AirCargoChallenge 2022

Technical Report

Team #02

UVigo Aerotech

INDEX

Introduction

We are UVigo Aerotech, an Aero Design team from Ourense (Spain) that is made up of a total of 27 members from the Aerospace Engineering taught at the EEAE (“Escola de Enxeñaría Aeronáutica e do Espazo”), Computer Engineering taught at the ESEI (“Escola Superior de Enxeñaría Informática”) and Business Administration/Law degrees; all of them located at the University of Vigo and belonging to the campus of the city of Ourense.

Team Organization

Internal Team Structure

UVigo Aerotech is divided into 5 different departments, in order to cover all needs of the project in an organized way:

- Structural Design Department: They are in charge of designing and simulating the internal structure of the model aircraft, as well as the management of the manufacturing process. Specifically, they designed the fuselage structure, the wings and the empennage. The entire structure must be sized to withstand the loads and stresses to which the aircraft is subjected during flight.

- Aerodynamics Department: They are responsible for designing the aerodynamic elements of the model, ensuring that the aircraft is capable of lifting the payload. The most noteworthy work carried out by this department are the CFD simulations, which allow checking the parameters of the wings, flaps and other elements of the model aircraft to guarantee its correct operation.

- Propulsion & Dynamics Department: This department assessed the electromechanical design and analysis of the given electric motor and propeller pair. Providing the numerical basis for the dimensioning of the rest of the aerodynamic properties of the plane addressed by the Aerodynamics Department, Propulsion and Dynamics also designed, simulated and tested the main motor structural mount, as well as the main and rear landing gears.

- Electronics Department: This department is in charge of designing, maintaining and implementing the circuits of the model aircraft. This includes designing control surface mechanisms, such as flaps. Also, its members choose the hardware and controller to be used for the electronics.

- Organization & Marketing Department: The members of this department are the ones who organize the team and manage its image; this includes designing the website, writing a bimonthly newsletter, preparing the annual dossier and other reports, as well as the administration of social networks. They also take care of contacting companies in order to obtain sponsorships and funding.

In order to unite the work of all departments, a Governing Board is held weekly and it is attended by the Team Leader and managers of each department.

Team Regulation

Regulation of Internal Regime

UVigo Aerotech is governed by its own Internal Regulation Regime, the document that establishes the necessary rules to organize and direct the entire team. It addresses such important issues as the ultimate goal of the association, the acquisition and loss of membership, the pilots' special regimen, the regulation of the Governing Board, the disciplinary system and the procedure for reforming the Regulation of Internal Regime.

Meetings

UVigo Aerotech organizes its work through 3 types of meetings: Department Meetings, Governing Boards and General Membership Meetings.

- In the first one, departments meet separately every one to two weeks, depending on the department, where new tasks and the progress made are revealed. These meetings also serve to dispel doubts and they are proposed by the manager of each department.
- The weekly Governing Boards, already explained above, serve to unite the work of all departments. It is attended by the Team Leader and managers of each department. In each of them, a constant monitoring of the team members is carried out, consistent tasks and deadlines are established and the most important decisions are made.
- Finally, the General Meetings are held monthly to inform the entire team of the most significant news and make decisions of general interest.

Financing System

As we are an association of university students, we do not have our own financing. For this reason, we use a sponsorship plan to be able to achieve our objectives. Through sponsorships, we give visibility to collaborating companies in exchange for financial or material support. Currently, our sponsorship plan has 4 levels: Alpha, Beta, Gamma and Delta.

- The Alpha level is awarded to companies whose contribution equals or exceeds 3,000 euros. Benefits associated with this level consist of incorporating the company logo on the wings and stabilizer of the model aircraft as well as on the official equipment, talking about the company in our social media, thanking them for their participation when presentations are held and appearing in the sponsors' banner and website.
- The Beta level is granted to companies whose contribution is less than 3000 euros but equal to or greater than 1500 euros. Benefits associated with this level consist of incorporating the company logo on the fuselage of the model aircraft, talking about the company in our social media, thanking them for their participation when presentations are held and appearing in the sponsors' banner and website.
- The Gamma level is granted to companies whose contribution is less than 1500 euros but equal to or greater than 250 euros. Benefits associated with this level consist of thanking them for their participation when presentations are held and appearing in the sponsors' banner and website.

- The Delta level is granted to comp<anies whose contribution is less than 250 euros. Benefits associated with this level consist of appearing in the sponsors' banner and website.

Time Schedule

The design of the aircraft began in September 2020, at the beginning of the 2020-21 season, with the aim of having all the physical design finished by the end of the season. In March 2021, the entire design of the aircraft was finished, so the team started working on its manufacture, obtaining the necessary formation through the professional advice from the sponsors. After two months, the parts of the aircraft were ready to be assembled. Finally, on June 30th, at the end of the season, the official presentation takes place.

During the 2021/22 season, the team has worked on improvements to the desing of the airmodel, in aspects such as its structure or electronics. All this, with the aim of improving the characteristics of the plane, as well as fixing the problems that have been appearing thoughout the manufacturing and assembly process of the first iteration.

Marketing

In the area of marketing the Organization & Marketing department is mainly responsible for the management of social networks and the public image of the team. For this we have an image manual that we use as a guideline for all the visual content of the team.

We are present in four social networks, Facebook, Instagram, Twitter and LinkedIn. In these we usually make weekly publications, we update the situation of the team and we echo our sponsors.

In addition to our RRSS, we have a Newsletter that we publish every two months. In it we interview our members, write technical articles and tell how we have progressed so far. Thanks to these, our readers know our situation during the season and can learn about various topics that we find interesting and that we come across during the design and implementation of the design.

In the team we have also a website. It has different sections where we present the team and the different departments. You can also find various press releases where we talk about the team. On the website, besides the information of our current model the CORV-0, you can also find the characteristics of the first design of the team the AZOR-0, among others.

Structural design

Fuselage

Skin

Our goal was to design a fuselage as aerodynamic as possible, so we decided to use an airfoil shape.

The chosen profile was of the Clark-Y type. That way, the fuselage's lower surface has a flat part that makes the union with the cargo container easier.

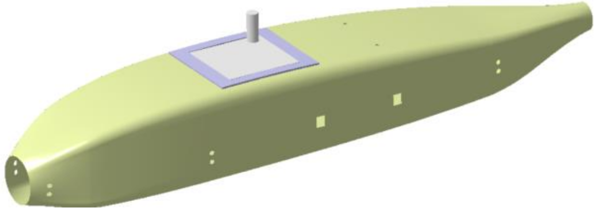


Fig. 1 Fuselage skin

To choose laminate, several simulations in Ansys ACP were carried out with different configurations. Finally, the best results were obtained with 2 layers of Twill [0,0] (total thickness of 0.46 mm) for the fuselage skins.

Internal structure

When designing the internal structure of the fuselage, the first thing that was defined was the number and position of frames. The placement of the frames was determined by taking into account the space necessary for the engine, wires and various electronical devices.

Frames were placed on each side of the hole where the location system of the model aircraft would be placed to provide greater stability.

Subsequently, the stringers were designed. Their main function is to provide greater stability to the frames, as well as to function as support for other elements. In addition, it also reinforces and stiffens the area in contact with the cargo container.

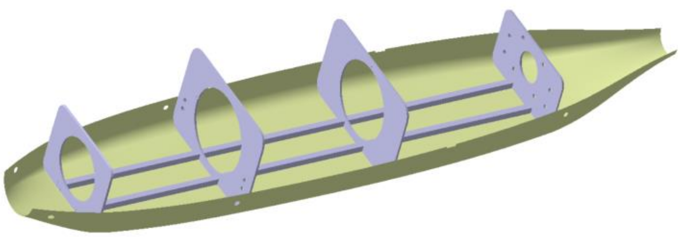


Fig. 2 internal structure of the fuselage

Measuring equipment support

For the placement of the measuring equipment, we have designed a 3D printed piece that works as a cover of the fuselage. In that way, we have an access inside the fuselage. In addition, the measuring equipment is perfectly integrated in the skin, reducing the aerodynamic resistance.

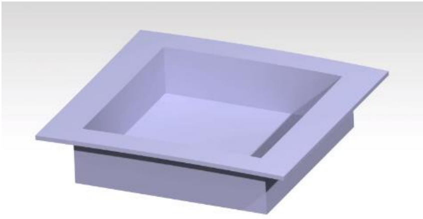


Fig. 3 Piece to hold the measuring equipment support

Wings

Skin

To choose of the laminate, just like in the fuselage, the best results were obtained with 2 layers of Twill [0,0] (total thickness of 0.46 mm). With this type of laminate, the carbon fiber has sufficient mechanical properties to withstand the efforts of the aerodynamic forces and transmit them to the ribs.

Internal structure

When designing the internal structure of the wing, different limiting factors were considered, from which the rest of the parameters were determined.

Firstly, it was decided that in the first half of the semi-wing there should be 2 beams (one close to the leading edge and the other to the trailing edge) to provide enough rigidity and stability. These beams go through the middle of each wing and through the fuselage. As the chord and thickness are decrease along the half-beam, it was decided that the second half would include only one spar in order to make better use of the little space. Furthermore, the last beam would not have to support as much stress as the first two (take a look at the simulation section), making the addition of the fourth beam unnecessary.

Later, we decided the number and arrangement of the ribs, different distributions, using from 6 to 9 ribs were proposed. After the FEM study, the option of 8 ribs distribution was chosen.

Starting from the ribs with their fixed position (at the root of the wing, gap between flap and aileron, wingtip) the rest are distributed so that the distances are equidistant. Regarding the profile of these, it is the same as the sections of the wing, but with a reduction of 0.46 mm along the entire perimeter (which is the thickness of the carbon fiber skins). We have included more ribs in the central zone because it will be the area of greatest stress due to the distribution of the wing's sustentation.

In the central part, a piece printed in PLA has been placed to transmit the efforts of the trailing edge beam to the beams that lift the fuselage.

Finally, during manufacturing some PLA reinforcements were added to the leading edge and trailing edge to improve the structural strength and increase the bonding surface of the two wings.

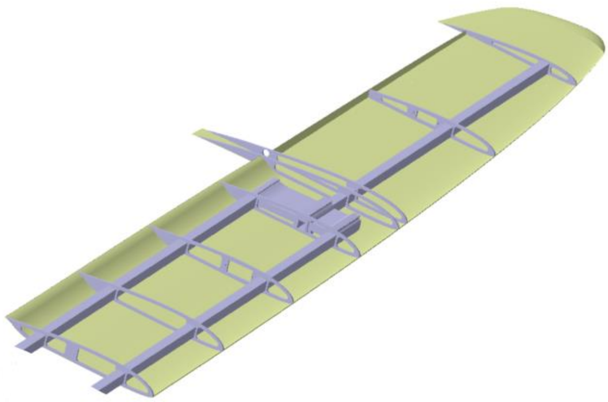


Fig. 4 Internal structure of the wing

Socket

This piece joins the skins of the wings with the fuselage. Its surface must adapt to the curvature of the fuselage and the profile of the wing. It has a very specific shape, so for its manufacture we decided to use 3D printing.

It is assembled using M3 screws in order to fix the wing skin with the fuselage.

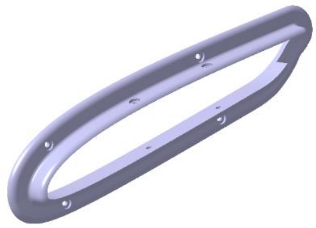


Fig. 5 Socket

Aileron

Skin

It will use the same as the wing, because the entire surface is manufactured in the same mold and the control surfaces are trimmed. For this reason, for the external surfaces two layer of carbon fiber twill were used with a total thickness of 0,46mm (two pieces, one for the extrados and another for the intrados).

Internal structure

The skin is combined with a solid core that needs to be as light as possible since it will not be under much structural stress.

To select the material for the core structural simulations were done under the same conditions with the following materials: foam h45, foam h60, balsa wood and PLA. After analysing the results, we determined that all the proposed materials could handle the conditions set for the test with a high factor of safety, so the selected material would be the least dense, which is the h45 foam made of PVC.

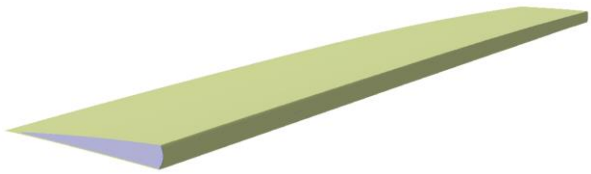


Fig. 6 Aileron Structure

Flap

Skin

The laminate will be the same as the wing, just like the aileron because the entire surface is manufactured in the same mold and the high-lift surfaces are trimmed.

Internal structure

After repeating the study carried out on the aileron, the same conclusions were reached. The skin of the flap is combined with a solid and light h45 foam core.

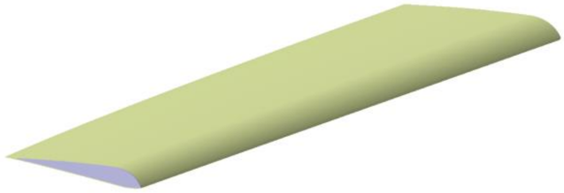


Fig. 7 Flap Structure

Empennage

Skin

After carrying out several simulations, we verified that with only one layer of twill it is enough to withstand the efforts of the empennage. In this way we manage to optimize the weight of the model aircraft.

Internal structure

The empennage is divided into two semi-stabilisers and an elerudder. To manufacture them, we use 4 molds to laminate the intrados and the extrados of each semi-stabilizer. Finally, we cut the surfaces of the elerudder and glue them to a core of foam h45, so the internal structure is the same as in the ailerons and flaps.

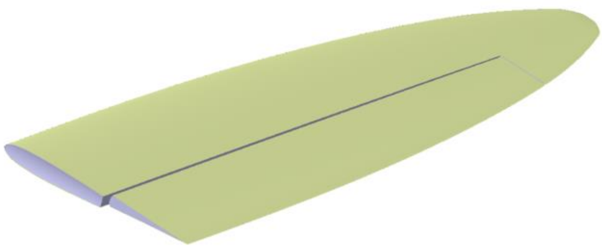


Fig. 8 Empennage structure

Fuselage-empennage union

To join the fuselage and the empennage, we use a purchased carbon fiber tube.

On the one hand, the tube is attached to the fuselage by using inside a piece of PLA that is screwed to the rear frame.

On the other hand, the empennage is attached to the tube by another 3D printed part, adapted to the profile of the semi-stabilizer, as can be seen in the following image.

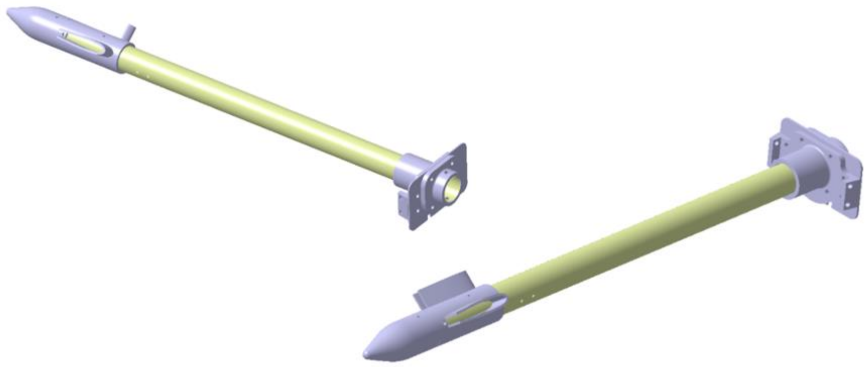


Fig. 9 Fuselage-empennage structure

Cargo Container

Skin

The external structure is made of an upper part with a thickness of 6mm and a fairing 0,8mm thick, a vortex generator of 5mm in thickness is in the tail of the compartment, all the pieces are 3D printed in PLA. The upper part has 9 pockets for it to be assembled to the fuselage via bolts.

Internal Structure

The internal structure is made out of frames, with stringers across. In the design phase it was decided to place 4 frames and to try 2 configurations for the stringers: one with straight stringers, and another with the stringers forming a lattice. After the stress analysis the lattice structure presented no advantage compared to the straight stringers, furthermore, the higher difficulty in the manufacturing process was another deterring factor in the use of this configuration.

The entire cargo container will be 3D printed.

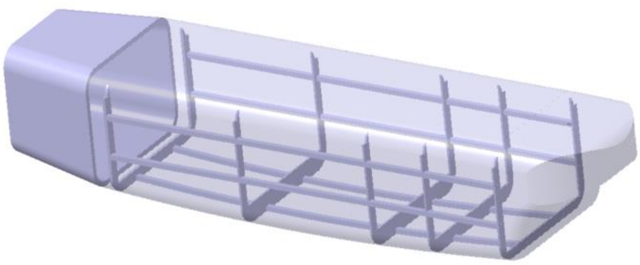


Fig. 10 Internal structure of the cargo container

Stress analysis

The FEM analysis has been a fundamental tool in making decisions on the design of our model aircraft and in weight optimization. We have taken the maximum efforts to which each structure is subjected to as loads and we have applied safety coefficients of at least 1.5 in all the simulations.

For the mesh, an inverse orthogonal quality of more than 0.8 with a maximum aspect ratio of less than 5 has always been sought to ensure a reliable result.

In the ACP studies, the materials have been modeled based on carbon fiber properties according to the main directions.

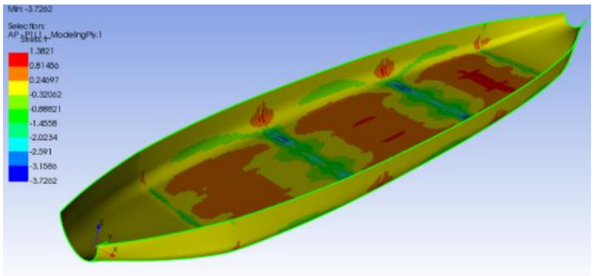


Fig. 11 ACP study of the fusselage

Aerodynamics

Preliminary design

Base parameters

The preliminary parameters that have been used to obtain the results are shown in the next table:

Magnitude	Value	Units	Commentary
Cl max	1.6	-	Downward approximation based on the designed profiles
Cd min	0.055	-	Approximation based on the CFD simulation.
Mass	5	kg	-
Aspect Ratio	10.7	-	-

Table 1 Design preliminary parameters

All initial data, except for previously known constants, have been calculated using approximations after the results obtained from the airfoils analysis, the CFD computations and the study of similar aircrafts.

Wing loading

The wing loading has been computed for the following flight stages (using the previous data):

- Sustained spin
- Take off distance
- Cruising speed
- Stall speed
- Climb rate

Results:

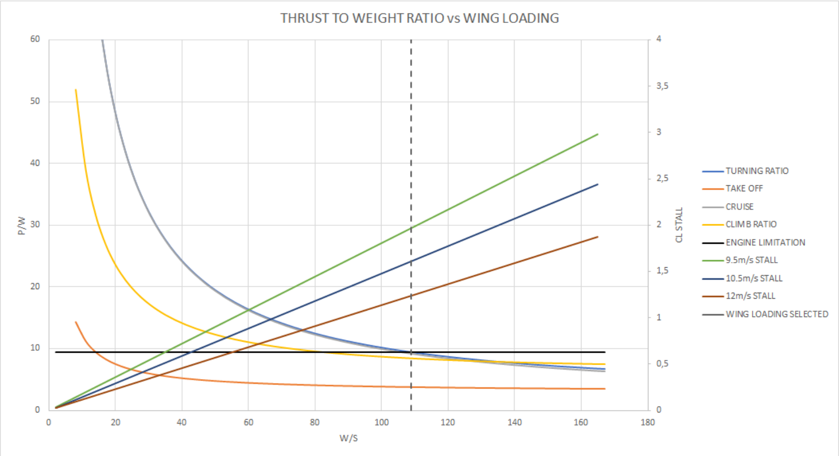


Fig. 12 Wing loading results

A high W/S has been selected in order to achieve higher speed, even at the expense of obtaining worse results of stall speed.

Following the recruitment criteria, the final choice has been 109N/m^2, reached at 1.47, with a take off CL of 1.7 at 10.23m/s.

Wing design

The design of the wings was carried out following the upcoming criteria:

- Maximizing the efficiency and performance for the competition scoring system.
- Maximizing the controllability of the aircraft.

Airfoil

The process of selecting the airfoil for the wings of our aircraft was fulfilled through xflr5 and an optimization algorithm.

The global type of analysis for the Particle Swarm algorithm gave us an optimization of a single selected airfoil by exploring through 200 segments how the effects of the variations of the points in the airfoil modified its performance. Every iteration was analysed through X-foil software.

This process gave us 6 airfoils that outperformed all the rest we analysed and, through another optimization process, we achieved the airfoil we used in our aircraft, with the maximum efficiency and performance in our case of interest: UVigo Aerotech 06.

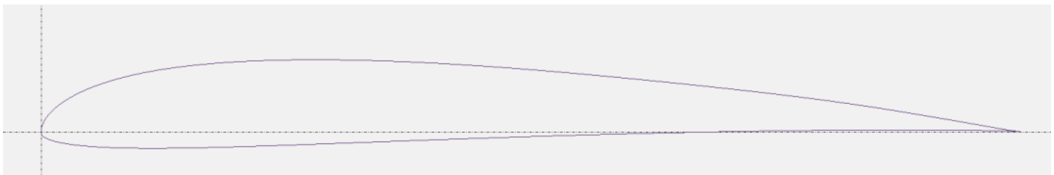


Fig. 13 UVigo Aerotech 06

Planform design

Trying to achieve high efficiency, we designed an elliptical wing with an Oswald factor approaching unity. This design was strongly conditioned by the sizing requirements of the competition.

After comparing different wing shape configurations (according to the previously calculated wing loading) we got our final wing configuration:

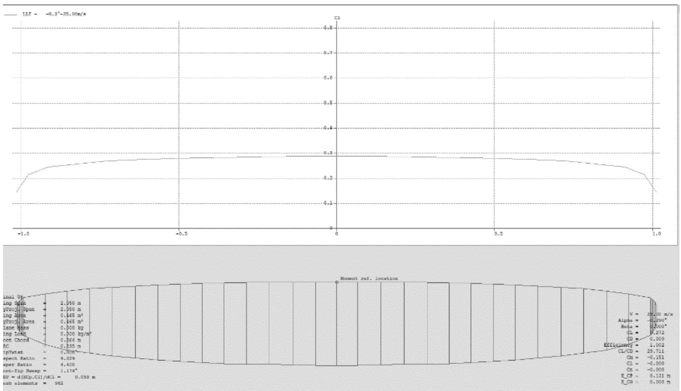


Fig. 14 Wing planform design

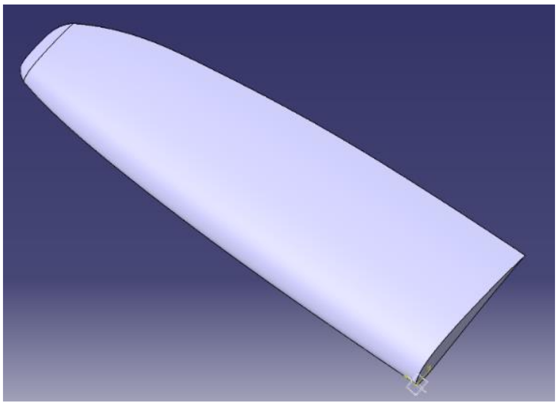


Fig. 15 Wing 3D CAD

Empennage Airfoil design

The empennage foil was selected according to the same criteria applied to the wings, by modifying the geometry in order to allow the best performance for the required capacities, taking into account the lift, drag and moments which the plane will generate. The software used to check the results will be XFLR5.

The preliminary airfoils were the HQ-7, the FX76-100 and the SD 8020, mainly symmetric to maintain the stability despite providing less lift, which is not the main function. Through different analysis, the result is a modified airfoil which presents a good lift to drag relationship, a high stall angle and in addition, a null moment due to its symmetry.

Once the foil is established, the next step is to determine the type and the sizing of the empennage. This airplane uses a V tail, due to its drag and weight reduction. This design also avoids hitting the tail during landing, making it safer. Nevertheless, V tail makes it harder both pitch and yaw moments and it also generates more stress when they produce them, but it can be reduced with an appropriate design which projections in the horizontal and vertical plane are the same as a conventional empennage.

Related to the sizing, it has been followed a Hamburg's University study to dimension a conventional design which is extrapolated to the V tail due to their projection characteristic. The preliminary projected surface of stabilizers is calculated according to the next equations, computing a range of cg positions with some estimations in most of the parameters used.

$$\frac{S_H}{S_W} = \frac{C_{L,\alpha,W} \cdot \overline{x_{CG-AC}}}{C_{L,\alpha,H} \cdot \eta_H \cdot \left(1 - \frac{\partial \varepsilon}{\partial \alpha}\right) \cdot \left(\frac{l_H}{c_{MAC}} - \overline{x_{CG-AC}}\right)} \qquad \frac{S_H}{S_W} = \frac{C_L}{C_{L,H} \cdot \eta_H \cdot \frac{l_H}{c_{MAC}}} \cdot \overline{x_{CG-AC}} + \frac{C_{M,W} + C_{M,E}}{C_{L,H} \cdot \eta_H \cdot \frac{l_H}{c_{MAC}}}$$

Equation 1 Horizontal stabilizer projected surface's equations

$$\frac{S_V}{S_W} = \frac{C_{N,\beta} - C_{N,\beta,F}}{-C_{Y,\beta,V}} \cdot \frac{b_W}{l_V}$$

Equation 2 Vertical stabilizer projected surface's equation

$$C_{N,\beta,F} = -\frac{360}{2 \cdot \pi} \cdot k_N \cdot k_{R,l} \cdot \frac{l_F^{\,2} \cdot d_F}{S_W \cdot b} \quad \text{in 1/rad} \qquad C_{N,\beta} \geq 0.001 \ 1/\deg = 0.0571/\text{rad}$$

Equation 3 Constants

Obtaining the next results:

- ➔ Horizontal area equivalent to the 10% of the wing's area with the current CG, 2-4cm behind.
- ➔ Vertical area equivalent to 5% of the wing's area, preliminary low, which will be bigger due to the lack of roundness of the fuselage.
- ➔ Extrapolating the data to the V-tail, the angle calculated is 32.75° with an area of 0.037m2. Both results are tested through CFD computations of the plane in order to get the best possible values, obtaining a higher total area of 0.075m2.
- ➔ Incidence angle affects plane's trim point, leading to a straight cruise flight without the L-rudders deflected. Through iteration an angle of -1° is the proper one to the advantages it presents and it also makes the design easier.

Control surfaces

Flaps

For the design of the flaps, CFD computations were carried out with different distributions, obtaining the best cl and cd results when the flap was separated by 1% of the chord horizontally and 0% vertically. Computations were also carried out with different deflections (25º, 27º, 30º), obtaining minimum and maximum cl and cd values.

Min

- Cl – 1.1969
- CD – 0.2372

Max

- Cl – 1.6042
- CD – 0.355

We use the minimum and maximum value data to calculate overall performance data on takeoff speed and distance.

- With the configuration of minimum values, we obtain takeoff in 38 m, generating 68 N at 14.12 m/s, optimal takeoff conditions. Thanks to these data we obtain that the minimum possible value would be the configuration of 25º to 7º AoA and 50% of the span for the flap arrives for takeoff.

- To calculate the distance, we will use the minimum configuration named but with 9º AoA, reaching a cl - 1.377 and a cd - 0.2337, with this we reach the takeoff speed (which in this case is 13.5 m/s) in just 31.70 m.

- Final configuration:

- V=13.5m/s
- S=31.70m
- Span=50%
- AoA=9º (can be lowered to 7.5º if necessary)
- Deflection=25º

Ailerons

Using 11.58% of the wing surface (recommended between 10 and 12%) and analysing its behaviour in XFLR5 at 20º and analytical calculation of the Roll Helix Angle and roll ratio, being 50°/s. The maximum deflection upwards is 25º and downwards 18.75º, respecting the ratio 1:0.75.

Stabilizers

For the sizing of the rudders, we will use analytical methods and CFD computations since they will determine the control of the aircraft. It is not recommended to use more than 30% of the stabilizer area, nor a deflection of more than 40º.

Basic equations of the empennage in V:

- Ahorizontal=AV*cos^2(Γ)
- Ahorizontal=AV*sin^2(Γ)

We calculate the neutral point, the minimum deflection and thanks to this we get the limit of the CG for our case. As a base rudder we will use one with 28% chord at the base, extending the axis perpendicular to the axis of the fuselage. This represents 23.5% of the total stabilizer area.

After the analytical calculation we will check with xflr5 simulating different deflection configurations of the empennage rudders. From 5º to 25, both positive and negative, obtaining flight values from 20º to -20º.

Cargo container

The cargo container design started by defining the number of blood bags. By defining the max possible configuration, we estimated their volume and created a square prism (a box), which will hold these bags. Then, we assumed a uniform weight distribution for the box and it was located longitudinally in order to not move the CG. This was made with the purpose of being able to fly the plane with or without the extra weight the payload adds.

For the exterior design, we started to create designs to make the box aerodynamic: to reduce its drag. We had some limits on the dimensions, but we took different approximations. The final decision was made through numeric comparation of these designs. The one who got the less drag on CFD computation was the one we chose.

Stability analysis

Analysis of the aircraft under different situations

When ongoing a crosswind flight after stablishing standard flight conditions, the momentum over Z axis of the body is analysed, obtaining as a result the chance of keeping the negative momentum that leads to an increase on the sideslip angle. To maintain the planned course is necessary to apply a correction by the pilot based on a lower deflection of the rudder.

Another situation we considered important is when the aircraft must perform a balked landing maneuver, in this situation a 3% ascent ratio is considered to analyse the momentum generated in the Y axis. A negative value is obtained meaning that the airborne tends to a positive pitch allowing it to be trimmed for an ascent ratio over 3 points.

Our third situation involves the possibility of the pilot to make the plane go through a stall, after analysing the trim for this situation we got a stall point between 12 and 14 degrees. So, our aircraft will not be able to reach a stall situation with flaps fully deployed. In this case that is not the optimum because we some control over the plane is loosed, but it can be attached by not fully deploying the flaps.

Stability of the aircraft after xflr5 analysis

We must get data to verify our aircraft is stable both horizontally and vertically. After this we have verified that our aircraft is stable in the horizontal plane when ongoing a perturbation meaning that it will be able to return to its horizontal equilibrium position, this is confirmed by a negative slope in the CM-alpha graph. Vertical axis has a stable condition too, as it is supported by a negative slope in the CM_{roll}-Cl graph and a positive one in the CM_{yaw}-Cn.

Stability of the aircraft after CFD analysis

To verify that our results in xflr5 are right we decide to conduct a CFD. For the horizontal stability we obtain an incidence of -1.04, that proves our previous analysis are accurate.

Stability analysis of the aircraft for the design of empennage

After a batch of analysis covering different types of empennage configurations covering factors that affect this part’s design, we obtained a series of results that guide us in the creation of a pattern for an empennage that will bring stability to the airborne.

Firstly, the optimum area of this part will be likely superior to 0.07 [m^2], being the best option 0.08 [m^2]. To follow, for a certain case of gravity centre and area we get a 2.5 [cm] static margin, meaning that a close to c/4 gravity centre is worth.

Next conclusion is that the empennage placement is not truly relevant if placed at 0.6 [m] or less. Also, the linkage between the wingspan and the longitude shows that bringing the empennage closer and making it slim is worth. In this context and taking in consideration that a high aspect ratio increases the aircraft’s performance, it is the best option to bring the empennage close to the body.

Finally, we obtain an effect of the angle with an intermediate point between 39 and 39.5 degrees.

Gravity centre of the aircraft analysis

The position of the CG is calculated via the position measurement of each component in CAD software and manual (calcsheet) calculation using the CG for discrete elements formula. Longitudinal stability is then verified by XFLR5 software. Assuming the slope of the moment graph is negative we assume the plane is stable.

The gravity centre of our airborne is considered variable in a closed range between 60 [mm] to 89 [mm] from the leading edge and at -30 [mm] in the vertical with the longitudinal axis of the plane.

Plane parameters

Cruise Speed		24.5 m/s
Max. Speed		25.05 m/s
Stall Speed		10.5 m/s
Range	Cruise	13703.22 m
	Max.	28757.16 m
Max. climb angle	Theoretical	62.25°
	Real	25.463°
Wing (at cruise)	Cl	0,27526882
	Cd	0,04479103
	Alfa	-0,12452714
Min. resistance		5.45 N
Max. efficiency		9

Table 2 Plane parameters

Graphic charts

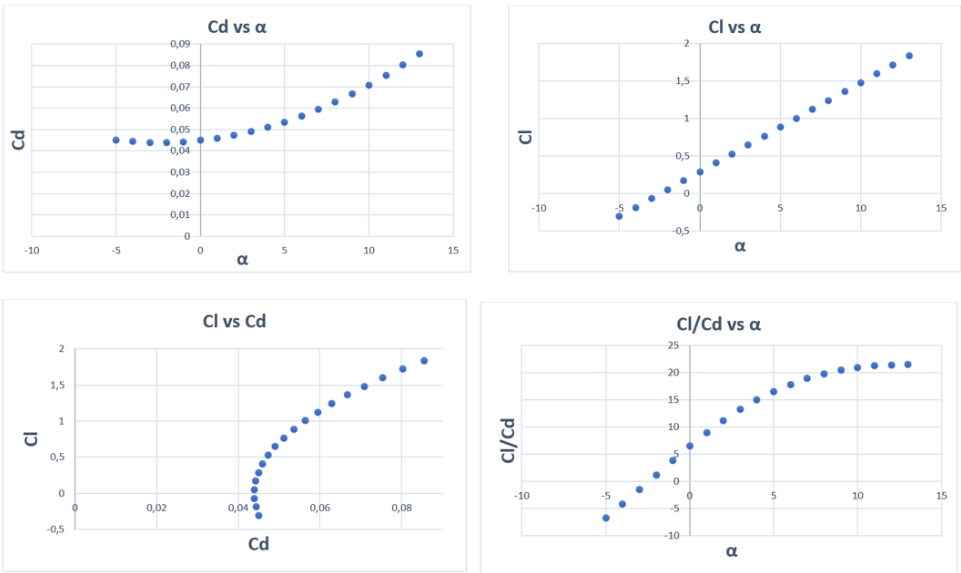


Fig. 16 Graphic charts

Propulsion & Dynamics

Structural Engine Support

To design and test the motor mount, the Propulsion and Dynamics department worked together with the Structures department.

The engine support design started with the basis of Topology Optimization over a flat sheet as seen in the image below, a refined and modified result of topology optimization over a flat sheet fully constrained in all four sides.

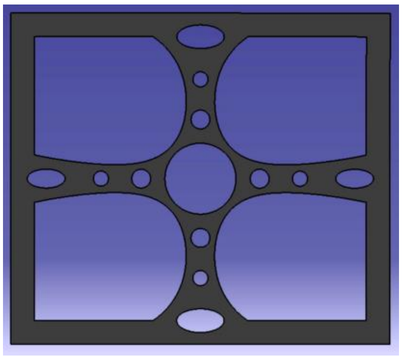


Fig. 17 Provisional Motor Mount

It later developed into a more convoluted geometry that took into consideration the main Fuselage skin shape and implemented a way to recreate the full constrain of all exterior sides via a relatively thin outer layer that mimics the fuselage skin, fitting inside of it thanks to tight tolerances.

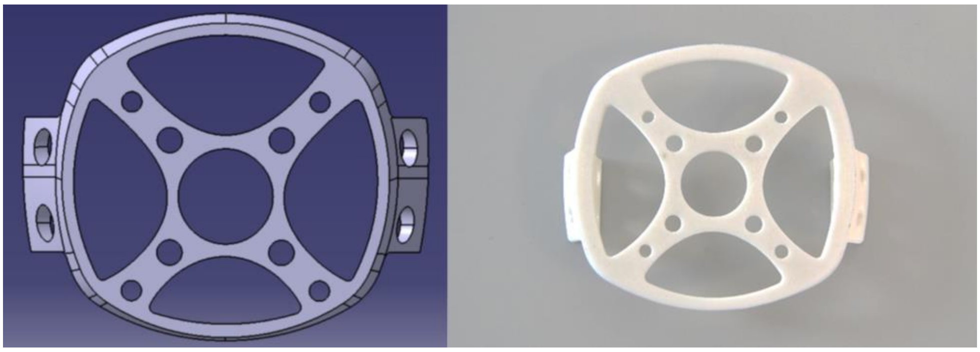


Fig. 18 Final motor mount. Left, CAD design; right, real assembly

The main engine support was 3D printed and the material chosen for it was commercial grade PLA.

The main engine assembly was therefore implemented via the main engine mount piece (RED) to adapt the given metallic engine mount (BLUE) that the engine came with.

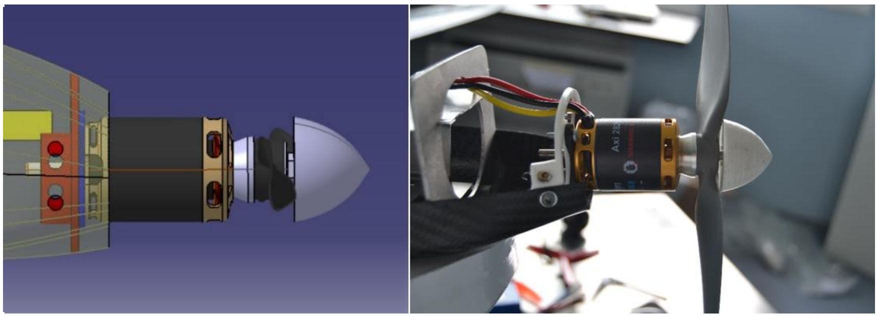


Fig. 19 Main motor assembly. Left, CAD design; right, real assembly.

Propeller cone

The propeller cone is the front piece of the airplane, used to order the air flow around the plane and to reduce the drag force to the minimum possible. The engine cone will not be under structural forces, so the trials will only be based on fluid simulations.

During the design procedure, there were several possibilities, but at the end we decided a final design, which is the one that will be explained.

The final design is the following:

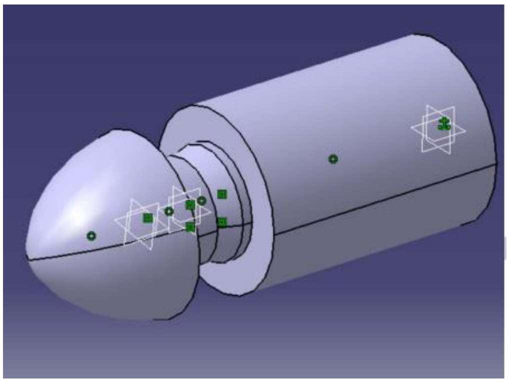


Fig. 20 Propeller cone CAD Design

This design was based on other planes, usually planes that right now are not in use, for example, from the period of WWII, the final result was decided as a result of experiments and intuition.

In the computation, the most important results are the Pressure Field and the Stream Lines, as well as the result of the drag force. For the simulation, the flow speed is 22 m/s, because it will be the cruise speed:

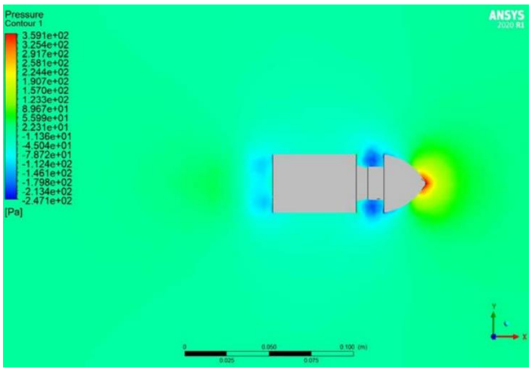


Fig. 21 Pressure field of the propeller cone

The maximum and minimum values are important because this pressure gradient will result in drag force.

If we see the streamlines in 3D, we can see how the flow is deflected.

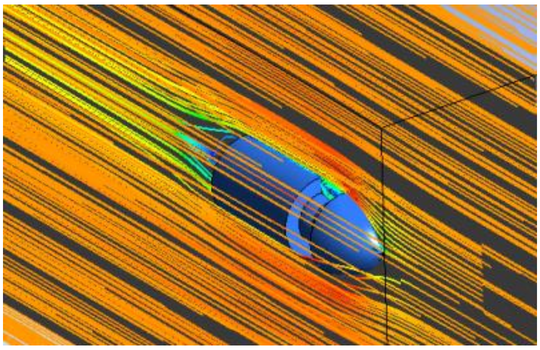


Fig. 22 3D streamlines of the propeller cone

Landing gear structure

The landing gear configuration chosen for the aircraft was a Taildragger because of its added simplicity and easiness to implement a much bigger angle of attack during take-off (we went for almost 10º at first, finally settled at 9º), reducing its take off distance.

The location of each component of the two-component landing gear system can be easily explained by the Static Equilibrium of all distributed weights as clearly seen in the next image.

Units: mm, g, N

CT = Center of Thrust.

Initial Data				
Mass	Xcg	Ycg	Weight[N]	Trasversal Area[m²]
4200	42.3865	4.43962	41.202	0.227

Distances							
CG-Nose	CG-back	Hcg	Wheel Base	CG-Nose min	H nose	H back	CG-CT
100	780	213.187	880	180	291.284	131.46004	19.808

Angle relative to the ground	
Calculation	H back correction
10.29375136	151.9056925

OP.1: TailDragger

Static Loads			
Fnose[N]	Fback[N]	%Wnose	%Wback
36.52	4.68205	88.6364	11.36363636

Dynamic Loads			
Fback[N] TakeOff	Fback[N] Landing	Fnose[N] TakeOff	Fnose[N] Landing
5.69953	3.664562	35.502471	37.5374
6.71701	2.6470786	34.484988	38.5549
7.7345	1.6295952	33.467504	39.5724

Controlability			
Ground contrability.Turns during taxiing	Wind Force		
	0.92710205	3.70841	14.8336328
	Wheel Track min		
N/A	9.594005375	38.376	153.504086

Table 3 Calculations of the static equilibrium

These calculations also provided us with Static and Dynamic Structural Loads for later design and validation of both landing gears.

Main landing gear

The main landing gear design was inspired by actual rigid designs seen in lightweight planes. The structure was chosen to be manufactured on Aluminium because it is very light and not too stiff, which help us to absorb part of the impact that it will have to take. Moreover, this material can be cold formed, so it was easily manufactured.

In order to reduce weight, we made holes in several regions of the main structure supported by simulations´ results.

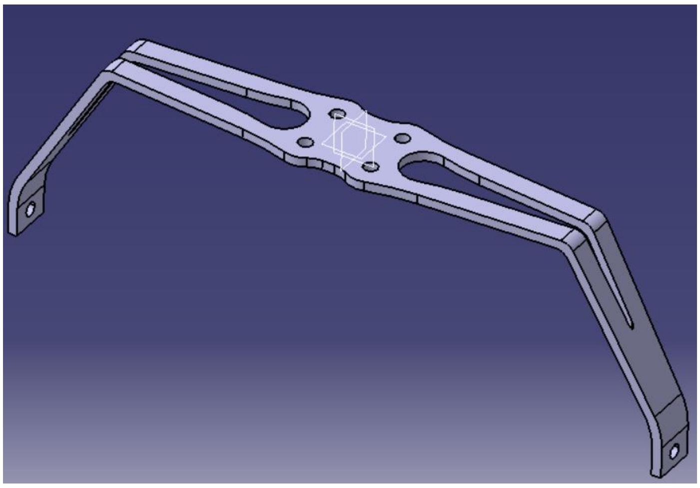


Fig. 23 CAD design of the main landing gear

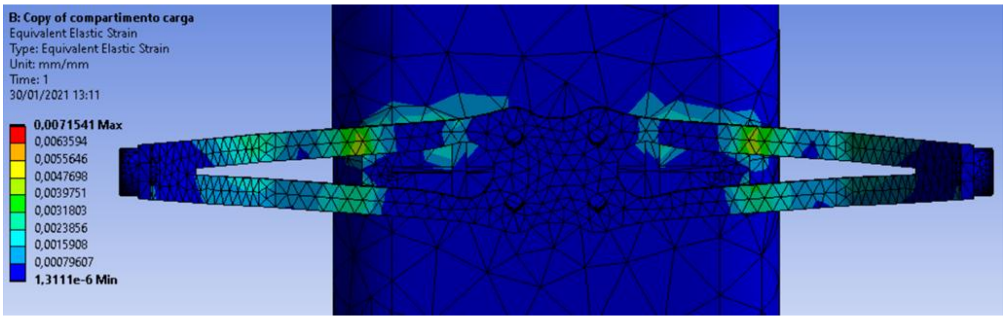


Fig. 24 Simulation of the main landing gear and cargo container

The wheels are inserted into the holes of each side.

Given that the aluminium piece is supported on the cargo container, it will be bolted together using another intermediate piece that had to be designed in order to fix the gear in that position:

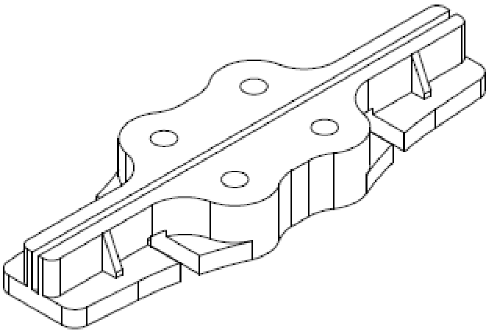


Fig. 25 Union of the main landing gear and cargo container

This piece, manufactured in FDM 3D printing in PLA material, can be seen in the image above, which lets us see the long perforations in order to let the stringers and ribs of the cargo bay pass through.

Finally, we design a piece to cover the heads of the bolts in order to make this structure more aerodynamic, as seen in the general images.

Fig. 26 Main landing gear. Left, CAD design; right, real configuration

Rear landing gear

The rear landing gear position was defined using the same calculations used for the main landing gear and exposed at the beginning of this chapter.

The design process was actually more convoluted than for the main landing gear so we are going to explain it briefly.

The first model was made from an aluminium hollow bar, twisted to have the desired form, and it had a bearing to allow the rotation of the whole assembly and enable turning on the track. The problem was that it drifted rolling because its own weight made a moment around its rotation axis. This is a common problem in landing gears with this configuration, it is called *Tailwheel Shimmy* and it's related to the camber angle of the rotating assembly.

Because of this problem, it was decided to implement an angle of 9 degrees (the inclination of the plane on land as stated previously) in order to compensate this moment, however, it would turn during the flight, causing problems to land safely since it often stayed in the 180º orientation prior to landing, which induced a huge but momentary turn speed and hence, instability.

Seeing that this problem didn't have a simple solution and, in an attempt to make all the plane systems simpler, we as a whole team decided to make the Rear Landing Gear fixed, considering the regulation of the ACC competition too.

Therefore, after many different iterations and small adjustments to reduce as much weight as possible (using topology optimization analysis in a similar fashion as the Engine Support), we came up with an aluminium design that conceptually resembles the main landing gear and is capable of withstanding heavy landings (as worst-case scenario), and prolonged use. To accomplish this while making it removable so that it can be easily stored, we also created a 3D printed PLA union between the plane's tube and the aluminium piece. Hence, the following assembly.

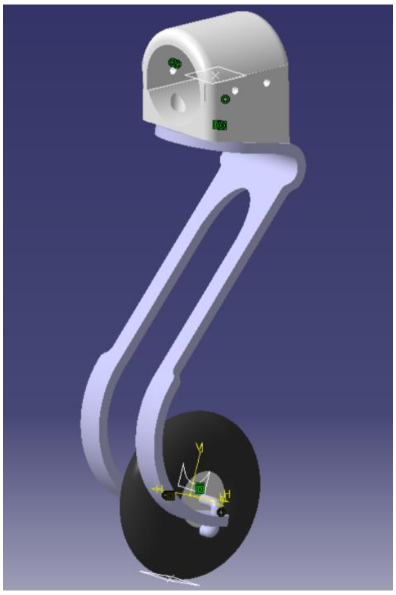


Fig. 27 CAD design of the rear landing gear

After a lot of FEM analysis and trials for a 'sweet spot' between mass, strength and compliance with the constraints that make the 9 degrees of inclination possible, an angle of 60 degrees and a hole with an arch shape at the top was decided upon.

This design enables it to absorb part of the impact without significantly deforming (around 1-2mm of displacement when landing). It also allows for a variety of widths for the aluminium sheet. 4mm of width comes with a trade-off; tougher, but heavier. That compares to its 3mm counterpart, which is more flexible, but less durable.

We finally settled for the 3 mm aluminium sheet mainly because of its reduced weight when compared to the 4 mm one, which gave the following deformation criteria, our main goal was to achieve a limited but perceptible deformation, withstanding of course, the loads of a heavy landing.

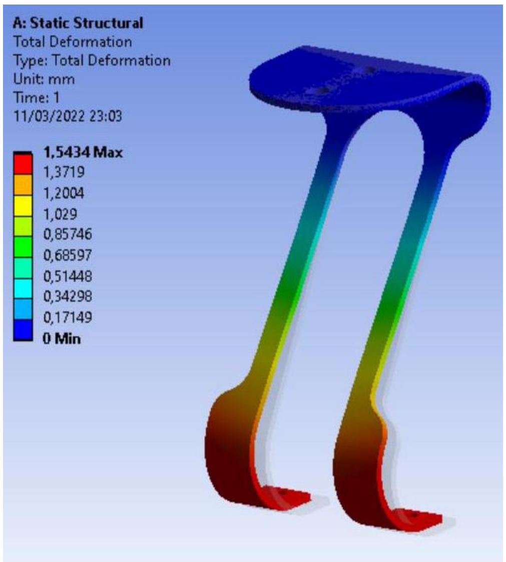


Fig. 28 Simulation of the rear landing gear

Electronics

Model mechanisms general lines

There are some design requirements and observations about aircraft mechanism that define the main points of its design process. First of all, we need components with a great potential and performance but with the lowest possible weight. Another important thing to take into account, is that we have to minimize aerodynamics impact, so we tried to place inside surfaces all parts that we can, but we have to consider that attainability and repair process have to be as easy as possible.

Due to that, one important point is servo choice. Finally, we used only one servo model. It is the EMAX ES3302 one. It's a light one and with enough potential. It offers 2.4 kgf.cm torque when is powered with 4.8 V and 2.8 kgf.cm when is powered with 6 V. Our receiver device gives 5 V outputs, so we will receive more or less 2.4 kgf.cm. It weighs 12.4 grams. Dimensions are a critical point too, and this servo is 23.17 mm long, 24.05 mm high and 9.17 mm wide. It has one screw hole at both sides that allow fixing it to some surfaces.

Another important point is mechanism wiring and servo placement. Therefore, servos are located inside of wings and stabilizers with an easy access and lowest possible aerodynamics impact. Wiring was made with longer cable than necessary that allows working easy with it.

Mechanisms control is made with Archer R8 receiver. This receiver gives regulated outputs of 5V. Each side of each mechanism is connected to one receiver channel. We prepare a custom Open TX program that allows us a correct control of the surfaces.

The receiver is located at the upper part of the third fuselage rib with a PLA part with a big hole where receiver is located. That part has a flat side in which one receiver is well fixed. Above receiver, a perforated part is joined to the rib with a screw.

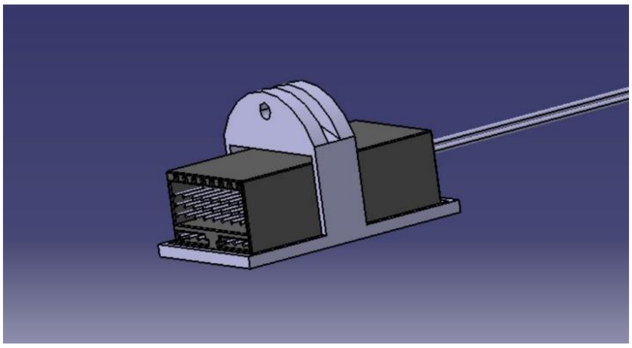


Fig. 29 Receiver and its bracket assembly

Battery used for mechanism is a 2s LiPo battery with 800 mAh capacity. It is placed above main battery and next to ESC in an aluminium plate between first and second fuselage rib fixed to them.

Although EMAX ES3302 servos have their own arms, we designed our own servo arms longer than EMAX ones with bigger holes to join it to mechanisms.

Aileron mechanism

The aileron was placed at the outer side of the wing, with a wingspan of 390 mm and a 84 chord. It has to deflect a maximum angle of 25º. Its drive mechanism was designed with an external actuator due to space limitations that reduce movement range, but servo has to be placed inside of the wing to reduce aerodynamics impact.

The design includes a traction bar parallel to wing ribs. The bar joins the servo arm in one side and a union part to the aileron. This piece is joined to the aileron in the rotation axis, so when the traction bar pushes the piece, the aileron rotates. The bar is a metallic threaded one with 3 mm diameter.

The servo is fixed to the second wing rib from the wing tip with two screws. The servo arm protrudes underside wing surface joining with traction bar. The servo is an EMAX ES3302 with dimensions of 23.17 x 9.17 x 24.05 mm, with 2,4 kgf.cm torque with a voltage of 4.8 V (torque increase until 2.8 kgf.cm with 6 V), enough to push the surface, that needs a 2,2 kgf.cm torque. It weighs 12.4 grams.

At the aileron ends, there is one bar in each one, coaxial to aileron rotation axis, that join the wing and the aileron. The external one has 1 mm diameter and the internal one 2 mm. That difference is because of the thickness limitation. The bars join wings at ribs, with a bearings that allow rotation.

To reinforce the mechanism and make a more reliable system, three little nylon fiber hinges with a 0.2 mm thickness were set between wing and aileron. These pieces have the following dimensions: 25 x 20 x 0.2 mm.

Aileron mechanism manufacturing process follows design line. To set properly the servo, wing rib was cut to allow correct placement and easy servo change. So, wing rib was filed until it was completely cut.

To join the servo arms or pushing pieces and traction bar, a spherical head was placed on both sides of the bar, that allows fix errors about parallelism and perpendicularity at rotation axis with traction bar and wing ribs. It is a commercial model, with a M3 metrics.

The pushing piece made of PLA with a 3D printer, was pasted on aileron at rotating axis point to allow a correct rotation of the mechanism. It has a long flat side fixed to the aileron surface and a protruding part with a 3mm perforation that allows joining it to spherical head, and, consequently, to the traction bar.

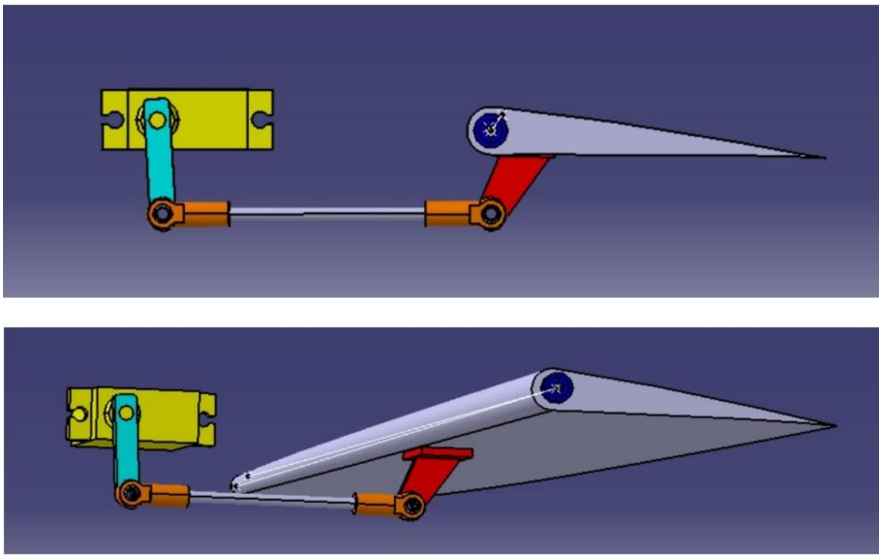


Fig. 30 Aileron Mechanism Assembly

Flap mechanism

Corv-0's flaps are situated on the nearest part of the main wings to the fuselage and extend from the first rib to the fifth of them all. The large area of these surfaces creates greater drag compared to other control surfaces, which results on the need of more powerful servos. These devices will be placed inside of the wing to provide better aerodynamics; that forces us to select small servos to be able to fit them inside. The selected devices are the EMAX ES3302. The flaps will be fowler type, so the mechanism has to provide horizontal separation as well as rotation, 2.64mm at 25º.

The flap mechanism needs a 4 kgf.cm torque, so we have placed two EMAX ES3302 servos to provide two times unitary torque (it means a 4.8 kgf.cm torque with 4.8 V power). Servo dimensions are 23.17 x 9.17 x 24.05 mm.

The servos were placed next to the third rib, each to one side of the rib. To fix them, we have designed a bench made of TPU with the 3D printer. We place one servo inside of each bench. That part is a piece with wing shape and has a whole with servo side and a groove to take out servo cable. Benches are pasted to rib and top wing skin.

The bottom wing skin has a whole with benches shape to allow access to the servos. We designed a TPU removable cover fixed to benches with four screws. The coves has also two holes in which servo arms go outside. To allow correct union, benches bottom side has threaded inserts, and screws are placed inside of them.

The final design has servos connected to flap with a metallic traction bar. It is a threaded one, with a 3mm diameter. The bar has a spherical heading on one side and a fork one in the other side. These headings allow parts unions and a make a more reliable system.

Flap mechanism is more complex than aileron or the stabilizer one due to the rotation axis position. We have to achieve a mechanism that places rotation axis out of the wing. To do that, we designed two parts: one fixed to flap surface and other fixed to the wing.

The wing fixed part is a rib extension that protrudes wing surface. It makes a more reliable and strong movement and rotation. It is like an arm with a whole in the end where the screw cross to act like union and rotation axis. It is a 3 mm diameter one.

The other part, the flap fixed one, is made in PLA at 3D printer. This one is placed at the nearest part to the wing. It is fixed to flap with a through screw. To do it, we put a PLA part inside of the flap with a whole that allows screw crossing. It has a hole too for axis and union screw.

We place this system in the ribs number two and four. The central one, where servos are located, has flap parts but rib doesn't have the extension. Here, we placed a PLA extension with the same shape and function.

V-Tail mechanism

The V-tail mechanism had to be able to operate perfectly the ruddervator but without adding a lot of weight to the plane or being so bulky that it would interfere with other embarked systems. Firstly, we tried placing the servos at fuselage, but it was hard to access and prepare, so we decided to place servos at empennage. Mechanism is so similar to the aileron one.

The main problem in the V-tail mechanism is the angle between the surfaces and the horizontal line. To solve that, we placed servos at empennage part in line with tail surfaces.

The servo is the EMAX ES3302 model. It gives 2.4 kgf.cm torque, enough to move tail surfaces because they are too small. Servo dimensions (23.17 x 9.17 x 24.05 mm) are bigger than the space that we have at empennage part, so servos are fixed partly out and partly inside. They are placed at protrude PLA part that join tail surfaces to empennage part, so that allows to align servo and surfaces.

The servo part that protrudes is the one with the arm. Arm is fixed to a metallic threaded traction bar with 3 mm diameter, that acts by rotating mechanism around centered axis inside ruddervators.

At the stabilizer's surface, a PLA part is pasted to transform linear movement of the traction bar into a rotation movement. It has a flat side fixed to the surface and a protrude with a hole to join with traction bar.

At both sides of the traction bar, two spherical headings are placed joining the bar to the servo arm and PLA part. These parts have a threaded hole with 3 mm diameter at both sides.

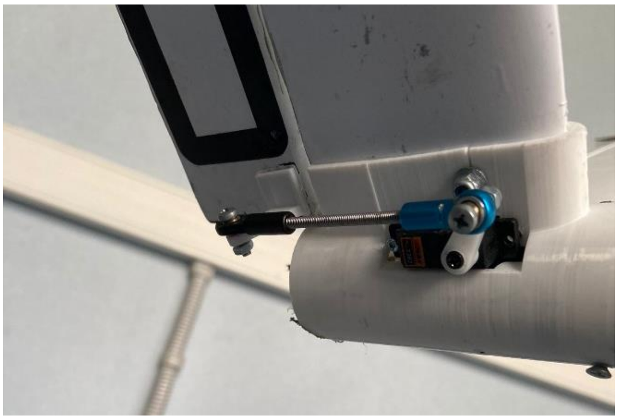


Fig. 31 V-Tail mechanism assembly

Manufacturing

Aluminium pieces

Our internal structure is made up of aluminium parts. The ribs and frames have been manufactured by laser cutting.

Fig. 32 Manufacturing the internal structure

3D printed pieces

The team has two Ender 3 for the manufacture of our parts. We mainly use PLA for printing rigid parts, but we also incorporate TPU in places subject to greater fatigue.

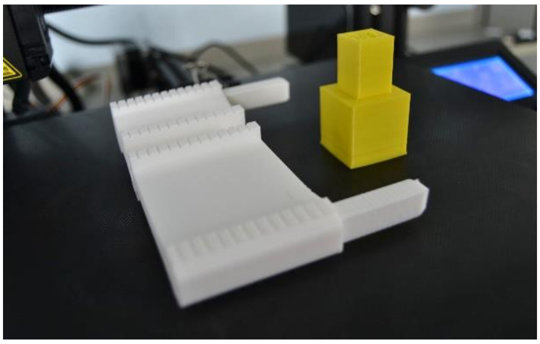


Fig. 33 Left, PLA piece; right, TPU piece

Carbon fiber pieces

The external surfaces of our drone are made of prepreg carbon fiber. In this way, our team has been able to learn one of the most used manufacturing processes in the aeronautical industry.

In relation to the materials, it has been decided that the molds used will be made of aluminium, due to its density, availability and the advantages it presents at the time of manufacture in terms of surface finishing and molds treatment needs. Other materials such as steel have been discarded due to their weight and the possibility of oxidation. Wood or foam molds was discarded because these materials are not compatible with the autoclave cure cycle since the pressure can make the molds collapse.

After cleaning the molds and applying release product and lay-up our carbon fiber layers on them, we put them the bleeder, the breather and then they are bagged into vacuum bags. Finally, the molds will be introduced with the prepreg in the autoclave to perform the curing cycle, keeping a temperature of 120º for 1 hour at 4 bar pressure

Thanks to the high quality of the molds and the extra pressure of the autoclave, we achieve a polished finish, where the milling marks are not noticeable. The goal is not to have to do manual work on the molds to save time and costs.

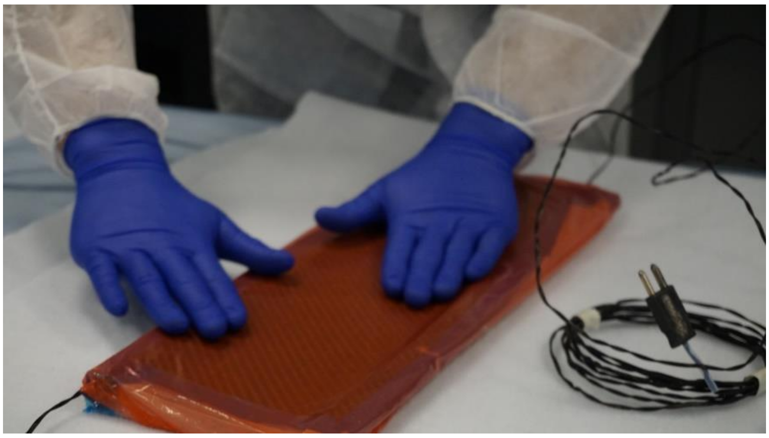


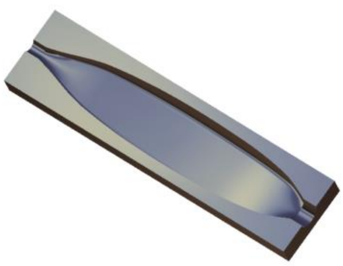
Fig. 34 Manufacture of carbon fiber parts

Fig. 35 Final result of our carbon fiber parts

Fuselage

For the manufacture of the semi-monocoque, two molds will be necessary, one for the upper part and the other for the lower part.

Top mold



Measurements (mm)

750x90x190

Weight

22,535kg

Units

1

Lower mold

Measurements (mm)

750x70x190

Weight

19,329kg

Units

1

Wings

Four molds are needed to manufacture the wings. Two for the upper surface and the other two for the lower surface of each half wing. Due to the symmetry present between each pair of molds, specifications will only be made on the intrados and extrados.

Intrados mold

Measurements (mm)

1080x40x320

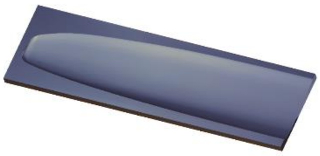
Weight

35.21kg

Units

2

Extrados mold



Measurements

(mm)

1080x45x320

Weight

34,545kg

Units

2

Empennage

For the manufacture of the empennage, two molds will be necessary, one for the intrados and the other for the extrados of the wing, since being in V, the empennage, is symmetrical.

Semi-top mold

Measurements

(mm)

450x155x20

Weight

2.951kg

Units

2

Lower half mold

Measurements

(mm)

450x155x20

Weight

2.951kg

Units

2

Joints

- The internal aluminium structure and the carbon fiber are glued using a two-component epoxy glue to in order to isolate the galvanic corrosion.
- Also, in parts such as the semi-stabilizer we have glued the foam and the carbon fiber with a bicomponent epoxy glue.
- The PLA structure of the cargo container is also glued with the same bicomponent epoxy glue.
- The 3D pieces are attached to carbon fiber or aluminium using screws standardized M3.
- In the aileron, we have glued layers of foam between the hinges and the carbon fiber. The goal is to hold the hinges. This joint has been made using an epoxy resin.

Outlook

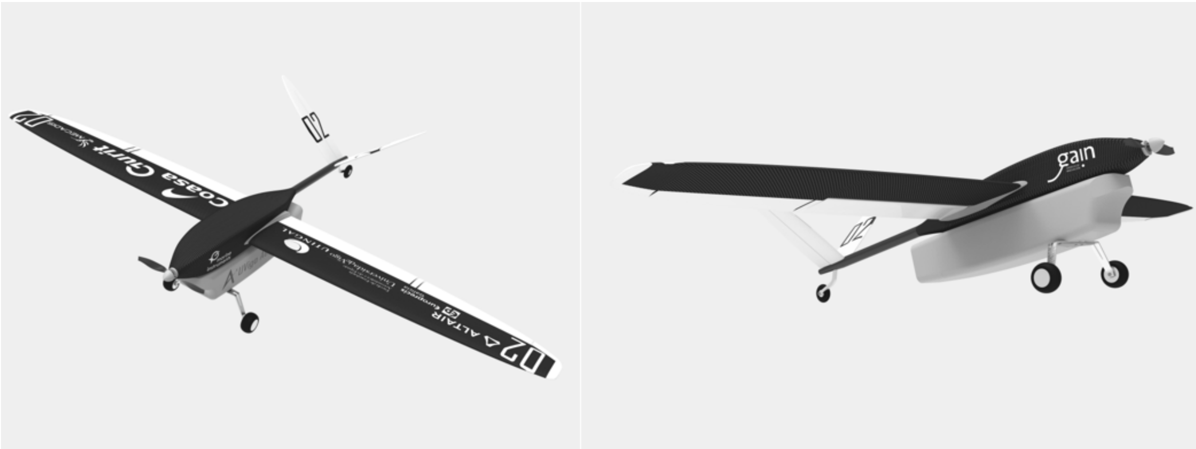


Fig. 36 CORV-0 (Render)

Fig. 37 CORV-0 (Real)

Conclusion

To sum everything up, we have developed an aircraft using some of the most novel techniques and materials in the field, such as additive manufacturing and the use of carbon fiber, allowing us to manufacture an airmodel that has an outstanding performance.

It also allowed all the members of the team to learn about the process of a plane's creation, from designing to manufacturing, as well as the experience of working in a team and having a real budget limitation.

Attachments

The molds will be introduced with the prepreg in the autoclave, keeping a temperature of 120º for 1 hour, following this cycle:

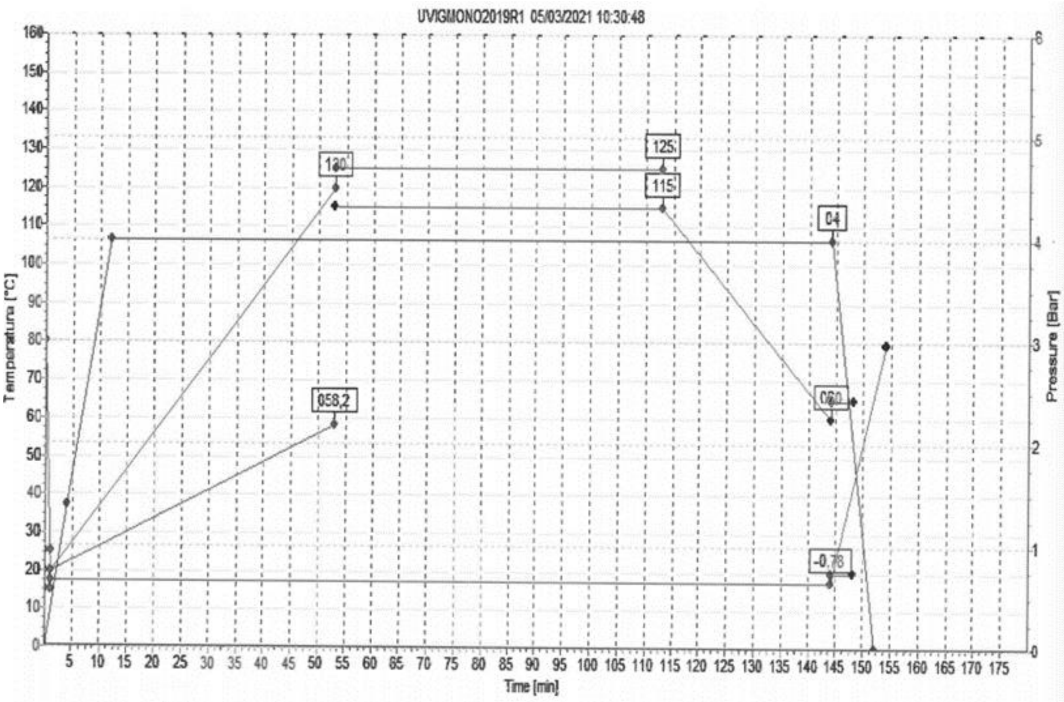


Fig. 38 Graph of the conditions during our autoclave cycles

These are some structural computations:

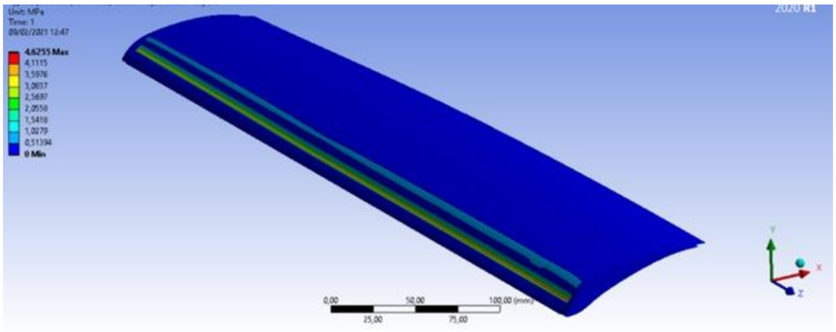


Fig. 39 Stress obtained with a foam h45 nucleus

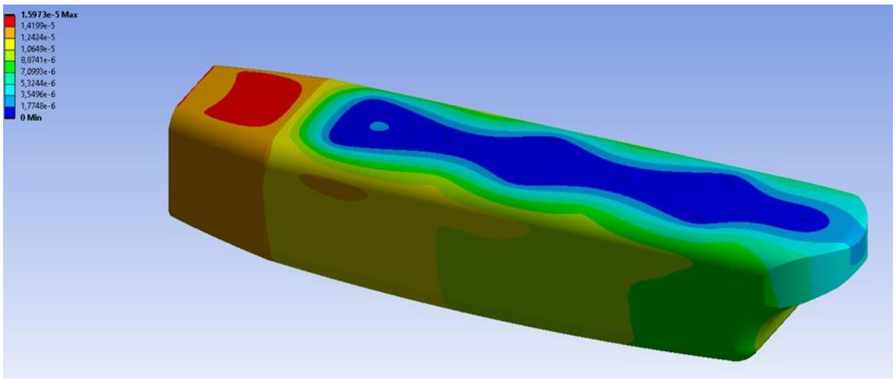


Fig. 40 Deformations with the weight on the landing gear.

This is our social media information:

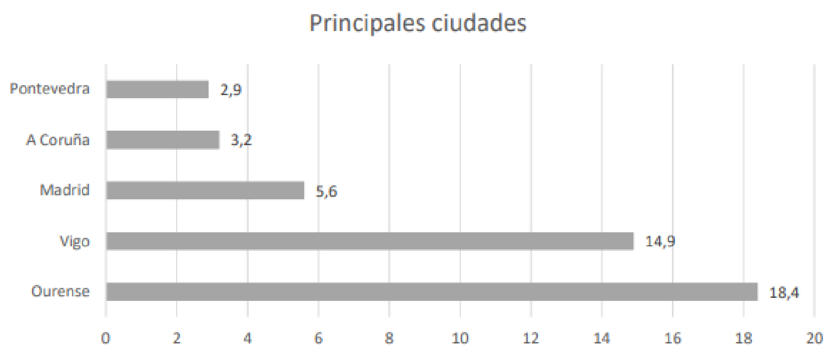


Fig. 41 Instagram account viewers' main cities

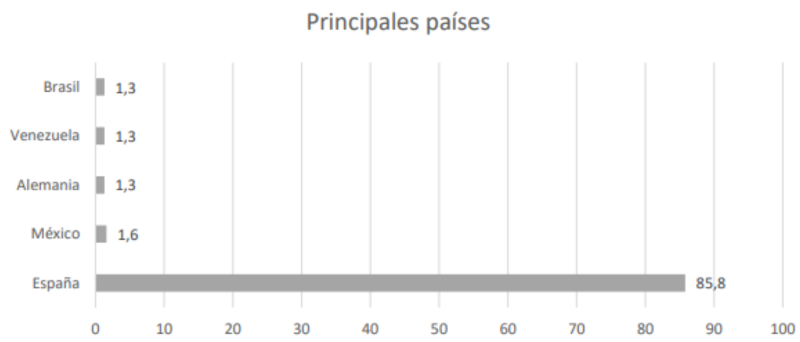


Fig. 42 Instagram account viewers' main countries

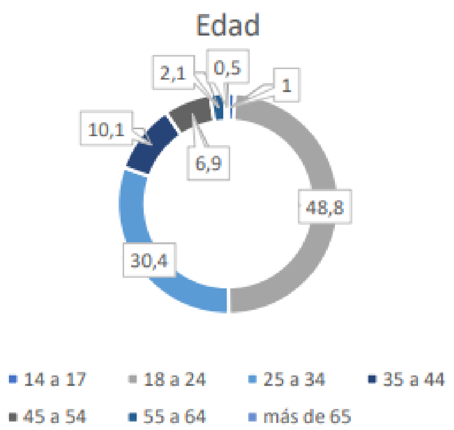
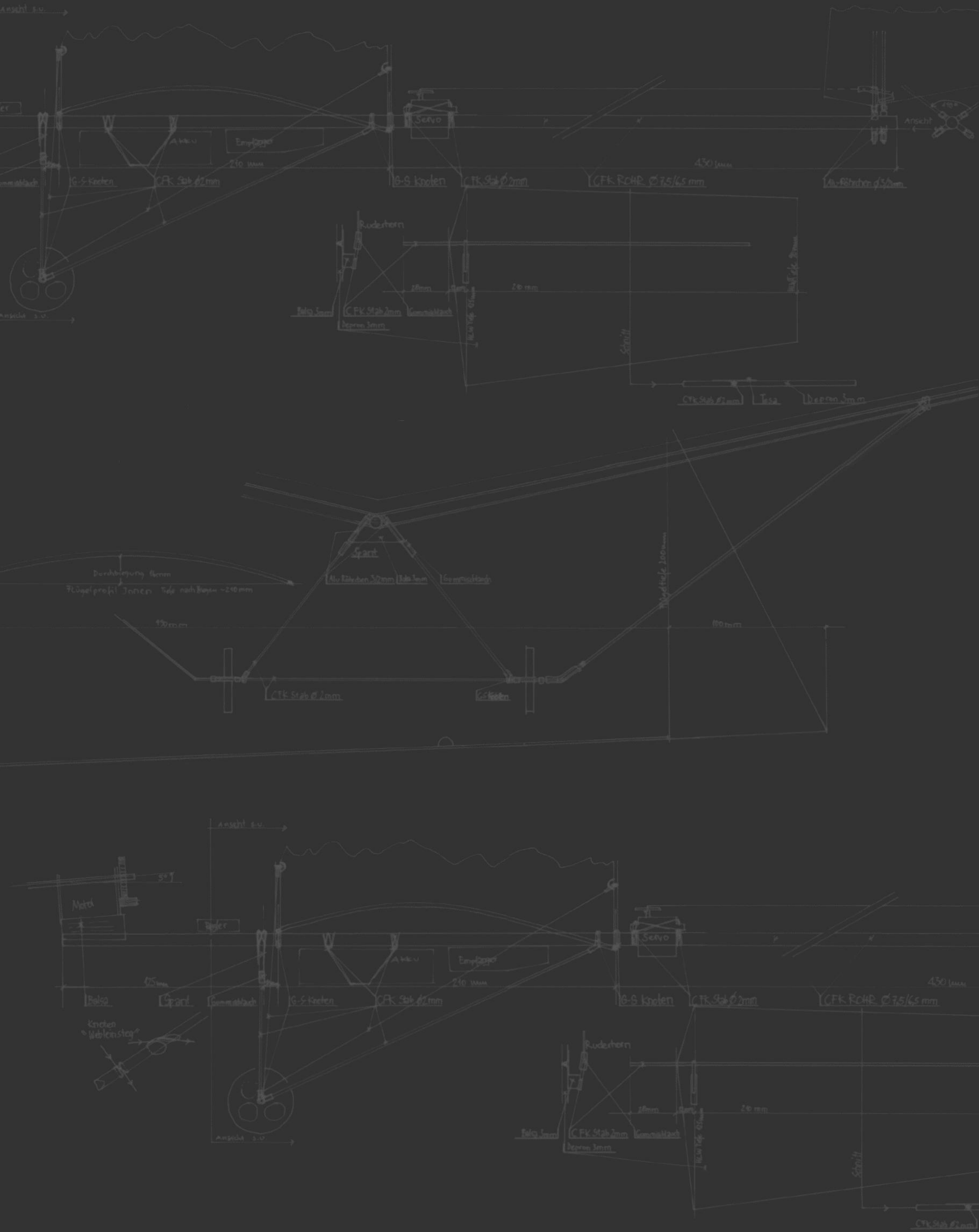
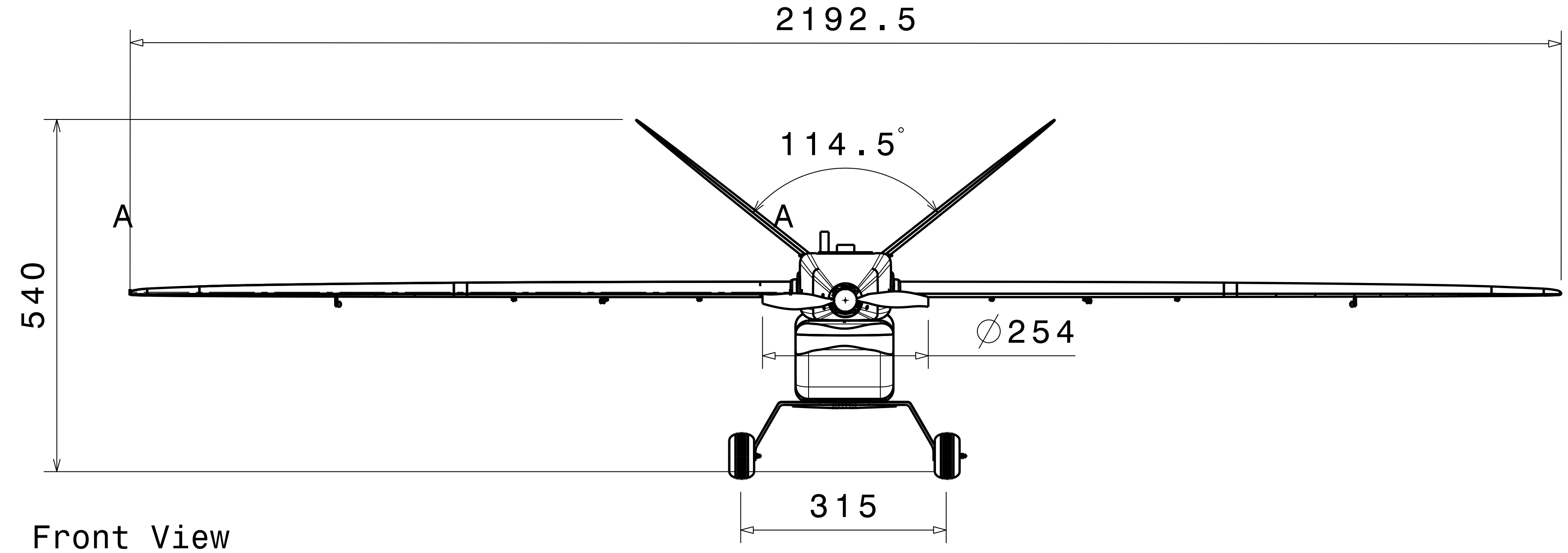


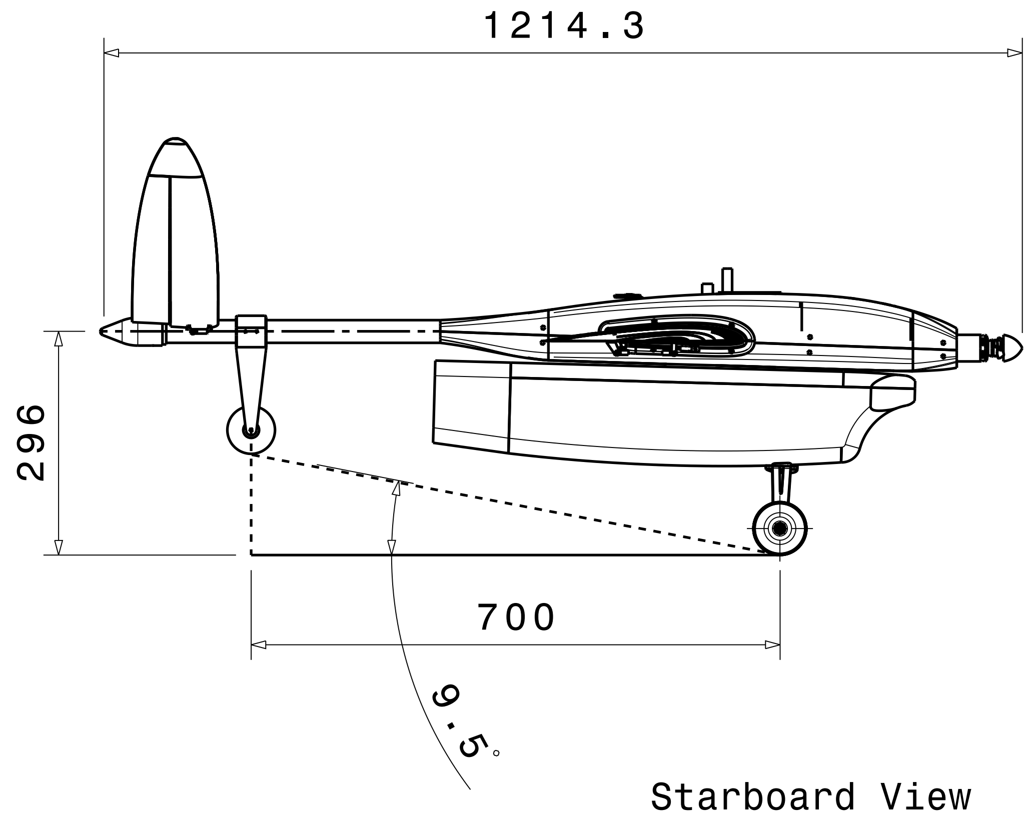
Fig. 43 Instagram account viewers' age range



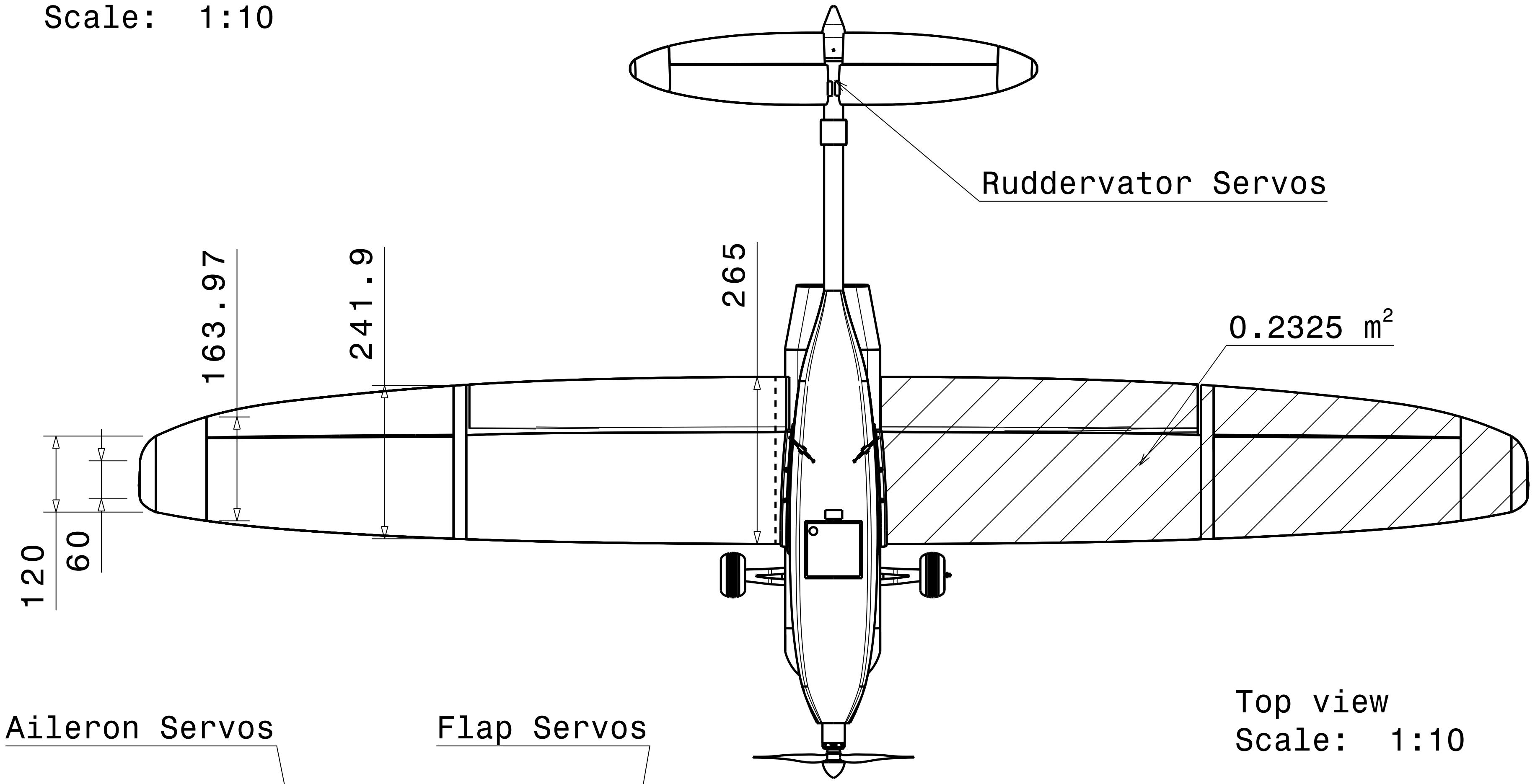
Servo
Akku
Ruderhorn
CFK Stab Ø2mm
G-S Knoten
CFK ROHR Ø7,5/6,5 mm
430 mm
240 mm
Spant
Motor
Balsa
Ansicht



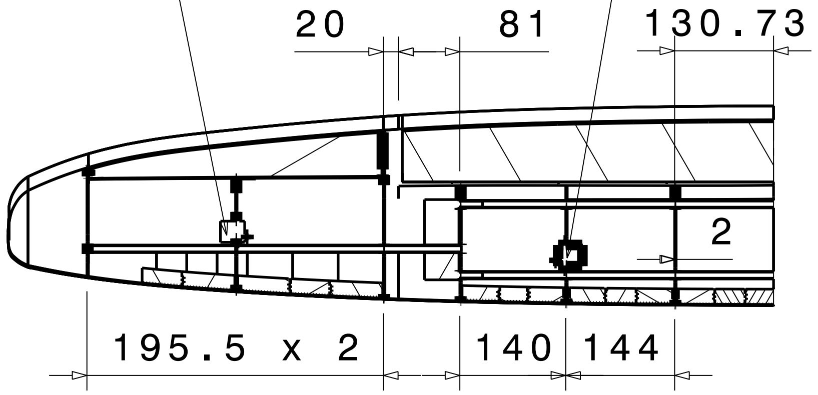
Front View
Scale: 1:10



Starboard View
Scale: 1:10



Top view
Scale: 1:10



Section view A-A
Scale: 1:10

Rib Spacing and
Structural Deisgn

UVIGO AEROTECH #02

Wing Airfoil	Aerotech 06
Empennage Airfoil	Custom Symmetrical
Wing Surface Area	0.465 m^2
Wing Aspect Ratio	10.7
Design Payload	1 Kg

Aircraft designation: Corv-0

Drawing Author:
Christian La Banca - Team Leader

Drawing and design property of UvigoAerotech and University of Vigo. Purposely made in compliance of Air Cargo Challenge 2022 regulations.

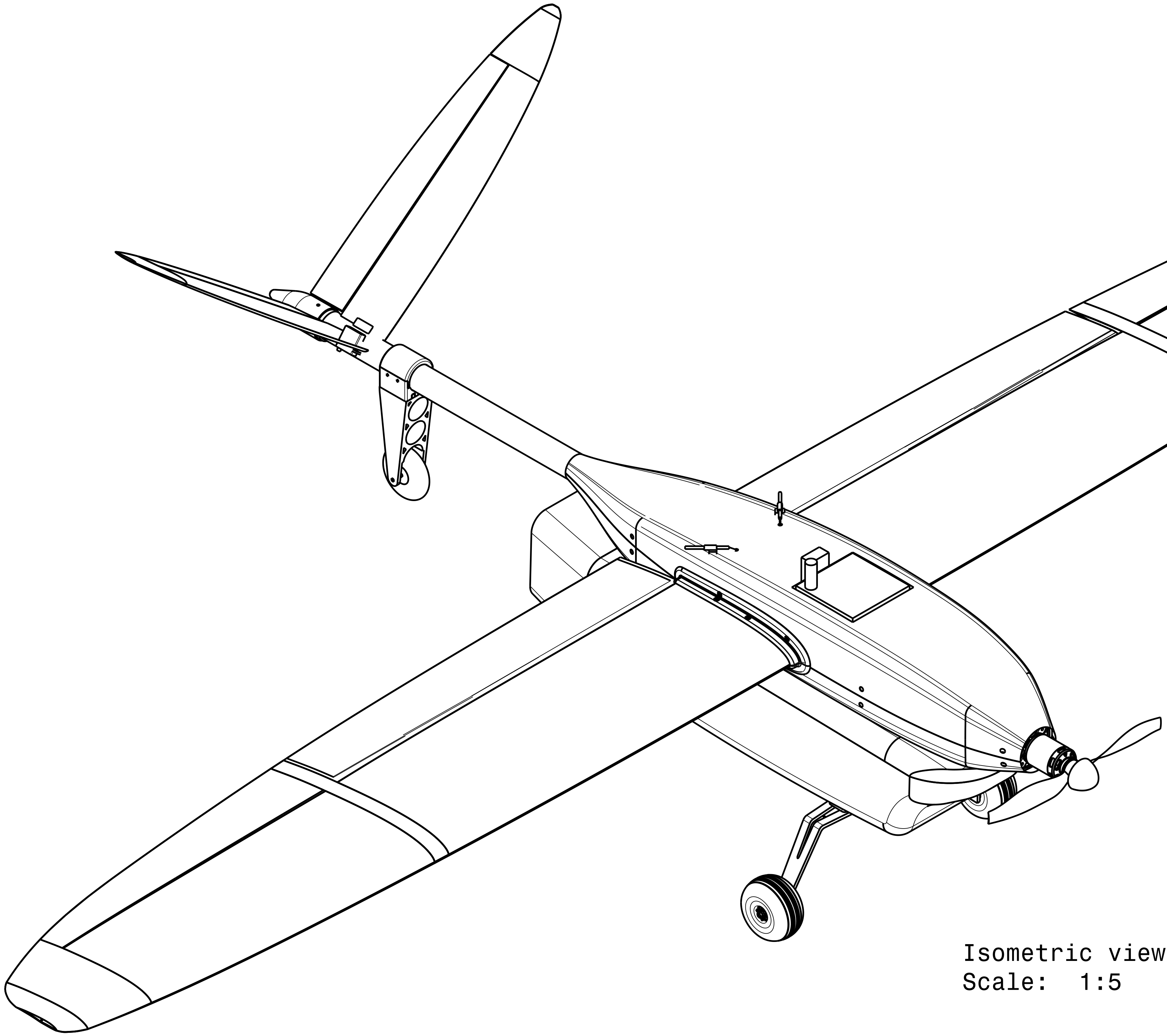
Drawing Validation:
Team Governing Board

SIZE A3 | DRAWING NUMBER 01

SCALE 1:10 | WEIGHT(kg) 4.1 | MMGS | SHEET 1/4

H G F E D C B A

4 3 2 1



Isometric view
Scale: 1:5

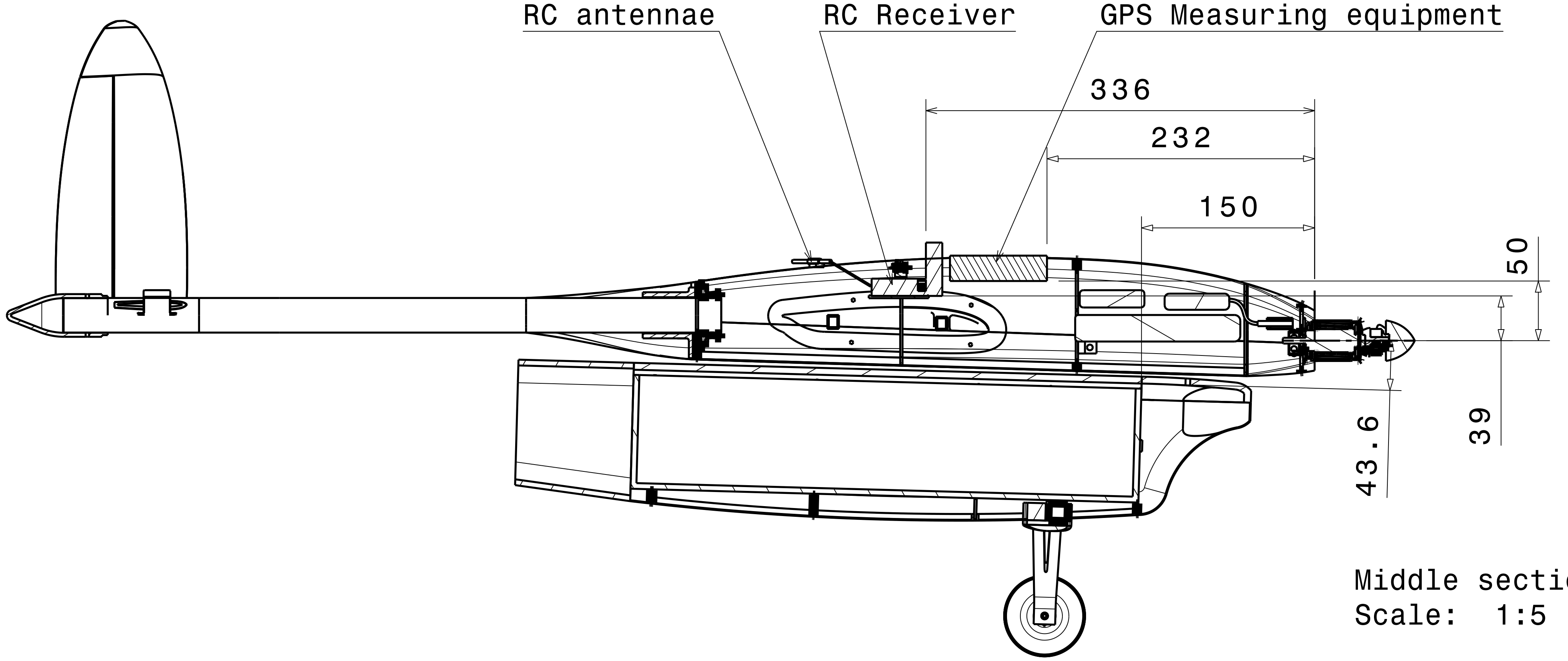
UVIGO AEROTECH #02	
Wing Airfoil	Aerotech 06
Empennage Airfoil	Custom Symmetrical
Wing Surface Area	0.465 m^2
Wing Aspect Ratio	10.7
Design Payload	1 Kg

Aircraft designation: Corv-0

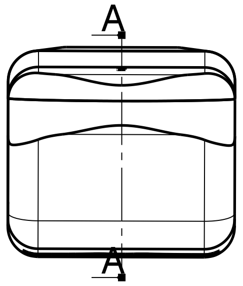
Drawing Author: Christian La Banca - Team Leader	Drawing and design property of UvigoAerotech and University of Vigo. Purposely made in compliance of Air Cargo Challenge 2022 regulations.
Drawing Validation: Team Governing Board	SIZE A3 · DRAWING NUMBER 02

SCALE	1:5	WEIGHT(kg)	4.1	MMGS	SHEET	2/4

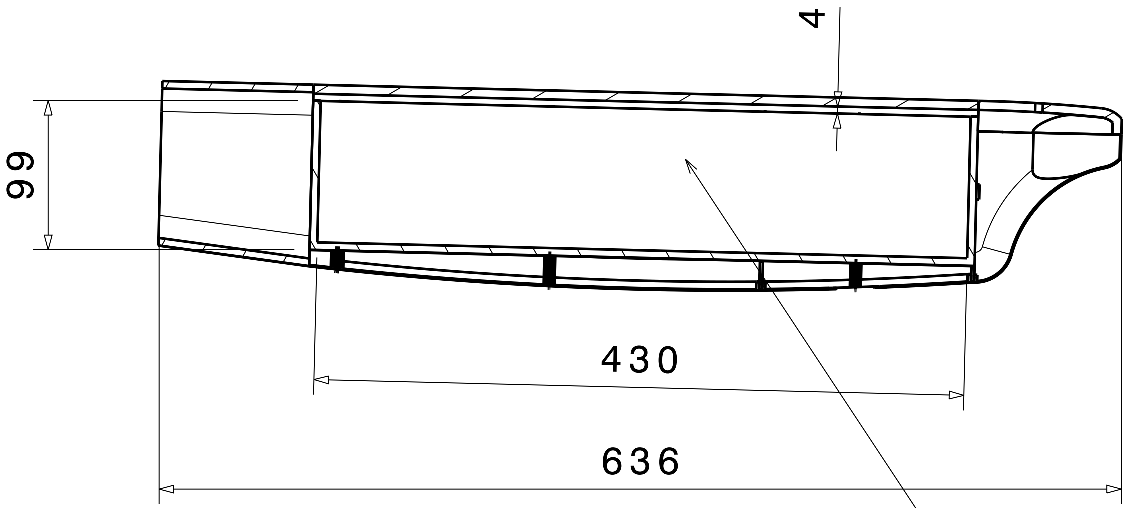
H G B A



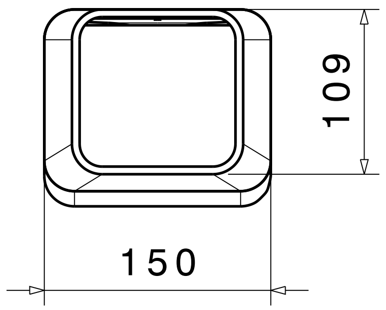
Middle section view
Scale: 1:5



Front view
Scale: 1:5



Middle section view
Scale: 1:5



Back view
Scale: 1:5

UVIGO AEROTECH #02

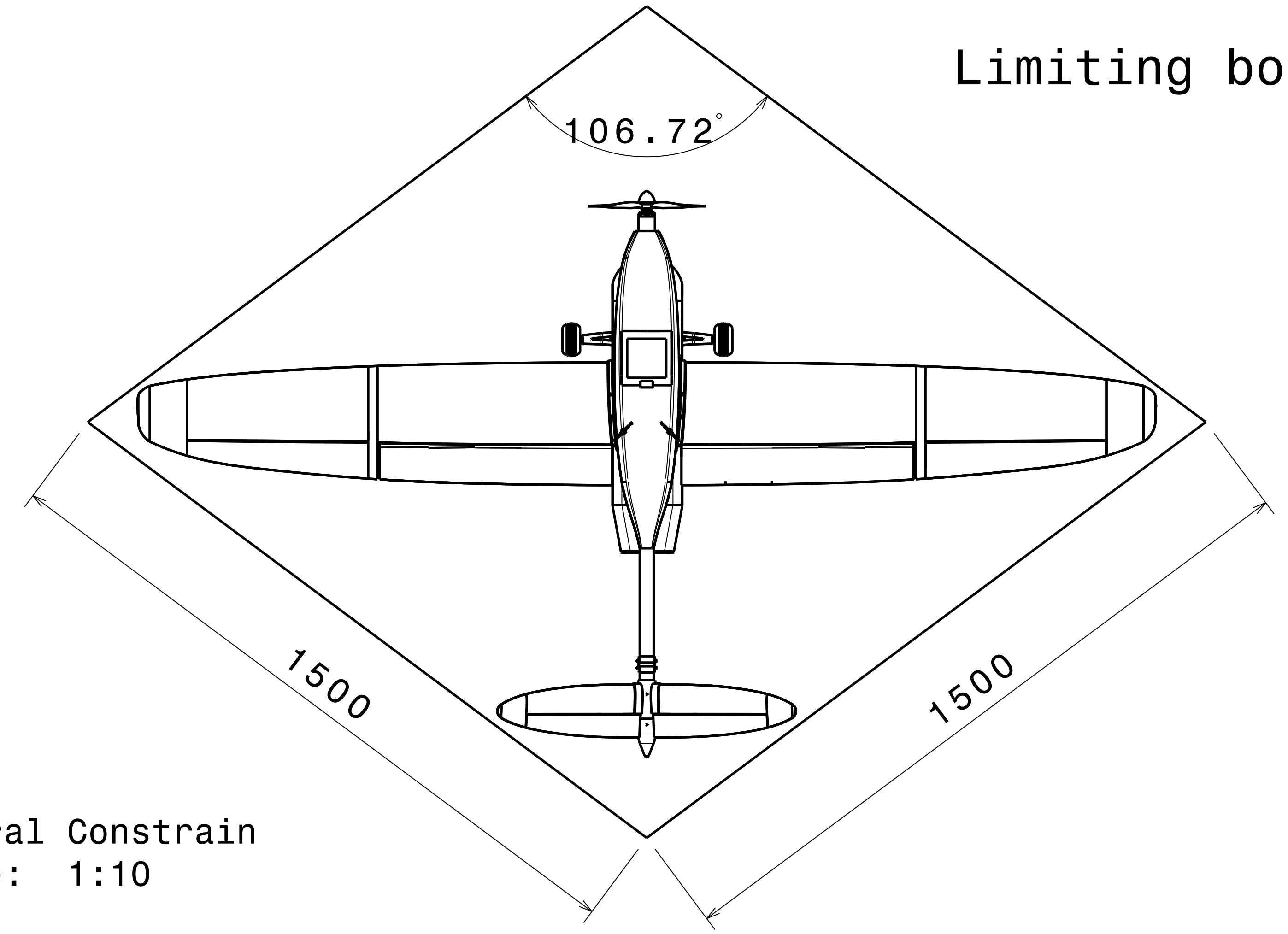
Wing Airfoil	Aerotech 06
Empennage Airfoil	Custom Symmetrical
Wing Surface Area	0.465 m^2
Wing Aspect Ratio	10.7
Design Payload	1 Kg

Aircraft designation: Corv-0

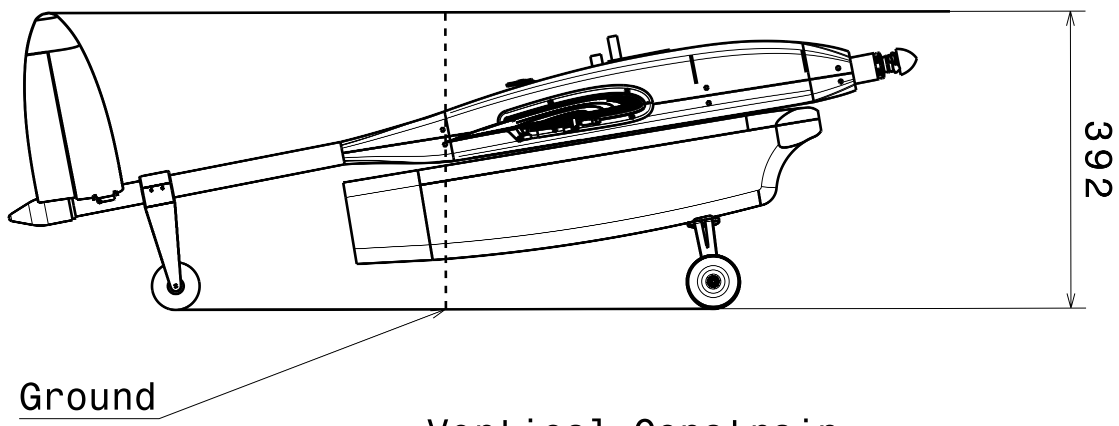
Drawing Author: Christian La Banca - Team Leader	Drawing and design property of UvigoAerotech and University of Vigo. Purposely made in compliance of Air Cargo Challenge 2022 regulations.
Drawing Validation: Team Governing Board	SIZE A3 — DRAWING NUMBER 03

SCALE 1:5	WEIGHT(kg) 4.1	MMGS	SHEET 3/4

Limiting box in Set-Up state

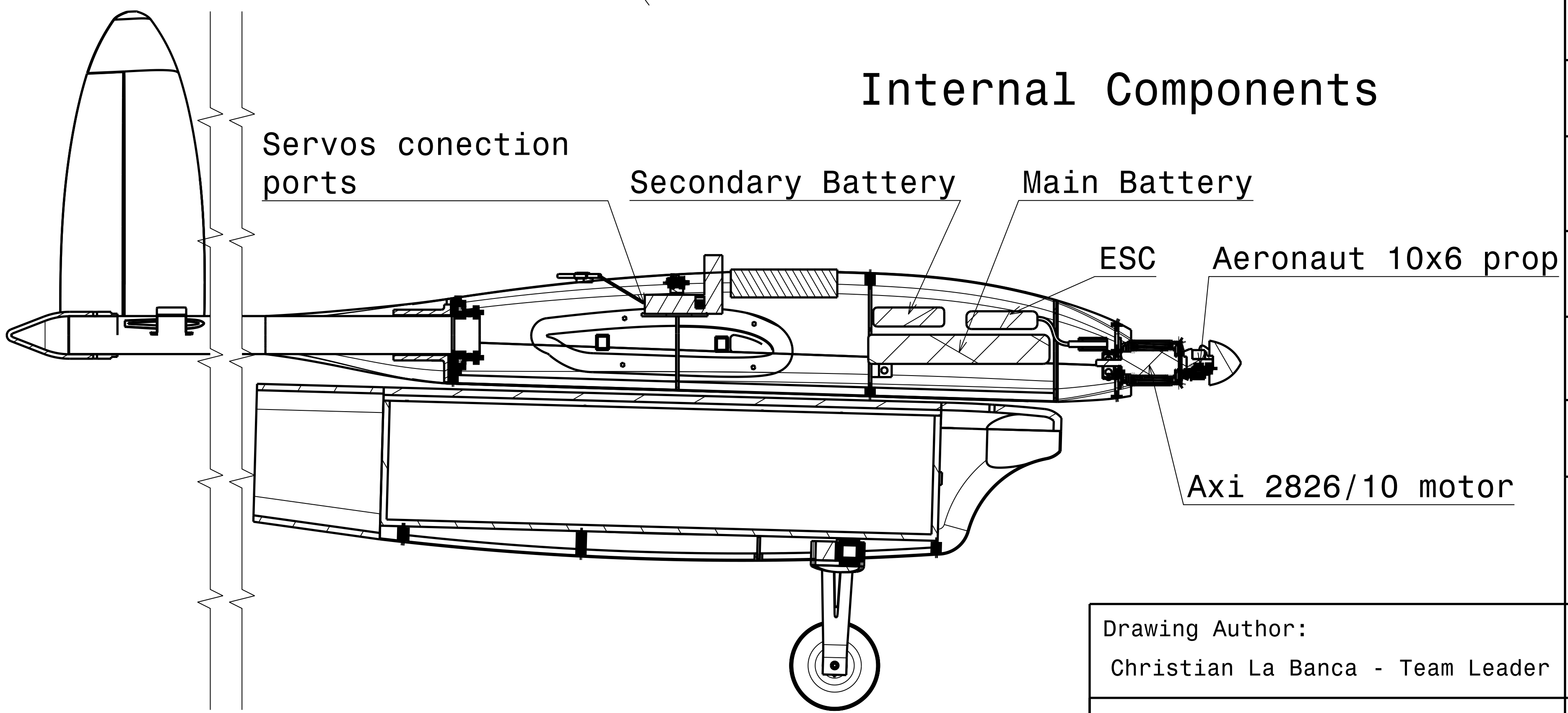


Lateral Constrain
Scale: 1:10



Vertical Constrain
Scale: 1:10

Internal Components



Section view. Internal components
Scale: 1:5

UVIGO AEROTECH #02

Wing Airfoil	Aerotech 06
Empennage Airfoil	Custom Symmetrical
Wing Surface Area	0.465 m^2
Wing Aspect Ratio	10.7
Design Payload	1 Kg

Aircraft designation: Corv-0

Drawing Author: Christian La Banca - Team Leader	Drawing and design property of UvigoAerotech and University of Vigo. Purposely made in compliance of Air Cargo Challenge 2022 regulations.	
Drawing Validation: Team Governing Board	SIZE A3	DRAWING NUMBER 04
	WEIGHT(kg) 4.1	MMGS	SHEET 4/4