UNIVERSIDAD PONTIFICIA ICAI ICADE COMILLAS MADRID

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

GRADO EN INGENIERÍA ELECTROMECÁNICA

Especialidad Mecánica

AIRFRAME MECHANICAL DESIGN, SETUP & ENHANCEMENT

Author: Belén Castro-Rial Resines

Director: Karl-Heinz Siebold

Madrid

June 2018

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Fdo.: Karl-Heinz Siebold　　　　Fecha: 23/05/2018

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June 2018

DISEÑO, CONFIGURACIÓN Y MEJORAMIENTO MECÁNICO DE UNA AERONAVE

Autor: Castro-Rial Resines, Belén.

Director: Siebold, Karl-Heinz.

Entidad colaboradora: Munich University of Applied Sciences.

RESUMEN DEL PROYECTO

La competición AUVSI SUAS, *Association for Unmanned Vehicle Systems International Student Unmanned Aerial Systems*, es una competición de sistemas aéreos no tripulados de la Asociación de sistemas de vehículos no tripulados (UAS). Requiere que los estudiantes diseñen, integren, informen y operen un UAS capaz de realizar satisfactoriamente vuelo autónomo, navegación (preprogramada), detección remota a través de sensores de carga útil a bordo, y la ejecución de un conjunto específico de tareas.

Esta competición se lleva anualmente a cabo desde 2002 en la estación aeronaval del río Patuxent (NAS), Webster Field, en el condado de St. Mary, Maryland. Ésta es la sede de la escuela naval de pilotos de prueba de Estados Unidos, y sirve como un centro de ensayo y evaluación de sistemas aéreos no tripulados.

La Misión SUAS 2018 es la siguiente: los servicios de emergencia están manejando un incendio forestal y han encargado un sistema aéreo no tripulado para localizar a una persona que necesita ser rescatada y para combatir el fuego liberando agua sobre ella.

Para participar, *Munich University of Applied Sciences* (MUAS) dividió las tareas en varios sub-equipos. Este proyecto trata del diseño mecánico del avión (*Airframe Mechanics*) del equipo de la MUAS. Es la segunda vez que participa, por lo tanto, se partió de una base de cómo estructurar el diseño.

Montaje final del avión.

El líder del equipo, Benjamin Bachmaier, adjudicó las tareas y estuvo siempre a disposición de recibir preguntas y dudas. Él tiene una gran experiencia en la construcción de UAS y ya había participado en la competición del año pasado.

El sub-equipo *Airframe Mechanics*, al que pertenecía la autora del presente proyecto, fue conformado por cinco alumnos, todos ellos estudiantes de intercambio. La mayoría de las veces se dividieron las tareas, trabajando en pequeños grupos: entre dos y tres miembros. Se establecieron reuniones semanales en las que los cinco ponían en común los avances, aparte de trabajar por separado cuando fuera necesario.

El avión del año pasado fue tomado como punto de partida, y a partir de ahí y junto con los requisitos de la competición de 2018, se diseñaron nuevas secciones, tratando de evitar los errores cometidos en el diseño previo, y manteniendo lo que había funcionado bien. Los principales desafíos encontrados fueron los siguientes:

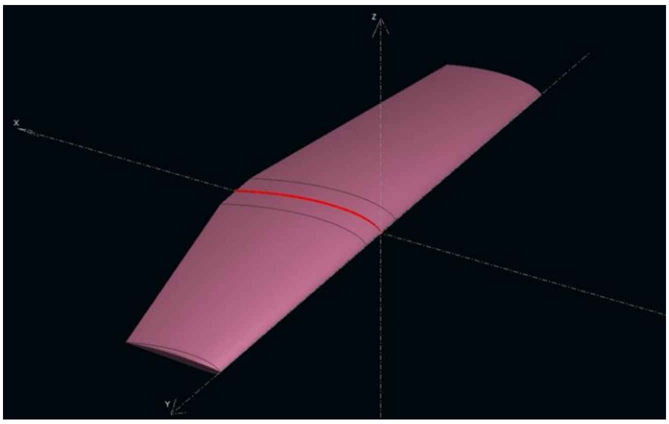
- ❖ Integrar las nuevas alas y diseñar un estabilizador que cumpla con los requisitos.
- ❖ Diseñar y construir los estabilizadores horizontal y vertical más ligeros manteniendo el compromiso de estabilidad y resistencia estructural.
- ❖ Rediseñar el cajón central del ala (*Wing Center Box-WCB*) para que se ajustase a los nuevos componentes electrónicos.
- ❖ Reducir la flexión del fuselaje al mínimo.

La primera tarea acometida fue la optimización de las alas. Para hacer el diseño conceptual se empleó el software de código abierto XFLR5.

Una vez recibido el diseño del ala, este equipo *Airframe Mechanics*, realizó algunos ajustes métricos para que fueran incorporados al resto del avión.

Las medidas más importantes del ala recibidas fueron las siguientes:

- Forma del perfil - Clark Y.
- Cuerda en el encastre - 400 mm.
- Cuerda en la punta - 260 mm.
- Envergadura total (ala y caja central) - 1,53 m.



Diseño de las alas en XFLR5.

Se añadió al diseño cierto ángulo de torsión (*twist*), para asegurar que la pérdida, o incapacidad del ala para seguir produciendo sustentación (*stall*), aparezca antes en el centro de las alas. Este ángulo es la diferencia entre el ángulo de incidencia entre el encastre y la punta del ala. De esta manera, el avión presenta un control continuo del ala y cierta resistencia al giro.

Al añadir el ángulo de torsión al diseño conceptual, se diseñaron unas piezas (*wing tips*) a encajar en la punta del ala, que, efectivamente, proporcionaran la diferencia de ángulo de ataque.

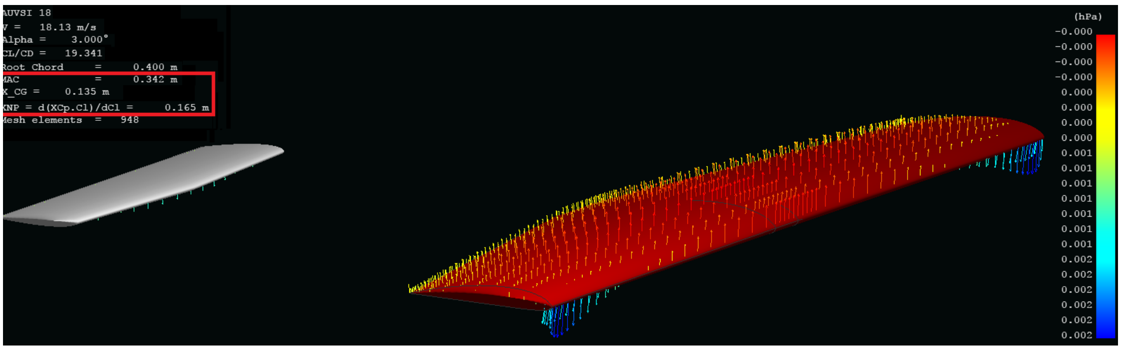
La fabricación de las alas consiste en unos segmentos de madera, denominados costillas, espaciados, con un núcleo de espuma de poliestireno, todo ello recubierto de un laminado de madera.

Estructura del ala.

La segunda labor fue el diseño del estabilizador horizontal. Todo este proceso consiste en iteraciones en el programa XFLR5.

El primer objetivo, basado en la experiencia de algunos de los miembros, es crear un diseño inicial que presente la mejor relación coeficiente de sustentación-coeficiente de resistencia (CL/CD: *lift -drag*) a una velocidad entre 16 y 18 m/s con un margen de estabilidad de alrededor del 8%, teniendo en cuenta que la masa de despegue estimada sería de unos 4 kg aproximadamente. Cambiando parámetros e iterando varios diseños diferentes, el equipo fue obteniendo poco a poco las medidas necesarias en XFLR5.

La siguiente imagen muestra el coeficiente de presión distribuido a través del avión completo. Como se puede observar, las alas producen una cantidad importante de sustentación en su superficie, y el estabilizador produce una fuerza nula aproximadamente. Esto es importante porque de lo contrario, surgiría cierta resistencia que deterioraría el rendimiento de la aeronave.



Distribución de presiones en las superficies.

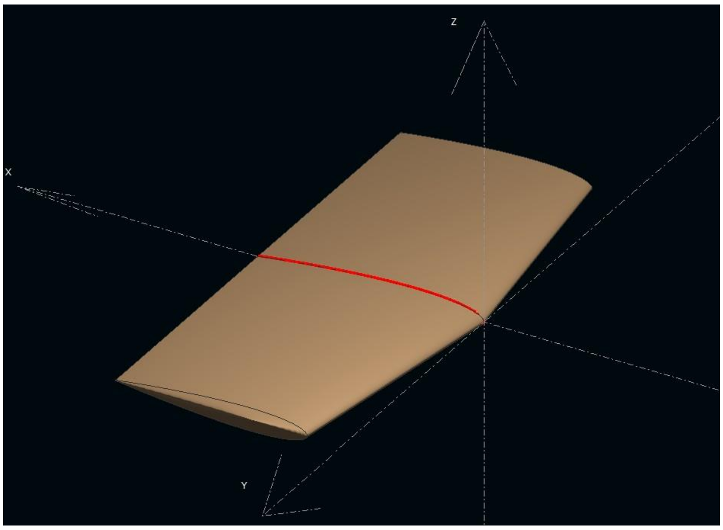
Para este avión, la mejor relación sustentación-resistencia se encontró a un ángulo de ataque (α) de 3 ° y una velocidad de diseño de 18 m /s. En este punto, se pudo observar en el programa que el coeficiente de momento sobre el eje de cabeceo (Cm), es muy cercano a cero. Esto demuestra que el punto de equilibrio del cabeceo (*pitch*) es efectivamente el punto de operación de la aeronave. También se obtuvo del programa que el avión no solo está en equilibrio, sino que además es estable. Esto implica que, si el avión sufre alguna perturbación intentando cabecear hacia arriba, por ejemplo, se producirá naturalmente un momento que lo compensará y lo devolverá a su ángulo de 3°, punto ideal para la velocidad y la relación CL/CD.

Otra medida física importante de la estabilidad de los aviones es cómo se enfrenta el avión ante las perturbaciones. Esta indicación se llama Margen de Estabilidad y se calcula analíticamente con la siguiente fórmula (valores tomados de XFLR5).

$$SM = -\frac{\partial C_m}{\partial \alpha} = \frac{X_{neutral\ point} - X_{center\ of\ gravity}}{Mean\ Aerodynamic\ Chord_{wing}} = \frac{0{,}165 - 0{,}135}{0{,}342} = 8{,}77\%$$

El avión no debe diseñarse para el margen de estabilidad más alto posible, ya que un avión demasiado estable no responderá con agilidad a los comandos recibidos. Entonces, básicamente, el piloto o piloto automático estaría peleando contra el avión para intentar maniobrarlo. Considerando la experiencia del equipo, un buen margen de estabilidad estaría entre 5% y 10%.

Del programa XFLR5 se obtuvieron directamente los datos buscados y, por lo tanto, las medidas óptimas del estabilizador a ser empleadas.



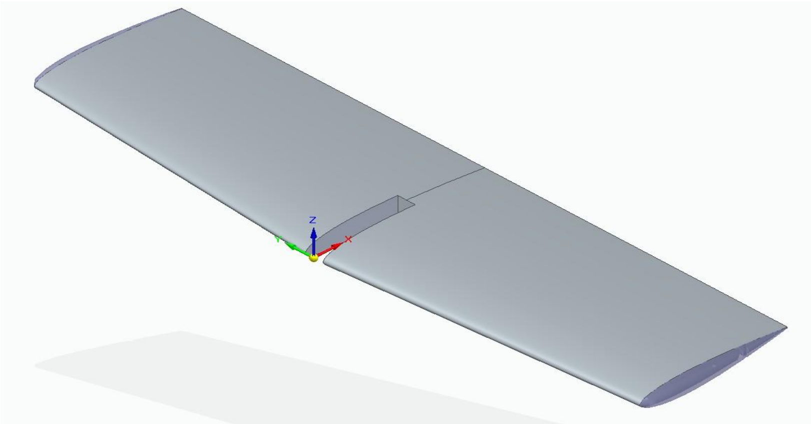
Diseño del estabilizador horizontal en XFLR5.

Un aspecto importante que mencionar, es el hecho de que la longitud total del avión es de 1,76 m. Se hicieron los cálculos necesarios para verificar si la flexión fuera significativa y resultó no serlo, por lo que el problema de la flexión del fuselaje se resolvió a la vez.

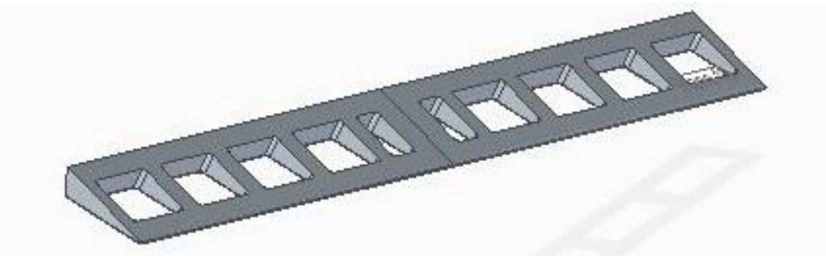
Las partes estructurales principales del avión (fuselaje y conexiones) son tubos hechos de fibra de carbono para la mejor relación resistencia-peso.

Teniendo en cuenta principalmente el peso y la resistencia del estabilizador horizontal, el grupo decidió fabricarlo como un núcleo de poliestireno cubierto por una fina lámina de madera. Sobre ella, una capa de plástico, que le proporciona impermeabilidad. El larguero central del mismo consiste en un tubo de fibra de carbono que la atraviesa a lo largo de toda la envergadura. De esta forma, se fabricaron dos piezas simétricas que se conectan a través de éste.

Para hacer la superficie de control, el elevador, se realizó un corte en torno al 70% de la cuerda del ala. Esta superficie de control, que forma un ángulo de 30º con respecto al resto del estabilizador visto desde el perfil, se fabricó por separado y le da libertad de movimiento.



Diseño de estabilizador horizontal en Solid Edge.



Diseño del elevador en Solid Edge.

El siguiente paso fue diseñar el estabilizador vertical, conformado por una parte fija, denominada la deriva (*fin*), y una móvil denominada timón (*rudder*). Su diseño fue hecho siguiendo las restricciones dadas. El estabilizador vertical junto con el horizontal, componen la cola del avión.

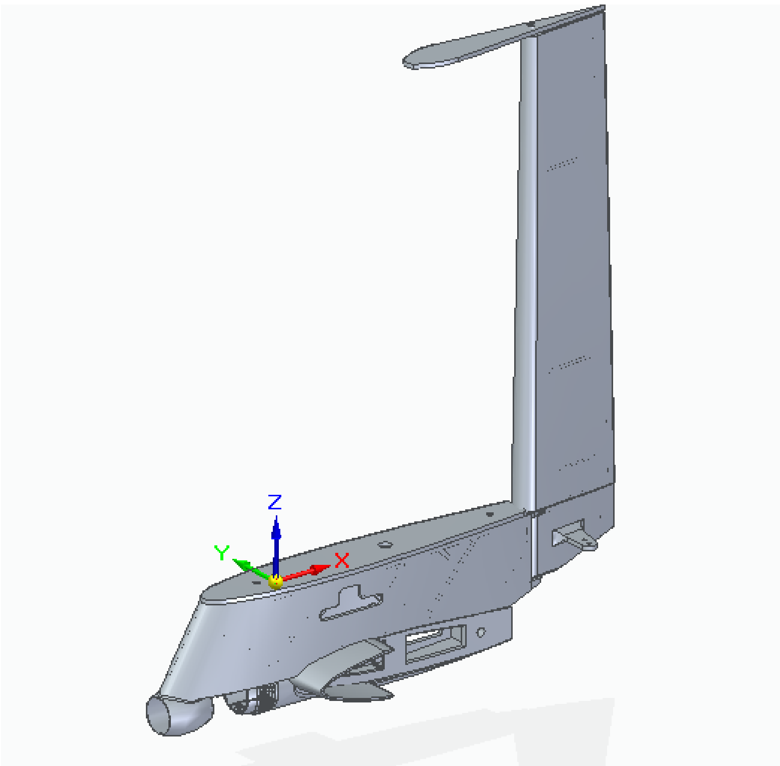
Las consideraciones que se tuvieron en cuenta son las siguientes:

- La prioridad es minimizar su peso sin pérdida de estabilidad. De esta manera, el objetivo principal fue combinar estas dos cualidades para optimizar el diseño.
- La superficie de control (*rudder)* deberá estar alrededor del 70% del cordón, al igual que el elevador.
- Debe adaptarse a la antena que recibirá los comandos del controlador de radio durante el vuelo controlado.
- Tiene que estar firmemente ensamblado al resto de la cola del avión.

Para optimizar el diseño, se decidió dividir el estabilizador en dos partes: una superior y una inferior.

La parte superior tendría un diseño muy simple y estaría construida de poliestireno y cubierta de madera, igual que el estabilizador horizontal. De esta forma, se puede asegurar un diseño más ligero sin la pérdida de estabilidad. La cuerda superior e inferior del mismo fueron diseñadas, para mecanizarlo en la cortadora de espuma de la Universidad.

La parte inferior tendría un diseño más complicado y se imprimiría en 3D. Esta parte se denomina sección central de la cola. Su objetivo principal es ensamblar firmemente el estabilizador horizontal y el vertical, además de unir toda la cola al fuselaje. Otra importante función de ésta es alojar los dos servos, y servir como conexión con la superficie de control *rudder*, también impresa en 3D.



Diseño del estabilizador vertical en Solid Edge.

Para la fabricación, la primera parte que se produjo fue la sección central de la cola (la inferior). Se hizo en una impresora 3D de la Universidad MUAS, y una vez obtenida, se incluyeron el pequeño tubo de carbono como conexión y el otro tubo de carbono de mayor sección como fuselaje, así como los servos.

El proceso de fabricación de la parte superior del estabilizador vertical fue el mismo proceso que el horizontal: primero, obtener el perfil de poliestireno en la máquina de corte de espuma, a continuación, cubrirlo de madera y finalmente aplicar un recubrimiento de plástico.

La última tarea fue el diseño del cajón central del ala: *Wing Center Box (WCB)*. El objetivo principal del mismo es conectar las alas con el fuselaje, así como alojar la placa electrónica.

El equipo realizó el diseño del WCB teniendo en cuenta los requisitos de espacio proporcionados. Como durante todo el proceso de diseño, el primer paso fue analizar el modelo del año pasado. El programa utilizado para acometer esta tarea fue Solid Edge.

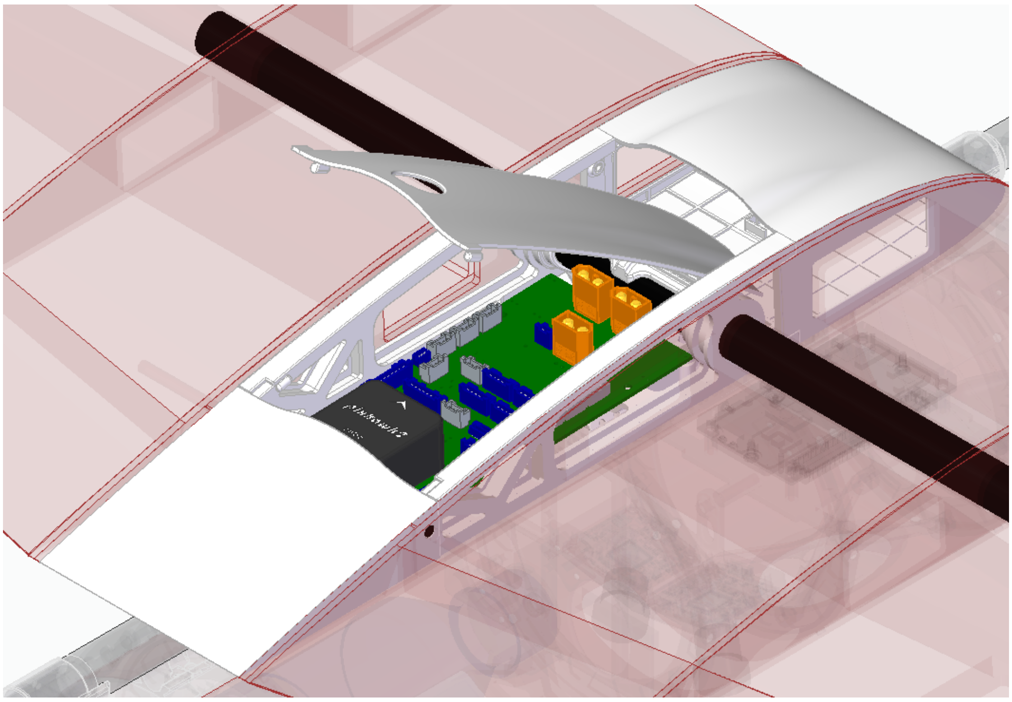
La forma en que se estructuró el diseño fue en cuatro partes: frontal, posterior, laterales y cubierta. Del diseño pasado, solo se reutilizaron los conectores entre el cajón y el fuselaje; el resto de las partes fueron rediseñadas.

El ala tiene un perfil CLARK Y de 400 mm de cuerda en el encastre. Eso significa que el cajón central debería tener el mismo perfil en sus laterales para posibilitar la conexión. Pero surgió un problema: la placa electrónica que se suponía que debía caber en el interior excedía las dimensiones del cajón; lo que llevó al equipo a hacer un diseño más complejo del inicialmente previsto.

El replanteo proyectado fue exceder suavemente el grosor previsto de las costillas del perfil en el eje longitudinal de la aeronave, disminuyendo gradualmente al grosor estándar de las alas. Este perfil fue estudiado para reducir la turbulencia creada por la forma no aerodinámica.

Durante el modelado de las piezas, la simetría del diseño fue todo el tiempo tenida en consideración.

En la siguiente figura se puede observar el resultado final:



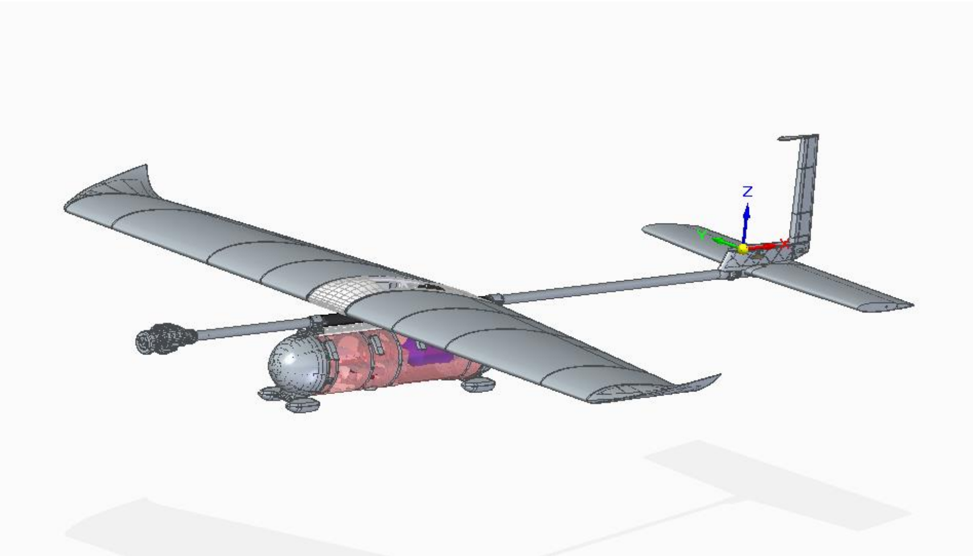
Diseño en Solid Edge del WCB abierto; en su interior, la placa electrónica.

La fabricación del WCB se realizó mediante impresión 3D, por lo que una vez completo el diseño, fue enviado a la impresora 3D de la MUAS.

Para concluir, es importante tener en cuenta al avión como un conjunto, cuyos elementos deben estar conectados entre sí. Por lo tanto, durante el diseño de todas las partes se tuvo en cuenta permanentemente las conexiones con el resto del cuerpo del avión.

Una vez que todos los equipos terminaron sus partes, éstas fueron ensambladas y se pudo observar con orgullo que el diseño final superó las expectativas.

A continuación, el diseño completo de la aeronave y el montaje final.



Diseño completo del avión en Solid Edge.

Montaje final del avión.

Desafortunadamente, en la primera prueba de vuelo, que se llevó a cabo el 22 de mayo de 2018, el avión se estrelló contra el suelo y se rompieron varios componentes importantes del mismo. Ya que la prueba se hizo con tan poco margen de tiempo, no hubo posibilidad de arreglarlo antes de la competición, y, por tanto, el equipo de la MUAS no pudo participar en la misma. Sin embargo, eso sirvió como motivación para analizar los errores e intentar arreglarlos para conseguir que el avión volara.

Durante el vuelo surgió un ángulo relativo entre la cola y las alas visto de frente. Esto produjo una fuerza lateral extra, a la vez que la pérdida de control del estabilizador, lo que produjo la caída. Se observó que esto se dio porque en la conexión entre la cola y el fuselaje había cierto juego que no se había tenido en cuenta previamente. Para solucionarlo, habría que cambiar las conexiones por unas que se ajusten firmemente.

Además, se observó que el tubo de carbono que servía como fuselaje, no era capaz de soportar las fuerzas durante el vuelo; por lo que para resolver ello simplemente habría que sustituirlo por uno más resistente.

En definitiva, el equipo no tomó la caída como un fracaso, sino como una oportunidad para aprender de los errores y optimizar ese avión al que se le había dedicado tanto tiempo y esfuerzo.

AIRFRAME MECHANICAL DESIGN, SETUP & ENHANCEMENT

Author: Castro-Rial Resines, Belén.

Director: Siebold, Karl-Heinz.

Collaborating entity: Munich University of Applied Sciences.

PROJECT SUMMARY

The AUVSI SUAS Competition stands for *Association for Unmanned Vehicle Systems International Student Unmanned Aerial Systems* Competition. It requires students to design, integrate, report on, and demonstrate an Unmanned Aerial System (UAS) capable of autonomous flight and navigation, remote sensing via onboard payload sensors, and execution of a specific set of tasks.

This competition is held annually since 2002 at the Patuxent River Naval Air Station (NAS), Webster Field, in St. Mary's County, Maryland. This is the site of the UAS Test & Evaluation Directorate.

The SUAS 2018 Mission is the following: Emergency services are handling a forest fire and have tasked an Unmanned Aerial System to locate a person needing rescue and to suppress the fire by releasing water on it.

In order to participate, Munich University of Applied Sciences (MUAS) divided the tasks in several sub-teams. This project is about the aircraft mechanical design (*Airframe Mechanics*) of MUAS team. This university takes part in it for second year, therefore we had an idea of how to structure the design.

Final plane assembly.

The team leader, Benjamin Bachmaier, distributed the tasks and was always available to receive questions and doubts. He has big experience building UAS and he had already been in last year's competition.

Our sub-team *Airframe Mechanics* had five members, all of us were exchange students. Most of the time we divided the work, hence the methodology we preferred was to work in small groups: between two and three members. We stablished meetings on a weekly basis in which we put all the information together, and then we performed personal work by our own.

Last year's plane was taken as starting point, and from there and the requirements of the 2018 Competition, new sections were designed, trying to avoid the mistakes that had been made while maintaining what had worked well. The main challenges we had to face were:

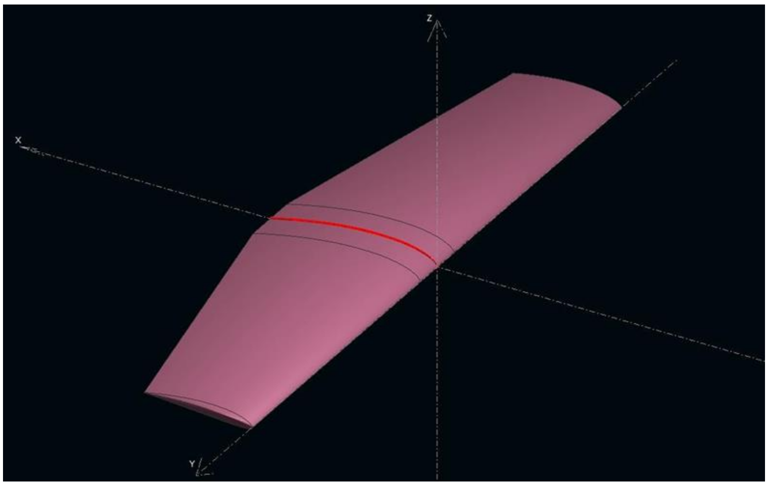
- ❖ Integrate the new wings and design a stabilizer that fulfills the requirements.
- ❖ Make the horizontal and vertical stabilizers lighter without decrease on stability and structural strength.
- ❖ Redesign the wing center box to fit the new electronic components.
- ❖ Reduce the bending in the fuselage to minimum.

First, we started with the wings. To make the initial design we used the open source software XFLR5.

We were given the design of the wing and, based on that model, our group changed some measures to incorporate them to the rest of the plane.

The most important measures of the main wing we had are:

- Airfoil – Clark Y
- Root chord – 400mm.
- Tip chord – 260mm.
- Total Span (wing and center box) – 1,53m.

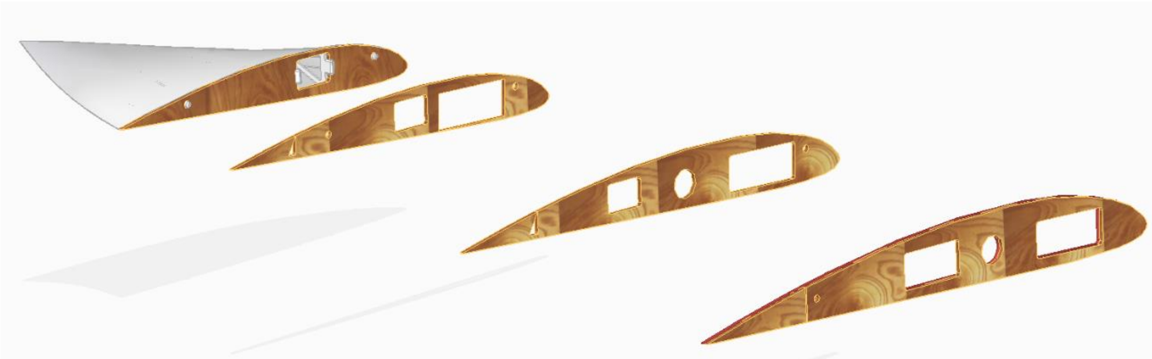


XFLR5 Wing design.

A twist angle was added by our group to that design, to ensure that a potential stall first appears on the center of the wings. This angle is the difference in the angle of attack of the root and tip chord and ensures that at stall speed the wing root stalls before the wing tips, providing the aircraft with continued aileron control and some resistance to spinning.

Since the twist angle was added, some tips were designed to aerodynamically optimize the prototype.

The wings manufacturing is by wooden made ribs equally spaced, filled with foam and with a wood sheeting.

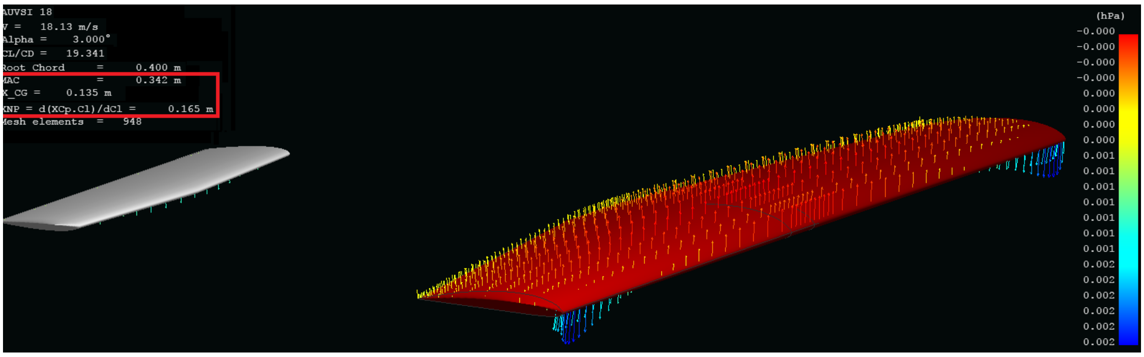


Wings' structure

Second task was to design the horizontal stabilizer. The whole process consists of iterations on the XFLR5 program.

The first goal, based on the leader of the team's experience, is to come up with an initial design that presents the best lift to drag ratio at an airspeed between 16 and 18 m/s with a stability margin of around 8%, keeping in mind that the that the estimated takeoff mass would be around 4kg. Changing parameters and iterating several different designs, the team obtained gradually the desired results on XFLR5.

The picture below shows the coefficient of pressure distributed through the whole plane. As it can be seen, the wings produce an important amount of lift in its surface, and the stabilizer produces approximately null force. Important detail because otherwise, certain drag would come up that would deteriorate airframe's performance.



Pressure distribution through the surfaces.

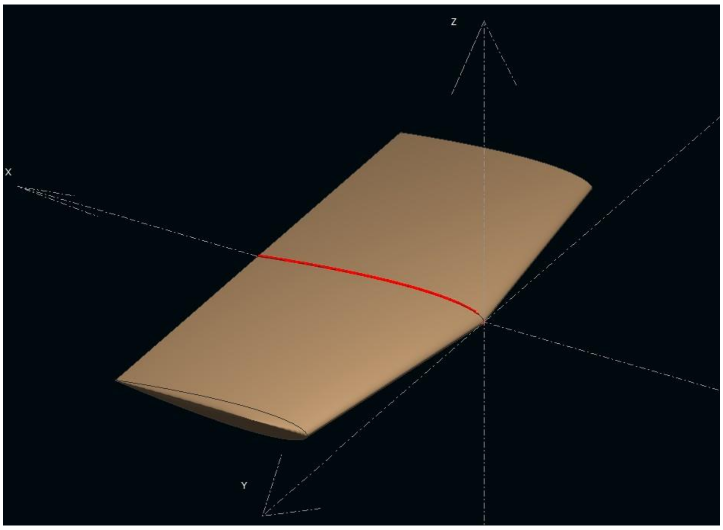
For this aircraft, the best lift to drag ratio was found at an angle of attack (α) of 3° and a design airspeed of 18 m/s. At this point, we could see in the program that the Cm (moment coefficient about the pitching axis) is very close to zero. This proves that the equilibrium point for the pitching force is indeed the aircrafts operating point. We also got from the program that the plane is not only in equilibrium, but also stable. It means that if the plane suffers any disturbance trying to pitch its nose up, for example, it will naturally produce a moment that fights this and returns the plane to its 3° angle of attack, the ideal point for velocity and lift to drag ratio.

An important physical measurement of the aircrafts stability behavior is how hard the plane will fight against such disturbances. This indication is called Stability Margin and can be calculated analytically with the following formula (values taken from XFLR5).

$$SM = -\frac{\partial C_m}{\partial \alpha} = \frac{X_{neutral\ point} - X_{center\ of\ gravity}}{Mean\ Aerodynamic\ Chord_{wing}} = \frac{0{,}165 - 0{,}135}{0{,}342} = 8{,}77\%$$

The airplane should not be designed for the highest stability margin possible, as a too stable plane won’t respond with agility for the commands given. So basically, the pilot or auto pilot would be fighting the plane to try to maneuver it. Considering the experience from the team, a good stability margin would be between 5% and 10%.

From the XFLR5 program we got directly the data we were purchasing, and therefore the horizontal stabilizer measures that were going to be used.



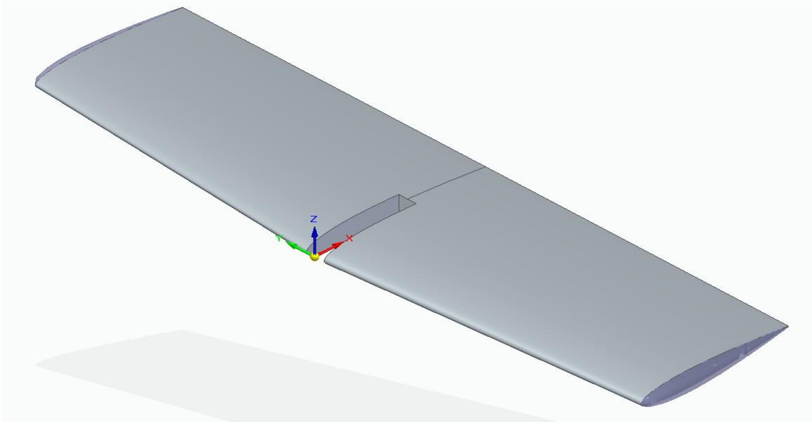
XFLR5 Horizontal stabilizer design.

One important aspect to be mentioned is the fact that the overall length of the plane is 1,76m. Some calculations were done to check if the flexion would be significant and it turned out that it was not, so the problem of the bending in the pipe was solved at the same time.

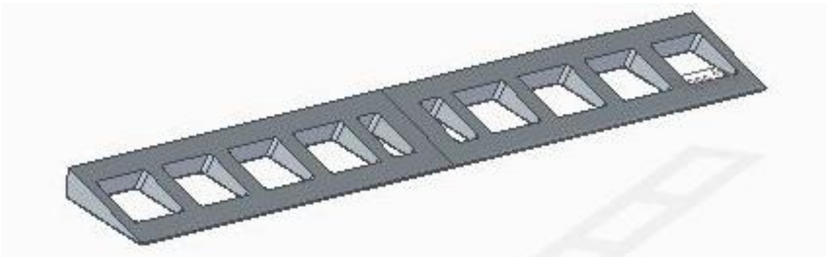
The main structural parts of the airplane (fuselage and spars) are carbon fiber made tubes for the best resistance-weight ratio.

Considering mainly the weight and resistance of the horizontal stabilizer, the group decided to manufacture it as a core of foam covered by a thin layer of wood. Over it, a plastic coating, that provides it with impermeability. It would have a carbon tube as the spar going through the span. This way, we could manufacture two symmetrical parts and connect them through it.

To make the control surface, the elevator, we made a cut on around 70% of the wing chord. This control surface, which has an angle of 30º with the rest of the stabilizer seen from the profile, was manufactured separately and gives it freedom of movement.



Solid Edge horizontal stabilizer design.



Solid Edge elevator design

Next step was to design the vertical stabilizer, composed of two parts: a fixed one, the fin and a mobile one or control surface, the rudder. Its design was made following the restrictions we were given. The vertical stabilizer along with the horizontal one is part of a set called aircraft tail.

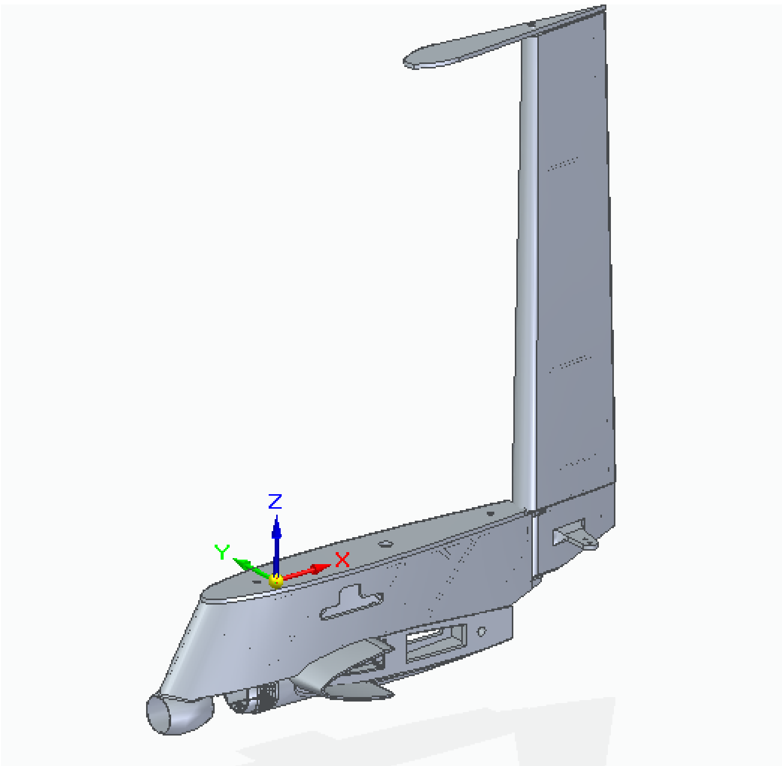
The considerations that were taken into account are the following:

- The priority is to minimize its weight without stability loss. So, the main goal was to combine these two qualities to optimize the design.
- The rudder control surface shall be at around 70% of the chord, like the elevator.
- It must fit the antenna that will receive the commands from the radio controller during controlled flight.
- It must be firmly assembled to the rest of the plane tail.

Therefore, the best idea we thought of was to divide the stabilizer in two parts: an upper and a lower one.

The upper would have a very simple design and it would be made out of foam and covered of wood, just as the horizontal stabilizer. That way, we could ensure a lighter design without stability loss. To manufacture it, we had to design the upper and lower chord so that it would be simple to obtain in the hot wire machine.

The lower part would have a more complicated design and would be 3D printed. This part is called tail center joint. Its main purpose is to firmly assemble the horizontal stabilizer and vertical stabilizer together, and to join the whole tail to the carbon tube tail boom of the aircraft. Another function is to carry the two servos, and to be connected to the rudder control surface, 3D printed as well.



Solid Edge vertical stabilizer design

For manufacturing, the first part that was produced was the tail center joint (the lower one). We could do it in a 3D printer of MUAS University, and once we obtained it, the little carbon tube as connection and the big carbon tube as pipe, as well as the servos, were included.

The manufacturing process of the upper part of the vertical stabilizer was the exact same process as the horizontal one: first, obtain the shape out of foam in the hot wire, then cover it of wood and apply a plastic coating.

Final task was the Wing Center Box design. The main purpose of the box is to connect the wings together with the fuselage, as well as to carry the electronic board.

Our team made a design of the wing center box taking in consideration all the space constraints we were given. As during the whole design process, first step was to analyze last year's wing center box performance. The program used to accomplish this task was Solid Edge.

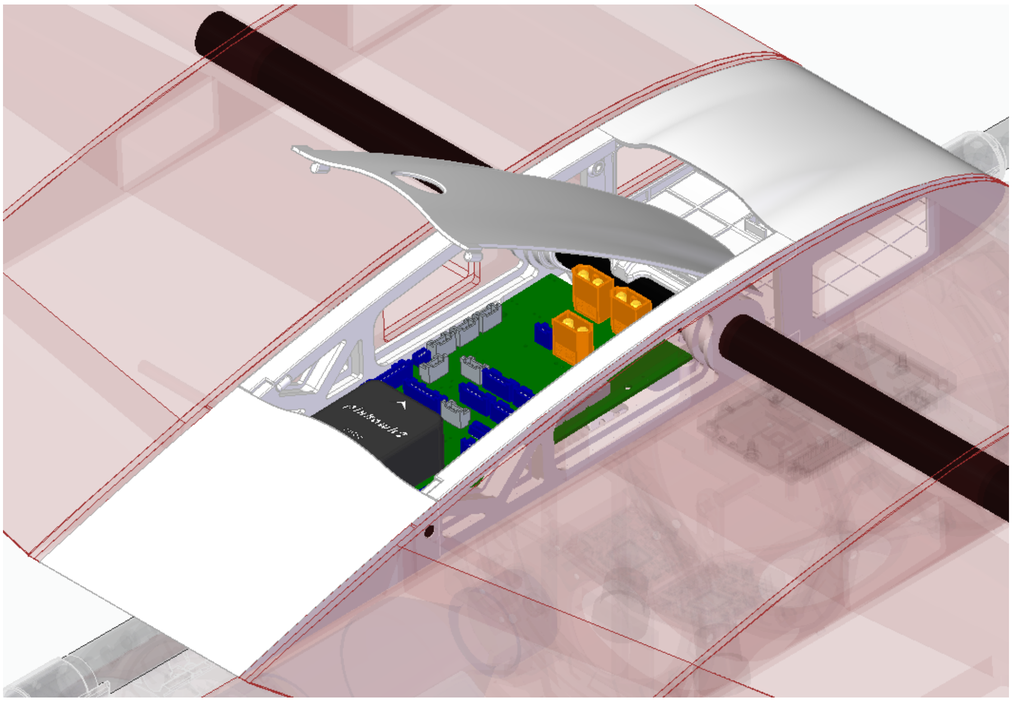
The way we structured it was in four parts: front, back, laterals, and a cover. From last year design, we only reused the connectors between the box and the fuselage; the rest of the parts were redesigned.

Our plane has a CLARK Y with 400 mm chord wing profile. That means, that the center box should have the same profile in its laterals to make the connections possible. But there was a problem: The electronic board that was supposed to fit inside exceeded the box; and that lead as to make a complex design.

The design that we constructed was a smooth one that smoothly exceeds the airfoil at his highest point and then comes back again making a slight curve. This profile was studied to reduce the turbulence created by non- aerodynamic shape.

During the modelling of the new parts, the symmetry of the design was the entire time taking in consideration.

On the following figure we can see the final result.



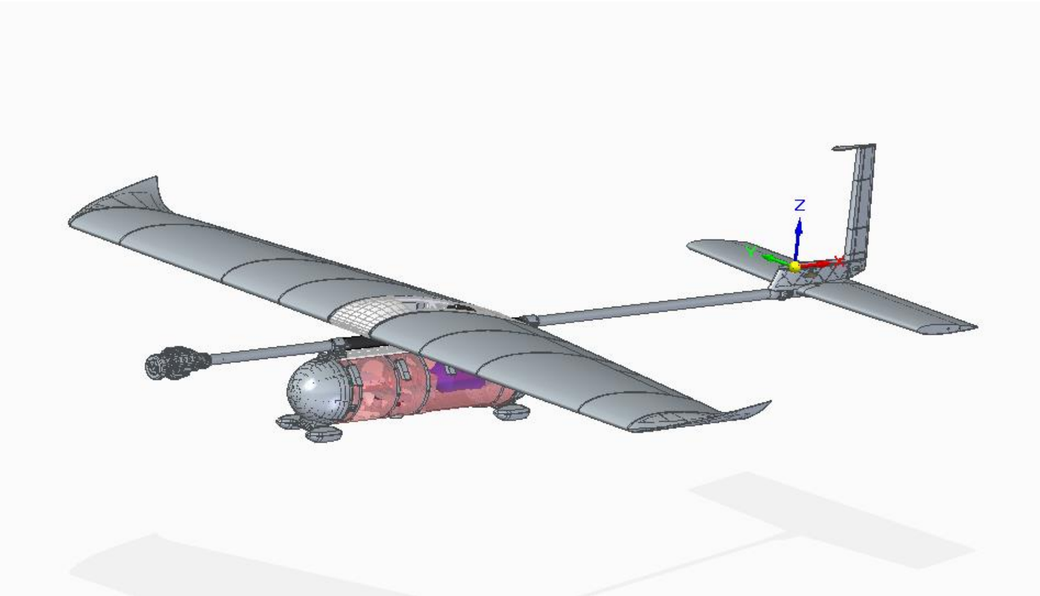
Solid Edge WCB opening design.

As already mentioned, the manufacturing of the Wing Center Box was by 3D printing, so once the design was completed we send it to the 3D printer in Munich University of Applied Sciences.

To conclude, it is important to think of the aircraft as an assembly, whose elements need to be connected one to another. Thus, during the design of all the parts we had in mind the connections, so that the whole body gets adjusted.

Once all the teams had their parts finished, we put them together and we could proudly say that the final design exceeded expectations.

Below is the whole aircraft design as well as the final assembly.



Solid Edge complete design.

Final plane assembly.

Unfortunately, in the first flight test on May 22, 2018, the plane crashed to the ground and several of its important components were broken. Since the test was done so close to the deadline, there was no possibility of fixing it before the competition, and, therefore, the MUAS team could not participate in it. However, that served as motivation to analyze the errors and try to fix them to get the plane to fly.

After analyzing the flight footage, a relative angle between the tail and the wings appeared, as seen from the front. This produced an extra lateral force, as well as the loss of control of the stabilizer, which caused the crash. It was determined that this occurred due to a certain game at the fuselage-tail connection that had not been previously considered. To solve it, we should replace the connections with ones that fit tightly.

In addition, it was observed that the carbon tube that served as a fuselage was not able to withstand the forces during the flight. To solve that, we should simply replace it by a more resistant one.

In short, the team did not take the crash as a failure. Instead, we took it as an opportunity to learn from the mistakes and optimize the plane to which so much time and effort had been devoted.

ACKNOWLEDGEMENTS

I would like to thank Munich University of Applied Sciences for giving me the opportunity to participate in this amazing project. I not only learned many aeronautical concepts, but also how to work as a team and learn from mistakes.

I would like to thank all the team members for their involvement and particularly the leader, Benjamin Bachmaier, for his dedication and willingness to help at all times.

I would also like to thank Prof. Siebold for directing the project.

Furthermore, I would like to thank Eva Arenas for supporting this project from Spain and for being available whenever I needed.

Additionally, I would really like to thank Julio Olavarría, for his voluntarily help in the editing process.

Finally, I must thank my family for their unconditional support and for always believing in me.

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1. INTRODUCTION

The AUVSI SUAS Competition stands for *Association for Unmanned Vehicle Systems International Student Unmanned Aerial Systems Competition*. It is designed to foster interest in Unmanned Aerial Systems (UAS), stimulate interest in UAS technologies and careers, and to engage students in a challenging UAS mission. The competition requires students to design, integrate, report on, and demonstrate an UAS capable of autonomous flight and navigation, remote sensing via onboard payload sensors, and execution of a specific set of tasks. The competition has been held annually since 2002. It has three major elements: The Technical Design Paper, the Flight Readiness Review Presentation, and the Mission Demonstration. The paper details a team's UAS design. The presentation details the team's testing and preparedness for the competition. The demonstration simulates a mission in which both the UAS and the team are evaluated. The mission consists of autonomous flight, obstacle avoidance, object detection, and air delivery.

The SUAS 2018 Mission is the following: Emergency services are handling a forest fire and have tasked an Unmanned Aerial System (UAS) to locate a person needing rescue and to suppress the fire by releasing water on it.

The competition is held at the Patuxent River Naval Air Station (NAS) Webster Field in St. Mary's County, Maryland. This is the site of the UAS Test & Evaluation Directorate.

In order to participate in this competition, *Munich University of Applied Sciences (MUAS)* divided the tasks in nine subteams: *Organizational structure, Systems Engineering, Airframe Mechanics, Electronics Compartment, Payload Bay Mechanics, Bottle Drop Mechanism, Mission Planning, Camera / Image Processing, Interoperability*.

This project is about the aircraft mechanical design (*Airframe Mechanics*), to participate in the SUAS Competition, with *MUAS* team. This university takes part in it for second year, therefore we had an idea of how to structure the design. We focused our work on improving the previous model and adapting it to the new requirements.

2. MOTIVATION

The 2016 SUAS Competition was held from June 15th to 19th. Among the 56 registered teams, 43 were accepted, 30 teams submitted a Technical Journal Paper, and 24 teams competed in Flight Readiness Review and Flight-Mission. That year, *Munich University of Applied Sciences* achieved the 7th position, being the best European aircraft.

Figure 1: Photo of 2016 AUVSI SUAS Competition

The 2018 SUAS Competition will be from June 13th to June 16th. A total of 71 teams have been accepted into the competition: 36 domestic, 32 international, and 3 high schools. As already stated, the motivation of the project is to participate in it and get the best place we can.

The *Airframe Mechanics* team consists of five students, and all of us were new in the aerospace field, particularly in this kind of projects. Anyway, from the beginning we were told that we shouldn't be worried, provided that anything with an engine could fly, so our task would be to make it the best we could. Therefore, we were very motivated during all the process and very excited about both our work, and how the project was becoming an actual plane.

3. REQUIREMENTS

Before starting the activities, our group received a work package that would serve as a guideline for what our deliverables are going to be, including some parts of the project deadlines and some flight requirements. The most important requirements are the following:

- ✓ Flight duration - 30 minutes.
- ✓ Overall takeoff weight - 5 kg.
- ✓ Payload capacity - 1 kg.
- ✓ Design airspeed - Between 16 and 18m/s.
- ✓ Size- all parts need to fit into the transport case which will take them from Munich to Maryland.

Last year's plane was taken as starting point, and from there, new sections were designed, trying to avoid the mistakes that had been made while maintaining what had worked well. The main challenges we had to face were:

- ❖ Integrate the new wings and design a horizontal stabilizer that fulfills the requirements.
- ❖ Make the horizontal and vertical stabilizers lighter without decrease on stability and structural strength.
- ❖ Redesign the wing center box to fit the new electronic components.
- ❖ Reduce the bending in the fuselage to minimum.

4. PROJECT GOALS

To begin the concept design of the airplane, it is needed to look at its main components and design them for the best aerodynamic results. It is important to think of the necessary requirements and what can be compromised for enhancing other features of the airplane.

To obtain the best results, last year's plane was taken as starting point, and the parts that needed to be improved looked as shown below.

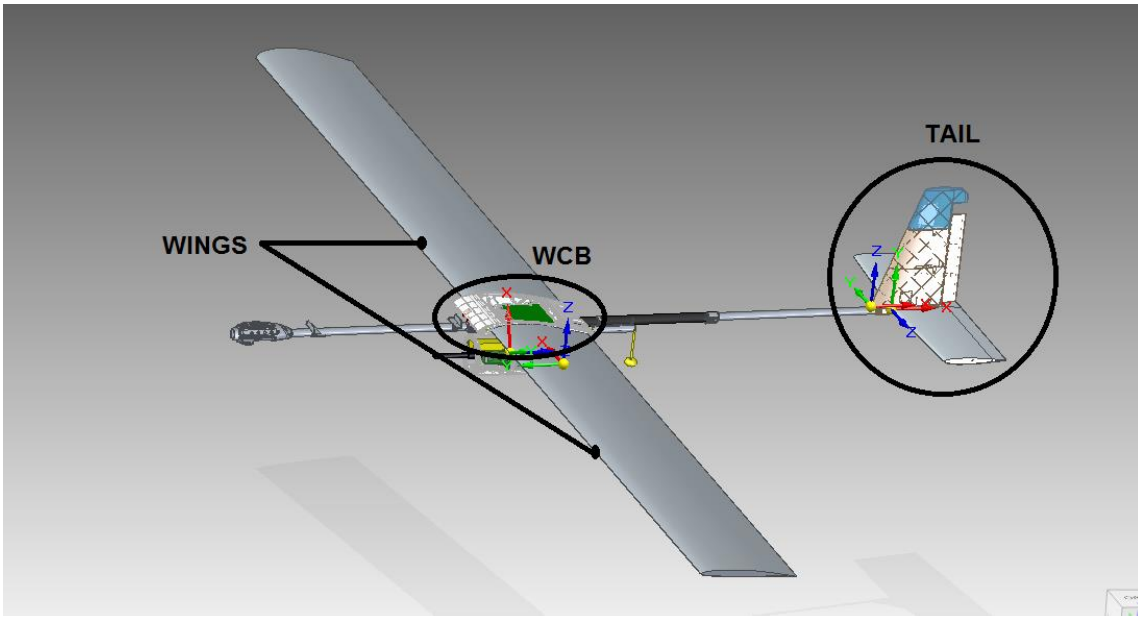

Figure 2: Last year design

We have focused our tasks in four parts:

- Wings: We were given an already existing design of them, and based on that model, our group changed some measures to make it the most aerodynamic as possible.

- Horizontal stabilizer: We were given the horizontal stabilizer airfoil profile, and based on last year design, we redesigned it completely, to fit it in the new wing's model.

- Vertical stabilizer: Together with the horizontal stabilizer it is part of the tail. Our main objective with the vertical stabilizer was to make it lighter as the last model without losing stability.

- Wing Center Box: The Wing Center Box (WCB) is the part of the airplane which connects the wing together with the fuselage and carries inside the electronic board. Because of the use of new parts, we had to create a model of it from the beginning.

5. WORK METHODOLOGY

As the competition will be held on June 2018, the airplane had to be finished by then, with a timeframe of approximately 2 months. Therefore, we have been working in the project since October 2017 and most of the work was performed by February.

The leader of the whole team is Benjamin Bachmaier, who distributed the tasks and was always available to receive questions and doubts. He is an aeronautic engineer who has a great knowledge about what we had to do. He has big experience building UAS and had already been in last year's competition.

Our sub-team *Airframe mechanics* had five members, all of us were exchange students. Most of the time we divided the work, hence the methodology we preferred was to work in small groups: between two and three members. We stablished meetings on a weekly basis in which we put all the information together, and then we performed personal work either at home or at university.

At the beginning, our weekly meetings were to get used to the required programs, as none of us were familiar with them. Once we got confident, we started with the design of the wings and elevator at the same time. We finished that task by the end of November, and then we started with the wing center box design. It was done by the beginning of January. The last assignment we had was to make the vertical stabilizer lighter, which was accomplished in January.

In this University the semester dates are different from the Spain ones, the first semester exams are in February and the second semester started in March. Hence, there was a break with the designing of the plane during February and we came back in March. Although the four main tasks I have mentioned were completed by then, there is always room for improvements and new tasks to perform. Once the second semester started, by middle of May, only three members of our team were left, and we accomplished other tasks like the manufacturing mainly, but also some design details were completed to optimize the plane performances. The three of us were selected to go to Maryland to the competition. The aircraft was assembled in May, when we could do some proof of flights as well.

I started with the redaction of the thesis in March and had it done by the beginning of May, so I could present it in Spain at the end of May.

Below is the my workplan schedule with the indicative dates:

	October 2017	November 2017	December 2017	January 2018	March 2018	April 2018	May 2018	June 2018
Wing								
Elevator								
Wing Center Box								
Vertical Stabilizer								
Other tasks								
Redaction								
Completed aircraft								
Proof of flight								
Competition								

Table 1:Schedule

6. RESOURCES

To make the initial design, our group used the open source software *XFLR5.* It is a flight surfaces analysis tool, like airfoils, wings and airframes with low Reynolds operation numbers. Our first challenge was to learn how it works and how to use it. It was available at the University, so during this task we mainly worked there.

Both for the design of the vertical stabilizer and the Wing Center box, we used *Solid Edge*, a 3D CAD solid modeling software. We were already familiar with it so there was no learning process. It was downloaded in the University, as well as in our personal computer, so we could work either at home or at the Faculty.

MUAS University has a wide range of machinery to obtain 3D pieces: foam cutters, hot wire machine, 3D printers... Thus, most of the designed elements were produced there. We have been told that we have unlimited budget, so we ordered some sections to external manufacturers as well.

Finally, to write the thesis itself, I have used *Microsoft Office Word*, available in my own Computer.

7. PROJECT DESCRIPTION

As already stated, none of us were very familiar with the aerospace field, so before starting we learned the basic concepts in order to understand what we were designing.

First, we learned about the parts that we were going to work in:

- Fuselage: It is the actual body of the plane: it serves as a connecting point for all its parts and holds the payload. our aircraft's fuselage is carbon fiber made tube.

- Wings: This is an important part because it works to help in balancing and improving the aircraft's stability when flying. This is the part that allows the plane to lift. There are two wings that are joined by a wing center box. The wings' shape is designed in order to get the best flight performance.
  We took the already existing wing design and based on that model, some measures were recalculated to optimize its aerodynamic results.

- Horizontal stabilizer: It helps the plane in maintaining its stability when flying. The wing will not be able to do it by itself. This is providing a counteracting force that helps when the aircraft faces disturbances while flying. At the horizontal stabilizer's trailing edge there is a hinged moving surface called elevator, whose main task is to control aircraft's pitch angle. Once we were given the airfoil profile of the horizontal stabilizer, we designed it completely, to fit it in the new wing's model.

- <u>Vertical stabilizer</u>: Together with the horizontal stabilizer it is part of the tail. It is intended to reduce aerodynamic side slip and provide direction stability. It is composed of two parts, a fixed one called fin and a mobile one, or control surface, called rudder.
  Our main objective with the vertical stabilizer was to make it lighter that the former model without stability reduction.

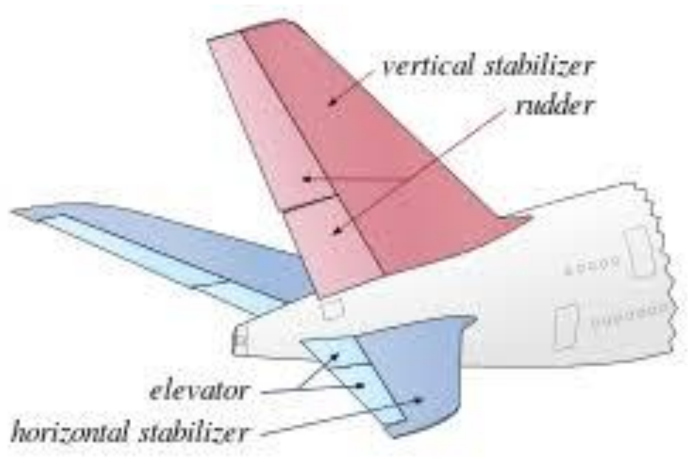

Figure 3: Scheme of a tail plane

- <u>Wing Center Box</u>: The Wing Center Box (WCB) is the part of the airplane which connects the wings together with the fuselage and carries the electronic board. Because of the use of new parts, we had to create a model from the very beginning.

To obtain the best results, we looked at the last year's design, and the elements that needed to be improved are shown in the following figure.

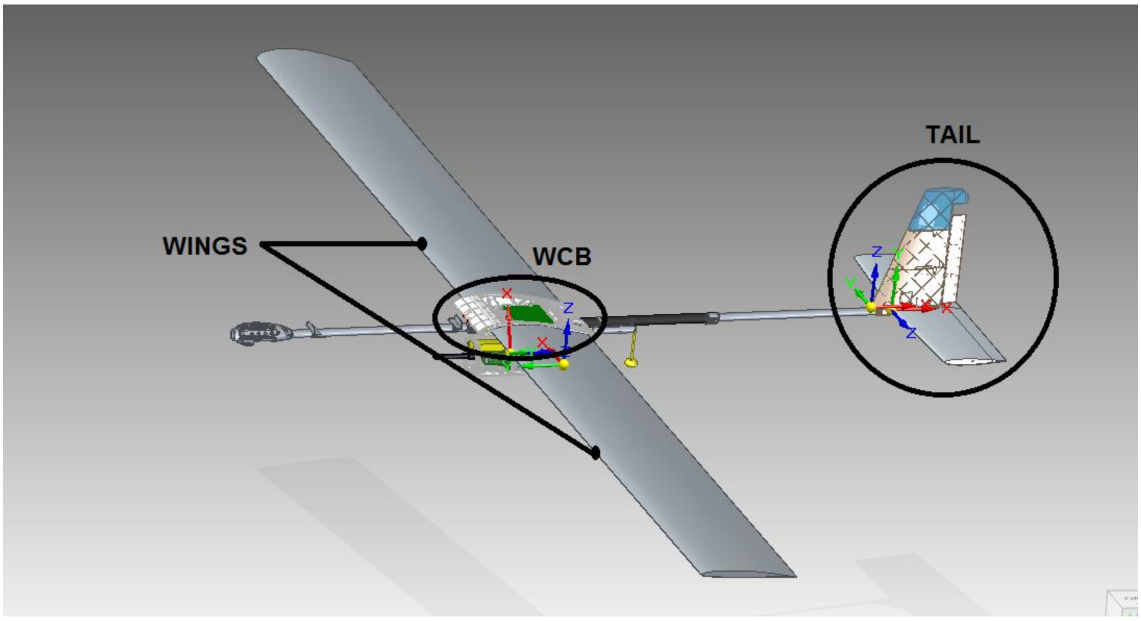

Figure 4: Last year design

Before starting we also studied a little bit the forces and moments that are exerted on the plane.

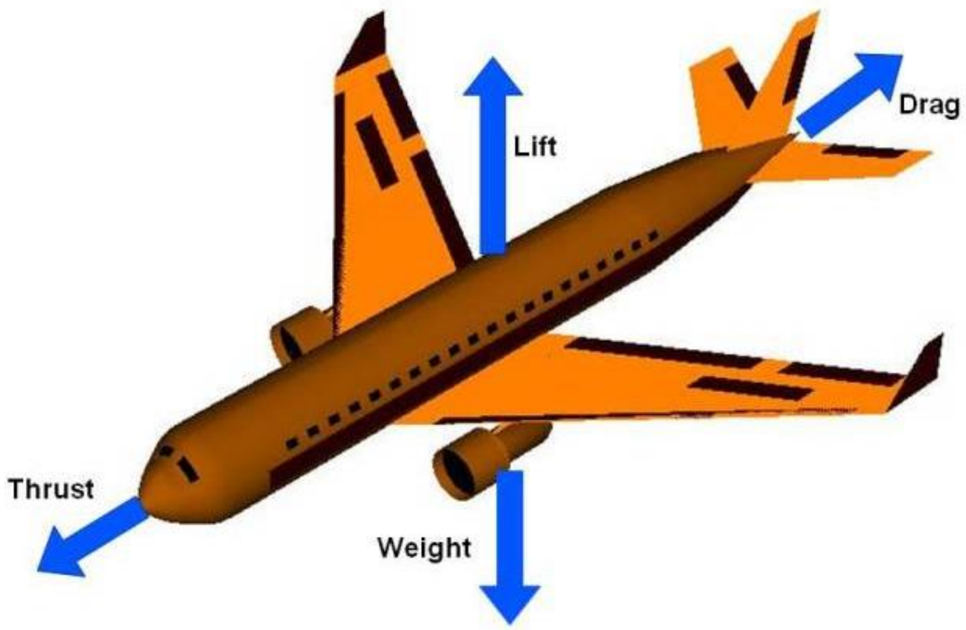

Figure 5: Forces acting on an airplane

- Drag: friction that resists the motion of an object moving through a fluid.

- Thrust: It is an aerodynamic force that must be created by the airplane to overcome the drag. Airplanes create thrust using propeller driven engines, jet-engines or rockets. Our plane will have a propeller driven engine.

- Lift: it is the force that enables the aircraft going upwards. Bernoulli's principle explains airfoil lift generation theory. Specifically, the air flowing over the top of the wing is accelerated by the asymmetrical wing shape, because it has to travel a longer distance than the air flowing along the bottom surface. This higher airflow velocity over the wing's upper surface, generates a pressure drop above the wing. The pressure differential between the bottom and top of the airfoil was the total resultant lift.

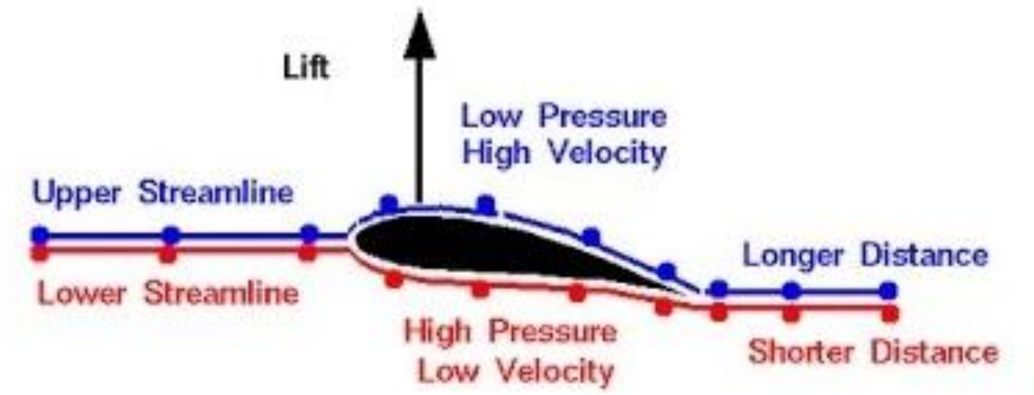

Figure 6: How lift is produced

- Weight: action of the gravity.

The moments acting on the plane are the following:

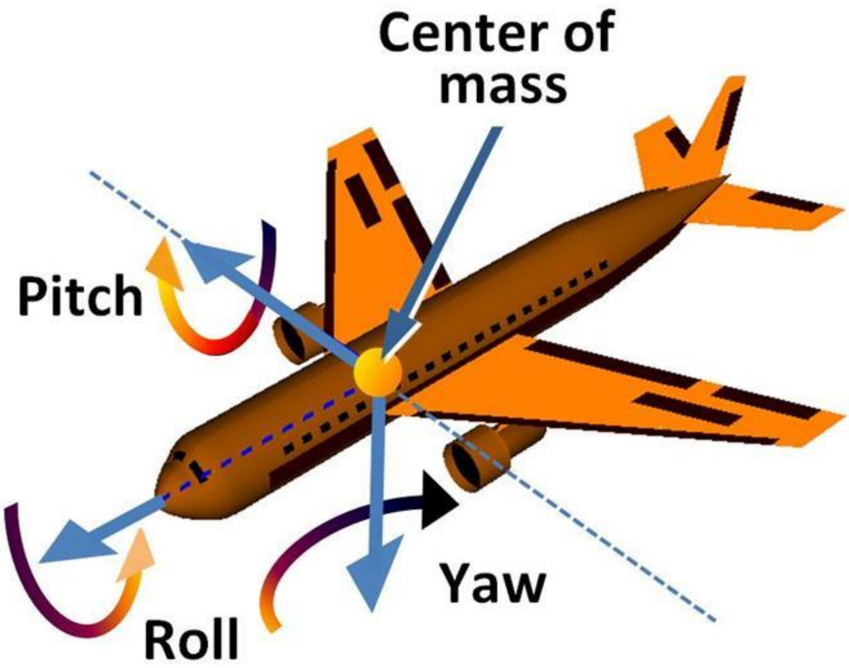

Figure 7: Moments acting on an airplane

Once we knew the basics, we could start working in the actual plane.

7.1. MAIN WING AND HORIZONTAL STABILIZER

To begin the concept design of the airplane, it is needed to look at its main components and design them for the best aerodynamic results. It is important to consider the necessary requirements and what can be compromised for enhancing other features of the airplane.

To make that initial design our group used the open source software XFLR5, available for download on http://www.xflr5.com/xflr5.htm. Our first challenge was to learn how it works and how to use it.

7.1.1. MAIN WING

We were given the design of the wing. Based on that model, our group changed some measures when designing the wing on XFLR5.

The most important measures of the main wing we had are:

- Airfoil – Clark Y
- Root chord – 400mm.
- Tip chord – 260mm.
- Center offset to fit the wing center box – 140mm.
- Total Span (wing and center box) – 1,53m.

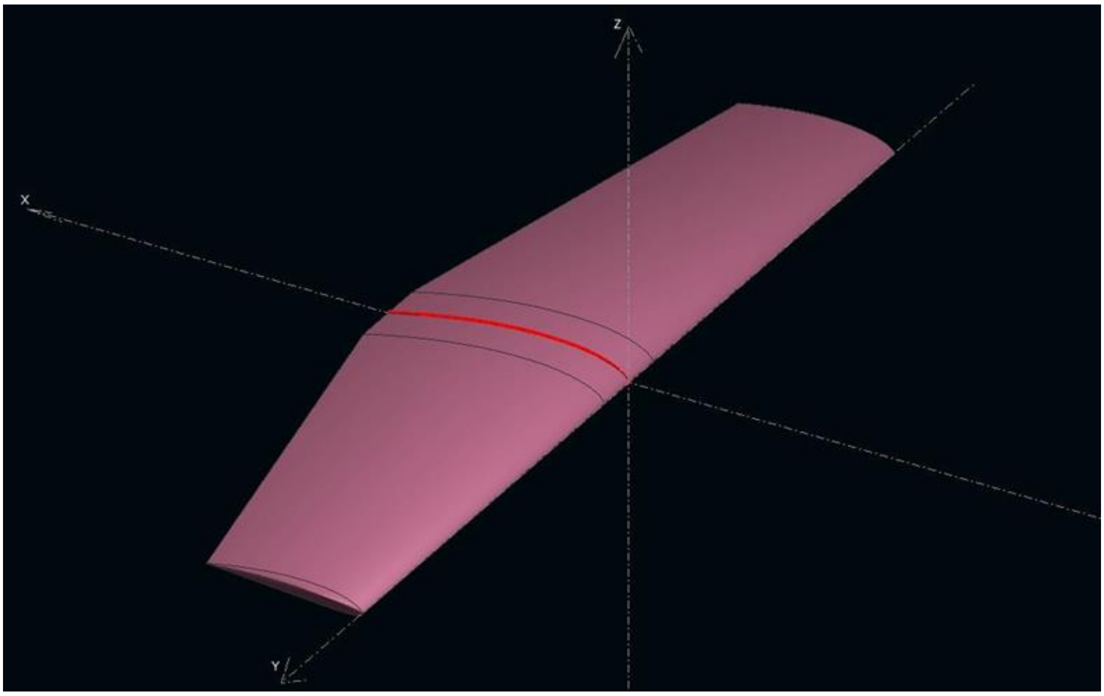

Figure 8: Wing representation in XFLR5.

A twist angle was added by our group to that design, to ensure that a potential stall first appears on the center of the wings. This angle is the difference in the angle of attack of the root and tip chord and ensures that at stall speed the wing root stalls before the wing tips, providing the aircraft with continued aileron control and some resistance to spinning. The picture below shows the effect.

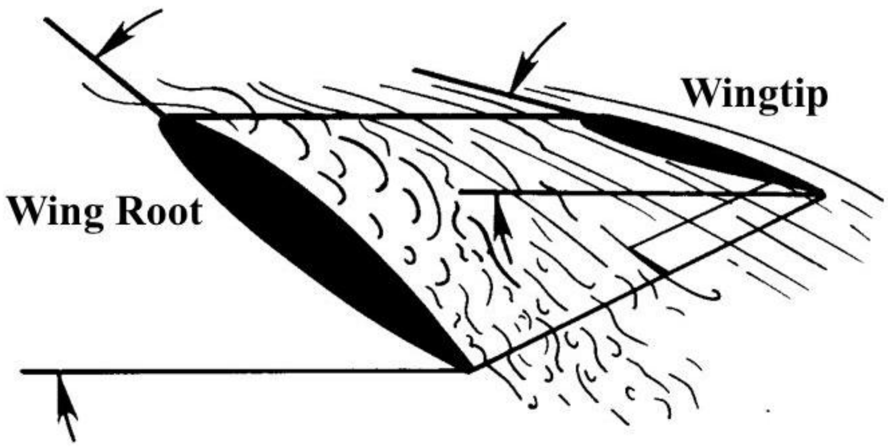

Figure 9: Explanation of the function of the twist angle.

Since the twist angle was added, some tips were also designed to aerodynamically optimize the prototype.

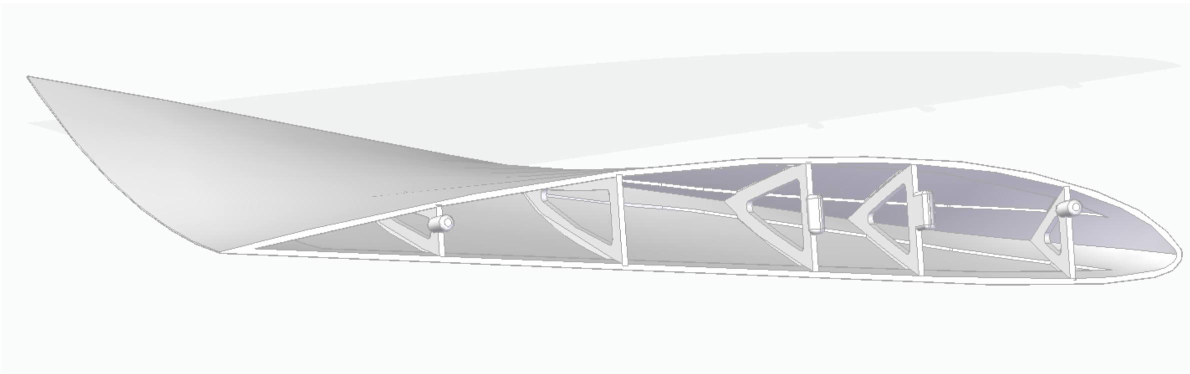

Figure 10: Design of the wing tip.

The wings manufacturing would be made by other members of the team, so I won't focus on that, but only for a complete overview of the plane, it is important to mention that they are wooden made ribs equally spaced, filled with foam and with a wood sheeting.

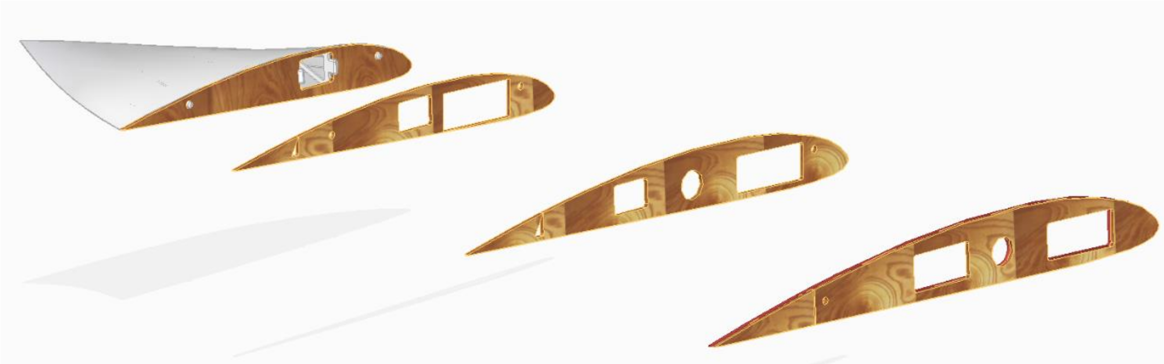

Figure 11: Structure of the wings.

7.1.2. HORIZONTAL STABILIZER

7.1.2.1. CONCEPT DESIGN

The whole process of designing the horizontal stabilizer consists of iterations on the XFLR5 program. That means analyzing the air flow design, interpreting the graphics and understanding which parameters need modification and which do not. By repeated iterations for deferent designs, an enhanced model can be achieved.

The parameters we were trying to achieve with our design of the horizontal stabilizer are the following:

- An angle of attack (α) that matches the best lift to drag ratio (CL/CD).
- Stability margin (∂Cm/ ∂α) at around 8%.
- Airspeed at around 17m/s.
- Area of the horizontal stabilizer to be around 10% of the wing area (told by the leaders of the team).

The first goal of the team, based on its experience, is to come up with an initial design that presents the best lift to drag ratio at an airspeed between 16 and 18m/s with a stability margin of around 8%, keeping in mind that the that the estimated takeoff mass would be around 4kg. Changing parameters and iterating several different designs with the goal of shortening the distance between the main wing and the horizontal stabilizer, the team achieved the desired results on XFLR5.

The picture below shows the coefficient of pressure distributed through the whole plane. As it can be seen, the wings produce an important amount of lift in its surface, and the stabilizer produces approximately null force. Important detail because otherwise, certain drag would come up that would deteriorate airframe's performance.

It also shows the simulated streamlines (purple lines) as well as the velocity in the surface (blue lines) at the designed airspeed.

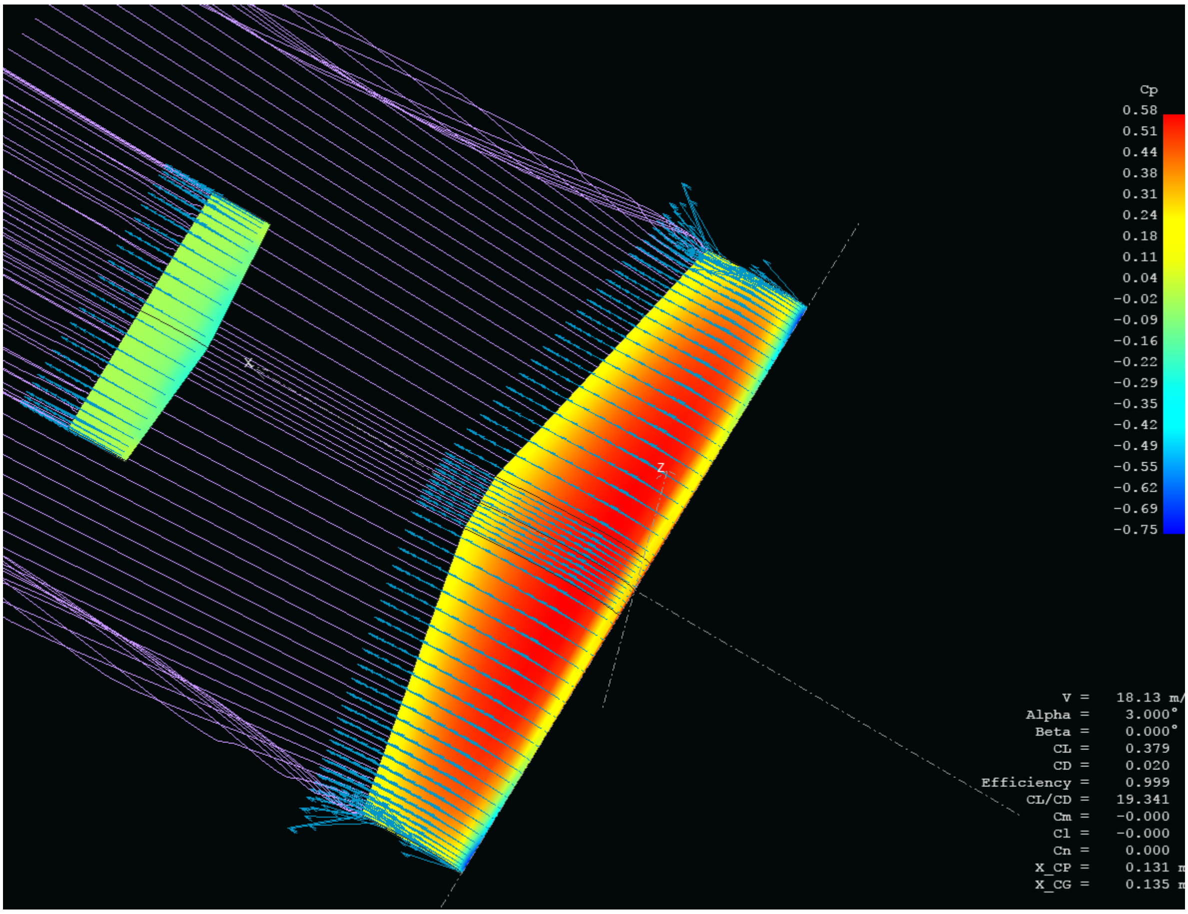

Figure 12: Representation of the Air Stream and Cp in XFLR5

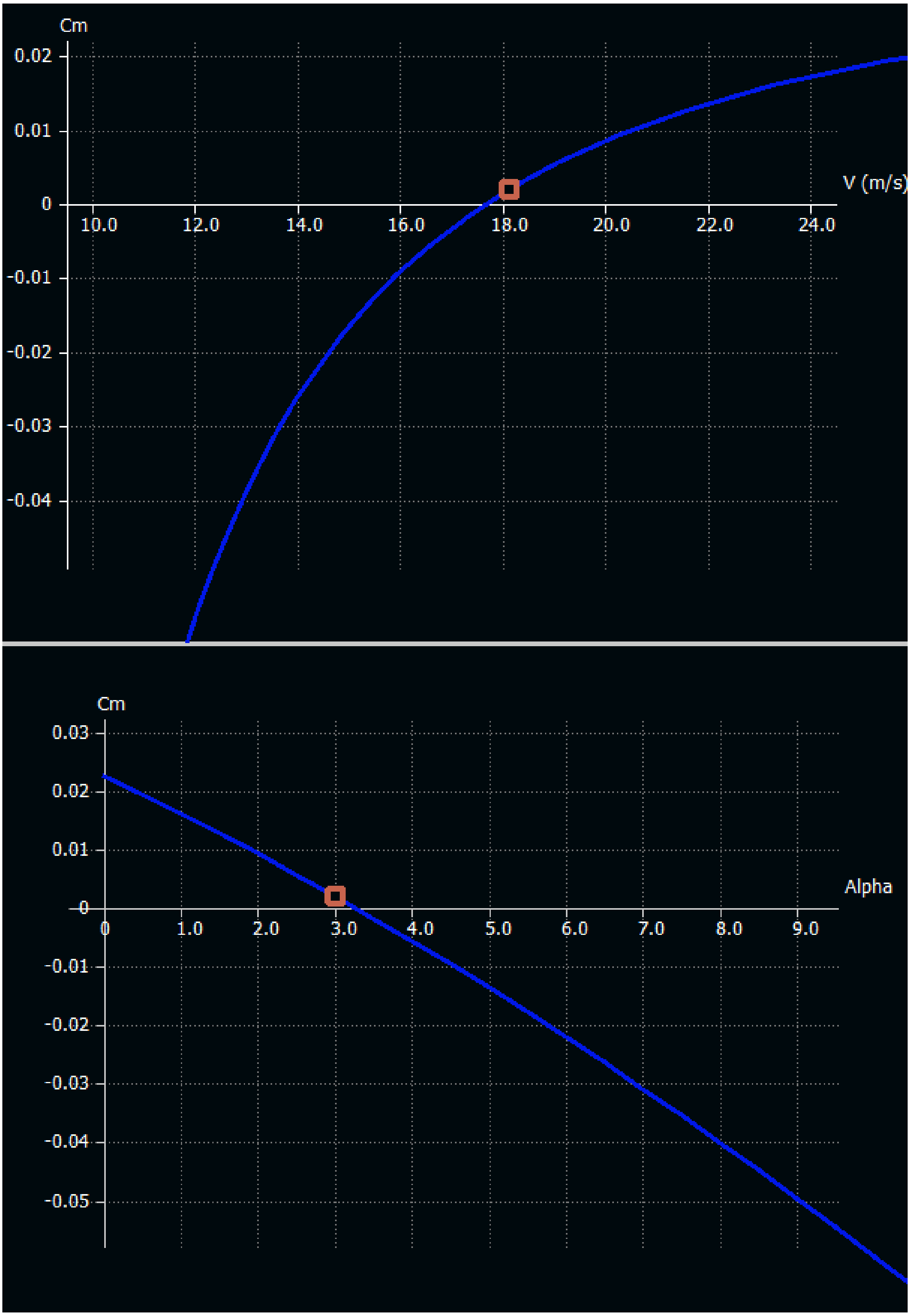

Figure 13: XFLR5 Analysis

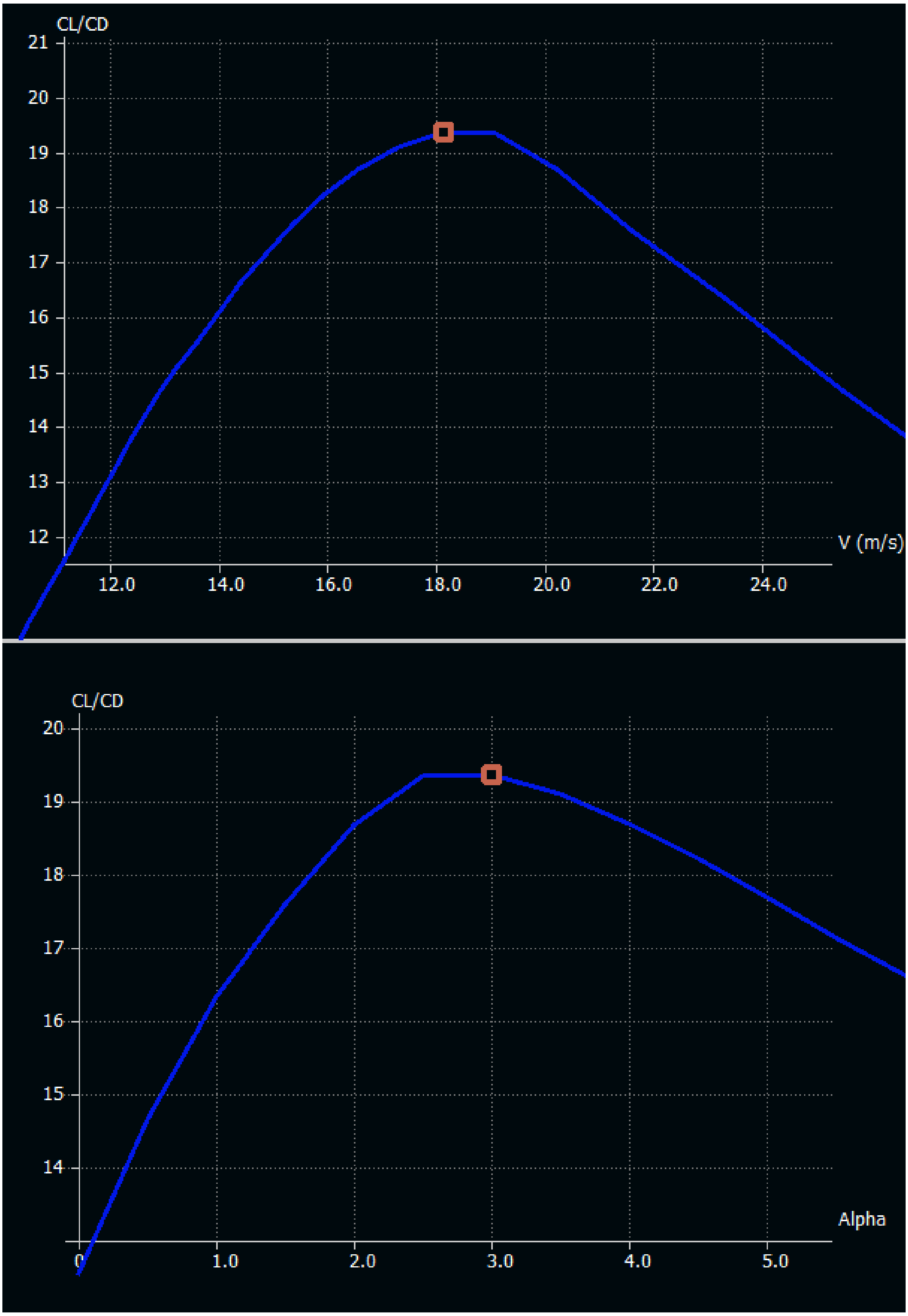

Figure 13: XFLR5 Analysis

For this aircraft, the best lift to drag ratio was found at an angle of attack (α) of 3° and a design airspeed of 18 m/s. At this point, it is possible to see on Figure 13 that the Cm (moment coefficient about the pitching axis) is very close to zero. This proves that the equilibrium point for the pitching force is indeed the aircrafts operating point. The negative slope on the Cm-alpha graphic shows that the plane is not only in equilibrium, but also stable. It means that if the plane suffers any disturbance trying to pitch its nose up, for example, it will naturally produce a moment that fights this and returns the plane to its 3° angle of attack, the ideal point for velocity and lift to drag ratio.

An important physical measurement of the aircrafts stability behavior is how hard the plane will fight against such disturbances. That can be discovered by analyzing the Cm-α slope. This indication is called Stability Margin and can also be calculated analytically with the following formula (values taken from Figure 14).

$$SM = -\frac{\partial C_m}{\partial \alpha} = \frac{X_{neutral\ point} - X_{center\ of\ gravity}}{Mean\ Aerodynamic\ Chord_{wing}} = \frac{0{,}165 - 0{,}135}{0{,}342} = 8{,}77\%$$

The airplane should not be designed for the highest stability margin possible, as a too stable plane won't respond with agility for the commands given. So basically, the pilot or auto pilot would be fighting the plane to try to maneuver it. Considering the experience from the MUAS team, a good stability margin would be between 5% and 10%.

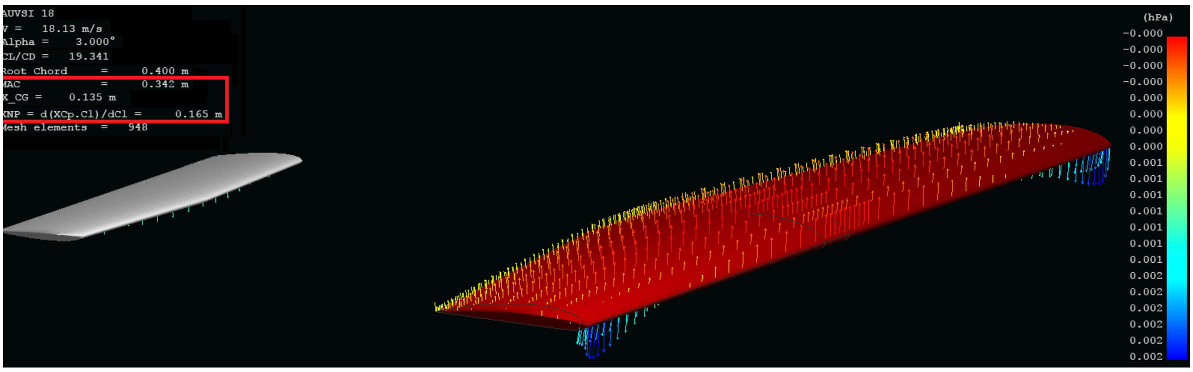

Figure 14: Distribution of pressures in XFLR5

The best point to operate is where the horizontal stabilizer produces no lift nor down force. The local force normalized by area plot on the airplane design shows on Figure 14 a tiny down force compared with the lift on the wing for the α=3° operating point. It is close enough to zero for stability and performance purposes.

From the XFLR5 program we got directly the data we were purchasing, and therefore the measures of the elevator that we were going to use.

Now that the main measures are defined, and we know that we will have a stable and maneuverable aircraft, the next step is to move forward into detail about how this part will fit into the rest of the aircraft, and also design its model on Solid Edge for the team to have an assembly file of the whole airplane.

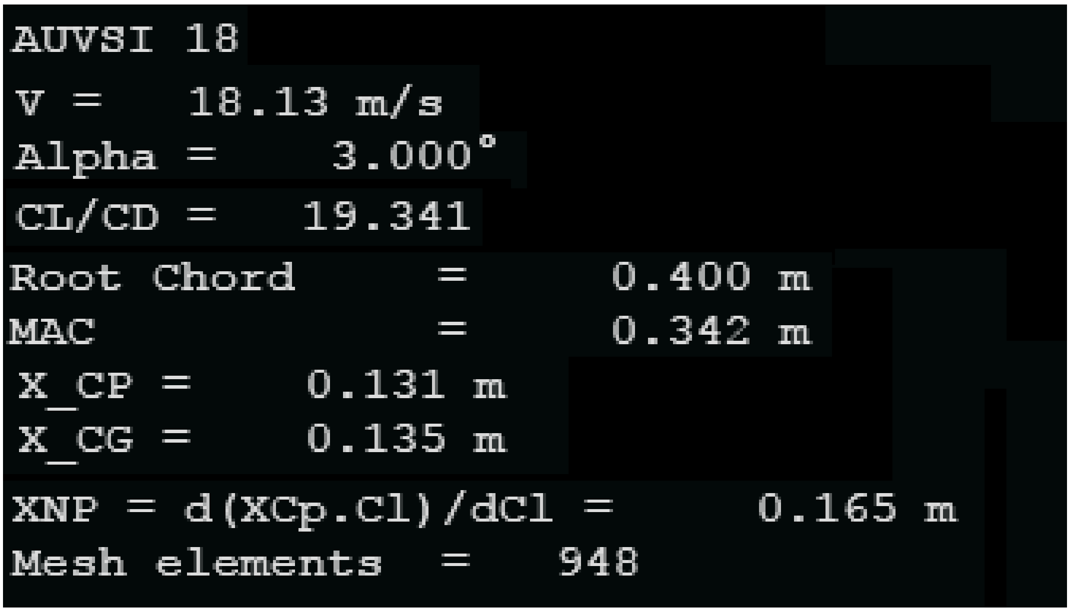

Figure 15: Final data from XFLR5

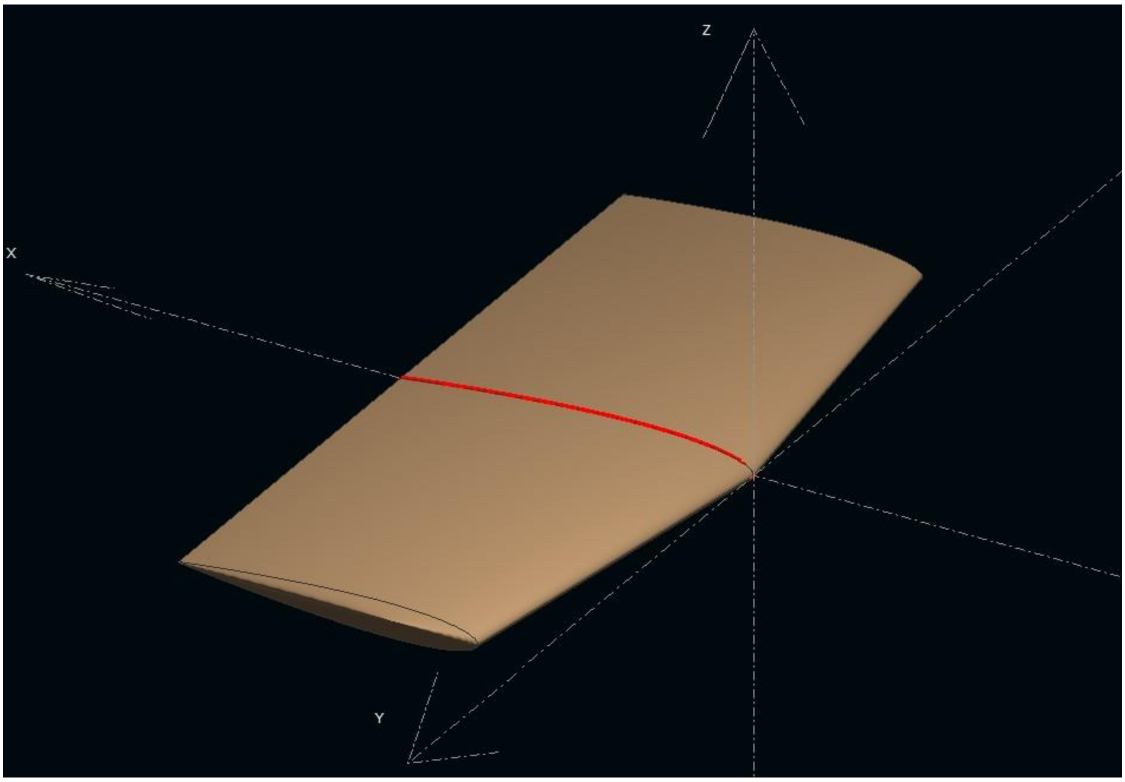

Figure 16: Representation of the horizontal stabilizer in XFLR5

Before going into the details of the design, it is important to focus a little bit on the overall of the plane, to properly understand its components as part of a whole. The general technical data table follows:

Overall dimensions		**Propulsion System**		**Performance**	
Length	1,76 m	Maximum Power	362 W	Stall Speed	10 m/s
Width	1,65 m	Propeller	12″ x 6″	Operation Speed	18 m/s
Height	0,43 m	Battery	14,8 V	Endurance	30 min
Weight	4,5 kg		2x3,5 Ah	Wing Loading	9 kg/m²
				Power Loading	80,4 W/kg
Wing		**Horizontal Stabilizer**		**Vertical Stabilizer**	
Span	1,65 m	Span	0,62 m	Span	0,25 m
Area	0,5 m²	Area	0,05 m²	Area	0,04 m²
Aspect ratio	5,45	Aspect ratio	7,69	Aspect ratio	1,59
Airfoil	CLARK Y	Airfoil	NACA 0012	Airfoil	NACA 0012
MAC	0,34 m	MAC	0,15 m	MAC	0,18 m

Table 2: Technical data

The first important aspect to be mentioned is the fact that the overall length of the plane is 1,76m; which is shorter than the last year one and therefore the problem of the bending in the pipe would be solved itself.

The main structural parts of the airplane (fuselage and spars) are carbon fiber made tubes for the best resistance-weight ratio. The wings are wooden ribs equally spaced, filled with foam and with wood sheeting, as already explained. The horizontal stabilizer is a foam core with a wood and plastic film coating. The vertical stabilizer, connections, center joints and tips of the wing are 3D printed. (developed follow). The payload bay structure is made of 3D printed rings covered with fiberglass reinforced plastic.

From the engines available to SAM, the Hacker A30-12XL was chosen to rotate the propellers. Two 3,5Ah batteries in 4S configuration provide power at 14,8V to this engine. The propeller was selected by analyzing different efficiency operating points of the engine with the help of the Drive Calculator software, seeking an 18 m/s velocity for the aircraft. The selected configuration is one with a 12″ span and an expected high twist of 6″ for a high-speed design. The transmission is direct, as a gearbox would reduce the operating speed or the efficiency, furthermore it would add more weight to the plane.

Below we can find a labelled diagram of the last design to understand all parts of the plane.

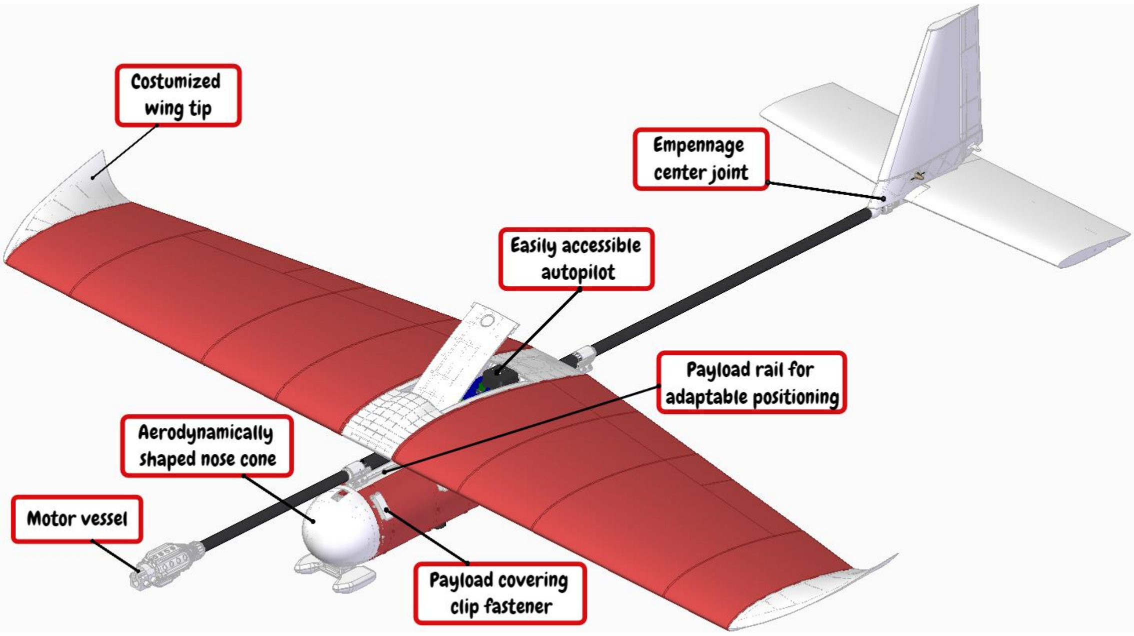

Figure 17: Labelled diagram of the aircraft

7.1.3.2. CAD MODEL AND MANUFACTURING

Taking into account mainly the weight and resistance of the horizontal stabilizer, the group decided to manufacture it as a core of foam covered by a thin layer of wood. It would have a carbon tube as the spar going through the wing span. This way, we could manufacture two symmetrical parts and connect them through it.

To make the control surface, we made a cut on around 70% of the wing chord, as rule of thumb. This control surface, which has an angle of 30º with the rest of the elevator seen from the profile, see in the following pictures, was manufactured separately and gives it freedom of movement.

Also, there will be a center joint attached to both the vertical and horizontal stabilizers, fixating them to the tail boom. This part will be explained later.

After doing these adaptations, here is how the horizontal stabilizer design looked like:

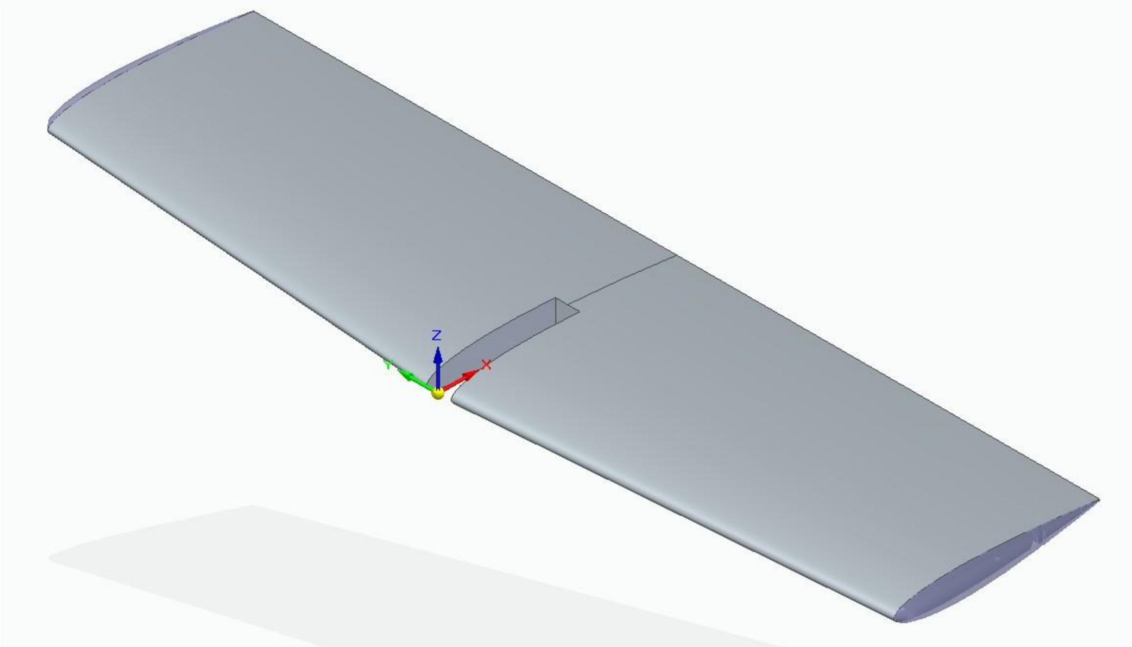

Figure 18: CAD model of the Horizontal stabilizer.

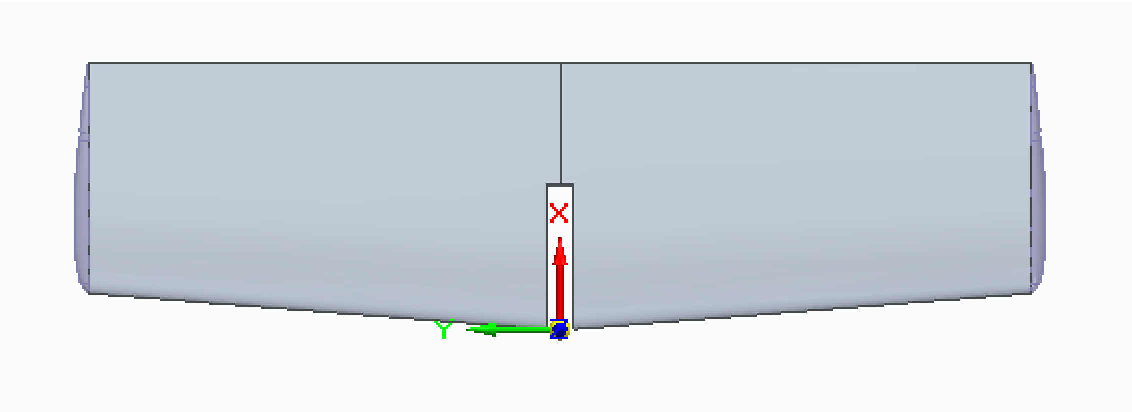

Figure 19: Top view of the CAD of the horizontal stabilizer.

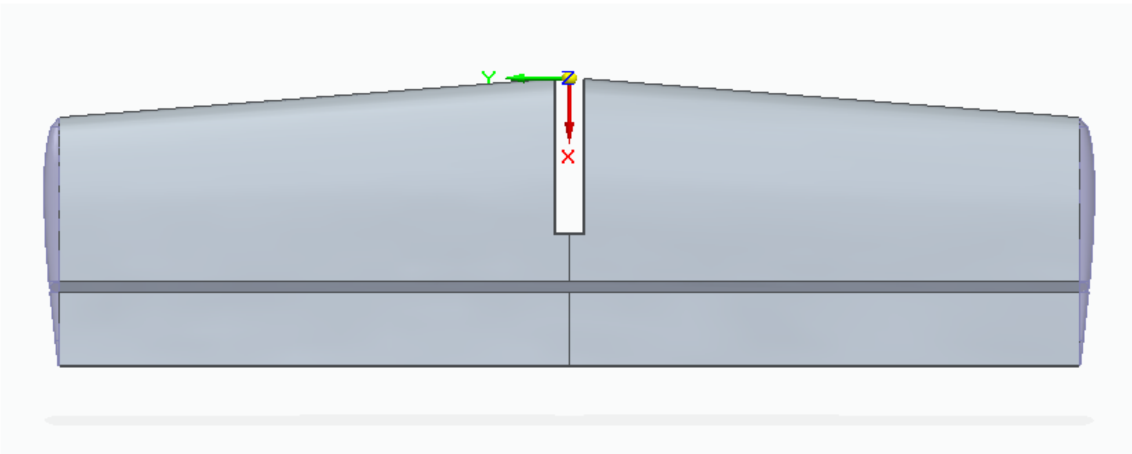

Figure 20: Bottom view of the CAD of the horizontal stabilizer.

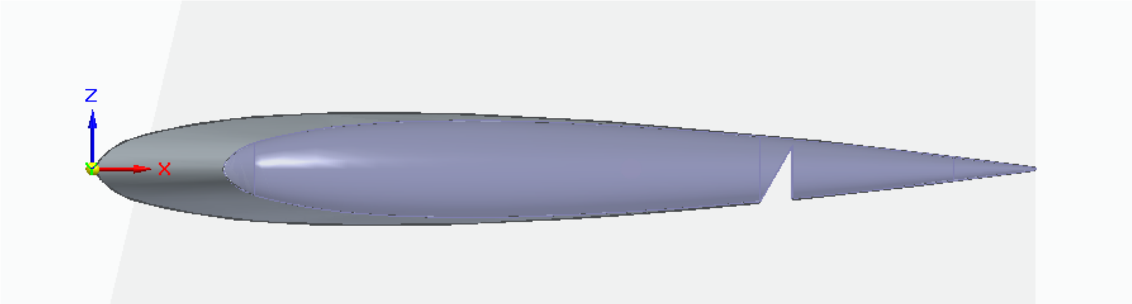

Figure 21: CAD profile of the horizontal stabilizer.

Although it was a good design, we knew that the final result of the foam parts wouldn't include the 30º at the end so that the control surface (elevator) could move. Therefore, we made another design only for that element. This design includes holes in it and so, weight is reduced to minimum. It would be made out of wood and it only one part.

In the following picture it can be seen how the first and second sketches looked like.

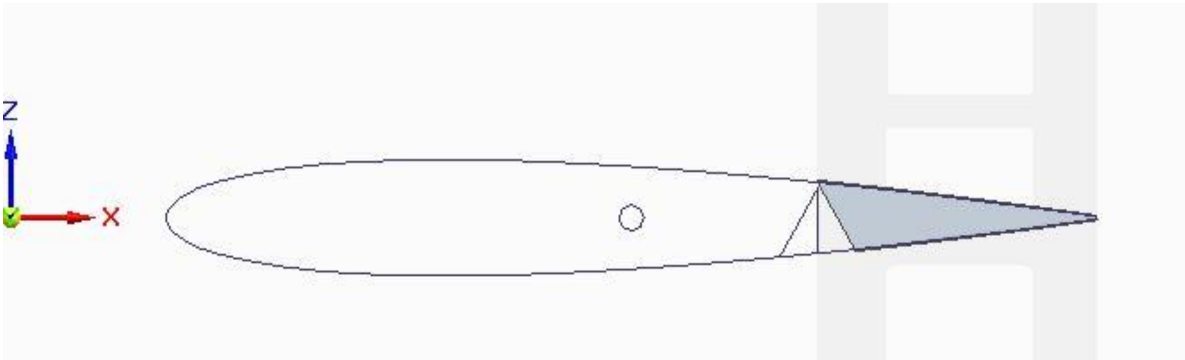

Figure 22: Sketch of the horizontal stabilizer and elevator profile.

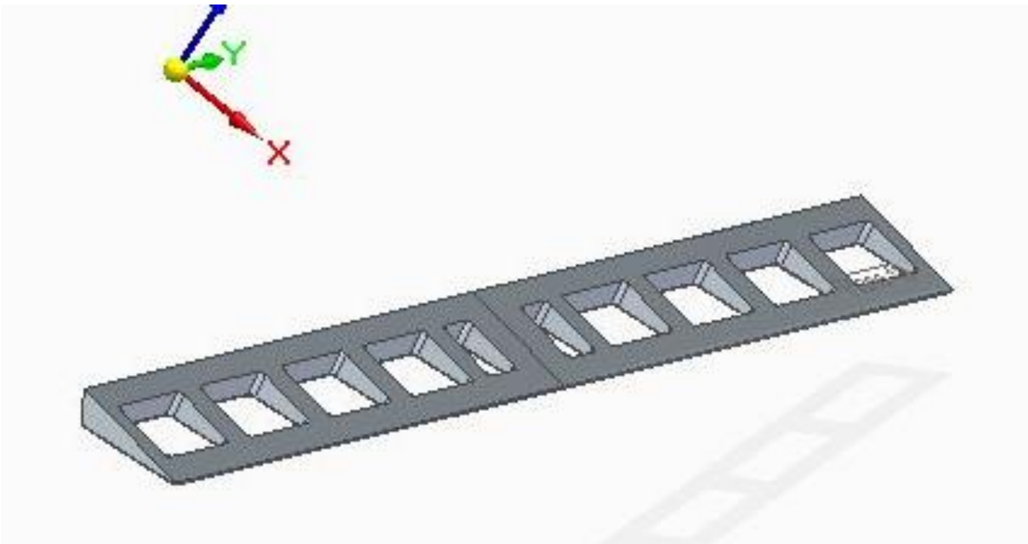

Figure 23: CAD model of the elevator.

After the design process, we started to manufacture. All the steps explained below, were done by members of the team in the lab.

First, the hot wire machine was used for manufacturing it.

As already explained, we divided the elevator in two symmetrical parts, because this way it would be easier to obtain in the machine.

The main and tip chords were milled out of 2mm wood planks. They were used as guides to make the foam hot wire cut for the core. Ten millimeters were taken off on each side for the elevator tip.

Once the foam shape was obtained, here is how it looked like:

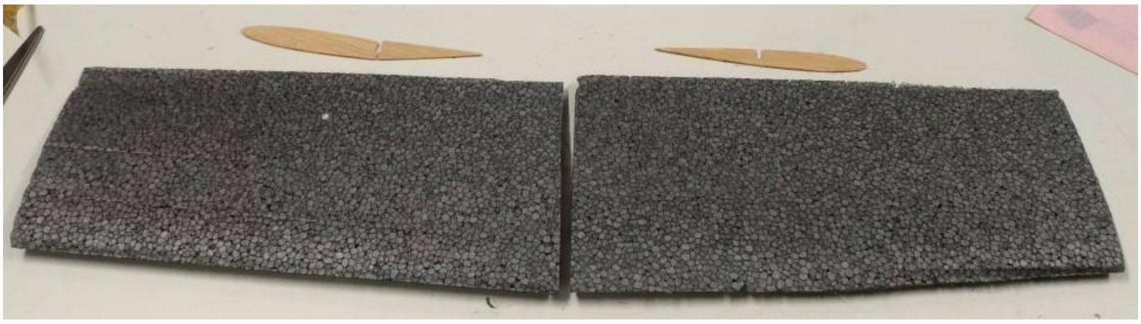

Figure 24: Foam structure of the horizontal stabilizer.

At the same time, we obtained the control surface. It was also produced in the hot wire machine and, as already said, it was made out of wood.

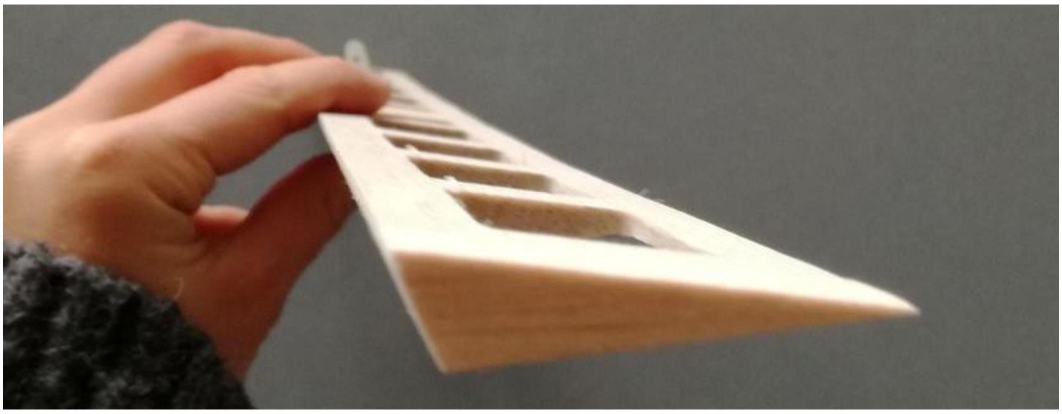

Figure 25: Elevator.

After having the foam parts, next step was to make a cut in the foam for the carbon tube and to stick the wood planks to the laterals:

Figure 26: Horizontal stabilizer with foam cut.

Then, we covered the foam with a thin layer of a Balsa wood.

This Balsa trees (ochroma lagopus) grow naturally in the humid rain forests of Central and South America. Its outstanding strength-to-weight ratio enables us to construct durable models that fly in a totally realistic manner. Balsa also absorbs shock and vibration well and can be easily cut, shaped, and glued with simple hand tools. So, it would give the stabilizer resistance as well as a smooth surface, very important to avoid turbulences.

The wood layer is estimated to be around one millimeter.

To stick the wood in the foam we used epoxy resin: we had two extracts and we mixed them in equal quantities to get the glue we needed.

We applied the resin in the foam in a very sparse way and just after that we put the wood on it, avoiding gaps in between that would trigger flight problems.

We had to be very fast in this process, as the mixed epoxy resin gets hot in approximately 5 minutes and after that it gets dry and it gets spoilt.

Once we had that, we covered the imperfections with a wood filler: *spatchel*, a product that creates wood in joins or gaps. We put some extra material to ensure that there were no holes and we waited until it was dry.

After that, we had to sand it with sand paper to obtain the smoothest surface we could.

The last step would be to coat everything out of a plastic cover that gives it impermeability.

This cover works through heat, so the way to put it over the parts was by ironing it with a special iron at 107ºC, and to take out the bubbles we used an available heater of the lab.

Below we can find the images of the whole process:

Figure 27: Epoxy extracts

Figure 28: Epoxy mix.

Figure 29: Part of the horizontal stabilizer covered out of wood

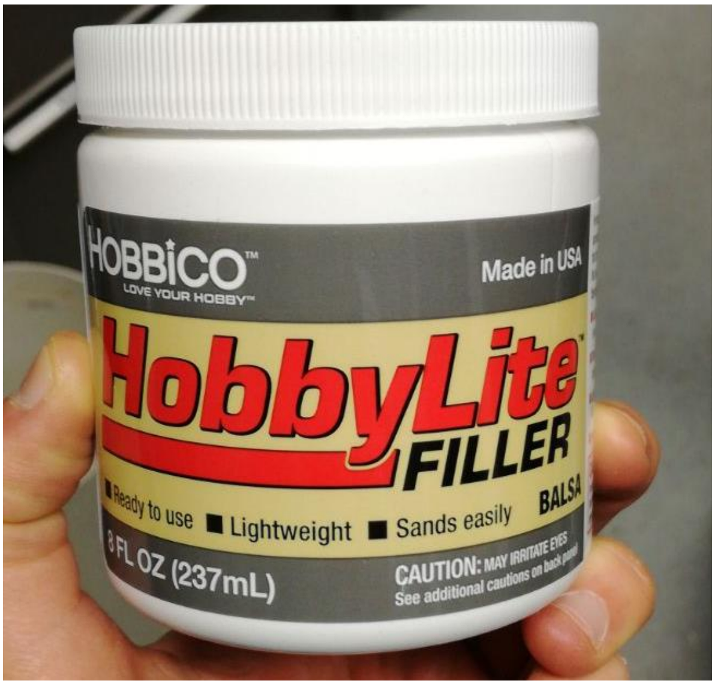

Figure 30: Wood filler.

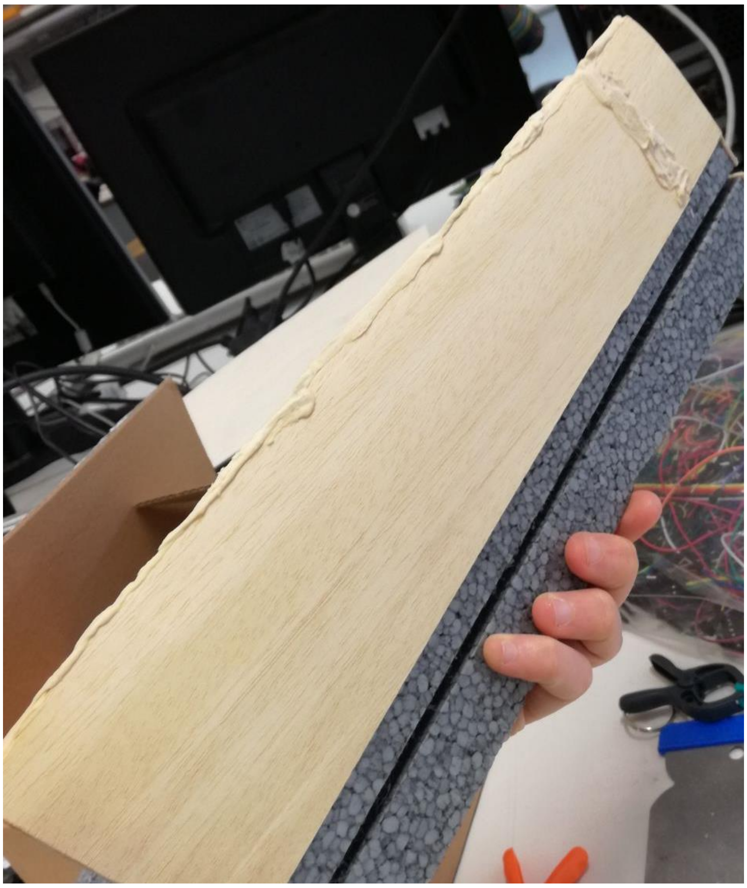

Figure 31: Wood filler on the stabilizer.

Figure 32: Heater for the plastic cover.

Figure 33: Iron for the plastic cover.

Figure 34: Process of covering with plastic.

Figure 35: Finished part of the horizontal stabilizer

Figure 36: How the finished parts of the horizontal stabilizer would fix.

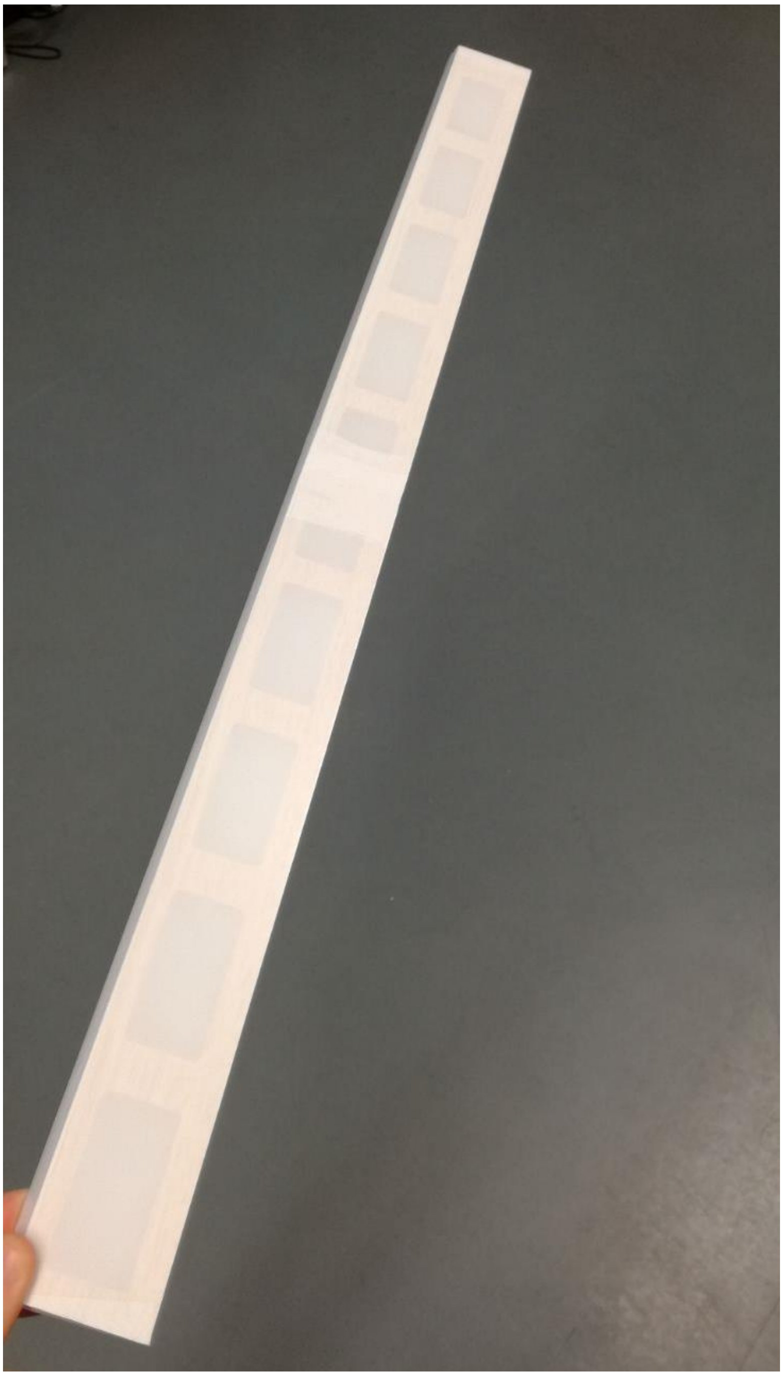

Figure 37: Elevator covered out of plastic.

7.2. VERTICAL STABILIZER

The fact that all parts of the aircraft will have to get assembled, is important to understand so that in every section I will make reference to another one.

The vertical stabilizer along with the horizontal one is part of a set called aircraft tail. But, while the elevator was designed from the XFLR5 analysis, the vertical stabilizer design was made following the restrictions we were given. As starting point, last year's tail design was considered, as shown in the figure below.

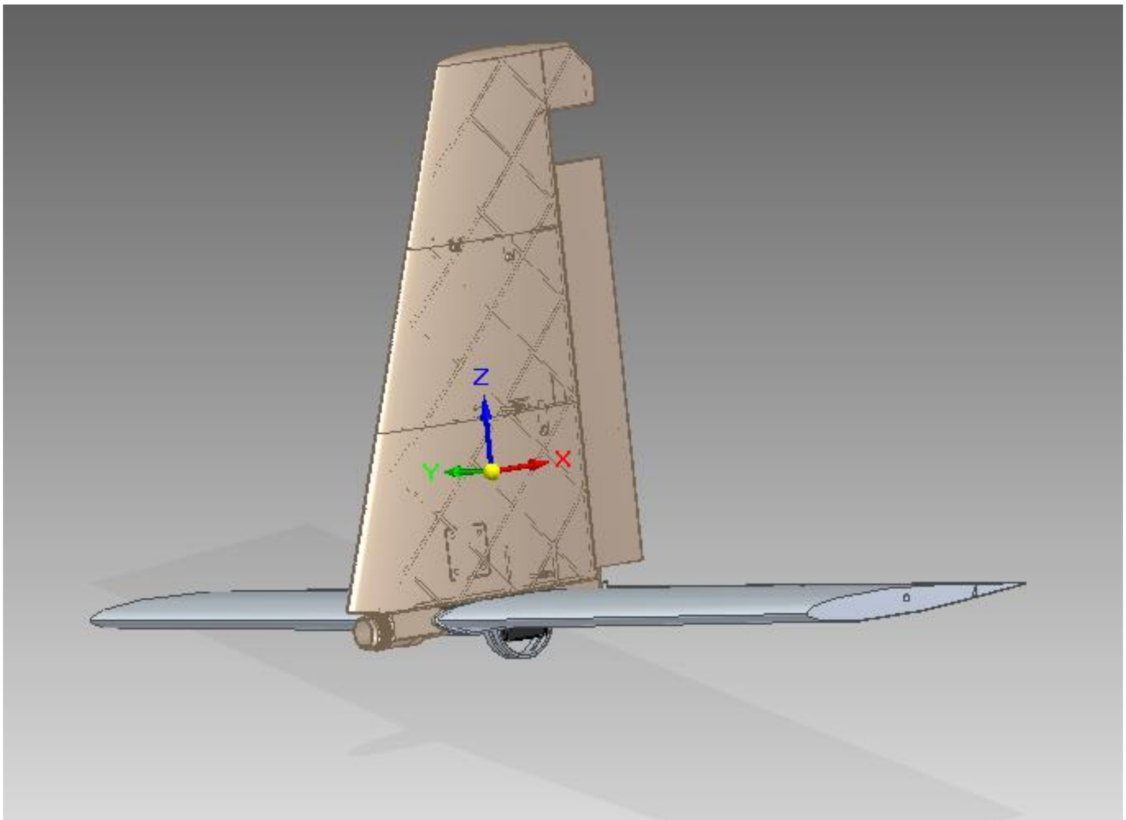

Figure 38: Tail design from last year.

As it can be observed, it was divided in two parts: vertical and horizontal. The vertical one was 3D printed and included in its design the connections to the horizontal one as well as to the carbon tube.

7.2.1. DESIGN

The considerations that were taken into account are the following:

- The priority is to minimize its weight. Last year’s design was a 3D printed vertical stabilizer. It was resistant and modular, which are great advantages, but it was too heavy. So, the main goal was to combine these two qualities to optimize the design.
- The rudder control surface shall be at around 70% of the chord, like the elevator.
- It has to fit the antenna that will receive the commands from the radio controller during controlled flight.
- It has to be firmly assembled to the rest of the plane tail.

Therefore, the best idea we thought of was to divide the stabilizer in two parts: an upper and a lower one.

The upper would have a very simple design and it would be made out of foam and covered of wood, just as the horizontal stabilizer. That way, we could ensure a lighter design without the stability loss. To manufacture it, we had to design the upper and lower chord so that it would be simple to obtain in the hot wire machine.

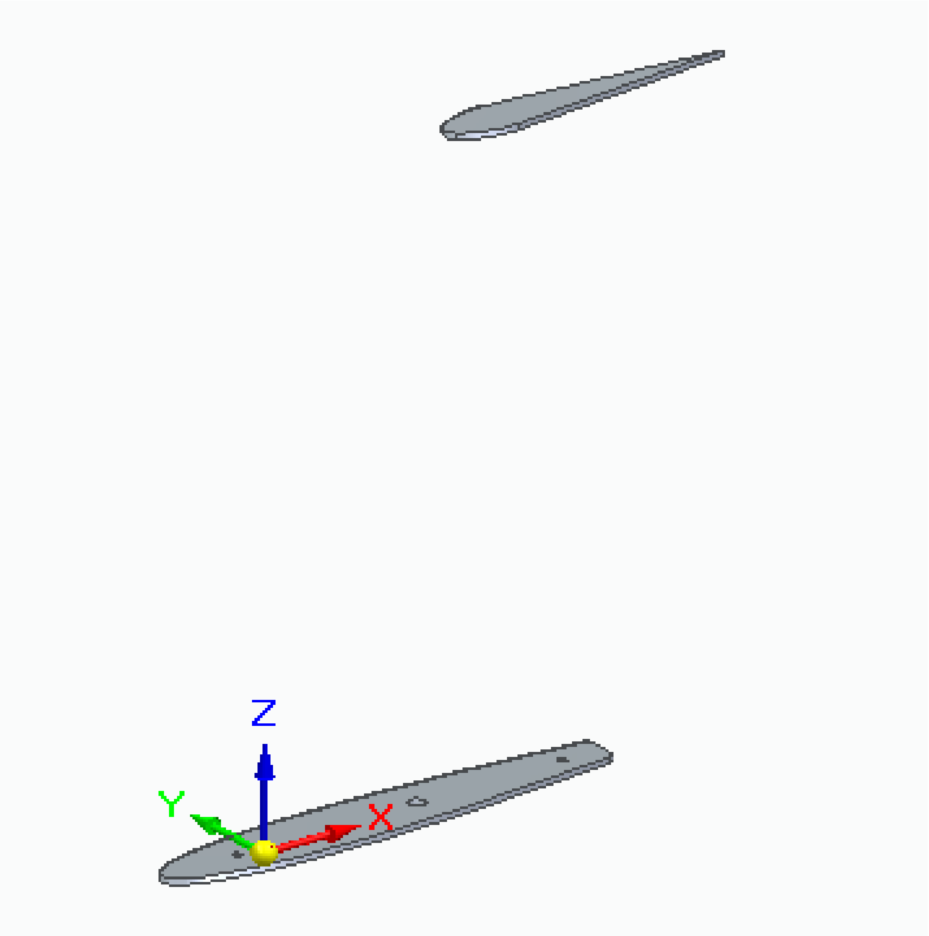

Figure 39: Chords of the vertical stabilizer

The lower part would have a more complicated design and would be 3D printed. This part is called tail center joint. Its main purpose is to firmly assemble the horizontal stabilizer and vertical stabilizer together, and also to join the whole tail to the carbon tube tail boom of the aircraft. It would also be connected to the ruder control surface, 3D also printed. The design of the control surface was made by other members of the team, but I will include some pictures so that it is easier to understand the whole body.

As already stated, the basic design requirements of the center joint are to fit into the center of the elevator, the lower part of the fin and have an entrance for the carbon tube. But has more functions: it also carries the two servos for the elevator and fin control.

Like always keeping in mind the weight requirements, we designed it to be light. But this part has also to be strong and resistant enough to hold all the parts together.

Here is the design of the tail center joint:

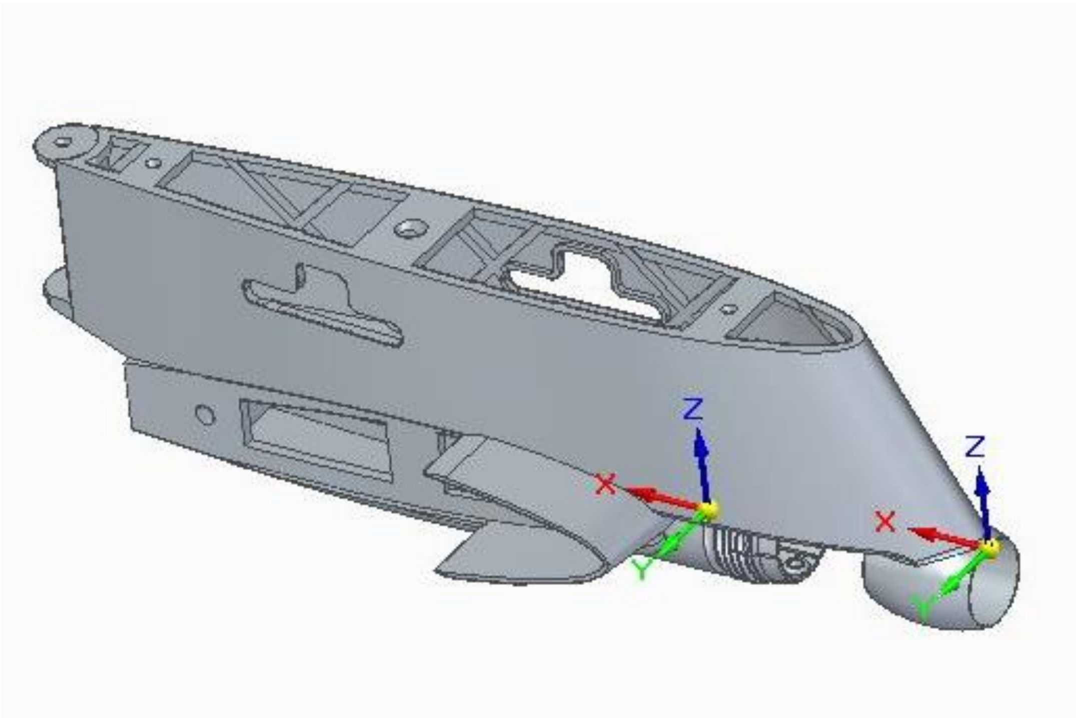

Figure 40: Tail center joint CAD design.

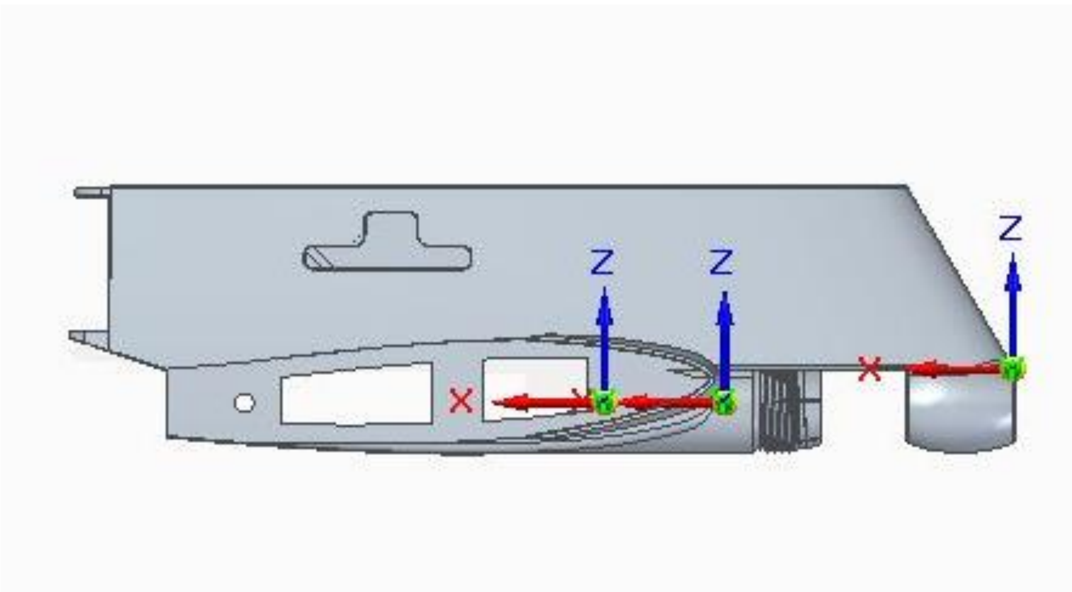

Figure 41: Profile view of the tail center joint.

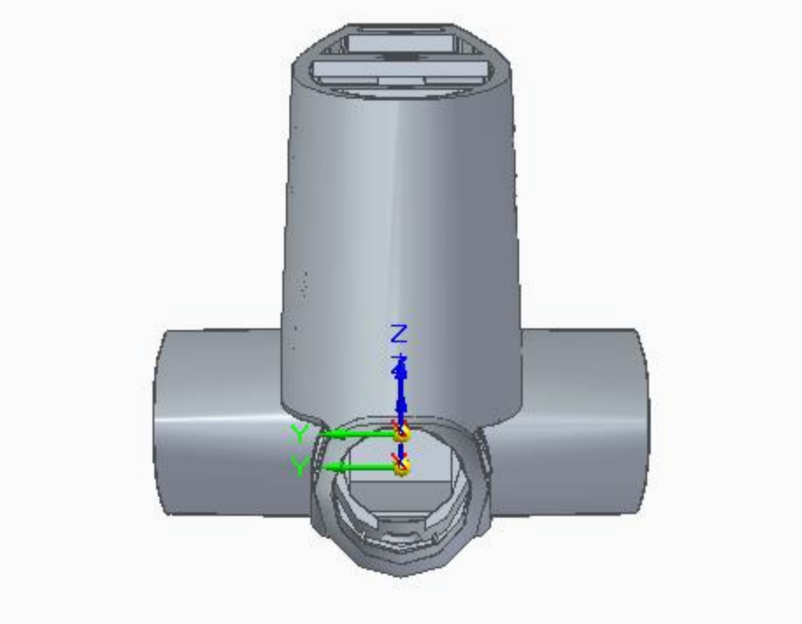

Figure 42: Front view of the tail center joint.

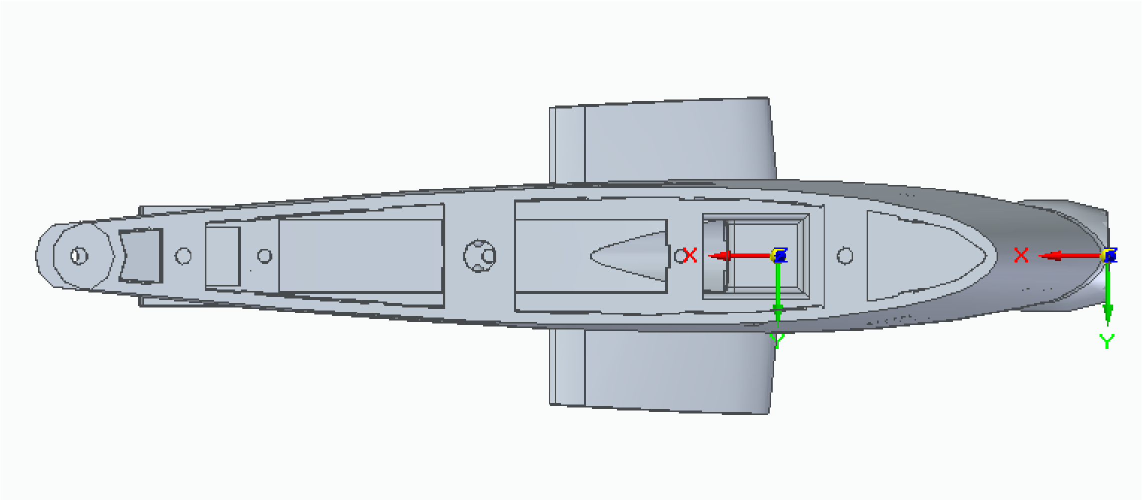

Figure 43: Top view of the tail center joint.

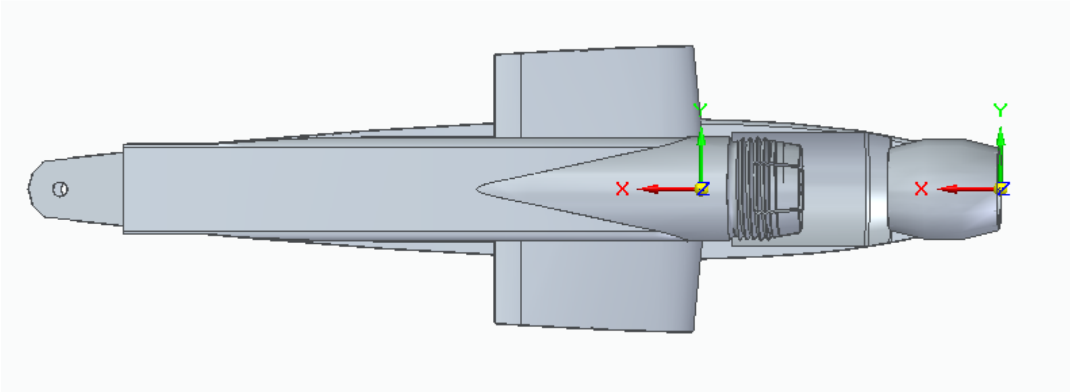

Figure 44:Bottom view of the tail center joint.

The whole assembly of the vertical stabilizer, including the tail center joint, control rudder and the chords of the upper part looks like below.

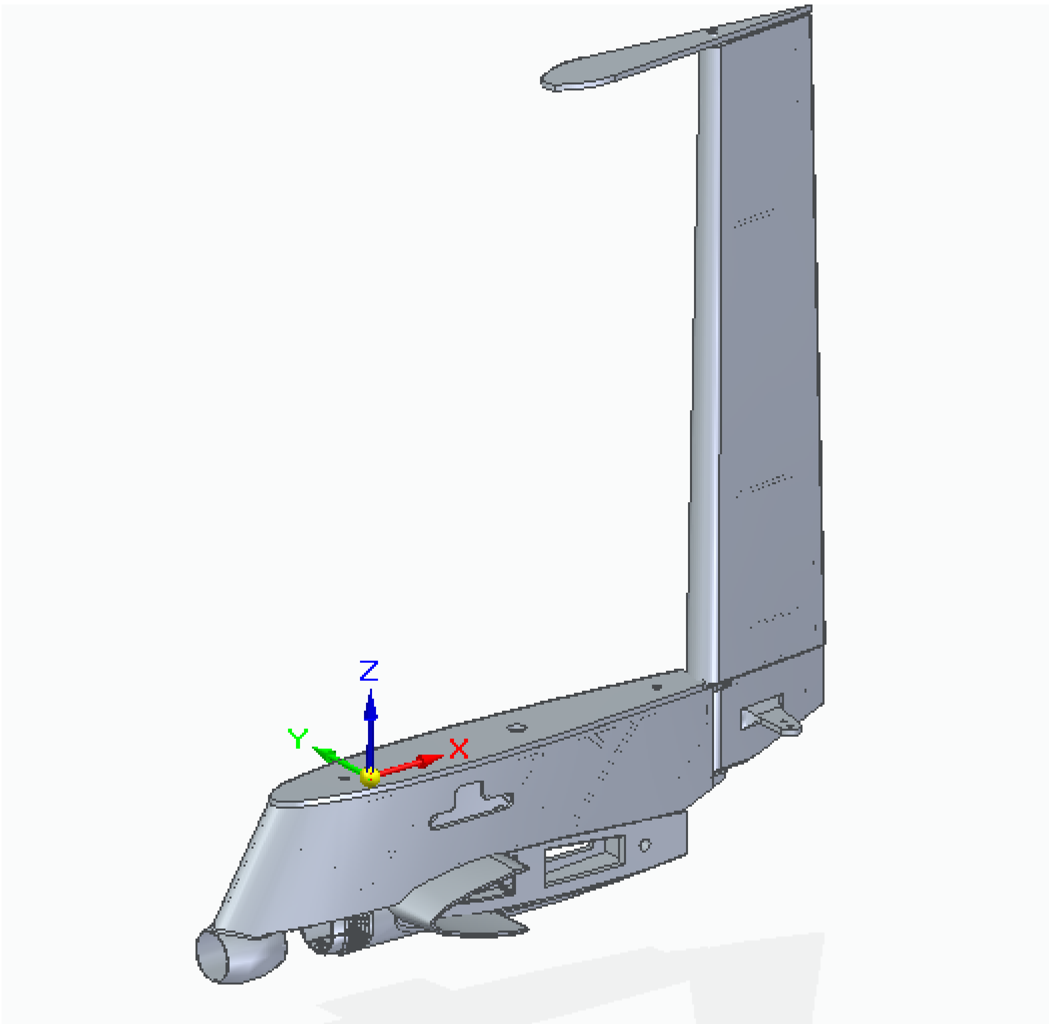

Figure 45: CAD of the tail center joint with rudder and chords.

7.2.2. MANUFACTURING

As already stated, the vertical stabilizer has two parts, the upper one made out of foam and the tail center joint, 3D printed.

The first one that was produced was the tail center joint (the lower one). We could do it in a 3D printer of MUAS University, and once we obtained it, the little carbon tube as connection and the big carbon tube as pipe, as well as the servos, were included. Here is the result we got:

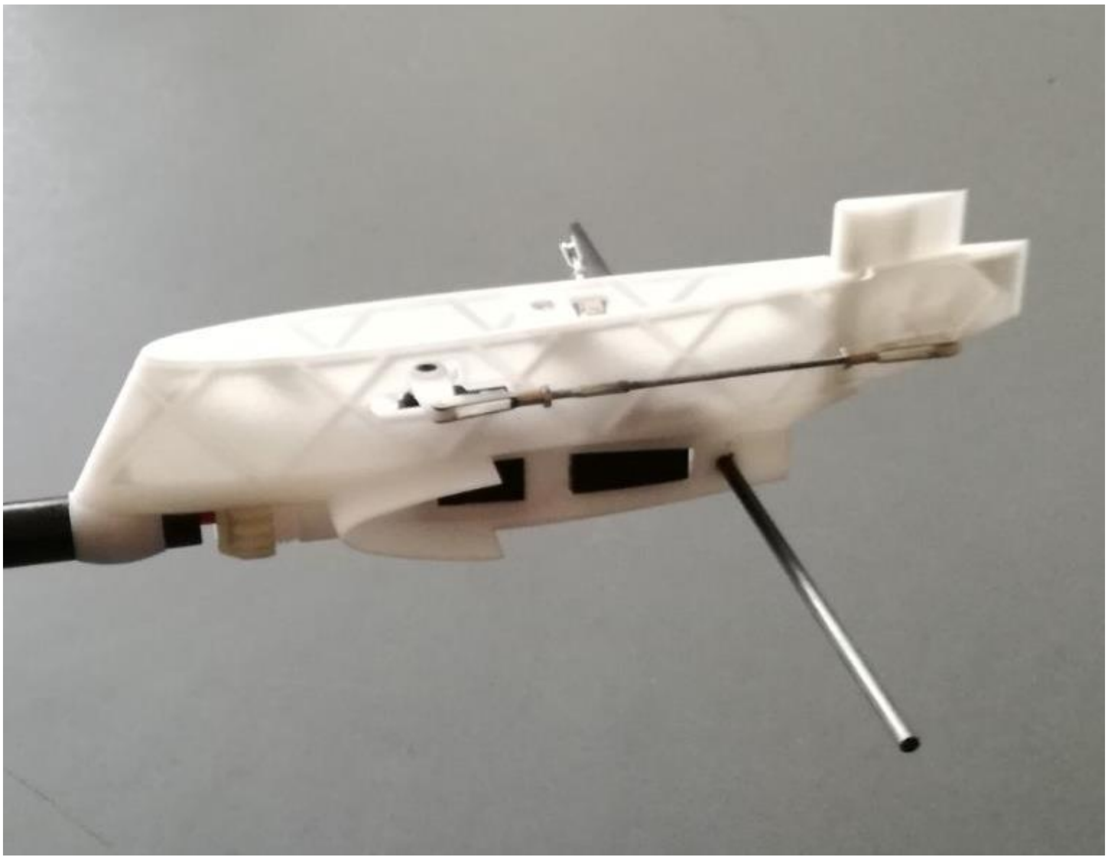

Figure 46: Manufactured tail center joint.

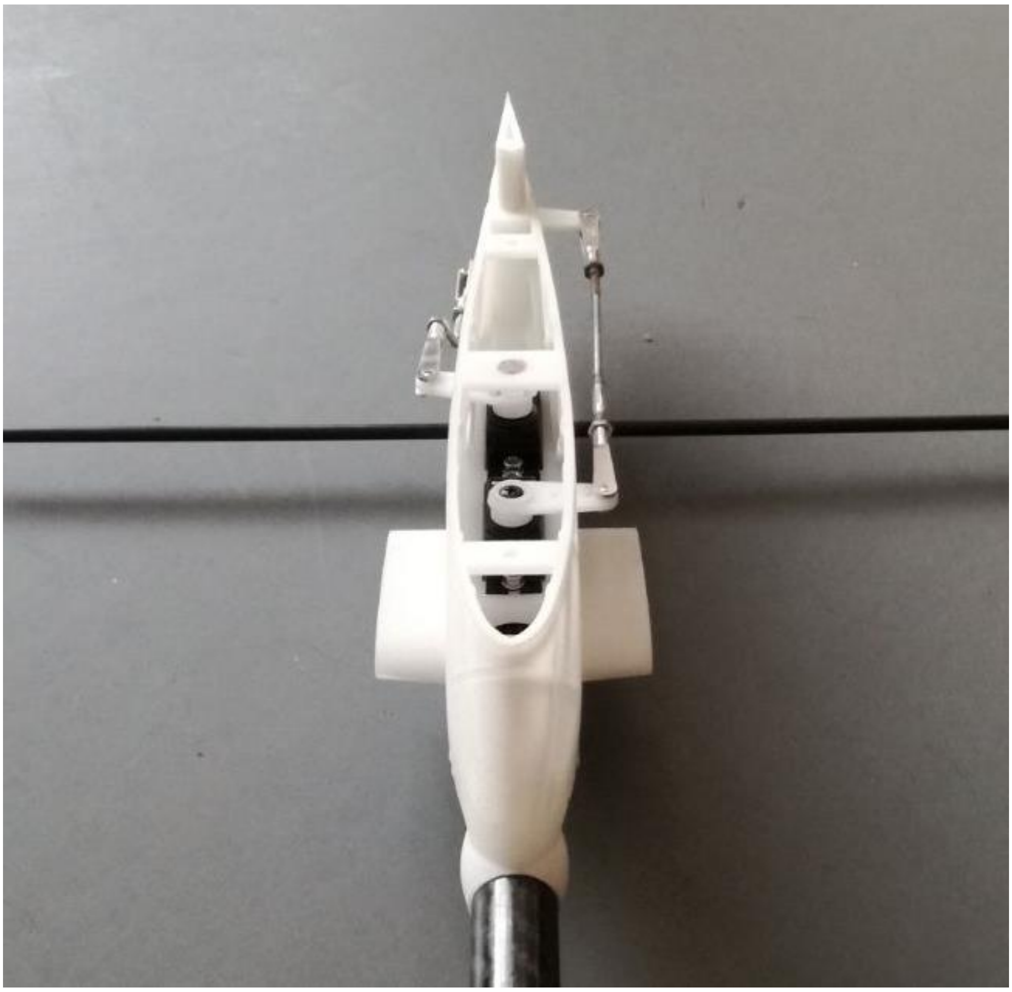

Figure 47: Front of the tail center joint.

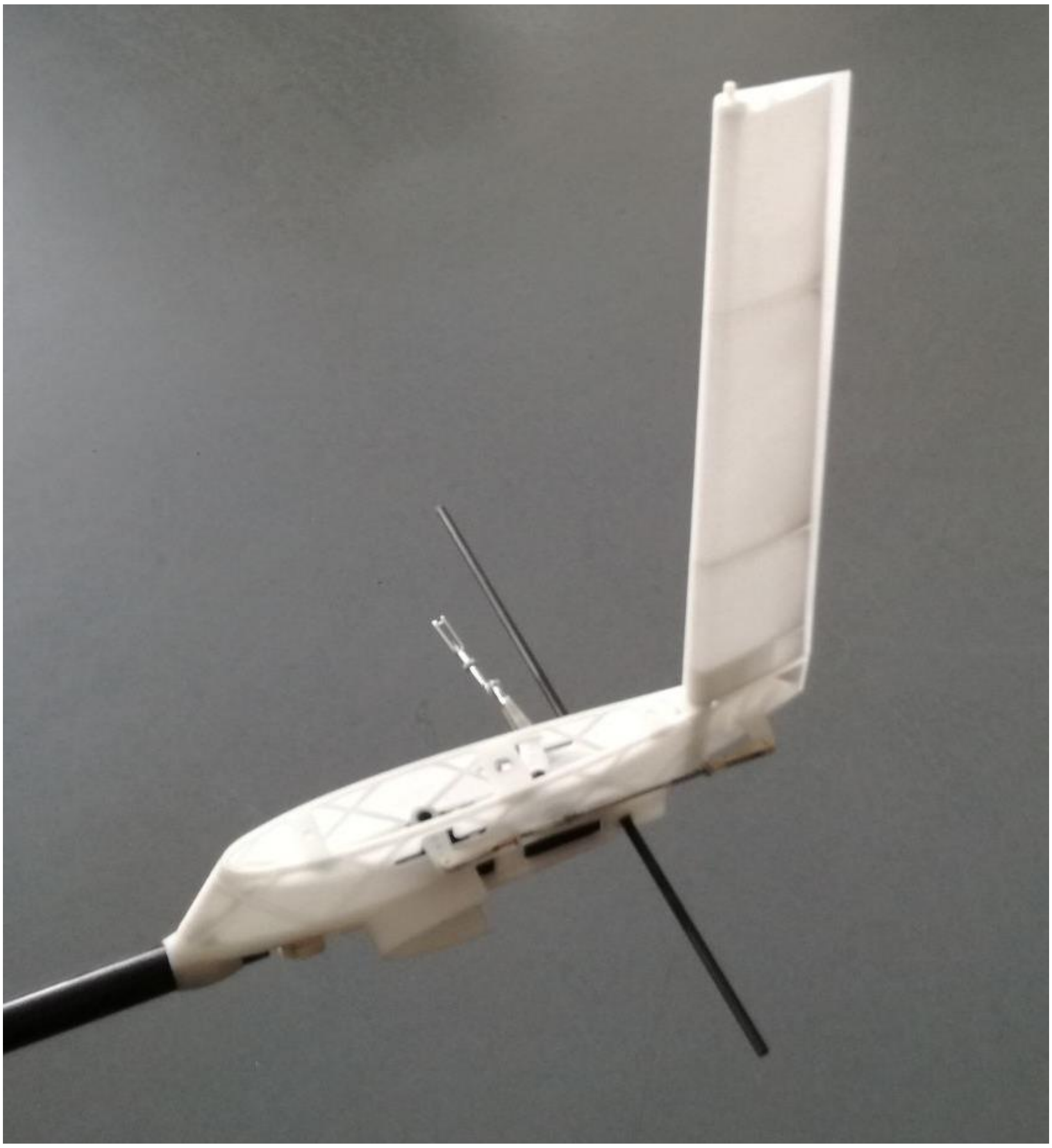

Figure 48: Tail center joint with rudder.

The manufacturing process of the upper part of the vertical stabilizer was the exact same process as the horizontal one: first, obtain the shape out of foam in the hot wire, then cover it of wood with epoxy resin, fill the gaps with spatchel and sand it. After that, apply a plastic coating.

This part includes a gap in the bottom in which the carbon tube to attach it to the joint goes through.

Figure 49: Vertical stabilizer covered out of wood.

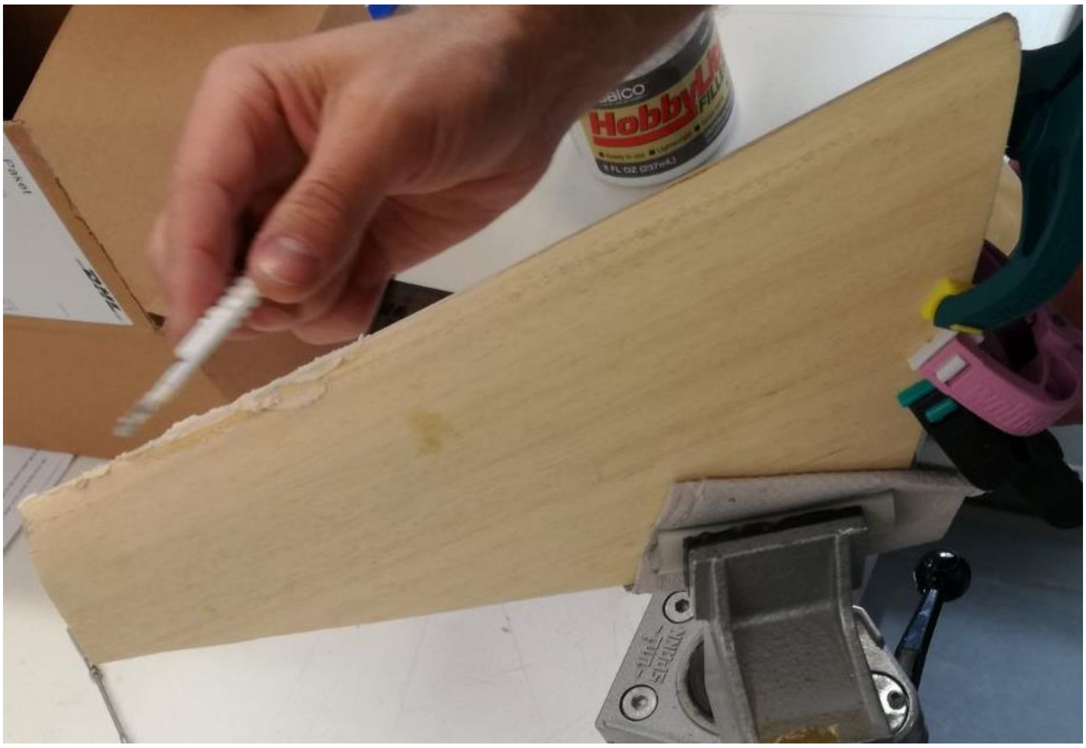

Figure 50: Process of applying wood filler on the vertical stabilizer

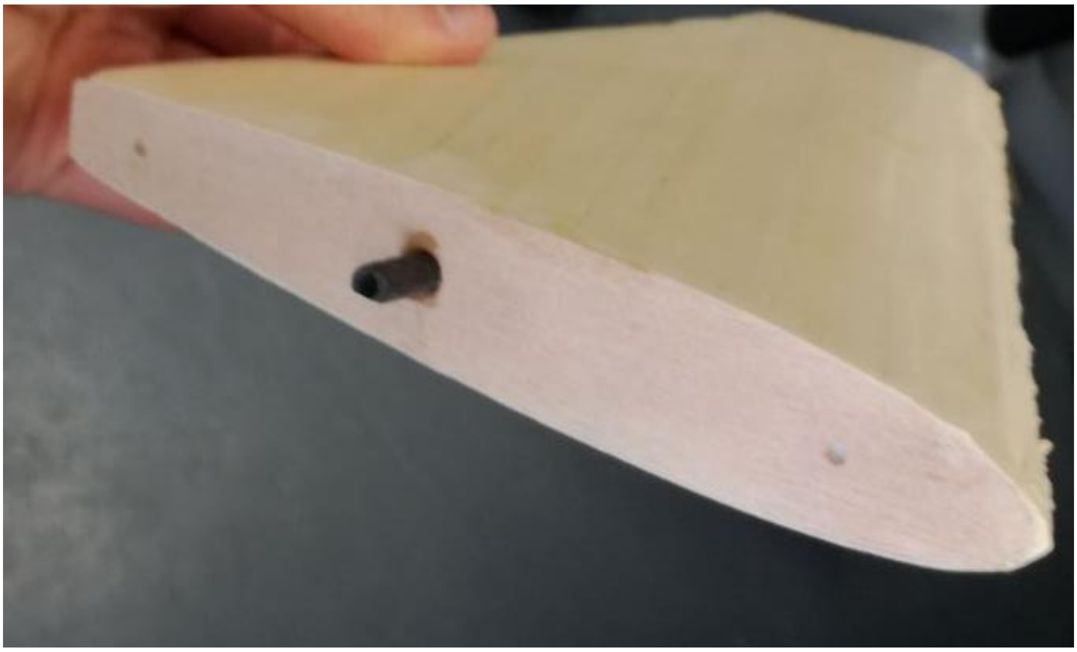

Figure 51: Bottom of the vertical stabilizer.

Figure 52: Sanded vertical stabilizer.

Figure 53: Vertical stabilizer with tail center joint.

Last step was to apply an overall plastic coating, to protect the airframe against adverse weather phaenomena.

Figure 54: Vertical stabilizer covered out of plastic.

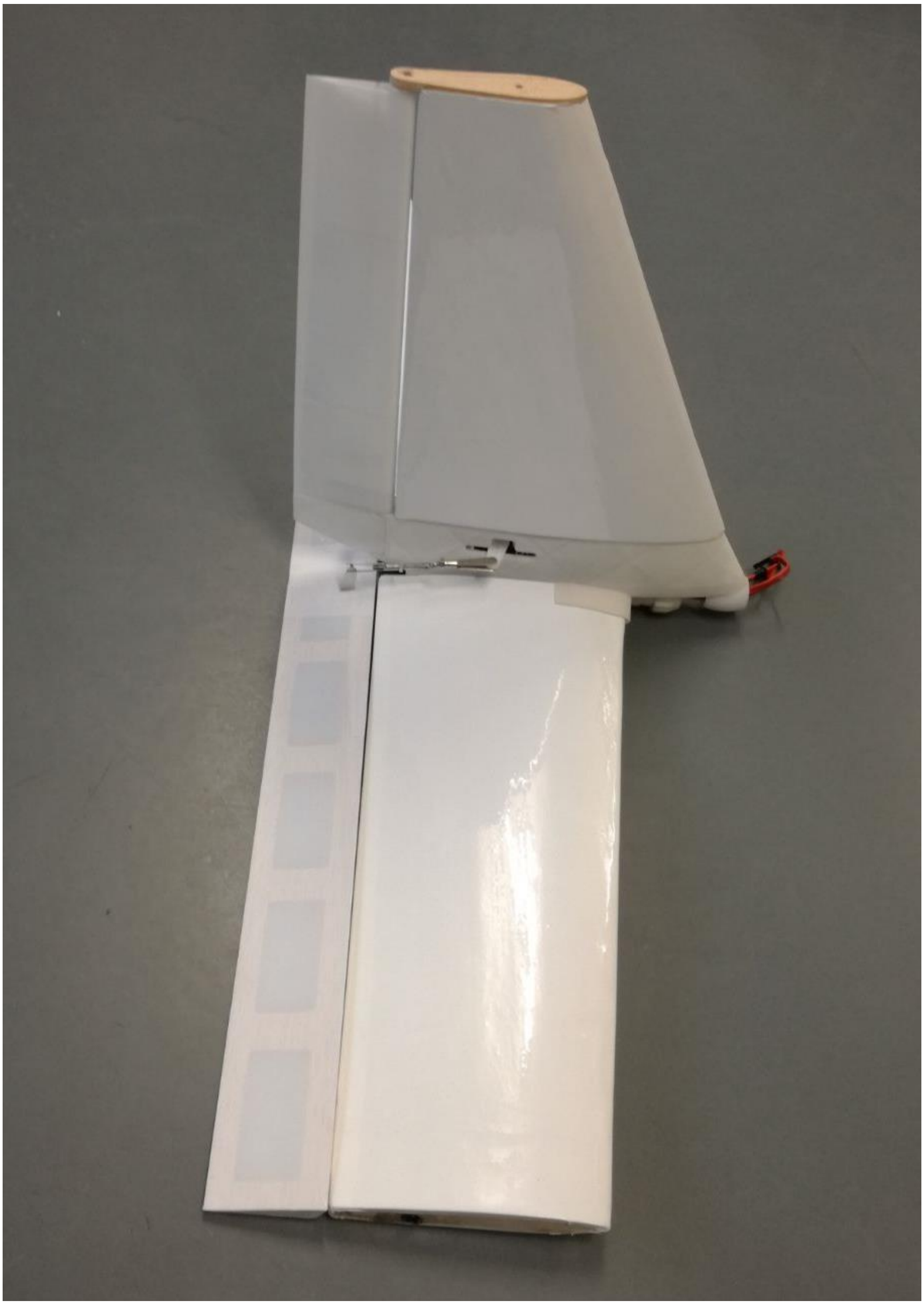

Figure 55: Profile of the whole finished tail.

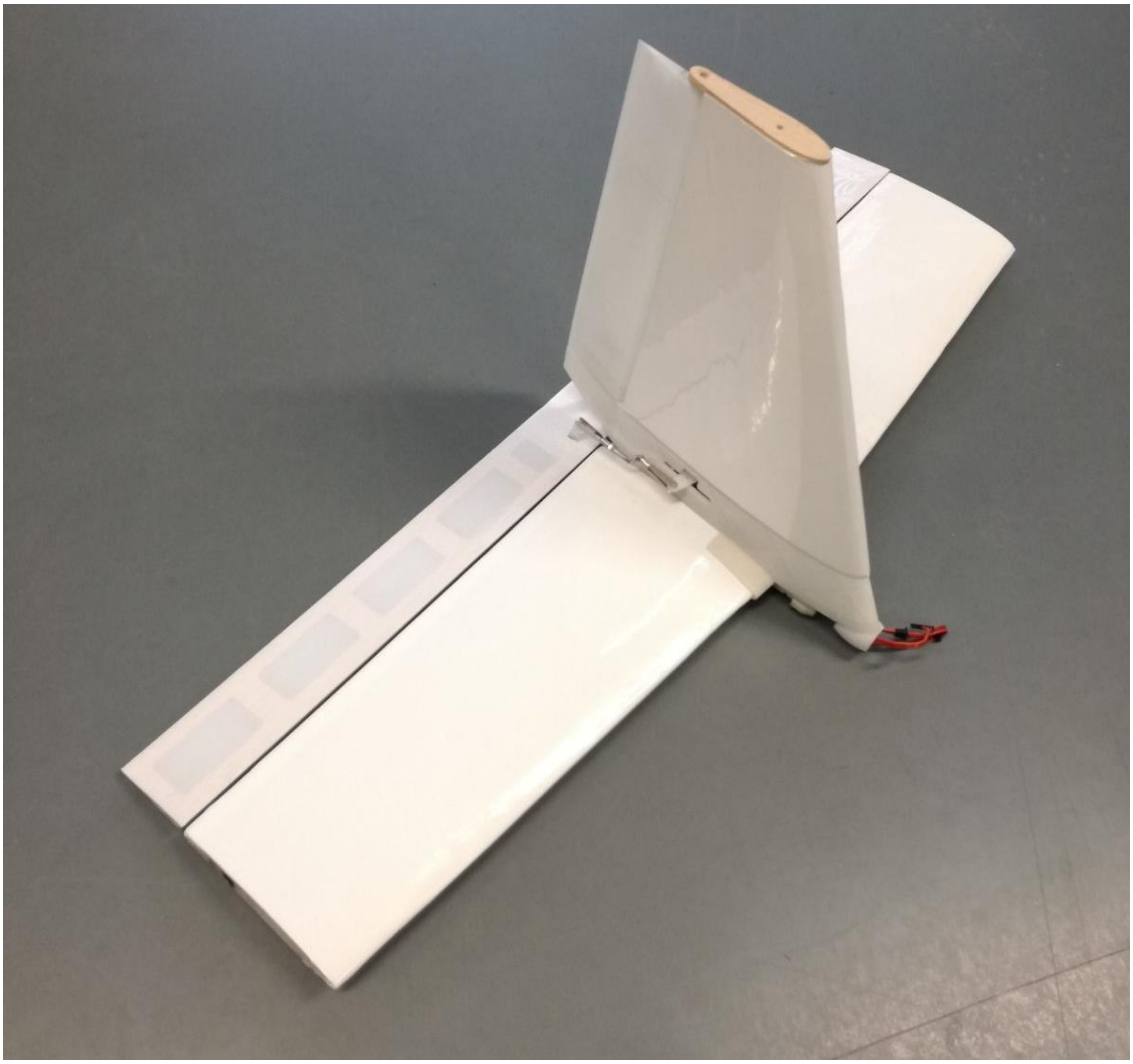

Figure 56: Whole finished tail.

7.3. WING CENTER BOX

7.3.1. DESIGN

The next task was to design the Wing Center Box. As already stated, the main purpose of the box is to connect the wings together with the fuselage, as well as to carry the electronic board.

First of all, our team made an initial design of the wing center box taking in consideration all the space constraints we were given. Nevertheless, there were some details which Benjamin finally slightly improved so that it completely fitted in the rest of the plane. So, this final WCB that will be shown and used for the AUVSI competition plane is the develop of our model with some alterations.

The program used to accomplish this task was Solid Edge.

As during the whole design process, first step was to analyze last year's wing center box performance.

The Solid Edge design had three main parts: front, back and laterals. It also had some connectors to join it to the rest of the plane: as it can be seen in the pictures, through a carbon tube. The cover that closed the box was made out fiber glass.

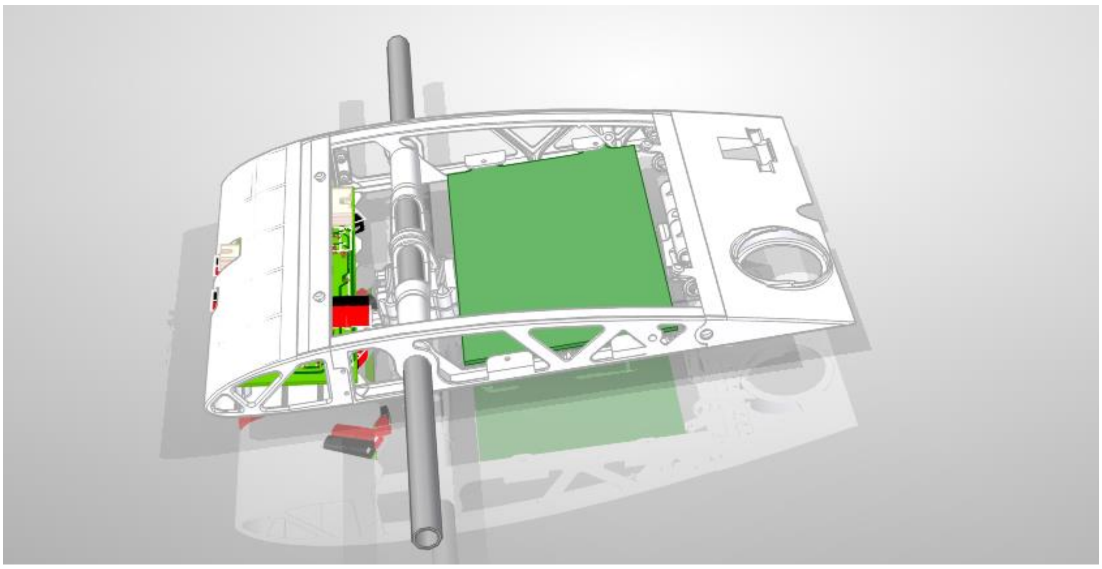

Figure 57: Last year WCB CAD design.

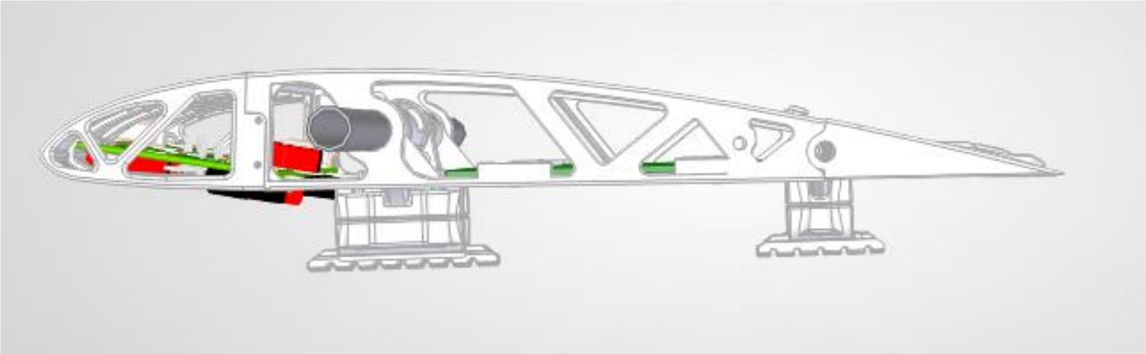

Figure 58: Profile view of last year WCB design.

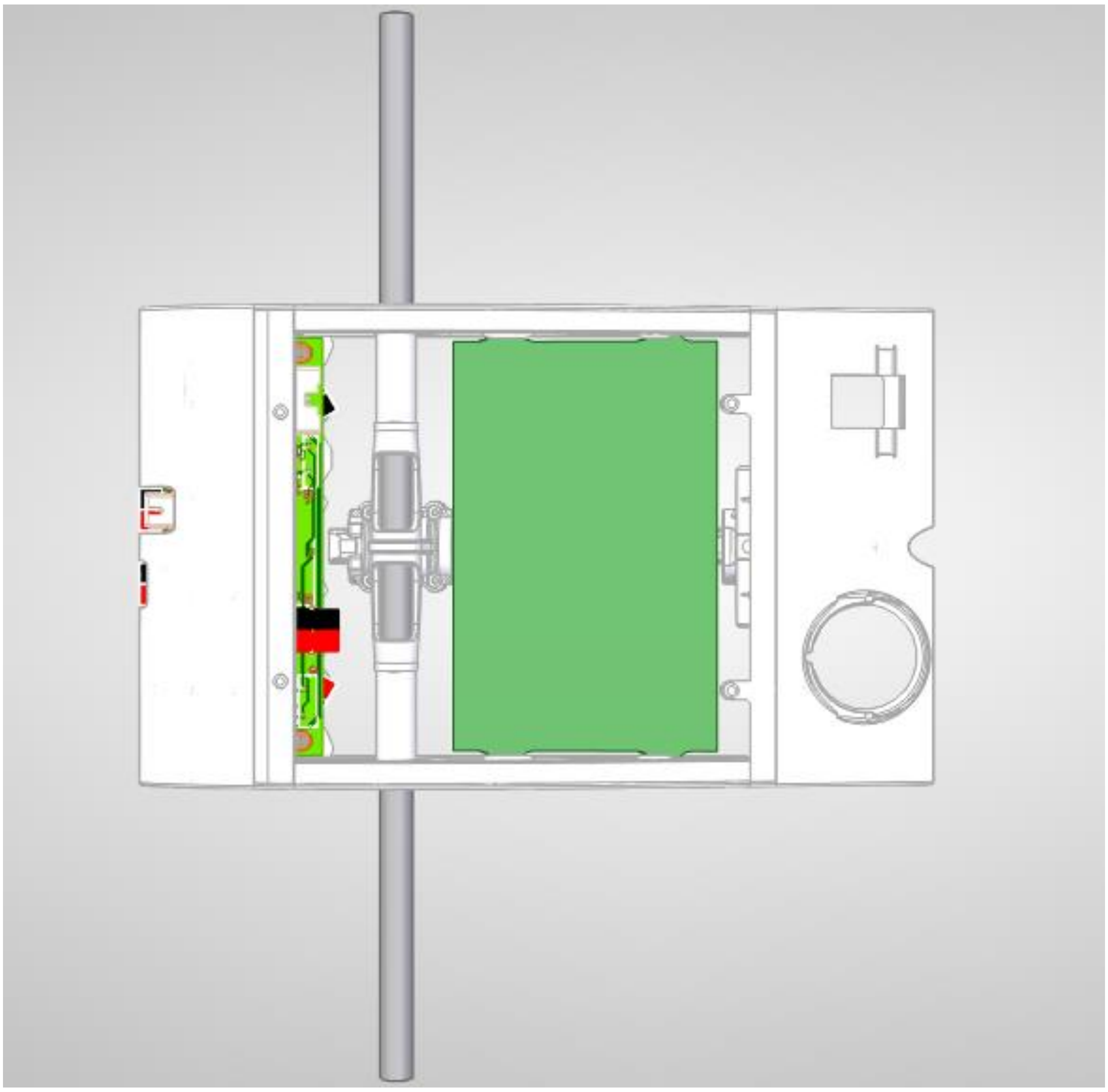

Figure 59: Top view if last year WCB design.

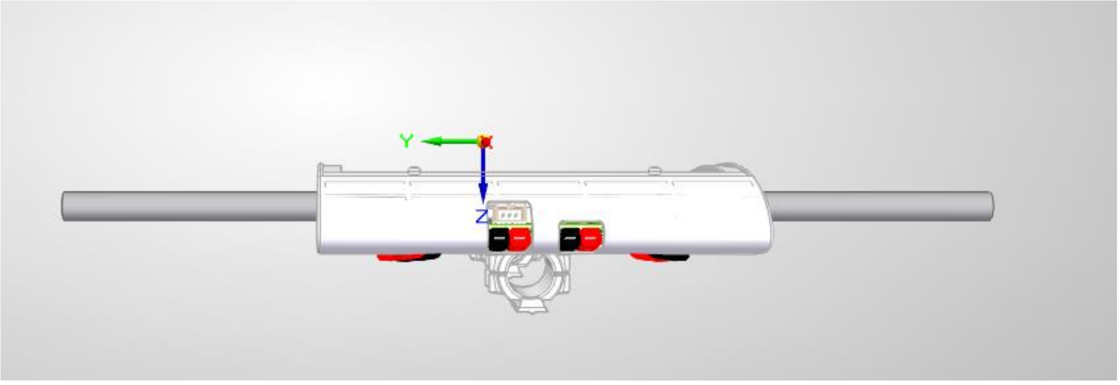

Figure 60: Front view of last year WCB design.

We were told that the last design was already good, but our task would be to adapt it to the new components, always having in mind that the last goal is to have an aerodynamic and light weight design.

Thus, we used the same structure: front, back, and laterals, with a cover. Last design was for a CLARK Y with 300mm chord wing profile, but the current plane would have a CLARK Y with 400 mm chord one. Therefore, we could only reuse the connectors, while the rest of the parts had to be redesigned.

Also, the new electronic board is different from the last year. Its area is smaller, but it is larger (in the z direction). From the bottom of the board to the top point (including the electrical connection that had to be plug in), there was a total distance of 3cm, so it exceeded the box. Thus, it was impossible to use the same idea of cover from the previous competition, which had the same shape as the wing airfoil and was made out of fiberglass.

Two options were considered, either do it again out of fiberglass or design it in CAD and print it. We selected the second choice, as the challenge would be to model it in Solid Edge, but once designed; it would be simply to produce it.

So that everything fit, our cover had to be higher. The design that we imagined was a smooth one that exceeds the airfoil at his highest point and then comes back again making a slight curve. This profile was studied to reduce the turbulence create by non- aerodynamic shape.

In order to make the profile as smooth as possible, we also redesigned the front and the back part. To achieve the most aerodynamic outline we got a bigger airfoil profile in the center of the WCB, which slightly get back to the wing dimensions in its laterals. That enables to reuse the same concept of laterals of the last design.

During the modelling of the new parts, the symmetry of the design was the entire time taking in consideration.

On the following figures we can see the final result:

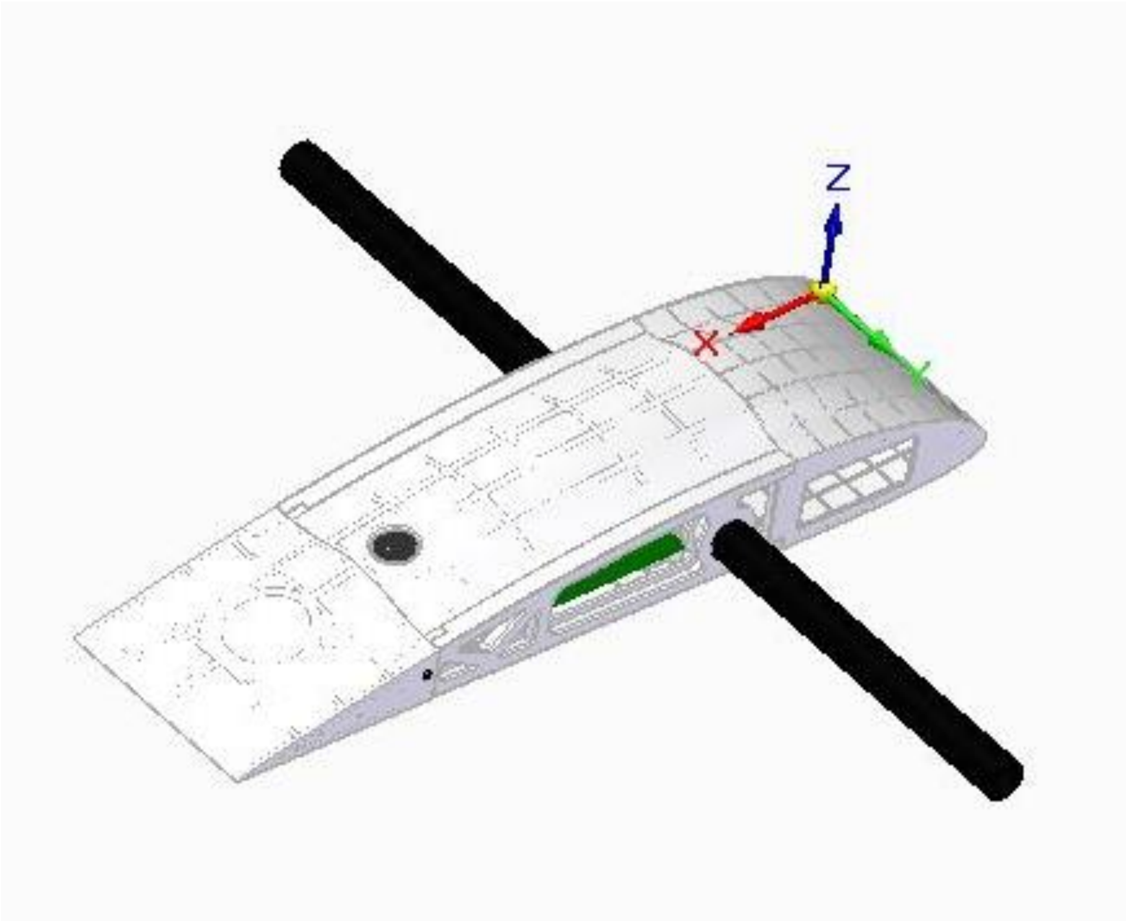

Figure 61: Wing Center Box CAD design.

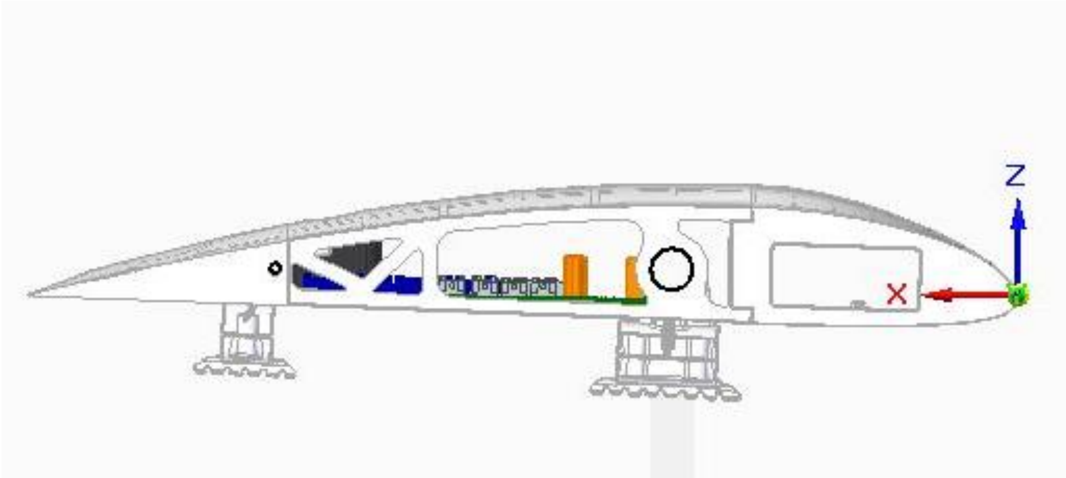

Figure 62: Profile view of the WCB.

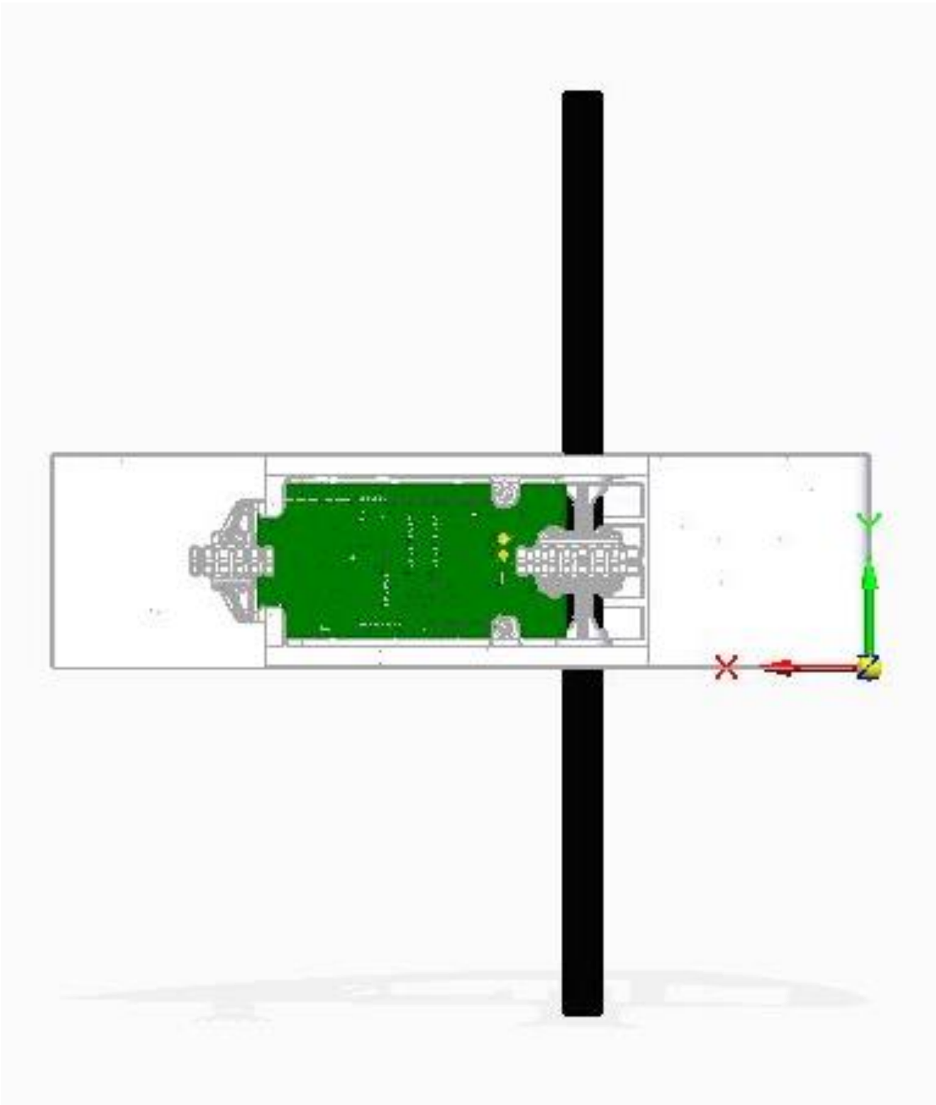

Figure 63: Bottom view of the WCB.

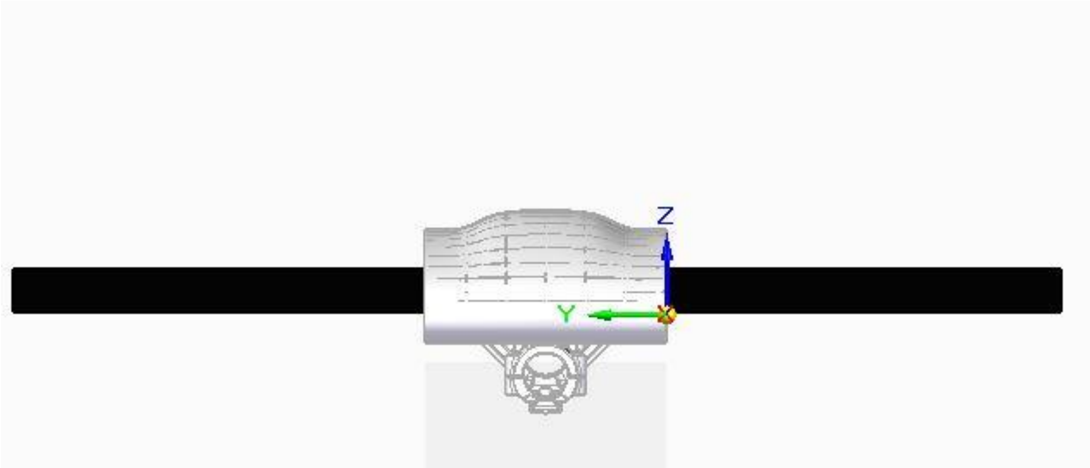

Figure 64: Front view of the WCB.

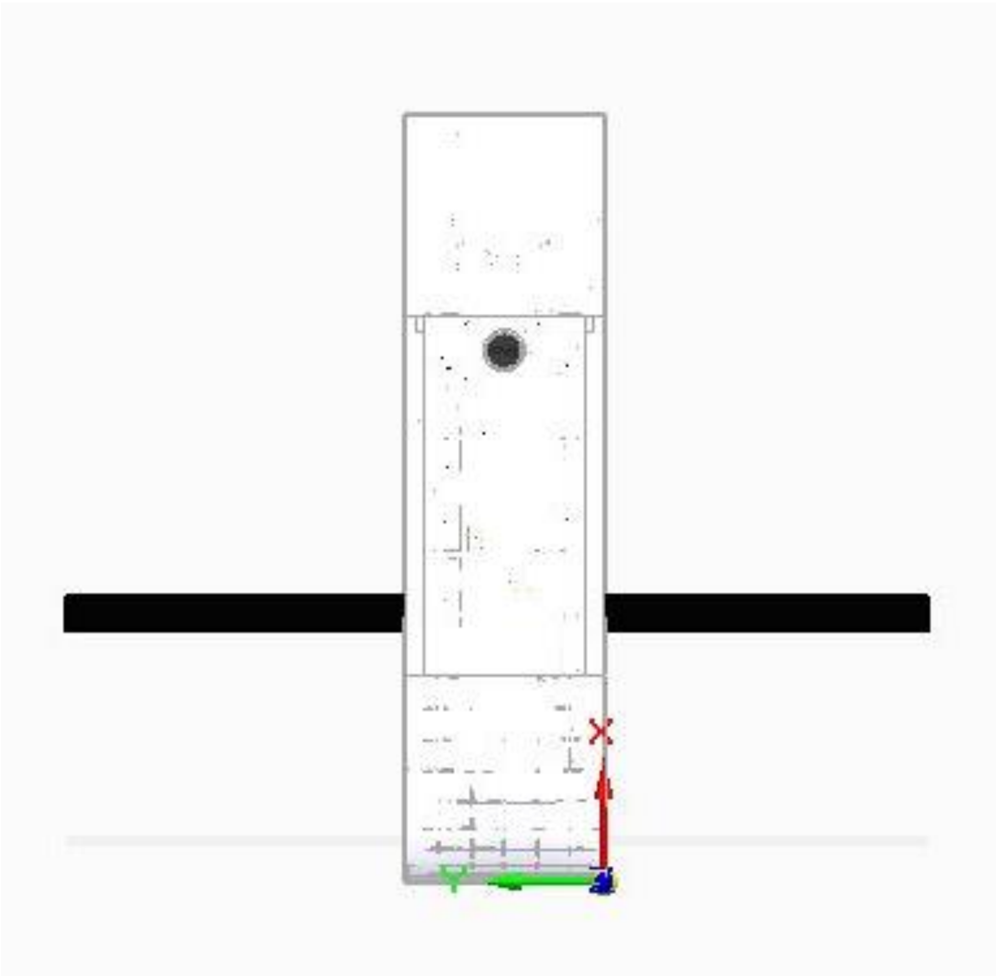

Figure 65: Top view of the WCB design.

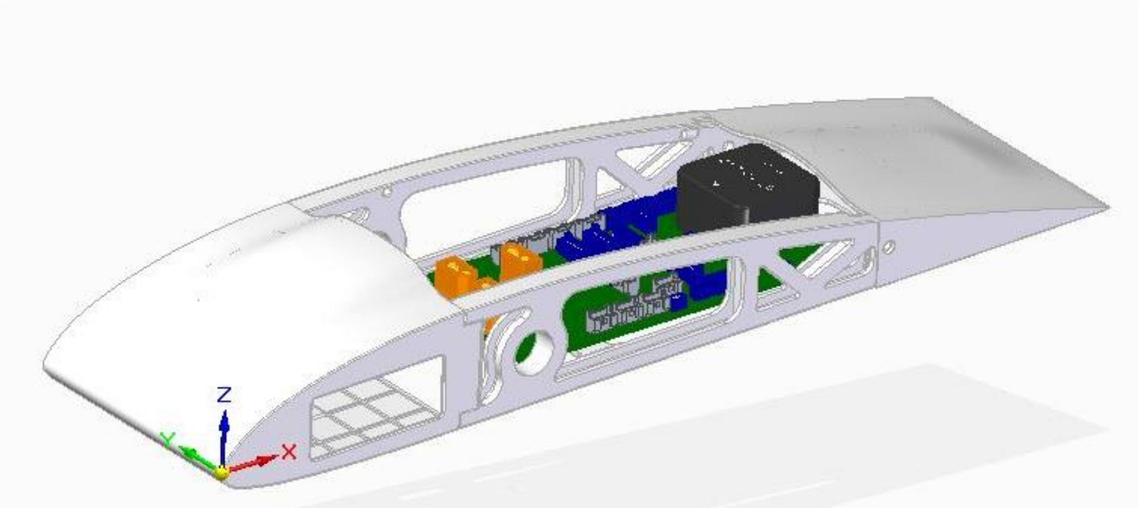

Figure 66: WCB design without cover.

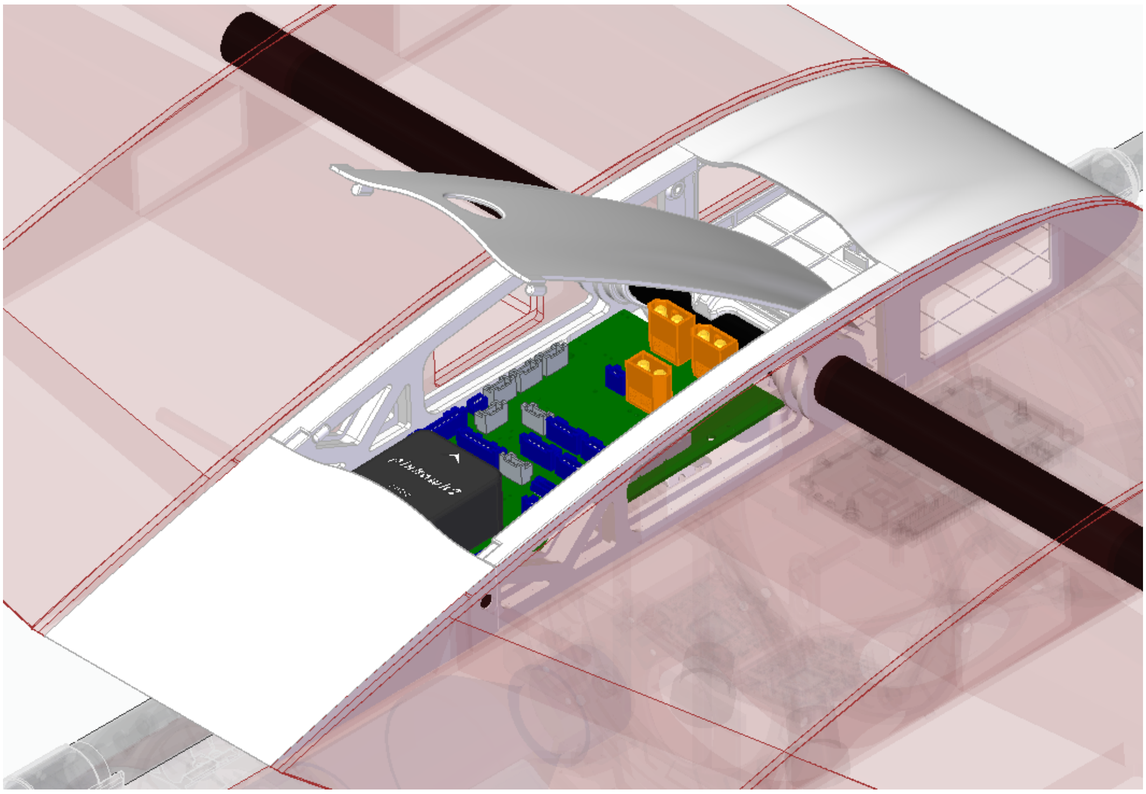

Figure 67: Opening of the WCB.

The cover is linked to the laterals through several ways: two knobs in the front part of the cover and two in the back part, as well as two tabs in its border. These three ways to enclose it make a robust design tight and therefore stable during the flight. The hole in the cover is to make it easy opening.

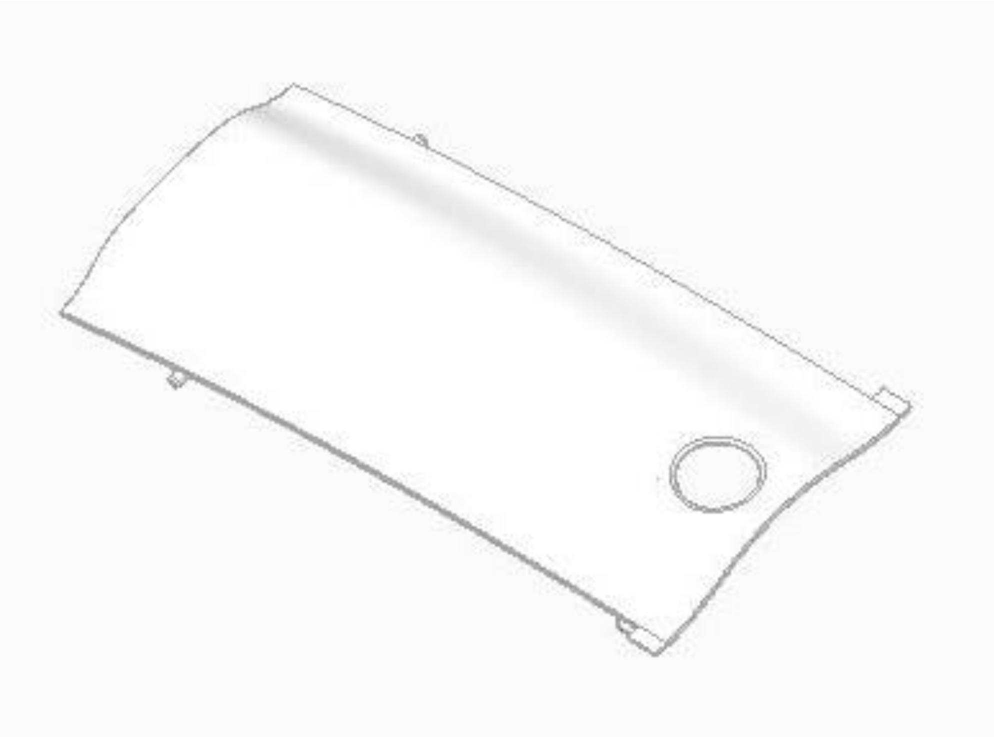

Figure 68: Top view of the WCB cover.

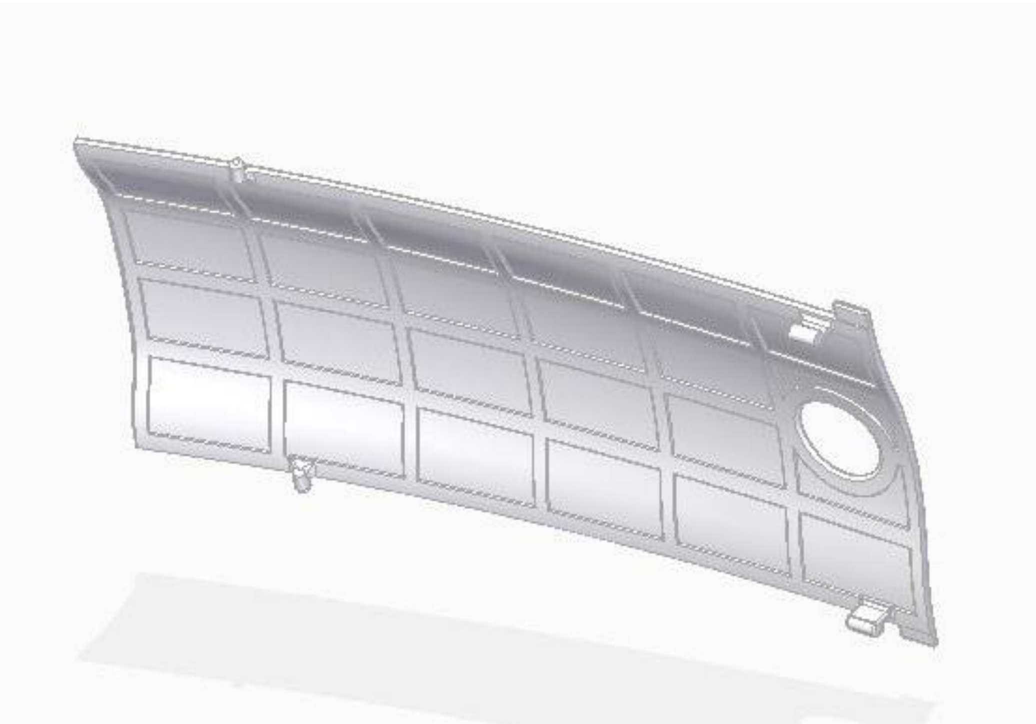

Figure 69: Bottom view of the WCB cover.

Figure 70: Profile view of the WCB cover.

Figure 71: Front view of the WCB cover.

As previously stated, the new electronic board had a different shape, which made it impossible to fit in the last WCB without modifications inside the box.

The laterals are the responsible for carrying the electronic board, so four tabs were included to its design: two in the front and two in the back. The front ones have holes so the connection there is through screws and the back ones have buttons. That makes the connection with the board as tight as possible. In addition, the design of the sides includes several ways to fit in the rest of the box. To the back it will be joined by a thin tube of carbon fiber, so in that part there are holes, in addition to protrusions that fit completely. The front has buttons to make the connection, so the laterals include gaps in there. There are two holes in the middle of the laterals, one in each part, so that a carbon fiber tube goes through them and connects it to the wings. In order to make the design lighter, several perforations were done so less material was used.

Figure 72: WCB laterals.

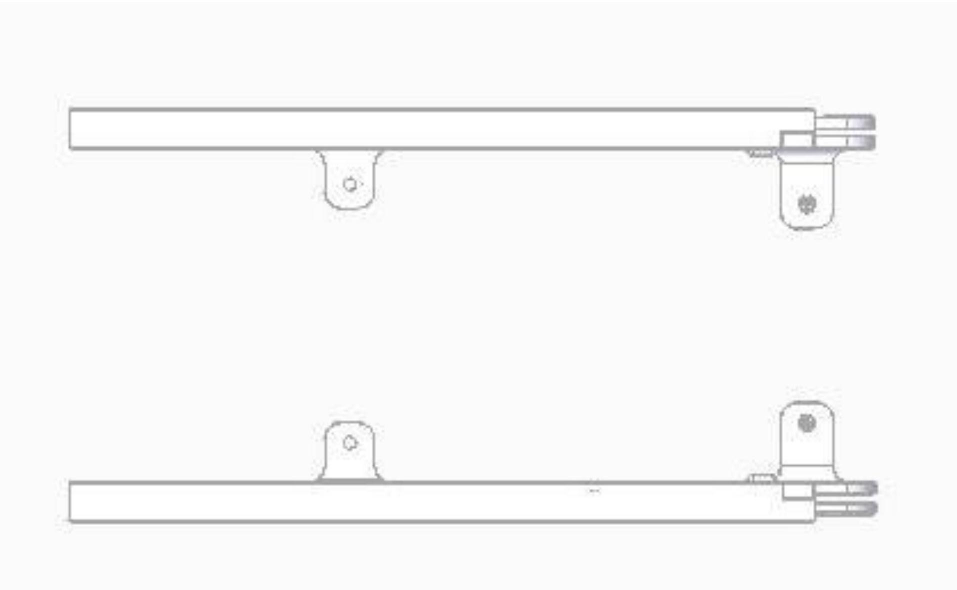

Figure 73: Top view of the WCB laterals.

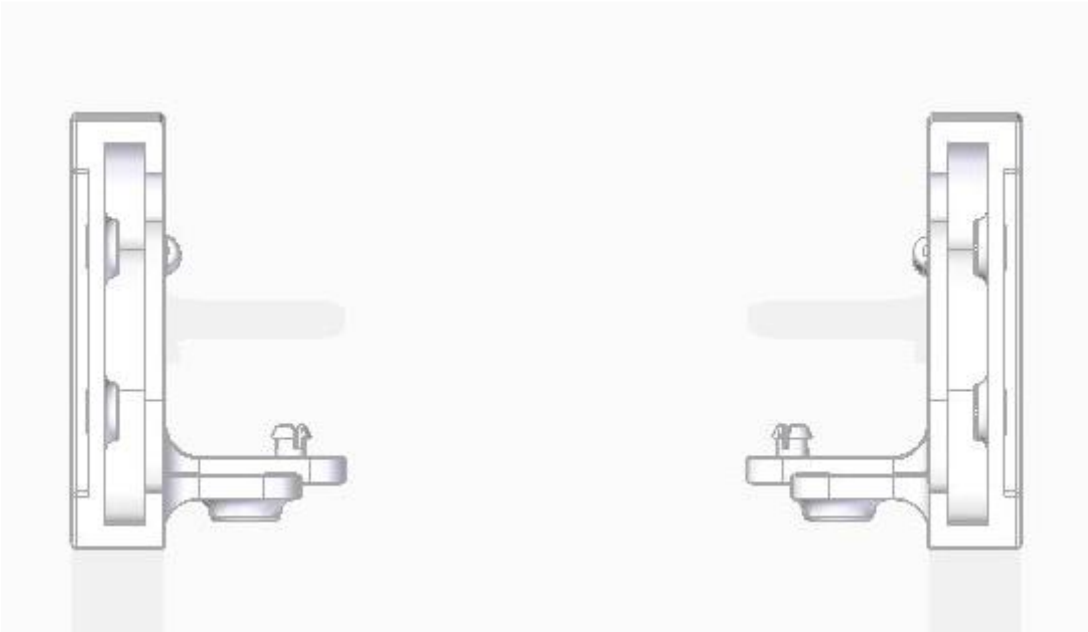

Figure 74: Front view of the WCB laterals.

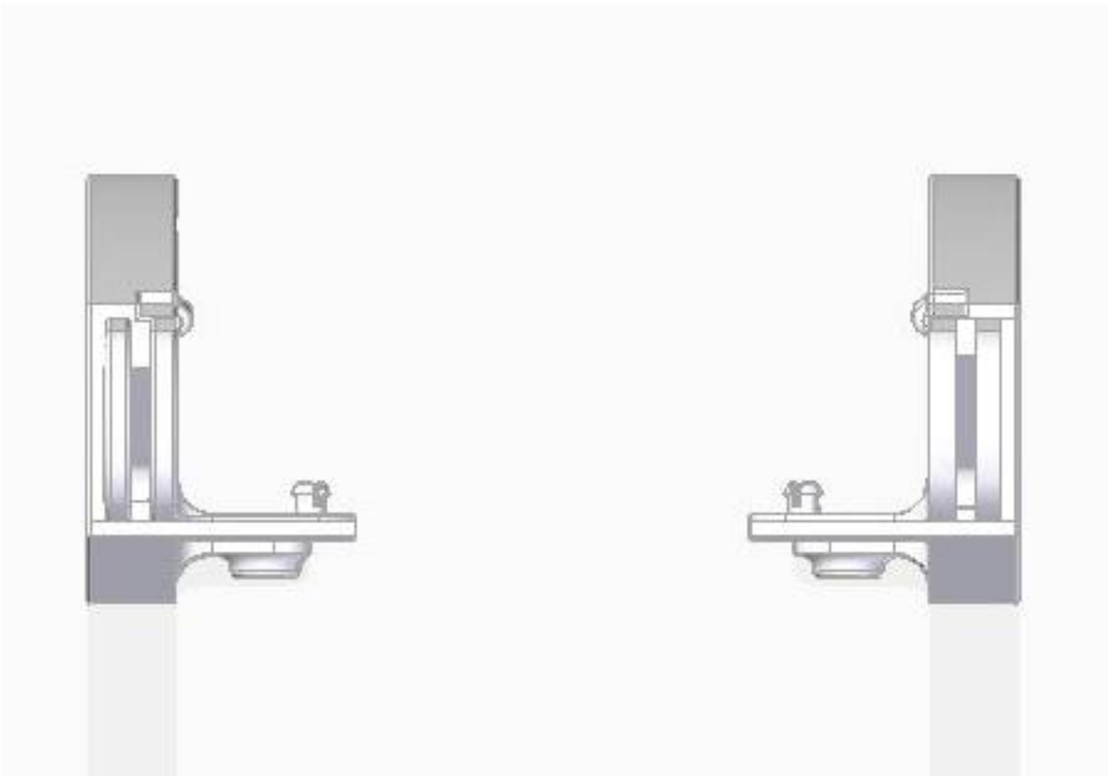

Figure 75: Back view of the WCB laterals.

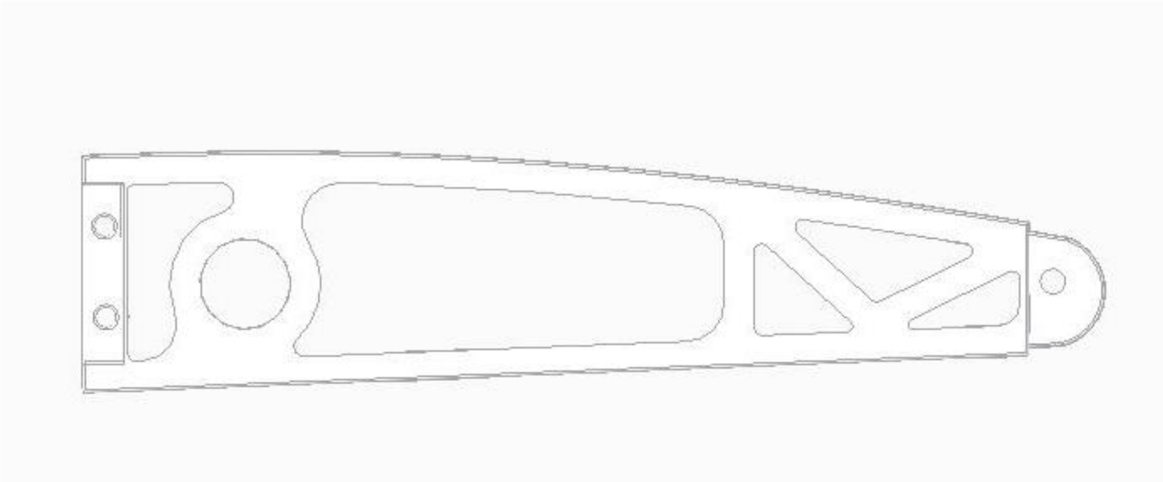

Figure 76: Profile view of the WCB laterals.

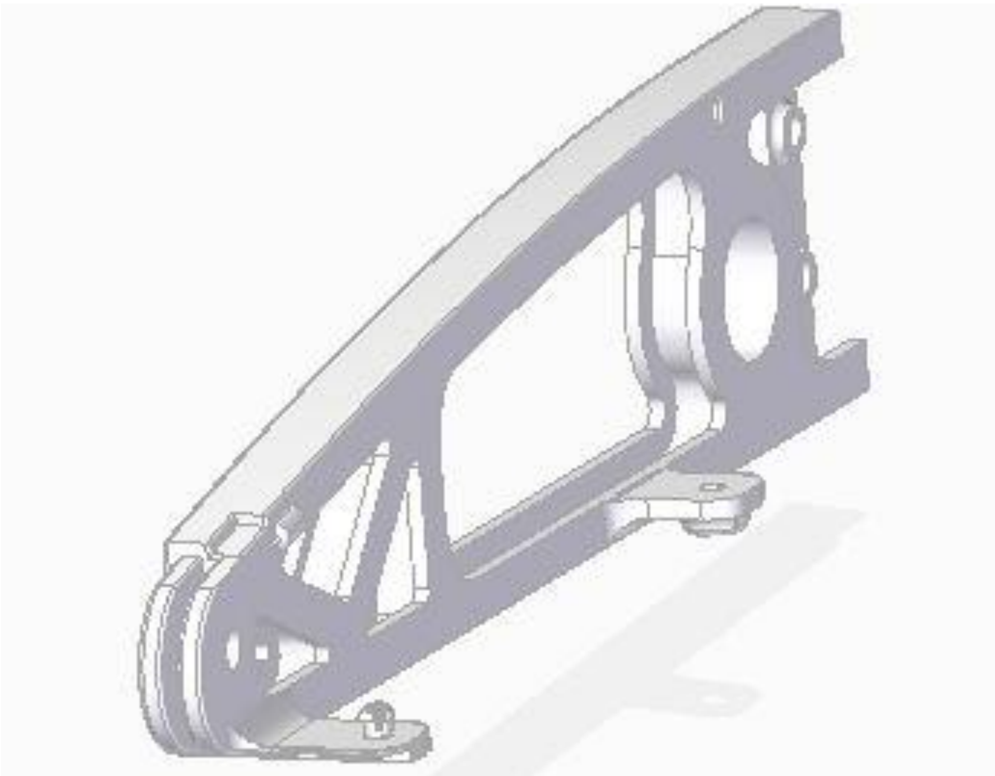

Figure 77: Inside of the WCB laterals.

The last elements we were required to insert in the WCB were the GPS antenna and the radio.

The GPS antenna must be in a specific position during the whole flight. It has to be facing the sky and cannot be shadowed by any metal or carbon elements. As the box will be made out of plastic (3D printer), there is no problem to put the GPS inside it.

We positioned it in the back part of the WCB, because it has enough place inside.

To hold it as robust as possible we designed a structure with its shape and size, to ensure that it does not move.

This back part also includes a connection to the laterals by two big holes with the same size of the laterals protuberating, so that it gets stuck.

The structure inside has a reinforcement so that it doesn’t suffer form stability loss with the lighter design.

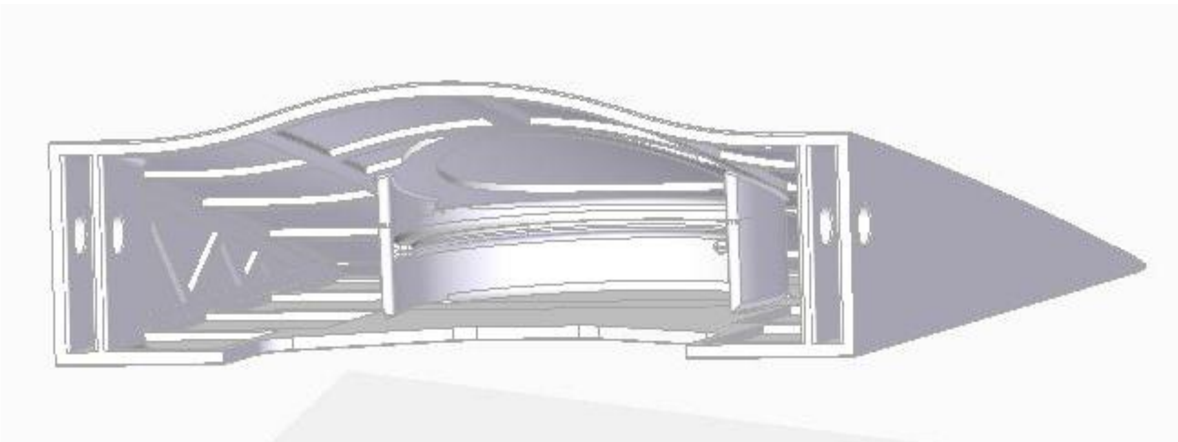

Figure 78: Back part of the WCB.

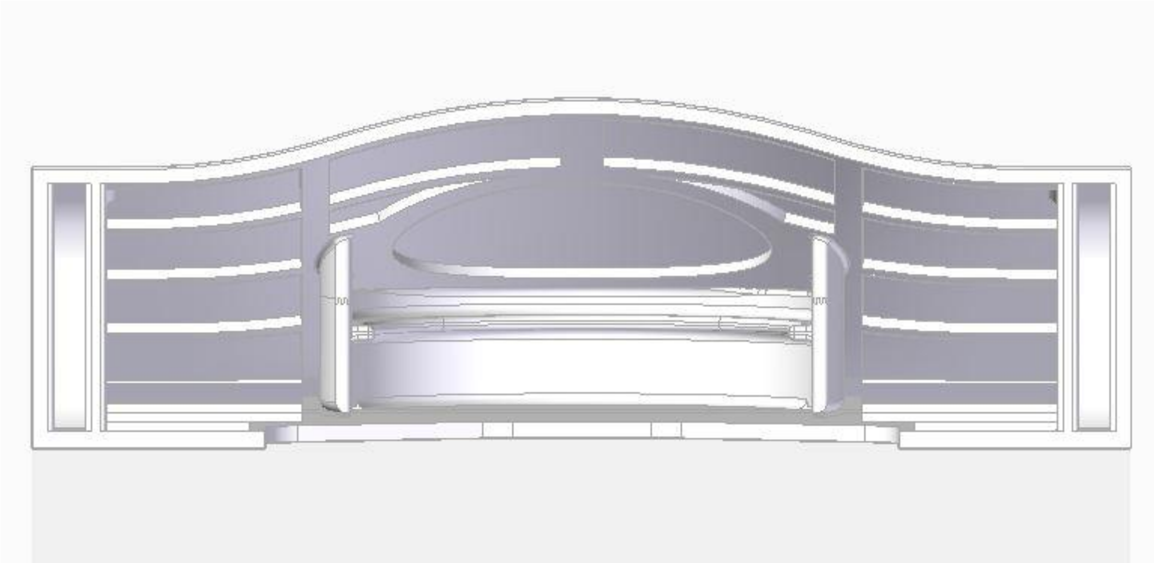

Figure 79: Front view of the back.

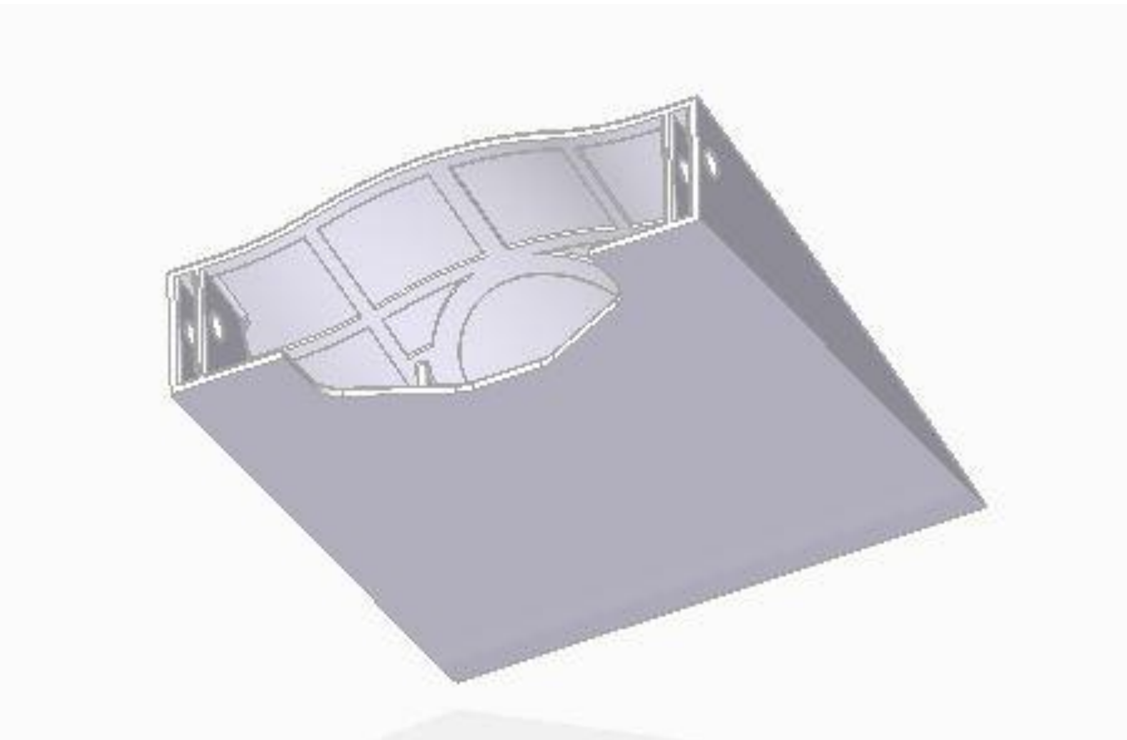

Figure 80: Bottom view of the back.

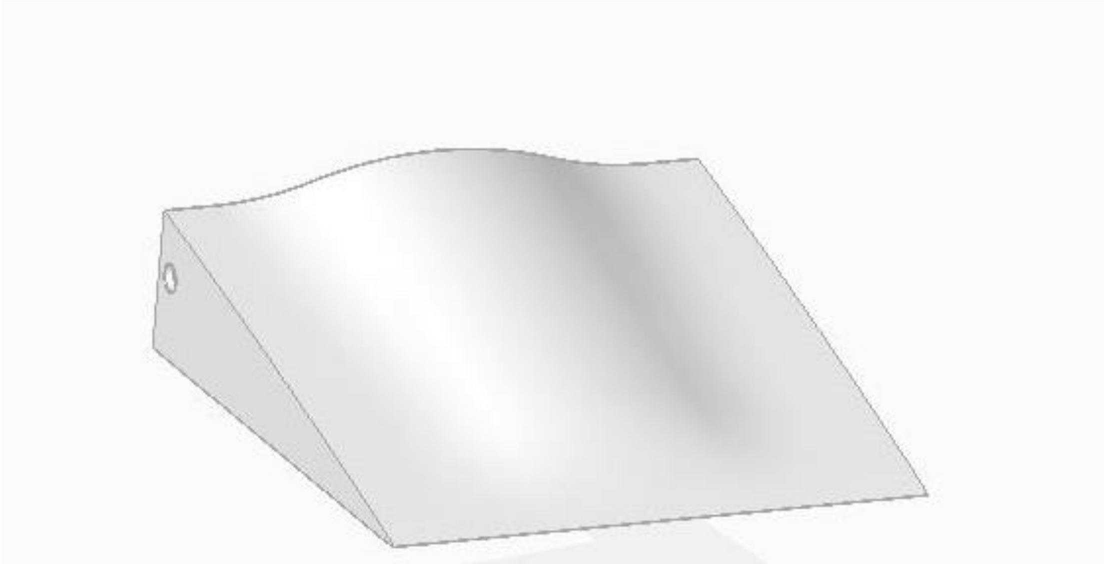

Figure 81: Back view of the back.

The radio has the same requirements as the GPS antenna, so positioning it inside the WCB would not lead any problems.

We designed a housing to fit it on the front part of the box. To hold it tightly it has the same shape as the radio and a system to adjust it with two taps in the sides that end with a triangular shape, so once the radio is introduced, it gets stuck. To release it, it is necessary to press the triangular parts.

The front part includes four buttons already mentioned to get fixated to the laterals. The structure has the same reinforcement concept as the rest of the box, as well as gaps in its laterals so it is stable as the same time as light.

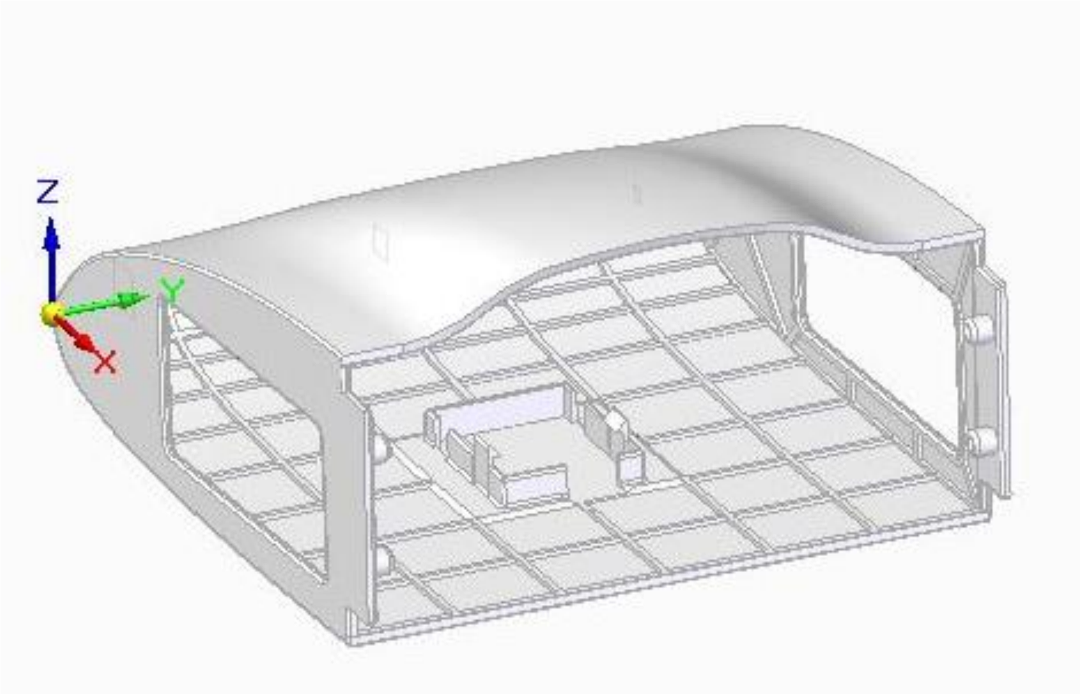

Figure 82: Front part of the WCB design.

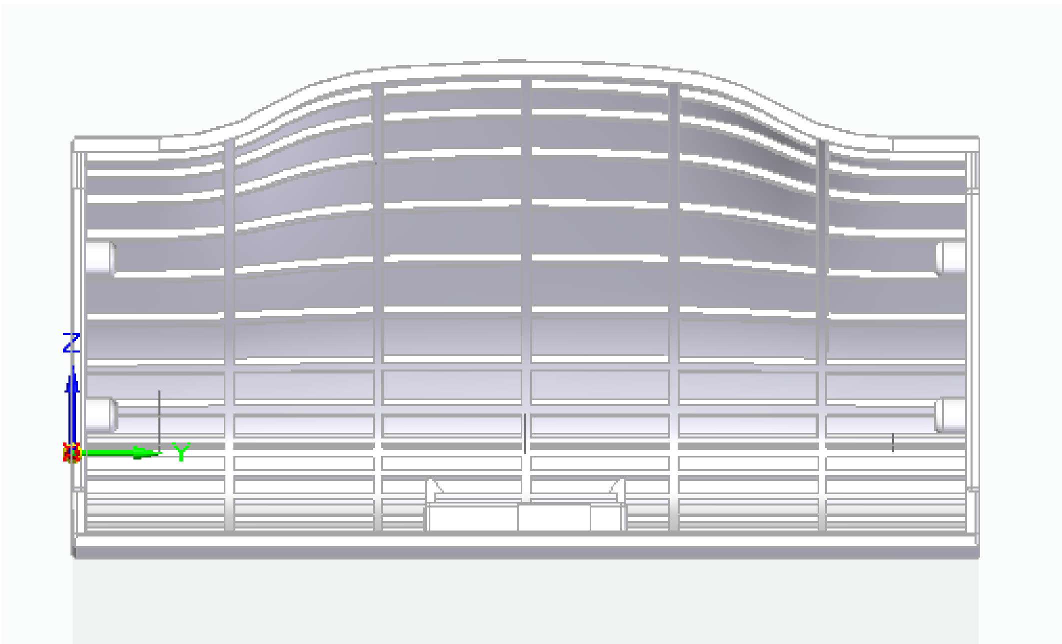

Figure 83: Inside of the front.

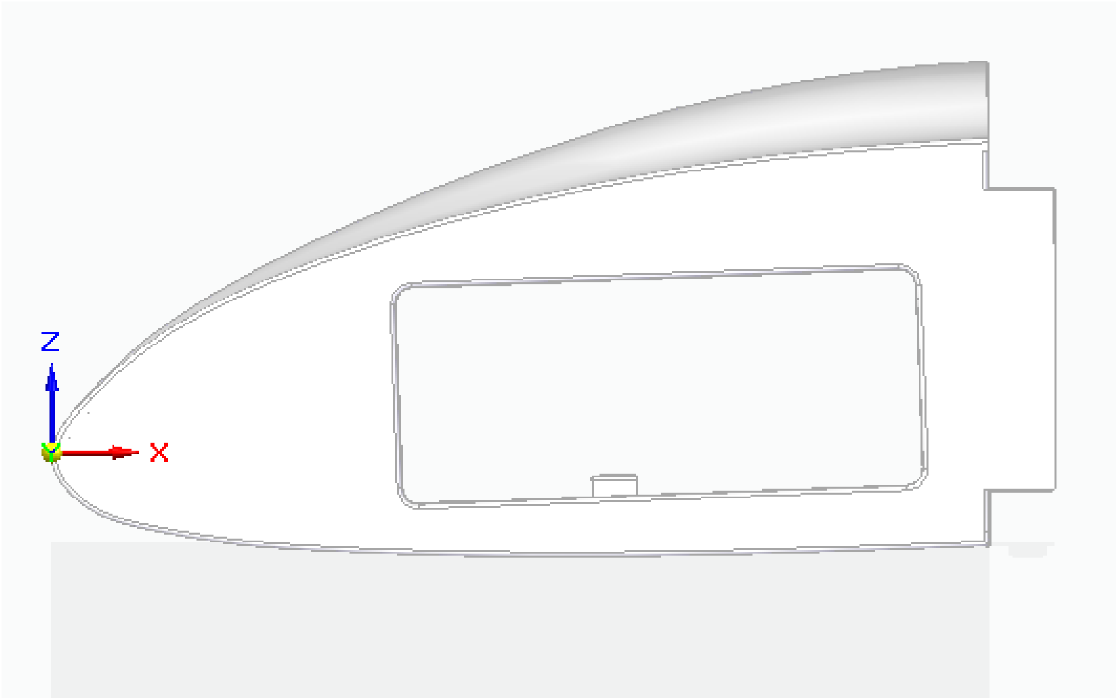

Figure 84: Profile view of the front.

The connectors between the carbon tubes and the wing center box were reused from the previous model, they only had to be rescaled in order to fit in our design. It is important to understand that the hole inside them in the longitudinal axis is for the pipe that will have the function of fuselage or body of the plane.

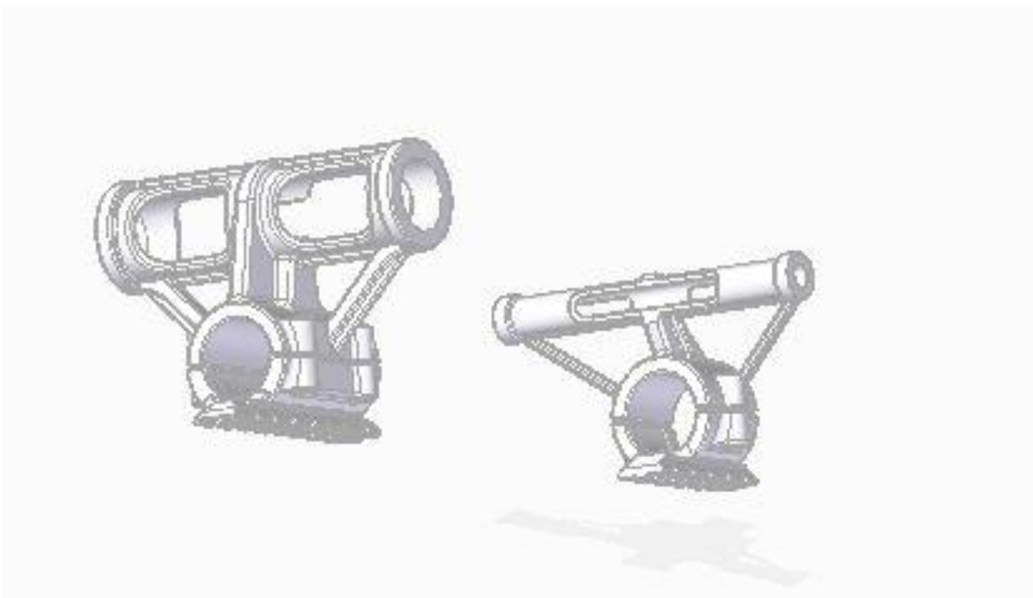

Figure 85: WCB connectors design.

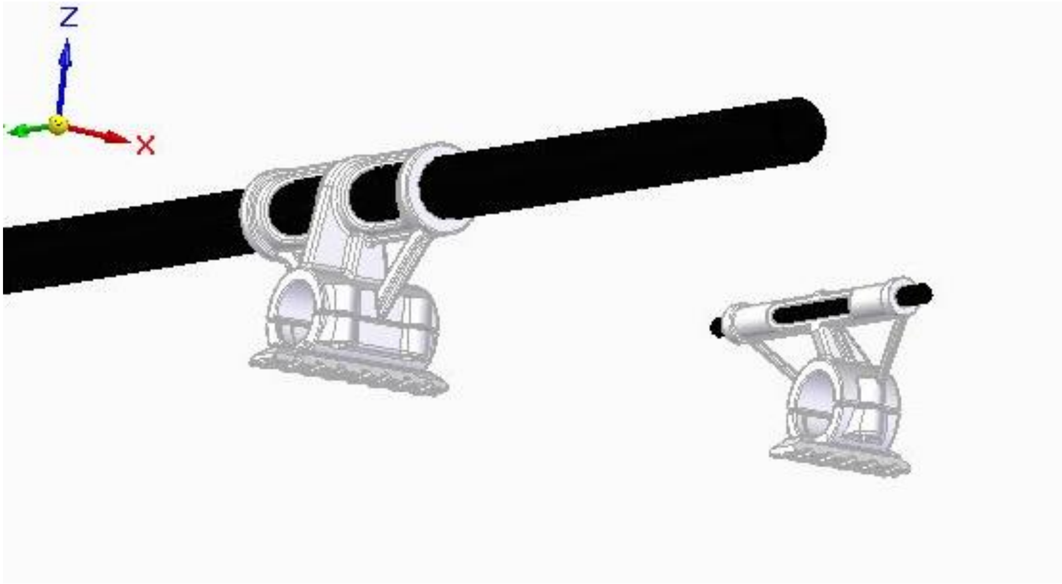

Figure 86: Connectors with carbon fiber tubes.

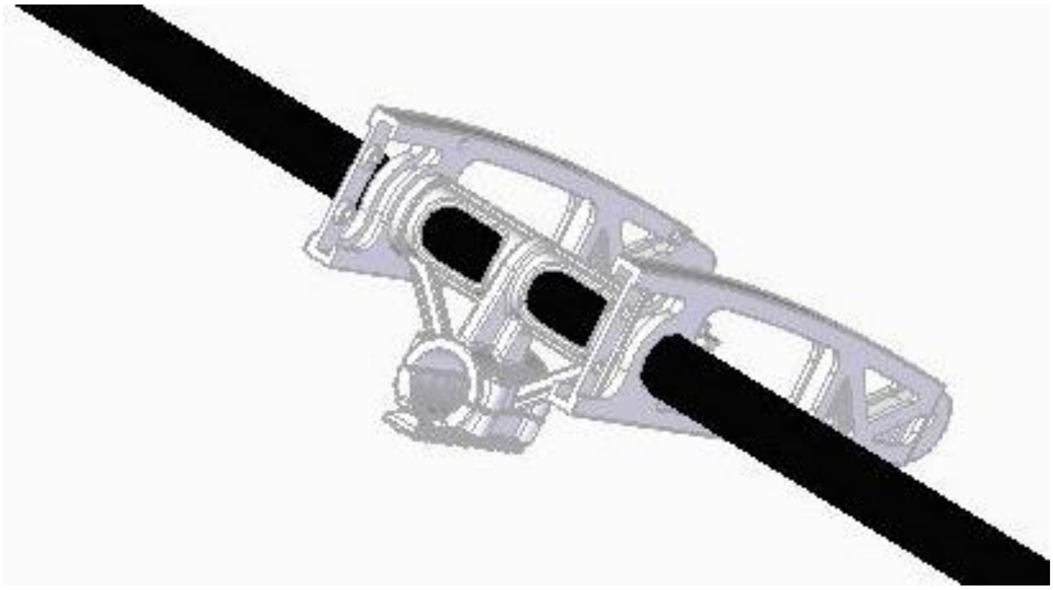

Figure 87: Front connectors with laterals.

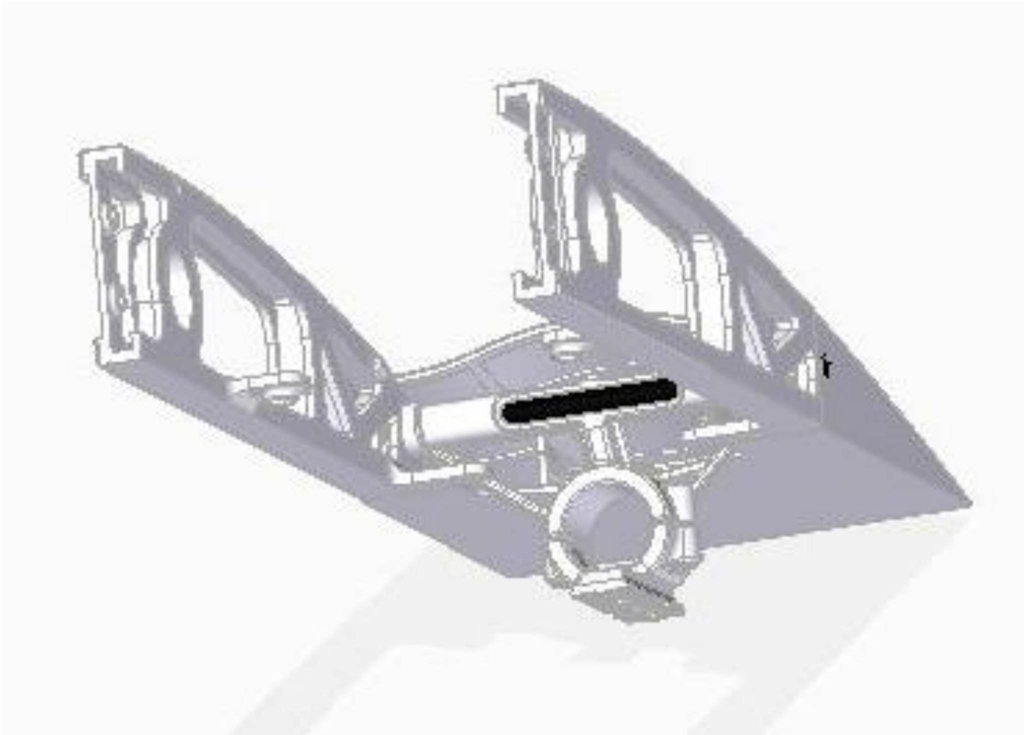

Figure 88: Back connector with laterals and back part.

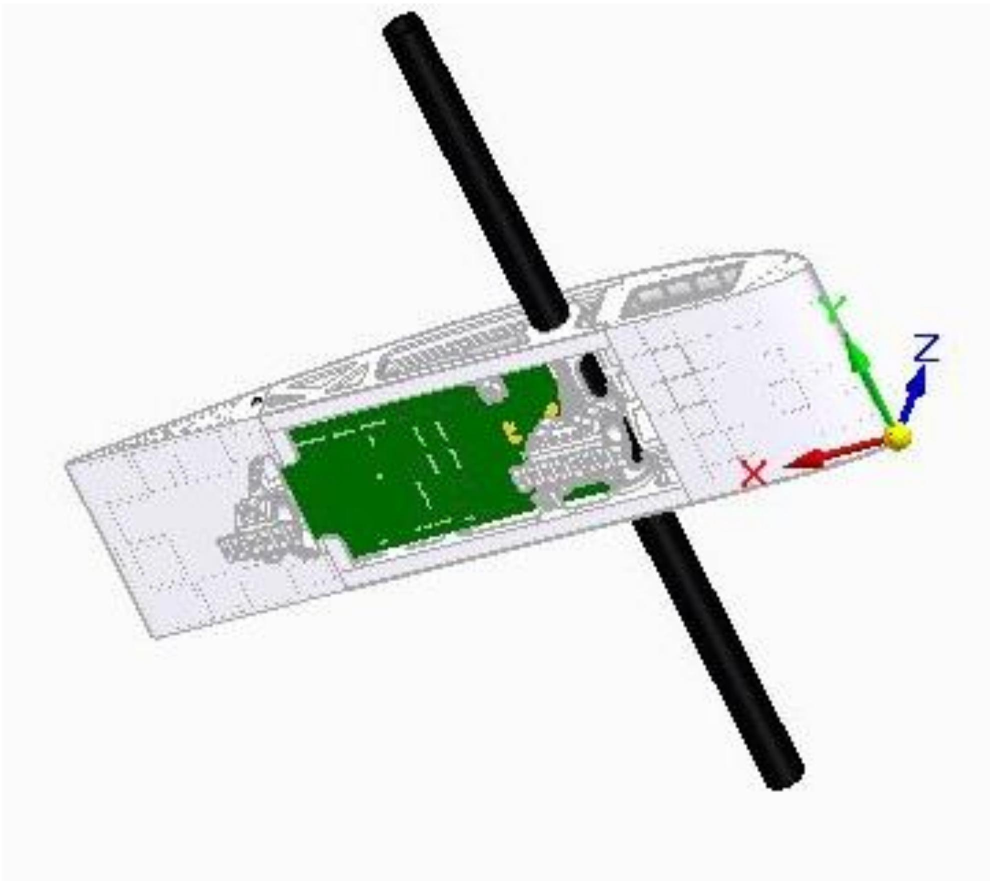

Figure 89: Back view of the connectors with the rest of WCB

7.3.2. MANUFACTURING

As already mentioned, the manufacturing of the Wing Center Box would be 3D printing, so once the design was completed we send it to the 3D printer in Munich University of Applied Sciences and the result was the following:

Figure 90: 3D printed WCB.

It is important the fact that the tubes used for joining the parts are carbon fiber made, and the University also supplied them.

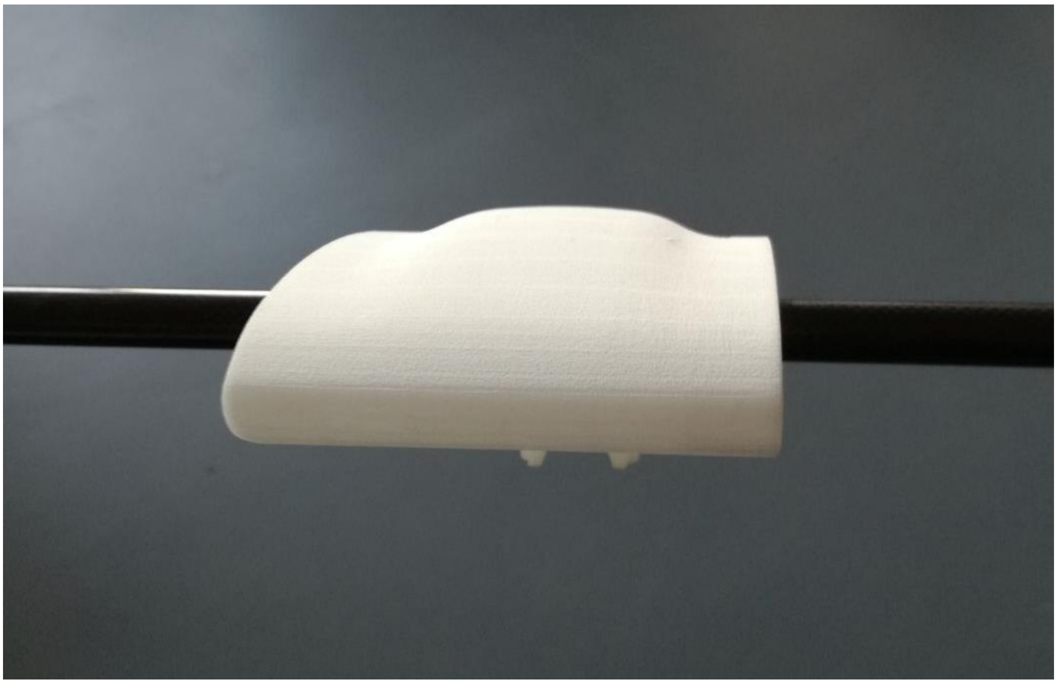

Figure 91: Front view of the WCB.

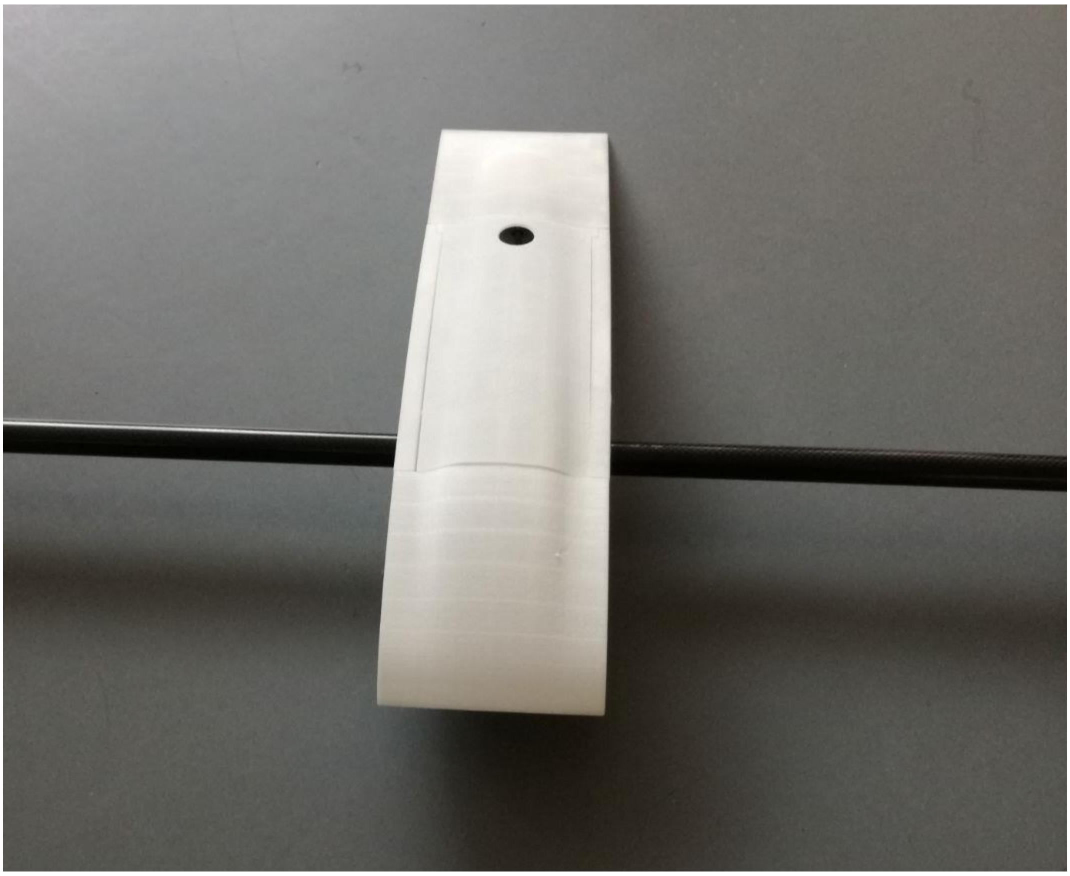

Figure 92: Top view of the WCB.

8. CONCLUSION

As already explained, the aircraft is an assembly, whose elements need to be connected one to another. Thus, during the design of all the parts we had in mind the connections, so that the whole body gets adjusted.

Once all the teams had their parts finished, we put them together and we could proudly say that the final design exceeded expectations.

Below is the whole assembly.

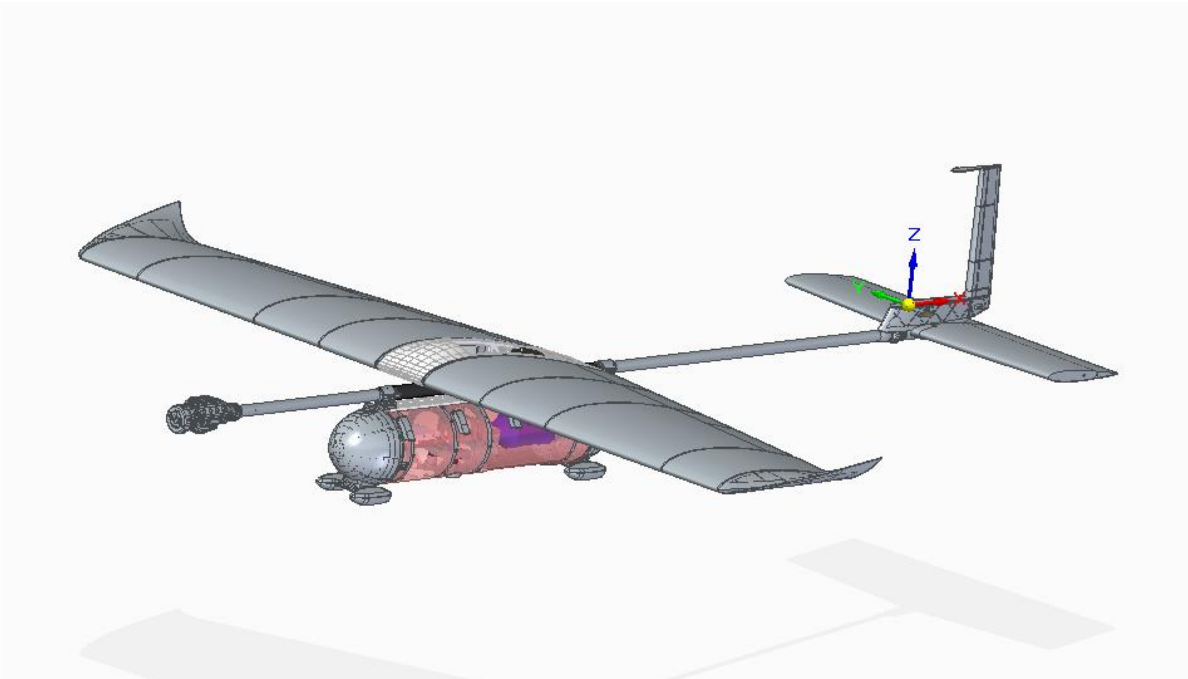

Figure 93: Whole aircraft design.

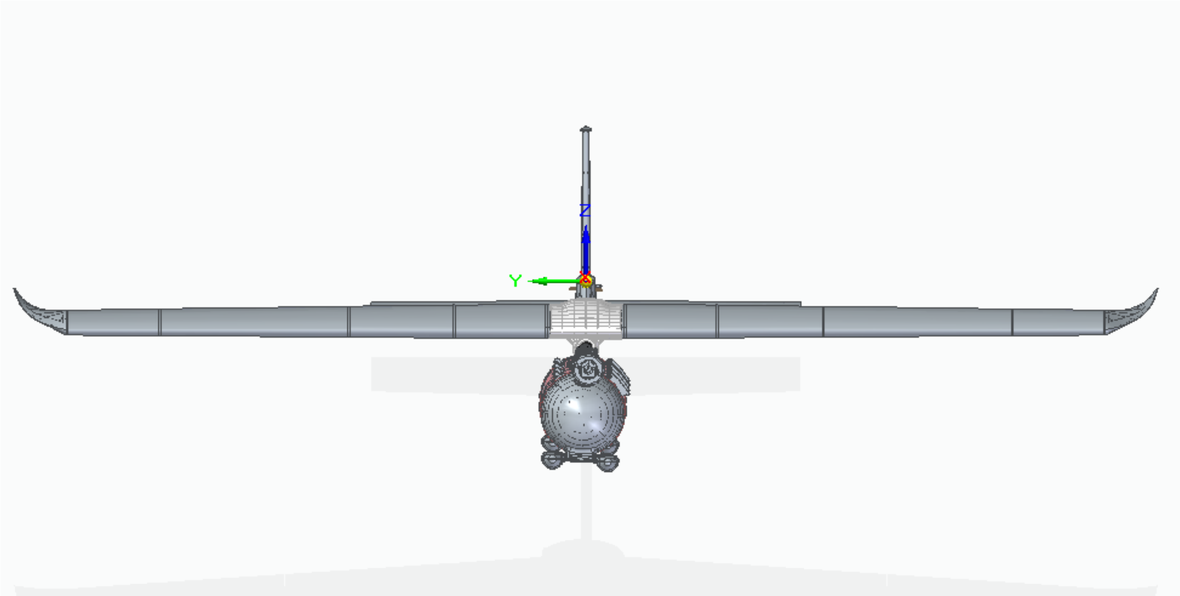

Figure 94: Front view of the aircraft.

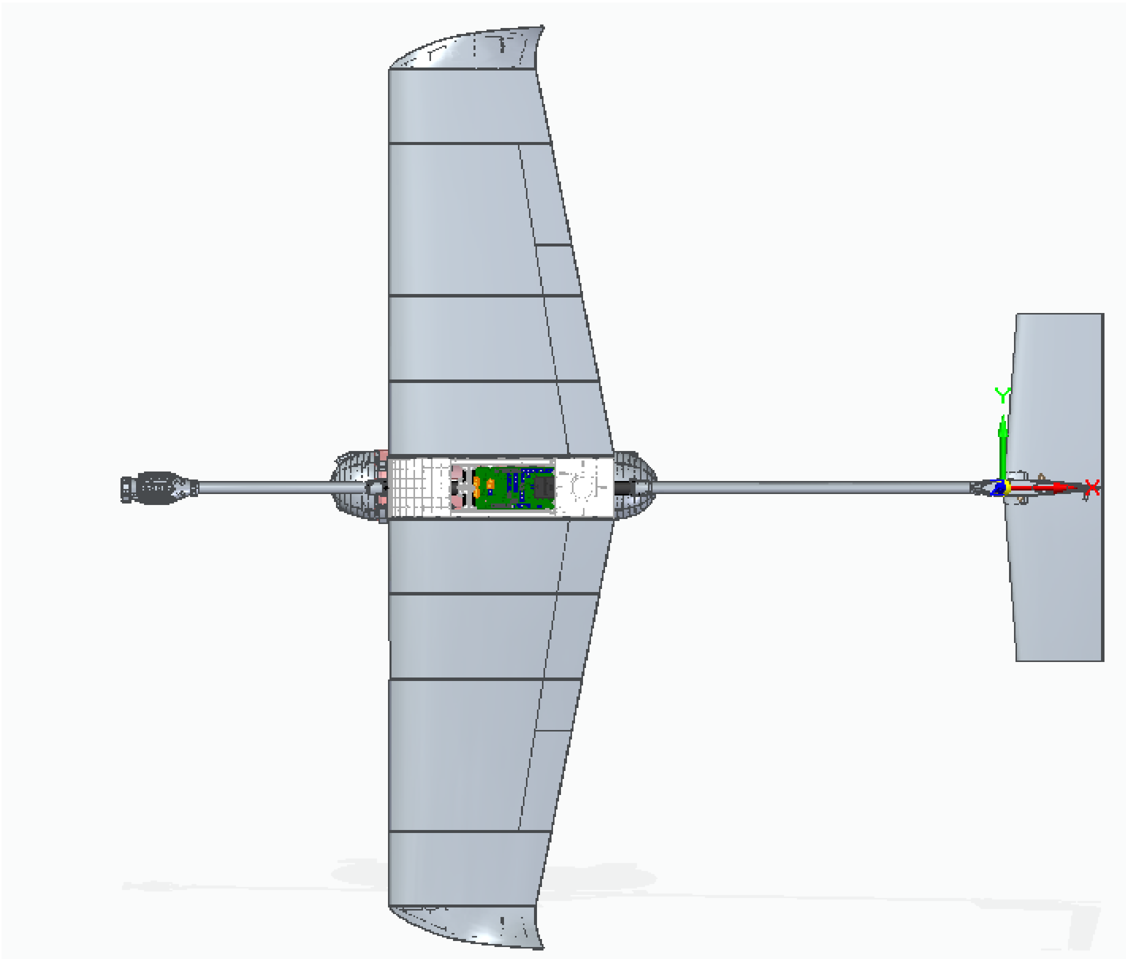

Figure 95: Top view of the aircraft.

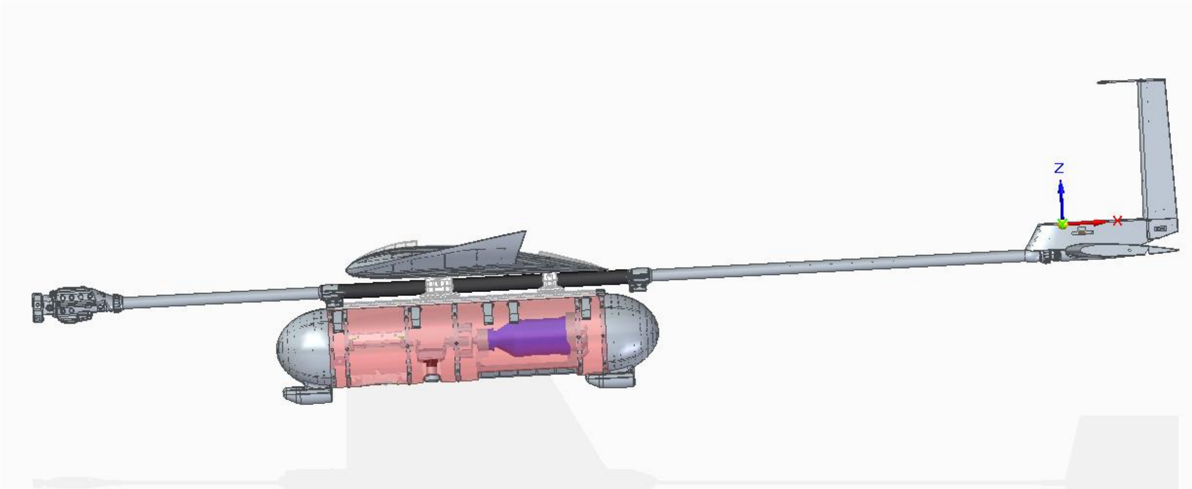

Figure 96: Profile view of the aircraft.

Figure 97: Manufactured aircraft.

Unfortunately, in the first flight test on May 22, 2018, the plane crashed to the ground and several of its important components were broken. Since the test was done so close to the deadline, there was no possibility of fixing it before the competition, and, therefore, the MUAS team could not participate in it. However, that served as motivation to analyze the errors and try to fix them to get the plane to fly.

After analyzing the flight footage, a relative angle between the tail and the wings appeared, as seen from the front. This produced an extra lateral force, as well as the loss of control of the stabilizer, which caused the crash. It was determined that this occurred due to a certain game at the fuselage-tail connection that had not been previously considered. To solve it, we should replace the connections with ones that fit tightly.

In addition, it was observed that the carbon tube that served as a fuselage was not able to withstand the forces during the flight. To solve that, we should simply replace it by a more resistant one.

In short, the team did not take the crash as a failure. Instead, we took it as an opportunity to learn from the mistakes and optimize the plane to which so much time and effort had been devoted.

9. REFERENCES

- Competition description, rules and requirements:
  - http://www.auvsi-suas.org/competitions/2018/
- Aviation basic concepts:
  - http://gkforeverybody.blogspot.de/2010/03/how-airplanes-work.html
  - www.grc.nasa.gov
  - https://www.quora.com/How-is-the-pressure-difference-created-between-2-sides-of-an-airfoil
- Flight analysis:
  - http://www.xflr5.com/xflr5.htm
- Balsa wood:
  - http://www.mat.uc.pt/~pedro/ncientificos/artigos/techbal.html