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FINAL PROJECT REPORT

DESIGN AND PRODUCTION PROPOSAL OF A UAV FOR THE MINING INDUSTRY

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ABSTRACT

This report provides an in-depth study on the current growth in the unmanned aerial vehicle (UAV) industry, specifically fixed-wing UAVs, culminating in an estimate of potential revenue taking into account existing competition and the target market sector. A detailed design of a UAV that could meet predefined mission requirements is presented, based on innovative production concepts primarily centered around carbon fiber manufacturing using Prepreg. Along with the design, a proposed method of manufacture for each of the UAV parts and corresponding operational conditions is proposed, supported by contemporary industrial tools such as a product structure, a Value Stream Map (VSM), and a Failure Mode and Effect Analysis (FMEA).

The proposal and UAV design were validated through computational analyses that include aerodynamic, structural, and stability analyses. The application of technical skills in various fields, including aerospace production methods, fluid mechanics, flight mechanics, mechanical design, and aircraft design, is evidenced throughout this report. The report concludes with the suggestion of possible improvements for a second phase of the project, as well as proposals for future work which could include improving the precision of the current proposal and other ways of optimizing the UAV's design and production.

Keywords:

- **Unmanned Aerial Vehicle (UAV)**
- **Carbon fiber Prepreg**
- **Aerospace production methods**
- **Computational analysis**
- **Value Stream Map (VSM)**
- **Failure Mode and Effect Analysis (FMEA)**

RESUMEN

Este informe proporciona un estudio comprensivo sobre el crecimiento actual en la industria de los vehículos aéreos no tripulados (UAV), particularmente en los UAV de ala fija, derivando en una estimación del potencial de ingresos considerando la competencia existente y el sector de mercado objetivo. Se presenta un diseño detallado de un UAV que se podría implementar para cumplir con los requisitos de misión previamente definidos, basado en conceptos de producción innovadores centrados principalmente en la fabricación con fibra de carbono mediante Prepreg. Acompañando el diseño, se propone un método de elaboración para cada una de las piezas del UAV y las condiciones operativas correspondientes, apoyado en herramientas industriales contemporáneas como es una Estructura de producto, un Mapa de Flujo de Valor (VSM), y un Análisis de Modo y Efecto de Falla (FMEA).

La propuesta y el diseño del UAV se validaron mediante análisis computacionales que incluyen análisis aerodinámicos, estructurales y de estabilidad. A través de este informe se evidencia la aplicación de habilidades técnicas en varios campos, incluyendo métodos de producción aeroespacial, mecánica de fluidos, mecánica de vuelo, diseño mecánico y diseño de aeronaves. El informe concluye con la sugerencia de posibles mejoras para una segunda fase del proyecto, así como propuestas para trabajos futuros que podrían incluir la mejora de la precisión de la propuesta actual y otras formas de optimizar el diseño y la producción del UAV.

Palabras claves:

- **Vehículo Aéreo No Tripulado (UAV)**
- **Pre-impregnado de fibra de carbono**
- **Métodos de producción aeroespacial**
- **Análisis computacional**
- **Mapa de Flujo de Valor (VSM)**
- **Análisis de Modos de Fallo y sus Efectos (FMEA)**

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Chapter 1. Business sector to target

Something that is undeniable today is the abrupt increase of drone technologies in the world today. The UAVS or Unmanned Aerial Vehicle, develop their technologies every year and offer greater benefits to different industries in order to reduce operating costs, monitoring security controls, industrial logistics planning, among a multitude of uses that different sectors are requiring day by day.

Today, the market value of the drone industry is estimated at $30.6 billion and is expected to increase to $55.8 billion by 2030 [1]. While it is estimated that 78% of global drone-related revenues are not related to the sale of hardware or software but rather to the provision of services through specialized companies, it indicates a potentially profitable and highly attractive industry sector to invest in, with a market value of up to 26 million euros by 2026 [2].

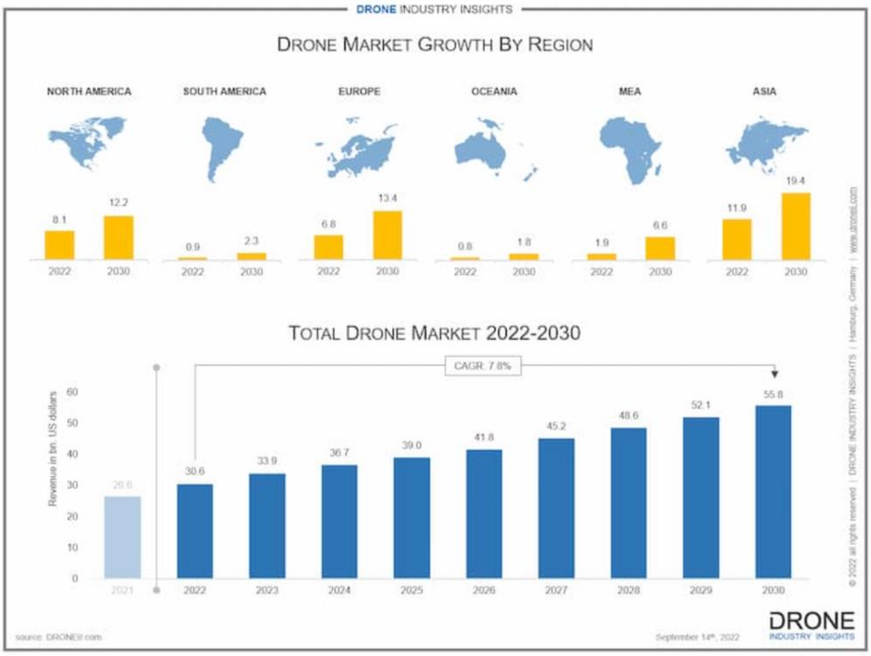


Figure 1. Drone market growth by region

One of the sectors where the use of drones has increased significantly is the mining sector, where although in 2008, 44% of mining companies reported having invested in drone technology, this has now increased by 65% [3].

The use of this technology not only represents for the mining industry in finding gold or precious materials, but rather in a series of advantages that within the administrative point of view of the mining company can be beneficial, such as:

- **Operational risk reduction:** Mining is one of the most dangerous industries in the world. It is estimated that mining employs about 1% of the world's workforce but generates 8% of fatal accidents [4].

- **Supply chain management**: The accuracy of a 3D mapping will allow to calculate the amount of material in storage piles and to know the stock immediately in order to speed up production tasks [5].
- **Understand complex situations through 3D mapping:** As with all field work, unforeseen events occur that could lead to a paralysis of operations, with the help of an external visualization it is possible in a few hours to detect irregular situations that would be impossible for the operator to see.
- **Generate contour lines and elevation maps over time**: Being able to store several days' worth of data allows operations managers to facilitate future decision making.
- **Speeding up through regulatory authorities:** The fact of being able to recreate maps in 3D allows to facilitate the communication to the authorities and thus reduce the permitting time for mining operations [6].
- **Facilitate communication for less technical personnel:** The use of three-dimensional tools provides a familiar interface for planning operations with operators, thus reducing training time for each operation [7].

As it can be seen, there are many advantages for mining use, and every day companies seek to develop more accurate solutions for an indispensable sector for the global economy and its production is increasing year by year.

This project seeks to deliver a UAV design proposal specially designed to satisfy this sector, but that will have the versatility to be adapted to sectors with similar requirements, such as agriculture, energy, or topographic terrain studies.

1.1 PLM Philosophy

The UAV to be designed will be mainly composed of composite materials and will be defined in this project through the PLM (Product Life Cycle Management) philosophy, which states that without the use of an efficient computer based PLM-system the maximum potential of composite materials cannot be achieved [8]. According to Abramovici, *"PLM has a management focuses addressing <u>all processes, activities, resources, data, information, and applications for the entire lifespan</u> of a product"* [9]. In addition, it can be said that the aim of PLM is *"to trace and manage all the activities and flows of data and information during the product development process and also during the actions of maintenance and support in order to identify a new business model that integrates engineering processes and different ICT tools"*[10].

Figure 2. PLM Concept

The use of composite materials has a series of structural advantages for the aerospace industry, where weight is an important factor when it comes to designing a project. Composite materials have a lower density than conventional materials used in airframes, which means that the aircraft skin can be designed thicker without increasing the weight too much. The fact that complex structures can be assembled in one piece, unlike conventional metallic structures which is practically impossible.

It has been studied that the weight savings of using a composite structure instead of a metallic structure is around 20-25%, which also allows not to generate an unnecessary expense of material to deliver strength and stiffness where it is necessary, but rather to increase these properties by using composites materials [11].

1.2 Market research and production target

The global fixed-wing drone market is a dynamic and rapidly expanding sector. In 2023, it is expected to generate a valuation of **USD 7,085.1 million**, reflecting its significant growth potential. One critical growth metric, the **Compound Annual Growth Rate (CAGR**), which represents the mean annual growth rate of an investment over a specified time period assuming compounding growth, is forecasted at **17.2%**. This substantial CAGR indicates that by 2033, the market could reach a staggering USD 34,643.5 million. Interestingly, in 2022, fixed-wing drone sales constituted nearly **21%** of the global drone market. While military applications continue to dominate fixed-wing drone usage, a substantial demand exists in the commercial sector, notably for mapping operations. This burgeoning market offers extensive opportunities for innovation and expansion within the UAV industry.

1.2.1 Sales analysis of fixed wing drone (2018-2022) V/S Market Outlook (2023-2033)

Sectors	Report Atributes	Details
North America	Market Share (2023)	~ 30.1%
	Market Value (2023)	US$ 2,133.3 Million
Europe	Market Share (2023)	~ 35.4%
	Market Value (2023)	US$2,508.8 Million
China	Market Share (2023)	~ 11.3%
	Market Value (2023)	US$ 806.6 Million
Global	Fixed wing drone market size (2022A)	US$ 5,866.5 Million
	Estimated market value 2023	US$7,085.1 Million
	Forecasted Market Value 2033	US$ 34,643.5 Million
	Market Growth Rate (2023-2033)	**~17.2% CAGR**
	Market share of top 3 Countries	**~ 40.8%**

Table 1. Market share per sectors

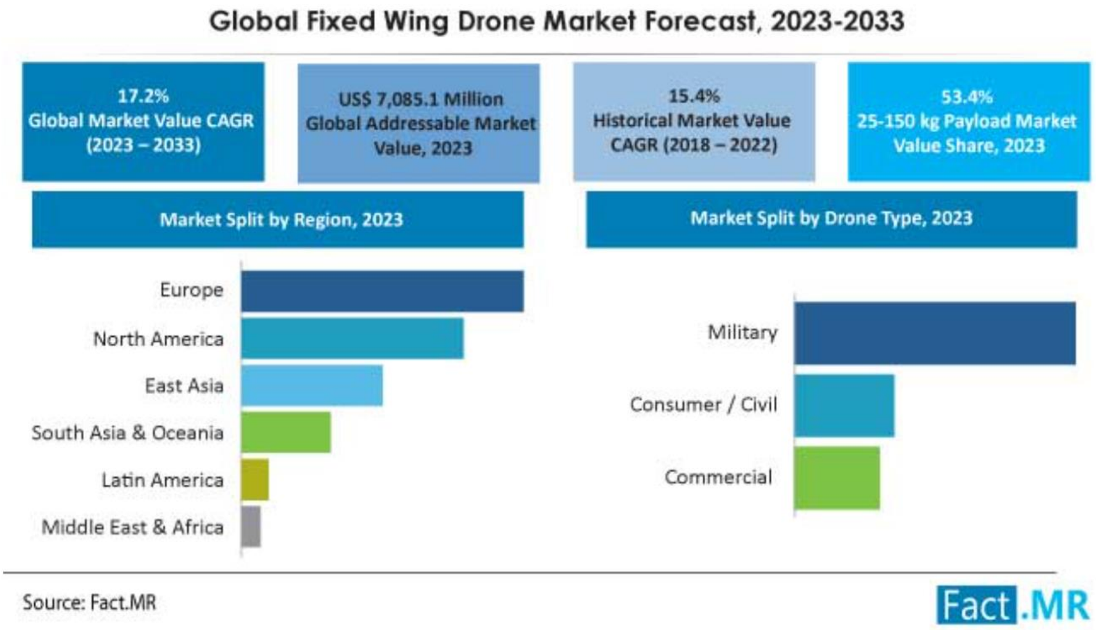
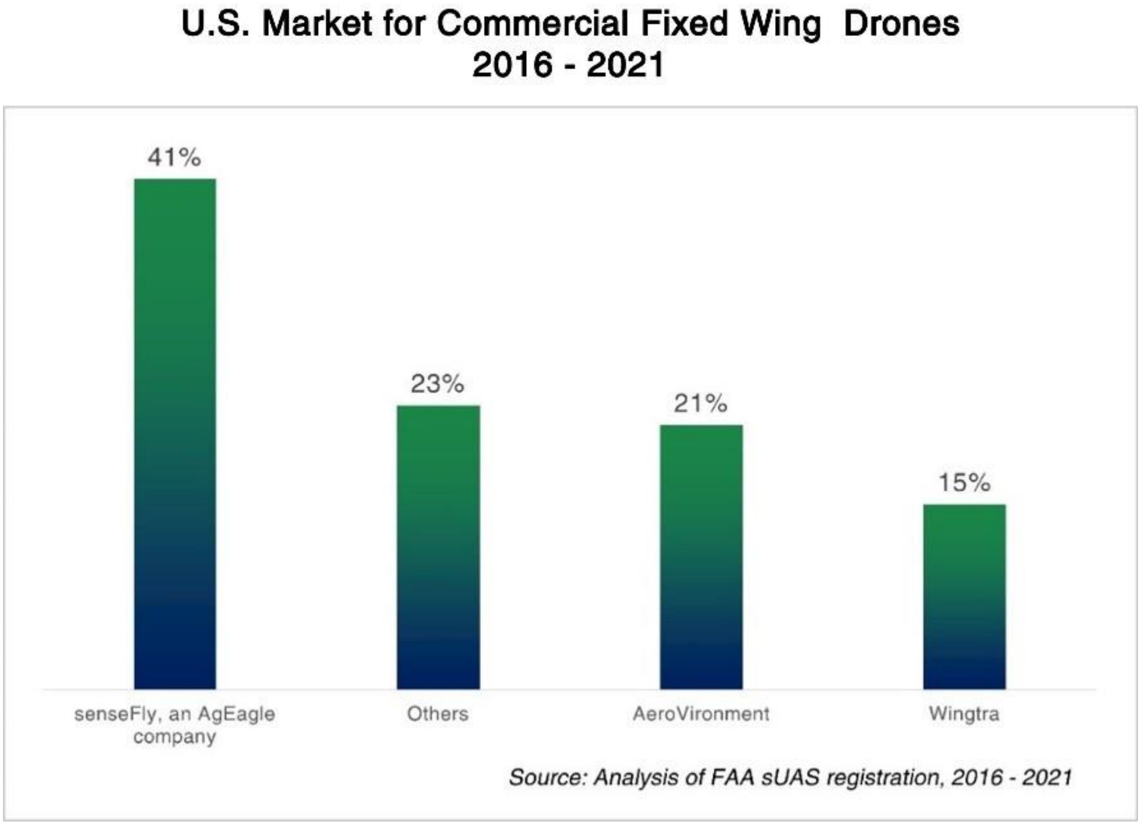


Figure 3. Global fixed wing drone market forecast 2023-2033

The significant growth forecasted, with a strong CAGR of 17.2% expected over the next decade, signifies a market on the cusp of exponential expansion. This advancement is not confined to the military sector, as commercial applications, particularly in mapping, also show great promise.[12]

1.2.2 Key Companies Profiled

Breaking into the established fixed-wing drone market requires careful strategizing, given the existing market players with secured customer bases. A critical first step involves determining the optimal production quantity that aligns with market demand. Understanding this is key to developing an effective entry strategy. Achieving a balance between producing enough units to meet potential demand, while avoiding overproduction, is crucial to maximize profitability and sustainability.



Source: Analysis of FAA sUAS registration, 2016 - 2021

Figure 4. U.S. Market for Commercial fixed wing drone 2016-2021

The Sensefly eBee X drone is currently a market leader, particularly in the United States, where it has been especially dominant. From 2016 to 2021, this drone accounted for a significant 40% of total fixed-wing drone sales in the US market. The popularity and high-performance of the Sensefly eBee X make it a key competitor in the industry. Understanding its appeal and features can provide valuable insights for new entrants looking to position themselves in this competitive market.[13]

1.2.3 Production target

By entering a competitive market like the UAV market, particularly the fixed-wing drone segment, requires a strategic approach. The number of units should be planned to sell in the first year largely depends on various factors including production capacity, target market size, market penetration strategy, pricing strategy, and competitive landscape.

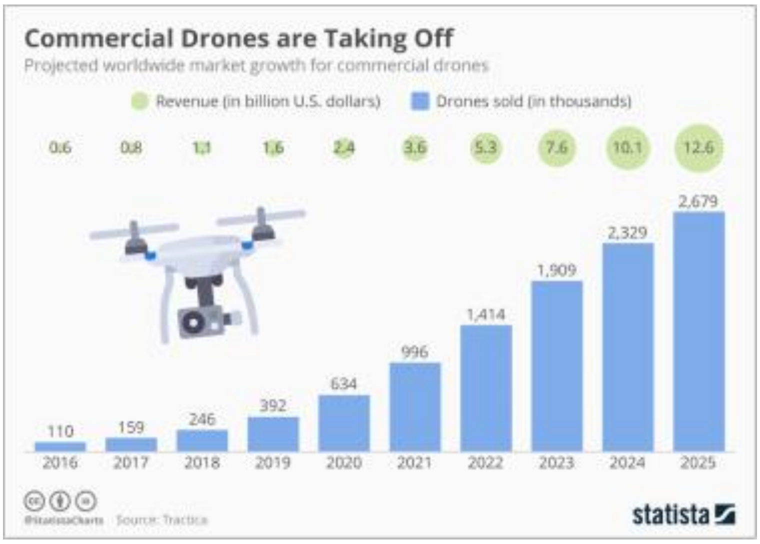


Figure 5. Total Drones sold by years [14]

It must be considered the scale of production, which is intrinsically linked to the current drone sales volume. In 2023, there were 1,909,000 drones sold globally, with fixed-wing drones representing 21% of these sales. This equates to approximately 400,890 fixed-wing drones sold in that year alone. Of these fixed-wing drones, 30% are used commercially for applications such as mapping, indicating an annual production of 120,267 drones in this specific category.[12]

	UAV Units	Total Market Share Percentage
Total UAV Expected to be sold (2023)	1,909,000	100%
Market Share for Fixed Wing UAV	400,890	21%
Market Share for Fixed Wing UAV in Europe	140,312	7%
Market Share for commercial Fixed Wing UAV	8,840	0.463%
Market Share Production Target	**136**	**0.007%**

Table 2. Production target units per total market share

Entering a new market with established competitors necessitates a cautious and strategic approach. Typically, aiming for a market share between **1% and 5%** is a common recommendation for new market entrants [15]. This gives a goal of producing and selling a number of drones that represent the desired market share. This careful and modest approach, while maintaining a competitive edge in innovation and quality, will form the basis of the market penetration strategy.

In addition, for the first year of sales, only exports within Europe are considered, considering that Europe is the **35% of the total market share**. It will be assumed that this percentage is distributed in the same way for this type of drones.

For this market share penetration, it will be seek to enter with **1%** of the total drones of the same type to be produced. This would represent **0.007%** of the total market share of UAV currently sold in the world with a total of about **136** units per year.

1.3 Advantages of the use of composite materials for this sector

An UAV (Unmanned Aerial Vehicle) made of composite materials could offer a number of significant advantages for the mining industry compared to UAVs made with more conventional materials.

Firstly, composite materials have a significantly higher strength-to-weight ratio than more conventional materials like aluminum or steel. This means that lighter and more robust UAVs can be designed, which can improve the vehicle's payload capacity and autonomy. For the mining industry, this could allow for longer duration, range surveillance and exploration missions, without sacrificing the ability to transport equipment and materials.[16]

In addition, composite materials can offer greater impact and fatigue resistance compared to more conventional materials. In the mining industry, where working conditions can be especially harsh and vibrations and jolts are common, this can be an important advantage. A UAV made of composite materials could be more resistant to vibrations and jolts, which could extend its lifespan and reduce maintenance and repair costs.

Another advantage of composite materials is their ability to resist corrosion and oxidation. In the mining industry, where vehicles are often exposed to extreme environmental conditions and aggressive chemicals, this could be an important advantage. A UAV made of composite materials could be more resistant to corrosion and oxidation, which could prolong its lifespan and reduce maintenance and repair costs.

Composite materials can also offer greater design flexibility. Conventional materials like steel and aluminum are relatively rigid and difficult to mold into complex shapes. In contrast, composite materials can be molded into practically any desired shape, which allows for a higher degree of customization and adaptation for a specific use. In the mining industry, this could allow for the creation of UAVs more suited for specific missions, such as surveillance of remote areas or exploration of underground tunnels.[17]

Also, composite materials are temperature resistant. In the mining industry, where temperatures can vary from extremely cold to extremely hot, this can be an important advantage. A UAV made of composite materials could be more resistant to extreme temperatures, which could prolong its lifespan and reduce maintenance and repair costs.

Finally, composite materials can be more environmentally friendly than more conventional materials. In the mining industry, where sustainability and environmental impact are becoming increasingly important, this can be a significant advantage. Composite materials can be recycled and reused more easily than conventional materials, which can reduce waste and decrease environmental impact. [18]

1.4 Mission requirements and limitations

The mining industry has historically been one of the most important and profitable in the world. However, the extraction of minerals and precious metals has become an increasingly complex activity, due to the location of the mines and the extreme conditions in which they operate. To address these challenges, the use of advanced technology, such as UAVs, has begun to play an increasingly important role in the mining industry. In this sense, the design of a UAV specifically for the mining industry, with capabilities to operate in high-altitude mines, could be of great help in carrying out specific missions.

In this context, it is important to identify the key mission objectives that a UAV designed for the mining industry should fulfill, as well as the limitations and challenges that should be taken into account when developing this technology. In particular, resistance to temperature and the ability to operate in altitude conditions are critical factors that must be considered to ensure that the UAV can effectively and efficiently fulfill its mission objectives.

Mission requirements	Value	Description
Speed	53 km/h	The drone needs to be able to fly at a speed of 53 km/h in order to efficiently cover large distances and complete missions within a reasonable time frame.
Altitude	5000 meters above sea level	The drone needs to be able to operate at an altitude of up to 5000 meters above sea level, which is the typical altitude of many mining locations. This requirement is important in order to ensure that the drone can be used in a wide range of mining operations.
Temperature	5 to 30ºC	The drone needs to be able to operate in a temperature range between 5 and 30ºC. This requirement is important because mining locations can experience a wide range of temperatures, and the drone needs to be able to operate in these conditions without any issues.

Table 3. Mission requirements

1.5 Different configurations

For this project, rotary wing configurations have been discarded, leaving only wing configurations for analysis. For this project it will be analyzed the advantages and disadvantages of different configurations that could meet the requirements of the mission.[19]

Figure 6. Conventional tail and delta wing configurations

Unmanned Aerial Vehicles (UAVs) can employ a conventional tail or delta wing configuration, each with its unique advantages. The conventional tail design, with its main wing and separate tailplane, provides stability and control across a wide range of speeds, making it beneficial for missions requiring steady, low-speed flight. In contrast, the delta wing design, characterized by its triangular, single large wing, offers superior maneuverability and excels in high-speed and high-altitude conditions. The choice between these configurations depends on the specific operational requirements and mission objectives of the UAV. [20]

Type of UAV	Advantage	Disadvantage
Conventional Wing	Easy to design and build.	Requires a longer takeoff and landing distance.
	Excellent performance in cruise flight at high speeds.	Lower aerodynamic efficiency at low speeds.
	Greater stability in flight.	Lower payload capacity.
Flying wing	Greater aerodynamic efficiency at low speeds.	Greater complexity in design and construction.
	Higher payload capacity.	Lower stability in flight.
	Lower aerodynamic drag.	More difficult to control and maneuver.

Table 4. Advantages and disadvantages per each configuration

In summary, the blended wing-body configuration presents significant advantages for UAVs used in the mining industry with low flight regimes. Despite the greater complexity in design and construction, this configuration can offer greater efficiency and payload capacity, making it a good option for mining industry applications.[21]

Chapter 2. State of art

2.1 Composite materials

Composite materials are engineered products made from two or more constituent materials with significantly different physical or chemical properties, which, when combined, produce a material with characteristics different from the individual components. The main advantage of composite materials is that they can be designed for specific applications, with their properties tailored to meet particular performance requirements. This project will be focused on Carbon Fiber Reinforced Polymer (CFRP), a type of composite material known for its high strength-to-weight ratio.[22]

2.1.1 Carbon Fiber Reinforced Polymer (CFRP)

Carbon fiber is a very strong and lightweight material with high tensile strength and high rigidity. It is five times stronger and two times stiffer than steel, and has a density of only one-quarter of that of steel. Because of these characteristics, carbon fiber has become a very popular material in the manufacturing of structural components for aviation, automotive industry, construction, and other sectors.

CFRP has several advantages compared to other structural materials. It is extremely strong and stiff, meaning it can withstand large loads and is very durable. It is also very lightweight, which means it can significantly reduce the total weight of a structure without compromising its strength. Additionally, it is corrosion-resistant and has excellent fatigue resistance.

However, it also has some disadvantages. It is a costly material and requires a complex manufacturing process, making it less accessible than other materials. Additionally, the compressive strength of CFRP is lower than its tensile strength, meaning it may be more susceptible to failure under certain loads.[23]

2.1.2 Fibers

Fibers are one of the main components of composite materials, and their choice is crucial to obtain the desired mechanical properties in the final product. Some of the important properties of fibers include tensile strength, stiffness, toughness, density, dimensional stability, fatigue resistance, chemical resistance, temperature resistance, among others. In the aeronautical industry, high strength and stiffness fibers such as carbon, glass, aramid, and some specialty fibers such as boron and graphene are commonly used. The choice of fiber will depend on the specific properties required for the particular application.

Figure 7. Carbon fibers

The arrangement and orientation of these fibers can significantly influence the properties of the final composite, allowing customization to specific application needs. By improving overall material performance, fibers contribute to the effectiveness of composite materials in a variety of industries.[24]

2.1.3 Matrix

In a composite material like Carbon Fiber Reinforced Polymer (CFRP), the epoxy resin acts as the matrix. Its role is essential as it binds the reinforcing fibers together, enabling stress transfer between them and contributing to the overall structural integrity of the composite. The epoxy matrix also protects the fibers from environmental damage and helps to distribute loads evenly, reducing the likelihood of failure under stress.

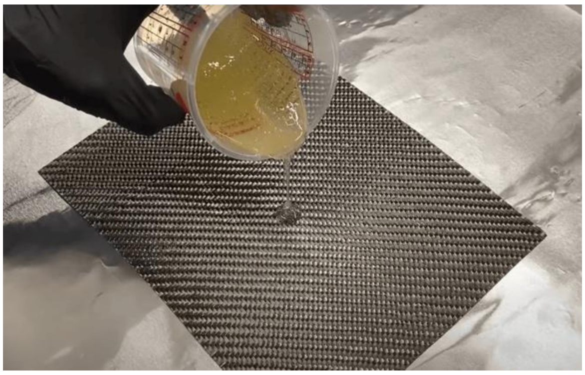


Figure 8. Epoxy resin

While the fibers provide the strength and stiffness, the matrix allows this strength to be effectively utilized by maintaining the fibers in their correct alignment and position.[24]

2.1.4 Considerations

When designing with composite materials like CFRP, there are numerous considerations to keep in mind. The orientation of the fibers within a layer significantly influences the mechanical properties of the composite. For instance, fibers aligned with the direction of the applied load can bear more stress, while a cross-ply orientation can enhance properties in multiple directions.

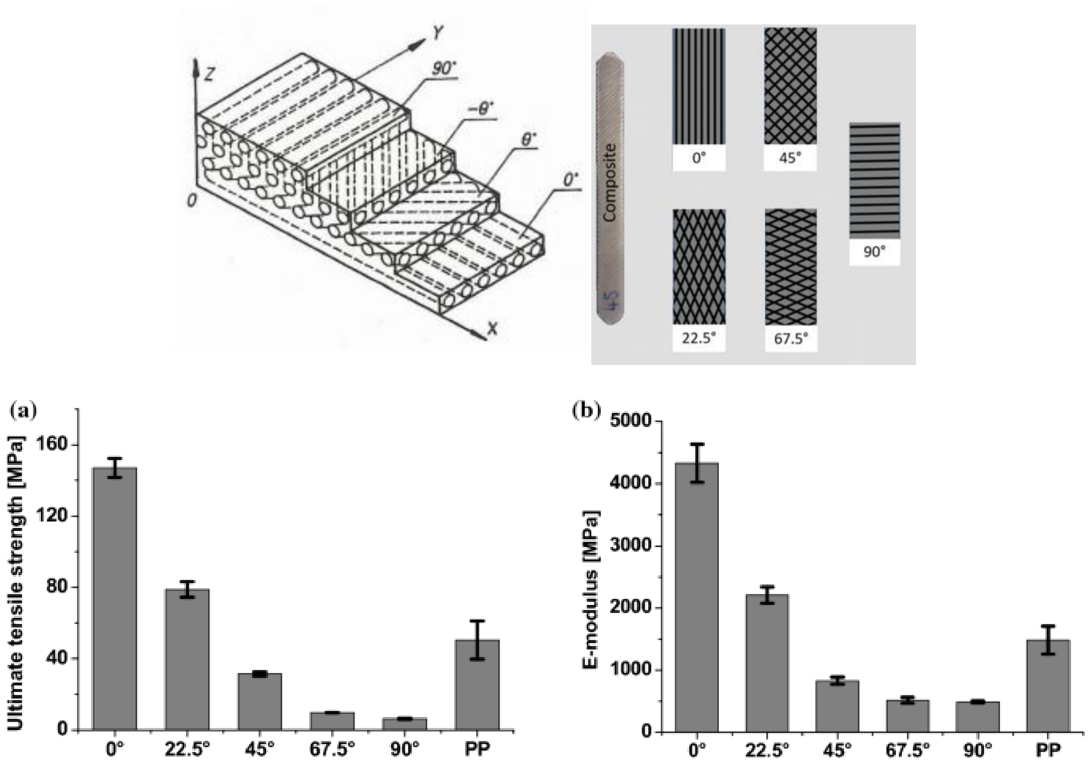


Figure 9. Mechanical properties variation in fibers orientations

In Figure 9 It can be seen how different fiber orientations can generate different mechanical properties for the polypropylene-lyocell composite. In this particular study it was shown that the fibers oriented at 0º and 90º have the highest tensile strength and stiffness, while the fibers oriented at +-22.5º and +-67.5º have a lower strength. Fibers oriented at +-45º have Intermediate strength.

Although fibers oriented at 0° and 90° may provide the greatest strength in certain situations, other orientations may be preferable for specific applications. For example, fibers oriented at ±45° may provide higher shear strength, while fibers oriented at ±30° may provide higher flexural strength. In addition, fiber orientation may also affect the deformation and fatigue resistance of the composite material.[25]

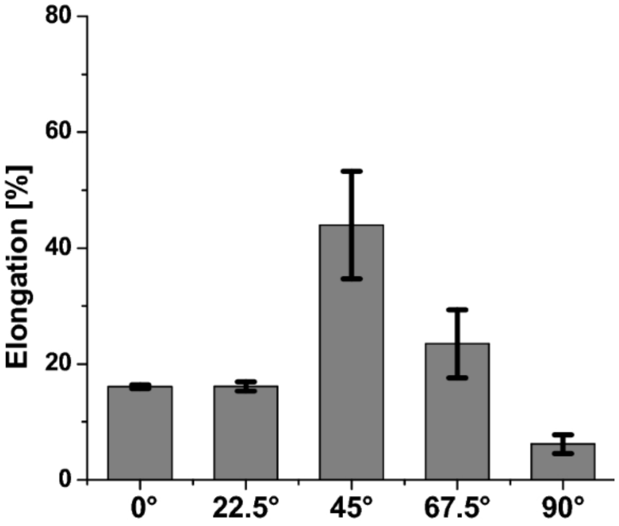


Figure 10. Percentage of elongation variation for different fibers orientations

The elongation of the fibers in a composite material depends to a large extent on their orientation. When the fibers are oriented in the direction of loading, i.e., in the longitudinal direction, the composite material has a higher tensile strength, but a lower elongation. On the other hand, when the fibers are oriented perpendicular to the loading direction, i.e., in the transverse direction, the composite material has a lower tensile strength but a higher elongation.

2.2 Production methods

2.2.1 Wet lay-up

Wet layup is a manual process for making composite parts by applying layers of fiber reinforcement to a mold, which are then wetted out with resin. This method is commonly used in prototyping and small-scale production due to its low cost and simplicity.

The process begins with the preparation of the mold, which must be cleaned and coated with a release agent. It is important that the surface must be completely clean, smooth and free of any contaminants that may cause defects in the final part. Then, the pre-cut carbon fiber layers are placed in the mold, often using a template to ensure correct placement of the layers.

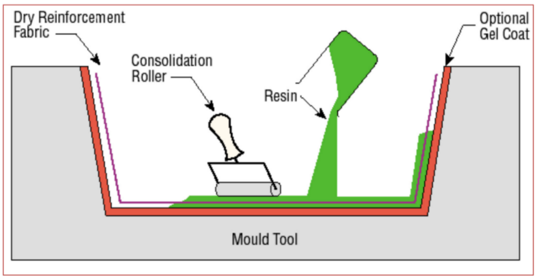


Figure 11. Wet lay-up process representation

It is important to ensure that enough resin is applied to completely saturate the carbon fibers. After resin application, excess resin is removed using the scraping technique, which ensures uniform resin distribution and elimination of air bubbles. The top layer is then covered with a plastic film to prevent the resin from evaporating during the curing process.

It is important to note that Wet Layup is a manual process, which means that it is susceptible to human error and that the quality of the final product is highly dependent on the skill of the operator. In addition, this process is generally slower and less efficient than other automated CFRP production methods. However, it is still a commonly used technique in the manufacture of small parts and prototypes.[26]

2.2.2 Resin Transfer Molding (RTM)

RTM (Resin Transfer Molding) is a composite manufacturing process in which liquid resin is injected into a closed mold containing the reinforcing fiber. The resin infiltrates through the fiber and cures to form the final part. It is a process suitable for producing high quality, complex parts in a wide variety of shapes and sizes.

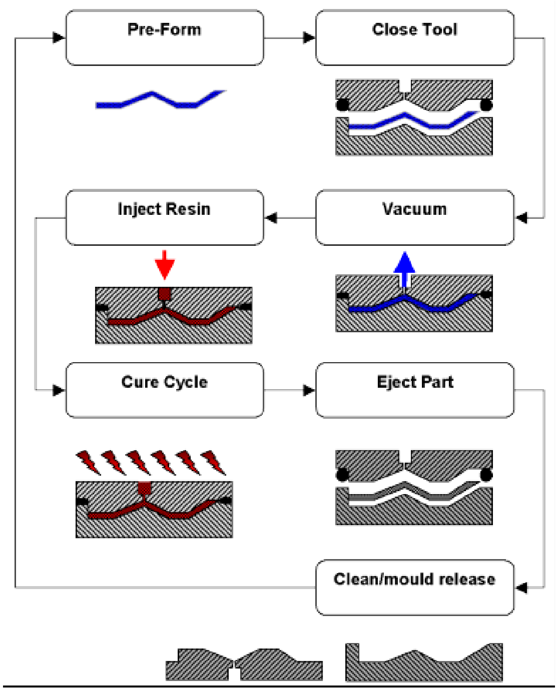


Figure 12. RTM Process flow representation

Classic RTM uses a closed mold system where the reinforcing fibers are placed into the mold, and then resin is injected to impregnate the fibers. The mold is typically two-sided, allowing for the creation of complex geometries with smooth finishes on all exposed surfaces. The pressure applied during the resin injection ensures good resin distribution and compaction, leading to high-quality parts.

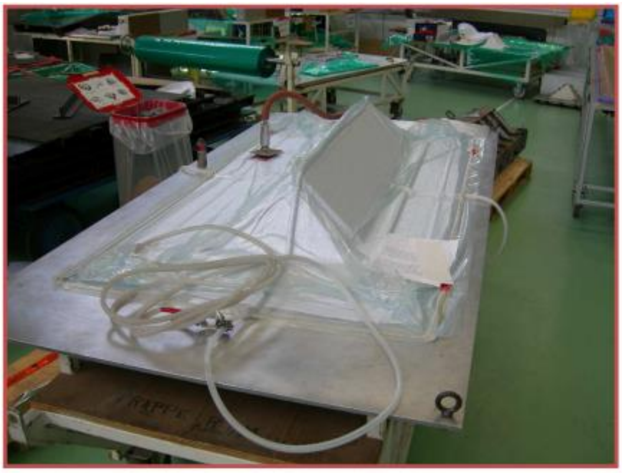


Figure 13. VARTM Process

A significant variation on this process is Vacuum Assisted Resin Transfer Molding (VARTM), sometimes referred to as infusion molding. This technique leverages the principles of RTM but uses vacuum pressure to draw the resin into the mold, rather than forcing it in with positive pressure. The vacuum is applied using a special bag placed over the laid-up fibers in a one-sided mold. This process allows for less equipment and lower injection pressures, making it more cost-effective, especially for large parts. However, it may not offer the same level of control over resin distribution and fiber compaction as traditional RTM.[27]

2.2.3 Prepreg

The prepreg method is an advanced composite manufacturing process used to produce high quality CFRP (carbon fiber reinforced plastic) parts with excellent mechanical properties. In this process, the carbon fiber is supplied already impregnated with a thermosetting resin and then cured under controlled temperature and pressure.

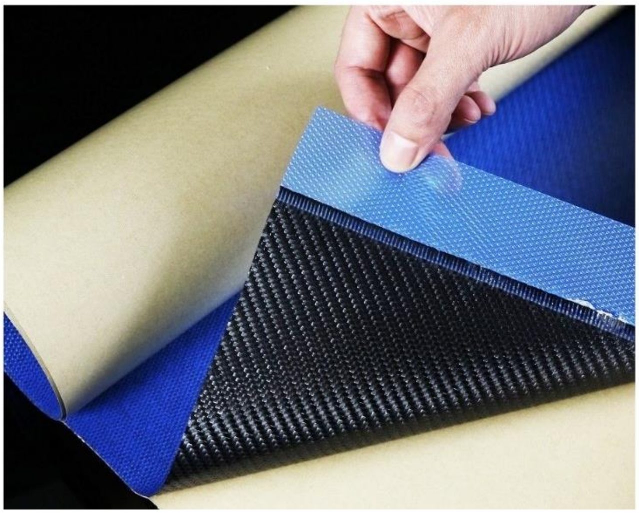


Figure 14. CFRP Prepreg

Prepregs are cold stored to slow the curing of the resin until the part is ready to be molded and fully cured. The use of prepregs offers several advantages in composite manufacturing. The resin-to-fiber ratio is precisely and uniformly controlled, which can improve the mechanical properties of the finished composite. Also, because the resin is already in the fiber, it does not need to be added during the manufacturing process, which can simplify the process and reduce the possibility of errors.

Prepregs typically require an autoclave curing process to ensure complete polymerization of the resin. During this process, the prepreg is subjected to high pressure and temperature to compact the fibers and cure the resin, resulting in a high-strength, low-weight material. However, room temperature curing prepregs are also available, although they tend to offer inferior mechanical properties to those that require autoclaving.[28]

2.3 Curing process

Resin curing in composite materials refers to the process of transforming thermosetting resin from a liquid or semi-liquid state to a solid, rigid, thermosetting state. This process is essential for the creation of durable and strong composite materials.

Curing is achieved by resin polymerization, which is a chemical process that transforms resin molecules into long, interlocking polymer chains. This is achieved through the activation of resin curing agents, which can be heat, UV light or a chemical catalyst.

- **Heat curing:** The resin is heated to a specific temperature for a specific period of time, which allows the resin curing agents to react and begin to form polymer chains. This process is ideal for creating durable and strong composite materials, but is slower than the UV light curing process.
- **UV light curing:** A photosensitive resin containing a light-curing initiator is used. The resin is exposed to a specific UV light that activates the initiator and triggers polymerization. This process is very fast and precise, making it ideal for applications requiring fast curing and high precision.
- **Chemical catalyst curing**: A catalyst is added to the resin that triggers polymerization. Once the catalyst is mixed, the resin is placed in the mold and cured at room temperature. This process is slower than the heat curing process, but is ideal for applications that require room temperature or low temperature curing.

Proper resin curing is critical to creating composites with optimal mechanical properties and durability. Failure to cure properly can result in reduced composite strength and stiffness, as well as increased susceptibility to environmental degradation and cracking over time.[29]

2.4 Demolding & cleaning process

The demolding and cleaning process in composite manufacturing is a crucial step in maintaining the efficiency and quality of production. After the curing process, the newly formed composite part is removed from the mold, a process known as demolding. This step requires careful manual handling to ensure the integrity of the composite part and avoid any damage to the mold.

Residual resin or other materials on the mold surface can affect the quality of subsequent parts and even cause damage to the mold over time. Therefore, the cleaning process is vital to maintain mold longevity and ensure consistent part quality. The mold cleaning process typically involves manual operations to remove cured resin and other debris from the mold surface.

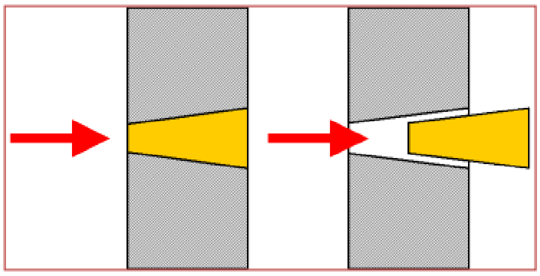


Figure 15. Example of demolding representation

One of the innovative cleaning techniques used in the industry is the use of cryogenic devices. These devices use the properties of extreme cold to remove unwanted materials from the mold. During cryogenic cleaning, high-pressure liquid nitrogen or carbon dioxide is used to rapidly cool the residual material on the mold, making it brittle. This extreme change in temperature causes the material to shrink, making it easier to be removed without causing damage to the mold surface.[30]

2.5 Final operations

The final operations in the composite manufacturing process encompass a range of activities, including trimming, drilling, finishing, and especially the inspection and testing of the finished part. These final checks are essential to ensure that the part meets the required specifications and can function as intended without failure.

Non-destructive testing (NDT) methods are particularly crucial in the inspection of composite materials. They provide ways to inspect the integrity of the parts without causing damage, therefore allowing any defects to be identified and addressed before the parts are put into service. Common defects in composite materials can include delamination, porosity, voids, or inclusions, all of which can significantly affect the part's performance.[31]

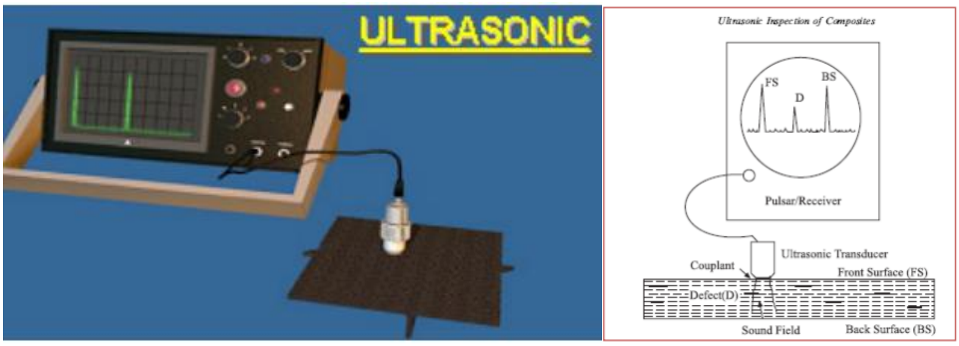


Figure 16. Ultrasonic method

Ultrasonic inspection is one of the most widely used NDT methods for composites. This technique uses high-frequency sound waves that are sent through the material. Any changes in the sound wave’s reflection can indicate the presence of flaws or changes in the material’s structure. For example, if there is a void or delamination inside the composite, the sound wave will reflect differently than it would from a solid, intact material. This difference can be detected and analyzed to determine the nature and location of the defect.

Another common method is radiographic testing, which uses X-rays or gamma rays to inspect the internal structure of the composite. Similar to how medical X-rays work, any defects will show up as changes in the transmitted radiation.

In addition to these techniques, other NDT methods like thermography are also used depending on the composite's nature and the expected types of defects. Ultimately, these final operations are critical for ensuring that the composite part has been manufactured correctly and is safe and ready for use.

Chapter 3. UAV Design

3.1 Design approach

The design of the UAV was largely inspired by the AgDrone, an agricultural drone known for its robust design and high efficiency. The AgDrone is a blended wide body type drone, a design concept that seamlessly merges the wing and fuselage.

Figure 17. Model inspiration

The adoption of the AgDrone as a design reference for the UAV design was principally due to its simplified control system and the mechanics of its aileron movement. Its practical and efficient design allows for enhanced flight. Moreover, the AgDrone served as a crucial guide in defining the wingspan for the UAV preliminary design.[32]

3.2 Airfoil

A suitable airfoil must be chosen to meet the mission requirements of a delta-wing UAV, since a large part of its total area is composed by the wings. To analyze the airfoil, XFLR5 software will be used to calculate the Reynolds number, which is an important parameter in fluid mechanics and affects the flow behavior of a fluid and can affect the performance of devices such as airfoils, propellers and pumps. To calculate the Reynolds number, several parameters such as velocity, density and viscosity of the air are needed. Assuming a standard temperature of 15°C and an average barometric pressure of 5180 Pa at an altitude of 4000 meters, the air density can be calculated.

$$\rho = \frac{p}{R * T}$$

Where:

- p = barometric pressure = 5180 Pa
- R = gas constant for dry air = 287 J/(kg*K)
- T = absolute temperature = 288.15 K (15°C + 273.15)

Therefore, the density of air at 4000 meters altitude is:

$$\rho = \frac{5180}{287 * 288.15} = 0.717\ kg/m\^{}3$$

To calculate the Reynolds number, it is needed to know the velocity of the UAV. At 55 km/h, the velocity in meters per second is:

$$V = 55\ km/h = 15.28\ m/s$$

The Reynolds number can be calculated as:

$$Re = \frac{\rho * V * c}{\mu}$$

Where:

- c = airfoil chord
- µ = kinematic viscosity of air

The kinematic viscosity of air at an altitude of 4000 meters can be estimated using an empirical equation, such as the Sutherland equation [33]:

$$\mu = \mu_{ref} * \left(\frac{T}{T_{ref}}\right)^{\frac{3}{2}} * \frac{T_{ref} + S}{T + S}$$

Where:

μ_{ref} = kinematic viscosity of air at a reference temperature T_{ref} = 273.15 K and a reference pressure P_{ref} = 101325 Pa

S = Sutherland constant for dry air = 110.4 K

The kinematic viscosity of air at 4000 meters altitude would be:

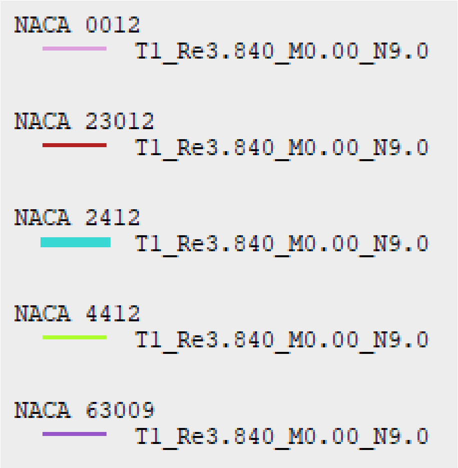
$$\mu = 1.46 * 10^{-5} * \left(\frac{288.15}{273.15}\right)^{\frac{3}{2}} * \frac{273.15 + 110.4}{288.15 + 110.4} = 1.199 * 10^{-5} \frac{m^2}{s}$$

Assuming an airfoil chord of 0.4 meters, the Reynolds number would be:

$$Re = \frac{(0.717 * 15.28 * 0.4)}{1.199 * 10^{-5}} = 3.84e + 6$$

This value indicates that the flow around the airfoil would likely be turbulent. There are some airfoils that are more suitable for turbulent flows and others for laminar flows. Generally, airfoils designed to operate in laminar flows have thinner profiles and smoother surfaces. In contrast, airfoils designed to operate in turbulent flows have thicker profiles and rougher surfaces.[34]

The aerodynamic analysis performed on XFLR5 for different NACA airfoils with different geometries, with the Reynolds number flow regime previously calculated, is shown in the following figures



NACA 0012
T1_Re3.840_M0.00_N9.0

NACA 23012
T1_Re3.840_M0.00_N9.0

NACA 2412
T1_Re3.840_M0.00_N9.0

NACA 4412
T1_Re3.840_M0.00_N9.0

NACA 63009
T1_Re3.840_M0.00_N9.0

Figure 18. Different airfoil analyzed divided by colors

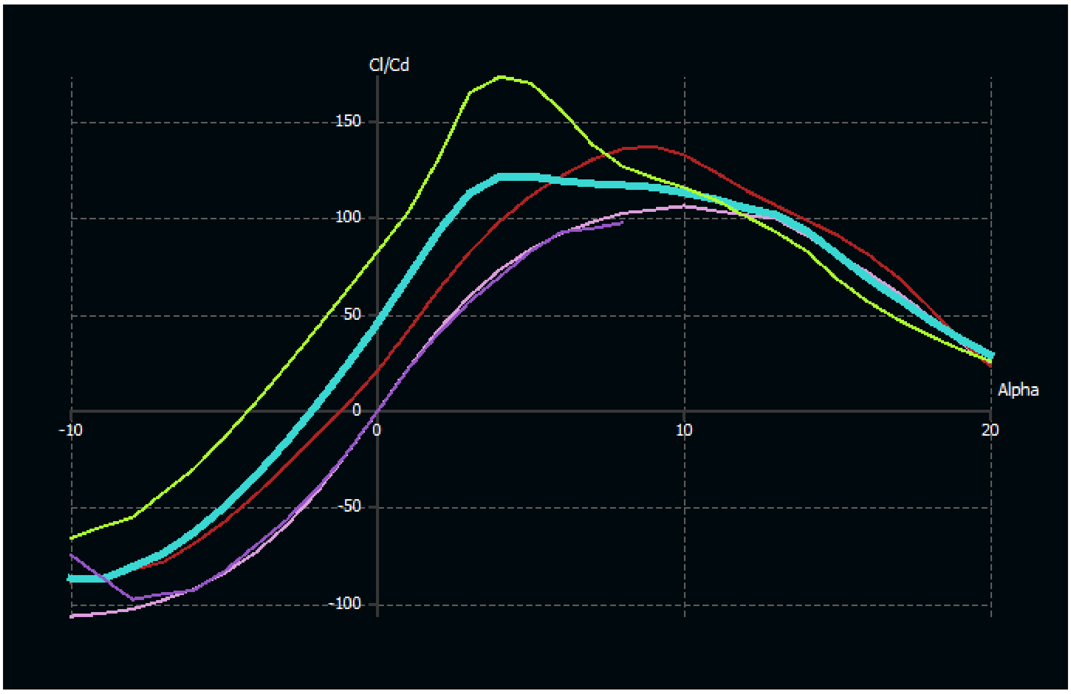


Figure 19. Cl/Cd Vs Alpha graph for different airfoils

The Cl/Cd versus alpha plot shows the efficiency of the airfoil in terms of the ratio of lift to drag. The slope of the curve indicates the efficiency of the airfoil, i.e., its ability to generate lift without increasing drag too much. An airfoil with a high slope on this graph is more efficient than one with a low slope. In addition, the maximum Cl/Cd point indicates the optimum angle of attack for the best lift-to-drag ratio. This graph is important for selecting an airfoil that has the right efficiency for the specific application.[35]

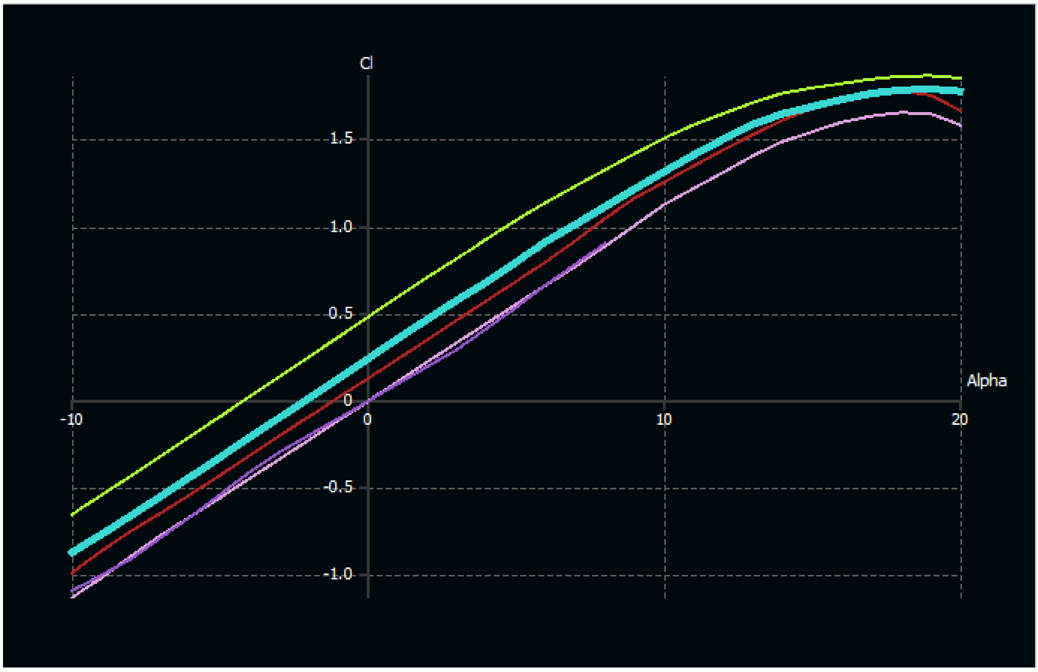


Figure 20. Cl Vs Alpha graph for different airfoils

Once again it can be possible to see that the NACA 4412 and NACA 2412 are the ones that generate the most lift within the airfoils under study.

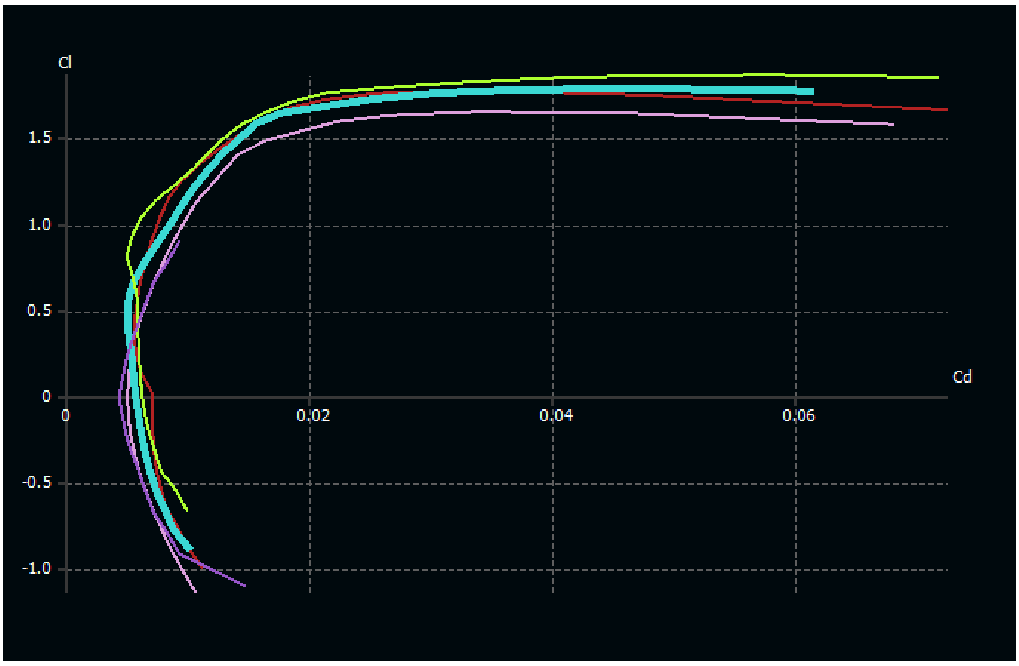


Figure 21. Cl Vs Cd graph for different airfoils

The NACA 4412 airfoil produces higher lift coefficients at low angles of attack and shows a smooth stall characteristic, ensuring a greater degree of stability and control for the UAV in various flight conditions.

Also, the NACA 4412 has a lower drag coefficient in comparison to the NACA 2412 at the same angles of attack, improving the UAV's energy efficiency. This means that the UAV would have a longer flight duration on the same amount of battery power, a critical factor for operational efficiency and mission accomplishment.

Finally, the thicker profile of NACA 4412 also offers better structural robustness, allowing it to handle the physical stress and strains during flight better than the thinner NACA 2412. This results in an overall enhanced structural integrity and durability of the UAV, thus extending its operational lifespan.

Chapter 4. Selection of production method

4.1 Preliminary production

The process will start with a test design in Wet lay-up. Firstly, It will created the molds using a CNC router to shape MDF (Medium Density Fiberboard) blocks. **MDF** is a material commonly used in mold manufacturing due to its ease of cutting and shaping. However, since MDF is porous, it requires some preparation before it can be used for carbon fiber layup. This preparatory process includes a sanding process to smooth the surface, followed by applying **Clear Coat** to seal the pores and provide a smooth, non-porous surface.[36]

Figure 22. MDF & PTFE

This preparatory process includes a sanding process to smooth the surface, followed by applying **Clear Coat** to seal the pores and provide a smooth, non-porous surface. After the Clear Coat has dried, a layer of resin is applied to enhance the durability of the mold and provide a solid surface for layup. Finally, a film of **PTFE** (polytetrafluoroethylene), also known as Teflon, is applied to the mold's surface. PTFE is a material that has excellent chemical and thermal resistance, and it's very slippery, making it an excellent release agent. This will allow the carbon fiber to easily detach from the mold once cured.

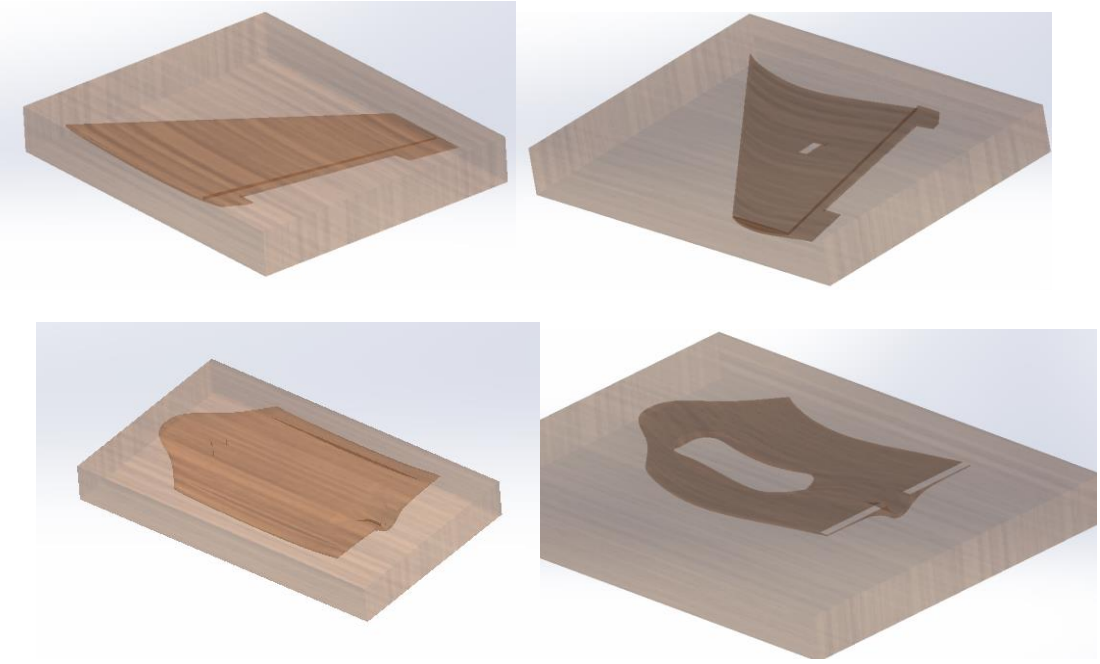


Figure 23. MDF Molds illustrations

Regarding the carbon fiber, **HX50 prepreg** will be used. Prepreg is a form of carbon fiber that has already been impregnated with resin, allowing for greater control over the fiber/resin ratio, and hence the final properties of the composite. Above the carbon fiber, a **Peel Ply PA 83g/m2** will be applied to absorb excess resin.[37]

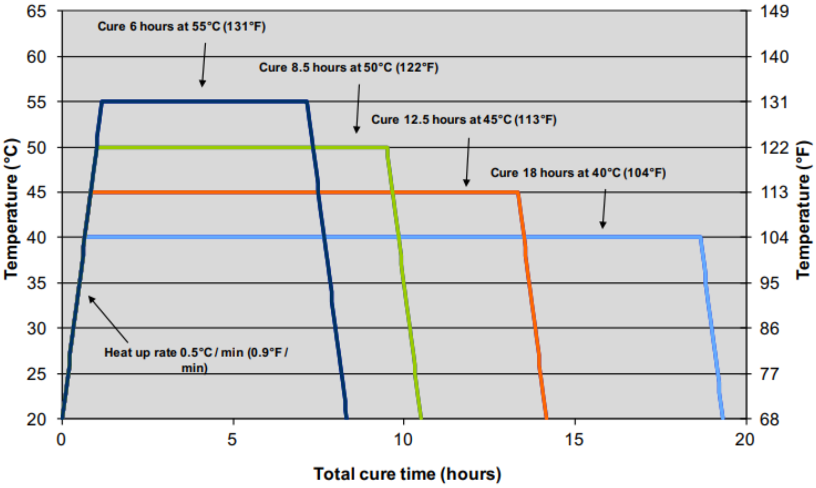


Figure 24. Initial Minimum cure Schedule for HX50 Prepreg

The next step is bagging, a process that involves placing the component in a vacuum bag and applying heat and pressure. It will be placed in an oven at 40ºC for 18 hours for an initial pre-cure. The heat up rate must be slow and will be in a rate of 0.5ºC/min for 40 minutes.

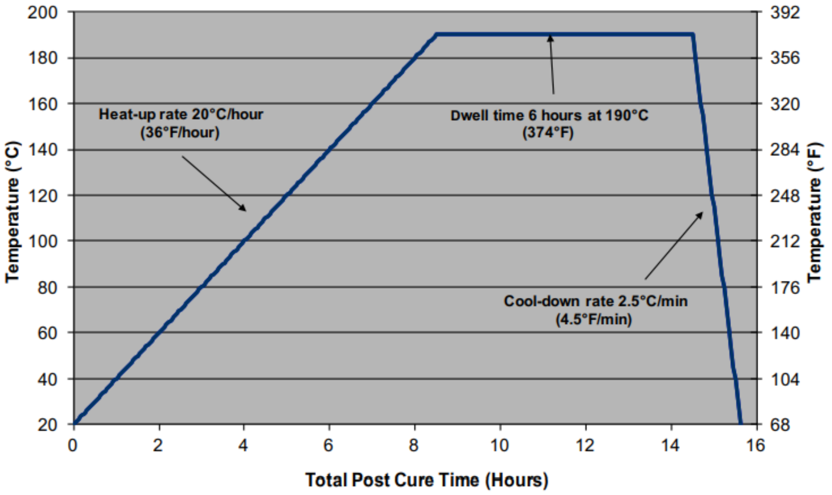


Figure 25. Initial post cure for prototype model

After this, a post-cure of 6 hours at 190ºC will be carried out, raising the temperature at a rate of 20ºC/hour over 9 hours, then cooling it at a rate of 2.5ºC/min for 70 minutes. This combination of heat and pressure will ensure the resin cures correctly and the carbon fiber achieves the desired stiffness and strength. The alternative used in the figure 25. will be the one that is painted light blue.[37]

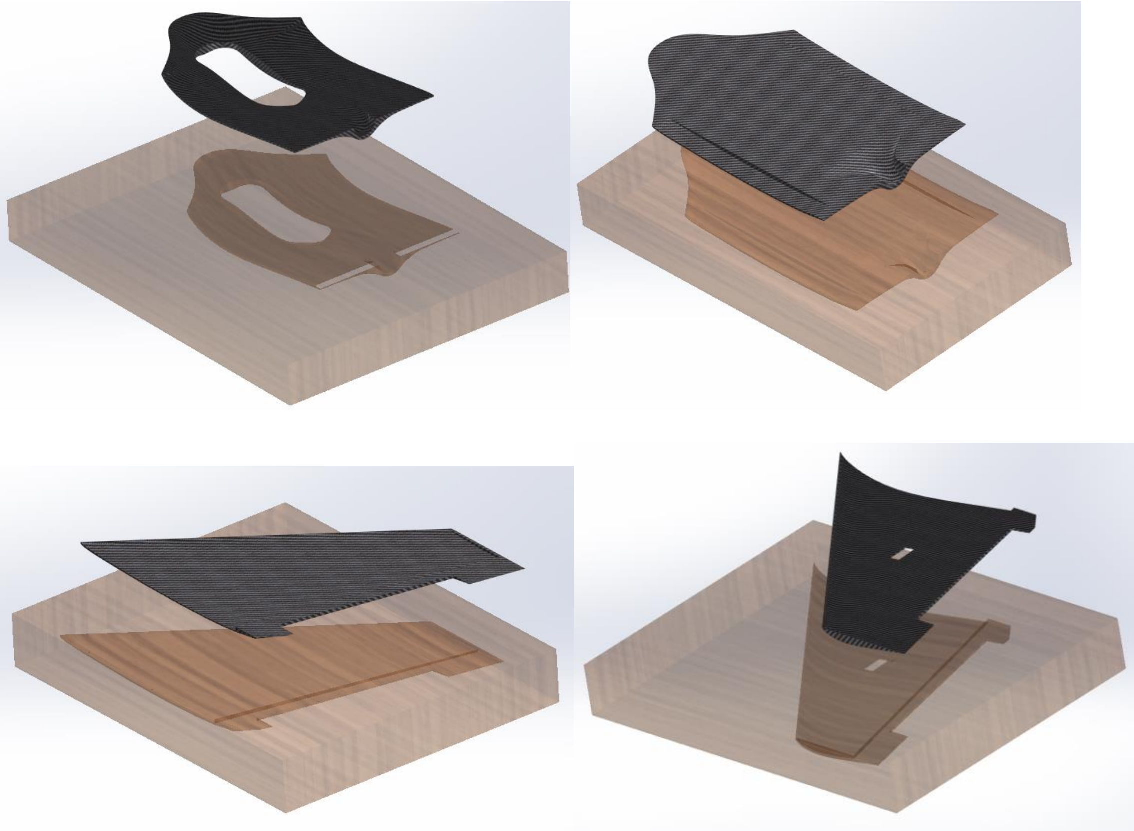


Figure 26. Wet lay-up prototype demolding illustration

Once the components have been fully cured and cooled, they will be bonded together using **Araldite 2015-1**, a durable and strong epoxy adhesive.

Figure 27. Araldite 2015-1

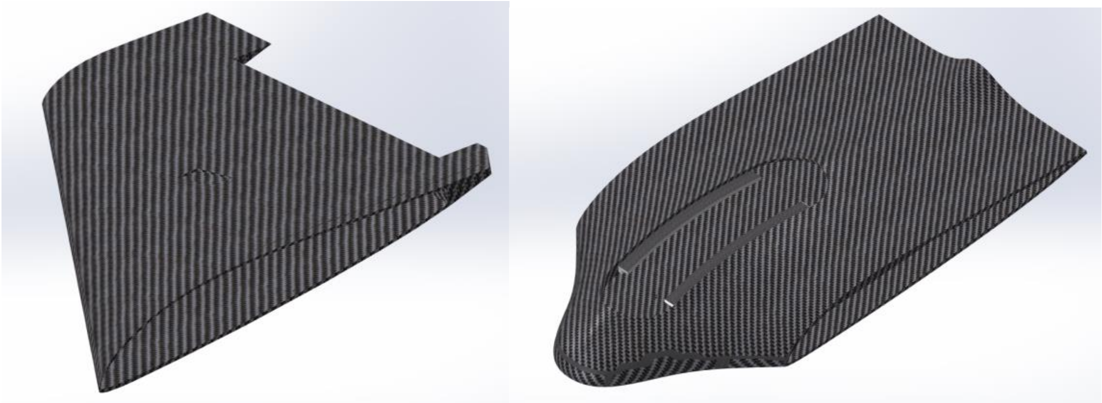


Figure 28. Final wings and fuselage Carbon fiber structure

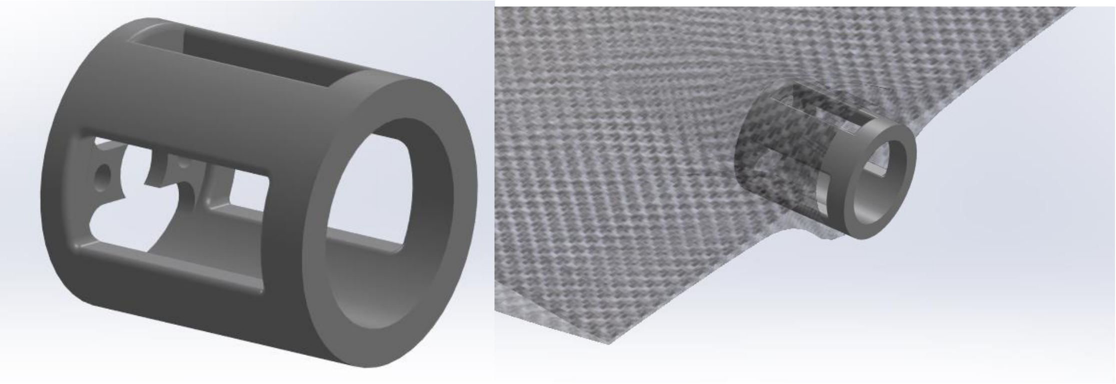


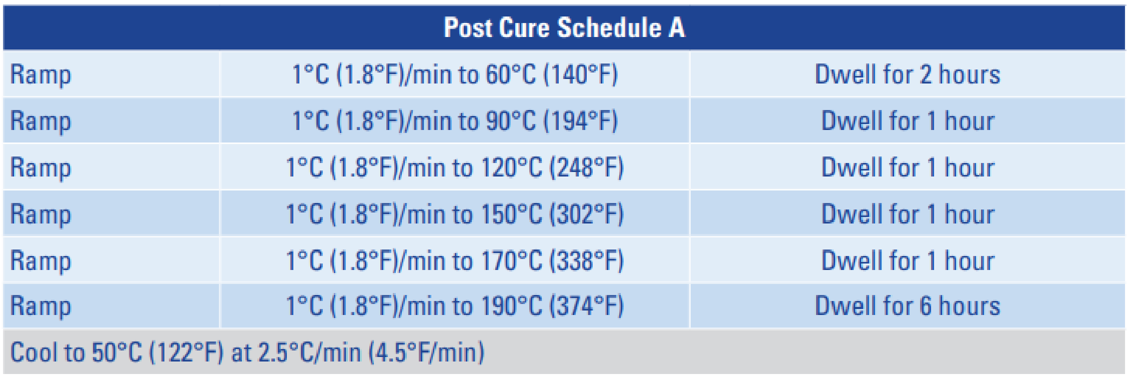
Figure 29. Assembly Motor mount with Araldite 2015-1

The preliminary wet lay-up process is essential in carbon fiber production as it aids in verifying and adjusting the design before the more intensive autoclave process. It helps identify potential design and material issues early on, avoiding costly reworks later. Wet lay-up also allows the feasibility check of fiber conformability and resin distribution. Furthermore, it is useful for prototyping and producing test pieces, facilitating understanding of the product and the process, and making necessary adjustments before transitioning to large-scale production in the autoclave. In essence, this preliminary stage can streamline the production process, leading to efficient large-scale manufacturing.

4.2 Production system

4.2.1 Carbon Fiber

For the industrial-scale production of the UAV's fuselage and wing structures, it will be employed an **Automated Tape Layup (ATL)** system, specifically designed to handle carbon fiber materials. The composite material chosen is a carbon fiber **Prepreg, HX50**, renowned for its consistency and high-quality performance. To ensure a smooth finish and absorb excess resin, **a peel ply layer** will be integrated during the layup process. High-quality, durable molds, made from aluminum will be used to form the precise shapes of the fuselage and wing parts. Each part will be created separately, followed by a curing process in the autoclave as recommended by the HX50 manufacturer. The resulting components will then be joined using a suitable adhesive, in this case, **Araldite 2015-1**, to complete the assembly of the UAV structure.[36]



Post Cure Schedule A		
Ramp	1°C (1.8°F)/min to 60°C (140°F)	Dwell for 2 hours
Ramp	1°C (1.8°F)/min to 90°C (194°F)	Dwell for 1 hour
Ramp	1°C (1.8°F)/min to 120°C (248°F)	Dwell for 1 hour
Ramp	1°C (1.8°F)/min to 150°C (302°F)	Dwell for 1 hour
Ramp	1°C (1.8°F)/min to 170°C (338°F)	Dwell for 1 hour
Ramp	1°C (1.8°F)/min to 190°C (374°F)	Dwell for 6 hours
Cool to 50°C (122°F) at 2.5°C/min (4.5°F/min)		

Figure 30. Post-cure schedule for Prepreg method

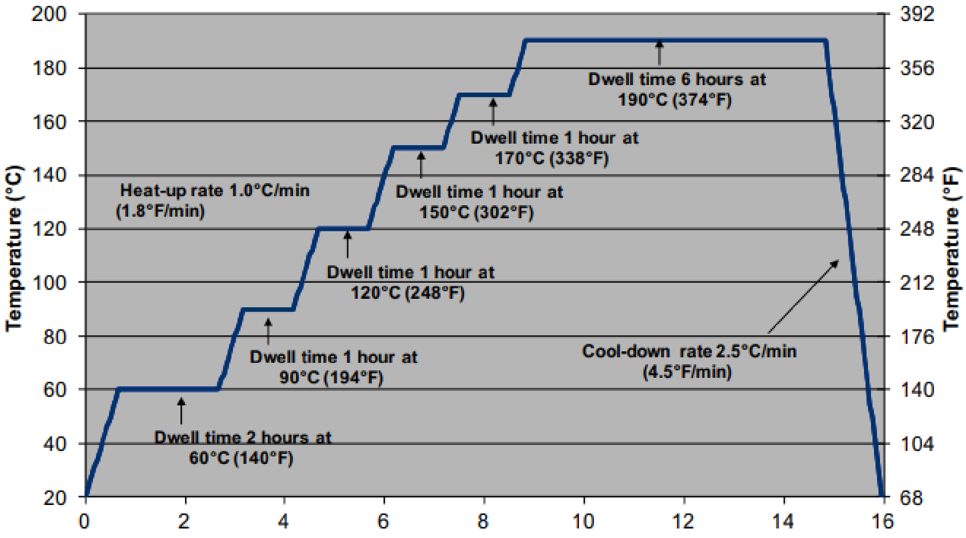


Figure 31. Staircase curing cycle Prepreg Method

The supplier of the HX50 prepreg provides a recommended curing cycle in a "staircase" format. This is a common method for curing composites, which involves gradual increments in temperature, with isothermal (or constant) periods at specific intervals. At these isothermal points, the temperature is held constant to allow the material to adapt and cure at that temperature level before moving to the next increase**. A curing pressure of 5 bar**[38] will be used. This pressure is maintained throughout the curing cycle to ensure proper consolidation of the layers of material.

4.2.2 3D Print

4.2.2.1 Preforms

3D printing technology will be leveraged to create preforms for additional parts. These include two supports for the UAV's lid, both winglets, and two ailerons.

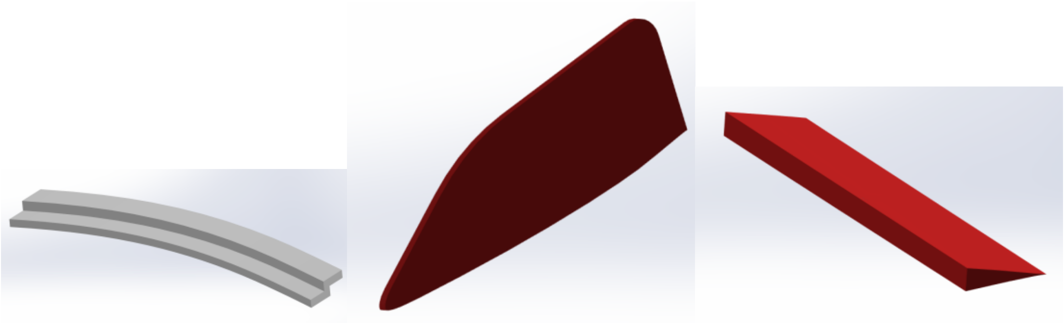


Figure 32. Preforms illustration 3D printed

These parts will be 3D printed using **PLA (Polylactic acid)**, a commonly used thermoplastic for 3D printing due to its easy processability and decent mechanical properties. Once the preforms have been printed, they will be covered with the **HX50 carbon fiber prepreg.**[36]

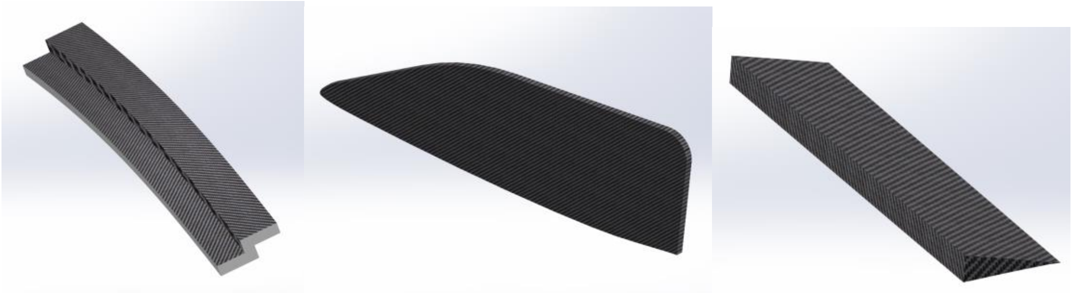


Figure 33. Final fiber carbon pieces

The parts will then be cured using a **Vacuum Assisted Resin Transfer Molding (VARTM)** process. This involves placing the part in a vacuum bag and then applying a vacuum to remove air and compact the laminate before allowing it to cure.

4.2.2.2 Final pieces

One such element is the joint that connects the aileron to the wings. This joint will be 3D printed using Thermoplastic Polyurethane (TPU), a material known for its high flexibility and toughness. The purpose of this TPU joint is to allow the aileron to flex when torque is applied by the servo that controls the mechanism. This flexibility ensures smooth operation of the aileron while minimizing the risk of mechanical failure due to rigid connections.[39]

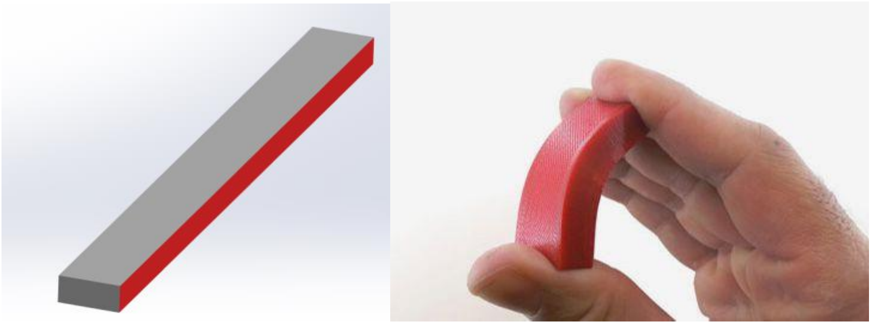


Figure 34. TPU Aileron-Structure joint

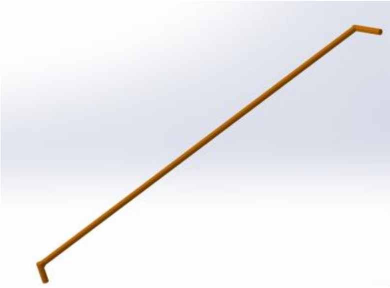


Figure 35. PLA Control rod

In addition to the flexible joint, the small rod that connects the servo to the aileron will also be 3D printed. However, unlike the joint, this rod will be printed using Polylactic Acid (PLA) instead of TPU. The rod needs to be rigid to efficiently transfer the torque from the servo to the aileron, and PLA provides the necessary stiffness

4.2.3 CNC

Certain components of a UAV, particularly those involved in the mounting and assembly of different parts, often require high strength, precision, and durability. In such cases, machined aluminum can be an excellent material choice.

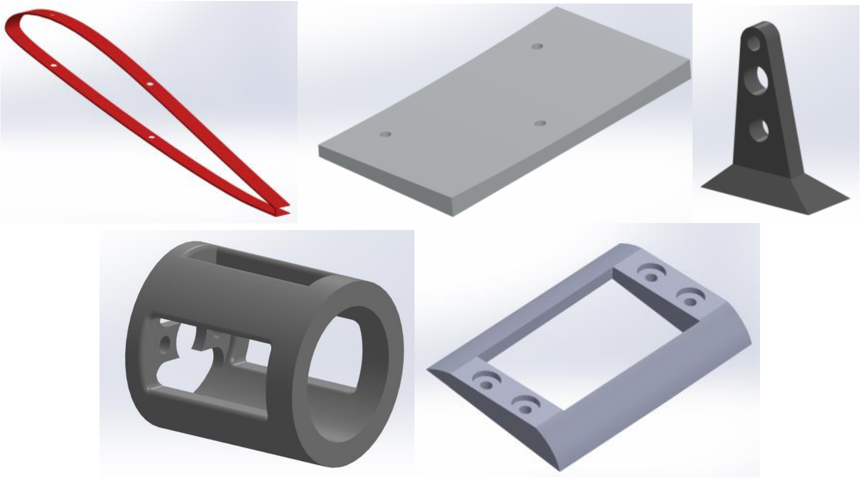


Figure 36. Machined aluminum pieces

These components include the wing-to-fuselage joint, the support for the UAV's gimbal, the mountain bracket that controls the ailerons, the motor mount and the support used to secure the servo to the wing.

4.3 Components

Into the components for the UAV project, please note that this is a preliminary proposal. The list is a initial vision, but it isn't a final design. Given the complex nature of a UAV, adjustments may be needed due to factors such as software compatibility and control testing. Therefore, while the list serves as starting point, it's subject to change as the design and development process progresses.

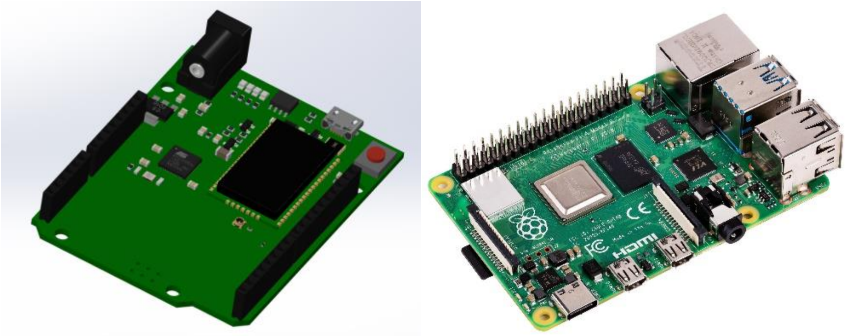


Figure 37. Raspberry Pi 4 Model B

Raspberry Pi 4 Model B: It is a single-board computer, which allows to run the flight control software and process the data from the sensors and the camera.[40]

Figure 38. T-motor U5 Lite KV400

T-motor U5 Lite KV400: It is a brushless DC motor specifically designed for multirotor applications. It offers high efficiency, high power, and smooth performance. It has a KV rating of 320 and can support a voltage of 6S (22.2v). Dimensions: Φ42.5×37.5mm. Weight: 156g. It generates thrust to lift and maneuver the UAV.

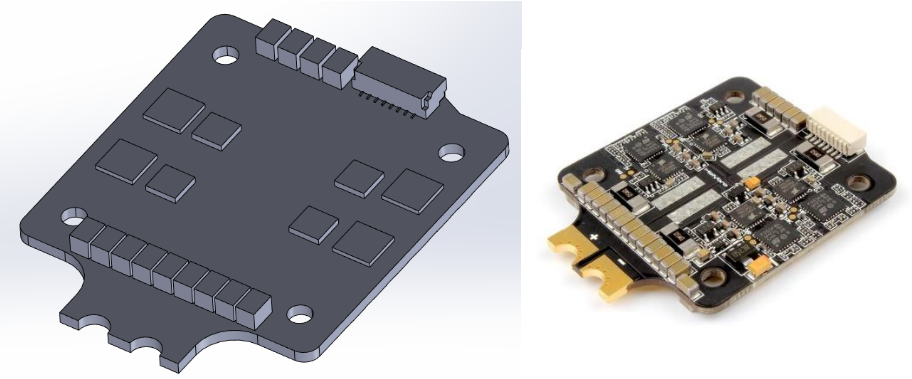


Figure 39. Holybro Tekko 32 65A

Holybro Tekko 32 65A 4IN1 ESC: It is an electronic speed controller that can handle a continuous current of 65A and a peak current of 80A. It supports 6S LiPo input and has an 8-layer PCB board that improves heat dissipation. Dimensions: 44x44. Weight: 15.8. It controls the speed of the motors based on inputs from the flight controller.[41]

Figure 40. NAZA-M Lite

NAZA-M Lite: It is an affordable and easy-to-use autopilot system with GPS. It provides functions such as auto take-off and landing, waypoint-based navigation, return to home, and failsafe. Dimensions: 45.5mm x 32.5mm x 18.5mm. Weight: 25g. It controls the UAV's flight path and provides GPS-based navigation.

Figure 41. Battery Gens Ace Tattu

Battery Gens Ace Tattu - 6S 9000mAh: It is a high capacity LiPo battery with 6 cells and a capacity of 9000mAh. It is rated for 22.2V and can discharge at a continuous rate of 25C. Dimensions: 165mm x 64mm x 59mm. Weight: 1200g. It provides power to the motors and all other electronic systems on the UAV.

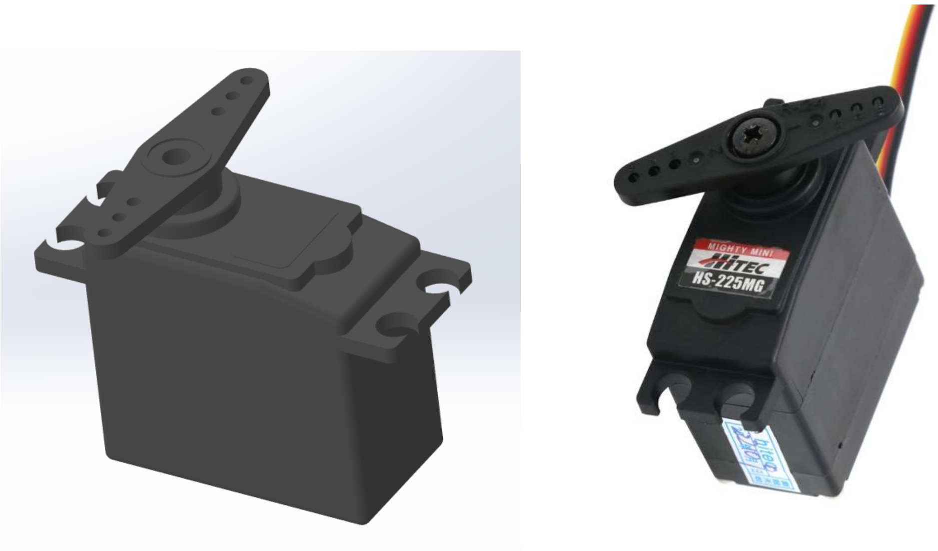


Figure 42. Servo Hitec HS-225MG

Hitec HS-225MG: It is a compact, metal-geared servo motor with a high torque output. It operates at 4.8-6.0V and has a speed of 0.14sec/60° at 4.8V. Dimensions: 32.4mm x 16.8mm x 30.8mm. Weight: 27g. It controls the movement of the ailerons.

Figure 43. USB/C-Port Charger

In addition to other features, the project incorporated a USB/C-port connector for external battery charging. This enhancement provides the flexibility of charging the battery while it's still within the UAV. However, should the need arise, it's also possible to manually remove the battery for charging or replacement.

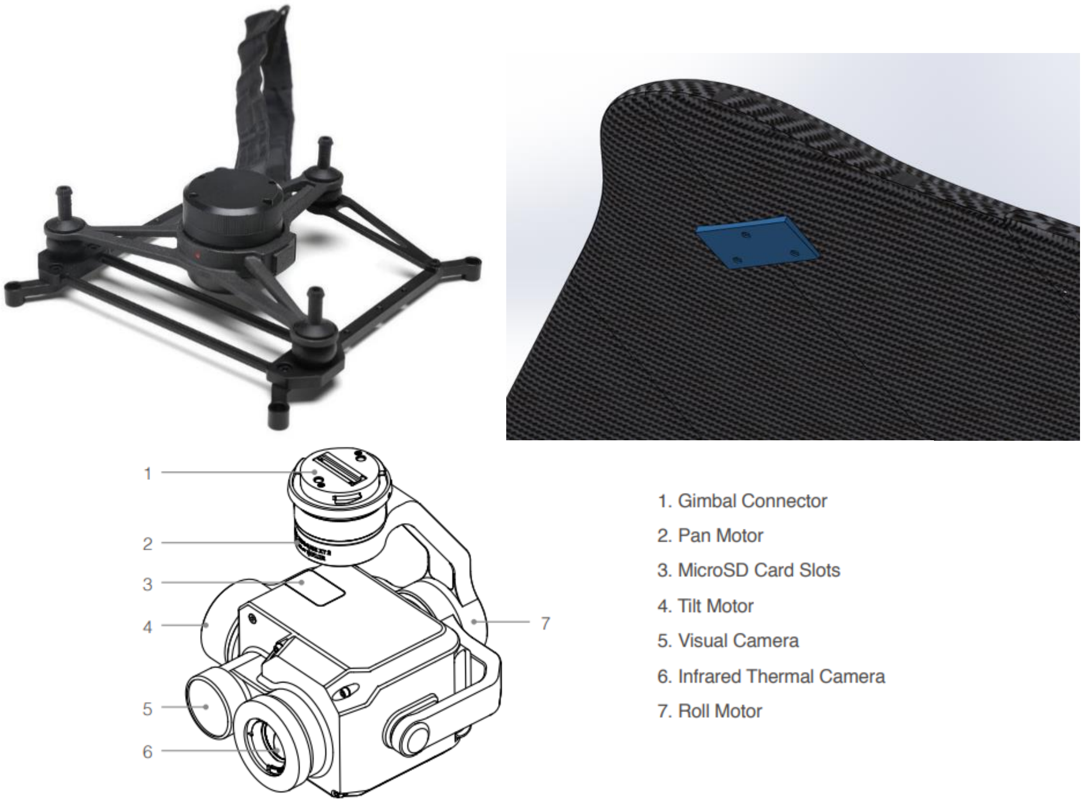


Figure 44. Camera H20T and mount[42]

Camera H20T: This is a hybrid multi-sensor camera with a 20 MP visible-light sensor, a 640x512 resolution thermal sensor, and a laser rangefinder. It provides real-time video feeds and can see in the dark using its thermal sensor. Dimensions: 76.9mm x 58.3mm x 63.7mm. Weight: 179g. It allows for aerial surveillance and data gathering.

Figure 45. Blades Graupner E-Prop 13x5mm

Graupner E-Prop: This is a high-efficiency propeller made from glass fiber reinforced plastic. It offers quiet operation, low vibration, and excellent aerodynamic design. The dimension varies as they come in different sizes to suit different applications

Note: It is important to clarify that the CAD representations of components and original models utilized in this project were obtained from various suppliers or public CAD libraries. These models were used solely for visualization purposes and do not represent proprietary designs. The goal was to leverage these resources to facilitate understanding and provide a clear depiction of the project without any intention of claiming them as my own design.

4.4 Assembly process

4.4.1 Fuselage

The next step involves assembling the mounting system for the top cover. Two key parts are required for this purpose, which will be securely attached to the top of the fuselage using a high-strength epoxy adhesive, **Araldite 2015-1**. These mounting parts serve as crucial elements for ensuring the top cover is securely fastened, while also allowing for easy removal when necessary.

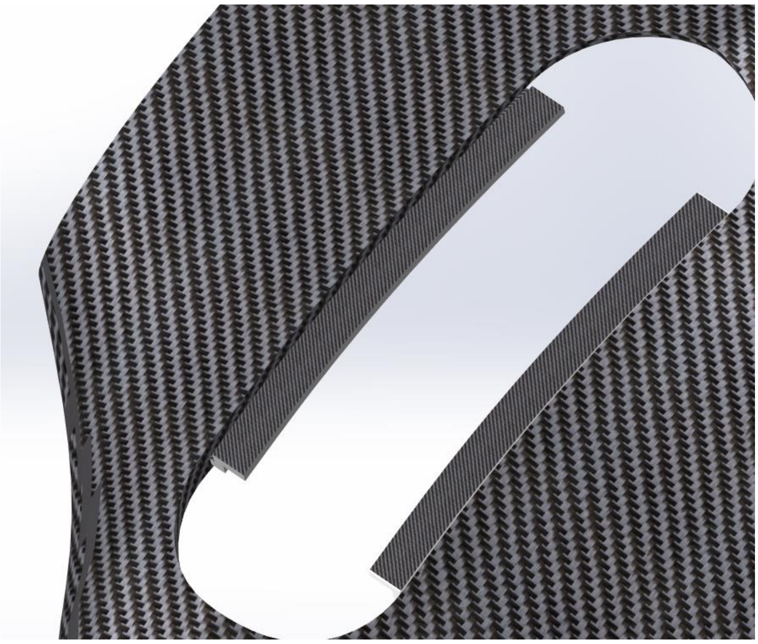


Figure 46. Cover supports propose

Joining these two halves forms the primary structure of the fuselage, defining the UAV's shape and providing the central body where other components will be attached. This process is instrumental in the overall structure and integrity of the UAV, thereby necessitating meticulous application of the adhesive to ensure a secure and lasting bond. The end result is a robust fuselage, a testament to the careful blend of precision engineering and advanced materials.

At the moment of gluing the upper and lower surfaces, the previously machined engine mount will also be glued with Araldite 2015-1.

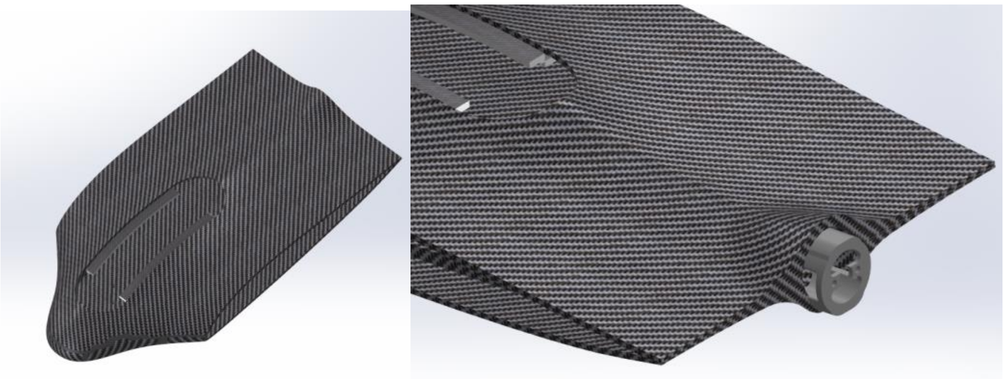


Figure 47. Final fuselage and Motor mount propose

The next pivotal phase involves the utilization of pre-machined aluminum joints. These critical components, precisely shaped through CNC machining, will be securely affixed to the ends of the fuselage using the Araldite 2015-1 epoxy adhesive. These aluminum joints play a significant role as they facilitate the connection between the fuselage and the wings of the UAV. Given their critical function in ensuring structural integrity and aerodynamic efficiency, their attachment to the fuselage demands careful application of the adhesive to guarantee a robust and enduring bond.

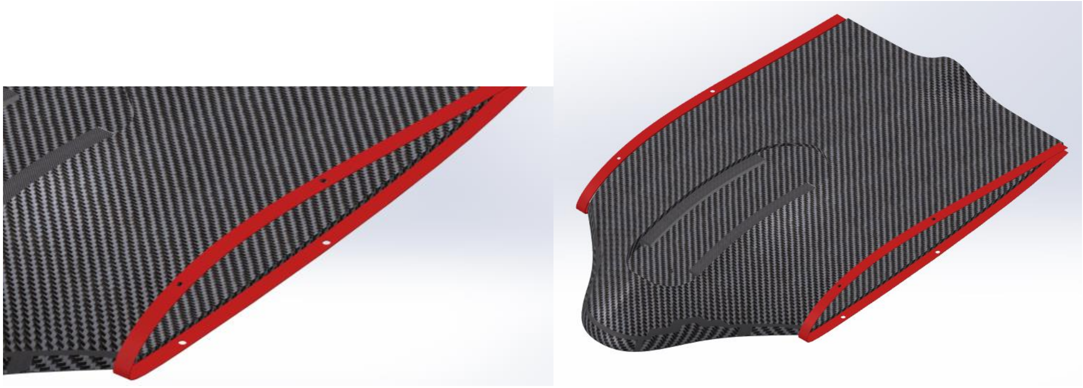


Figure 48. Wings-Fuselage joints

4.4.2 Wings

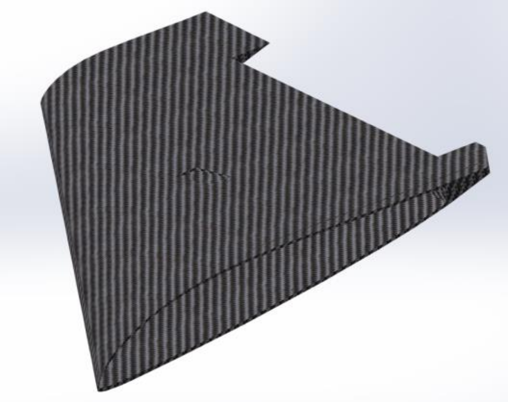


Figure 49. Final Wing structure

The second step in assembling the UAV wings involves preparing the carbon fiber components to accommodate the inserted nuts.

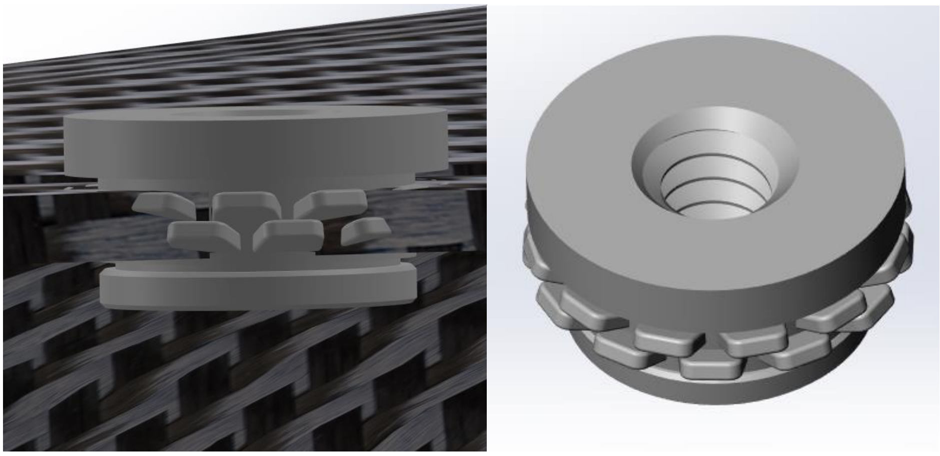


Figure 50. Inserted nuts

Given the strength and resilience of carbon fiber, it necessitates the use of a high-quality and durable drill bit material. A tungsten carbide drill bit is typically used due to its exceptional hardness and wear resistance, allowing it to cleanly cut through the carbon fiber. [43]

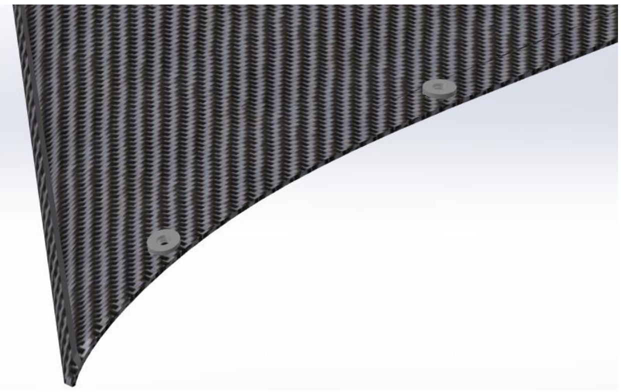


Figure 51. Inserted nuts inside of the wing structure

Initially, a precise hole is drilled at a predetermined location using a tungsten carbide bit, with the hole's size matching the specific insert's recommended diameter. Usually, this is slightly smaller than the outside diameter of the insert, as the insert is designed to press-fit tightly into the hole. After drilling, the hole is meticulously cleaned with a cloth and isopropyl alcohol to eliminate any debris or dust that may interfere with the fitting process. Finally, the Press-Fit Threaded Insert is inserted into the cleaned hole using a press-fit tool or a soft-faced mallet, ensuring a straight, snug fit. These steps, performed with precision, result in a secure and sturdy connection point within the composite part.

The next step in the UAV assembly involves working with a small TPU (thermoplastic polyurethane) joint. This flexible component, created through 3D printing, will be securely affixed to the wing structure using the Araldite 2015-1 epoxy adhesive, consistent with the established assembly procedures.

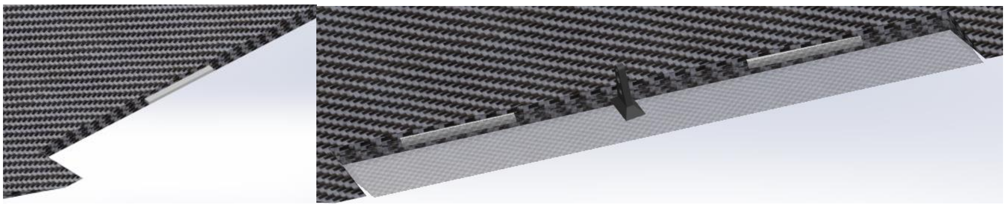


Figure 52. TPU Aileron joints

Moving forward in the UAV assembly, the next phase involves the attachment of the mounting brackets to the aileron and the designated space on the wing to accommodate the servo motor.

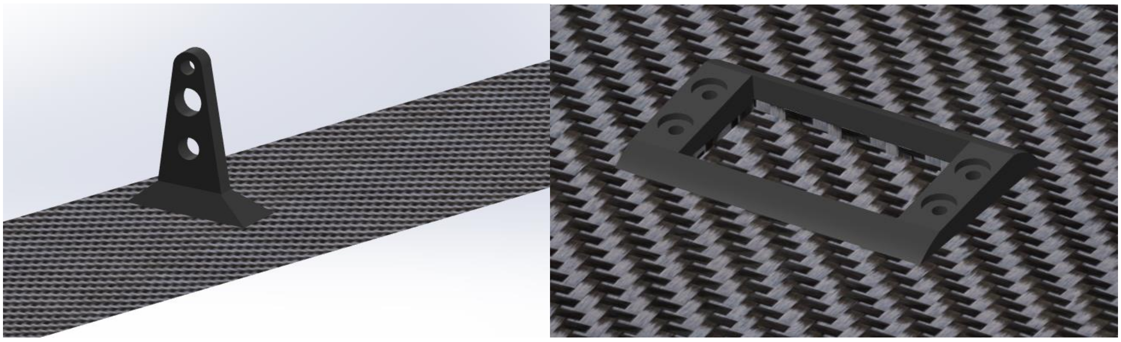


Figure 53. Mountain brackets

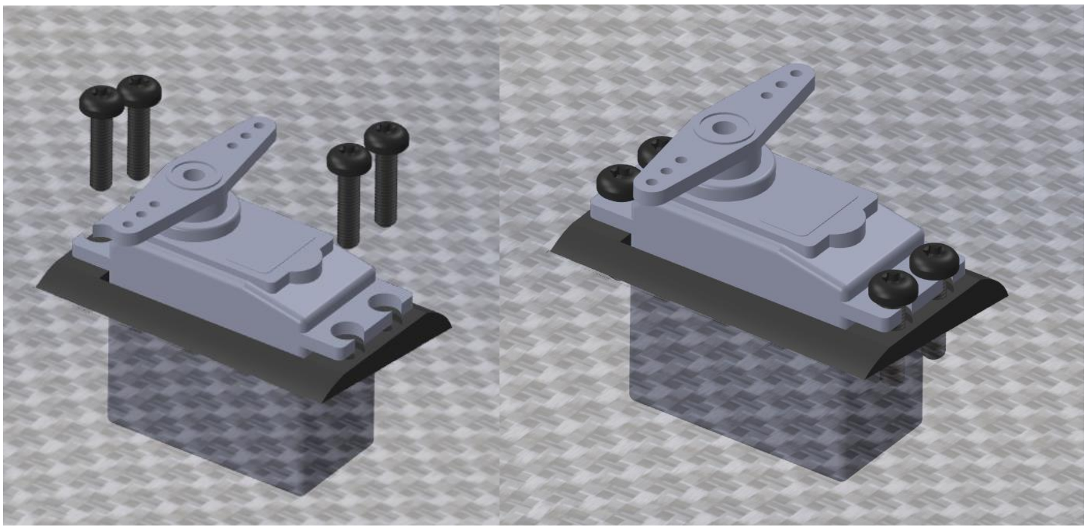


Figure 54. Assembly of the servo in the mountain bracket

The connection of the servo to the mounting bracket will be performed by 4 M3x4mm screws designed for this type of servo.

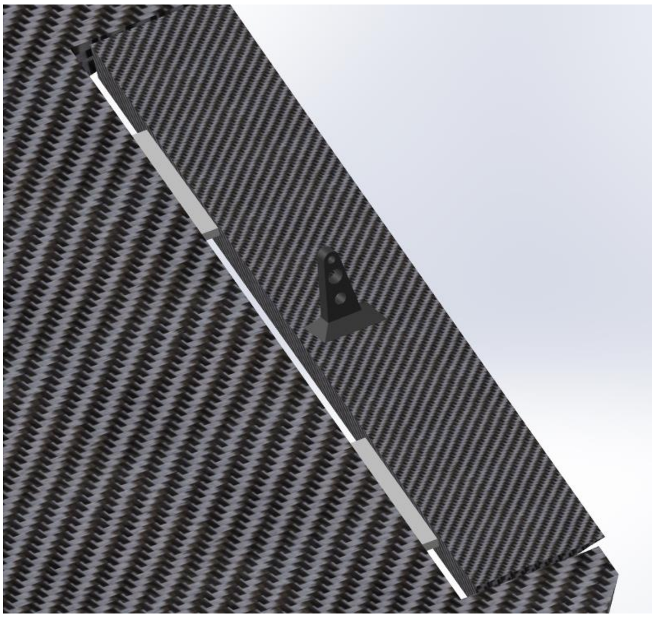


Figure 55. Aileron control propose

Continuing the assembly process of the UAV wings, the subsequent stage involves attaching the aileron to the previously affixed **TPU joint** on the wing structure. This crucial assembly step will be executed using Araldite 2015-1 epoxy adhesive, following the established bonding procedures.

The next phase involves the integration of the winglets to the wing structure. This process will be conducted using **tungsten tools** to drill two holes, subsequently accommodating two screws that will unite these integral components.

Figure 56. Winglet assembly

It is incorporated two **M1.4x4mm** machine screws to affix the winglets to the wing structure. These screws were chosen specifically for their suitability to the task at hand, offering robust and reliable fastening while also being compatible with the pre-drilled holes.

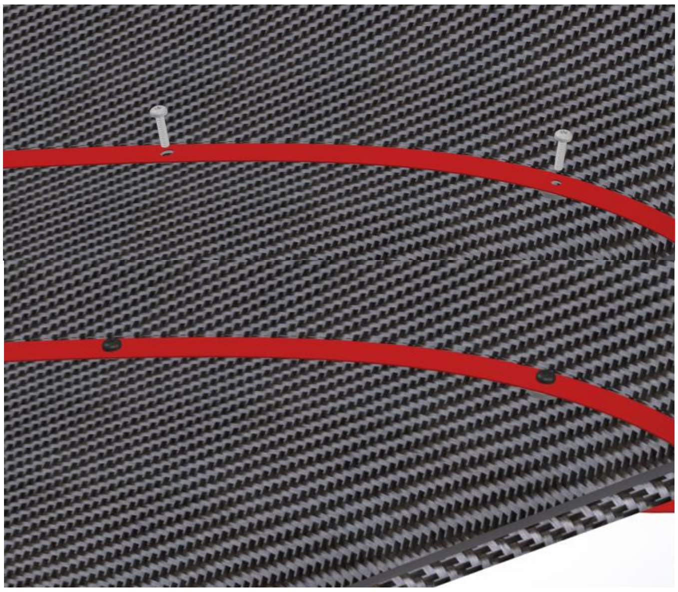


Figure 57. Wing assembly

It will be employed **M4x12mm** machine screws to secure the fuselage to the wings. These screws are specifically designed to fasten into the previously installed nut inserts embedded in the wing structure.

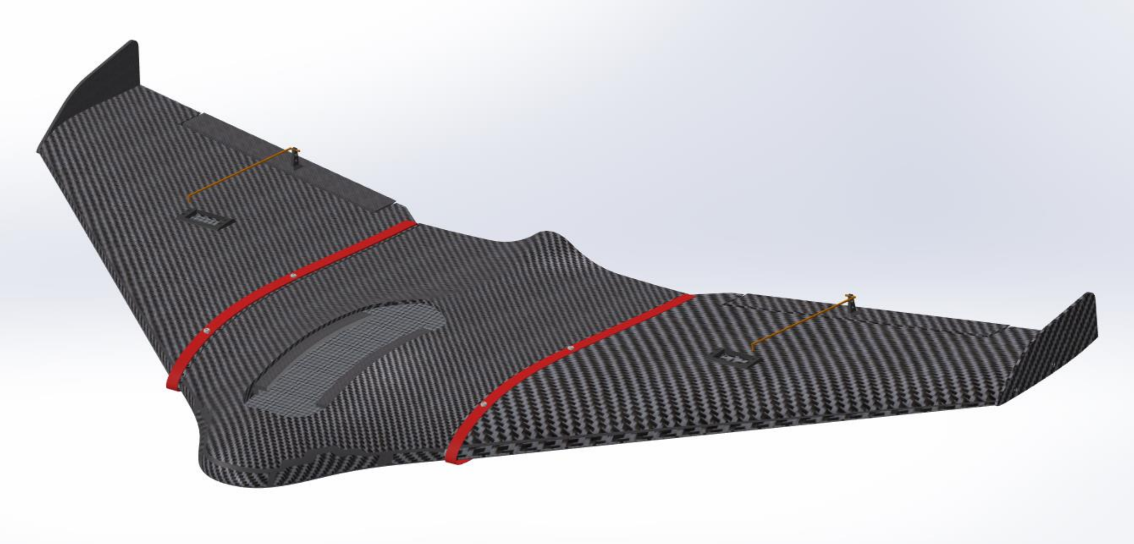


Figure 58. Final UAV structure

4.4.2.1 Non-Permanent Assembly

In the design and assembly process of the UAV, one of the main considerations is the secure mounting of the critical electronic components such as the Raspberry microcontroller and the Electronic Velocity Controller (EVC). For this purpose, high-resistance 3M Velcro will be utilized. This Velcro provides a flexible yet strong connection that can withstand the demands of UAV operation, making it a suitable choice for securing these vital components in the UAV.

Figure 59. High resistance 3M Velcro

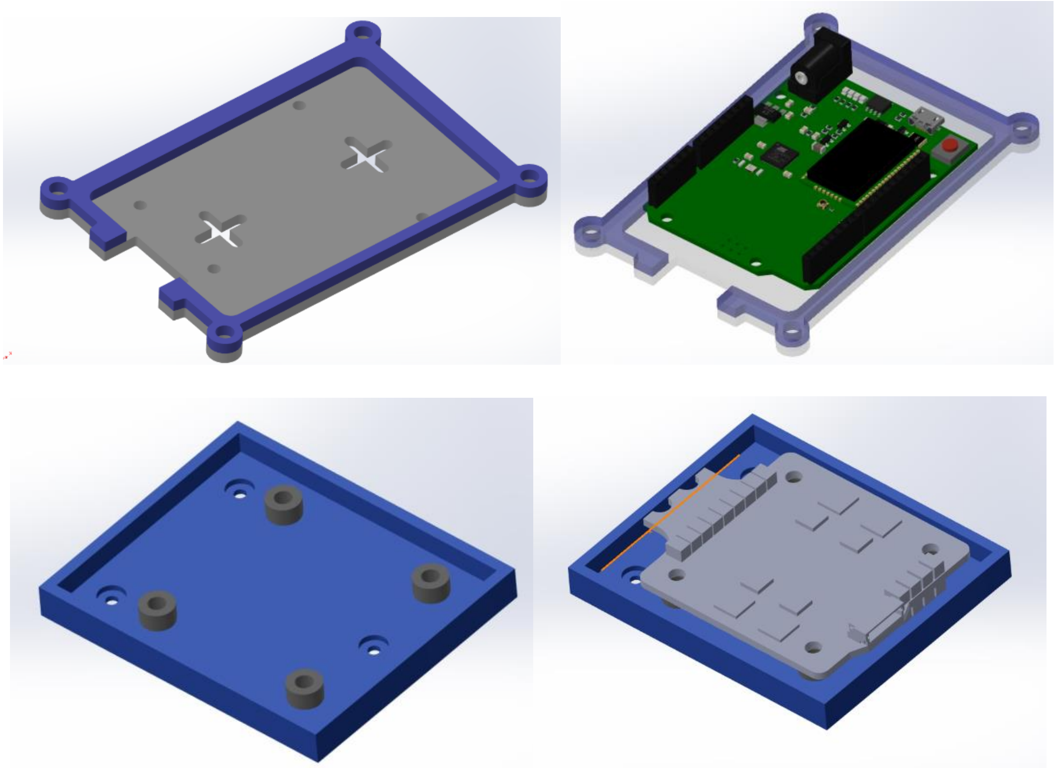


Figure 60. Components munt

Further, the mountings for these components have been designed with additional screw holes. This provides the versatility to use screws for added security and robustness if required, as determined by flight testing. The use of screws could be particularly useful if the components demonstrate insufficient fixation with the Velcro during dynamic flight conditions.

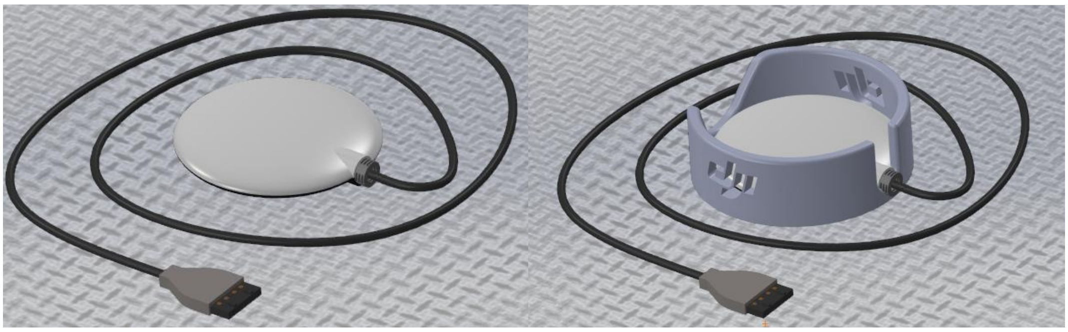


Figure 61. GPS Mount

When considering the mounting of the GPS NAZA-M Lite, a dedicated approach has been taken due to the critical role this component plays in the UAV's operation. For this particular component, it will be used a casing designed and manufactured by DJI, the original manufacturer of the GPS unit.

4.5 Final Lay-out components propose

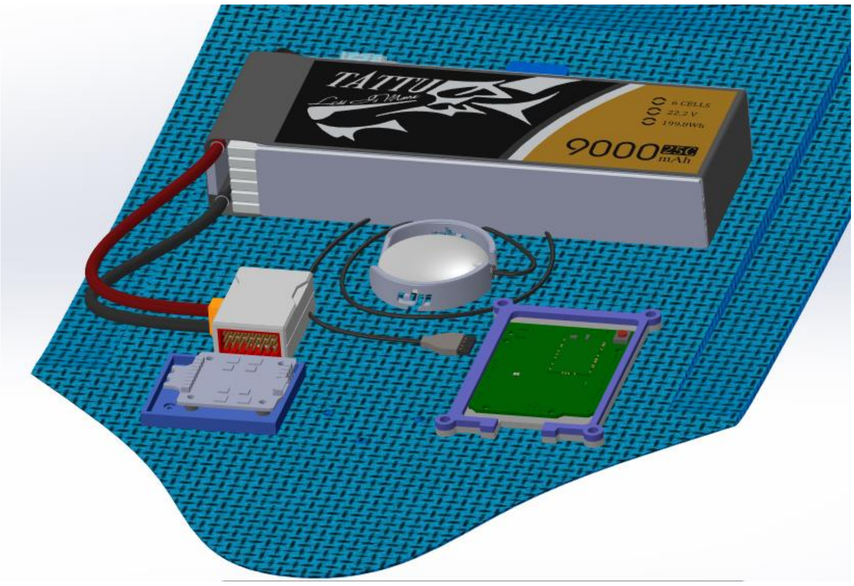


Figure 62. Lay-out preliminary propose

The previous figure presents a proposal for the layout of the components within the internal surface of the UAV. Furthermore, this specific component layout will be utilized in the computational validation phases for stability analysis.

Chapter 5. Product Structure

The "Product Structure" is a hierarchical diagram that illustrates the organization of a product, typically from a manufacturing perspective. This product structure includes all components, parts, and assemblies that make up the final product, represented in a staggered manner to reflect how they are put together in the final product.

In the following section, it will be summarized the main processes involved in the production of the UAV parts, structured into three primary process: The ATL Prepreg Method which involve the use of ATL to create the structure for both the fuselage and the wings structure. Then we have the 3D print preforms which will continue the prepreg method, and finally, the CNC for pieces which require a very high dimensional accuracy. Please note that the procedures outlined here are simplified and assume the manufacturing of components with general features.[44]

ATL Prepreg Method		
Process	**Description**	**Tools**
Packaging	Proper packaging of the part for storage or shipping.	Box and packing elements
NDT	Testing to ensure the integrity and quality of the part without damaging it.	- Ultrasound machines -X-ray Machine
Finishing	Final cleaning and polishing of the part, if necessary.	-Polisher machine
Inspection	Inspection of the part to ensure it meets desired specifications and standards.	-
Trimming	Trimming of excess and final shaping of the part.	-Cutting tools
Unload	Removing the part from the curing equipment	-Protective gloves -Lifting equipment
Curing Cycle	Applying heat and pressure to harden the part	-ATL -Vacuum pump
Bagging	Preparation and placement of the vacuum bag for curing.	-Vacuum bag -Sealant tape -Vacuum bag -Breather cloth
Layup	Application of the prepreg in the desired shapes and layers.	-Mold -ATL
Tempering	Warming the prepreg to room temperature.	Oven if it is necessary
Storage Prepreg HX50	Proper storage of materials to ensure their quality and longevity.	-Prepreg material -Climate-controlled storage facility

Table 5. ATL Prepreg method

3D Print Preforms-Prepreg Method		
Process	**Description**	**Tools**
NDT	Inspect the part for any internal defects.	-Ultrasound machines -X-ray Machine
Cleaning	Clean the part to remove any residues or debris.	Cleaning solutions
Trimming	Cut and trim the part to the final size.	-Cutting tools
Debagging	Remove the vacuum bag and sealant tape.	-Cutting tools
Curing	Allow the part to cure in an oven.	Oven
Vacuum Bagging	Bag the part and create a vacuum seal.	Vacuum bag, sealant tape, breather cloth, vacuum pump
Layup Prepreg	Apply the prepreg material onto the preform.	Prepreg material
Preform Cleaning	Clean the preform to remove any residues.	Cleaning solutions, cleaning cloths
Preform Inspection	Inspect the preform for any defects.	Inspection tools (e.g., microscope, calipers)
3D print preform	Design and print the 3D structure of the part.	3D printer, 3D printing filament/material, 3D design software

Table 6. 3D Print Preforms-Prepreg method

CNC		
Process	**Description**	**Tools**
Packaging	Package the part for storage or transport.	Packaging materials
Final Inspection	Inspect the final part for any defects.	Calipers
Part Finishing	Apply any needed finishing processes (e.g., sanding, coating).	Sanding tools, paint, coatings
Part Cleaning	Clean the part to remove any residues.	Cleaning solutions
Part Inspection	Inspect the part for any machining defects.	Inspection tool (e.g. Microscope, calipers)
CNC Machining	Machine the part using the CNC machine.	CNC Machine, cutting tools, coolant/lubricant
CNC Setup	Set up the CNC machine for the job.	CNC Machine, machine vise/clamps, cutting tools
CNC Programming	Design and code the part to be machined.	CAD/CAM Software, CNC code

Table 7. CNC method

These procedures do not determine exactly the structure of a product structure, It can be check the appendices chapter to find the complete product structure scheme following the UAV parts division.

Chapter 6. Value Stream Mapping (VSM)

Value Stream Mapping (VSM) is a lean manufacturing technique used to analyze, design, and manage the flow of materials and information required to bring a product to a customer. It provides a visual representation of every process involved in the workflow, allowing for a comprehensive understanding of the current state of the process, and helping to envision a future, more optimized state.

VSM plays a critical role in identifying waste in a system, such as excess inventory, unnecessary transport, overproduction, or excess motion, among others. It enables an organization to see the total lead time and the value-adding time in its processes

In the subsequent section, a catalog of tasks associated with various manufacturing methods is presented. These processes have been distilled into their principal stages to serve as a preliminary guide for estimating manufacturing durations. It's important to note that the tasks have been assumed to have uniform durations for similar parts, which is a simplification for computational ease.[45]

ATL Prepreg Method		
Process	**Time (hours)**	**Accumulated time (hours)**
Packaging	0.5	27
NDT	1	26.5
Finishing	1	25.5
Inspection	1	24.5
Trimming	2	23.5
Unload	1	21.5
Curing Cycle	16	20.5
Bagging	1	4.5
Layup	1	3.5
Tempering	2	2.5
Storage Prepreg HX50	0.5	0.5

Table 8.ATL Prepreg method VSM

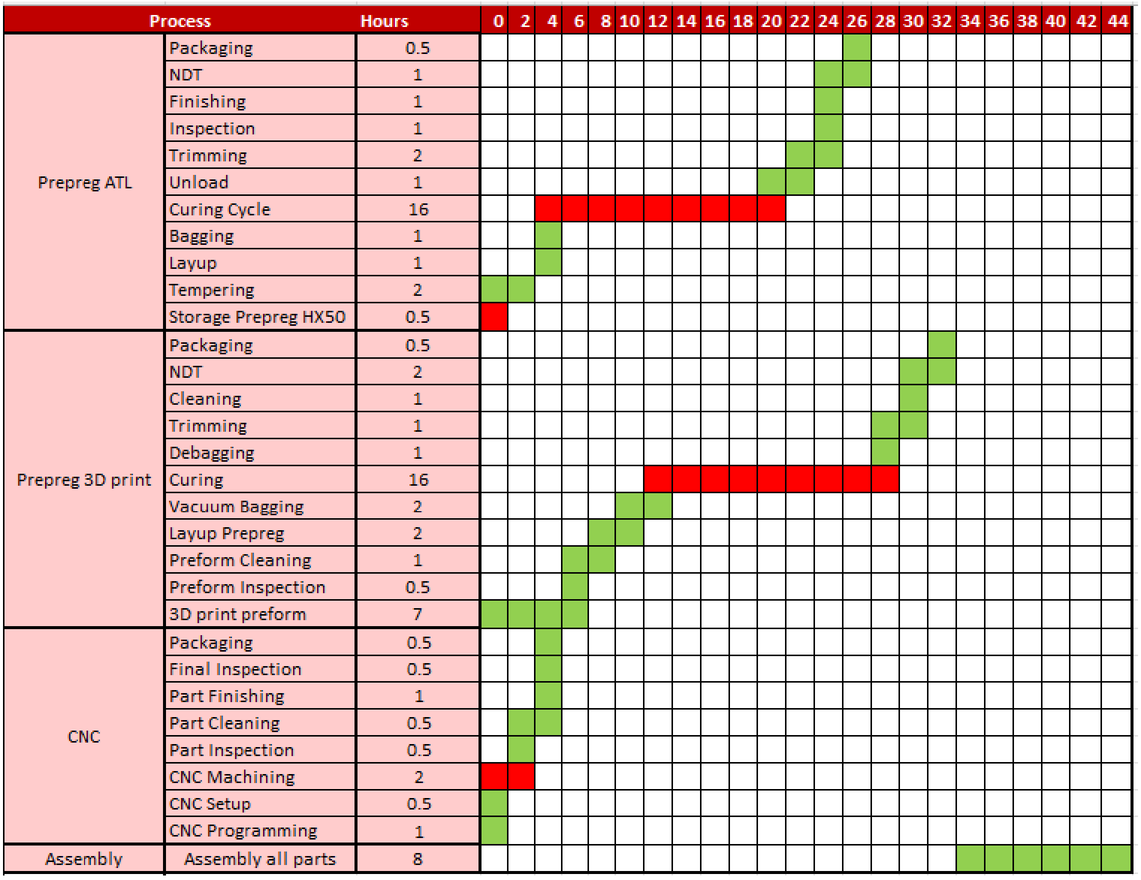
3D Print Prepreg		
Process	**Time (hours)**	**Accumulated time (hours)**
NDT	2	33.5
Cleaning	1	31.5
Trimming	1	30.5
Debagging	1	29.5
Curing	16	28.5
Vacuum Bagging	2	12.5
Layup Prepreg	2	10.5
Preform Cleaning	1	8.5
Preform Inspection	0.5	7.5
3D print preform	7	7

Table 9. 3D Print Prepreg method VSM

CNC		
Process	**Time (hours)**	**Accumulated time (hours)**
Packaging	0.5	6
Final Inspection	0.5	5.5
Part Finishing	1	5
Part Cleaning	0.5	4
Part Inspection	0.5	3.5
CNC Machining	2	3
CNC Setup	0.5	1
CNC Programming	1	0.5

Table 10. CNC method VSM

The precise timings should be established empirically through observation and measurement during a real production day. This approach ensures an accurate reflection of the unique conditions and parameters of a specific production setting.



Process		Hours	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44
Prepreg ATL	Packaging	0.5														🟩									
	NDT	1													🟩	🟩									
	Finishing	1													🟩										
	Inspection	1													🟩										
	Trimming	2												🟩	🟩										
	Unload	1											🟩	🟩											
	Curing Cycle	16			🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥												
	Bagging	1			🟩																				
	Layup	1			🟩																				
	Tempering	2	🟩	🟩																					
	Storage Prepreg HX50	0.5	🟥																						
Prepreg 3D print	Packaging	0.5																	🟩						
	NDT	2																🟩	🟩						
	Cleaning	1																🟩							
	Trimming	1															🟩	🟩							
	Debagging	1															🟩								
	Curing	16							🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥								
	Vacuum Bagging	2						🟩	🟩																
	Layup Prepreg	2					🟩	🟩																	
	Preform Cleaning	1				🟩	🟩																		
	Preform Inspection	0.5				🟩																			
	3D print preform	7	🟩	🟩	🟩	🟩																			
CNC	Packaging	0.5			🟩																				
	Final Inspection	0.5			🟩																				
	Part Finishing	1			🟩																				
	Part Cleaning	0.5		🟩	🟩																				
	Part Inspection	0.5		🟩																					
	CNC Machining	2	🟥	🟥																					
	CNC Setup	0.5	🟩																						
	CNC Programming	1	🟩																						
Assembly	Assembly all parts	8																		🟩	🟩	🟩	🟩	🟩	🟩

Table 11. Time schedule per process

As seen in the following image, the tasks are approximated based on the assumption that they are independent of each other. This independence implies that there is no interference between tasks even if they are carried out simultaneously. Therefore, the machinery and resources allocated to one task will not hinder or impede the execution of another task. This non-interference facilitates a smoother production process and allows for better utilization of resources, ultimately contributing to increased productivity and operational efficiency. This assumption of independence, however, should be validated in a real production environment for a more accurate assessment.

6.1 Validation of production target

In the development of the manufacturing strategy for this UAV project, the production target was established as 136 UAVs per year. This target is based on market research, customer demand, and strategic business objectives. To assess the feasibility of this production target, it is essential to conduct an analysis that evaluates the required production capacity and the resources available.

Assuming a standard working day is 8 hours, and a work week consists of 5 days, we have approximately 2080 working hours in a year:

$$52\,weeks\,*\,5\frac{days}{week}*\frac{8hours}{day}\;=\;2080\,Working\;hours.$$

Let's subtract holidays and scheduled maintenance periods from this total. Assuming 10 public holidays and 2 weeks for maintenance, we subtract 80 hours from the total working hours, leaving us with approximately 2000 effective working hours per year. Considering that only about 75% of these hours are "man-hours" of actual productive work, we end up with 1500 "man-hours" per year.

The production time per drone, excluding the curing process which happens overnight, is 44 - 16 = 28 hours. Therefore, theoretically, in a year, we could produce:

$$\frac{1500\,\frac{hours}{year}}{28\,\frac{hours}{drone}} \approx 53\,\frac{drones}{year}$$

This calculation suggests that with one shift working five days a week, it would not be possible to reach the target of 130 drones per year. However, considering the curing process happens overnight, we could potentially set up a two-shift system, effectively doubling the production time available. In a two-shift system, we would have approximately 3000 "man-hours" per year.

$$3000\,\frac{hours}{year} \div 28\,\frac{hours}{drone} \approx 107\,\frac{drones}{year}$$

Even under this two-shift system, reaching the target of 136 drones per year remains challenging, indicating that further optimization of the production process may be required.

Chapter 7. Cost

In this chapter, it will be conducted a preliminary cost analysis for the UAV's production, providing insights into potential financial implications. We assess costs associated with raw materials, machinery operations, and other components cost. This evaluation helps understand the monetary requirements for the production of the UAV and its potential profitability.

7.1 Raw materials cost

The following section presents a preliminary cost analysis, focusing primarily on the raw materials necessary for the UAV's construction. The following section presents a preliminary cost analysis, focusing primarily on the raw materials necessary for the UAV's construction.

Structure	Quantity	Approx. Cost/Unit	Approx. Cost
Carbon Fiber prepreg	0.528 kg	40 EUR/kg	**21.12**
TPU	0.00408kg	13 EUR/Kg	**0.053**
PLA	0.07862kg	8 EUR/kg	**0.62**
Aluminum	0.01926kg	2.29 EUR/kg	**0.044**
Peel ply PA 83g/m2	2m2	4.22 EUR/m2	**8.44**
PTFE film	2m2	0.88EUR/m2	**1.76**

Araldite 2015-1 Adhesive	50ml	0.7313 EUR/ml	**36.56**
Total			**68.61**

Table 12. Raw materials cost [46]

From this preliminary study, an approximate cost of nearly 69 euros per UAV in terms of raw materials can be inferred.

However, these are just estimates and actual costs may vary. Prices are subject to fluctuations depending on supplier rates, market conditions, and the specific quantities required. Therefore, direct engagement with suppliers is recommended to acquire more accurate costings. Regardless, this analysis provides a useful foundation for budgeting and financial planning for the production of the UAV.

7.2 Components cost

The following section encompasses a preliminary cost estimation for the various components required for the UAV assembly. This includes key parts such as the Raspberry Pi, motor, electronic speed controller (ESC), battery, flight controller, GPS, servo, camera, propeller blades, and the charging port. This preliminary cost analysis takes into account bulk pricing for some components, with quantities over 100 units as quoted by supplier service websites like Alibaba.

Component	Name	Quantity	Approx. Cost/Unit @ 100U	Approx. Cost
Microcontroller	Raspberry	1	35.21	**35.21**
Propulsion system	T-Motor U5 Lite KV400	1	100	**100**
Electronic velocity controller	**Holybro Tekko 32 65A**	1	100	**100**
Battery	**Gens Ace Tattu - 6S 9000mAh**	1	400	**400**
Flight controller +GPS	NAZA-M Lite	1	15	**15**
Servo	Hitec HS-225MG	2	40	**80**
Camera	H20T	1	6400	**6400**
Blades	Graupner E-Prop	1	70	**70**
Charge port	-	1	2	**2**
Total (EUR)				**7067**

Table 13. Component costs

Based on this preliminary cost analysis, the estimated total cost for all the necessary components of the UAV sums up to around 7067 euros. It's important to highlight that the camera, priced at approximately 6400 euros, represents the most significant portion of this cost. Hence, any cost optimization strategy should consider this component with priority.

7.3 Production cost

To estimate the cost of running certain pieces of manufacturing equipment for the production of the UAV, it is required to consider the power requirements of each machine, the duration they will be operating, and the cost of electricity. Let's consider these machines are located in Spain where the cost of electricity is **€0.20626 per kWh** (at the moment of this estimation). For the equipment, we'll be looking at some specific models:

- **Automated Tape Laying (ATL) machine**: A model similar to the Accudyne Systems' Small Parts ATL is assumed to be operating **16 hours a day**. However, power ratings for such machinery are often not readily available and can greatly vary based on the machine's size, operational intensity, and specific customizations. In this case, let's estimate the power rating at about **15kW.**

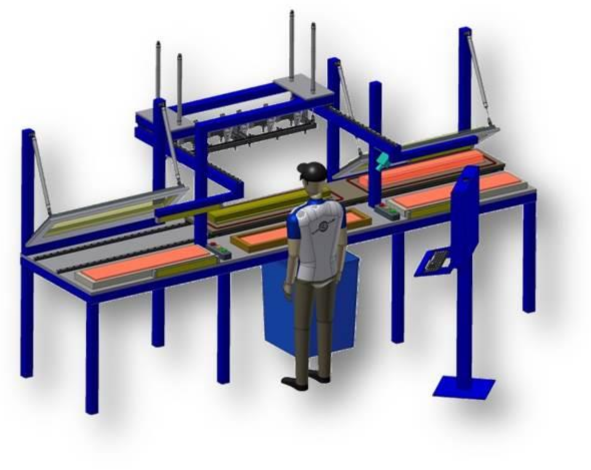


Figure 63. ATL Accudyne Systems' Small Parts

- **CNC Machine:** A Haas Mini Mill is a commonly used CNC machine that has a power requirement around the **11.2 kW range. It's assumed to be operating for 2 hours a day.**[47]

Figure 64. Haas Mini Mill

- **Industrial Oven:** We'll consider a model similar to the Despatch LBB Forced Convection Benchtop Oven for the calculations, which is expected to run for **16 hours a day**. Benchtop models like this one have relatively lower power requirements, but it can still vary. Let's assume it requires about **4.2 kW.**[48]

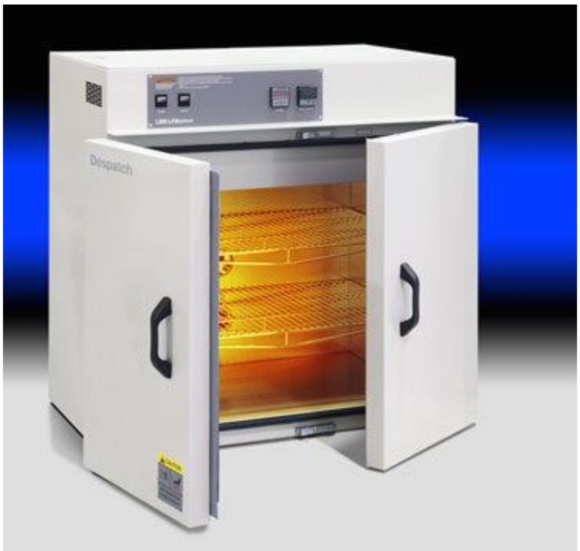


Figure 65. Oven Despatch LBB Forced Convection

- **Vacuum Pump**: The Edwards RV8 Two Stage Rotary Vane Pump is a model that could match the power requirements we're looking for. This model is rated at about 0.45 kW, but considering heavy load and continuous usage in an industrial setting, we'll consider it consumes **0.09 kW and it runs for 16 hours a day.**[49]

Figure 66. Vacuum pump Edwards RV8 Two Stage Rotary Vane pump

The total power consumed by each piece of equipment in a day can be calculated as the product of the power rating (in kW) and the number of hours it operates. Summing these up gives the total power consumed in a day for all the equipment. Multiplying this value by the cost of electricity gives us the cost of operating the equipment for a day.

With these power ratings in mind, we can now calculate the energy usage for each machine by multiplying its power by the duration of use:

$$ATL\ Machine: 15kW\ *\ 16h\ =\ 240kWh$$

$$CNC\ Machine: 11.2W\ *\ 2h\ =\ 22.4kWh$$

$$Oven: 2.2kW\ *\ 16h\ =\ 96kWh$$

$$Vacuum\ Pump: 0.09kW\ *\ 16h\ =\ 40kWh$$

Adding up these energy consumption values gives us the total energy usage:

$$Total\ Energy\ =\ 80kWh\,(ATL)\ +\ 22.4kWh\,(CNC)\ +\ 160kWh\,(Oven)\ +\ 40kWh\,(Pump)\ =\ 299.04kWh$$

Finally, we multiply this total energy usage by the cost of electricity (0.20626 €/kWh), resulting in the total energy cost for the day:

$$Total\ Cost\ =\ 320kWh\ *\ 0.20626\,€/kWh\ =\ €61.68$$

Therefore, under these assumptions, the estimated energy cost for a day of production would be approximately €84.

$$Final\ estimation\ cost = 7220\ EUR$$

Chapter 8. Failure Mode and Effect Analysis (FMEA)

The Failure Mode and Effect Analysis (FMEA) is a systematic, proactive tool for evaluating a process to identify where and how it might fail, and to assess the relative impact of different failures. It is used to identify actions to mitigate the risk of those failures. The results of an FMEA are often recorded in a table that can be referred to later on for process improvement and risk mitigation.[50]

The table typically includes the following columns:

- **Process**: What part of the process is being considered?
- **Potential Failure Mode**: What could go wrong?
- **Failure Effect(s):** What would the consequences be?
- **Potential Cause(s):** Why might the failure happen?
- **Current Controls**: What is currently done to prevent or detect the failure?
- **Recommended Actions**: What should be done to better prevent or detect the failure?
- **Severity (S):** How serious would it be if the failure happened?
- **Occurrence (O**): How often might the failure happen?
- **Detection (D):** How likely is it that the failure would be found before it impacts the customer?
- **Risk Priority Number (RPN):** The product of severity, occurrence, and detection. It ranks potential failures in the order they should be addressed.

The RPN can help prioritize the various strategies of addressing different failure modes. An item with a high RPN should be addressed first as it represents the highest risk.

For the full table, please refer to the appendix. The top four issues, based on their RPN values, are:

- **Mold Design (RPN 96):** The creation of the mold is the very first step in the production process. If there's an error in the design, all subsequent steps will be affected, leading to defective parts or even a complete UAV failure. The error in the mold can come from a design flaw or a manufacturing defect. Implementing detailed design reviews, simulations, and quality control checks can mitigate these risks.
- **Laminating in Mold (RPN 96):** During the lamination process, air bubbles may form within the laminate. This can lead to structural weaknesses, which may not be evident immediately but could lead to failure during operation. Implementing proper lamination techniques, possibly automating the process, and performing regular quality checks can help reduce this risk.
- **Parts Joining (RPN 96):** Joining parts incorrectly can lead to weak joints, which could compromise the structural integrity of the UAV. As this is often a manual process, human error can be a significant factor. Providing comprehensive training on the

proper application of the adhesive Araldite 2015-1, coupled with quality control measures, can mitigate this risk.

- **Motor Mounting (RPN 81):** If the motor is not mounted correctly, it could lead to an impaired UAV operation or even complete motor failure during flight. This again may be due to human error or defects in the mounting hardware or the motor itself. Proper training for technicians and regular inspections can help avoid this issue.

In conclusion, it is essential to highlight that the values assigned to Severity (S), Occurrence (O), and Detection (D) in the FMEA, which are used to calculate the Risk Priority Number (RPN), are intended for reference purposes only. These values have been determined based on the initial understanding of potential failure modes and their impacts on the UAV manufacturing process.

However, these are preliminary assessments and need to be verified under actual manufacturing and operational conditions. Different organizations may have varying experiences and thus assign different values to Severity, Occurrence, and Detection. Additionally, as new data and experiences are gathered from the production line and field use, these scores should be regularly reviewed and updated.

Chapter 9. Analysis validation

In the design and production of Unmanned Aerial Vehicles (UAVs), verification analysis plays a vital role in ensuring the effectiveness, safety, and viability of the proposed model.

9.1 Aerodynamic analysis

In the process of designing and producing a UAV, one of the key areas that must be thoroughly analyzed is the aerodynamic performance. This component of the analysis involves determining how the UAV will interact with the air it is flying through and how these interactions will impact its flight performance. For this UAV, one of the mission requirements set is a stable flight speed of at least 14 m/s. Therefore, the aerodynamic analysis will focus on this flight condition, examining the lift and drag forces the UAV experiences at various angles of attack.

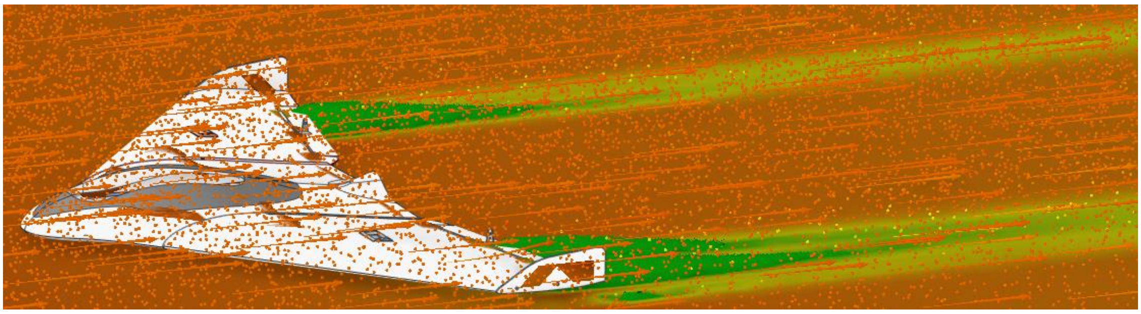


Figure 67. Aerodynamic Analysis

it was discovered that the UAV experiences stall at an angle of attack of 15º. Stall is a sudden reduction in the lift produced by a wing, caused by the airflow separating from the wing's surface. Beyond this angle, the lift decreases dramatically, which could lead to a loss of control of the UAV. Therefore, the stall angle marks the upper limit for the angle of attack for safe operations.

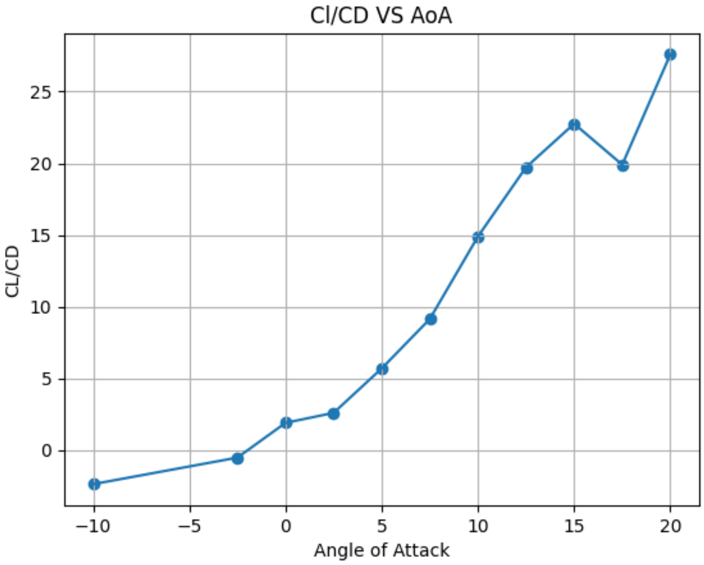


Figure 68. Cl/Cd VS AOA results from Aerodynamic analysis

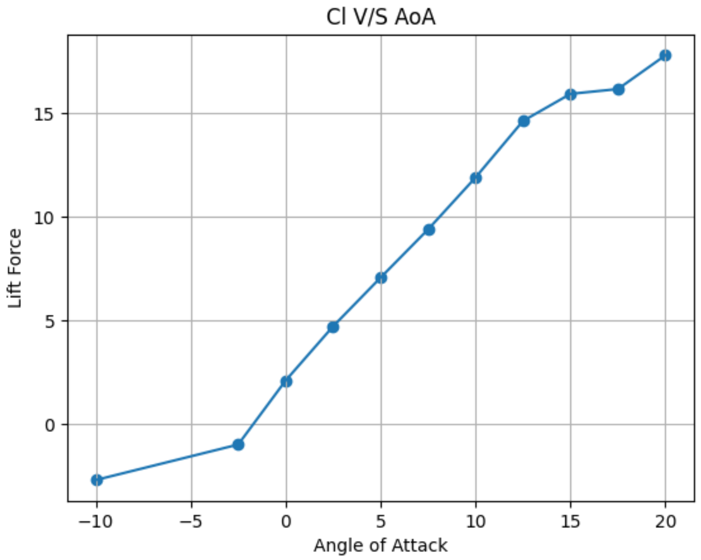


Figure 69. Cl VS AOA results from Aerodynamic analysis

Aerodynamic analysis			
V_{total}	14 m/s		
AoA	**Lift Force (N)**	**Drag Force (N)**	**L/D**
-5	-2.69171	1.13771	-2.3659
-2.5	-0.98129	1.90472	-0.51519
0	2.10512	1.1038	1.907157
2.5	4.71927	1.811997	2.604458
5	7.06775	1.23916	5.703662
7.5	9.39173	1.02682	9.146423
10	11.896	0.798557	14.89687
12.5	14.6218	0.741286	19.72491
15	15.9273	0.699782	22.76037
17.5	16.1611	0.811891	19.9055
20	17.7864	0.644601	27.59288

Table 14. Aerodynamic analysis results

These forces of lift and drag, now identified through the aerodynamic analysis, will be used to validate the structural integrity of the UAV in the following structural analysis. In a sense, the aerodynamic analysis provides the external forces that the UAV structure must withstand.

9.2 Structural analysis

The structural analysis is an essential part of the UAV design and manufacturing process. It involves understanding how the UAV will behave under various loading conditions and whether it will be able to withstand those loads without failure. According to the forces obtained in the aerodynamic analysis, a structural analysis was performed in Ansys in which the forces were distributed according to their components obtained for each of the angles of attack.

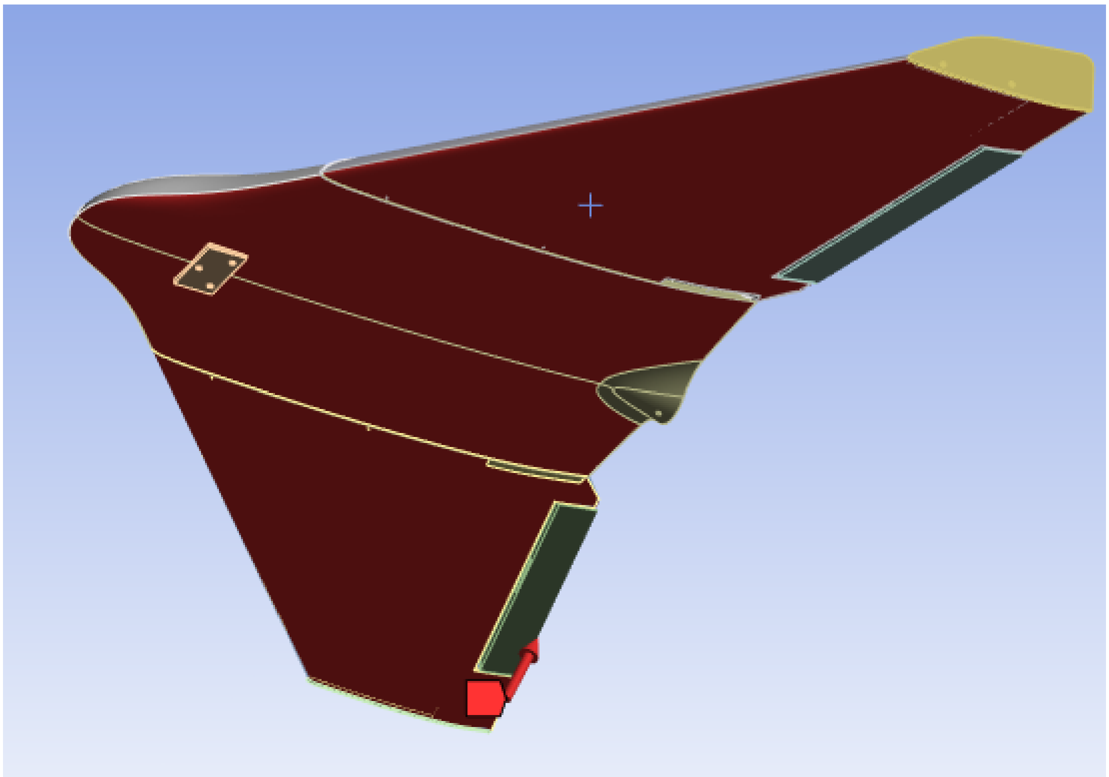


Figure 70. Forces representation

The aerodynamic forces previously calculated were applied to the lower surface of the UAV as part of the structural analysis. The forces were introduced by their components respect to the angle of attack.

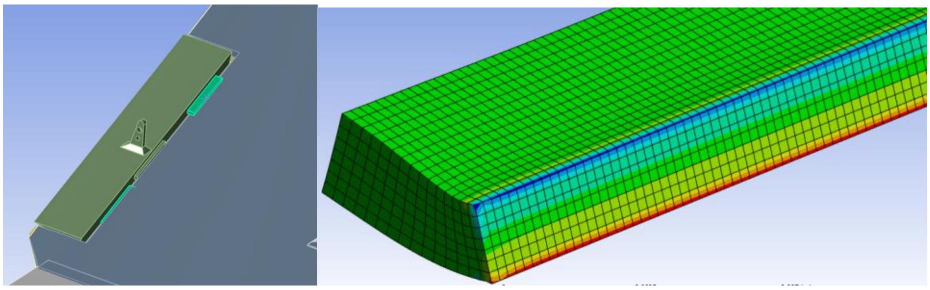


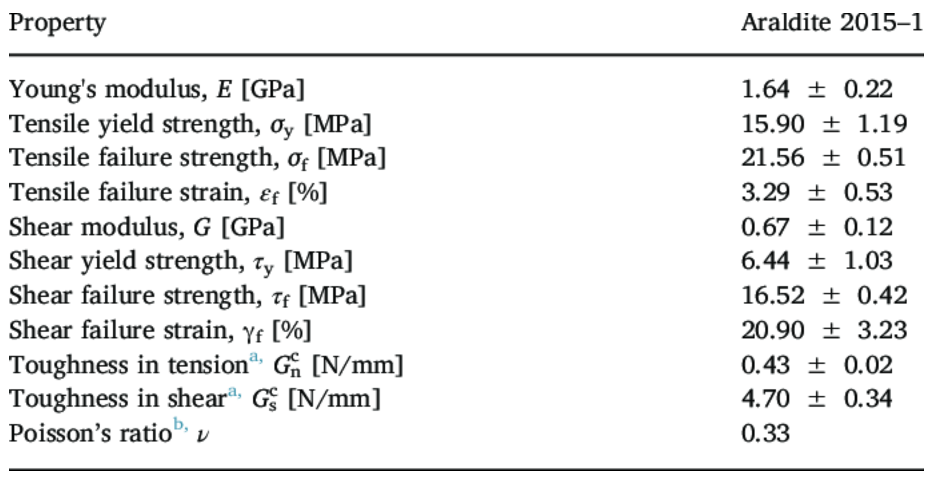
Figure 71. Structural analysis Aileron-Wing joint

One such area of concern was the adhesive bond holding the ailerons together. The ailerons are attached to the rest of the UAV using a small piece of TPU and Araldite 2015-1 adhesive. Given that this connection point is subject to the entire aerodynamic force exerted on the UAV, it was crucial to conduct a detailed structural analysis to ensure that the adhesive bond would hold under these conditions.

AoA	Lift (N)	Drag (N)	Equivalent stress (Pa)	Total Deformation (m)	Shear stress (Pa)	Normal stress (Pa)
-5	-2.69171	1.13771	267710	7.782E-07	13653	138440
-2.5	-0.981285	1.90472	83395	9.818E-08	3540.5	43657
0	2.10512	1.1038	261500	9.464E-07	92907	134910
2.5	4.71927	1.811997	554920	2.007E-06	198060	282490
5	7.06775	1.23916	744830	2.752E-06	273880	378660
7.5	9.39173	1.02682	983540	3.551E-06	354410	484580
10	11.896	0.798557	1240800	4.412E-06	441230	587500
12.5	14.6218	0.741286	1522300	5.38E-06	538510	728560
15	15.9273	0.699782	1657600	5.843E-06	585090	790580
17.5	16.1611	0.811891	1682900	5.947E-06	595240	805200
20	17.7864	0.644601	1849700	6.502E-06	651290	878750

Table 15. Structural analysis results

Several results were obtained from these analyses, including the equivalent stress, total deformation, shear stress, and normal stress. The equivalent stress is a representative stress that combines the effects of all the individual stresses acting on a point. Total deformation indicates how much the UAV's structure is likely to deform under the applied loads. Shear stress is the stress caused by forces acting parallel to each other but in opposite directions, while normal stress is the stress caused by forces acting perpendicular to each other. Each of these parameters provides valuable insight into the structural performance of the UAV and can help identify potential areas of failure.



Property	Araldite 2015–1
Young's modulus, E [GPa]	1.64 ± 0.22
Tensile yield strength, σ_y [MPa]	15.90 ± 1.19
Tensile failure strength, σ_f [MPa]	21.56 ± 0.51
Tensile failure strain, ε_f [%]	3.29 ± 0.53
Shear modulus, G [GPa]	0.67 ± 0.12
Shear yield strength, τ_y [MPa]	6.44 ± 1.03
Shear failure strength, τ_f [MPa]	16.52 ± 0.42
Shear failure strain, γ_f [%]	20.90 ± 3.23
Toughness in tension[a,] G_n^c [N/mm]	0.43 ± 0.02
Toughness in shear[a,] G_s^c [N/mm]	4.70 ± 0.34
Poisson's ratio[b,] ν	0.33

Table 16, Mechanical properties of Araldite 2015-1[51]

From the results obtained, it is possible to conduct a simple failure analysis using the von Mises yield criterion, which is often used to predict the onset of yield. This principle states that yielding begins when the equivalent (von Mises) stress exceeds the yield strength of the material.

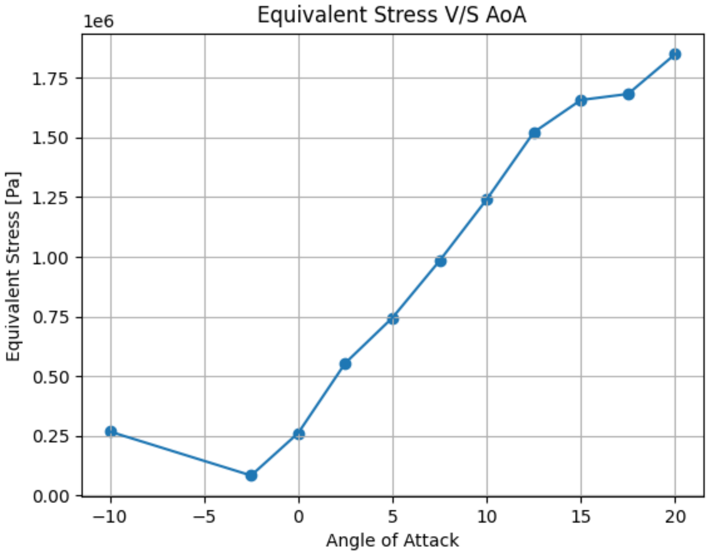


Figure 72. Equivalent stress VS AOA results.

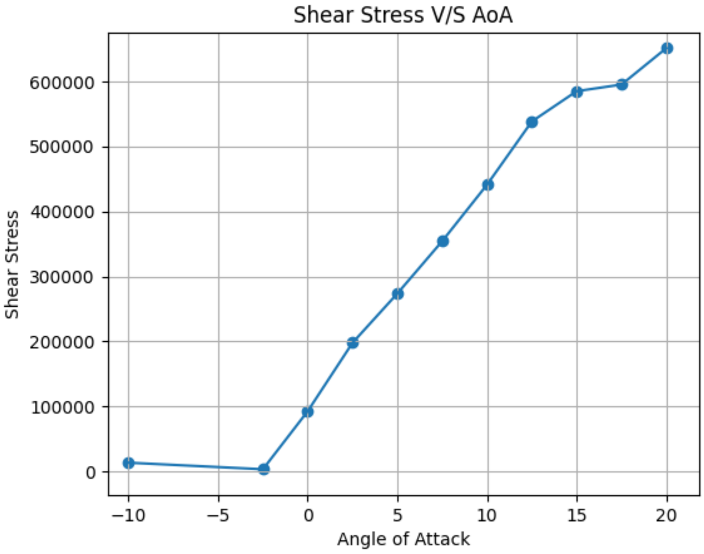


Figure 73. Shear stress VS AOA results

From the Araldite properties and the results obtained at maximum angle of attack.

- Maximum von Mises Stress (σv) = 1.8497 MPa
- Maximum Shear Stress (τ) = 0.65129 MPa
- Tensile Yield strength (σy) = 15.9 MPa
- Shear Yield Strength (τy) = 6.44 MPa

For von Mises criterion, if $\sigma v > \sigma y$ then failure is expected to occur.

$$1.8497\ MPa < 15.9\ MPa$$

Hence, under the applied loading, the material does not yield or fail according to the von Mises criterion.

Next, it will be check for shear failure. If the applied shear stress $\tau > \tau y$, the material will fail in shear.

$$0.65129\ MPa < 6.44\ MPa$$

In conclusion, the results of the structural analysis showed that, under the conditions considered, there is no clear risk of structural failure. However, it's important to bear in mind that these results are based on simulations. They must be validated through experimental testing to ensure that the UAV can withstand the forces it will encounter during actual flight. The structural analysis provides a solid foundation for this testing and can help guide the development of a safe and reliable UAV. However, it is not a substitute for the invaluable data gained from real-world testing and flight trials.

9.3 Stability analysis

The stability analysis of a UAV is crucial to ensuring that it maintains controlled, steady flight, particularly when subjected to external forces such as wind gusts. The fundamental basis for this analysis is the distribution of mass within the UAV. With a multitude of different components, each with their own weight and position within the structure, the overall mass distribution significantly affects the UAV's balance and stability. Essentially, the UAV's ability to achieve a theoretically stable state depends heavily on how these components are arranged within it.

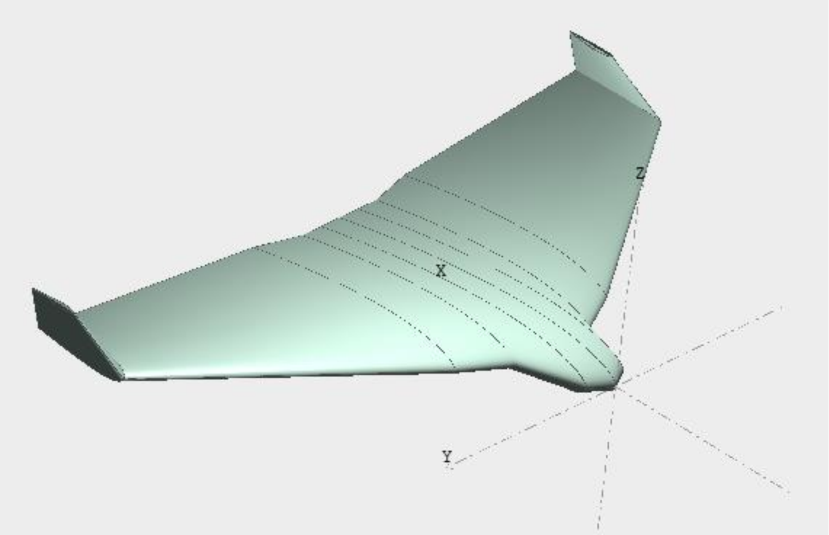


Figure 74. XFLR5 UAV representation in scale

The UAV has been meticulously designed to scale in XFLR5, enabling an extensive longitudinal stability analysis. Longitudinal stability refers to the aircraft's stability in its pitch motion, that is, the nose-up or nose-down movement around the lateral axis. Assumptions were made to simplify the analysis, the UAV was considered as a single wing entity, giving the impression of behaving like a blended wide body aircraft. This assumption enabled a more streamlined approach to the stability analysis.

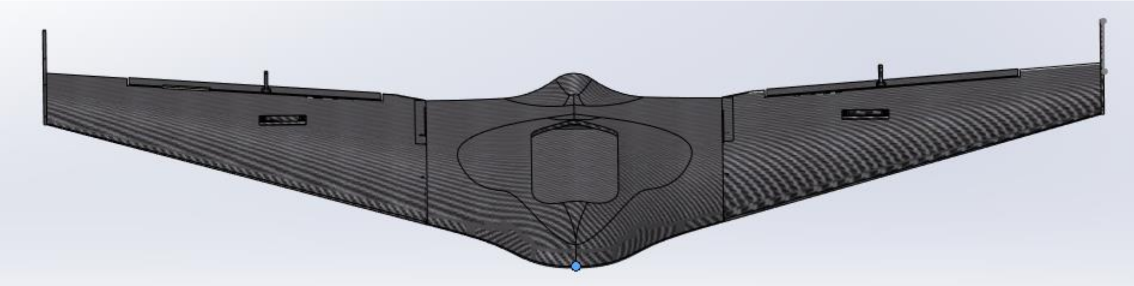


Figure 75. Solid works UAV model coordinates reference

A unique coordinate system was set up for the UAV to facilitate the distribution of loads according to the layout of the SolidWorks model. The coordinate system provides a reference for positioning the various components within the UAV and calculating the center of gravity. This step ensures that the distribution of mass and therefore the stability characteristics calculated in XFLR5 are consistent with the physical design of the UAV.

Coordinates	Value
X	326.44
Y	4.87
Z	-0.03

Table 17. Center of gravity coordinates

Figure 76. Center of mass calculated by Solid works

The center of gravity of the UAV model, as determined from the SolidWorks model, was identified. The center of gravity is the point where the weight of the UAV is perfectly balanced, and it significantly impacts the UAV's stability and control. If the center of gravity is too far forward or aft, the UAV may become uncontrollable.

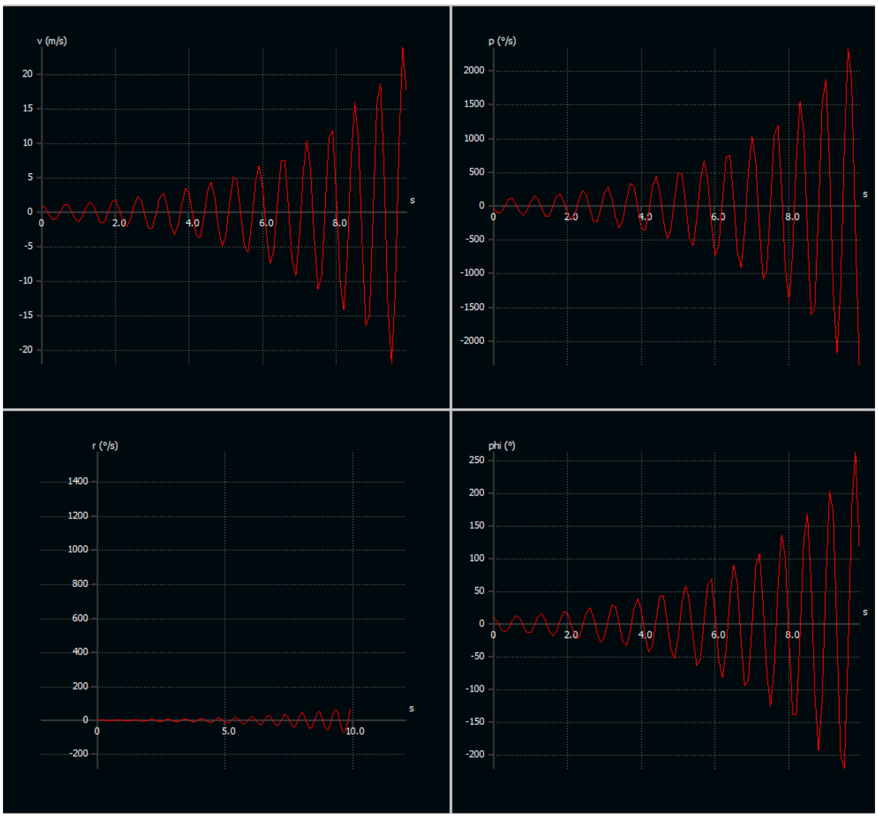
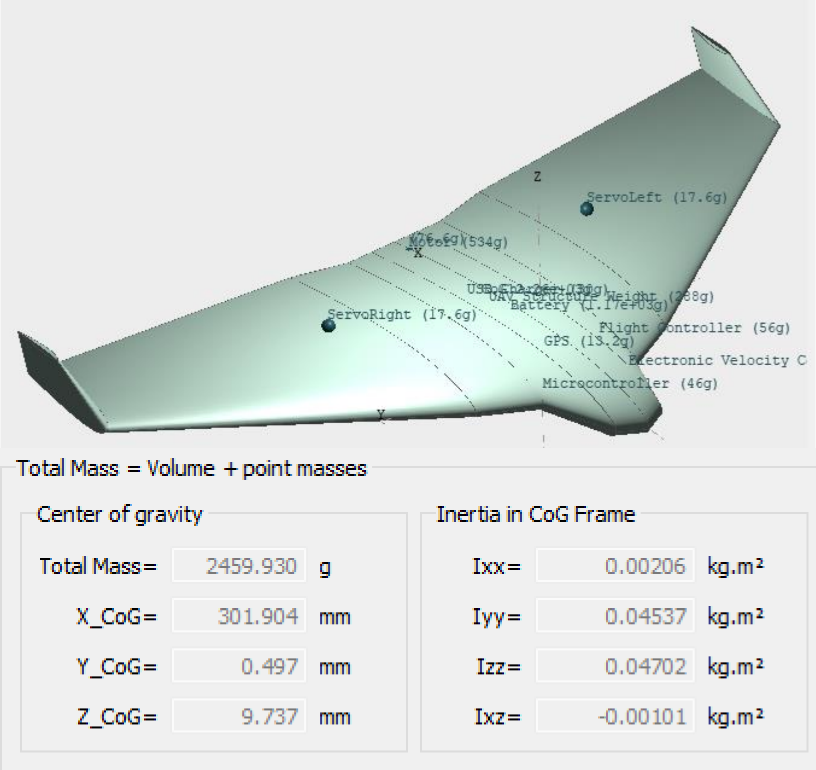


Figure 77. Initial stability analysis

The stability calculations were then input into the XFLR5 model, revealing that the UAV was unstable. The importance of this revelation cannot be overstated. It highlights the criticality of stability analysis in the design phase of UAVs. Detecting instability issues before the UAV is manufactured or tested can save time and resources and prevent potential accidents during flight tests.

	Coordinates			
Components	**x**	**y**	**z**	**Weight (g)**
Motor	489.19	-0.26	0	534
USB	367.63	-3.99	2.3	30
Bateria	279.62	18.01	1.74	1172.46
Flight controller	180.18	10.16	-60.56	56
GPS	205.11	5.27	5.46	13.19
Electronic velocity controller	110.42	2.59	-52.77	9
Raspberry	133.04	7.13	63.33	46
Servo Left	390.07	32.65	-202.19	17.57
Servo Right	390.07	32.65	202.19	17.57
Motor Mount	507.81	-5.7	0.05	76.6

Table 18. Center of mass of every components and coordinates



Total Mass = Volume + point masses

Center of gravity

Total Mass= 2459.930 g

X_CoG= 301.904 mm

Y_CoG= 0.497 mm

Z_CoG= 9.737 mm

Inertia in CoG Frame

Ixx= 0.00206 kg.m²

Iyy= 0.04537 kg.m²

Izz= 0.04702 kg.m²

Ixz= -0.00101 kg.m²

Figure 78. XFLR5 with every mass components

Subsequently, each component, along with its approximate weight and coordinates according to the proposed layout, was incorporated into the stability analysis. This detailed approach ensured that the effect of each component on the overall stability of the UAV was considered, providing a more accurate depiction of the UAV's stability characteristics.

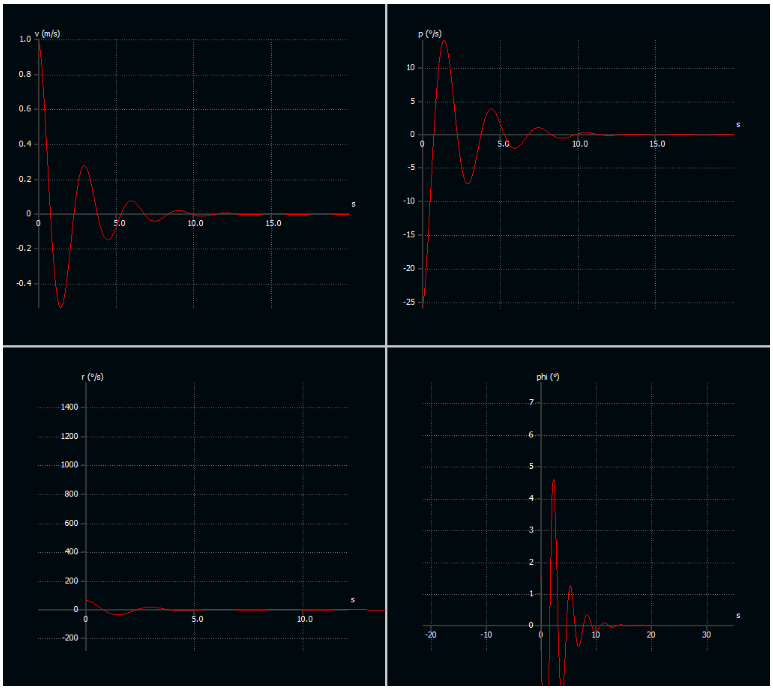


Figure 79. Stability response with the components initial

The analysis revealed that by moving the center of gravity towards the nose of the UAV, the UAV could be made stable. However, the time it took for the UAV to return to equilibrium after being disturbed was still quite prolonged. A prolonged recovery time could lead to unstable flight conditions and make the UAV difficult to control.

Total Mass = Volume + point masses

Center of gravity

Total Mass= 2459.930 g

X_CoG= 282.847 mm

Y_CoG= 0.497 mm

Z_CoG= 9.737 mm

Inertia in CoG Frame

Ixx= 0.00206 kg.m²

Iyy= 0.05028 kg.m²

Izz= 0.05193 kg.m²

Ixz= -0.00140 kg.m²

Figure 80. Stability response with final components layout

Through iterative adjustments to the layout, it was found that moving the battery—the heaviest component—20mm towards the nose of the UAV and thereby shifting the center of gravity, resulted in a significant improvement in stability. The UAV now demonstrated a nearly instantaneous response time to stability disturbances, which is an important characteristic for maintaining control of the UAV in various flight conditions.

Chapter 10.Conclusions

In this project, a detailed analysis of creating a fixed-wing unmanned aerial vehicle (UAV) designed for mapping operations in the mining industry has been carried out. The initial market study revealed significant growth in the UAV sector, providing a solid justification to proceed with the design and development of this product. A preliminary analysis of the competition and target market was conducted, which helped establish a market entry strategy.

The proposed design for the UAV included a production approach centered on using Prepreg carbon fiber. A manufacturing method was developed for each of the UAV's parts, and operating conditions were set. As part of the validation process, computational analyses were carried out, which included aerodynamic, structural, and stability studies.

Furthermore, various production management tools were developed, such as the product structure, value stream mapping, and Failure Mode and Effects Analysis (FMEA). Through these methods, potential quality issues during the production process could be identified and addressed.

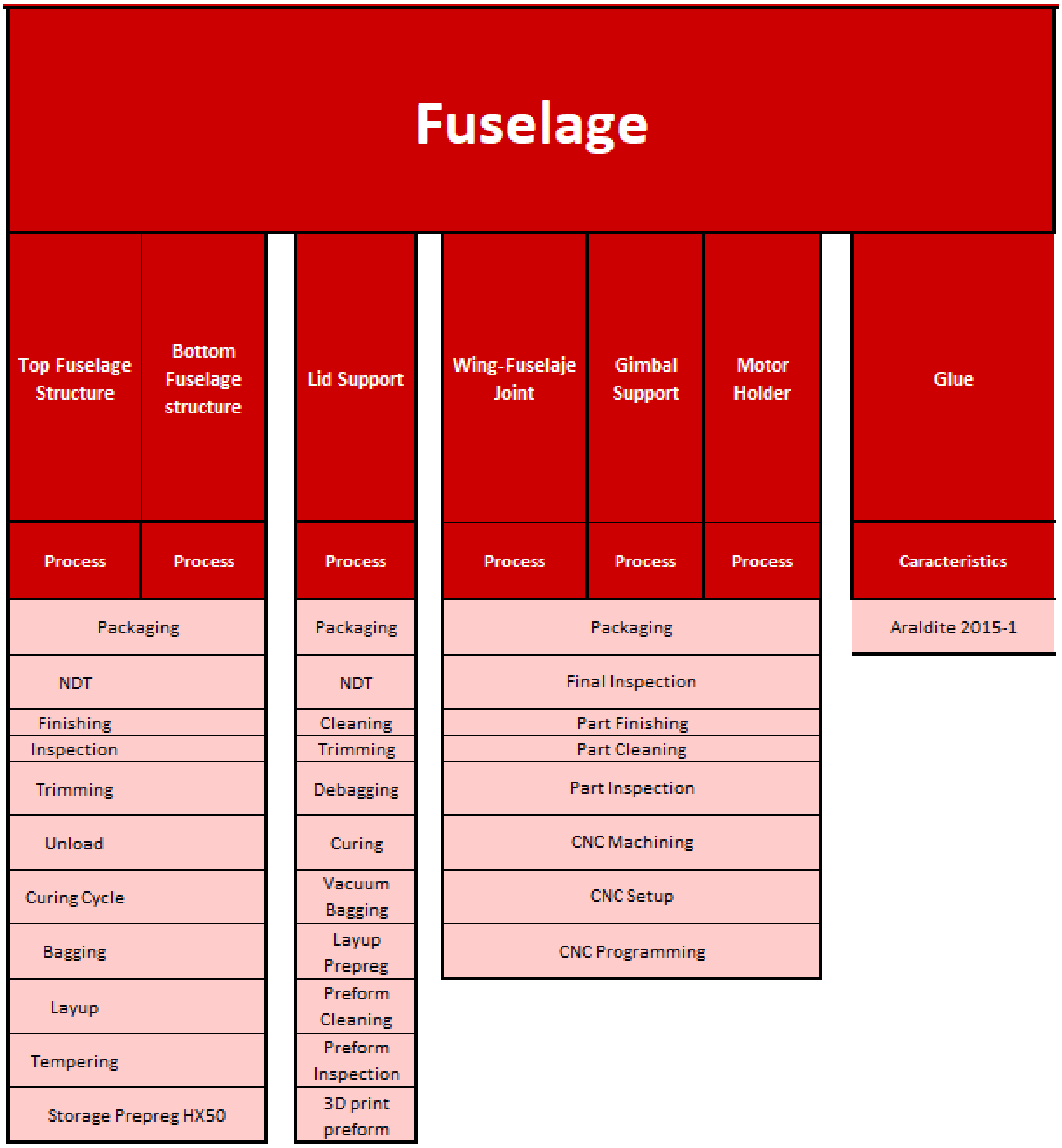
In summary, this project has demonstrated the application of technical skills in various fields such as aerospace production methods, fluid mechanics, flight mechanics, mechanical design, and aircraft design. As the project moves into its next phase, various lines of future work have been proposed, all of which promise to continue improving and optimizing both the product and the production process.

Chapter 11. Future works

1. The future work for this project could first begin with the physical prototype development. After completing the design and computational analysis of the UAV, the production of physical prototypes will provide real-world data to validate the computational results. This stage of development involves translating the digital design into a tangible object using the defined production methods. It provides an opportunity to scrutinize the product’s assembly process and functionality before full-scale production.
2. Following the creation of prototypes, an energy efficiency study should be conducted. This research would delve into the UAV's power consumption, analyzing its battery life and the area it can cover during mapping operations. The outcome of this study would enable optimization of the UAV's flight parameters and battery usage, contributing to a more autonomous and extensive operational capability.
3. In tandem with the energy efficiency study, developing an advanced flight control system can be pursued. This could involve integrating the UAV with a market-available software system to enhance its flight stability, maneuverability, and overall performance. Customizing this system to suit the specific mission requirements of the UAV will ensure that it delivers optimal operational efficiency.
4. As the UAV design matures, an analysis of alternative materials and production methods should be undertaken. This investigation will enable a comparative study, both qualitative and quantitative, of different manufacturing methods and materials. The goal would be to identify any opportunities for improvements in efficiency, cost, and product quality that alternative materials or methods may offer.
5. The project can then transition to focusing on quality control plans. These can be reactive, addressing issues as they arise; proactive, anticipating potential problems and putting measures in place to prevent them; or predictive, using data analysis to forecast future issues. A robust quality control plan will contribute to a reliable and high-quality product.
6. Concurrently, developing maintenance and repair procedures is critical. These procedures will ensure the UAV's longevity and reliability in the field. This includes creating a detailed maintenance schedule, outlining necessary checks and replacements, and establishing a set of procedures for diagnosing and repairing common faults.
7. The project should undertake a comprehensive study of safety measures and risk mitigation in both the operation and production of the UAV. This study would safeguard not only the operators and users of the UAV but also the workers involved in its production. Ensuring safety at all stages of the product's life cycle is of utmost importance.
8. As the production scales up, a cost and profitability analysis will become increasingly important. This analysis will help to optimize the production process, identify areas for cost reduction, and ensure that the project remains financially viable as the production volume increases.

9. With a finalized product, the development of marketing and sales strategies for the UAV will be paramount. These strategies should highlight the unique selling points of the UAV, identify target markets, and outline a plan for reaching potential customers.
10. Parallel to the marketing initiatives, exploring renewable energy options such as solar cells can be examined. Harnessing renewable energy sources could significantly increase the UAV's operational efficiency and reduce its environmental impact.
11. As the UAV nears market readiness, the requirements for airworthiness certification should be analyzed. This would ensure that the UAV meets all regulatory standards for safety and operation, making it legally compliant for commercial use.
12. Lastly, future research could explore new applications for the UAV in various sectors beyond mining. Identifying new markets can potentially increase the UAV's profitability and ensure its relevance in a rapidly changing technological landscape.

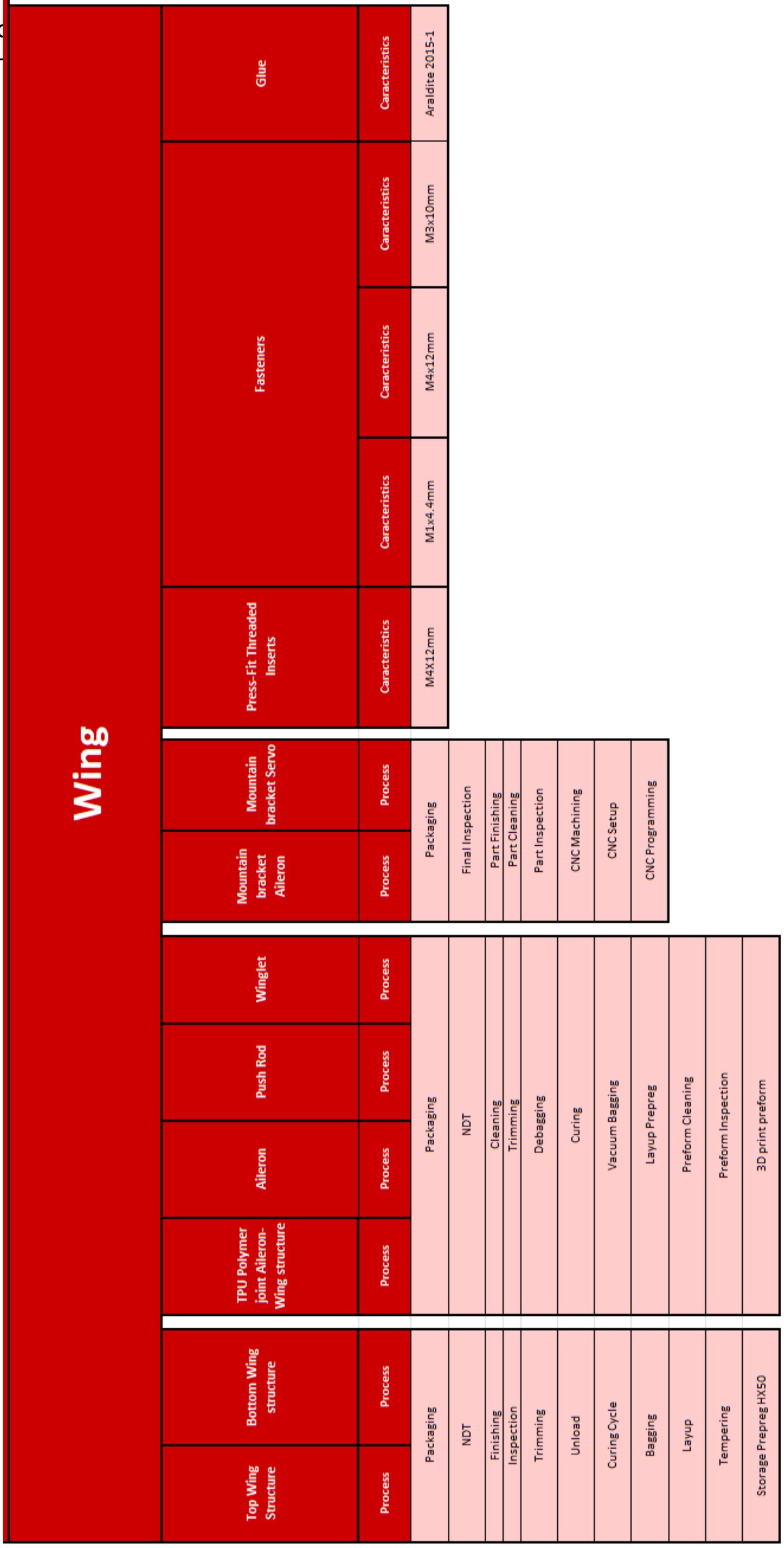
APPENDICES



Fuselage

- Top Fuselage Structure — Process
- Bottom Fuselage structure — Process
  - Packaging
  - NDT
  - Finishing
  - Inspection
  - Trimming
  - Unload
  - Curing Cycle
  - Bagging
  - Layup
  - Tempering
  - Storage Prepreg HX50
- Lid Support — Process
  - Packaging
  - NDT
  - Cleaning
  - Trimming
  - Debagging
  - Curing
  - Vacuum Bagging
  - Layup Prepreg
  - Preform Cleaning
  - Preform Inspection
  - 3D print preform
- Wing-Fuselaje Joint — Process
- Gimbal Support — Process
- Motor Holder — Process
  - Packaging
  - Final Inspection
  - Part Finishing
  - Part Cleaning
  - Part Inspection
  - CNC Machining
  - CNC Setup
  - CNC Programming
- Glue — Caracteristics
  - Araldite 2015-1

Annex 1 Product structure Fuselage.



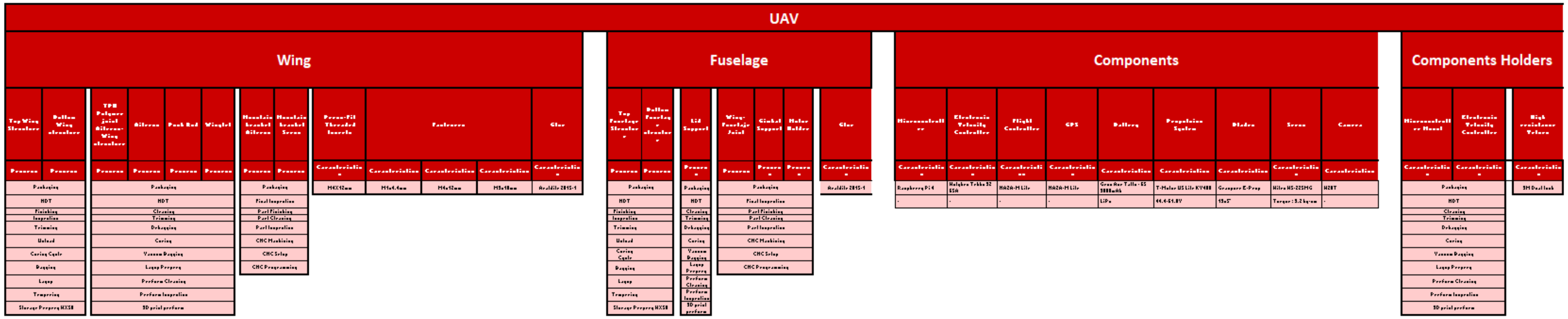
Annex 2. Product structure Wings

<table>
<tr><th colspan="4">Components Holders</th></tr>
<tr><td>Microcontroller Mount</td><td>Electronic Velocity Controller</td><td></td><td>High resistance Velcro</td></tr>
<tr><td>Caracteristics</td><td>Caracteristics</td><td></td><td>Caracteristics</td></tr>
<tr><td colspan="2">Packaging</td><td></td><td>3M Dual lock</td></tr>
<tr><td colspan="2">NDT</td><td></td><td></td></tr>
<tr><td colspan="2">Cleaning</td><td></td><td></td></tr>
<tr><td colspan="2">Trimming</td><td></td><td></td></tr>
<tr><td colspan="2">Debagging</td><td></td><td></td></tr>
<tr><td colspan="2">Curing</td><td></td><td></td></tr>
<tr><td colspan="2">Vacuum Bagging</td><td></td><td></td></tr>
<tr><td colspan="2">Layup Prepreg</td><td></td><td></td></tr>
<tr><td colspan="2">Preform Cleaning</td><td></td><td></td></tr>
<tr><td colspan="2">Preform Inspection</td><td></td><td></td></tr>
<tr><td colspan="2">3D print preform</td><td></td><td></td></tr>
</table>

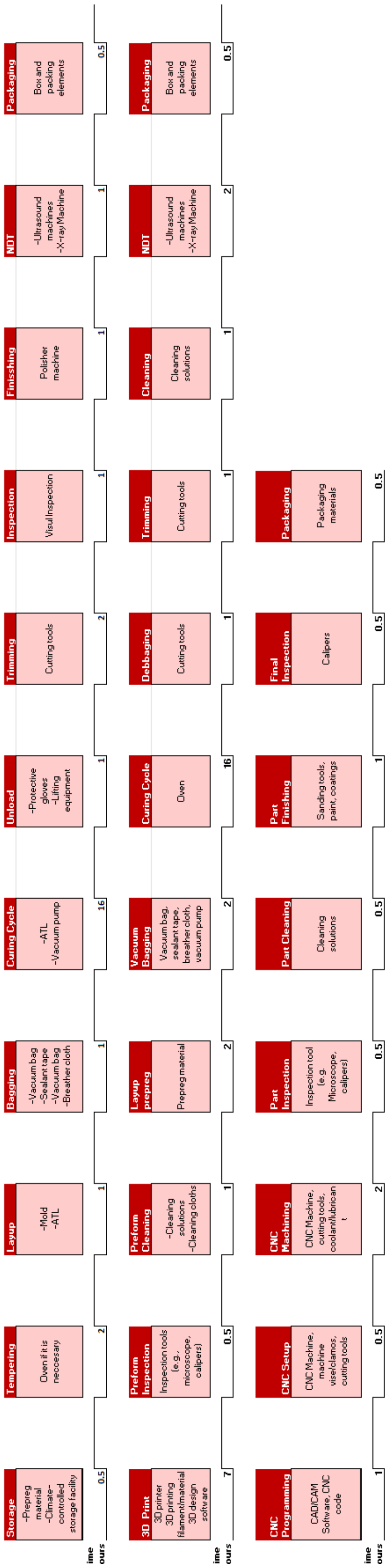
Annex 3. Product structure Components holder

Components								
Microcontroller	Electronic Velocity Controller	Flight Controller	GPS	Battery	Propulsion System	Blades	Servo	Camera
Caracteristics	Caracteristics	Caracteristics	Caracteristics	Caracteristics	Caracteristics	Caracteristics	Caracteristics	Caracteristics
Raspberry Pi 4	Holybro Tekko 32 65A	NAZA-M Lite	NAZA-M Lite	Gens Ace Tattu - 6S 9000mAh	T-Motor U5 Lite KV400	Graupner E-Prop	Hitec HS-225MG	H20T
-	-	-	-	LiPo	44.4-61.8V	13x5''	Torque : 3.2 kg-cm	-

Annex 4. Product structure Components



Annex 5. Final Product structure



Annex 6. Value Stream Map

No	Process	Potential Failure Mode	Failure Effect(s)	Potential Cause(s)	Current Controls	Severity	Ocurrence	Detection	RPN	Recommended Actions
1	Mold design	Incorrect mold	Defective parts	**Mold design errors**	**Design reviews and simulation**	**8**	**3**	**4**	96	**Detailed mold design check**
2	Carbon fiber cutting	Incorrect cut	Defective parts	**Measurement errors or cutting equipment faults**	**Visual inspection and equipment calibration**	**7**	**3**	**4**	84	**Proper measurement and cutting practices**
3	Laminating in mold	Air bubbles in laminate	Weakening of structure	**Poor lamination process or defective mold**	**Visual inspection**	**8**	**4**	**3**	96	**Proper lamination techniques training**
4	Curing	Incomplete curing	Weak or deformed parts	**Incorrect curing temperature or time**	**Curing process monitoring**	**7**	**3**	**3**	63	**Check oven and curing time settings**
5	Demolding	Damage during demolding	Damaged parts	**Abrupt or incorrect mold removal**	**Visual inspection and training**	**6**	**2**	**4**	48	**Proper demolding practices**
6	Parts joining	Weak joint	Fragile structure	**Incorrect application of Araldite 2015-1**	**Visual inspection and strength tests**	**8**	**3**	**4**	96	**Proper adhesive application training**
7	Drilling for threaded inserts	Incorrectly positioned hole	Weakened structure, incorrect assembly	**Incorrect tool positioning**	**Precise measurement, training**	**7**	**2**	**4**	56	**Check and calibrate the drilling tool**
8	Nut insertion	Incorrect insertion	Weakened structure, incorrect assembly	**Error during insertion**	**Visual inspection, training**	**6**	**2**	**4**	48	**Proper nut insertion training**
9	Motor mounting	Motor poorly mounted	Incorrect UAV operation	**Error during mounting**	**Visual inspection, training**	**9**	**3**	**3**	81	**Proper motor mounting training**
10	Aileron mounting	Aileron poorly mounted	Incorrect UAV operation	**Error during mounting**	**Visual inspection, training**	**8**	**2**	**4**	64	**Proper aileron mounting training**
11	Wing mounting	Wings poorly mounted	Incorrect UAV operation	**Error during mounting**	**Visual inspection, training**	**8**	**2**	**4**	64	**Proper wing mounting training**
12	3D printing	Printing errors	Defective parts	**Printer calibration errors**	**3D printer maintenance and calibration**	**7**	**2**	**3**	42	**Regular printer maintenance and calibration**
13	Assembly of fuselage and wings	Incorrect assembly	Weak structure, Incorrect UAV operation	**Incorrect alignment during assembly**	**Visual inspection, training**	**8**	**3**	**3**	72	**Proper assembly training**
14	Insertion of threaded inserts	Poorly inserted inserts	Weakened structure	**Incorrect tool use**	**Visual inspection, training**	**6**	**2**	**3**	36	**Proper tool use training**
15	CNC machining of aluminum parts	Incorrect machining	Defective parts	**Machining errors**	**Visual inspection and calibration of CNC machine**	**7**	**3**	**4**	84	**Regular machine maintenance and calibration**
16	Fitting of the motor	Incorrect fit	Impaired UAV operation	**Incorrect placement or fitting of the motor**	**Visual inspection, training**	**8**	**2**	**3**	48	**Proper fitting training**
17	Joining of upper and lower fuselage	Incorrect joining	Weakened structure, Incorrect UAV operation	**Incorrect use of Araldite 2015-1**	**Visual inspection, strength tests**	**8**	**3**	**3**	72	**Proper adhesive application training**
18	Software and control compatibility tests	Incompatibility issues	Impaired UAV operation	**Incorrect software or control testing**	**Software and control compatibility tests**	**9**	**3**	**2**	54	**Proper software and control testing**
19	Insertion of servo motor	Incorrect insertion	Impaired UAV operation	**Incorrect insertion technique**	**Visual inspection, training**	**7**	**2**	**4**	56	**Proper insertion technique training**
20	Assembly of winglets	Incorrect assembly	Incorrect UAV operation	**Incorrect assembly technique**	**Visual inspection, training**	**7**	**2**	**3**	42	**Proper assembly training**

Annex 7. FMEA

Type of Component	Component	Main Features	Dimensions	Weight
Microcontroller	Raspberry Pi 4 Model B	1.5GHz 64-bit quad-core ARMv8 CPU, 2GB-8GB LPDDR4 SDRAM, Dual-band 802.11ac wireless networking, Bluetooth 5.0, Gigabit Ethernet	85mm x 56mm x 20mm	46g
Motor	T-Motor U5 Lite KV400	High efficiency, high power, 400KV, 6S voltage support	Diameter: 60mm, Height: 33mm	178g
Electronic Speed Controller	Holybro tekko 32 65A 4IN1 ESC	65A continuous current, 80A peak current, 6S LiPo support, 8-layer PCB board	44x37x6mm	21g
Battery	Gens Ace Tattu - 6S 9000mAh	6-cell LiPo, 9000mAh capacity, 22.2V, 25C discharge rate	165mm x 64mm x 59mm	1200g
Autopilot System	NAZA-M Lite	Easy to use, GPS, auto take-off and landing, waypoint navigation, return to home, failsafe	45.5mm x 32.5mm x 18.5mm	25g

Servo Motor	Hitec HS-225MG	Compact, metal-geared, high torque, operates at 4.8-6.0V, speed of 0.14sec/60° at 4.8V	32.4mm x 16.8mm x 30.8mm	27g
Camera	Camera H20T	Hybrid multi-sensor, 20 MP visible-light sensor, 640x512 resolution thermal sensor, laser rangefinder	76.9mm x 58.3mm x 63.7mm	179g
Propeller	Graupner E-Prop	High-efficiency, quiet operation, low vibration, excellent aerodynamic design	11" diameter, 5" pitch	15g

Annex 8. Components detailed description

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