University of Minho
School of Engineering

# Hangar 9 Solo Trainer Aircraft Structure Restoration

## Master's in Aerospace Engineering

## Projeto Aeroespacial

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# 1. Main Mission Definition

The group's main mission is to physically restore the UAV (Unmanned Aerial Vehicle) structure, ensuring optimal flight conditions in all phases.

# 2. UAV Repair

The UAV repair process started with the identification of all the damaged components and structures, which resulted in the damage report. This document can be consulted in Annex A. The tasks performed in the scope of UAV repair are described in the following subsections.

## 2.1. Cover removal

At its initial condition, the UAV was fully covered, exhibiting a graphical identity identical to all the commercial model airplanes, as presented in Figure 1. The cover removal was the first task performed for two main reasons: (i) the identification of all the areas that required repair was possible only after this step as the cover could hide damaged areas and components, and (ii) the process could itself damage the structure as the peel off could remove wood layers.

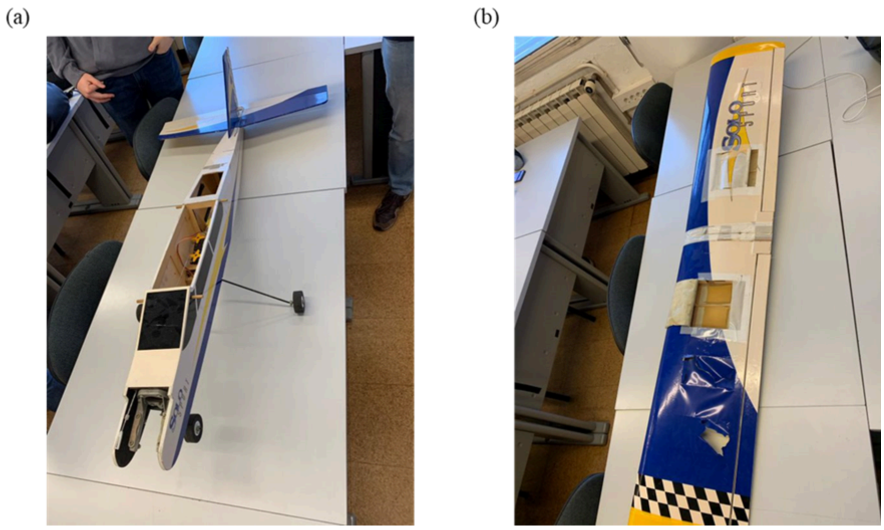


**Figure 1 -** UAV model before cover removal (a) fuselage and horizontal and vertical stabilizers and (b) wing.

Due to their curved geometry, which makes handling them more difficult, and the low thickness of the balsa wood applied, wings are the most sensitive structures and, thus, the most challenging ones. Such characteristics led to the group's decision to start by removing the cover from the wings. Some regions showed a lack of glue, and, thereby, the cover was detached from the wood balsa beneath it. These were the points that the group used to start to carefully peel off the cover. The process went smoothly, and no additional damage occurred. The cover from the fuselage and the horizontal and vertical stabilizers was then removed, and, as it was with the wings, the process was carried out without major issues.

After removing the cover (see Figure 2), the whole structure was sanded to remove the glue residues to create a clean and smooth surface suitable for the application of the new cover chosen - Oracover®.

**Figure 2 -** UAV after cover removal.

## 2.2. Ribs replacement

During the analysis process, problems and damage were identified in 9 out of 16 ribs. In order to ensure the structural integrity and functionality of these elements, the group chose to replace all the damaged ribs using wood balsa of the same thickness and following the same geometry profile, including the cutout to reduce the element's weight.

In a balsa wood board  with a thickness of 2,5 mm and using as model one of the original ribs (Figure 2 (a)), the rib contour was drawn, after which it was cut using a bistoury. Although the dimensions were kept as close as possible to the original ones, some adjustments were needed to place the ribs at their positions inside the wing's structure. In this sense, small cuts were made, and sanding of the ribs was performed to allow the ribs to fit the dimensions required. The ribs were then glued to the wing's structure using wood glue, as presented in Figure 2 (b).

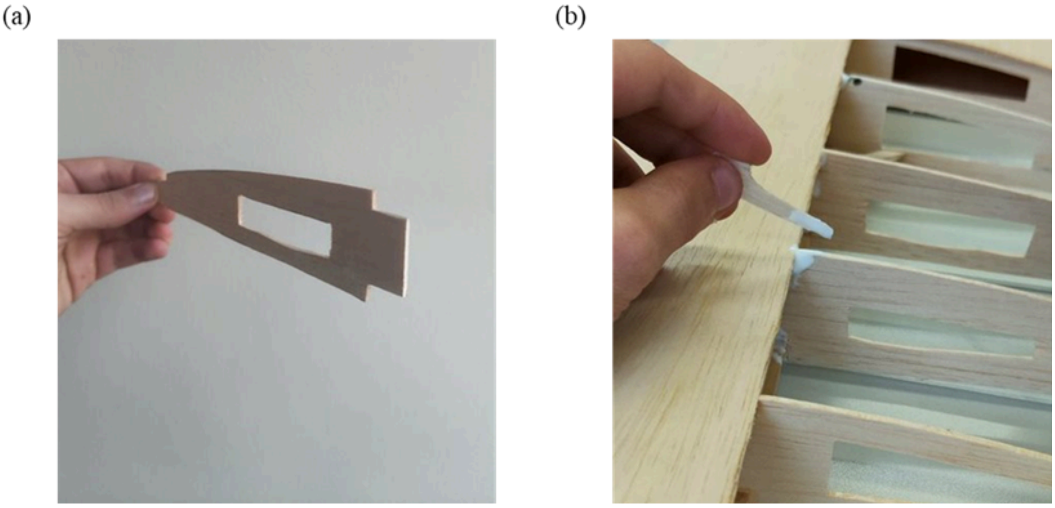

**Figure 3 -** (a) rib model and (b) ribs attachment to the structure using wood glue.

Finally, after a rest time to ensure that the glue had already dried, the attachment regions were carefully sanded to remove any glue excess.

**Figure 4 -** Wing after ribs replacement.

### 2.3. Repair of the fuselage opening for motor-ruddle connection

A metal rod connects the servomotor placed inside the fuselage with the ruddle through an opening existing at the back region of the first. However, such a fully open design allowed the rod to deflect, as there was no lateral constraint to its movement, which, in turn, could compromise its integrity and functionality.

Using a wood balsa board with a thickness of 5 mm, a new piece (see Figure 5) with the same outer geometry as the back opening of the fuselage was placed there, after which a cut whose width was close to the rod diameter was made. The opening length was determined by positioning the ruddle at two extreme positions: fully up and fully down. Such a modification of the original structure allows the connecting rod to move free in the vertical, as the opening length is compatible with the stroke required to allow the ruddle full control.

(a) (b)

**Figure 5 -** New piece placed at the back of the fuselage with an opening to allow the ruddle control (a) top view and (b) back view.

## 2.4. Repair of the fuselage back cover

The fuselage's back region was severely damaged, as can be observed in Figure 6, where a top cover was missing.

**Figure 6** - Fuselage's back region severely damaged.

To repair the damage, the first step was to remove the remaining parts of the previously existing cover and properly sand the region to remove residues and smooth the surface. Afterward, measurements were made to define the design of the top cover to be made, which was drawn on a wood balsa board whose thickness was 5 mm. The cover was cut from the board using a bistoury and sanded to fit the opening.

Additionally, three holes to allow screwing will be made manually using a drill, and a keyway to allow the vertical stabilizer assembly was cut using the bistoury.

The cover was then placed at the fuselage's back region and glued using wood glue, as presented in Figure 7.

**Figure 7 -** Placement of the top cover at the fuselage's back region.

After completely drying, the whole region was carefully sanded to remove the glue residues, granting a smooth surface.

## 2.5. Horizontal Stabilizer repair

Along with the placement of the top cover at the fuselage's back region, the horizontal stabilizer was also repaired. As can be seen in figure 8, the screw holes that attached it to the fuselage were wide and did not guarantee good cohesion between parts.

**Figure 8 -** Screw holes before intervention.

The holes were previously covered with a paste made from balsa chips and glue (figure 9 (a)), leaving it to dry for some time. Once the surface was completely dry, it was carefully sanded to make it uniform, as can be seen on figure 9(b). These holes will be reopened when the fuselage is assembled, and correspond to the blue dots visible in the back region represented in figure 7.

(a) (b)

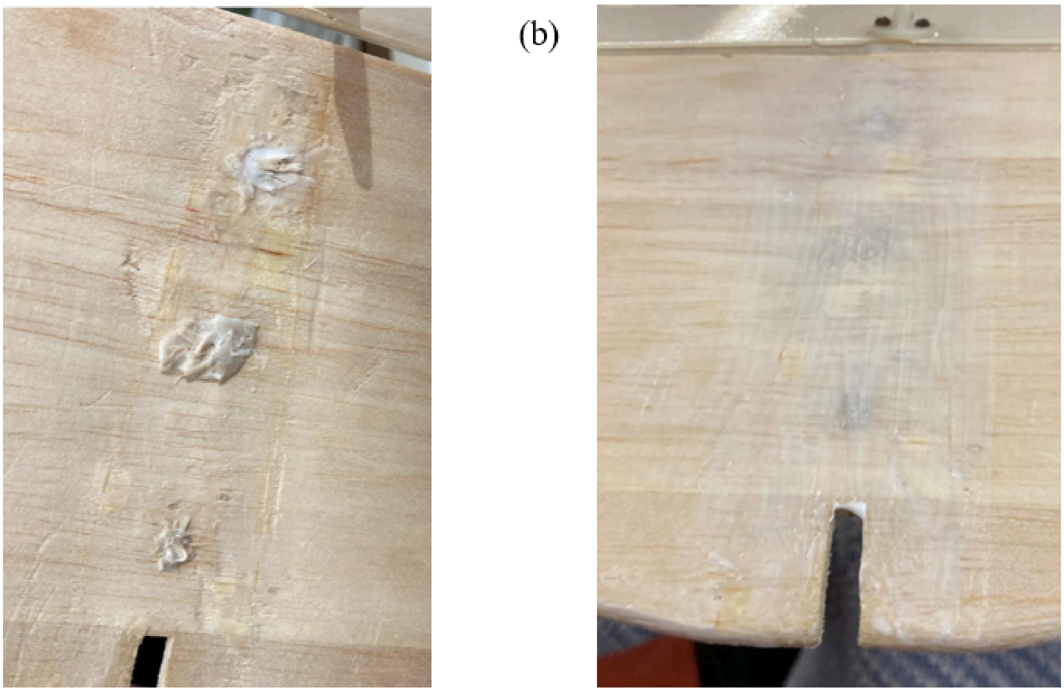

**Figure 9-** Screw holes during intervention (a) and after intervention (b).

## 5. Hole repair in left wing

Among the repairs identified, an accident occurred with the left wing: localized excess pressure caused a hole measuring around 3x4 cm area, visible in figure 10.

**Figure 10 -** Left wing hole.

The approach to the problem initially involved transforming a hole of imprecise dimensions into a square-shaped hole, measuring around 4 centimeters per side, and building a grid with 5mm thick balsa sticks (figure 11a), placed on the inside of the wing. Starting by building the grid warp, and after drying, placing the weft, it was possible to fill the square with a 5 mm piece of balsa of the same dimensions, the edges of which were completed with wood glue. The final result exceeded expectations, as the area appears to be reinforced, as can be seen in figure 11b.

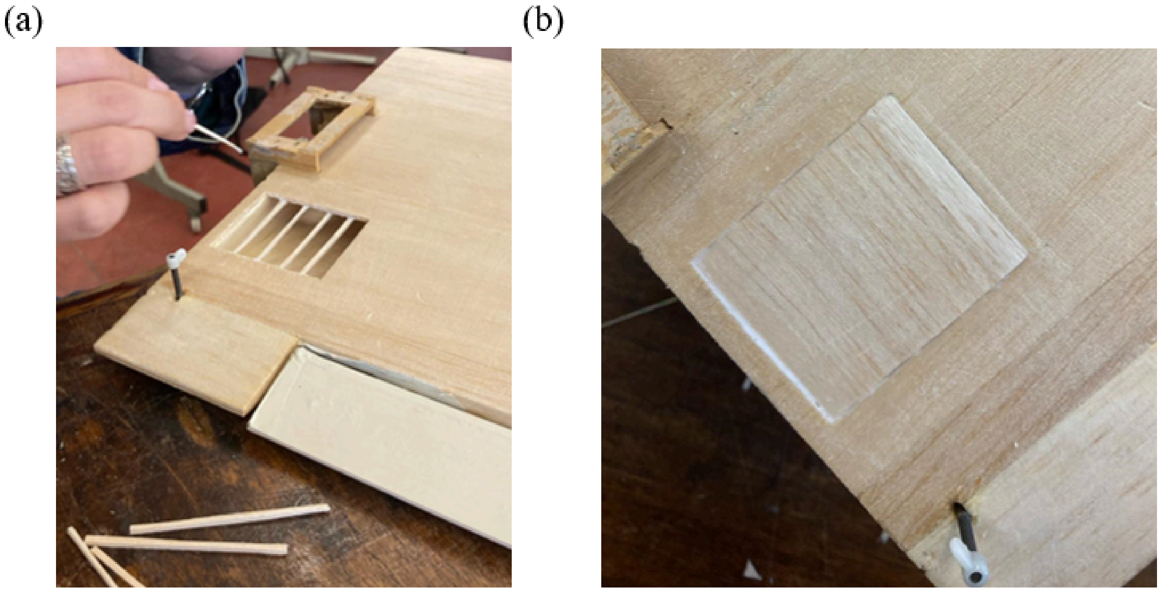

**Figure 11** - During and after reconstruction of the hole in the left wing.

# 3. Aircraft New Cover

After repairing the UAV damages, the group had to select a new material to cover the UAV once again. So, the next step was to determine which type of material was best suited for our application. After a thorough investigation, we narrowed our options to two materials: Vinyl & Oracover.

In order to decide which of these materials had the better qualities we compared them in five fields:

- Material
- Weight
- Application procedure
- Durability
- Cost

Regarding the type of material, Oracover presents more desirable qualities since it's a thermo-shrink polyester film, so it can adjust and fixate properly to the surface of our UAV. Besides that, it also has good bond properties when applied on wood. On the other hand, Vinyl is just a PVC film, which sticks to the surface by applying pressure, so it's more prone to form air bubbles and to unstick from the surface in flight conditions.

Looking at the weight of both materials, Oracover has half of Vinyl's density. Oracover has a density of 55-60 g/$m^2$, meanwhile Vinyl has a density of 100-125 g/$m^2$. Since the UAV shall have as little weight as possible, the Oracover was the best option regarding this parameter.

The application procedure for the Oracover requires a heat source such as Heat Iron, or a hairdryer, because only when applied under heat, the Oracover adhesion properties will be activated. This procedure it's complex and requires practice to get it perfect, being specially hard to perform on curves and tight spaces. Opposed to the Oracover, Vinyl has an easier application method, because this material sticks just by applying pressure, but requires careful handling to avoid air bubbles.

The Oracovers durability has high resistance to tearing and punctures once applied, is resistant to most fuels and chemicals used in RC aircraft such as Nitro fuel, gasoline, epoxy, and has excellent UV resistance, this means that it doesn't fade or become brittle over time, since our aircraft will be very exposed to this type of radiation, this point becomes crucial. On the other hand, Vinyl is more prone to peeling at the edges, is necessary to apply more adhesive when it peels, which is visible, and doesn't have as good of UV resistive properties as the Oracover, becoming brittle faster .

Taking cost into account, Oracover is more expensive than Vinyl, however, since it has better properties than Vinyl for our application, this extra cost is acceptable.

So, the chosen material to coat our UAV is the Oracover.

Due to the wings' shape complexity, the Oracover application was first done in these elements, as it was expected that they pose the greatest challenge.

Initially, two Oracover - transparent and white - were intended to be applied: the first in the open region of the wings, so the ribs geometry and avionics connection elements could be observed, and the latter in the remaining areas. However, during the application, it was observed that the transparent Oracover was not able to be glued to the balsa, detaching from the surface as the heat source was removed. Such attempt is shown in Figure 12.

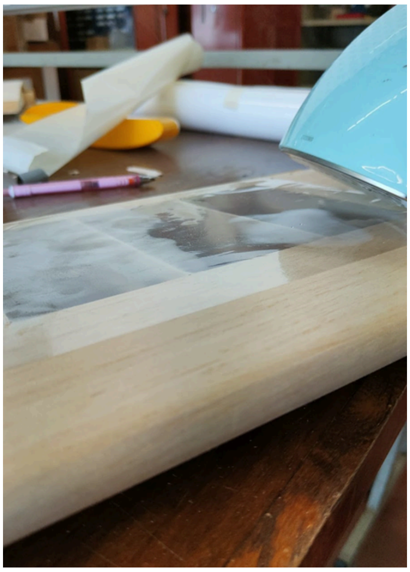

**Figure 12** - Transparent Oracover application attempt.

The application process started with sanding the ribs' surface to ensure that the Oracover could perfectly glue to them. Afterwards, two portions of Oracover with the dimensions needed to cover the upper and lower halves were cut. After placing the Oracover piece over one half at a time, a hot iron was used to activate the glue and attach it to the surface. Once the temperature reached by the iron was not high enough to fully activate the glue, a hairdryer was used to enhance the adhesive properties. The process is presented in Figure 13. A ruler was pressed along the surface to reduce the air bubbles, enabling a smoother finish. Also, the Oracover pieces ends were placed in line with the airflow, so the detachment could be prevented.

(a) (b)

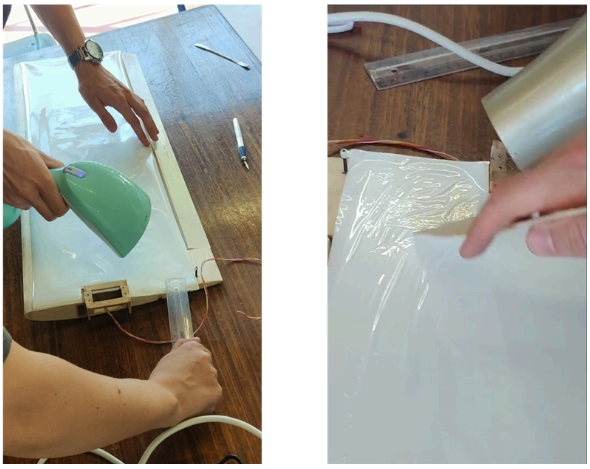

**Figure 13** - Oracover application procedure (a) using the iron and (b) using the hairdryer.

One hole in each wing was needed to accommodate an LED, which was made using a cutter (see Figure 13a ) in both the balsa wood and the Oracover, as shown in Figure 14.

**Figure 14** - Hole made in the wings to allow the LED connection.

Due to some details, namely coupling elements that allow the assembly of the UAV, some cutouts had to be done to enable the full coverage of the wings. The final result is presented in Figure 15.

**Figure 15** - Wing covered with Oracover.

# 4. Balancing the Aircraft

A crucial step in the structure development is the determination of the center of gravity (CG) location.

The center of gravity (CG) of an aircraft is the point at which the gravitational force is considered to act and it affects the aircraft's longitudinal stability and flight performance. The center of pressure (CP), on the other hand, is the point along the mean aerodynamic chord where the resultant of the aerodynamic forces (primarily lift) is considered to be concentrated.

For a controlled and stable flight, the relationship between the center of gravity (CG) and the center of pressure (CP) is crucial. The CG should be located slightly ahead of the CP to generate a nose-down moment that can be balanced by the horizontal stabilizer at the tail.

Having this in mind, it is crucial to understand where the aerodynamic center of the airplane is located. To find this information, the group regarded on the Hangar-9 instruction Manual, which presented that the recommended aerodynamic center, and gravity center, shall be found in $3''$ from the leading edge of the wing. To verify if this would be a viable assumption we made the following calculations:

$$3,0\ in\ =\ 7,62\ cm$$

Knowing that the airfoil chord length is 24,5 centimeters:

$$7,62\ /\ 24,5\ =\ 0,31 \approx ⅓$$

Considering these results, we can accept the initial location of the center of pressure (CP) and center of gravity (CG) for a first flight, with the understanding that adjustments should be made based on the requirements and specifications of subsequent missions, since it’s common for model airplanes to have both centers located approximately at ⅓ of the chord length from the leading edge.

Knowing where the center of gravity should be located, the next step involves defining how we will determine the actual CG of the airplane. To find the center of gravity, after all components are properly installed, we will support the aircraft by its wings at the calculated point, as demonstrated in the following figure.

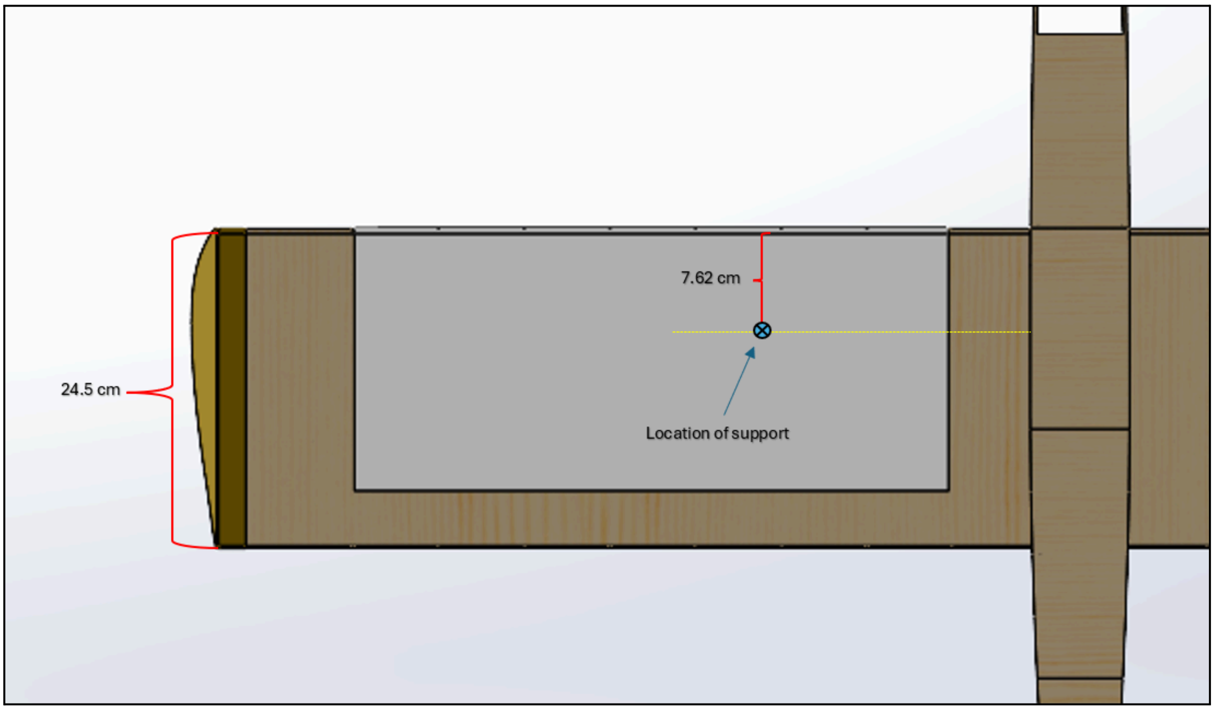


**Figure 16** - Right wing support point position.

After supporting the aircraft at the designated support point on each wing, it will be possible to verify if it is balanced. In case that the aircraft cannot maintain a stable position, adjustments to the internal components placements will be necessary, in order to achieve balance.

It is also necessary to consider that the measurement should be performed with the fuel tank half full to find an intermediate point for the center of gravity. The CG can vary between ⅓ and ¼ of the wing chord, depending on the amount of fuel in the tank.

It should be noted that the measurement of the aircraft's center of gravity will be performed with the airplane in its normal position and not inverted. This is because the aircraft is a high-wing design, with the wings located at the top of the fuselage and most of the weight located beneath them, as presented in the figure 17.

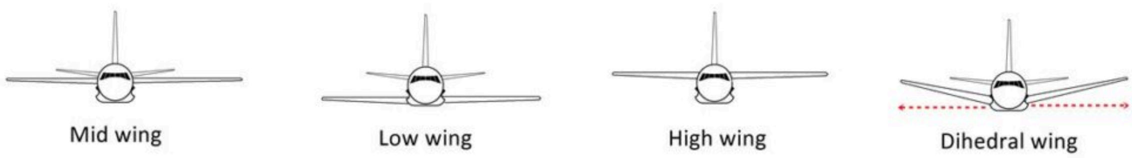


**Figure 17** - Types of wings configuration.

# 5. UAV Block Diagram

The UAVs structure interacts directly with servo motors stored inside the fuselage and wings. In order to have a better understanding of how this interaction works, we can look at the mechanism diagram represented on figure 18, which translates the behavior of each element.

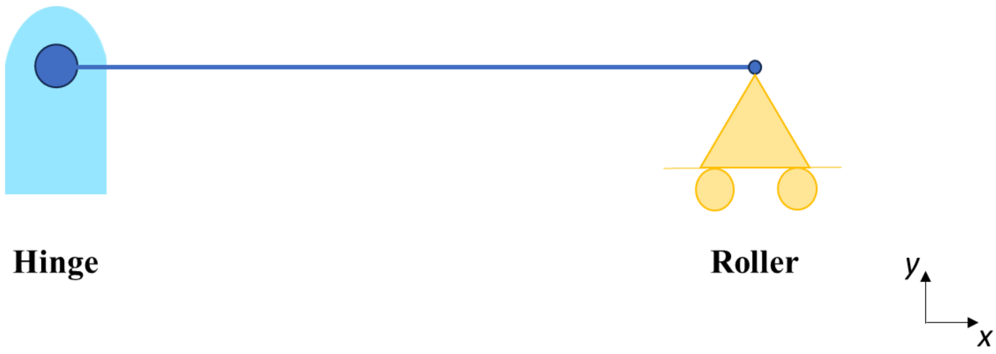


**Figure 18** - UAV Servo Motors Mechanism Diagram.

All the servo motors will be connected to the elements they control through rods. These rods will be coupled to the servo motors, exhibiting rotation in such end. On the other end, coupled to the element that it controls, only translation in *xx* direction is allowed, which then results in their rotation.

The servo motors layout is composed of the first three servo motors which will be installed in the fuselage. On the other hand, the Servo Motor 4 will be placed in a small compartment between the UAVs wings.

The diagram represented on figure 18, shows where each servo motor will act over on the plane:

- Servo Motor 1: Controls the Nose Wheel direction & the Engine Throttle position;
- Servo Motor 2: Controls the Rudder direction;
- Servo Motor 3: Controls the Elevator position;
- Servo Motor 4: Controls the Ailerons position from both wings.

# 6. Aircraft Cover Design

Taking into account that the airplane will be almost entirely white, there was a need to assign a distinct visual identity to it.

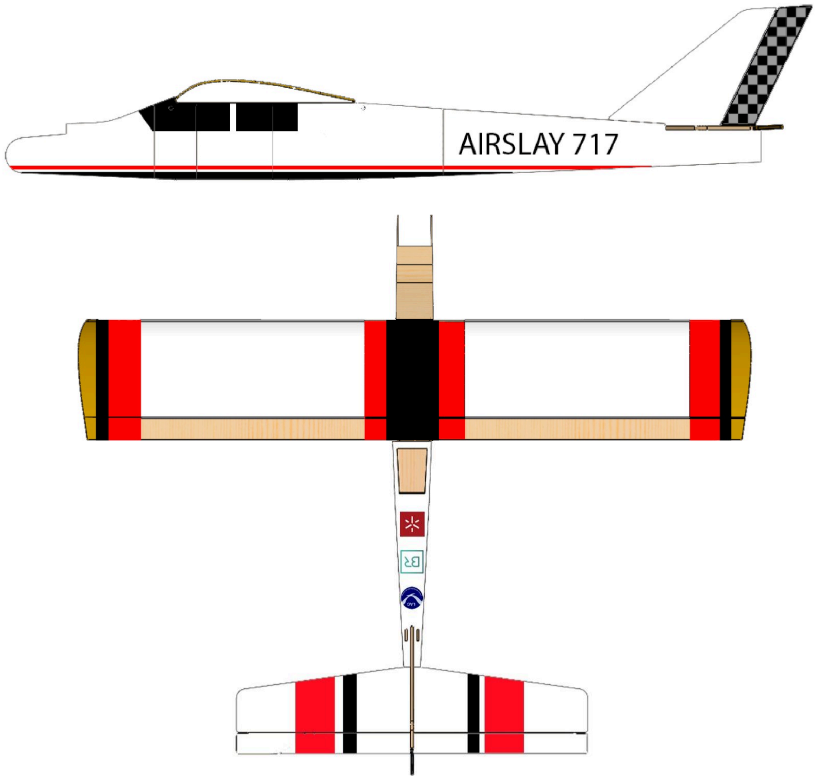


**Figure 19** - Visual Elements Design.

As can be seen in the above images, we used two main colors for the design of the visual elements that will be added: black was chosen because it contrasts well with white, and red was selected to represent the university's color as well as to give the airplane a more interesting appearance.

Additionally, the emblems of the entities that helped us in the conception of this project were included on the airplane, such as the LAC symbol, the BiRD Lab logo, the university emblem, and finally, our own patch. It is also worth noting that the names of everyone in our class will be listed on the underside of the airplane's fuselage.