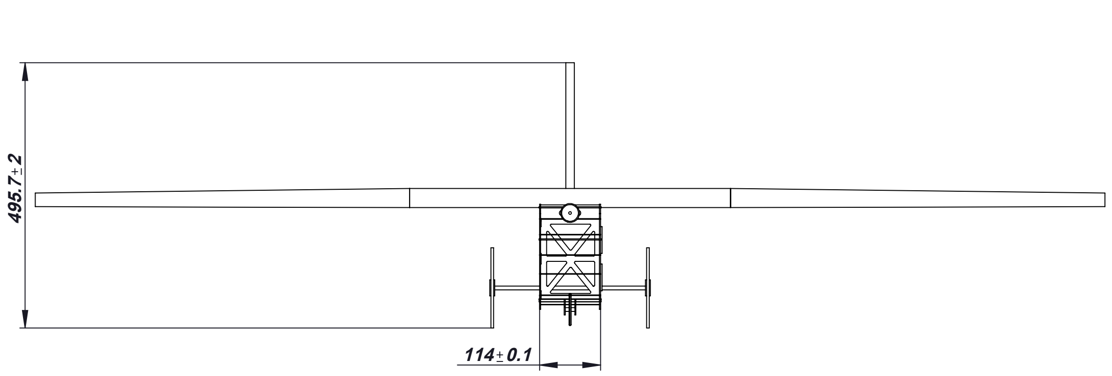
Table 8: Budget summary

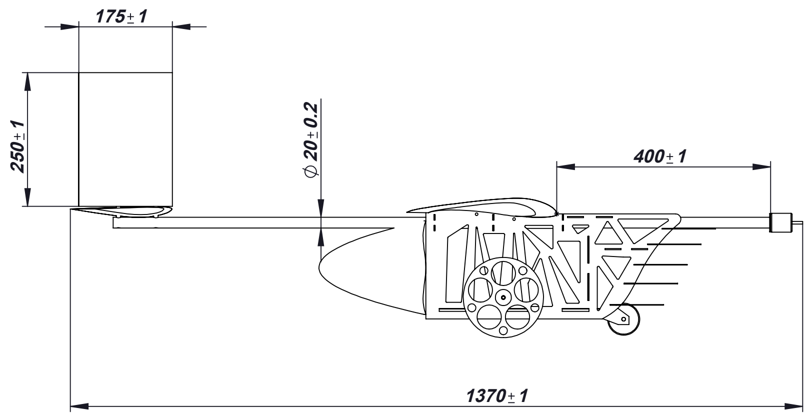
TRENCALÒS TEAM - ACC'22 BUDGET				
Expenses				
Concept	**Item**	**Units**	**Price [€]**	**Total [€]**
Electronics	Battery	2	39.00	78.00
	Servos	4	28.09	112.36
	ESC	1	50.32	50.32
	Servo cables	1	8.00	8.00
	Propeller	5	3.47	17.35
	Engine	1	91.00	91.00
	Connectors	20	0.25	5.00
	Receiver	1	32.98	32.98
Materials	Glass Fiber 300 gsm (sqm)	25	3.00	75.00
	Glass Fiber 163 gsm (sqm)	10	2.30	23.00
	Glass Fiber 80 gsm (sqm)	25	2.00	50.00
	Carbon Fiber roving (kg)	0.25	250.00	62.50
	Carbonweave CW 29 gsm	4	140.00	560.00
	Aramid roving (m)	50	0.12	6.00
	Epoxy resin	2	22.00	44.00
	MDF Hidrófugo	1	350.00	350.00
	Carbon fiber tube diameter 8 (m)	1	17.50	17.50
	Carbon fiber tube diameter 10 (m)	1	21.34	21.34
	Carbon fiber tube diameter 20 (m)	1	32.67	32.67
	Cotton flocks (500 g)	1	10.00	10.00
	Rohacell IG-F 31	1	85.01	85.01
	Paint	2	24.00	48.00
	Balsa	1	40.00	40.00
Consumables	Brushes x5	2	6.06	12.12
	Protection gloves	1	8.00	8.00
	Solvents (L)	4	4.00	16.00
	Peel ply (x100 linear m)	1	20.00	20.00
	Vacuum bags (sqm)	20	2.40	48.00
	Perforated film (x10 sqm)	1	20.00	20.00
	Priming wax (0.5 L)	1	18.00	18.00
	Breather (sqm)	10	2.10	21.00
Inscriptions	Enrolment	7	250.00	1750.00
Total expenses				**3733.15**
Incomes				
Concept	**Item**	**Units**	**Price [€]**	**Total [€]**
UPC INSPIRE (20-21)	Grant	1	1500.00	1500.00
UPC INSPIRE (21-22)	Grant	1	2500.00	2500.00
Total incomes				**4000.00**
Total balance				**266.85**

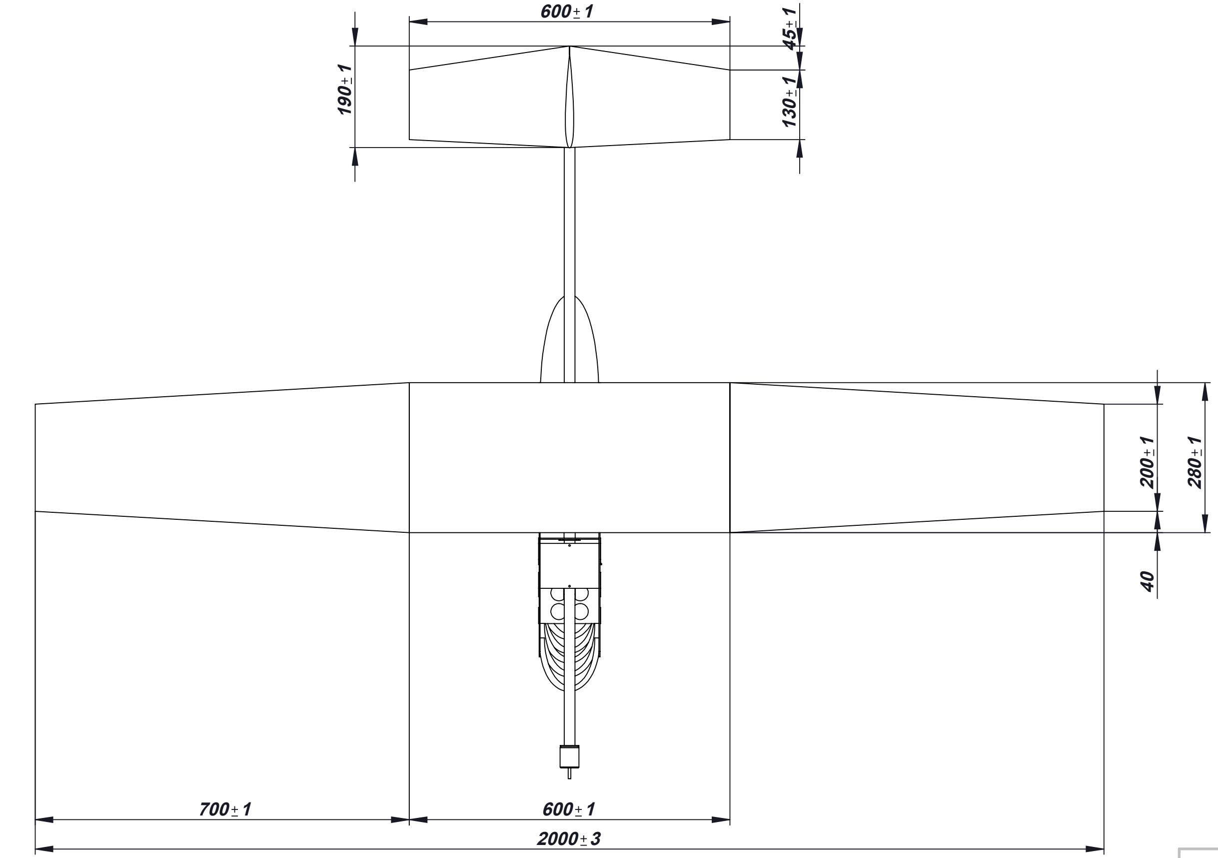
C Electronic design


M
ESC
BAT
BAT
RX BAT
BEC
GPS
GPS
S
S
LG S
RX
S
S
Cable legend:
Positive
Negative
Input signal
Output signal
Component legend
x1 Motor (M)
x1 Electronic Speed Controller (ESC)
x2 LiPo motor batteries (BAT)
x1 Receiver battery (RX BAT)
x4 Control surface servos (S)
x1 Landing gear servo (LG S)
x2 GPS module (GPS)
x1 Radio receiver (RX)

D Drawings

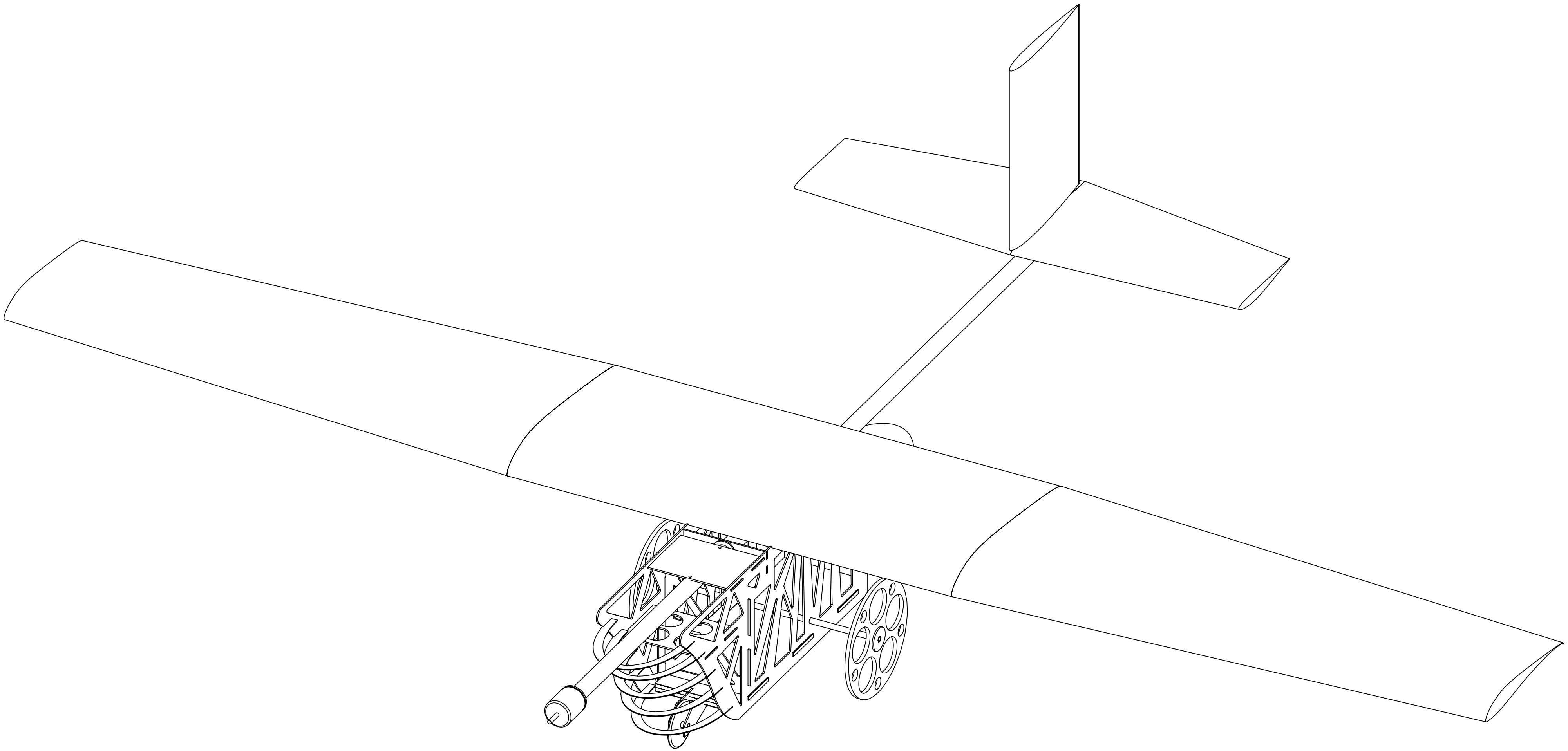




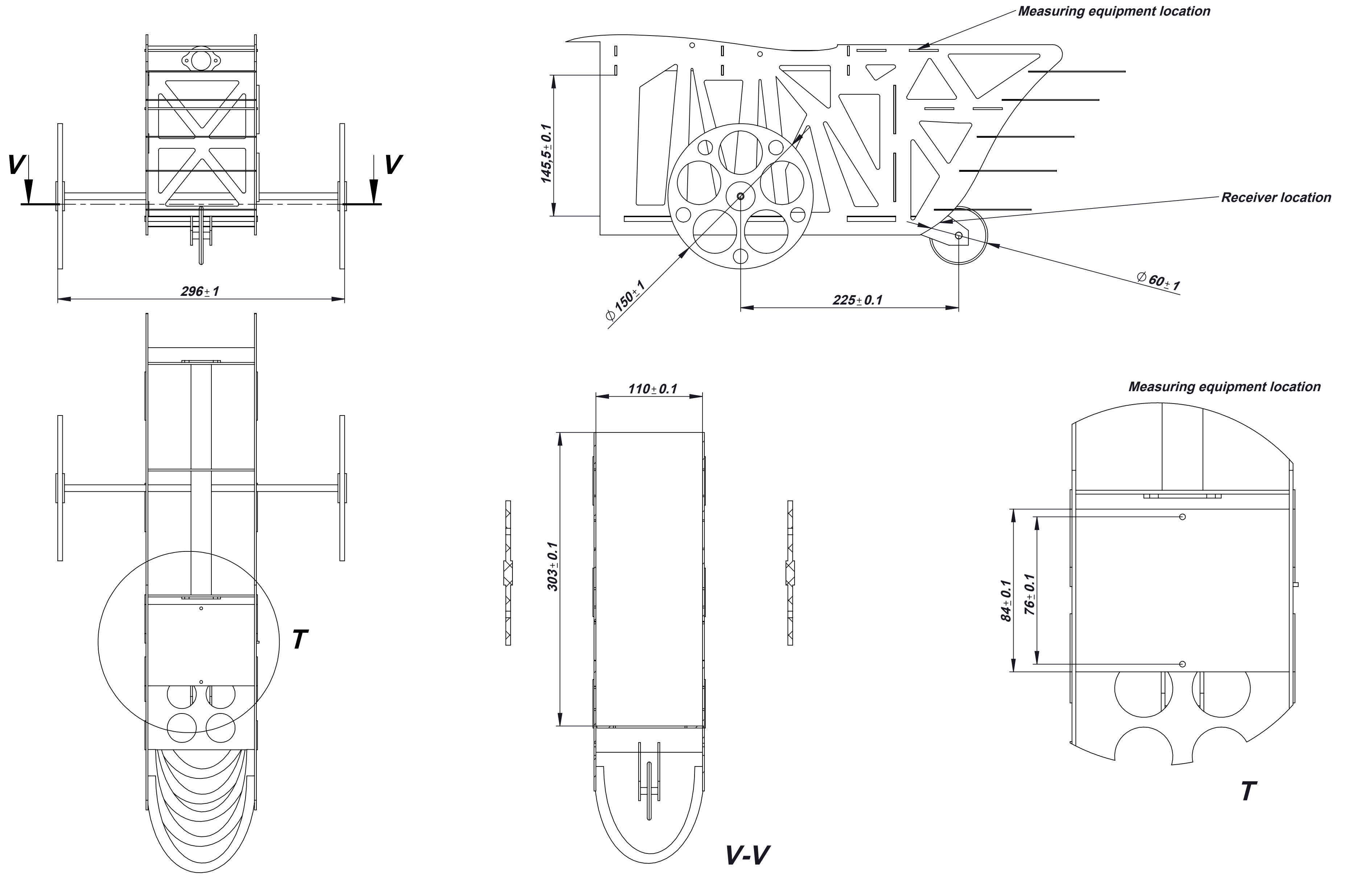


General dimensions		Aerodynamic performance	
Length	1370 mm	C_{Lmax}	1.85
Height	496 mm	$(C_L/C_D)_{max}$	12
Width	2000 mm	C_{D0}	0.058
Wing		**Propulsion and Electronics**	
Airfoil	Selig S1221	Motor	AXI 2826/10 v2
Surface	0.504 m^2	Propeller	APC 10x6E
Span	2000 mm	Receiver	FrSky X8R
MAC	255 mm	ESC	Hobbywing platinum Pro v3
Aspect Ratio	7.94	**Performance**	
Taper Ratio	0.714	MTOW(40m)	6 kg
Incidence angle	0º	Max Speed	23 m/s
Tip twist	0º	Climb rate	1.7 m/s
Vertical tail		**Horizontal tail**	
Airfoil	NACA 0009	Airfoil	Inverted Eppler E205
Surface	0.044 m^2	Surface	0.096 m^2
Height	250 mm	Height	600 mm
MAC	175 mm	MAC	160 mm
Aspect Ratio	1.42	Aspect Ratio	3.75
Taper ratio	1	Taper ratio	0.68
Incidence angle	0º	Incidence angle	0º
Tip twist	0º	Tip twist	0º
Volume coef.	0.032	Volume coef.	0.540

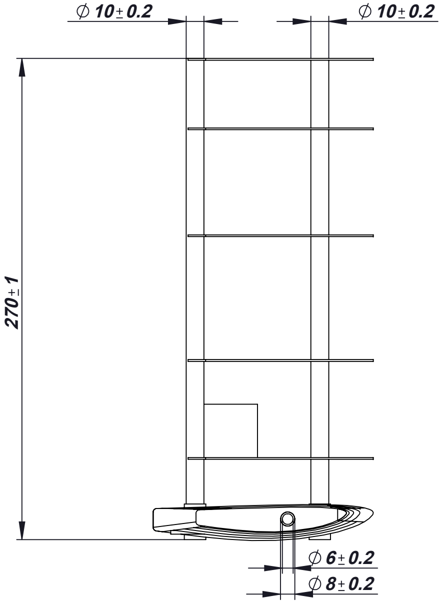
Competition:	DRAWING	DATE	UPC TERRASSA	ESEIAAT
ACC 2022	1/4	01/05/2022		
SCALE 1:10	3-view drawing		TEAM 01 Trencalòs Team	

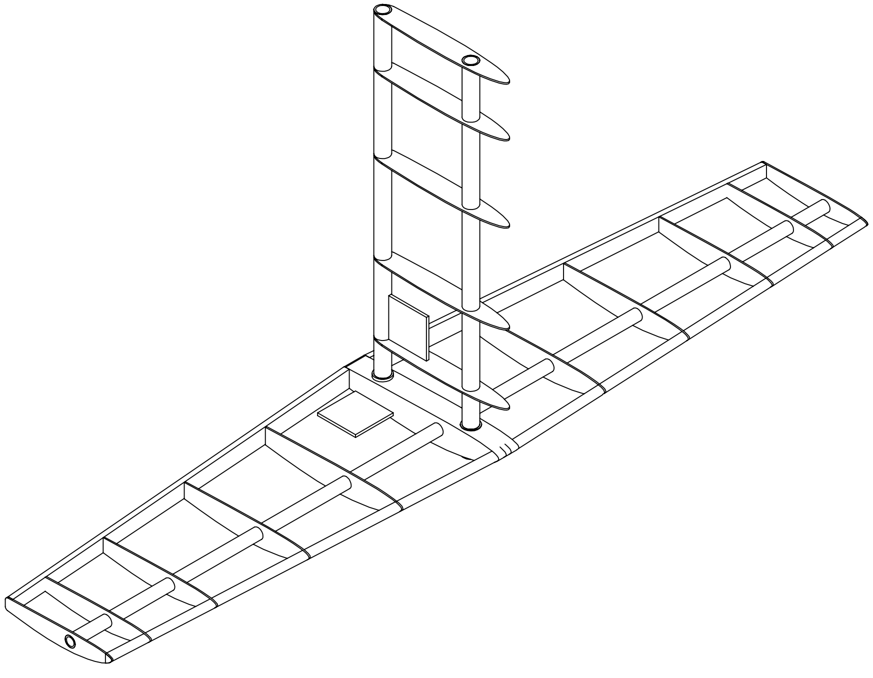


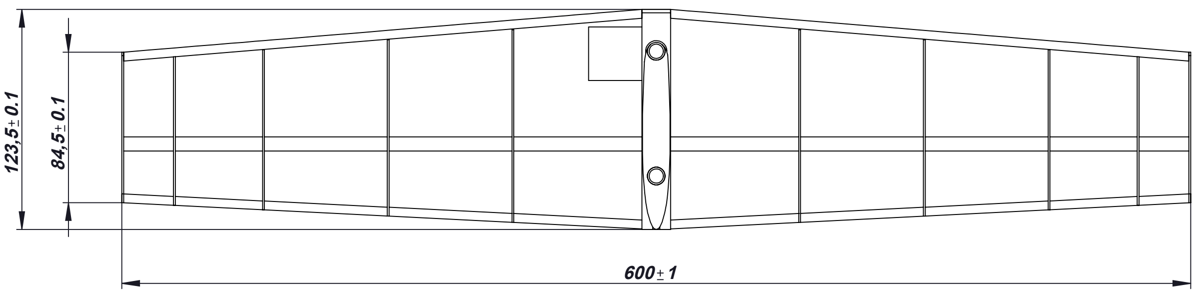
Competition:	DRAWING	DATE		UPC TERRASSA	ESEIAAT
ACC 2022	2/4	01/05/2022			
SCALE 1:5	Isometric drawing			TEAM 01 Trencalòs Team	



Competition:	DRAWING	DATE		UPC TERRASSA	ESEIAAT
ACC 2022	3/4	01/05/2022			
SCALE 1:4	Cargo bay drawing			TEAM 01 Trencalòs Team	







Competition:	DRAWING	DATE		UPC TERRASSA	ESEIAAT
ACC 2022	4/4	01/05/2022			
SCALE 1:3	Tail inner strcture drawing			TEAM 01 Trencalòs Team	