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ESCUELA DE INGENIERÍAS INDUSTRIALES

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ESCUELA DE INGENIERIAS INDUSTRIALES

Grado en Ingeniería Mecánica.

Diseño de las alas de un vehículo aéreo no tripulado (UAV)

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TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO: Design of HALE UAV wings

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Annotation

High altitude long endurance unmanned aerial vehicles are developed very quickly nowadays because they bring us the possibility of complete different tasks such as geological, topographical mapping, and communication links; this, combined with the progress of solar cells and electric batteries development makes HALE UAV designing a cutting-edge industry that has a great deal to say about how communications will be in the future.

This research about early design stages of the wings for a solar-powered HALE-UAV is a multidisciplinary development which bring together a study about different engineering features.

First of all energetic supply calculations will be defined, then performance of the aircraft at take-off, at steady flight and landing, drawing upon computer programs and managing engineering fields such as electronic, flow dynamics, machine design, structural analysis and programming.

The following sections will describe how to project the wings of an HALE-UAV, the analysis about this first design and how to improve it in future work.

The work also will include a design by computer for manufacture the HALE UAV, a flight test by computer and a report about economic future market entry.

Structure: introduction, project development, conclusions and suggestions, references.

Thesis consist of: 79 p. text without appendixes, 50 pictures, 16 tables, 10 graphics, 36 bibliographical entries.

Appendixes included.

Keywords: High Altitude Long Endurance, aircraft, design, Unmanned Aerial Vehicle, Computer Aided Design, Solar Airplane, Glider, Design Methodology.

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Glossary

- Symbols

- W_{TO}: Aircraft maximum take-off weight [N]
- m : weight [kg]
- $P_{elect\ tot}$: Total Power compsumption [W]
- S_{ref} : Wing reference area [m^2]
- g : Gravity [m/s^2]
- T: Temperature [K]
- P: Pressure [Pa]
- ϱ: Density [kg/m^3]
- μ: Dynamic viscosity [kg /m·s]
- Re: Reynolds number [-]
- δ: declination [rad]
- φ: altitude [rad]
- ω: Instantaneous hour angle [rad]
- A: Solar altitude angle [rad]
- $M (z,A)$: Air mass [-]
- Tr : Transmittance [-]
- I_0 : Extra-terrestrial irradiance [W/m^2]
- I_b : Available hourly radiation per meter square [W/m^2]
- M: Mach number [-]
- i_w: Wing incidence [º]
- AR: Aspect Ratio [-]
- λ_R: Taper Ratio [º]
- C_R : Root Chord [m]
- C_T : Tip Chord [m]
- b: wingspan [m]
- α_T :Twist angle [º]
- Λ: Sweep angle [º]
- Γ :Dihedral angle [º]
- α_a :Angle of attack at take-off [º]
- α_c: Angle at cruise speed [º]
- Cl: airfoil lift coefficient [-]
- Cd: airfoil drag coefficient [-]
- Cd_{par}: parasitic drag coefficient [-]
- Cd_f: form drag coefficient [-]
- Cd_{ind}: induced drag coefficient [-]
- Cm: airfoil pitching moment coefficient [-]
- e: Oswald's efficiency factor [-]
- η_{bec}: Efficiency of step-down converter [-]
- η_{sc}: Efficiency of solar cells [-]
- η_{cbr}: Efficiency of curved solar panels [-]
- η_{sd}: % Wing covered by solar cells [-]
- η_{chrg}: Efficiency of battery charge [-]
- η_{dchrg} : Efficiency of battery discharge [-]

- η_{ctrl}: Efficiency of motor controller [-]
- η_{grb}: Efficiency of gearbox [-]
- η_{mot}: Efficiency of motor [-]
- η_{mppt}: Efficiency of MPPT [-]
- η_{plr}: Efficiency of propeller [-]
- I_{med}: Hourly radiation per square meter at daylight [W/m^2]
- P_{av}: Power consumption of avionics system [W]
- P_{pld}: Power consumption of payload instruments [W]
- ξ_{sc}: Relation between Power and weight of solar cells [W/kg]
- k_{enc}: Mass density of encapsulation (flax fiber) [kg/m^2]
- H_{LiS}: LiS cells Specific energy [W·h/kg]
- T_{night}: Number of hours without sunlight [h]
- T_{day}: Number of hours with sunlight [h]
- T : Thrust Force [N]
- L: Lift Force [N]
- D: Drag Force [N]
- k_{mppt}: [kg/W]

- Acronyms

- HALE: High-Altitude Long Endurance
- UAV: Unmanned Aerial Vehicle
- CAD: Computer Aided Design.
- ISA: International Standard Atmosphere
- MAC: Mean Aerodynamic Chord [m]
- PB: Probability
- SV: Severity
- SE: Seriousness
- VH: Very High
- H: High
- M: Medium
- L:Low
- VL: Very Low

1. Preface

1.1. Introduction

The objective of this bachelor thesis will be to introduce the design of an Unmanned Aerial vehicle (UAV) High-Altitude Long Endurance (HALE) aircraft which has to be able to work at high altitudes powered by solar energy. In this thesis, it will be designed the aircraft wings, selecting a number of parameters and optimizing others, making feasible a determined task at high altitude.

I. Who is an HALE?

An High-Altitude Long Endurance plane is an airplane which works in a good way at high altitude (above the tropopause) and it is been able to fly long distances with no landing needed.

The tropopause is the borderline between the troposphere and the stratosphere; it's located between 9000 meters (at the poles) and 17000 meters in the equator, and it has an average height of 11000m. At this height the temperature is almost constant, and the sun irradiance gets higher due to the lack of clouds.

The conception of HALE airplanes was developed in 80s as a search in the field of Unmanned Aerial Vehicles, most of them built for military and surveillance flights, but they won´t become a reality until 2000s when solar powered industries were highly developed, new fuels such as Hydrogen and new materials such as carbon fiber were integrated.

Figure 1: NASA Global Hawk UAV military HALE

Scientific applications include ozone monitoring, collection of data for weather and global warming studies, as well as new applications like turning HALE UAVs into new atmospheric satellites, cheaper than actual satellites and easier to replace.

Commercial applications include aerial surveying, geological and topographical mapping, and communication links. Solar powered UAV can be employed in many of the above mentioned missions due to its cost effectiveness, environmental efficiency, and also because it is capable of long endurance flight and does not require much maintenance.

HALEs have large amount of sizes, shapes and operating modes, but in general there are two general classifications:

According to how the aircraft is piloted:

- Manned vehicles: a person inside the aircraft is responsible of handling the plane.

The pilot controls the flight of the aircraft by working its flight controls while other team members such as navigators or flight engineers are involved in operating the aircraft's flight systems on ground.

- Unmanned aerial vehicles (UAVs): is an aircraft without a human pilot aboard.

UAVs are a component of an unmanned aircraft system (UAS); which include a UAV, a ground-based controller, and a system of communications between the two. The flight of UAVs may operate with various degrees of autonomy: either under remote control by a human operator or autonomously by on-board computers. [2]

According to how the propulsion is produced:

- Those which run with fuel; Kerosene, Gasoline, Hydrogen.

Most of them run on internal combustion engines and store an amount of fuel in one or more deposits. The main advantage of this kind of aircraft is their efficiency, since the method of storage this energy is lighter than other devices such as solar cells, fuel cells or batteries in general.

- Those which run with electricity:

In this case, the aircrafts are propelled by electric motors powered by electricity stored in batteries, the main advantage is the autonomy. An aircraft which run transforming a free energy source as the sun into electricity could be totally autonomous.

On the other side the problems with solar energy are well known; solar cells are expensive and have a bad efficiency, also sunlight is needed and batteries are heavier than fuel deposits.

Figure 2: Atlantik Solar UAV.

In this study, we will emphasized in HALE UAVs run by electricity; slower and lighter aircrafts which run with electricity, powered by solar cells placed in the aircraft wings. The task will be to optimize the amount of solar cells needed, with the aircraft weight, choosing the best materials, designing the wing framework and airfoils. Then will be carried out a structural analysis, dynamic and static, as well as an economical study.

The advantages of Solar HALE UAV aircrafts over standard ones are:

- They don't need fuel.
- They are environmental friendly ("zero emission").
- They can stay in the air for a long period of time.
- They can operate in high altitudes above the normal air traffic, thought this can be done with an manned aircraft , the pilot would need a pressure suit.
- They are much more weather independent, because they operate in the stratosphere with stable weather conditions.

The main disadvantage is that the operation in high altitudes requires aircraft with large wings due to the limited power available, speed and payload of a Solar HALE is limited.

II. Applications

Our final purpose is being able to integrate cloud seeding flares in the aircraft; cloud seeding it is a way of manipulation of the climate trying to change the quantity or the type of rainfall that falls down of the clouds by means of the dispersion of substances in the air.

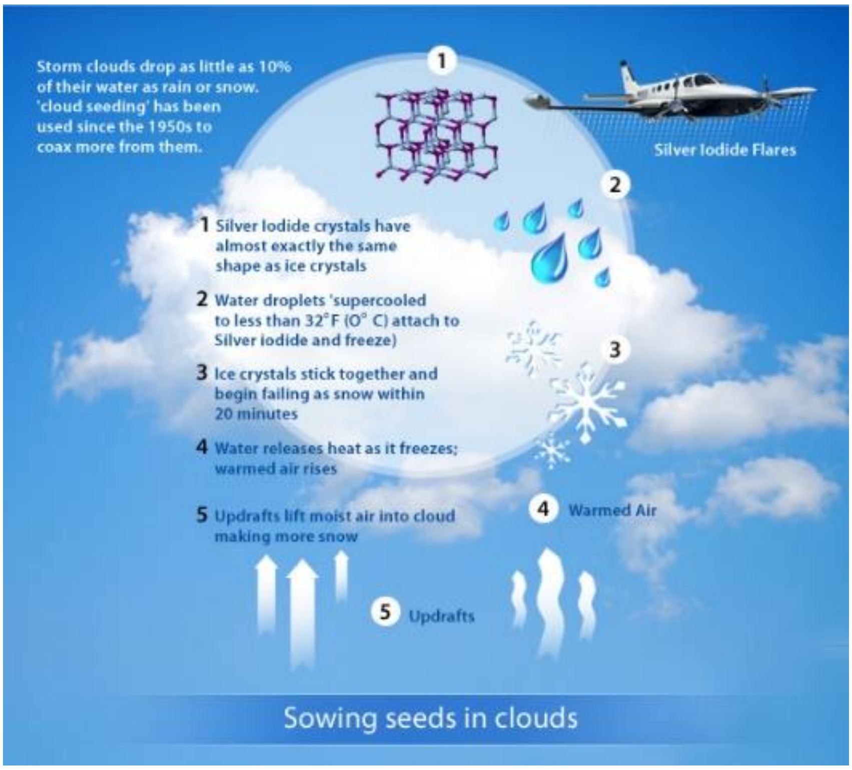


Figure 3: How it work cloud seeding

1.2. Motivation

My personal motivation of carrying out this project is to complete my studies in Mechanics Engineering. My purpose at the moment to accept this challenge is to learn and to deal with a specific problem that an engineer has to solve.

In addition, I think is a good opportunity to work in a team project, using computer simulation and CAD programs. Nowadays, all companies work is based in computer programs and it has a lot of importance in a lot of industries. With this research, I have the possibility to improve my skills in CATIA and the opportunity to work with another programs such as XFLR5, OpenVSP, and excel. It is a good opportunity that I couldn't let pass thinking of my future and my entrance in the world of employment.

Finally there was an experience integrating different studies from my specialization, such as avionics, aerospace engineering, electronics, energy engineering and science of materials. It is a good chance to learn how different fields combine each other in order to design an industrial device.

1.3. Objective

The principal objective of this research is to find a solution of a real engineering problem, as far as we concerned design an assembly composed by several elements which have to be optimized in order to qualify some requirements such as supply of enough amount of energy, provide power to lift up the aircraft to the correct altitude as well as giving an accurate relation between weight, resistance and dimensions.

Moreover, the work must be cooperative, and we have to solve every team member problems, due all the parts depend with each other.

1.4 Analysis of similar devices

HALE UAVs have a lot of different configurations, sizes and shapes. Due to this we select six different UAVs with specifications similar to those suggested.

The conditions proposed are:

- Around 25 m. of wingspan
- Do not exceed 12m of length.
- Do not exceed 3.5 m. of height
- Electrical power: do not exceed 2000 W.

UAV	Span [m]	MAC [m]	S_{ref} [m^2]	Weight [kg]	Motors	AR	Alt. cruise flight [m]
Zephyr 7	18	1.55	27.9	35	2	11.6	18000
Zephyr 88 Model S	25	2	40.4	62	2	15.5	18000
EAV-3	22	1.9	42.2	53	2	11.5	14000
Pathfinder	30	2.4	72.5	254	6 (firstly 8)	12.4	19000
I-29 Phoenix	38.2	1.5	56.8	270	2	25.7	15000

Zephyr 7

The Zephyr 7 is a High Altitude Pseudo-Satellite (HAPS) aircraft built by the British multinational defense technology company QinetiQ, after sold to Airbus Defence and Space. This UAV co-holds the official endurance record for an unrefueled, unmanned aerial vehicle with its flight from 9 July to 23 July 2010, lasting 336 hours, 22 minutes and. Record claims have been verified by the Fédération Aéronautique Internationale (FAI) for both duration and altitude, at 21,562 m., more than doubled the previous endurance record for unmanned flight.

The aircraft has been designed for use in observation and communications, but it has potential military applications as an Earth observation and communications platform.

It has a structure made of carbon-fiber and a weight of 35 kg with a little payload of less than 3 kg. It has a cruise speed of 56 km/h and is able to flight at 20000m height and it is driven by two Newcastle University custom permanent-magnet synchronous motors, 0.60hp (0.45 kW).

With a wingspan of 18 m. divided in two sections:

- First section measure approximately 7 meters from the axis, and is fully covered by solar cells.
- Second section has a dihedral of 16º and measures 2 meters, this section isn't covered by solar panels.

Figure 4 - Zephyr 7 at night flight.

Zephyr 8 – Model S

Zephyr S is the name of the production variant of the Zephyr 8 vehicle. It has its wings covered by light solar sheets whereby a Lithium-Sulphur battery is charged during the day, which powers the aircraft at night; it represents a substantial improvement in the overall design. It has a 25m wingspan versus the Zephyr-7's 18m, yet the structure is considerably lighter. This allows it to carry more batteries (40% of the Zephyr-8's roughly 60kg mass is dedicated to energy storage) and more payload - up to 5kg.

Zephyr S wing configuration is low wing instead of the high wind of his predecessor. Their wings also includes winglets, this devices are disposed to reduce aerodynamic resistance impairing the airflow turbulences near the wing tips in fixed wings aircrafts.

Figure 5 -Zephyr S

EAV-3

On 25th August, 2016 Korea Aerospace Research Institute (KARI) announced that Korea's first high-altitude solar unmanned aerial vehicle (EAV-3) had successfully finished a flight of 90 minutes in the stratosphere that 18.5 kilometers high on August 12. This made Korea become the third country in the world to master this kind of technology.

About the wings in this model there aren't dihedral angles, instead it has ailerons, and a characteristic shape near the wingtip called Hoerner type.

Figure 6 - EAV-3 by Korea Aerospace Research Institute

Pathfinder

Pathfinder is a HALE built by NASA powered by solar cells and a fuel cells system. It has a wingspan of 30 m and it is propelled by 6 electric motors. It was the first HALE UAV built, and it reached an altitude of 15240 m in a 12 hours flight duration which was taken place from Armstrong Flight Research Center in California.

Despite the aircraft weight is considerably heavier than the others, is interesting to see wing configuration in this aircraft, divided in two bodies which contain landing wheels.

Figure 7- Pathfinder UAV

I-29 Phoenix

I-29 Phoenix is a HALE UAV project designed by the Warsaw Institute of Aviation.

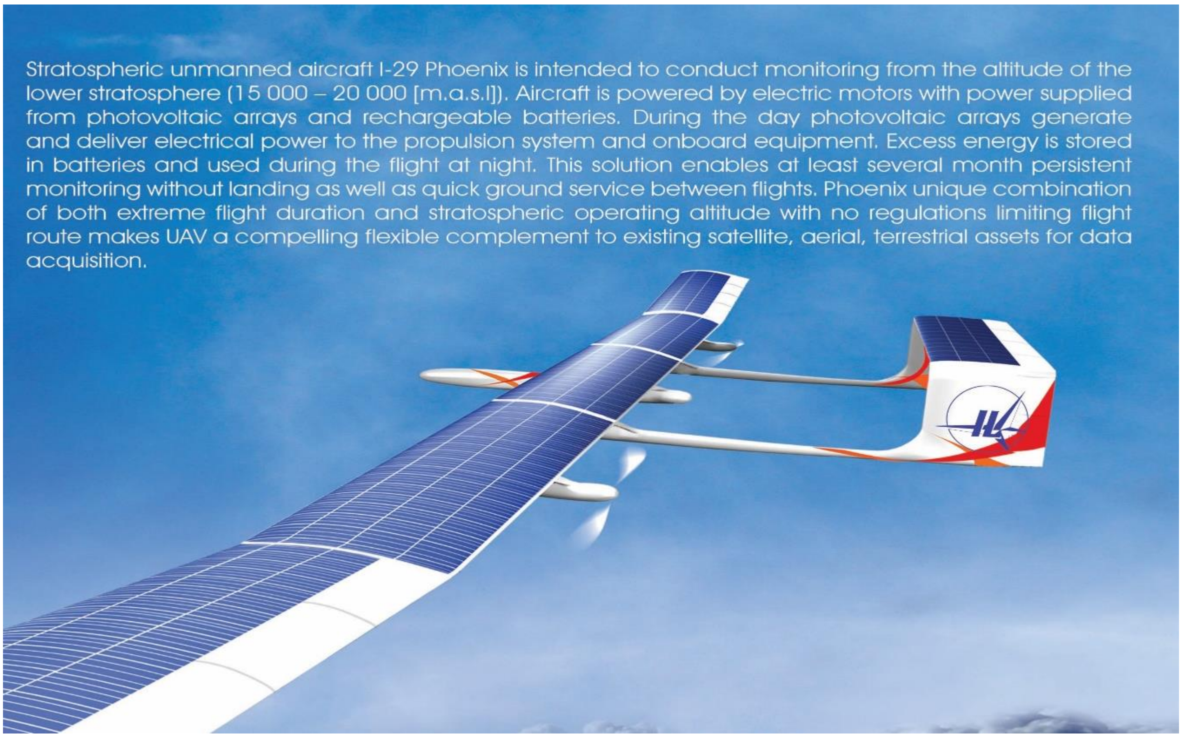


Figure 8- I-29 Phoenix prototype by Warsaw Institute of Aviation

2. Report and Predesign

2.1 Essential Concepts

An aircraft has to be able to lift its weight at a determined speed; called stall speed; and maintain a constant cruise speed during the flight at a determined altitude.
Due to this, during the take-off, and the cruise flight, there are four forces involved:

- **Weight:** a force that is always dragged to the center of the earth. The magnitude of the weight depends on the mass of all the aircraft and is distributed throughout the airplane. But we'll take the center of gravity as the point which the UAV rotates about.
- **Lift:** to overcome the weight force, airplanes generate an opposing force called lift. Lift is generated by the motion of the airplane through the air and is an aerodynamic force and is perpendicular to the flight direction. The magnitude of the lift depends on several factors including the shape, size, and velocity of the aircraft. Most of the lift is generated by the wings. Aircraft lift acts through a single point called the center of pressure.
- **Drag:** When the aircraft is moving through the air, there is another aerodynamic force present. The air resists the motion of the aircraft and the resistance force is called drag. Drag is directed along and opposed to the flight direction. Like lift, there are many factors that affect the magnitude of the drag force including the shape of the aircraft, the "stickiness" of the air, and the velocity of the aircraft. Like lift, drag acts through the aircraft center of pressure.
- **Thrust:** To exceed drag, the HALE use a propulsion system to generate a force called thrust. The direction of the thrust force depends on how the engines are attached to the aircraft. The magnitude of the thrust depends on many factors associated with the propulsion system including the type and number of engines, the kind of electrical motor used and the weather conditions at different heights.

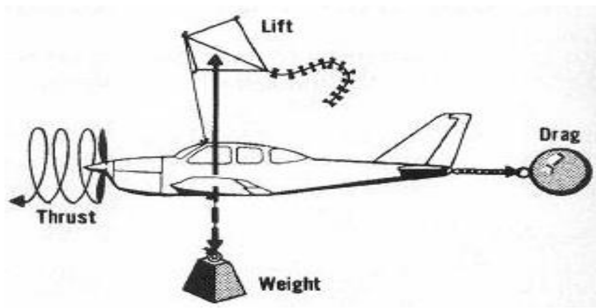


Figure 9: Four forces acting on the aircraft in flight.

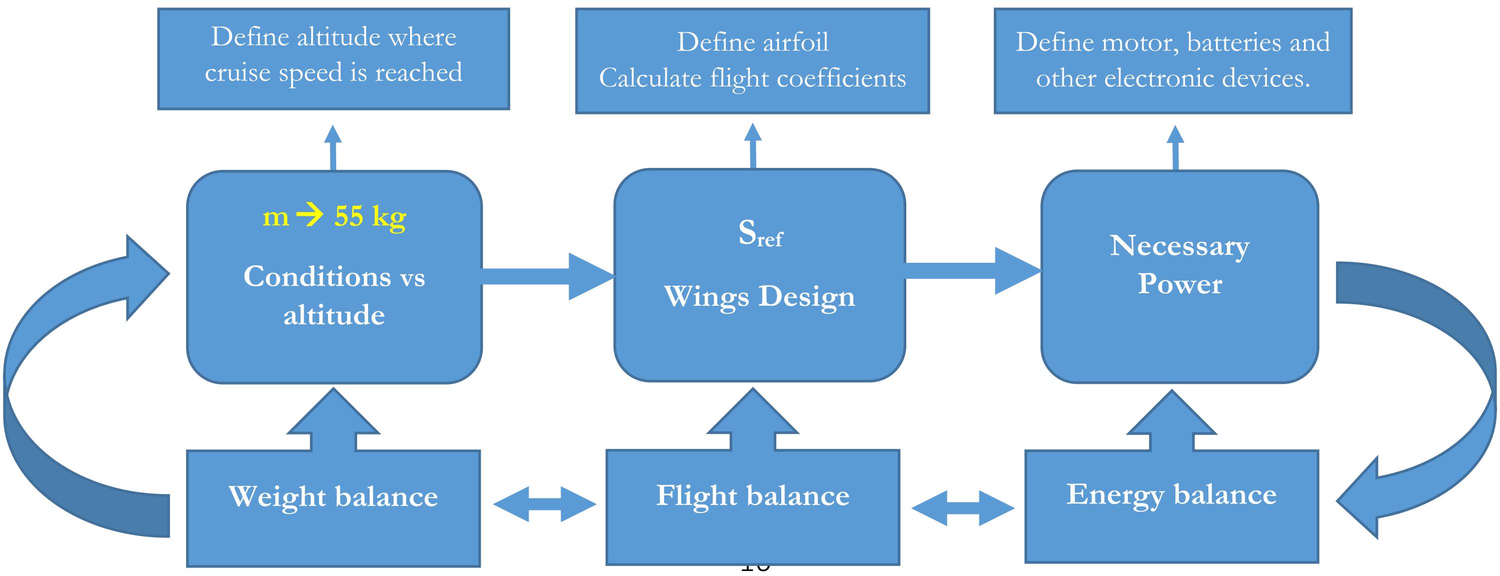
2.2 Schematic Layout

The objective in this thesis it will be design a UAV powered by electric motors with energy collected in batteries, which were loaded by solar cells located in the wings of the aircraft.

The first parameters necessaries to be included are three: aircraft maximum take-off weight (W_{TO}), engine Power (P) and wing reference area (S_{ref}), this three parameters must be estimated after determine other parameters such as the shape of the airfoil or the wing structures.

- **Aircraft maximum take-off weight (W_{TO}), [kg]:** As the aircraft operates using solar power, it needs to be as light as possible in order to reduce the power needed to fly it, while still outstanding strong and supporting the other components.
- **Total Power consumption (P_{elect}), [W]:** As the batteries will be the heaviest part of the aircraft, the amount of energy consumed by the plane to keep the aircraft entirely operational it has to be optimized; the propeller motors, the avionics system, the electronic components and the landing system.
- **Wing reference area (S_{ref}), [m^2]:** As the energy will be collected by solar cells, the upper surface of the wings will be covered by ultra-thin solar panels which will be responsible for provide energy to the electronic devices of the aircraft, in addition to recharge the batteries during the daylight.

First of these parameters, aircraft maximum take-off weight, will be determined first of all, it will be a weight set of 50 kg. The way to proceed will be summed up in the next graphic:



2.3 Conditions at different altitudes

It's necessary to know the variation of different parameters as the aircraft lifts, therefore, we have to study that parameters in relation with altitude; first of all we have to decide the altitude where the UAV reach cruise speed, in comparison with other HALE UAVs

As the aircraft flight range should be between 0 m. at landing and 18000 m. at is maximum altitude, we will calculate each parameter from sea level to 18000m. per 1000 m. This parameters were calculated according the International Standard Atmosphere (ISA) for conditions of the coldest day of the year in Vilnius.

- **Gravity [m/s²]:** gravity goes down as the altitude increases, it has not an important influence at high speed and changes as equation (1); where g is the gravity at different points, R is the Earth's radius, G is the gravitational constant equal to (6.674×10^{-11}), M is the Earth mass (5.972×10^{24} kg) and z is the altitude.

$$g = \frac{GM}{(R+z)^2} \qquad (1)$$

- **Temperature [K]:** in the atmosphere temperature goes down as the altitude increases until tropopause is reach, tropopause is located at 11000 m., when this borderline is exceed temperature becomes constant, between 0 and 11000 m. temperature follow the next equation; (2), where T (z) is the temperature at different height points, λ is a constant equal to 0.0065 K/m, and T_0 is the temperature at sea level.

Until tropopause (0-11000m): $$T(z) = T_0 + \lambda \cdot z \qquad (2.1)$$

Stratosphere (11000-20000m): $$T(z) = T_{11000} \qquad (2.2)$$

- **Pressure [Pa]:** Pressure also goes down as the altitude increases, following ideal gas law (3) where $R_{air} = 287\ m^2 \cdot s^{-2} \cdot K^{-1}$ and integrating we can express P(z) according to T(z) and T_0 with the following equations (4.1, 4.2).

$$P \cdot V = RT \qquad (3)$$

Until tropopause (0-11000m): $$P(z) = P_0 \cdot \left(\frac{T(z)}{T_0}\right)^{g/R\lambda} \qquad (4.1)$$

Stratosphere (11000-20000m): $$P(z) = P_{11000} \cdot e^{g \cdot [(z-11000)/R \cdot T(z)]} \qquad (4.2)$$

- **Density [kg/m³]:** Density (ϱ) also goes down as the altitude increases, and integrating from ideal gas law we can calculate ϱ at different altitudes, (5.1, 5.2).

Until tropopause (0-11000m): $\rho\ (z) = \rho_0 \cdot \left(\frac{T(z)}{T_0}\right)^{\left[\left(\frac{g}{R\lambda}\right)-1\right]}$ (5.1)

Stratosphere (11000-20000m): $\rho\ (z) = \rho_{11000} \cdot e^{g\cdot[(z-11000)/R\cdot T(z)]}$ (5.2)

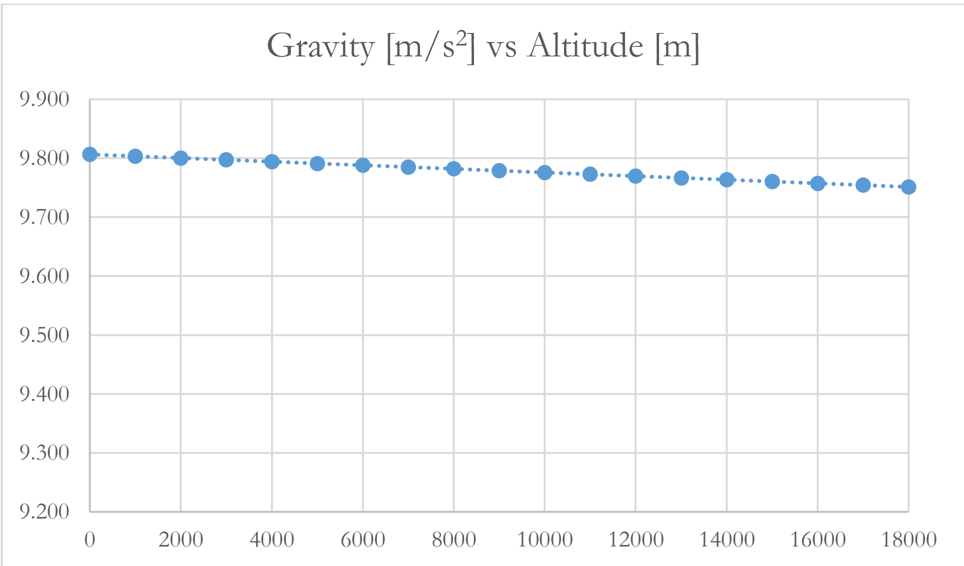
- **Dynamic viscosity [kg /m·s]**: Dynamic viscosity (μ) goes down as the altitude increases, and it depends only with temperature as it is defined in equation (6), where μ_0 is constant equal to $1.75x10^{-5}$ and *n* is a constant which vary between 0.8 to 0.9 according to the kind of airfoils, we set as 0.85.

$$\mu\ (z) = \mu_0 \cdot \left(\frac{T(z)}{273}\right)^n \quad (6)$$

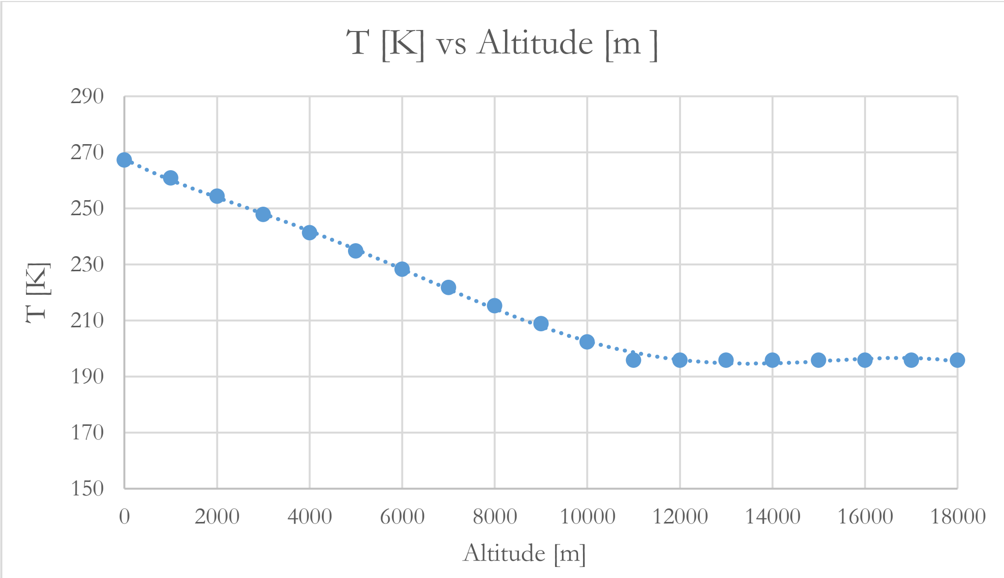
- **Reynolds number (Re) [-]**: Reynolds number will be important to know how the plane will work at cruise flight, it depends on speed (v), density, dynamic viscosity and thickness (D). It is described in equation (7)

$$\mathrm{Re} = \frac{\rho D v}{\mu} \quad (7)$$

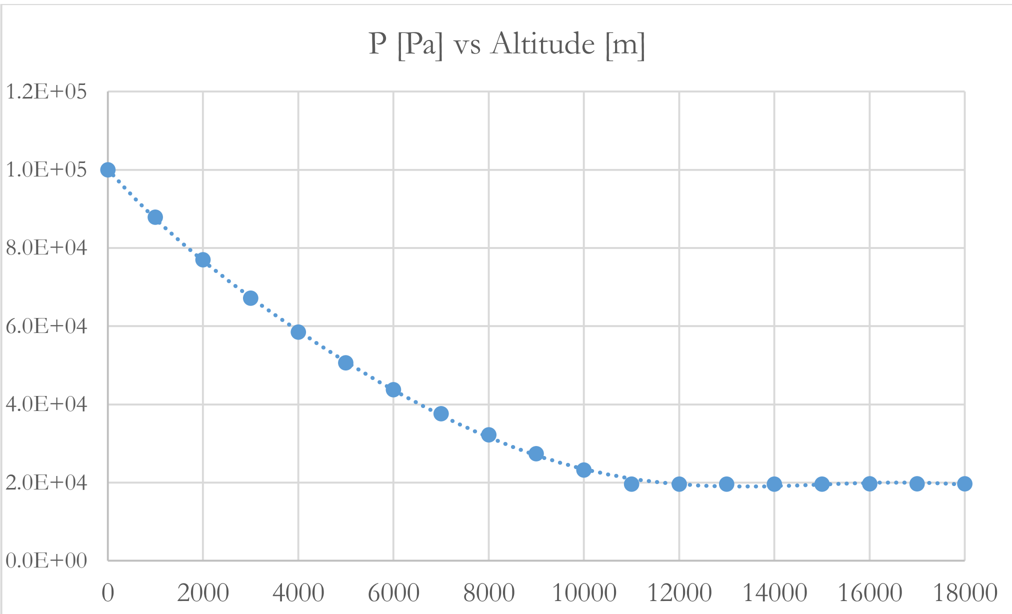
Implementing this parameters in tables, according to International Standard Atmosphere (ISA) values, using average temperatures in the coldest month in Vilnius (December) we can see in graphics how temperature, pressure density and viscosity change altitude between 0 to 18000m.



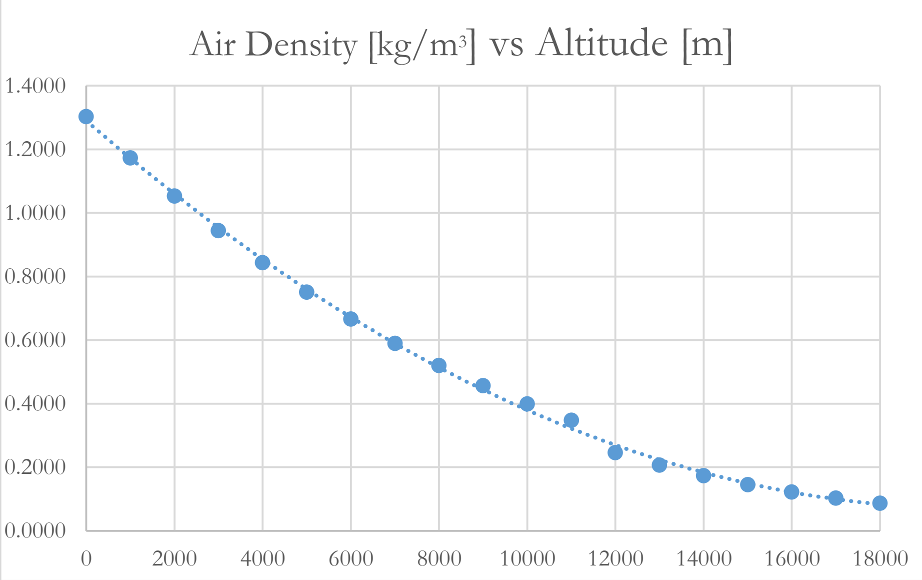
Graphic 1



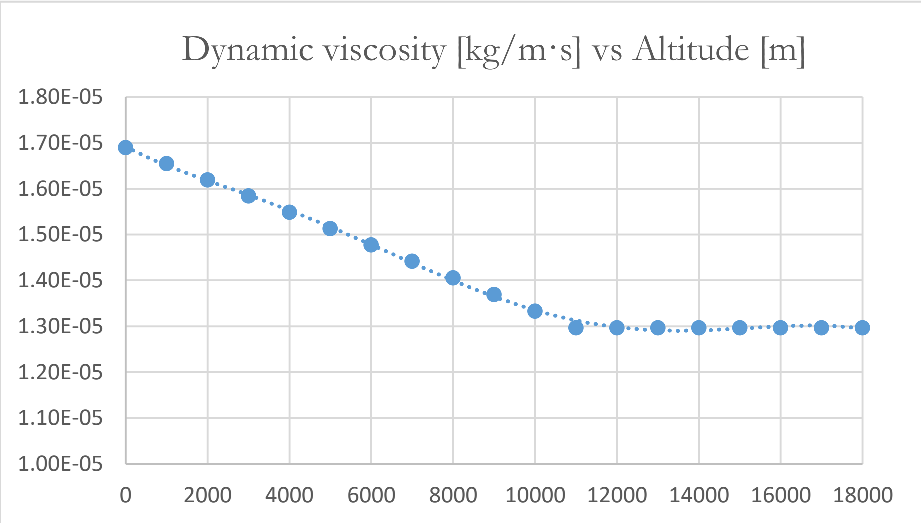
Graphic 2



Graphic 3



Graphic 4



Graphic 5

- **Conclusions:**

With this factors we get a first impress about the environment where the aircraft will work; and this parameters will be needed so as to calculate the forces produced at different altitudes.

As it is presented in the tables; temperature, pressure and dynamic viscosity is nearly constant above 10000-12000 m; so it's concluded that it is a good environment to reach steady flight. However, air density doesn't reach a steady area; so it has to be considered after, to know the better altitude where the drag, thrust, weight and lift forces reach an appropriate balance.

- **Available hourly radiation per meter square [W/m^2]**:

In order to find the atmosphere height were the aircraft reach their cruise altitude it is necessary to know the available hourly radiation per meter square, I - [W/m^2].

For these calculations as this is an UAV which works at a high altitude the studies of (Bailey and Bower, 1992) to calculate available solar power at altitudes above 2 km. it will be used.

First of all, the aircraft has to be able to fly on any day of the year, so it has to be designed on the coldest day of the year in Vilnius; which is defined by the latitude (φ), and the declination (δ) and at 21 of December are the following:

- φ: 0.9545 rad = 54.689 deg.
- δ: 0.1252 rad = 7.1724 deg.

Also it's needed to calculate the instantaneous hour angle (ω) which can be estimated using (8), where *h* is the hour of the day:

$$\omega = \frac{(15 \cdot h - 180)\pi}{180} \qquad \textbf{(8)}$$

With this parameters the solar altitude angle A [rad] will be estimated as equation (9) according to Bailey and Bower, 1992:

$$\mathrm{A}\,(h) = sin^{-1} \cdot [\cos\omega\ \cdot \cos\delta\ + \sin\delta\ \cdot \sin\varphi] \qquad \textbf{(9)}$$

After this, air mass *M (z, A)* is defined as the trail length of sunlight or the quantity of atmosphere that solar radiation can pass through. At sea level, it can be estimated using (10):

$$M(0, A) = \sqrt{[1229 + (614 \sin A)\ ^2]} - 614 \sin A \qquad \textbf{(10)}$$

From sea level to 20000m it is estimated as (11):

$$M(z, A) = \mathrm{M}(0, A) \cdot \frac{P(z)}{P(0)} \qquad \textbf{(11)}$$

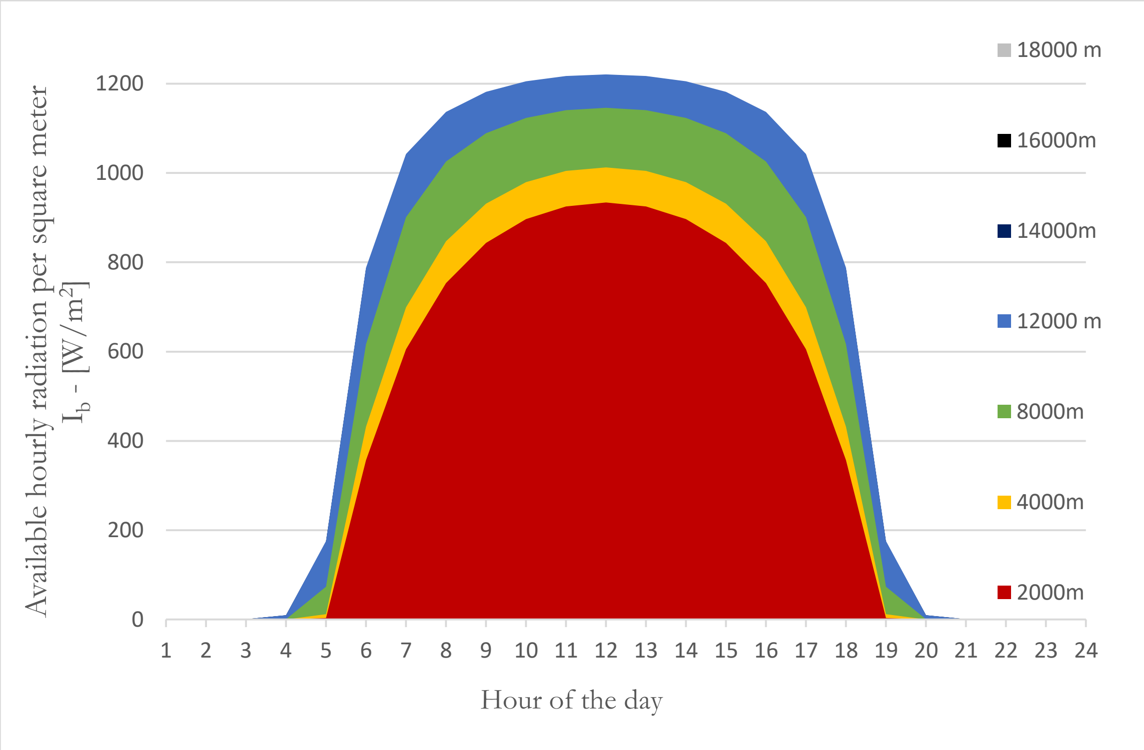
As it is known the air mass at a certain altitude and the hour of the day; the transmittance (*Tr*) can be found using equation (12):

$$Tr(h, z) = 0.5[e^{-0.65 \cdot \mathrm{M}(z,A)} + e^{-0.095 \cdot \mathrm{M}(z,A)}] \qquad \textbf{(12)}$$

Finally it is possible to estimate the available hourly radiation per meter square I_b [W/m²] as a multiple of the extra-terrestrial irradiance (I_0) and the transmittance (*Tr*) at a given altitude and hour angle where the average value of I_0 1353 W/m². (13)

$$I_b(h,z) = I_0 \cdot Tr \qquad \textbf{(13)}$$

Taking this data to a graphic it is possible to realize which amount of radiation per meter square at different altitudes.



Graphic 6

- **Conclusions:**

With these parameters we have a first impression about where the aircraft can reach cruise speed; as it is shown in the previous table, the available hourly radiation per square meter it's almost constant and the maximum above 12000 m. so due to this it is selected an altitude above 12000m as the cruise speed altitude.

Also it will be calculated the total average hourly radiation per square meter at daylight (between 4 am to 20pm) at different altitudes:

- At 2000m : 570.3 [W/m² h]
- At 4000m : 610.0 [W/m² h]
- At 8000m : 872.4 [W/m² h]
- At 12000m : 982.5 [W/m² h]
- At 14000m : 981.0 [W/m² h]
- At 16000m : 980.8 [W/m² h]
- At 18000m : 980.6 [W/m² h]

Also it's possible to define the time of sunlight radiation and the time without sun:

- T_{night}: around 9 hours.
- $T_{daylight}$: around 15 hours.

This data will be needed to check the wing surface needed to provide enough energy to the aircraft during the flight.

2.4 Preliminary design

This section focuses in determinate the basic shape and size of the wings, to carry out this process we are supported by a computer program OpenVSP (http://www.openvsp.org/), it's a free CAD system developed by NASA that will help us to sketch the structure of the aircraft, as well as start the design of other parts of the HALE UAV.

The key function of the wing is to generate sufficient lift force, and stabilize the UAV at the moment of landing, and at cruise speed. Furthermore, the wings surface, has to contain enough solar panels to charge the batteries and supply power to the different aircraft elements, so it has to be a balance between weight, size, surface, power, lift and drag forces and thrust.

During this preliminary design, several parameters should be decided, although this parameters must be optimized in an iterative process after some calculations. The parameters to analyze will be the following ones:

I. **Number of wings**
II. **Type of wing (high, mid, or low wing)**
III. **Cross section and airfoil**
IV. **Aspect Ratio (AR)**
V. **Wing incidence (iw)**
VI. **Taper Ratio (λ_R)**
VII. **Root Chord (C_R)**
VIII. **Tip Chord (C_T)**
IX. **Mean Aerodynamic Chord (MAC)**
X. **Span (b)**
XI. **Dihedral angle (Γ)**
XII. **Angle of attack (α_a) and angle at cruise speed (α_c)**

I. Number of wings.

The three possible options are monoplane (one wing), biplane (two wings), triwing.

<u>Selection</u>

As the weight is quite compromised by the number of wings a monoplane will be selected since the wingspan length will be significant.

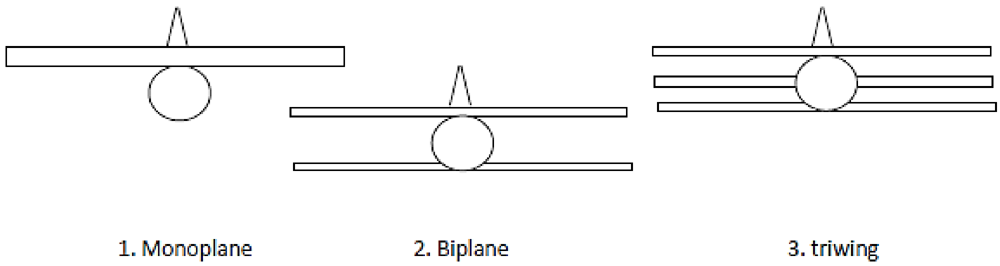


Figure 10: Different configurations of number of wings.

II. Type of wing (high, mid, or low wing)

Other of the wing parameters that should be choose at the early stages of wing design procedure is the wing location relative to the fuselage centerline. This factor will influence the design of other components as aircraft tail and landing gear.

There are four principal options for the place of the wing:

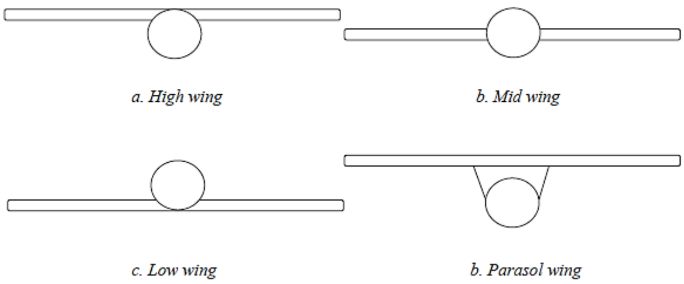


Figure 11: Different configurations of types of wings.

a) High wing: The wing is connected to the fuselage in the aircraft upper area.

On the one hand, the installation of engine on the wing is easier and the propeller clearance is higher compared with low wing configuration, also the wing produce more lift compared with mid and low wing, and due to this, the aircraft will need a lower stall speed and will be more stable. Furthermore, facilitates the installation of longeron what makes the wings lighter. On the other hand, the drag force will be higher than in the others, the horizontal tail must be larger and this configuration tend to produce heavier aircrafts.

b) Mid Wing: The wing is connected in the middle of the aircraft fuselage.

The mid wing is aerodynamically streamliner compared with other configurations and has less interference drag than low-wing and high-wing.

On the contrary, the aircraft structure is heavier, due to the necessity of reinforcing wing root at the connection with the fuselage and that makes the mid-wing configuration more expensive compared with high and low-wing configurations.

c) Low wing: The wing is connected below the fuselage.

The aircraft take off performance is better; compared with a high wing configuration due to the ground effect, makes the tail and the wings lighter.

The main disadvantage is that the wing generate less lift force, the stall speed should be higher and the wing has less contribution to the aircraft dihedral effect, thus the aircraft is less stable.

d) Parasol wing: The wing is above the fuselage, hanged by some support elements.

It is usually employed in hang gliders or amphibian aircraft, in addition, the wing it is heavier and has more drag, compared with a high wing configuration.

Selection

The selection criteria consist of taking the principal design objectives of the wing, and deliver them by weight in our project; then by seeing the advantages and disadvantages, the objective will be choose the best. As may be seen in the table 7 the better option will be the high wing, since is more stable, and need lower stall speeds.

Design objectives	Weight [%]	High Wing	Mid Wing	Low Wing	Parasol
Stability	30%	+	+	-	=
Stall Speed	20%	++	+	-	+
Weight	20%	+	-	++	=
Land-Take off performance	15%	-	+	++	-
Cost	15%	=	-	=	-

Table 1

III. Cross section and airfoil

The primary function of the wing is to generate lift force. This will be generated by a special wing cross section called airfoil. Wing is a three dimensional component, while the airfoil is two dimensional section. Because of the airfoil section, two other outputs of the airfoil, and consequently the wing, are drag and pitching moment. The wing may have a constant or a non-constant cross-section across the wing. [Mohammad Sadraey Daniel Webster College]

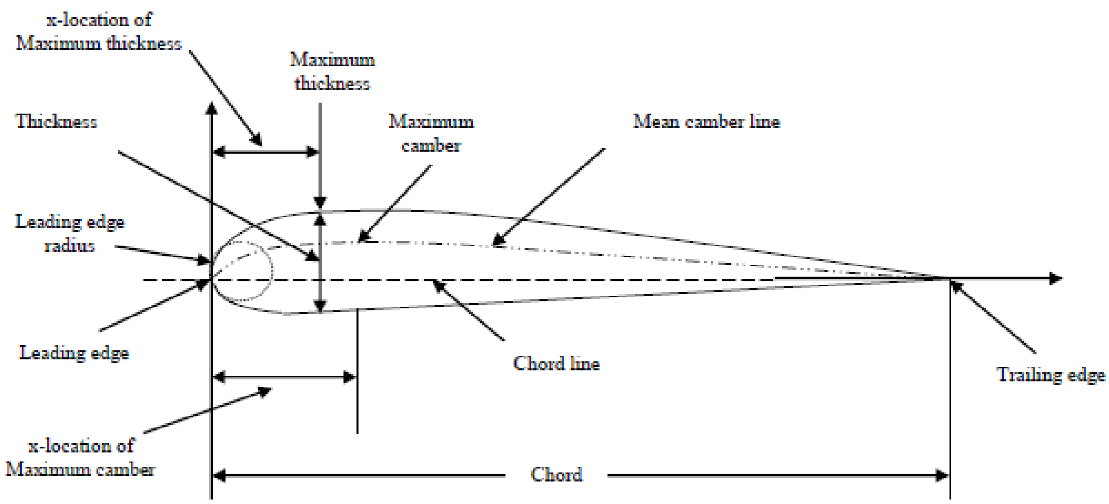


Figure 12: Parameters and geometry of an airfoil.

Since aerodynamic performance is vital to fulfil all the flight requirements, the aircraft designed intend to be considered to have characteristics of a sailplane or a motor-glider. A sailplane is defined as type aircraft, which creates low amounts of drag for a given amount of lift; which is best achieved with the use of long, thin type wings.

Considering this characteristic, three airfoils were preselected to compare: Clark-Y 11.7% smoothed, E214 (11.1%) - Eppler E214 and Wortmann FX 63-137

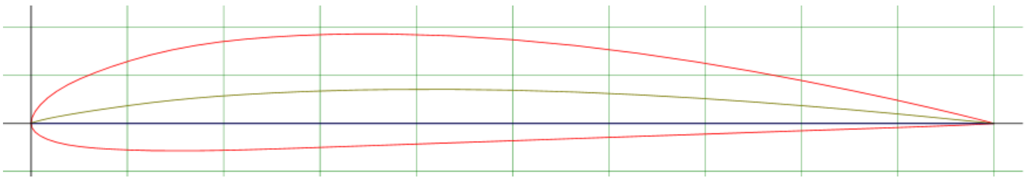


Figure 13 - Clark-Y (11.7%) smoothed

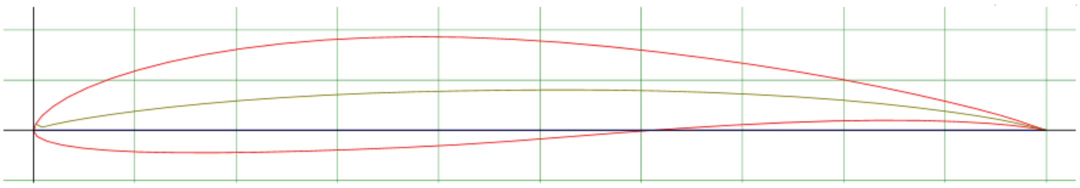


Figure 14- E214 (11.1%) - Eppler E214.

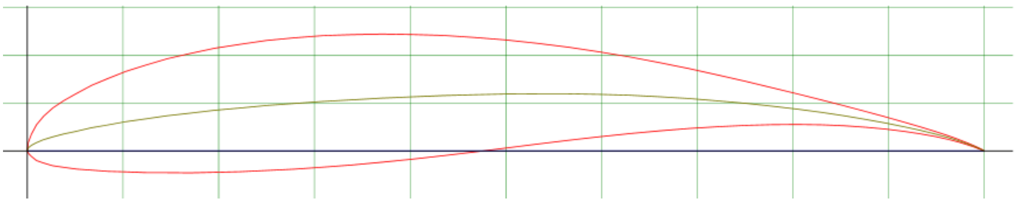


Figure 15 - Wortmann FX 63-137.

An analysis will be performed drawing upon XFLR5, a computer analysis tool for airfoils, wings and planes operating at low Reynolds numbers. The procedure consist on calculating the principal parameters (Cl, Cd, α, stall angle, zero-lift angle and his relations) with a group of approximately Reynolds numbers given, and a Mach number (M).

The Reynolds numbers depends on thickness of the airfoil and speed, parameters which haven't determined yet; so speed will be set as 60 km/h → 16.67m/s (considering wind speed as 0 m/s at high altitude), that would be a good cruise speed, in addition the thickness will be determined as 0.25m

About the Mach number is calculated as (14) where v is the speed and c is the speed of sound in the medium, at 15000 m. c is approximately 300m/s

$$M = \frac{v}{c} \quad \textbf{(14)}$$

$$Re = \frac{\rho D v}{\mu} \quad \textbf{(7)}$$

$v \approx 16.67$m/s	D ≈0.25m	$c \approx 300$m/s
ρ= [1.3, 0.086 kg/m^3]	μ= [1.35·10^{-5}, 1.69·10^{-5} kg/m·s]	M ≈ 0.055

Replacing this parameters in equation (7), with ρ and μ previously evaluated (go to 2.3); a range of Re numbers between [2·10^5, 2·10^4] is received.

This parameters will be implemented in three different analysis by XFLR5 with angles of attack between (-10º and 20º), and the result are shown in the next table.

Airfoil	Clark-Y smoothed [1]	Eppler E214 [2]	Wortmann FX 63-137 [3]
Thickness (%)	11.7% at 30.9% chord	11.1% at 33.1% chord	13.7% at 30.9% chord.
Camber (%)	3.5% at 43.5% chord	3.7% at 56.9% chord	6% at 53.3% chord
Max. Cl	1.3 at Re=2·10^4	1.351 at Re=1·10^4	1.6 at Re=2·10^4
Max. Cl Angle (º)	15º	11 º	12º
Max. Cl/Cd	68	83	75
Max. Cl/Cd Angle(º)	5º	5 º	2º
Stall Angle (º)	10º	10-11 º	10º
Zero-Lift Angle	-3.5º	-4.5 º	-7º

Table 2

<u>Conclusion</u>

With the results given it will be decided to continue with E214 (11.1%) - Eppler E214 airfoil for the following reasons:

- Better performance at very low Reynolds numbers (green lines in graphic 2)
- Less thickness and due to this; lighter structure.

- Better stall characteristics, the stall angle is reached in a gentle way, Cl is almost constant between 10-11º.
- Best relation between Cl and Cd.
- Acceptable zero lift angle, and good max. Cl/Cd angle.

[1] **[2]** **[3]**

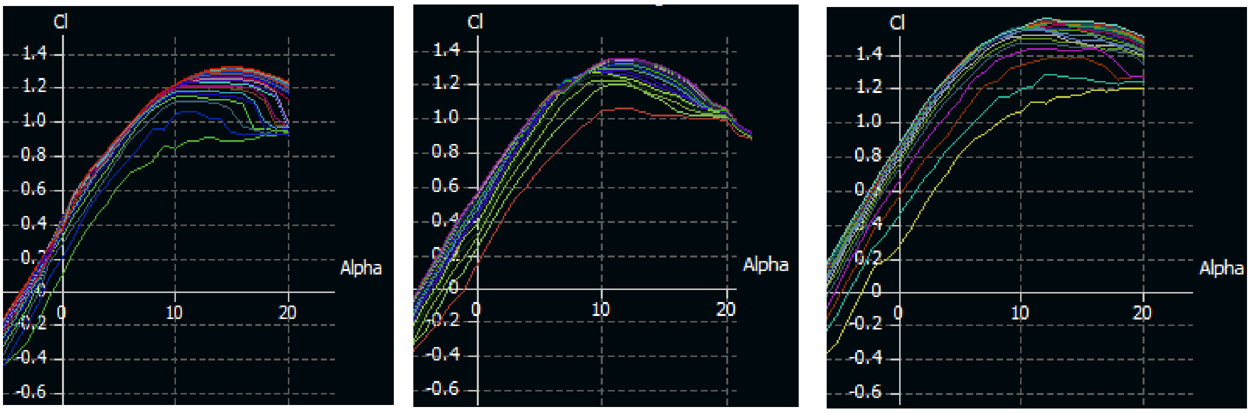


Image 16 - Cl/ α - Comparison between the diferent select airfoils.

IV. Aspect Ratio (AR)

In aeronautics, the aspect ratio of a wing is the ratio of its span to its mean chord. It is equal to the square of the wingspan (b) divided by the wing area (equation 15)

$$\mathrm{AR} = \frac{b^2}{S} = \frac{b}{MAC} \quad \textbf{(15)}$$

Typical aspect ratios for motor-gliders and HALE UAVs is between 10 and 25. [2], so this gives us an idea of how wingspan, MAC and wing area should be.

V. Wing incidence (i_w)

The wing incidence (iw) is the angle between fuselage center line and the wing chord line at root. The wing incidence must satisfy the following design requirements:

- The wing must be able to generate the desired Cl during take-off and cruising flight.
- The wing must produce minimum drag during cruising flight.
- The wing setting angle must be such that the wing angle of attack could be safely varied during take-off operation.
- The typical number for wing incidence for most aircrafts is between 0 to 4 degrees.

VI. Taper Ratio (λ_R)

Taper ratio (λ_R) is defined as the ratio between the tip chord (Ct) and the root chord (Cr). It varies between 0 (delta wing) and 1 (rectangular wing).Furthermore it affects the aircraft in some ways:

- The taper will reduce the wing weight.
- It will increase the cost of the wing.
- It improves the aircraft lateral control.

Taper Ratio in gliders it's usually between 0.7 and 0.9, so at the first time it is select a value of 0.8.

VII. Root Chord (C_R)

The Root Chord is the chord length at the nearest point of the fuselage, in our case the axis of the fuselage.

VIII. Tip Chord (C_T)

The Tip Chord is the chord length at the further point of the fuselage, in each wing section.

IX. Mean Aerodynamic Chord (MAC)

Mean Aerodynamic Chord is the average chord length of a tapered, swept wing.

The subsonic airfoil theory shows that lift due to angle of attack acts at a point on the airfoil 25% of the chord aft of the leading edge.

All the parameters are explained in the next image:

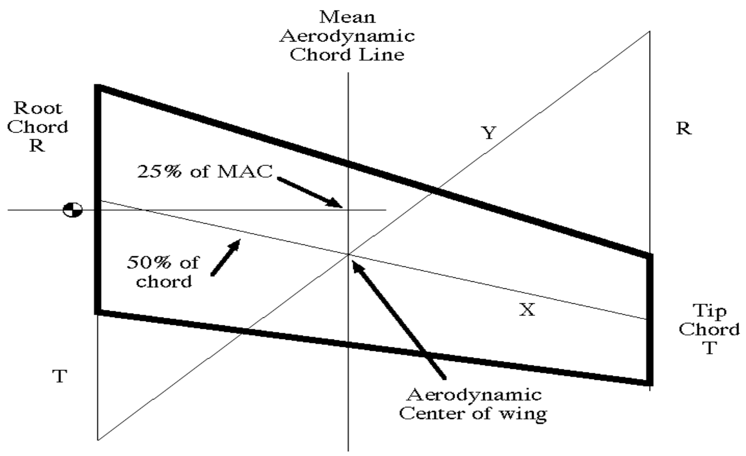


Figure 17- Wing parametres related with chord.

X. Span (b)

The wingspan (or just span) is the maximum extent across the wings of an aircraft. It will be determined when we calculate the wing surface, but if we look in perspective of similar devices we could range between 15 and 30m.

XI. Dihedral angle (Γ)

The angle between the chord-line aircraft of a wing with the "xy" plane on a front view is denoted as the wing dihedral.

The advantages of introducing a dihedral angle (positive) are:

- It produces a restoring moment which stabilizes the plane in case of wind gusts.
- Another effect of wing dihedral effect is increasing the ground clearance, since aircraft wings, nacelles and propellers must have a minimum amount of ground clearance

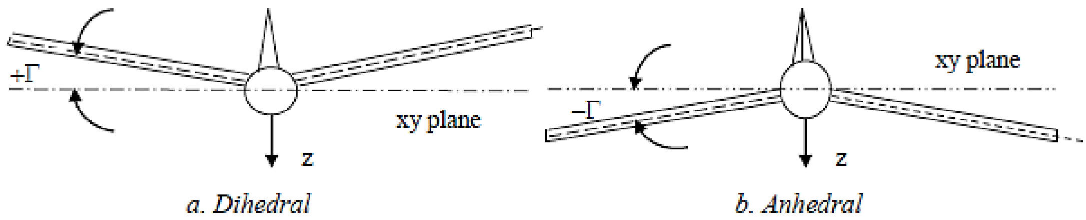


Figure 18 - Dihedral angle definition.

Most of the HALE UAVs analyzed as similar devices have dihedral angles, in the second section of the wings, thus our design should have a dihedral angle between 10 and 15 degrees for giving stability to the aircraft; it will be set first as 14º.

XII. Angle of attack at stall speed (α_a) and angle at cruise speed (α_c)

The angle of attack is the angle between the chord line of the airfoil and the vector which defines the relative motion between the body and the fluid. At stall speed, the angle of attack has to provide higher Cl (lift force), and cruise speed angle has to minimize Cd (drag force).

Using table 8 we get that $\boldsymbol{\alpha_a}$ will be between **8 to 10º** that will be in a safe zone were the aircraft don´t reach the critical angle of attack that produces stall, and Cl will be 1.2.

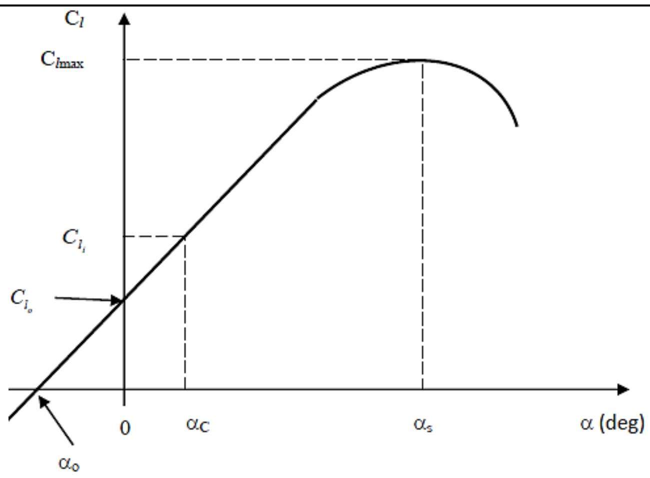


Figure 19 - Relation between Cl and α

Using XFLR, the angle were Cd is minimum can be calculated; Cd is around 0.01 and 0.025; which give us a Cl between 0.5 and 0.7 that results in a cruise speed angle of 2-4º. With this parameters wing incidence angle (i_w) can be set as 1-2º.

Sketch in OpenVSP.

First of all we implement the selected airfoil as a file (.DAT), then we need to set and area, which according to similar devices we set Sref as 30 m2. Wingspan is approximately 20m, replacing this values in equation 15 it is obtained an aspect ratio of 13.33, and a MAC of 1.5 m.

We can translate this data and set a root chord of 1.8, with a taper ratio of 0.8 and a dihedral angle of 13º, 8.5 m from the fuselage axis, obtaining the next preliminary wing design.

NOTE: the winglets are necessary to increment stability at take-off and landing, are predesign in a preliminary way with the program.

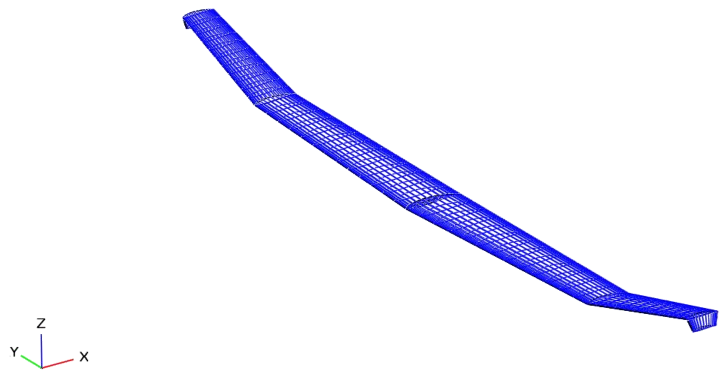


Figure 20 - Wing preliminary design in OpenVSP.

2.5 Conceptual Design and motor selection

Now that we have the preliminary design of how can be the wing, it's time to set a cruise flight altitude. It has to be over 11000 m so it's decided 15000m as a good option, since it's in the middle of the range we have taken results (between 11000 and 18000). Then, it´s possible to calculate relation between cruise speed and wing area, since carrying out a forces balance, and setting the weight plane as 55kg, next equation can be solved if Cl is taken as 0.65 to produce less drag force (from preliminary design).

$$mg = Cl \cdot \frac{\rho}{2} \cdot S \cdot v^2 \qquad (16)$$

A relation between the wing area and the cruise speed is given:

$$S \cdot v^2 \approx 10400$$

S – Wing area (m^2)	v – cruise speed (m/s)	km/h
25	20.36	73.3
30	18.59	66.92
35	17.21	61.96
40	16.1	57.96

Table 2

Implementing the same equation at take-off with a Cl of 1.2 (best lift force) we get the relation between wing area and stall speed:

S – Wing area (m^2)	v – stall speed (m/s)	km/h
25	5.01	18.04
30	4.57	16.45
35	4.23	15.23
40	3.95	14.22

Table 3

Lower speed at stall is preferred, because the aircraft will be unable of accelerate on its own, since it won't have powerful propellers to reach high speeds on the ground, and this propellers could hit the ground. In addition the cruise speed suggested is around 60 km/h, so the wing area will be between 35 and 40 m^2.

Because of this, stall speed will be between 14.22 and 15.23 km/h, so now that we have an idea about wing surface, speed and aspect ratio it's time to introduce another force balance at steady flight; now between drag force and thrust:

$$T = Cd \cdot \frac{\rho}{2} \cdot S \cdot v^2 \qquad (17)$$

Where *Cd* can be approximated using XFLR5, which give us a value of *Cd* = 0.025, it also can be calculated as the sum of induced coefficient drag, form coefficient drag and parasitic drag.

$$Cd = Cd_{ind} + Cd_f + Cd_{par} \qquad (18)$$

$$Cd_{ind} = Cl/(e \cdot \pi \cdot AR) \qquad (19)$$

$$Cd_f = 0.0776 \cdot [log_{10}(Re) - 1.88]^{-2} + 60Re^{-1} \qquad (20)$$

$$Cd_{par}\ (v = 16.67, D = 0.25,\ MAC = 1.5\ \ Carbon\,fibre) \approx 0.005 \qquad (21)$$

Replacing $S \cdot v^2$, approximated *Cd* and density at 15000 m. we get the approximated thrust *T*:

$$T \approx 18.824\ N$$

T is the thrust produced by the propellers and will be calculated with a Propeller Static & Dynamic Thrust Calculator and javaprop program [9] introducing Aircraft speed and propeller inputs such as RPM (revolutions per minute), propeller pitch and diameter.

Considering aspects such as aircraft weight, flight altitude, and power limitation (2000W) it is decided to select two brushless DC Motors BG 75x75 SI (40V, 450W) from German company Dunkermotoren® with specifications written in the next page:

Previously it is calculated an approximately Thrust of 18.824 N at steady flight, our purpose it's to approximate it selecting motor and propeller parameters:

With a speed of 3600 rpm, with a propeller 0.8 meters in diameter and a pitch of 12 inches (0.40m) we get a thrust of *23.34 N* for the two motors which should be enough to keep the aircraft at steady flight.

With the selected motors and parameters from preliminary design, a chart can be designed to define a plausible range.

Parameter	Range
Wingspan (b)	20-26 m
Wing Surface (S_{ref})	30-40 m^2
Solar Cells Surface (S_{sc})	20-30 m^2
AR	11-20
MAC	1.2-2 m
Cruise Speed	16-18 m/s
***Cl* at cruise**	0.6-0.7
***Cd* at Cruise**	0.02-0.03
Thrust at cruise	18 -25 N
Stall Speed	4.5-3.9 m/s
***Cl* at Stall**	1.1-1.25
***Cd* at Stall**	0.04-0.05

Table 4

» BG 75 SI | cont. 450 W, peak 950 W

- *With integrated speed controller for 4-Q operation*
- *Excellent control characteristics due to an integral magnetic encoder with a resolution of 4x1024 pulses per round*
- *The target speed can be set using a 0...+10 V (optional -10 V...+10 V) analog voltage input*
- *The motor is supplied as a standard with two connection plug (power stage and logik)*

- Mit integriertem Speedcontroller für 4-Quadrantenbetrieb
- Durch den integrierten magnetischen Geber mit einer Auflösung von 4x1024 Pulsen pro Umdrehung werden ein großer Drehzahlbereich erreicht
- Die Drehzahlsollwertvorgabe erfolgt standard mäßig über einen Analog-spannungseingang 0...+10 V (optional -10 V...+10 V)
- Der Motor ist standardmäßig mit 2 Anschlusssteckern versehen (Leistung, Logik)

Data/ Technische Daten		BG 75x25 SI		BG 75x50 SI		BG 75x75 SI
Nominal voltage/ Nennspannung	VDC	24	40	24	40	40
Nominal current/ Nennstrom	A*)	12.1	8.3	16.0	11.2	12.7
Nominal torque/ Nennmoment	Ncm*)	61	71	76	98	116
Nominal speed/ Nenndrehzahl	rpm*)	3900	3820	4050	3900	3700
Friction torque/ Reibungsmoment	Ncm*)	5.7	5.7	7.2	7.2	9
Stall torque/ Anhaltemoment	Ncm**)	195	250	220	365	410
No load speed/ Leerlaufdrehzahl	rpm*)	4450	4400	4340	4100	3825
Nominal output power/ Dauerabgabeleistung	W**)	250	284	320	400	450
Maximum output power/ Maximale Abgabeleistung	W	400	415	580	765	950
Torque constant/ Drehmomentkonstante	Ncm A-1**)	6.7	11.5	6.2	10.8	11.3
Peak current/ Zulässiger Spitzenstrom (2 sec.)	A*)	50****)	50****)	50****)	50****)	50****)
Rotor inertia/ Rotor Trägheitsmomentt	gcm²	240	240	437	437	620
Weight of motor/ Motorgewicht	kg	1.6	1.6	2.2	2.2	2.8
Recommended speed control range/ Emphohlener Drehzahlregelbereich	rpm	1 ... *Rated speed*/ Nenndrehzahl				

*) ΔJ_W = 100 K; **) J_R = 20°C ***) *at nominal point*/ im Nennpunkt ****) *limited by software*/ durch Software begrenzt

Figure 21- Motor specifications. [14]

2.6 Optimization of solar panel area

Estimating the amount of the solar panels required to produce enough power to keep the aircraft working at different altitudes, is the greatest challenge in this kind of design. The objective is achieving the energy that is collected during a day from the solar panels has to be equal to or higher than the electrical energy needed by the airplane.

The task at this moment will be optimize wing surface with the range of parameters previously calculated, in an iterative process to find the best wing surface and the cruise speed.

I. Solar Sheets

A solar cell is, basically, a simple semiconductor device that transforms light into electric energy. The conversion is accomplished by absorbing light and ionizing crystal atoms, thereby creating free, negatively charged electrons and positively charged ions.

As it is explained before, the most compromising point of the aircrafts parameters is the weight, so the most important thing of the solar cells selected it will be their density; this has to be the lowest as possible.

Companies such as Micro Link ® or Nanosolar ® have developed solar cells which are very flexible and will conform to curved surfaces. Despite this kind of cells don't have the better efficiency comparing with others, they have the best relation between power and weight (ξ_{sc}), which it is around 1,000 W/kg.

$$m_{sc} = \frac{P_{elec\,tot}}{\xi_{sc}} \qquad (22)$$

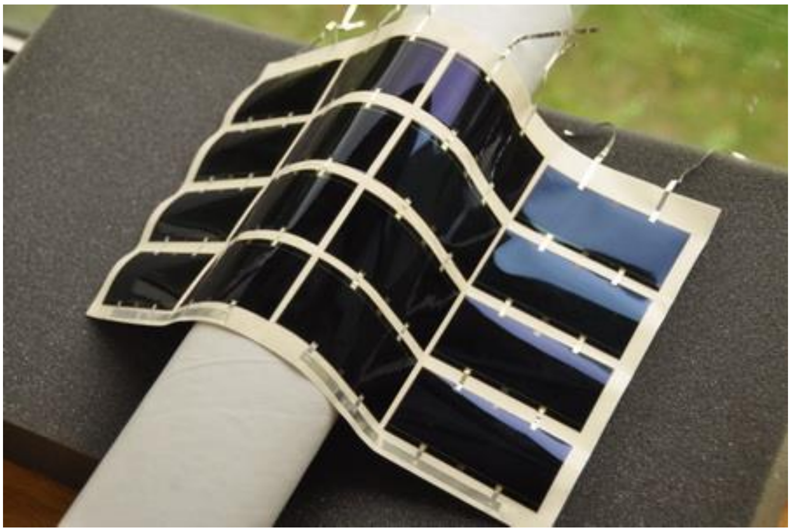


Figure 22- Solar Sheet by Microlink [15]

II. Batteries

The weight is again the restrictive element in this selection, there are numerous kinds of Lithium-Ion/Polymer batteries, but Lithium Sulfur Rechargeable cells are selected; this kind of batteries provide the best relation of specific density around 500 W·h/kg.

From 2015 few companies started to commercialize the technology on an industrial scale; companies such as Sion Power have partnered with Airbus Defence and Space to test their lithium sulfur battery technology in the Zephyr.

Another company, OXIS is developing a range of standard Lithium Sulfur pouch cells with the next characteristics:

- Nominal voltage: 2.1 V
- Typical capacity: 10 – 35 Ah
- Specific Energy, H_{LiS}: Up to 400 Wh/kg → 500W·h/kg targeted in 2018.
- Energy density: 170W·h/l → 350W·h/l possible.

The Li-S chemistry is recognized to have less environmental impact in comparison to other batteries such as Li-ion. The Li-S cells utilizes sulfur in place of heavy metals such as cobalt or nickel which have a significant ecological impact. Furthermore, the sulfur used in manufacture is a recycled product.

Necessary mass of the batteries will be calculated as:

$$m_{bat} = \frac{T_{night}}{\eta_{dchrg} \cdot H_{LiS}} P_{elec\ tot} - m \frac{g h_{cruise}}{\eta_{dchrg} \cdot H_{LiS} \cdot 3600} \qquad (23)$$

Figure 23- Solar Cell baterie based on LiS by OXIS[16]

III. MPPT Converter.

The MPPT is a device required to adapt the voltage of the solar panels in order to offer the highest power possible. With the growth of the photovoltaic market, there are a lot of commercially available MPPTs, although they are used for different applications they are never built for low weight.

The MPPT is a high efficiency DC-DC converter with an adjustable gain between the input voltage (the solar cells) and the output voltage (the batteries) as we can see in the next graphic.

The converter also works changing the input voltage for other devices as servomotors, radio, GPS, speed controllers…

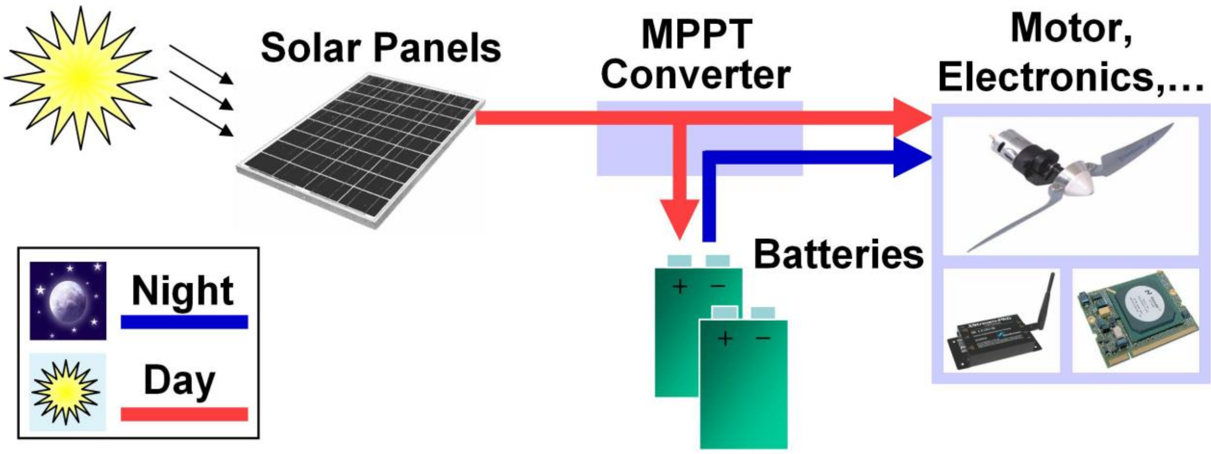


Figure 24: Schematic diagram of solar aircraft working.

The maximum power required at the MPPT level is directly given by the maximum power output of the solar modules, which is proportional to their area.

$$m_{mppt} = k_{mppt} I_{max} \eta_{mppt} \eta_{sc} \eta_{cbr} A_{sc} \qquad (24)$$

The process consist in solving next equations proposed by Andrè Noth [2]:

$$P_{lev} = T \cdot v\text{Cruise} \qquad (25)$$

$$P_{elec\,tot} = \frac{1}{\eta_{ctrl} \cdot \eta_{mot} \cdot \eta_{grb} \cdot \eta_{ctrl}} P_{lev} + \frac{1}{\eta_{bec}} (P_{av} + P_{pld}) \qquad (26)$$

$$S_{sc} = \frac{\pi}{2\eta_{sc} \cdot \eta_{cbr} \cdot \eta_{mppt} \cdot I_{max}} \left(1 + \frac{T_{night}}{T_{day}} \frac{1}{\eta_{chrg}\eta_{dchrg}}\right) P_{elec\,tot} \qquad (27)$$

$$S_{ref} = \frac{S_{sc}}{\eta_{cbr}\eta_{sd}} \qquad (28)$$

The fixed parameters are the following ones:

SYMBOL	UNIT	VALUE	DESCRIPTION
e	-	0.8	Oswald's efficiency factor
η_{bec}	-	0.65	Efficiency of step-down converter
η_{sc}	-	0.1	Efficiency of solar cells
η_{cbr}	-	0.8	Efficiency of curved solar panels
η_{sd}	-	0.8	% Wing covered by solar cells
η_{chrg}	-	0.85	Efficiency of battery charge
η_{dchrg}	-	0.9	Efficiency of battery discharge
η_{ctrl}	-	0.95	Efficiency of motor controller
η_{grb}	-	0.9	Efficiency of gearbox
η_{mot}	-	0.88	Efficiency of motor
η_{mppt}	-	0.95	Efficiency of MPPT
η_{plr}	-	0.85	Efficiency of propeller
I_{med}	[W/m^2]	980.79	Hourly radiation per square meter at daylight
P_{av}	[W]	100	Power consumption of avionics system
P_{pld}	[W]	0	Power consumption of payload instruments
ξ_{sc}	[W/kg]	1000	Relation between Power and weight of solar cells
k_{enc}	[kg/m^2]	0.11	Mass density of encapsulation (flax fiber)
H_{LiS}	[W·h/kg]	500	LiS cells Specific energy
T_{night}	[h]	9	Number of hours without sunlight
T_{day}	[h]	15	Number of hours with sunlight
T	[N]	18.01	Thrust at cruise speed

Table 6

Once the equations have been solved after some iterations with excel, for a mass of 50 kg we get the next parameters with whom it started our CATIA design:

SYMBOL	VALUE	UNIT	DESCRIPTION
$P_{elect\ tot}$	**626.64**	W	**Total Power consumption**
v_{cruise}	16.78	m/s	Steady speed
Cl_{cruise}	0.65	-	Lift coefficient at cruise
Cd_{cruise}	0.024	-	Drag coefficient at cruise
v_{stall}	4.065	m/s	Stall speed
Cl_{stall}	1.2	-	Lift coefficient at take off
Cd_{stall}	0.041	-	Drag coefficient at take off
S_{ref}	36.82	m^2	Wing surface
S_{sc}	23.56	m^2	Wing surface covered by solar cells
AR	16.98	-	Aspect Ratio
MAC	1.472	m	Mean aerodynamic chord
C_R	1.8	m	Root chord
λ	0.75	-	Taper ratio

Table 7

Conclusion

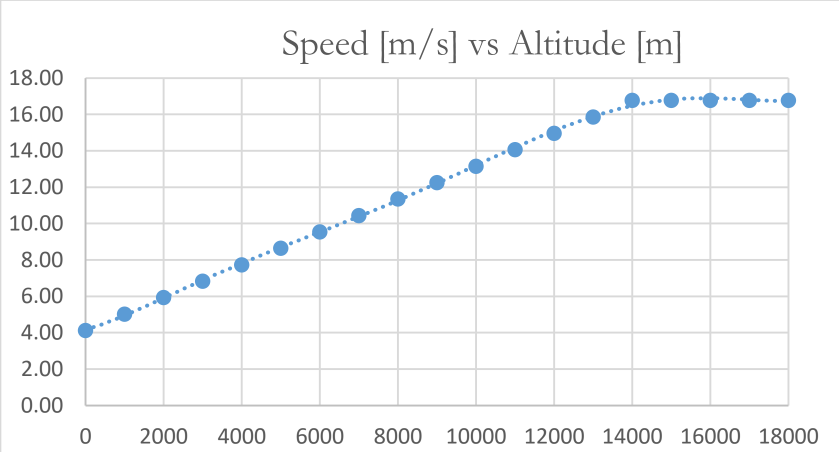
Resulting values looks according to the ranged ones before, what means that we can continue calculating flight forces and coefficients in a more accurate way, using XFLR5.

It has to be stressed that this kind of design is still an approximately design; since designing an aircraft of this dimensions an characteristics requires a lot of time as well as a large team, good equipment and experienced people.

2.7 Flight Balance

Flight balance consist in analyzing four forces involved at flight (weight, lift, thrust and drag), assuming all of them acting in the center of pressure (center of pressure and center of gravity should be similar). Drag vs Thrust must be positive to make the plane accelerate, and Lift vs Weight can be positive to lift the airplane and negative to descend.

According to last calculations, with the stall and cruise speed founded, speed values are interpolated, increasing from 4.13 m/s (stall speed) at 0 meters altitude to a 16.78 m/s. Despite this transition won't be totally constant because of the variable sub regions in the atmosphere, thus it's assumed.



Graphic 7

By getting speeds and data from section 2.3 (conditions at different altitudes) it will be possible estimate Reynolds number for each altitude and aircraft speed; this will allow us to know drag and lift coefficients in each flight phase.

Altitude z [m]	s_{aprox} [m/s]	Re [-]	C_{Dpar}	C_{Df}	C_{Dind}	C_D	C_L
0	4.13	60066	0.001	0.0102	0.030	0.041	1.2
1000	5.03	67329	0.001	0.0098	0.028	0.039	1.15
2000	5.93	72880	0.001	0.0095	0.026	0.036	1.11
3000	6.84	76889	0.001	0.0094	0.024	0.034	1.06
4000	7.74	79515	0.001	0.0093	0.022	0.032	1.02
5000	8.64	80911	0.001	0.0092	0.020	0.030	0.97
6000	9.55	81219	0.001	0.0092	0.018	0.028	0.93
7000	10.45	80575	0.002	0.0092	0.016	0.027	0.88
8000	11.36	79107	0.002	0.0093	0.014	0.026	0.83
9000	12.26	76935	0.002	0.0094	0.013	0.024	0.79
10000	13.16	74171	0.002	0.0095	0.011	0.023	0.74
11000	14.07	70920	0.002	0.0096	0.010	0.022	0.70
12000	14.97	53245	0.003	0.0107	0.010	0.024	0.69
13000	15.87	47420	0.003	0.0112	0.009	0.023	0.65
14000	16.78	42105	0.003	0.0117	0.009	0.023	0.65
15000	16.78	35364	0.003	0.0126	0.009	0.024	0.65
16000	16.78	29703	0.003	0.0136	0.013	0.029	0.78
17000	16.78	24948	0.003	0.0147	0.018	0.035	0.92
18000	16.78	21954	0.003	0.0159	0.025	0.044	1.10

Table 8

Taking two dimension axis, we can do two forces summation balances, first in Y axis with involves:

- Lift (*L*), is a force generated by the motion of the airplane through the air and is an aerodynamic force and is perpendicular to the flight direction and we calculate it with equation (29)
- Thrust (*T*) [9 -excel]; since the incidence angle (i_w) is selected as 2º, by trigonometry thrust can be divided in two projections; no only one more significantly in X axis, but also another in Y axis in lift direction, and as the attack angle varies with altitude Y projection of *T* varies depending of the height.
- Weight (W); varies with altitude as it is explained in section 2.1 due to g acceleration variability.

$$L = \frac{1}{2}\rho v^2 S_{ref} Cl \qquad (29)$$

Altitude z [m]	**Lift Force ↑ [N]**	**Thrust Force ↑ [N]**	**Weight ↓ [N]**	**F_{LTOT} [N]**
0	490.32	28.01	490.3239	**28.01**
1000	631.02	26.21	490.1701	**167.05**
2000	757.32	24.41	490.0164	**291.71**
3000	863.35	22.61	489.8628	**396.10**
4000	945.62	20.81	489.7092	**476.72**
5000	1002.55	19.01	489.5557	**532.00**
6000	1034.11	17.21	489.4023	**561.91**
7000	1041.47	4.83	489.2489	**557.05**
8000	1026.70	4.26	489.0956	**541.87**
9000	992.49	3.70	488.9424	**507.24**
10000	941.90	3.14	488.7893	**456.25**
11000	78.25	2.57	488.6362	**392.18**
12000	695.83	2.01	488.4832	**209.36**
13000	619.03	1.44	488.3303	**132.14**
14000	577.47	0.88	488.1774	**90.17**
15000	488.02	0.88	488.0246	**0.88**
16000	491.88	0.88	487.8719	**4.88**
17000	487.29	0.88	487.7193	**0.45**
18000	489.36	0.88	487.5667	**2.67**

Table 9

Forces involved in X axis are

- Lift (*L*), is a force generated by the motion of the airplane through the air and is an aerodynamic force and is perpendicular to the flight direction and we calculate it with equation (30)
- Thrust (*T*) [9 - excel]; since the incidence angle (i_w) is selected as 2º, the more significantly thrust is in X direction.

$$D = \frac{1}{2}\rho v^2 S_{ref} Cd \qquad (30)$$

Altitude z [m]	Thrust Force→ [N]	Drag Force ← [N]	F_{DTOT} [N]
0	199.27	16.85	**182.42**
1000	186.46	21.09	**165.38**
2000	173.66	24.69	**148.96**
3000	160.85	27.54	**133.31**
4000	148.04	29.57	**118.47**
5000	135.24	30.82	**104.42**
6000	122.43	31.32	**91.11**
7000	110.60	32.37	**78.23**
8000	97.68	31.72	**65.96**
9000	84.76	30.61	**54.15**
10000	71.83	29.14	**42.69**
11000	58.91	27.42	**31.49**
12000	45.99	23.82	**22.17**
13000	33.07	21.90	**11.18**
14000	20.11	20.09	**0.02**
15000	20.11	18.32	**1.79**
16000	20.11	18.44	**1.67**
17000	20.11	18.69	**1.42**
18000	20.11	19.62	**0.49**

Table 10

Attack angle

At stall, the lift is maximum but the drag is high too. After this point, the behaviour is more difficult to predict or simulate, but basically the drag still increases but without being followed by the lift that drops. Thus, the interesting and safe zone for an airplane is before the stall point, for glider especially at the point where the

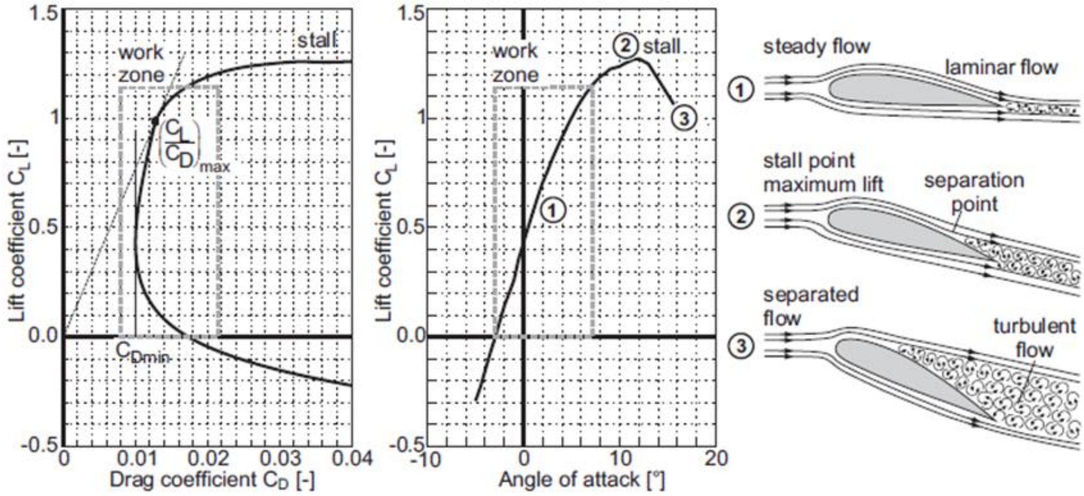


Figure 25:Lift and drag coefficients depending on the angle of attack..

Reynolds number also have influence on the drag and lift coefficient, changing the slope of the curves and the zero lift angles. Therefore we implement an analysis in XFLR for each *Re* obtained before.

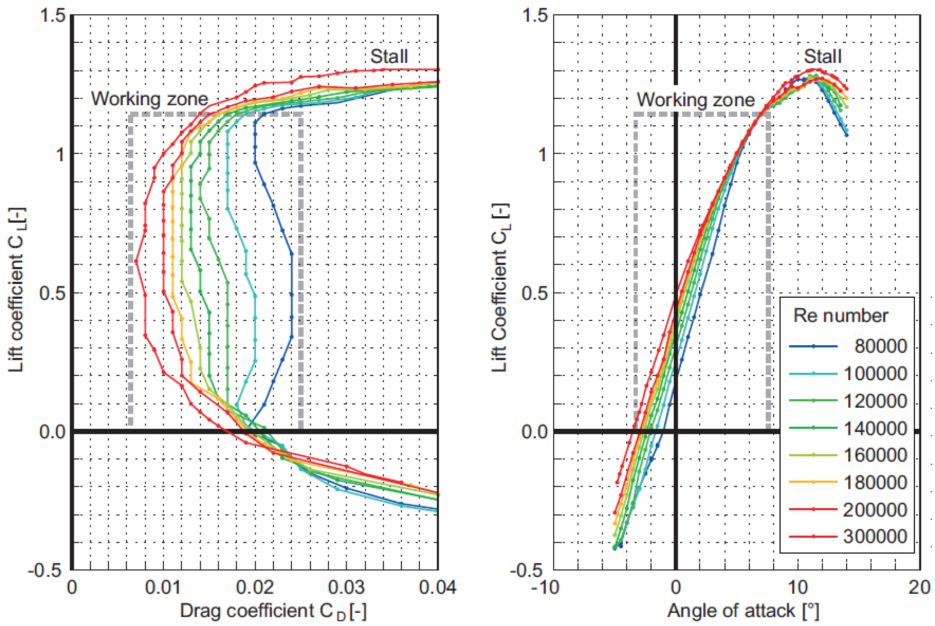


Figure 26: Example of how affect changing Reynolds in drag coefficient, and safety working zone

The results given for a Batch analysis in XFLR for Reynolds numbers from 20000 to 85000 are the following ones:

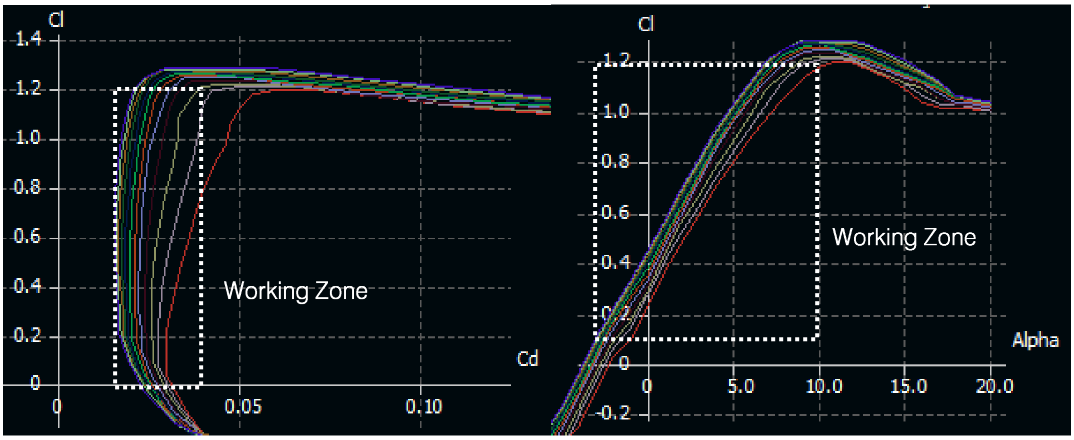
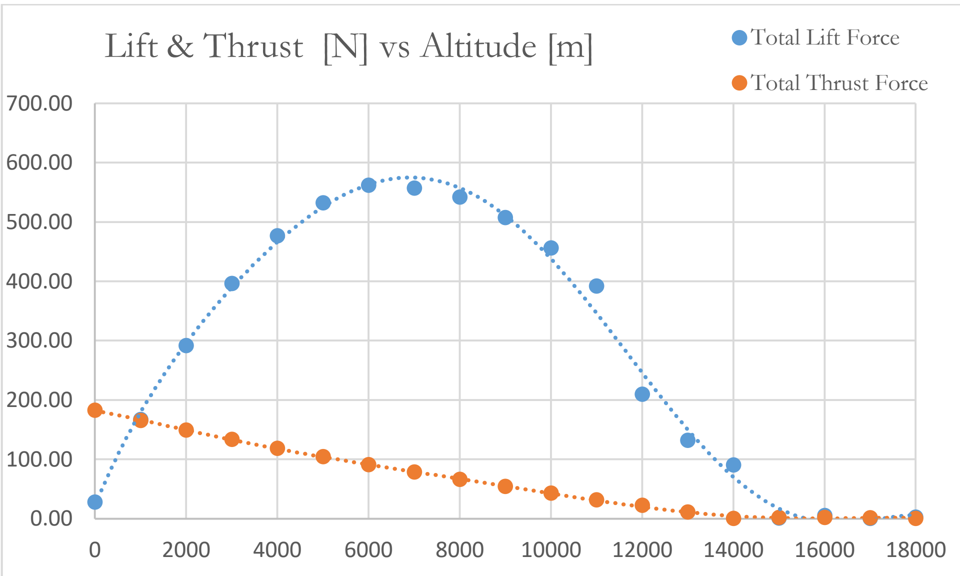


Figure 27: Cl Cd and alpha diagrams and safety working zone in the aircraft

XFLR provides similar graphics to compare with theoretical ones, and the results seems very accurate, so it's possible to conclude the flight balance satisfactorily.

As we can see in next Graphic, summations of Lift and Thrust forces tend to 0 (inertia) from 14000 to 18000m, which it will be steady flight area of the aircraft.



Graphic 8

3. General configuration and assembly.

According to the results of the preliminary design it's possible to define the general configuration which consist in a sequence ribs placed in a tubular profile longeron; and two guides to make the structure rigid; one of the guides will be a strap, and the other a guide which resembles the final part of the airfoil.

3.1. Materials.

Wing structure properties needed are mostly 4:

- Density has to be lowest as possible.

As the aircraft has to be lighter as possible, and the wingspan are very large, the type of material which comprise the structure need the best relation between strength an weight, that means the lowest density, with acceptable young modulus.

- Strenght, and resistance to fatigue

Strength of a material is the force per unit area at failure, divided by its density. Any material that is strong AND light has a favorable Strength/Weight ratio. Since the HALE will spend a lot of time at flight; it will be necessary that the parts thereof will need a good resistance to fatigue

- Good Rigidity

Wing structure contain very long pieces, so to favor the good assembly between pieces, this parts has to be as rigid as possible

- Thermal expansion/contraction has to be very low.

The work area of the HALE UAV will vary between 20ºC to -60ºC so all the configuration would be very affected if the parts experiment changes of dilation or contraction.
Known all of this important characteristics it is decided to choose Carbon Fiber as main material of all wing structure, since it fulfils every property quite well:

Figure 28: Carbon Fiber tubular profile.

- Density:

Density of usual carbon fiber is between 1.6 and 1.8kg/m^3, but with some treatments done by American companies Kureha ® and Oxeon is possible to reduce it by 20-30% compared to conventional carbon fiber without losing other properties.

- Strength, and resistance to fatigue

Resistance to fatigue in Carbon Fiber Composites is good. However when carbon fiber fails it usually fails catastrophically without significant exterior signs to announce its imminent failure.

Material	Modulus of Elasticity		Tensile Strength		Density (g/cc)
	Metric (Gpa)	English (ksi)	Metric (Mpa)	English (ksi)	
Carbon fiber T700S (epoxy composite)	120	17,500	2550	370	1.57
Alloy steel AISI 5130	205	29,700	1275	185	7.85
Aluminum 7075-T6	71.7	10,400	570	83	2.81

Figure 29: Comparison between Specific Streng in different materials for aeronautic structures. [20]

- Good Rigidity

Rigidity or stiffness of a material is measured by its Young Modulus and measures how much a material deflects under stress. Carbon fiber reinforced plastic is over 4 times stiffer than Glass reinforced plastic, almost 20 times more than pine, 2.5 times greater than aluminum

- Thermal expansion/contraction has to be very low.

Linear thermal expansion coefficient of carbon fiber is $-0.8 \cdot 10^{-6}\ K^{-1}$ against $23.1 \cdot 10^{-6}\ K^{-1}$ of aluminum or $(12\text{-}13) \cdot 10^{-6}\ K^{-1}$ of steel; so it will endure so low temperatures.

3.2. Connection units.

The aircraft will have some assemblies and connections between the different parts, and this joints need to be strongest and lightest as possible, for this reason, parts tend to be large and resistant.

Since most pieces are on carbon fiber is not very recommended to mix carbon fiber with aluminum, because this metal reacts with the components of carbon fiber making collapse.

So it is decided to choose some epoxies adhesive (PT326) Permabond ® Engineering Adhesives, which is a high performance polyurethane adhesive which is color matched to the carbon fiber to give a perfect aesthetic finish, as well as high strength, impact resistance. This composite bonding adhesive offers flexibility and peel strength and will not crack off.

PERMABOND ®PT326 is a 2-part, room temperature curing polyurethane adhesive. It is ideal for use on a wide variety of substrate materials including metals, plastics and composites.

Their characteristics are:

- It has excellent environmental and chemical resistance.
- Adhesion to a wide variety of substrates
- Cures at room temperature
- Easy 1:1 mix ratio by volume
- Good resistance to impact and vibration
- Thixotropic, non-slump rheology
- This product is not recommended for use in contact with strong oxidizing materials

Shear strength* (ISO4587)	Steel: 12-20 MPa *(1700-2900psi)* FRP Glass Epoxy: 5-7 N/mm^2 *(700-1000psi)* FRP Glass Polyester: 12-14 N/mm^2 *(1700-2000psi)* Carbon Fibre: 9-11 N/mm^2 *(1300-1600psi)*
Tensile strength ISO 37	16-25 MPa *(2300-3600psi)*
Elongation at break ISO 37	<15%
Hardness ISO 868	65-75 Shore D
Coefficient of thermal expansion (ASTM D-696)	85 x 10^{-6} 1/K
Peel strength (aluminium)	150-170 N/25mm

Figure 30: Typical Performance of Cured Adhesive.

Here below it will be shown the join between different parts of the aircraft:

- **Longeron units**

Two tubular profiles join by four guides with a length of 40 cm where adhesive will be applied, in that way, longerons joint also will be reinforced by a film of carbon fiber

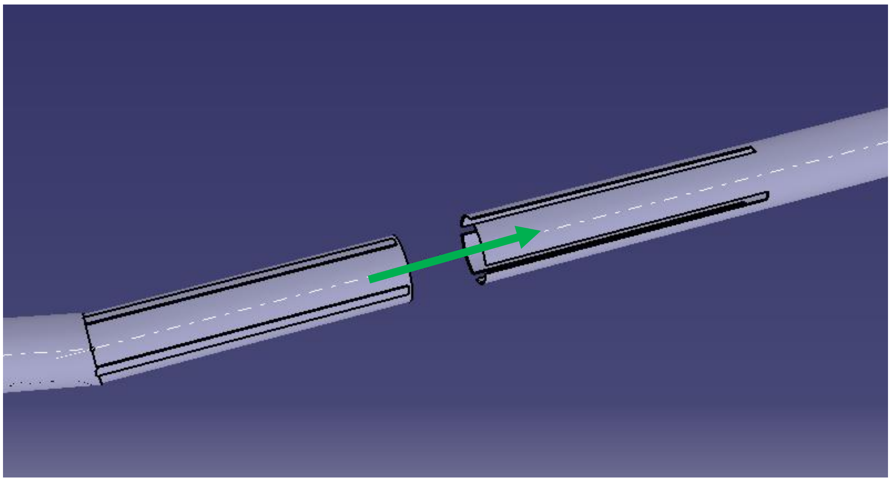


Figure 31: Connection between two longerons

- **Ribs – Longeron – Guides - Straps:**

Ribs are joined to the longerons with adhesive, and a guide and a strap cross all the wing in order to give strength to the structure, both of them will be joined also with epoxy adhesive.

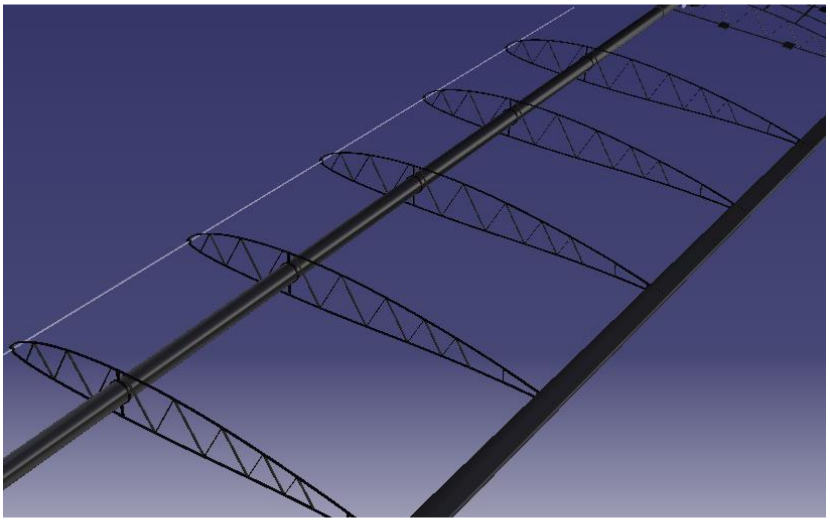


Figure 32: Ribs conexion, final result

Ribs will be introduced at a time from one of the extremes till reach their position, once it will be there, an operator will glue it in his position. This procedure will be repeated with all the ribs, once they will be aligned, the guide will be placed.

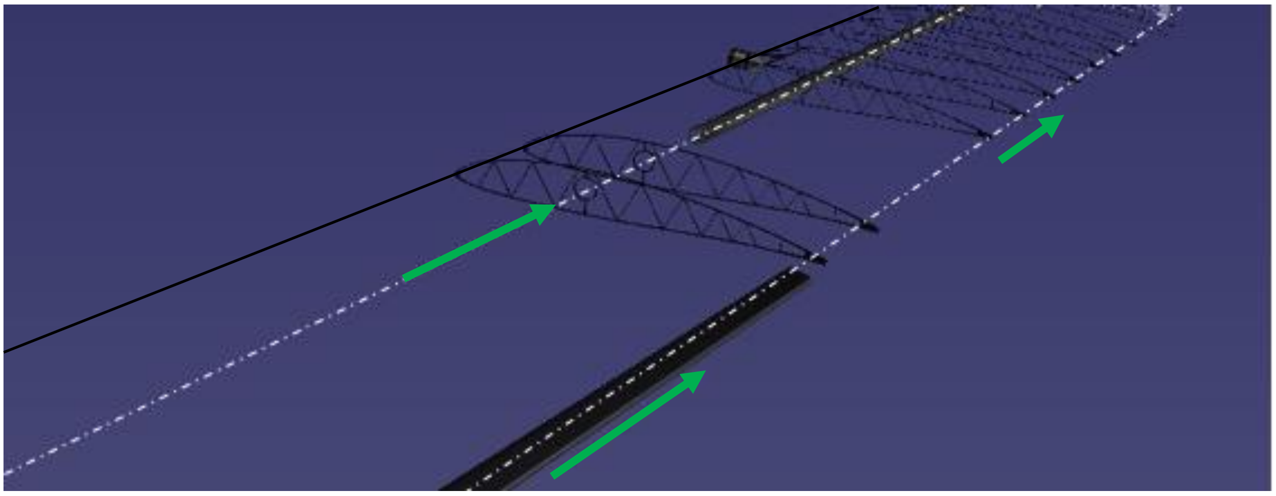


Figure 33: Placement procedure..

- **Motor - Wings**

Union between motor a wing structure will be carry out by 4 standardized screws (ISO 1207 SCREW M3x12- GRADE A), 4 stainless steel nuts M3 and his respective silicon washers.

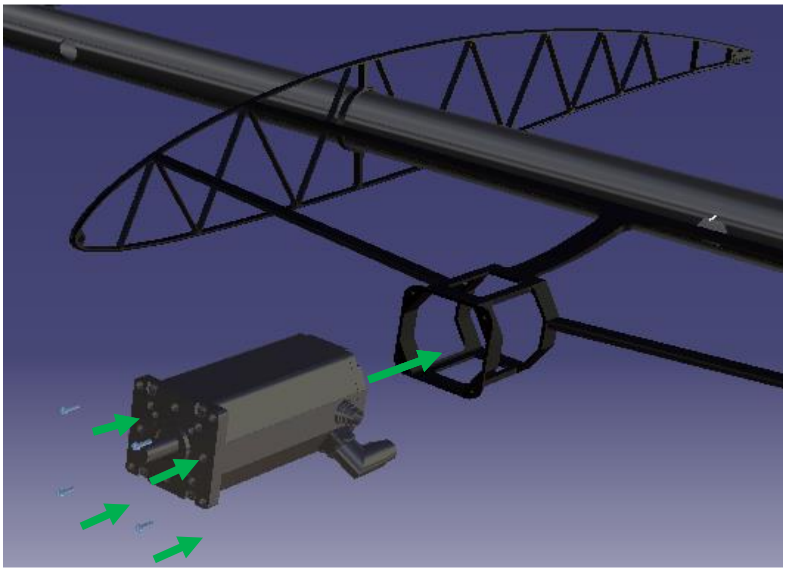


Figure 34: Union between Motor and ribs 8-9 structure.

- **Wings-Body**

The longerons are joined by a piece with T shape and two M20 bolts made by the company, in addition this assembly will be joined to the body with 6 screws (ISO 7046-2 SCREW M8x45-H1 - GRADE A). and his respective M8 nuts and washers, since the contact between carbon fiber and stainless steel has to be avoid as far as possible.

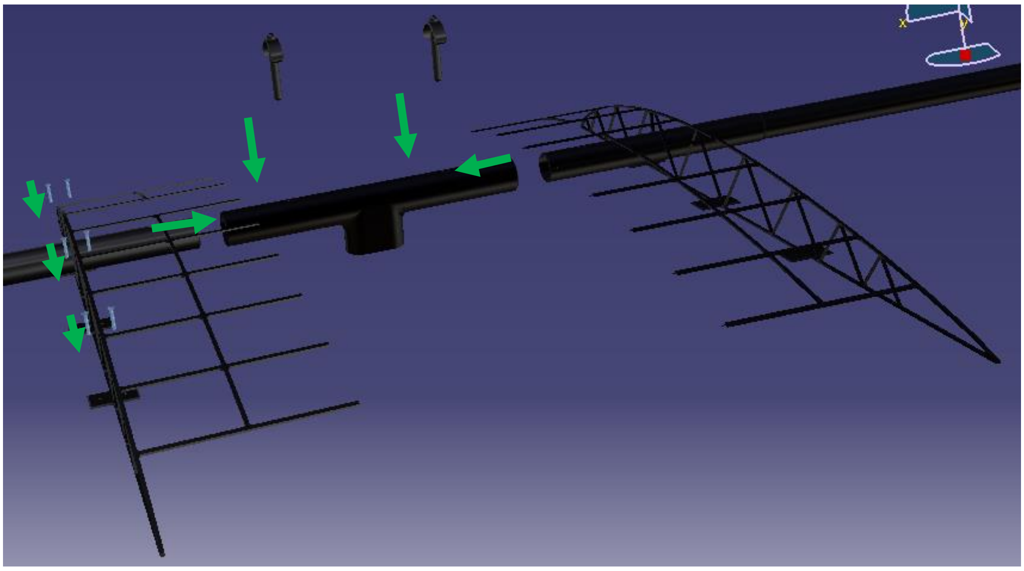


Figure 35: Union mechanism between wings and body.

3.3. Flow analysis.

In this section is revised how the 3D design perform its aerodynamics. Due to the complexity of the generation of surfaces for SolidWorks and the calculation time needed only the cruise flight postulation was assumed.

Firstly the mesh is created which, for this rough analysis, is the ideal one for optimize the operations and get valid estimated aftermaths.

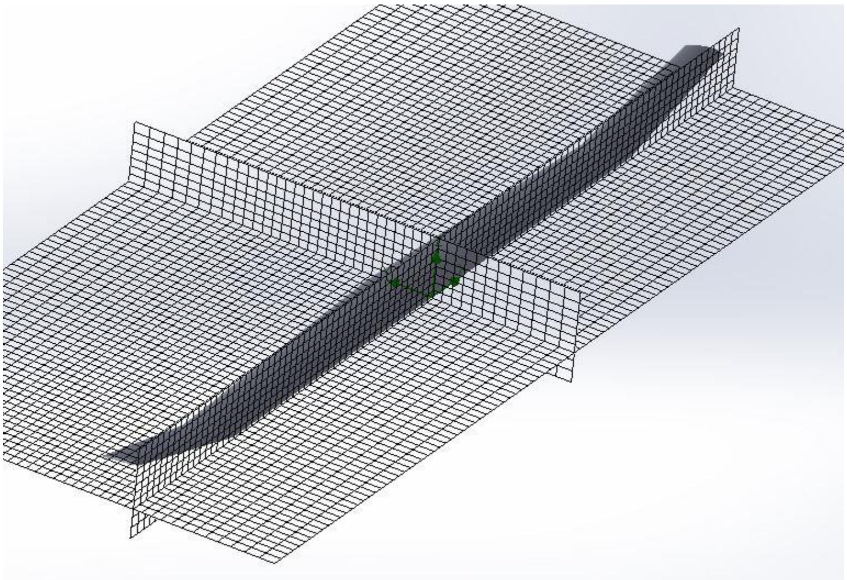


Figure 36: Geometry Mesh.

Once the mesh is created and the boundary conditions such as air density at 15000m high and temperature of -50ºC are applied is possible to see the air flow around wing surface.

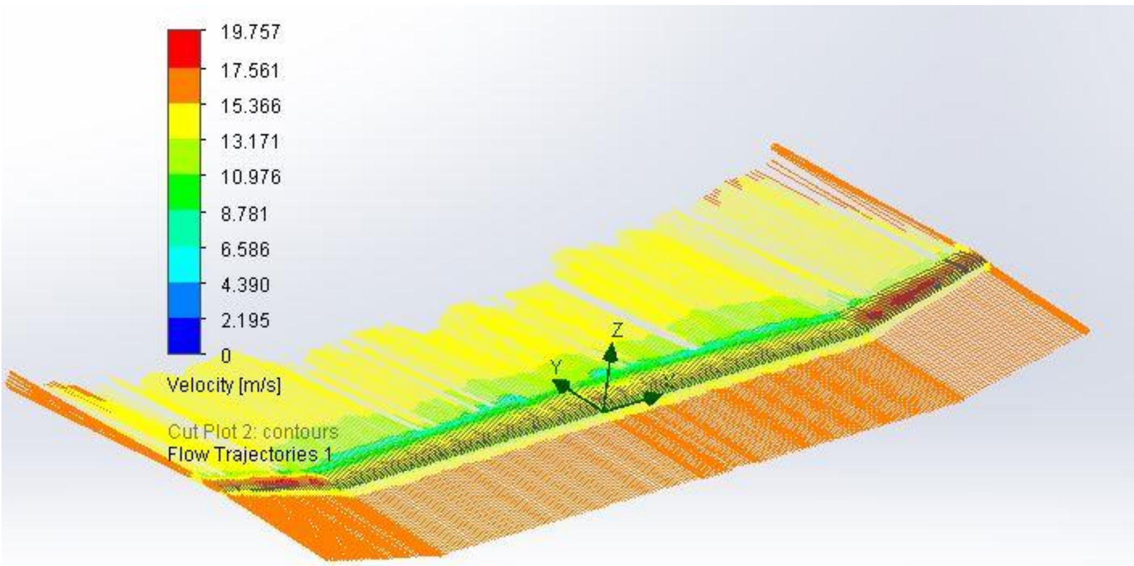


Figure 37: Flow velocity around the wing

This flow is not greatly disturbed and the speed decreased from 17 m/s to 10 m/s, then the drag is not really high for this shape. It is remarkable seeing that in the dihedral area the speed increases to 19m/s.

It is noted that the air flow in the end part of the wing suffer more turbulence, that's the reason why a winglet will be introduced.

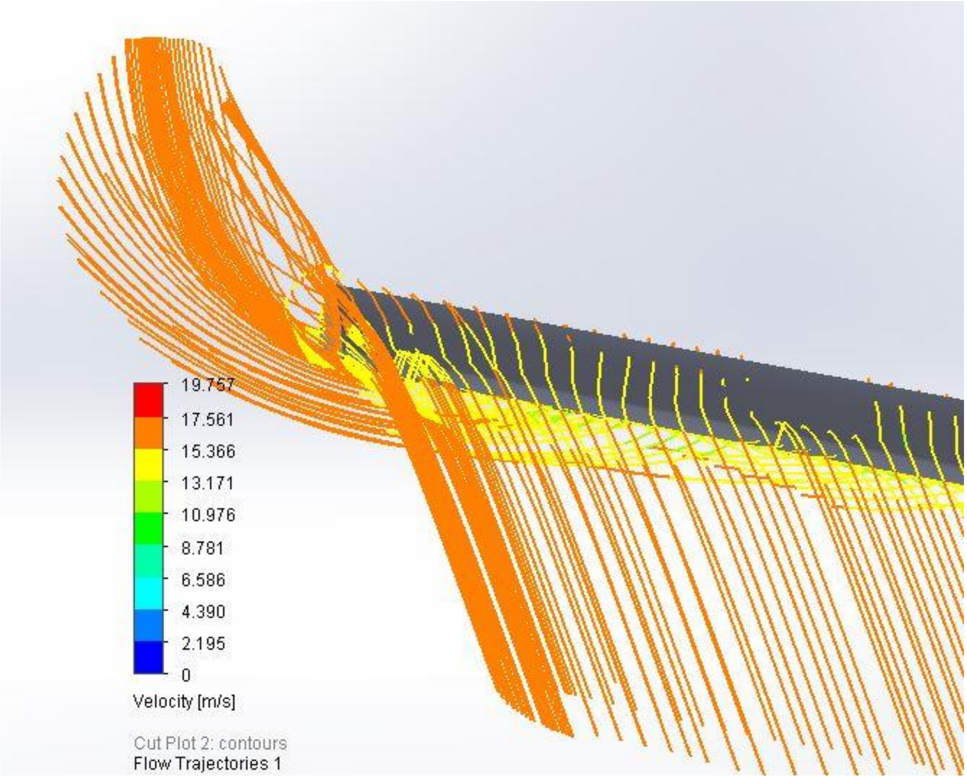


Figure 38: Flow velocity around the end part of the wing.

Taking a lateral view it's possible to see that air speed doesn't decrease significantly.

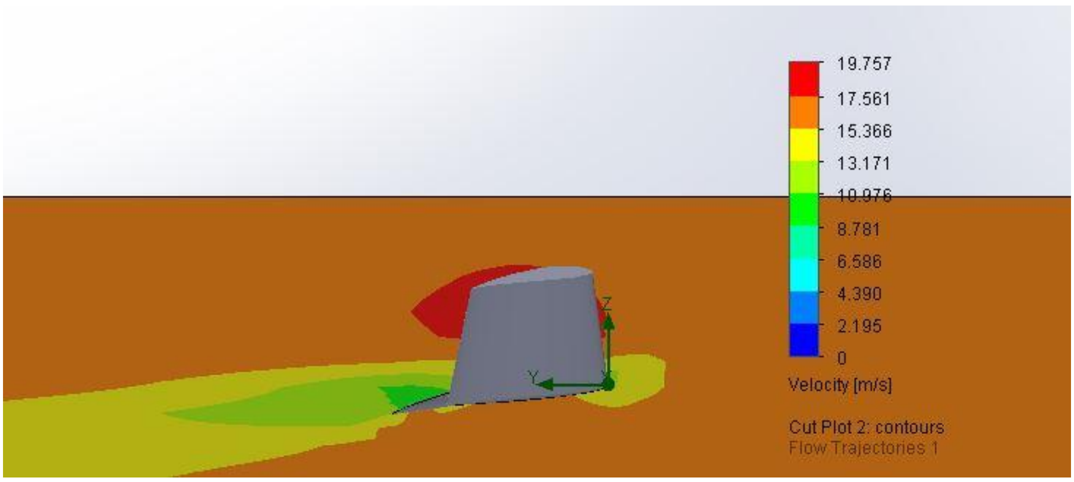


Figure 39: Flow velocity profile.

Regarding other parameters such as pressure is seen that is similar all around the wing

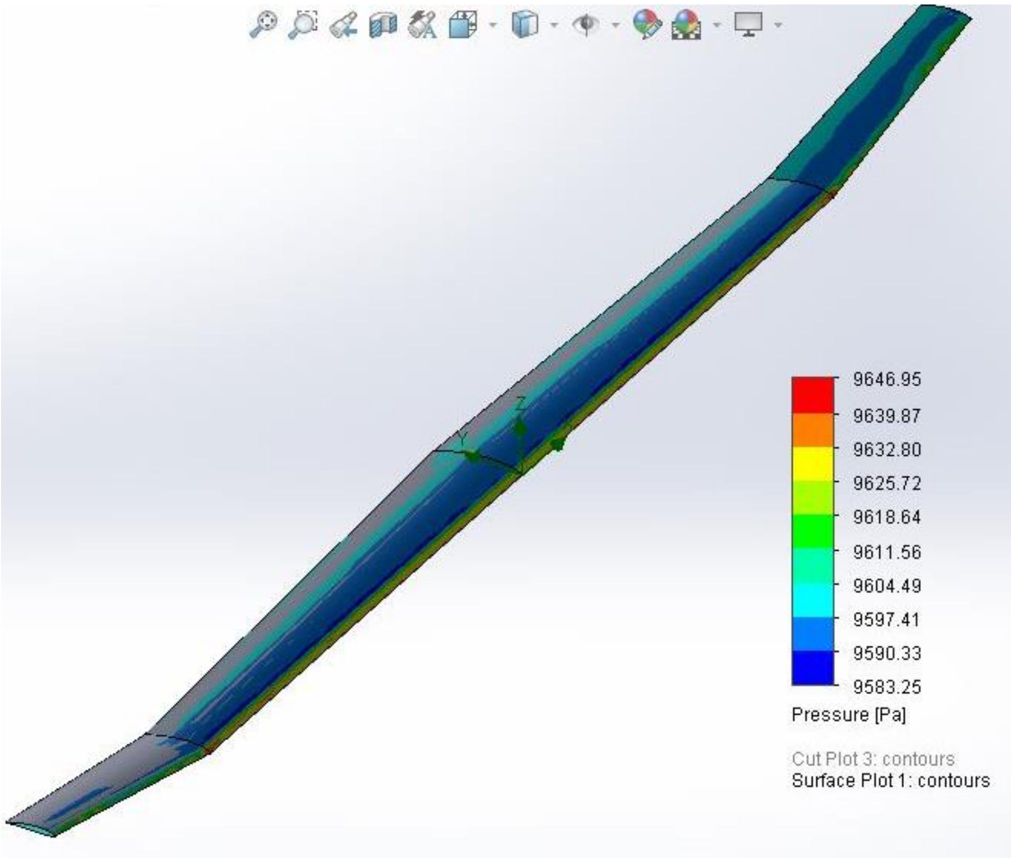


Figure 40: Pressure around the wing

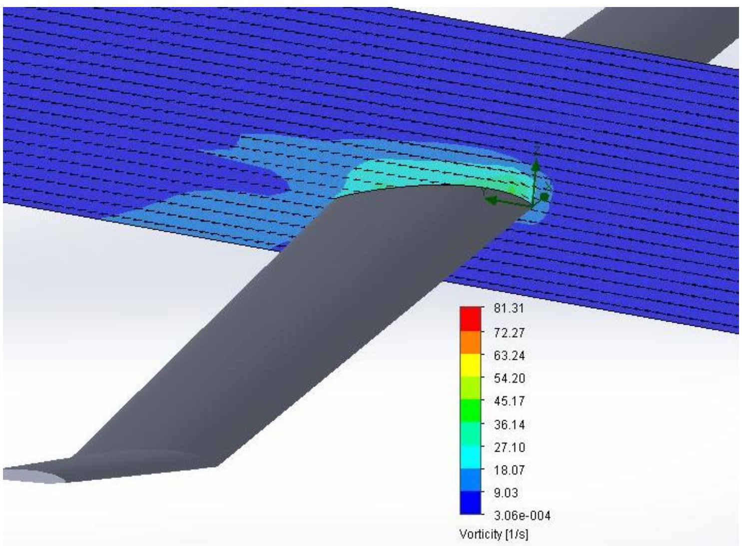


Figure 41: Vorticity around the wing

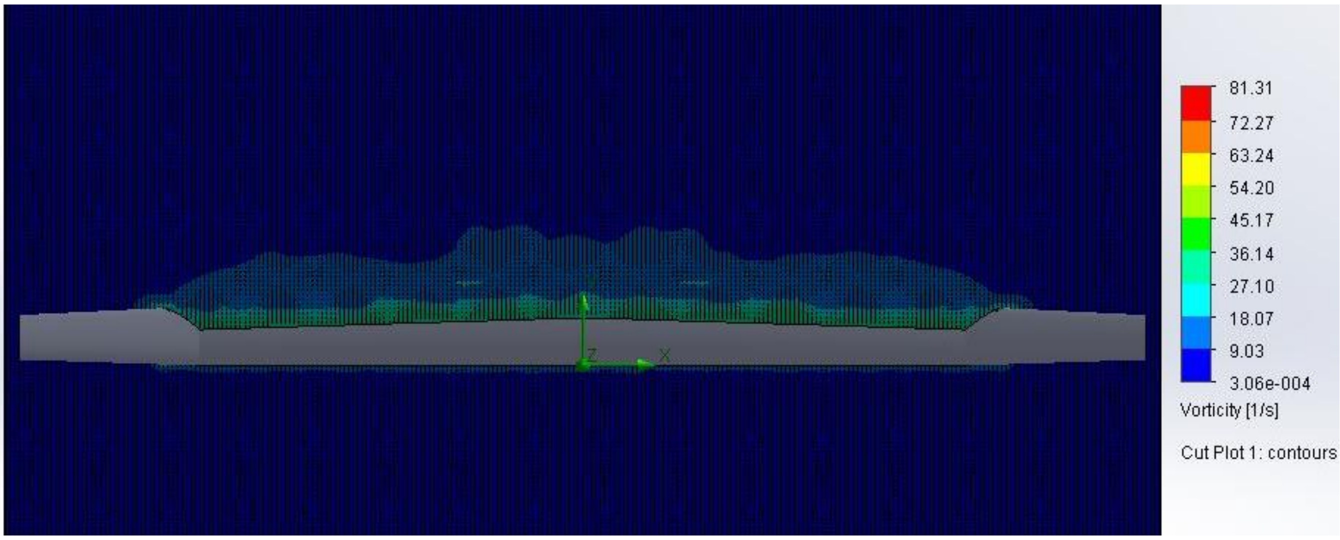


Figure 42: Vorticity from top view

Finally, forces are analyze in order to compare lift and drag forces; there is more drag than assumed before, but it will be in the range of allowed values.

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
GG Av Total Pressure 1	[Pa]	9623.36	9623.36	9623.36	9623.36
GG Av Velocity 1	[m/s]	16.305	16.305	16.304	16.306
GG Force 1	[N]	271.539	271.218	270.419	271.713
GG Force (Y) 1	[N]	79.577	79.676	79.509	79.847
GG Force (Z) 1	[N]	259.617	259.250	258.446	259.716

Figure 43: Forces at steady flight

3.4. Stress analysis.

This section is mentioned how strong the structure is and if it would bear the required loads. In addition will be discussed the way to improve the design in future work. The study will analyze two ribs, the sixth one, placed at 4250mm from symmetry axis, and rib nº 14, placed in the dihedral area at 11000 m from the symmetry axis.

I. Rib nº 6

Boundary conditions

The loads are applied on the low side (Lift force) of 490N meanwhile the fix constrains are where the tubular longeron are placed, and where the strap and guides are located.

Stress analysis

In this image can be seen that, first of all, the elastic limit is not reached so any point of the rib became plastic which means that all the rib is not broken.

Secondly, can be appreciated that, almost all rib, is dark blue, and the trusses are more pressed, so the resistance behavior of the rib is good enough, no material will be removed

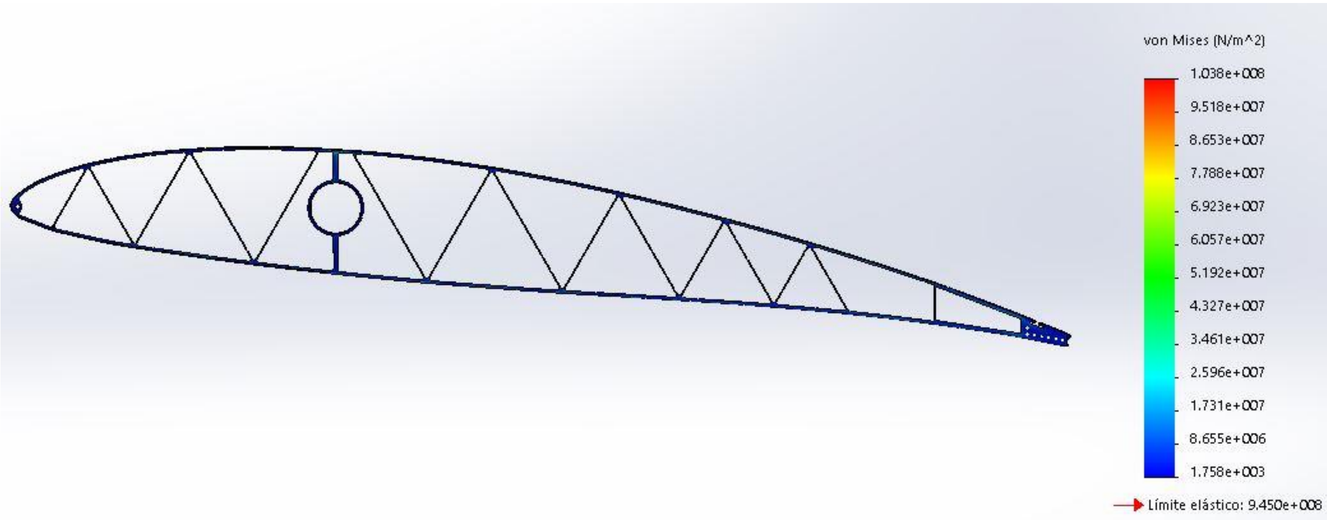


Figure 44: Von Mises analysis (Stress).

Displacements analysis

In this analysis can be showed up the maximum displacements are about 0.87mm. So, the previous reasoning from the stress analysis is still true but with this information, at that red zone, that process should be done carefully.

Due to this it’s possible to reconsider the trusses configuration and the thickness of the airfoil extrusion, but as the rib will be cover with a resistant flax fiber, final resistance will be higher.

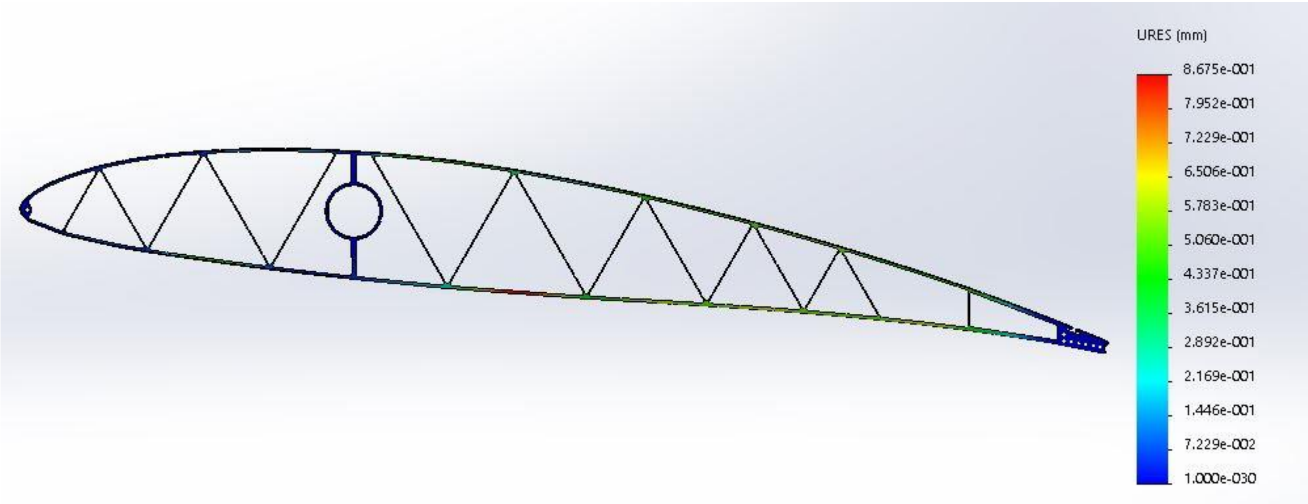


Figure 45: Displacement analysis

Deformation analysis

Carbon fiber is a very rigid material, so deformation is very low in all the rib.

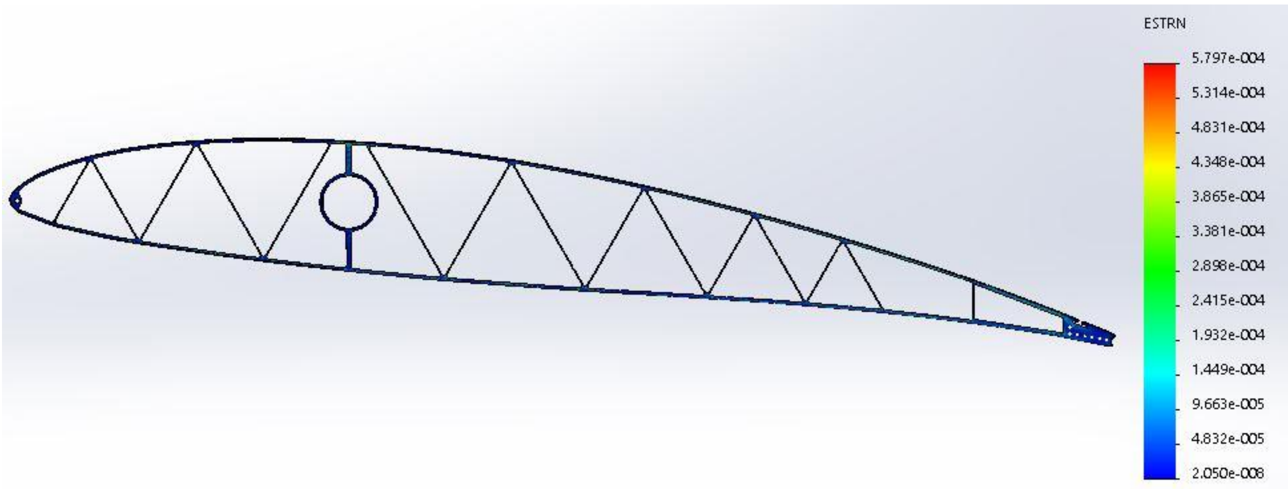


Figure 46: Deformation analysis

II. Rib nº 14

Boundary conditions

The loads are applied on the low side (Lift force) of 490N meanwhile the fix constrains are where the tubular longeron are placed, and where the strap and guides are located.

Stress analysis

In the next image can be seen that, first of all, the elastic limit is not reached so any point of the rib became plastic which means that all the rib is not broken.

Secondly, can be appreciated that, almost all rib, is dark blue, and the trusses are more pressed, so the resistance behavior of the rib is good enough, no material will be removed

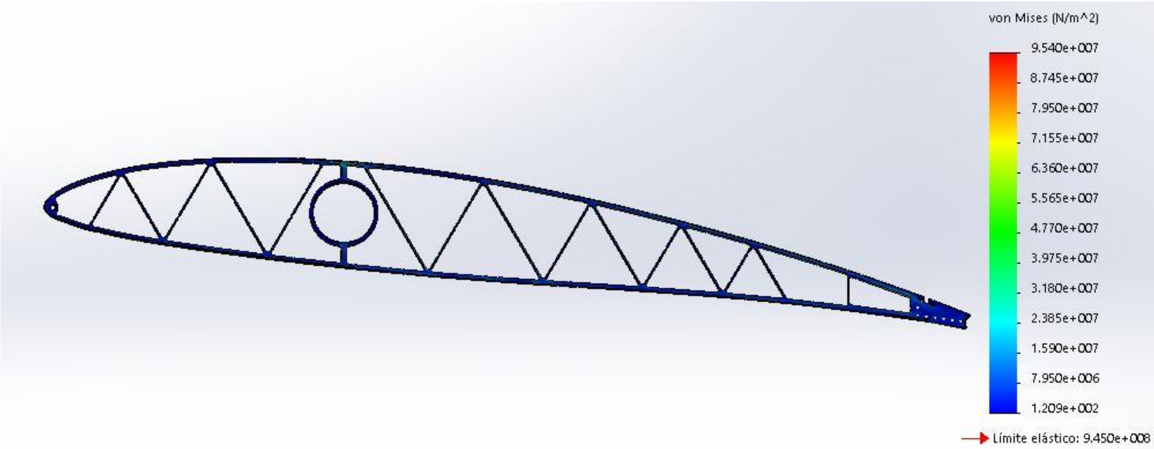


Figure 47:Von Mises analysis (Stress).

Displacements analysis

In this analysis can be showed up the maximum displacements are about 0.428mm. So, the previous reasoning from the stress analysis is still true but with this information, at that red zone, that process should be done carefully.

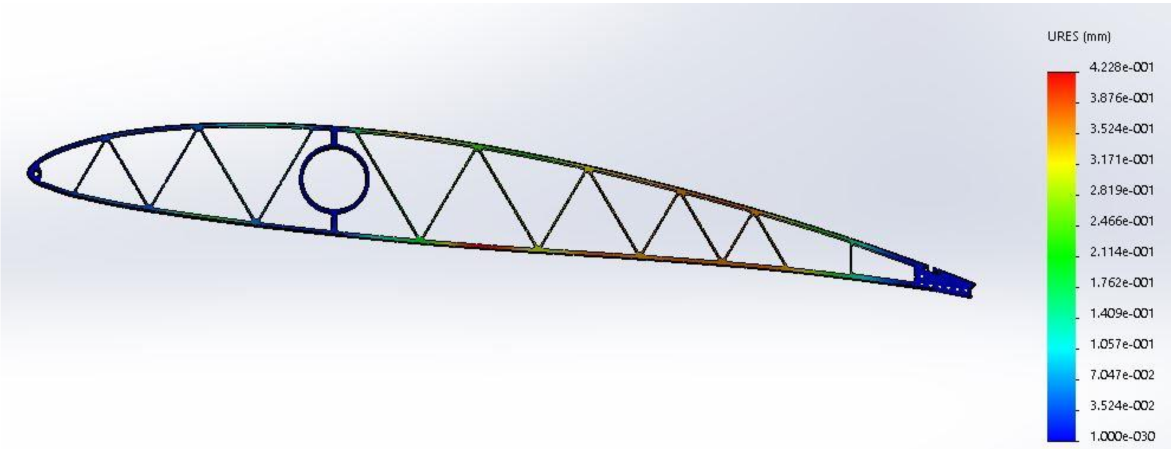


Figure 48: Displacement analysis

Deformation analysis

As it is said carbon fiber is a very rigid material, so deformations are very low in all the rib.

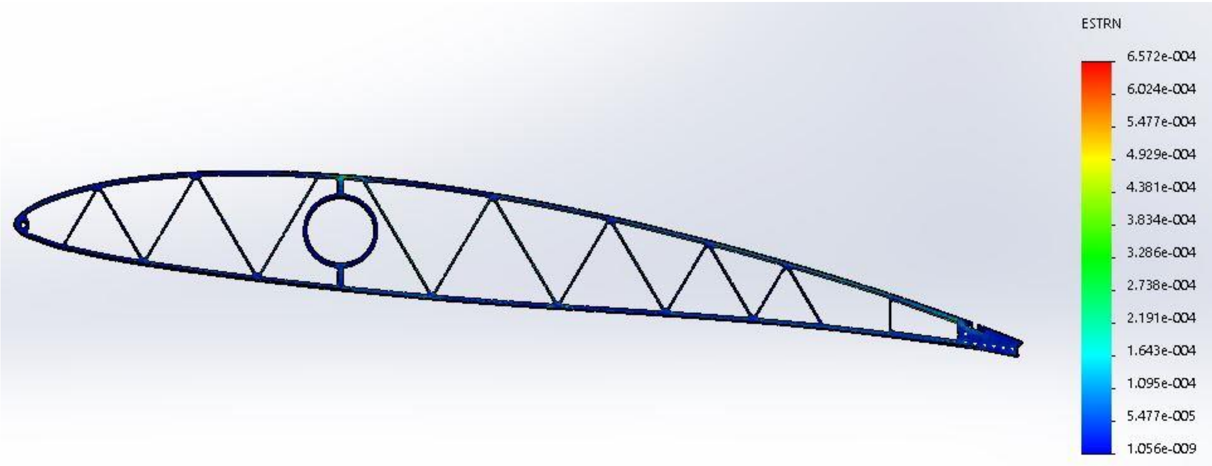
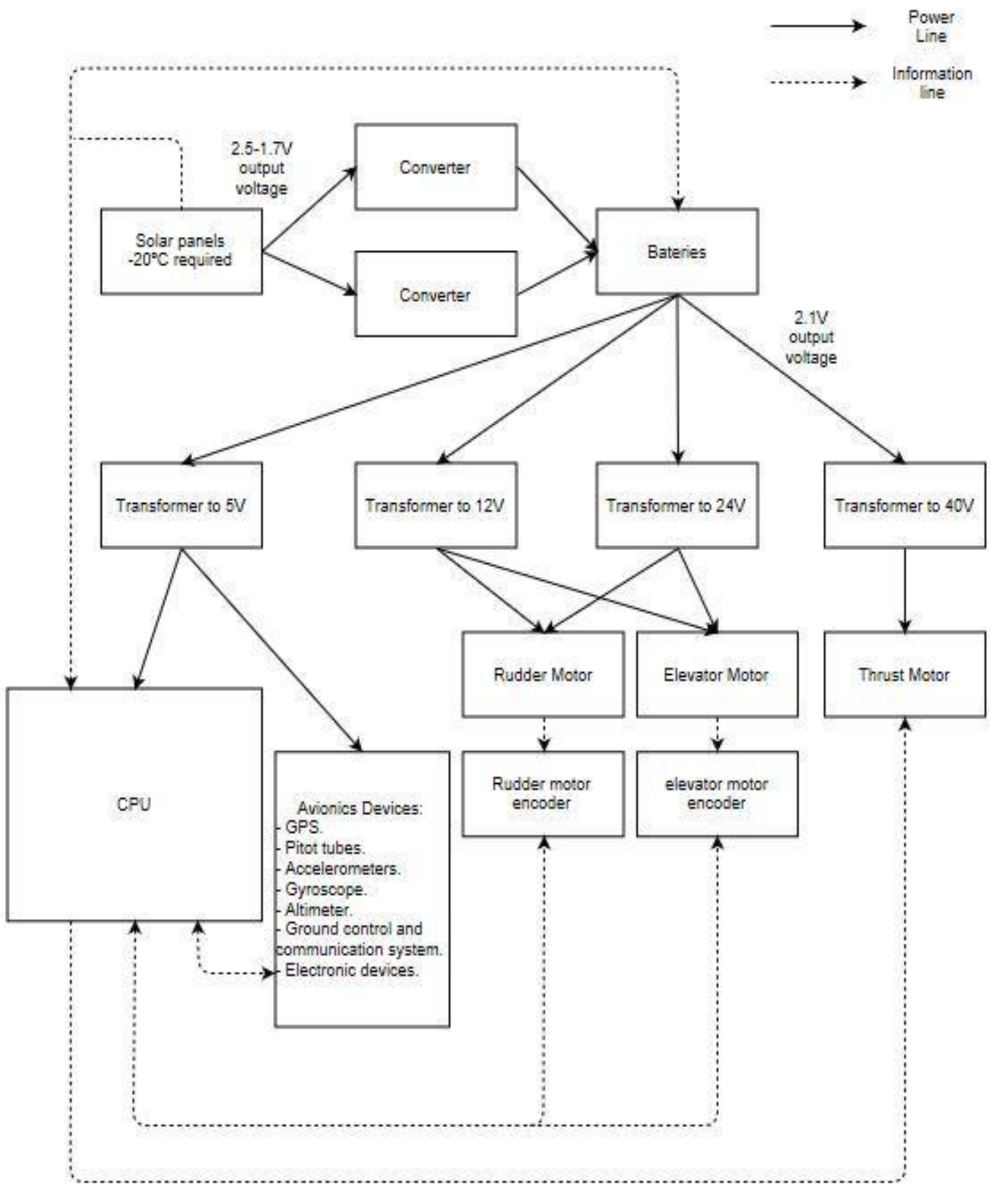


Figure 49: Deformations analysis

4. Description of control system.

The following flow chart shows the global control:



In this scheme is important to denote the two different flows, the power supply line and the information or command line.

The first one starts at the solar panels where the energy is collected at 2.5 volts if the variables are optimum. It passes through the converter to enable the stocking the energy in the batteries. Once in the batteries the output voltage is 2.1 volts so a transformer is needed for supply of energy to any device. Finally, the energy is consumed by all gadgets.

The second one is the recollection of information by the CPU and the command or information sending by the CPU to all the devices. First, the CPU recollect information about the solar panels and the battery as the energy the produce, the efficiency, the energy in stock or about any problems they could have. Second, is important to talk about the information flow between CPU and avionic devices which helps the aircraft to be piloted; they give all information about aircraft pitch, yaw, roll angles, altitude, positioning… and the CPU analyze all that information, acts according to the installed automatic operations mappings and send the needed information to the base of operation on ground to enable the piloting.

Finally, the actuation according to the mapping goes on the control surfaces and on the thrust motor to change pitch, yaw and roll angles, change the altitude and change the speed or brake. For the control of the angles is needed to know the positioning angle of the servomotors of the control surfaces by the encoder.

The information about the condition about all devices and it efficiency is supply to the CPU and to the base of operation too.

5. Determination of the requirements of safety work using the device.

5.1. Main aim.

The purpose of the study will be analyse and study possible risks and preventive actions to implement in the assembly line of design and manufacture of the HALE UAV.

5.2. Process.

In the line, several pieces and parts come for being assembly in the aircraft later. Aircraft chassis will be placed in a bench, and a small bridge crane will be used to place the large longerons as well as the ribs and tail structure.

5.3. Workstations.

In this process, several people will be in charge of different operations:

- <u>Head of Unit:</u>

The person who plan, control, coordinate and supervise all the assembly line activities, in order to ensure a good performance of all the process. This supervision will be as specific and periodic.

He/ She will be moving throughout all the workstations constantly, generally walking, and is in contact with contaminant agents such as noise or gases.

- Maintenance technician:

Their function is to guarantee a good work with several machines to improve the efficiency in the assembly line if it will be necessary repair or substitute equipment and devices, in consequence he/she is in contact with all the operators in the unit.

- Assembly worker:

They are in charge of place and built the parts, as well as the connection units. They will be helped with all the work tools such as screwdrivers, adhesives, bolts and so on. They keep relation with all the other workers.

- Forklift operator

Their function consist on transport material and parts from one place to another, this function imply to know the work area, which must be properly signalled.

5.4. Risks and safety evaluation.

Once the risks are identified, we must evaluate in order to plan corrections actions to control them. The risk criteria is divided between; probability and severity:

- Probability:

According to the frequency the risk takes place.

  - High probability: the risk is taken often, and the damage will happen almost always.
  - Medium probability: the risk might occasionally occur, damage will happen at times.
  - Low probability: The occurrence is very rare.

- Severity

According to the capacity of harm the workers, or the materials.

  - High severity: it can cause permanent disabling injuries, including the potential loss of life, and material losses very serious.
    For example: amputations, major fractures…
  - Medium: the risk might occasionally occur, damage will happen at times.
    For example: burns, minor fractures, sprains …
  - Low: the injuries aren´t disabling, or the loss of material is slight.
    For example: minor impacts, eyes irritations, cuts…

According to this classification is set the next table, to check the **seriousness (SE)** of the risks:

		Severity (SV)		
		High	**Medium**	**Low**
Probability (PB)	**High**	Very High (VH)	High (H)	Moderate (M)
	Medium	High	Moderate	Low (L)
	Low	Moderate	Low	Very Low (VL)

Table 11

RISK AND SAFETY EVALUATION		Page nº 1
Company:	HALE UAV builder.	Date:
Position:	**Head of Unit**	Nº of workers:
Nº Ref	1.1	

IDENTIFICATION		EVALUATION		
RISK FACTORS AT WORK (AGENTS AND OTHER DESCRIPTIONS AT WORK)	**IDENTIFIED RISKS**	**PB**	**SV**	**SE**
1.1.1. Physical static load (taken postures)	Occupational disease produced by physical agents	M	L	L
1.1.2. Movement on foot throughout assembly line	People falling on the same level	L	L	VL
1.1.3. Movement on foot throughout assembly line	Crashing into immobile objects.	M	L	L
1.1.4. Movement on foot throughout assembly line	Crashing into mobile objects	M	L	L
1.1.5. Movement on foot throughout assembly line	Crashing into other objects and tools	H	L	M
1.1.6. Intrusion in restricted areas	Running over with vehicles	M	H	H
1.1.7. Slopes and steps	People falling on different level	M	L	L
1.1.8. Noises	Occupational disease produced by physical agents	M	M	M

RISK AND SAFETY EVALUATION					Page nº 2
Company:	HALE UAV builder.	Date:			
Position:	**Maintenance technician**				
Nº Ref	1.2	Nº of workers:			

IDENTIFICATION		EVALUATION		
RISK FACTORS AT WORK (AGENTS AND OTHER DESCRIPTIONS AT WORK)	**IDENTIFIED RISKS**	**PB**	**SV**	**SE**
1.2.1. Tighten tool	Crashing with other objects and tools	M	L	L
1.2.2. Maintenance tasks	People falling on the same level	L	L	VL
1.2.3. Maintenance tasks	Crashing into immobile objects.	M	L	L
1.2.4. Maintenance tasks	Crashing into mobile objects	M	L	L
1.2.5. Maintenance tasks	Crashing into other objects and tools	M	L	L
1.2.6. Maintenance tasks	Step over objects	M	L	L
1.2.7. Repairs and machines manipulation	People falling on different level	M	L	L
1.2.8. Repairs and machines manipulation	Occupational disease produced by physical agents	M	M	M
1.2.9. Repairs and machines manipulation	People falling on the same level	L	L	VL
1.2.10. Repairs and machines manipulation	Electric contacts exposure	M	H	H
1.2.11. Repairs and machines manipulation	Toxic substances exposure	L	M	L
1.2.12 Repairs and machines manipulation	Fires	L	H	M
1.2.13 Repairs and machines manipulation	Entrapment between objects	M	M	M
1.2.14 Noises	Occupational disease produced by physical agents			

RISK AND SAFETY EVALUATION					Page nº 3
Company:	HALE UAV builder.	Date:			
Position:	**Assembly worker**				
Nº Ref	1.3	Nº of workers:			
IDENTIFICATION			**EVALUATION**		
RISK FACTORS AT WORK (AGENTS AND OTHER DESCRIPTIONS AT WORK)		**IDENTIFIED RISKS**	**PB**	**SV**	**SE**
1.3.1.	Unspecified, handling tool.	Crashing into other objects and tools	M	L	L
1.3.2.	Screwdriver	Crashing into other objects and tools	L	L	VL
1.3.3.	Screwdriver	Crashing into immobile objects.	M	L	L
1.3.4.	Continuous handling	Entrapment between objects	M	L	L
1.3.5.	Continuous handling	Crashing into other objects and tools	H	L	M
1.3.6.	Continuous handling	Occupational disease produced by physical agents	M	H	H
1.3.7.	Noises	Occupational disease produced by physical agents	M	L	L
1.3.8.	Continuous handling	Overexertion	M	M	M
1.3.9.	Monotony of daily work.	Non included risk between Occupational diseases	H	L	M
1.3.10.	Movement on foot throughout assembly line	Crashing into other objects and tools	L	M	L
1.3.11.	Movement on foot throughout assembly line	People falling on the same level	L	M	L
1.3.12	Movement on foot throughout assembly line	Crashing into immobile objects.	M	L	L
1.3.13	Footwear and clothing	Step over objects	L	L	VL

RISK AND SAFETY EVALUATION					Page nº 4
Company:	HALE UAV builder.				
Position:	**Forklift operator**	Date:			
Nº Ref	1.4	Nº of workers:			

IDENTIFICATION		**EVALUATION**		
RISK FACTORS AT WORK (AGENTS AND OTHER DESCRIPTIONS AT WORK)	**IDENTIFIED RISKS**	**PB**	**SV**	**SE**
1.4.1. Forklift	Falling of mobile objects	H	L	M
1.4.2. Forklift	Falling detached objects	M	L	L
1.4.3. Forklift	Entrapment between vehicles, or machines	L	H	M
1.4.4. Forklift	Running over with vehicles	M	H	H
1.4.5. Wire and electric conductors	Electric contacts exposure	M	H	H
1.4.6. Loading and unloading area	People falling on the same level	L	M	L
1.4.7. Loading and unloading area	Crashing into immobile objects.	M	L	L
1.4.8. Loading and unloading area	Crashing into other objects and tools	H	M	H
1.4.9. Loading and unloading area	Running over with vehicles	H	M	H

6. Environmental requirements

The following report about environmental requirements are for the UAV construction and its operation but not for the construction of the warehouse or the antennas or some needed structures to enable development of the project.

6.1. Population and social aspects

At this term, the negative influence because of the UAV production mainly is the immigration and what it causes, because of the needed of professional workers that is probably to need them from another country. This immigration derives in problems such as more pollution, worse medical care or more traffic. Other problems as losing jobs, noise, or losing agricultural lands or woods are critic too.

On the other hand, some profit features are the development of the communications and infrastructure and with more population the real-estate sector will rise and make the economy to grow in this country.

Anyway, this benefits and disadvantages are not a real big deal due to the incoming population and its impact is not that big.

6.2. Flora and fauna

About flora and fauna are all problems and they are while the use of the UAV. These problems are about bird population and creation new buildings. Even the creation of the radio-communication could make some problems with some animals depending in the wavelength. Another problem is the light contamination if there are some night operations and the noise and dust that the creation of the UAV origin.

6.3. Soil and landscape

In this section, the problems are mainly the usage of chemicals that can go through the ground and contaminate the soil, as well the glycol used in freeze prevention has to be carefully employed.

Another problem is the deforestation for the construction of all the buildings needed for the project. This may cause a visual impact on the landscape and make the soil unstable and uncompressed without the tree roots.

Other minor problems are dust dispersion, ground erosion, soil contamination due to the wastes or alteration of soil structure or composition.

Some things to reduce this impact for being a green project is plant trees and reduce the carbon footprint.

6.4. Surface and ground water

As happened with the soil, the chemicals and the residues on the ground can dive into the ground and arrive the underground water.
Special care must be taken for oils and wastes that can generate these phenomena.

6.5. Impacts on air and climate change

At this point is important to mention the carbon footprint that the business and it employees can make so is important to reduce it as possible as it can be.

Is important to mention another emission as greenhouse gases, NOx, HC, or sulfides. As is showed before one of the options to reduce this impact is to pant a wood. Another step to take is reduce those emissions by using a solar powered, bio-fuel or another ecofriendly solution for all the energy supply.

6.6. Immovable and cultural heritage

In any building construction some unknown features or archaeological sites can be destroyed so a geological study is needed. As well the vibration can cause some collapses so that reinforces the idea of carrying out a geological study.

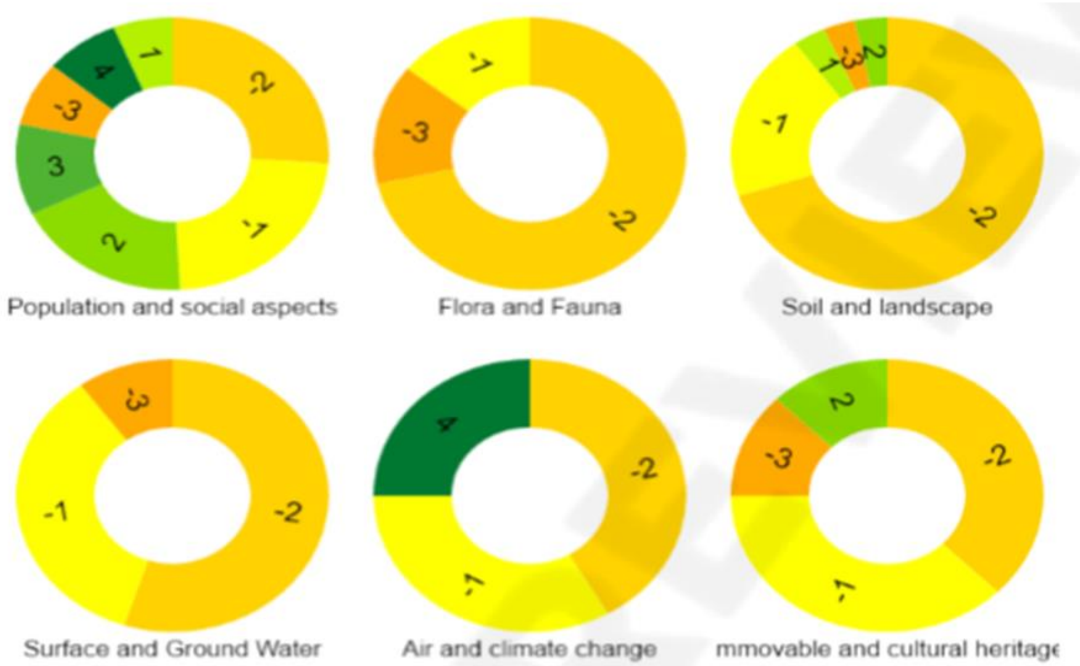


Figure 50: Enviromental study.

7. Economical calculations

Manufacture planning is important to know potential of sales and profits. The procedure consists in analyzing fixed and variable costs, carrying out a market research and calculate the break-even point.

Calculating the break-even point is a key financial analysis tool used by business owners. Once you know the fixed and variable costs for the product your business produces or a good approximation of them, you can use that information to calculate your company's breakeven point.

Estimating the price of different elements of the HALE UAV is the first task to do; this procedure will consist on divided cost in fixed and variables:

- Fixed costs are those does not change with an increase or decrease in the amount of goods or services produced; in the case of the task at hand, the fixed costs are the price of the cast, molds and the industrial plant building.
- A variable cost is a corporate expense that varies with production output. Variable costs are those costs that vary depending on a company's production volume; they rise as production increases and fall as production decreases. Cost of devices as CPU, accelerometers, gyroscopes, motors, and others as prices of carbon fiber, batteries and solar sheets.

7.1. Prices List

Researching the market, a list of investment costs is made:

STRUCTURAL		
Carbon Fiber	300	€/kg
TOTAL	15000	€/tot
Solar panels	850	€/m²
TOTAL	31450	€ - 37 m² aprox.
Batteries	312.5	€/kg
TOTAL	2500	€ - 8 kg aprox.
Flax Fiber covering	77.5	€/m²
TOTAL	9300	€ - 120m² aprox.

Table 12

Structural materials like carbon fiber, covering, or solar panels depends on the size of the plane, with this data it is possible to form an idea of how much cost the aircraft chassis.

DEVICES	
Gyroscope	79.30 €/unit
Accelerometer	65.45 €/unit
Altimeter	21.90 €/unit
Camera	169.99 €/unit
Motor BG 75x75	572.00 €/unit
Servomotors	70.00 €/unit
GPS	39.95 €/unit
Communication system	200.00 €/unit
Temperature sensor	23.80 €/unit
Compass	123.17 €/unit
Electric flow sensor	43.91 €/unit
Converter	400.00 €/unit
Light sensor	22.73 €/unit
Transformer 5V	15.50 €/unit
Transformer 12V	60.72 €/unit
Transformer 24V	54.70 €/unit
Transformer 40V	260.15 €/unit
CPU	1500.00 €/unit
Speed Sensor	55.00 €/unit

Table 13

This devices conforms the part called as Avionics system, and the prices are easily found in companies' websites.

FIXED MANUFACTURING		
Molds	10000	€/unit
x75	750000	€ aprox.

Table 14

Fixed manufacturing costs are harder to estimate, but based on other carbon fiber molds prices of similar shapes, 10000€/ mold it is the approximation made.

LABOR COST				
Nº	Operators	total time: 2 months	[h]	320
x4	Skilled labor	10	€/h	12800
x10	Unskilled labor	5	€/h	6400
x5	Maintenance	3	€/h	3840
	TOTAL (1 HALE UAV)	**23040**	€	

Table 15

Each team group has to integrate their devices and materials, resulted in the next prices table:

PARTS		
WING	cover	elements (€)
Surface	73.00	5657.50
Mass	21.60	6480.00
Devices	31450.00	34595.00
	572.00	1144.00
	Total	**47876.50**
TAIL		
Surface	21.62	1675.86
Mass	18.20	5460.00
Devices	70.00	140.00
	55.00	55.00
	Total	**7697.40**
BODY		
Surface	20.00	1550.00
Mass	15.00	4500.00
Devices	3448.77	3793.64
	Total	**9843.64**
TOTAL	**65417.54** €	

Table 16

7.2. Break-even point calculation

As the HALE UAV market doesn't have many competitors, the team decided to make 10 aircraft to earn profits. This means to cause that break-even point should be reach when the tenth HALE UAV be sold.

Break-even analysis can be solved as:

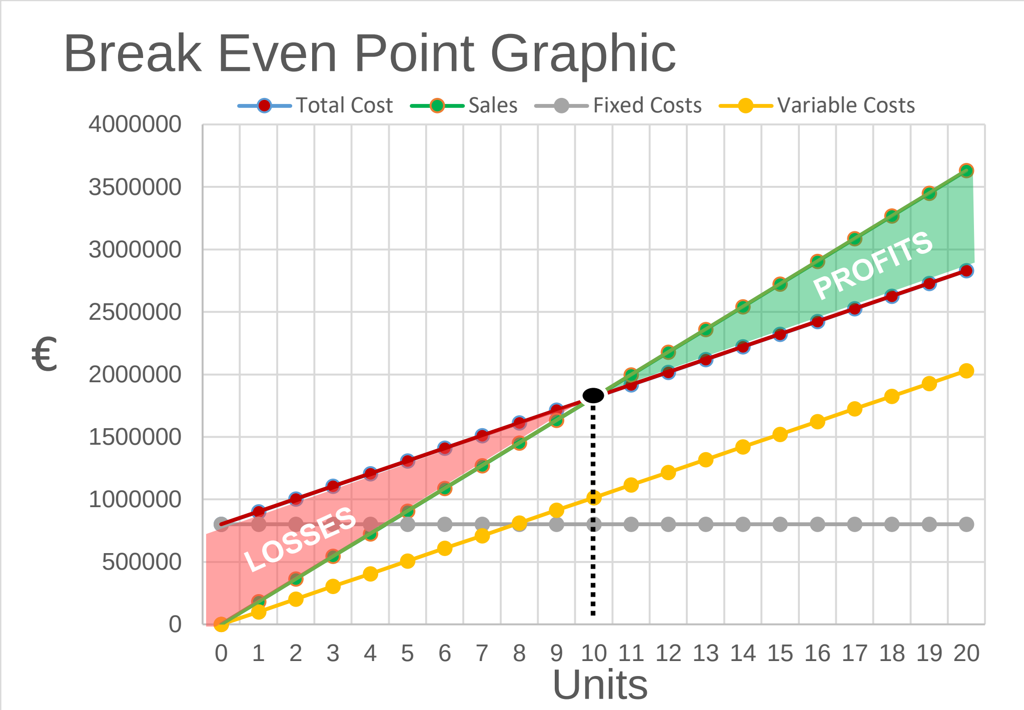
$$Breakeven\ point\ [UNITS] = \frac{Fixed\ Cost}{Sales\ Price\ per\ Unit - Variable\ Cost\ per\ Unit} \quad (30)$$

As number of units will be 10, and Fixed Cost and Variable Cost per Unit has been calculated, it's easy to solve equation (30), obtaining Sale Price per Unit.

Variable Cost per unit	**101423.79 €**
Fixed Cost	**800711.90 €**

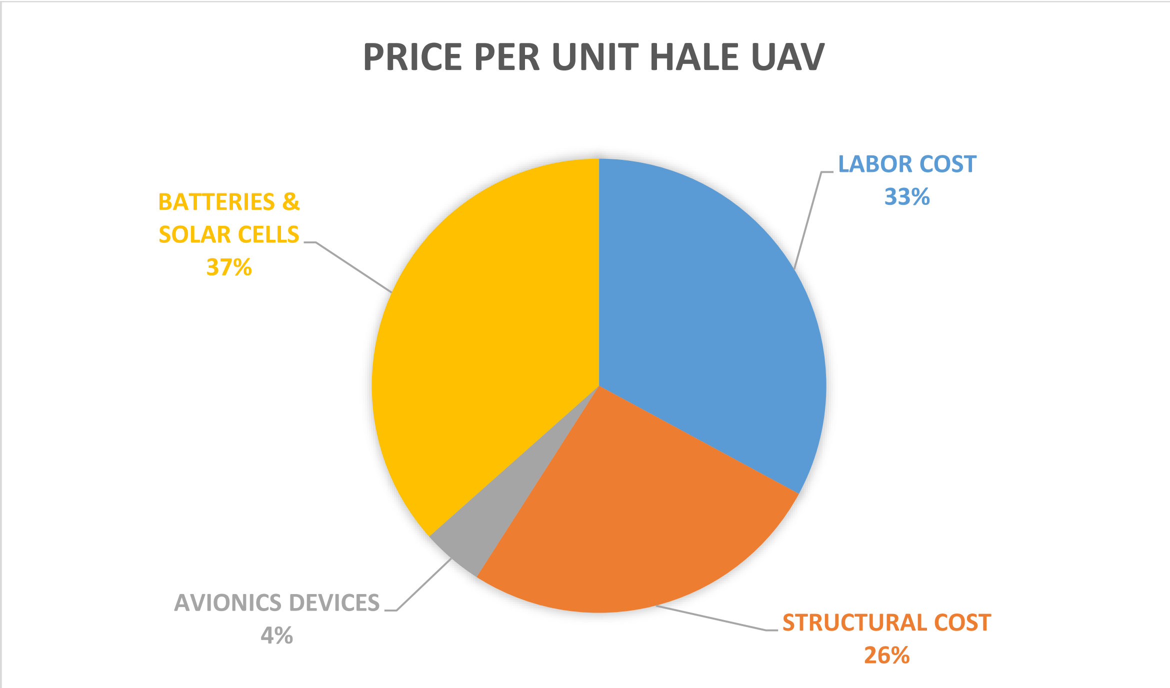
PRICE PER UNIT	**181495 €**

According to last data it's possible to design the Break-even Point graphic:



Graphic 9

And the percentages of the price of variable costs for a unit of HALE UAV.



Graphic 10

8. Conclusions

Designing an aircraft is a hard task that involves a large team and numerous predesign stages; for this reason, this study will require considerable improvements and reassessments in order to make it a feasible development.

It has been impossible to solve all the difficulties that were arisen, but that's is normal considering that this kind of projects took years to perform a good design, several problems will be introduce as conclusions that could be solved in the future:

During the flight the build-up ice on motors, wings and mobile parts is the most critical one because, with temperatures around -50 ºC is easy for the ice to appear and make the UAV to fall for different reasons, in fact a zephyr 7 model crash because ice broke the gearbox:

- Ice on the wing can change the shape of the wing airfoil and make the HALE UAV to stall and fall.
- Ice on the thrust motors, and gear box can break them up and leave the UAV without propulsion, (that happened with the first zephyr prototype)
- Ice on control surface and mobile parts can block the movement paths not allowing the stability trim and the plane to become stalled.
- Any piece of ice make the plane to get heavier and, with many ice, make the plane collapse because of that extra weight and fall.

Working in such an extreme atmosphere (-50ºC) could make components as batteries, GPS, CPU or any other stop working, what would mean the loss of the UAV.

As it looks, the ice is a very hard problem and not easy to solve due to even the big airliners have problem with the ice and they can only prevent it with some fluids spreads on the wings for taking off. So, for this issue, some solutions are thought and shown as follows:

Use carbon fiber for the volumes where the electronic components are. The carbon fiber has a small coefficient of conductivity [around 0.044W (m·ºC)] what makes the heat not to go away. It would be internally coated with metallized polyethylene terephthalate, polyimide or aluminum foil to reflect all the radiation and it would be externally coated by some treatment which makes the fiberglass impermeable and makes the surface actuate as hydrophobic material. Besides, fiberglass is a very light composite what is ideal for aeronautical applications.

Installing resistances in critical places as inside the volumes where the electronic components are, in the leading edge of the wings and tail and on the mobile parts, although this increment the total power consumption of the plane, it would help to keep all the critical areas warm.

Using anti-ice-oil for the thrust motors to keep them in working temperatures and stop the freezing.

Most of these solutions makes the plane heavier and introduce some constructional issues or makes the UAV much more expensive, so this another issues should be taken in account for future work.

9. Annex – Excel

- Conceptual design – Solar cells cover area

AT 15000 m				
Cruise speed	16.63	59.875972		
e	0.85			
C_l	0.65	2° 3°	C_l / C_d =	27.083
C_d	0.0240			
g	9.760493	m·g =	$\frac{1}{2}\rho v^2 S_{ref} Cl$	
ρ	0.1448	488.02464	488.0246424	
		T=	$\frac{1}{2}\rho v^2 S_{ref} Cd$	
$C_d/C_l^{1.5}$	0.045797	22.22	18.01937141	

SYMBOL	UNIT	VALUE	DESCRIPTION
e	-	0.85	Oswald's efficiency factor
η_{bec}	-	0.65	Efficiency of step-down converter
η_{sc}	-	0.1	Efficiency of solar cells
η_{cbr}	-	0.8	Efficiency of curved solar panels
η_{chrg}	-	0.85	Efficiency of battery charge
η_{dchrg}	-	0.9	Efficiency of battery discharge
η_{ctrl}	-	0.95	Efficiency of motor controler
η_{grb}	-	0.9	Efficiency of gearbox
η_{mot}	-	0.88	Efficiency of motor
η_{mppt}	-	0.95	Efficiency of MPPT
η_{plr}	-	0.85	Efficiency of propeller
I_{max}	[W/m²]	980.79	Maximm irradiance
P_{av}	[W]	110	Power consumption of avionics system
P_{pld}	[W]	0	Power consumption of payload instruments
k_{sc}	[kg/m²]	0.027	Mass density of solar cells
k_{enc}	[kg/m²]	0.1	Mass density of encapsulation (flax fiber)
Se	W·h/kg	500	Specific energy

POWER - ENERGY - SOLAR CELL AREA

	Assumed	needed
Plev [W]	**300**	**299.7**
Pavionics [W]	**110**	
	0	

$P_{elec\ tot}$ [W]		**637.85**
m bat [kg]		**7.94**
m mppt [kg]	**0.000420**	**0.75**
m prop [kg]		**0.77**
m flax (wings) [kg]		**4.55**

Assumed CV Area -Scv- [m2]		**23.984**
E elec tot day [KJ]	**62164.31**	

WEIGHT BALANCE

PART	ELEMENT	WEIGHT [Kg]	
WINGS	Motors	5.6	**30.57**
	Solar cells	0.65	
	Encapsulation	4.55	
	Propellers	0.77	
	Wings Estructure	19	
BODY	MPPT	0.75	**15.69**
	Batteries	7.94	
	Avionics system	1	
	Body structure	6	
TAIL	Tail structure	15	**15.16**
	Servo Motors	0.16	
OTHERS	Wiring	1	
TOTAL		**62.42**	

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