UNIVERSIDAD DE VALLADOLID

ESCUELA DE INGENIERIAS INDUSTRIALES

Grado en Ingeniería Mecánica.

Diseño de los estabilizadores verticales y horizontales de un vehículo aéreo no tripulado (UAV)

Autor:
Pablo Marcos García

Responsable del intercambio:
Marta Herráez Sánchez

Universidad de Destino:
Vilnius Gediminas Technical University

Valladolid, Julio, 2017.

TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO: **Design of of HALE-UAV vertical and horizontal stabilizer**

ALUMNO: **Pablo Marcos García**

FECHA: 07/06/2017

CENTRO: **Faculty of Mechanics – Vilnius Gediminas Technical University**

TUTOR: **Robertas Urbanaviçius.**

Index

LIST OF FIGURES

LIST OF TABLES

LIST OF GRAPHICS

GLOSSARY

Symbols

W_{TO}: Aircraft maximum takeoff weight [N]

m: mass [kg]

S: 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]

AR: Aspect Ratio [-]

λ: Taper Ratio [º]

C_{Root}: Root Chord [m]

C_{Tip}: 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 takeoff [º]

α_c: Angle at cruise speed [º]

Cl: airfoil lift coefficient [-]

Cd: airfoil drag coefficient [-]

Cm: airfoil pitching moment coefficient [-]

V: Volume coefficient [-]

Acronyms

HALE: High-Altitude Long Endurance

UAV: Unmanned Aerial Vehicle

CAD: Computer Aided Design.

ISA: International Standard Atmosphere

MAC: Mean Aerodynamic Chord [m]

1. Preface

1.1. Introduction

One of the biggest part of this planet is the atmosphere in which can be done a lot of things, since investigation to surveillance; but normally, to do this kind of operations is needed a manned aircraft, probe-balloons with non-recoverable material or drones that cannot exceed low altitude. For this reason, is very interesting to develop a new kind of aircraft, environmental-friendly and unmanned to allow the scientist to investigate, monitoring the ozone in the atmosphere, to use them as atmosphere satellites for communication or even 3D mapping, or to enable countries with poor rain do the “cloudseeds”.

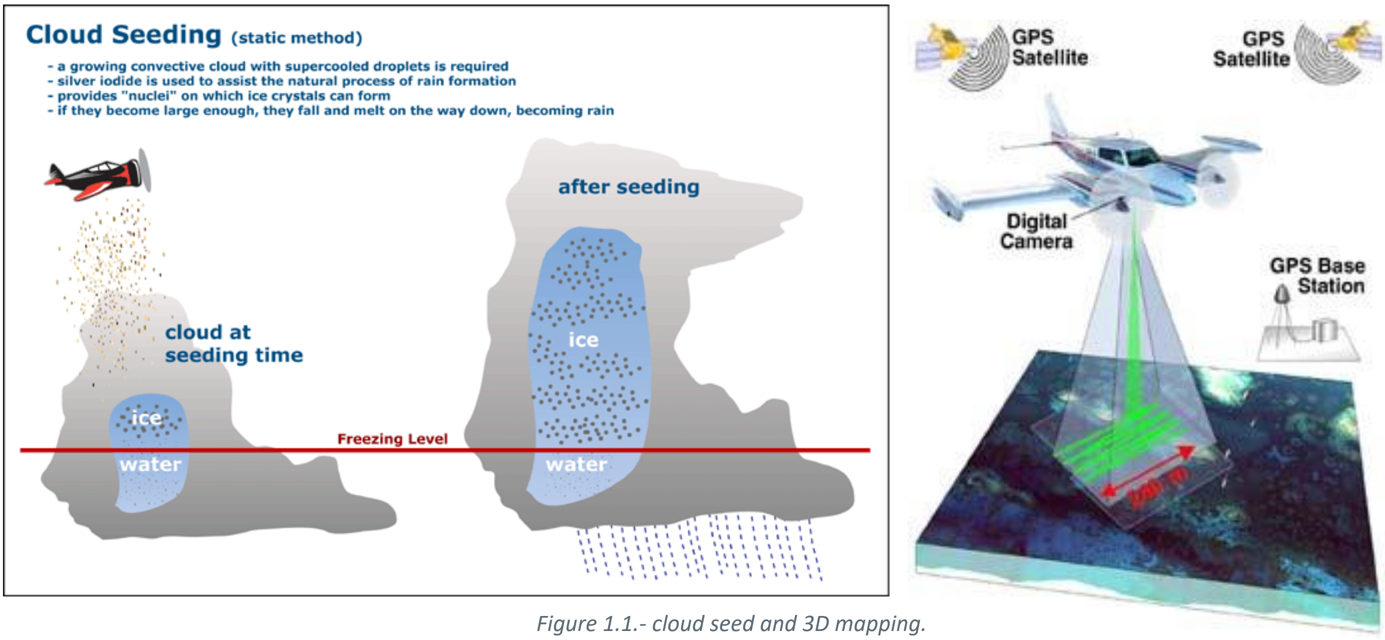


Figure 1.1.- cloud seed and 3D mapping.

Is important to denote other similar aircrafts and the design phases for this plane.

1.1.1. HALE-UAV

1.1.1.1. HALE

HALE is the acronym for High Altitude Long Endurance. This kind of aircrafts can reach the stratosphere without landing for considerable periods of time.

The very first time when an article about long endurance was published was on 1984 when M.D. Maughmer (University Pennsylvania State) and D.M. Somers (NASA Langley) *Design and experimental results for a high-altitude, long-endurance airfoil.* Then interest of Maughmer and Somers was to develop such aircraft to enable the communications, recover weather data and obtain information about cruise missiles. Due to this first concept and the objectives that aim for, the following researches were in direction of develop a sneaky military aircraft for surveillance and for obtaining information.

The tropopause is the borderline between the troposphere and the stratosphere; it's located in average at 13000 meters. At this point the temperature is almost constant but very low, and the sun irradiance gets higher due to the lack of clouds. Due to these conditions is necessary to solve the problems as frozen wings, frozen motors, frozen telemetry components, communication problems, etc. The possible solutions adopted to overpass these issues will be commented ahead.

1.1.1.2. UAV

UAV is the acronym for Unmanned Aerial Vehicle, are aircrafts that without a human pilot abroad that allows these planes to control the flight and the operation from a station.

Most of this kind of aircrafts are the common drones that nowadays are all around, that enable the developing of new sensors and structures to improve the most autonomous flight.

Today we have drones for civil and transport uses but it was conceiving as a military aircraft. Due to this, when the people talk about UAV or HALE or the combination of both is not hard to think about a military aircraft. This thought is changing with the time and developing non-military planes. As this is changing more and more companies can bet in the develop of this technology as could be *DJI* or *Syma.*

As well, drones are used in very beneficial cases as firefighting, events surveillance, danger spots surveillance, unsafety places recognition and so on.

Figure 1-1.- Military UAV (RQ-4 Global Hawk).

Figure 1-2.- Civil drone (DJI Phantom 2).

1.1.1.3. Combination of both technologies

The combination of these two meanings gives an aircraft capable of do some complex operations that manned aircraft cannot do. This kind of aircrafts are provided with sensors, actuators, tools, software, computing technology and real-time communications systems that let the "pilots" do them work as they are in the aircraft. Furthermore, these elements enable the aircraft to do any operation for which it is intended.

This kind of aircrafts can do either the function of a drone and a GPS as could be from surveillance, recognition, collecting data of big portions of land, weather information to positioning monitoring to drive autonomic cars or communications repeater.

As seen before, the most of these drones have military proposals as could be the *RQ-4 Global Hawk*, but here are also non-military ones as could be *Airbus Zephyr* which is designed for observation and communications relay.

For these planes 2 technologies are used:

- Solar powered: It have the advantage at high altitude there are not any cloud that could reduce the solar irradiation over the solar panels and the solar energy never ends. The contras of this type of aircrafts are the complex design of the wings and the battery weight due to the need to be able to fly at night and have enough power to do it.

Figure 1-3.- Solar powered aircraft (Zephyr).

- Liquid-hydrogen powered: This kind of fuel enable the plane to be sneaky due to the exhaust gases are no as heat as a jet-motor could expulse, and the structure is not so complex and big as a solar powered UAV. The contras of this type of design is the limited fuel and build a space to keep it and, also, the change of the gravity center.

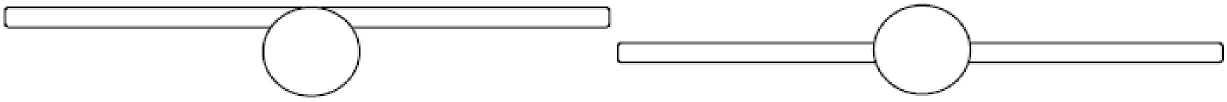
Figure 1-4.- Liquid-hydrogen powered (Eurohakw).

- Nuclear powered: There are no UAV with this technology but there are some investigations that aim to reach this point. This would have the advantage of enable the aircraft to do almost global operations from where it is launched without any steam (allows even more stealth) but with the disadvantages of nuclear power.

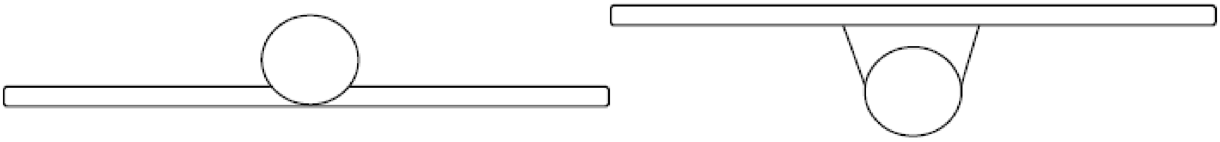
1.1.2. Design Phases

For design an aircraft, firstly, is needed to design the wings especially for this aircraft in which the wing design is crucial to obtain power for the batterie. Moreover, is important to design the wings to make the plane the most stable it could be to allow autonomous flight.

To design a wing the first step should be decide the position of the wing; it could be low wing, high wing, mid wing or parasol wing.



a. High wing *b. Mid wing*



c. Low wing *b. Parasol wing*

Figure 1-5.- Position of the wing [29].

The selection of the position of the wing depends on the requirements. For the UAV in this project the most important requirement is the stability, then the selected wing is a high wing to do not compromise the drag coefficient.

After this, is needed to select the airfoil. This step is very critical since in this element depends the aircraft lift. Depending in the shape of the airfoil and in the angle of attack will be a different lift, drag and pitch, which is very important for the aircraft stability.

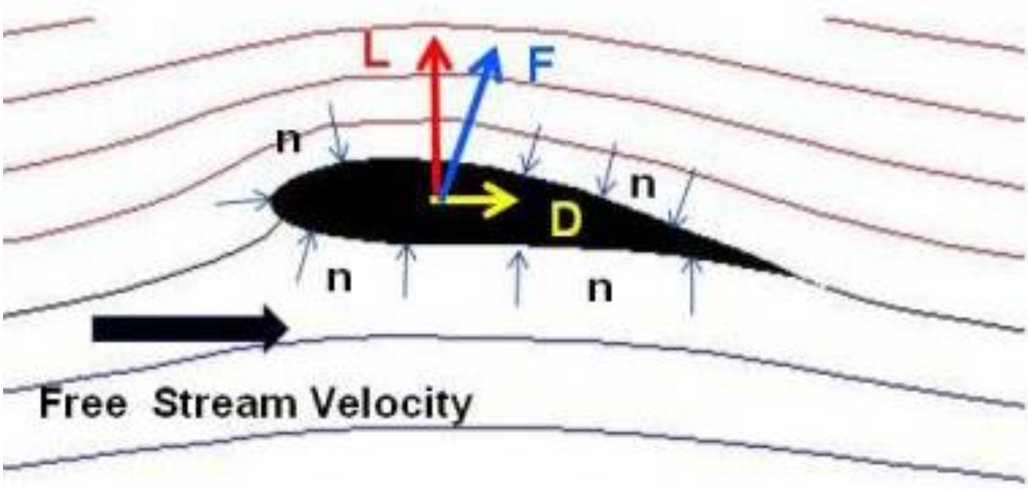


Figure 1-6.- Flow and forces around an airfoil

The lift will depend on the airfoil and on the angle of attack of the airfoil being higher in the taking off operation to have a higher lift and make the plane climb up. This operation must be done carefully because there is a point, called stall point, or stall angle, where the drag force is greater than the lift force and make the wing to stall, to do not generate enough lift force to stay in the air.

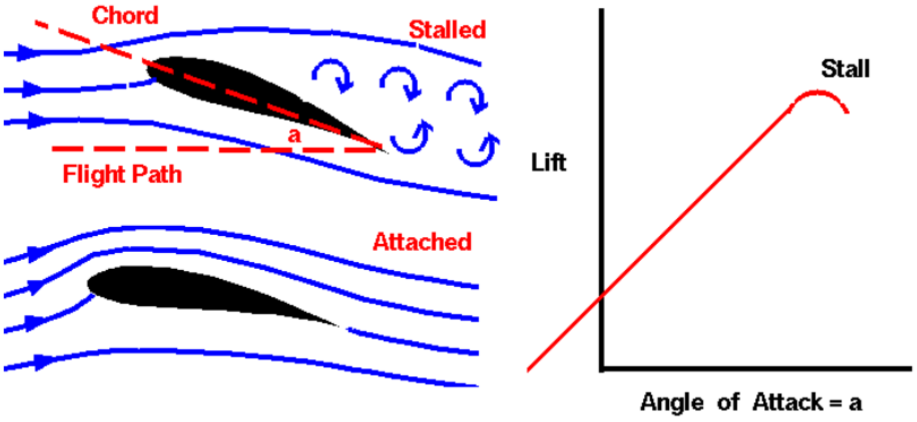
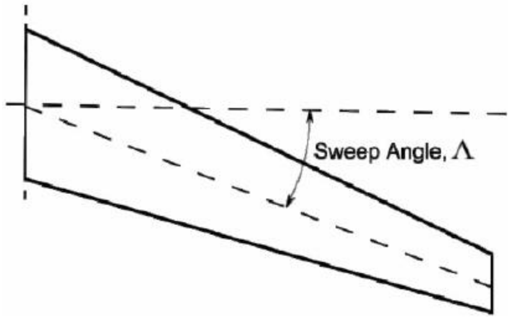


Figure 1-7.- Angle of attack effect on an airfoil

Next step should be choosing the right parameters for sweep and dihedral angles that provides the aircraft more stability. Sweep angle makes the with not to have compression phenomena at the leading edge of the wing, especially in supersonic planes, meanwhile the dihedral angle improves the roll stability increasing the angle of attack (and the lift) on the downer wing if the aircraft starts to roll.

Then, the designer should calculate other parameters as aspect ratio, incidence angle or set angle or the taper ratio.

Last step is to compare the results from the wing designed and the requirements and decide if the wing fix them or not. If not, is necessary to repeat the steps above until the requirements are satisfied and optimize the wing.



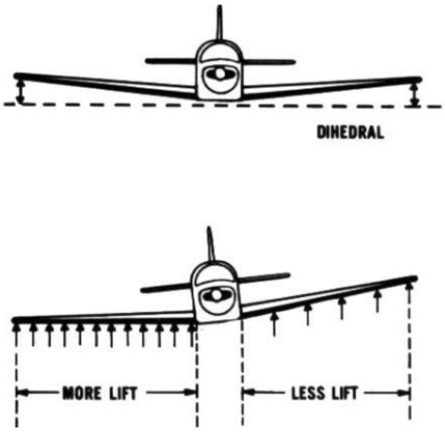


Figure 1-8.- Sweep and Dihedral angle [29].

After this, the second phase, is to design the body. At this point is important to design a body that do not create a lot of drag and have enough space for all the elements for the control and to carry out the operations. Also, it has the undercarriage to enable a safety landing. With all this, the body must be the lightest possible to allow the plane to fly easy.

Figure 1-9.- Glider tear shaped.

Finally, the last phase is to design the tail, the stabilizators (vertical and horizontal), the elevators and the rudder. This part fixes all imbalances that can be caused by the irregular distribution of forces along the body and trim the aircraft balance in every part of the flight mission. This part helps to pitch and yaw the aircraft if it haves to change the direction. The design steps will be described later.

1.2. Motivation

The motivation on this project is to improve the air-crafting knowledge dealing to the lack of knowledge in one field and solve that problem using the technology.

This work is a very good opportunity to improve my computer skills as well, using programs as MATLAB to improve the knowledge about such programming language; CATIA, using all what I have learned in the university about this program; SolidWorks learning how to use it and its possibilities.

1.3. Objective

The objective is to design a suitable aircraft with which is possible to resolve all the problems in the way of the final concept. Is a good way to feel like in a company when a new problem is proposed and the team should work in the same way to achieve the best result, dealing one with each other and sharing ideas.

1.4. Initial statements and values

The very first statement is that this is an early concept about the design of the HALE-UAV, so all parameters could be improved in a future work.

WING-SPAN	25.7 (m)
MAC	1.32 (m)
SURFACE	38 (m^2)
AR	17.4
ROOT CHORD	1.8 (m)
WEIGHT OF EACH MOTOR	3.2 (kg)
SOLAR PANEL WEIGHT	4.03 kg
WING STRUCTURE WEIGHT	Máx. 8 (kg)
STALL SPEED	4.065 (m/s)
CRUISE SPEED	16.7 (m/s)
ATTACK ANGLE AT TAKING OFF	8 (º)
CRUISE ATTACK ANGLE	2 (º)
CRUISE HIGH	10-17 (km)
LIFT COEFFICENT AT TAKING OFF (Cl)	1.2
CRUISE LIFT COEFFICENT (Cl)	0.65
PITCH MOMENT (Cm) TAKE OFF	-0.085
PITCH MOMENT (Cm) CRUISE	-0.105
DRAG COEFFICENT (Cd)	0.04-0.02
FUSELAGE ANGLE AT TAKING-OFF	8º
FUSELAGE ANGLE AT CRUISE OPERATION	0 (º)
MAXIMUM FUSELAGE DIAMETRE	1.2 (m)
MAXIMUM FUSELAGE HEIGHT	3.5 (m)
TAPER RATIO	0.75
AIRCRAFT WEIGHT	50 (Kg)
GRAVITY CENTER POSITION FROM THE AIRCRAFT COMMENCEMENT	3.3 (m)
ZERO LIFT WING ANGLE OF ATTACK	3.6 (º)
STALL ANGLE	12 (º)
DISTANCE BETWEEN MOTORS	12.750 (m)
DISTANCE FROM THE AIRCRAFT COMMENCEMENT TO THE MAIN WHEEL	3.5 (m)
POSITION (X, Z) OF THE GRAVITY CENTER	(3.3,0.6) (m)
WING HIGH	1.033 (m)

1.5. Essential concepts about aerodynamics

Is needed that an aircraft lifts its own weight and payload weight and fly at a determinate speed. To enable this is necessary that the plane overcome the gravity or the weight force, and the drag force:

- **Lift:** Is the force generate by the difference of pressure originated by the asymmetry in the wing direction of an airfoil what makes the wind go faster by one face than the other. This parameter depends on the airfoil shape, airfoil-air relative speed, density and angle of attack. For simplify this force is said that it acts by a point called the center of pressure.
- **Thrust:** Is the force originated by the motor and which allows the aircraft to move forward (and sometimes backwards or to brake). The direction of this force depends on the position of the motors relative to the aircraft and the magnitude depends on the motor-group power; as well depends on density and propeller shapes.
- **Weight:** Is the opposite force at lift and it is created by the aircraft mass and the gravity attraction. As well, to simplify this force it is said that it operates through the center of gravity.
- **Drag:** this is the opposite force at thrust and it makes the aircraft to need more energy that it would need. This force is always when there are movement and it goes in the opposite way. It depends mainly in the speed, density and viscosity but in the shape of the UAV too.

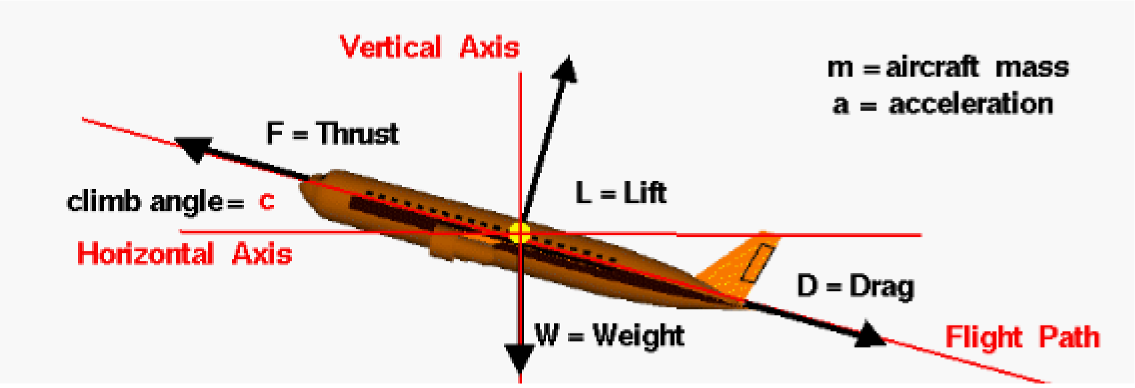


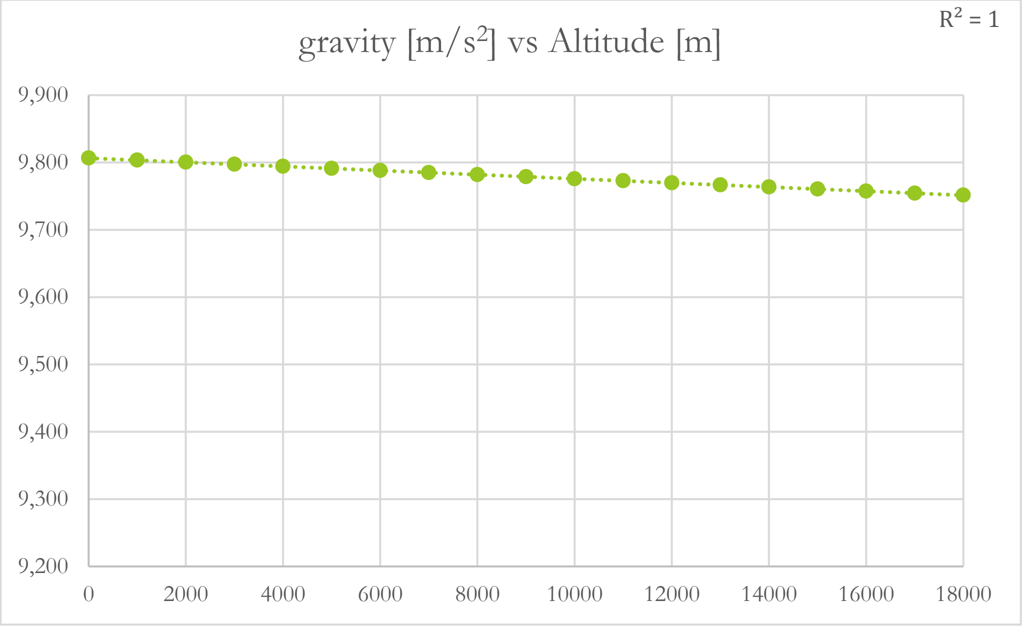
Figure 1.2.- Aircraft forces.

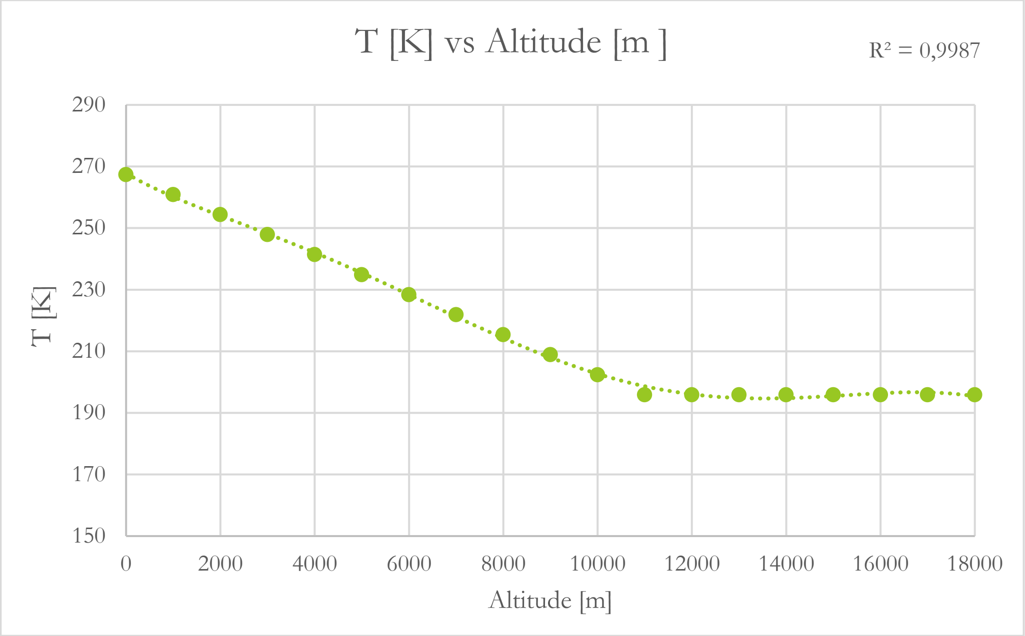
1.6. Conditions at different altitudes

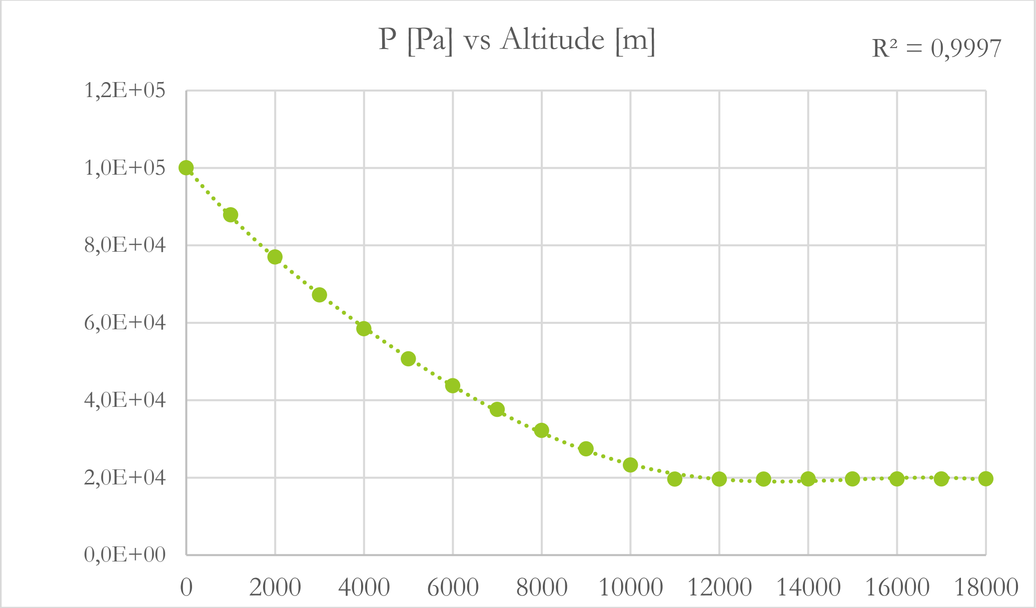
Due to this aircraft's operations, it needs to overcome different conditions at different altitudes and be stable in all of them so they are showed up here:

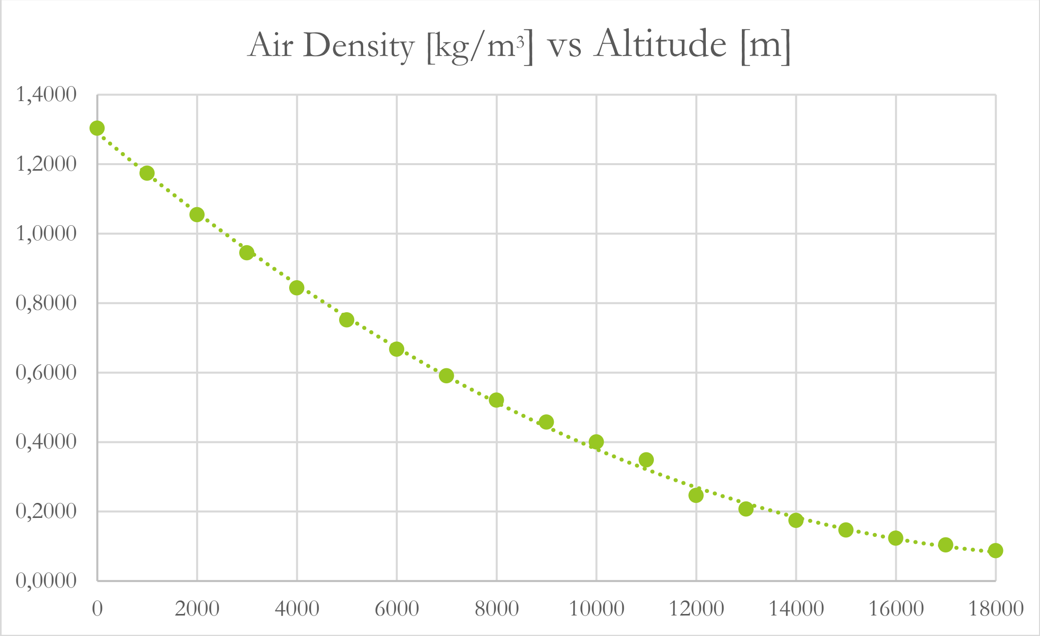
- **Gravity:** The force between 2 bodies are weaker as the bodies are getting separated from each other, so when the UAV is climbing the force that makes the plane return to earth is less strong.
- **Temperature:** The temperature goes down while the aircraft is climbing until it arrives the tropopause, located at 11000-13000 m more or less, where the temperature keeps stable.
- **Pressure:** As there are less air mass above, the atmospheric pressure is less as the plane climb.
- **Density:** Taking the air as an ideal gas, is possible to relate the temperature and the pressure to the air mass and the volume it occupies, or in other words is possible to relate the pressure, the temperature and the density of the air.
- **Viscosity**: It goes down as the aircraft climb due to the decrement on the temperature.

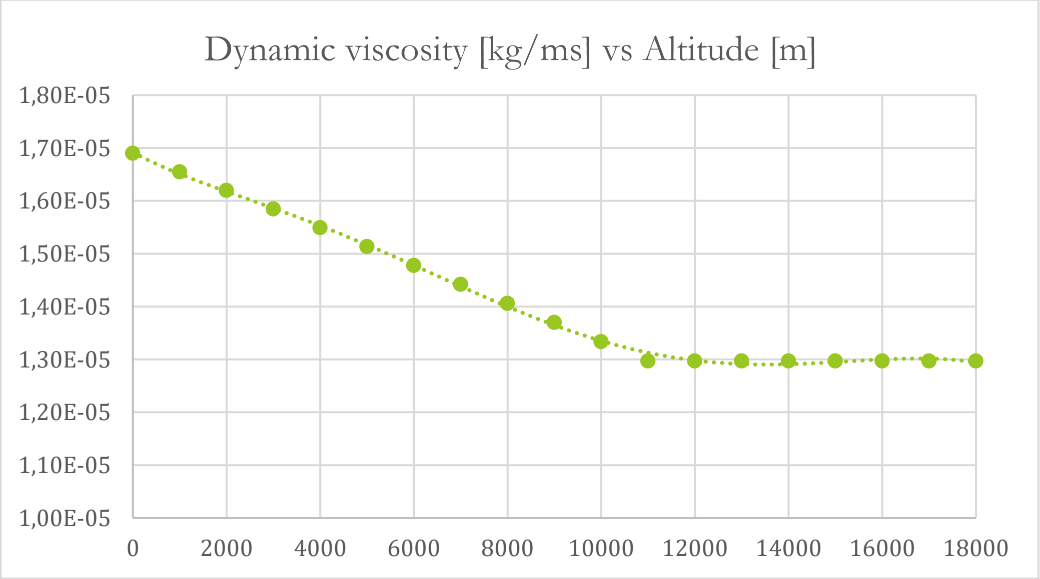
Thanks to previous calculation in the other components of the aircraft is possible to plot the different variations as follows:




T [K] vs Altitude [m]
R² = 0,9987
T [K]
290
270
250
230
210
190
170
150
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Altitude [m]


P [Pa] vs Altitude [m]
R² = 0,9997
1,2E+05
1,0E+05
8,0E+04
6,0E+04
4,0E+04
2,0E+04
0,0E+00
0
2000
4000
6000
8000
10000
12000
14000
16000
18000


Air Density [kg/m³] vs Altitude [m]
1,4000
1,2000
1,0000
0,8000
0,6000
0,4000
0,2000
0,0000
0
2000
4000
6000
8000
10000
12000
14000
16000
18000


Dynamic viscosity [kg/ms] vs Altitude [m]
1,80E-05
1,70E-05
1,60E-05
1,50E-05
1,40E-05
1,30E-05
1,20E-05
1,10E-05
1,00E-05
0
2000
4000
6000
8000
10000
12000
14000
16000
18000

2. Tail design

As is showed before, the tail has 2 main surfaces, horizontal and vertical. The steps for design them are different so the following lines describes how to design them for the solar powered UAV-HALE in this document, the decisions selected and the advantages and disadvantages from each decision.

2.1. Horizontal tail design

The main phases to design a vertical tail or a horizontal tail are different but the first step for both are the same.

First is required to select the main requirements for our tail should satisfied for our aircraft. The list of design requirements that must be considered and satisfied in the selection of tail configurations for an UAV-HALE is as follows [29]:

1. Longitudinal trim.

2. Directional trim.

3. Lateral trim.

4. Longitudinal stability.

5. Directional stability.

6. Lateral stability.

7. Manufacturability and controllability.

8. Operational requirements.

9. Airworthiness (e.g. safety, tail stall, and deep stall).

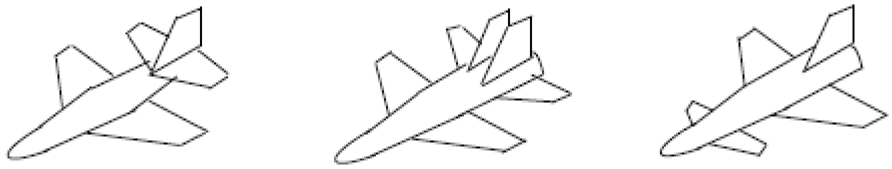
10. Survivability (e.g. spin recovery).

11. Cost.

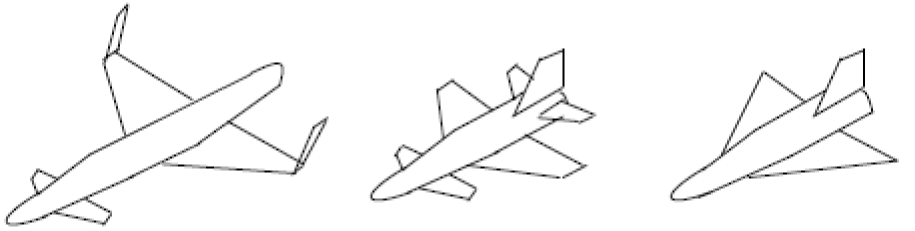
12. Competitiveness (Or economically feasible).

13. Size limits.

The tail configurations that satisfied the general requirements are like follow:



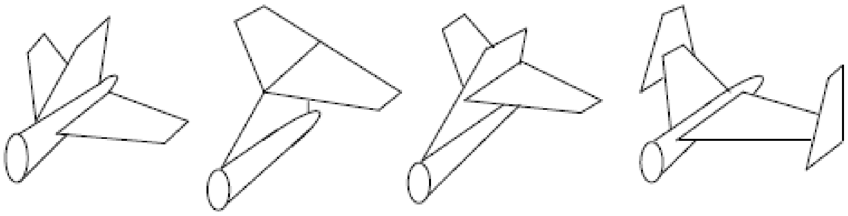
1. Aft tail and one aft vertical tail 2. Aft tail and two aft vertical tails 3. Canard and aft vertical tail



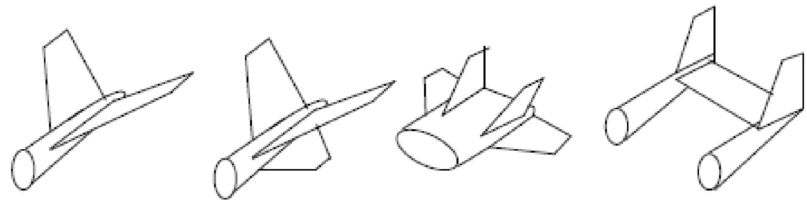
4. Canard and two wing vertical tail 5. Triplane 6. Delta wing with one vertical tail

Figure 2.1.-Aircraft tail basic tail configuration [29].

Due to simplicity, effectiveness and cost, an aft tail and one vertical tail configuration is selected for our UAV. Is important to denote that, for the same requirements, not only one vertical configuration satisfied the requirements so the tail configuration depends mainly on designer's choice.



1. Conventional *2. T-tail* *3. Cruciform* *4. H-tail*



5. V-tail *6. Y-tail* *7. Twin vertical tail* *8. Boom mounted*

Figure 2.2.- AFT configurations [29].

Once the tail configuration has been chosen as aft, is needed to select an aft configuration. This tail configurations are as follow:

A T-tail configuration is selected for our UAV due to the advantages that this configuration provides. In the searching for the most stable aircraft this configuration is out of the regions the wing creates as wing wake, wing downwash, wing vortices, and motor turbulence flow. This make to the horizontal tail have more efficiency and safer structure, that mean a smaller horizontal area and less tail vibration and buffet. Whit this configuration the vertical tail is out of the horizontal tail wing wake region and out of end-plate effect then it results in smaller vertical area too.

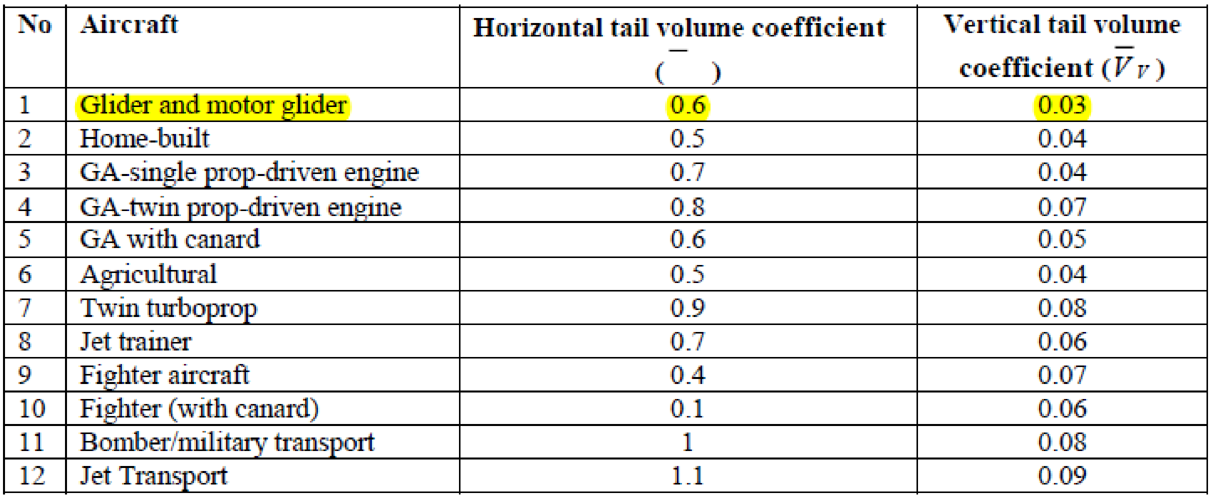
In the other hand, there 2 important disadvantages. These disadvantages are: heavier vertical tail since it should have the required structure to support the horizontal tail and the elements to control the moving surfaces; the other drawback is the deep stall, this is a critical situation where the wing and the horizontal tail are stalled and the horizontal tail and the elevator have reduced their efficiency that make the plane lock in the deep stall with not possibility of go out of that situation. To avoid the deep stall in a T-tail configuration is needed to ensure a stable pitch at the initial stall; extend the horizontal tail span substantially beyond the motor; or/and employ a mechanism to enable full down elevator angles if a deep stall occurs to make able to take out the plane from that situation.

The following step is to calculate the optimum horizontal arm to trim the aircraft horizontal stabilization. The horizontal arm serves as the arm for the tail pitching moment about aircraft cg to maintain the longitudinal trim. The trim depends on 2 parameters, the arm and the horizontal surface; when the first raises the second must decrease and if the first decrease the second must rise. So, the calculation is to have the optimum arm with the optimum surface that do not generate so much drag and do not weight much. The formula to calculate it is the following one:

$$l_{opt} = K_c \sqrt{\frac{4\overline{C}S\overline{V}_H}{\pi D_f}}$$

Equation 2.1

Where K_c is a correction factor for the aft portion of the fuselage which tend to be 1 for our aircraft for have cylindrical-conical shape, $\bar{C}$ is the wing main chord, S is the wing surface, D_f is the maximum diameter of the fuselage and $\overline{V_H}$ is the horizontal volume coefficient which for a first approximation of the horizontal tail arm is needed to take it from the following table:



No	Aircraft	Horizontal tail volume coefficient ( )	Vertical tail volume coefficient ($\bar{V}_V$)
1	Glider and motor glider	0.6	0.03
2	Home-built	0.5	0.04
3	GA-single prop-driven engine	0.7	0.04
4	GA-twin prop-driven engine	0.8	0.07
5	GA with canard	0.6	0.05
6	Agricultural	0.5	0.04
7	Twin turboprop	0.9	0.08
8	Jet trainer	0.7	0.06
9	Fighter aircraft	0.4	0.07
10	Fighter (with canard)	0.1	0.06
11	Bomber/military transport	1	0.08
12	Jet Transport	1.1	0.09

Table 2.1.- Horizontal and vertical volume coefficient for different aircrafts [29].

This UAV is similar to a motor glider then a value of 0.6 is chosen for the horizontal tail volume coefficient. The result of this operation gives 6.19 m in the first iteration but there are some longitudinal size requirements and doing some iterations with the body project and its requirements the final value was fixed on 5.98m; that maybe makes the tail heavier and the surface bigger and it makes the plane less manageable or quick in the moves, anyway is the optimum arm.

The following step is to calculate the horizontal platform by the following equation:

$$\bar{V}_H = \frac{l\,S_h}{S\,\bar{C}} \rightarrow S_h = \frac{S\,\bar{C}\,\bar{V}_H}{l}$$

Equation 2.2

And the wing-fuselage pitching coefficient that provides a measure of how feasible the aircraft to climb or go down:

$$C_{m_{owf}} = C_{m_{af}} \frac{AR\cos^2(\Lambda)}{AR + 2\cos(\Lambda)} + 0.01\alpha_t$$

Equation 2.3

Where $C_{m_{af}}$ is the wing airfoil section pitching moment coefficient, AR the wing aspect ratio, Λ the wing sweep angle and α_{twist} is the wing twist angle.

The values obtained for these parameters are S_h = 5.64 m^2 and C_{mwf} = -0.09 which means that the aircraft on its own goes down.

And is needed to calculate the wing-fuselage lift cruise coefficient as:

$$C_L = \frac{2W_{avg}}{\rho V_C^2 S}$$

Equation 2.4

The result for this parameter is C_L = 0.65.

With these parameters is able to calculate the desired lift coefficient for the horizontal tail as follow:

$$C_{m_{owf}} + C_L(h - h_o) - \eta_h \overline{V}_H C_{L_h} = 0$$

Equation 2.5

That result in a value of C_{Lh} = -0.33 and a maximum lift coefficient for the horizontal tail of $C_{Lh\ max}$ = 0.91.

By the result in this equation we can decide the horizontal tail airfoil. Is decided to select a symmetrical N.A.C.A. airfoil so the following graph can help about the selection of the correct airfoil:

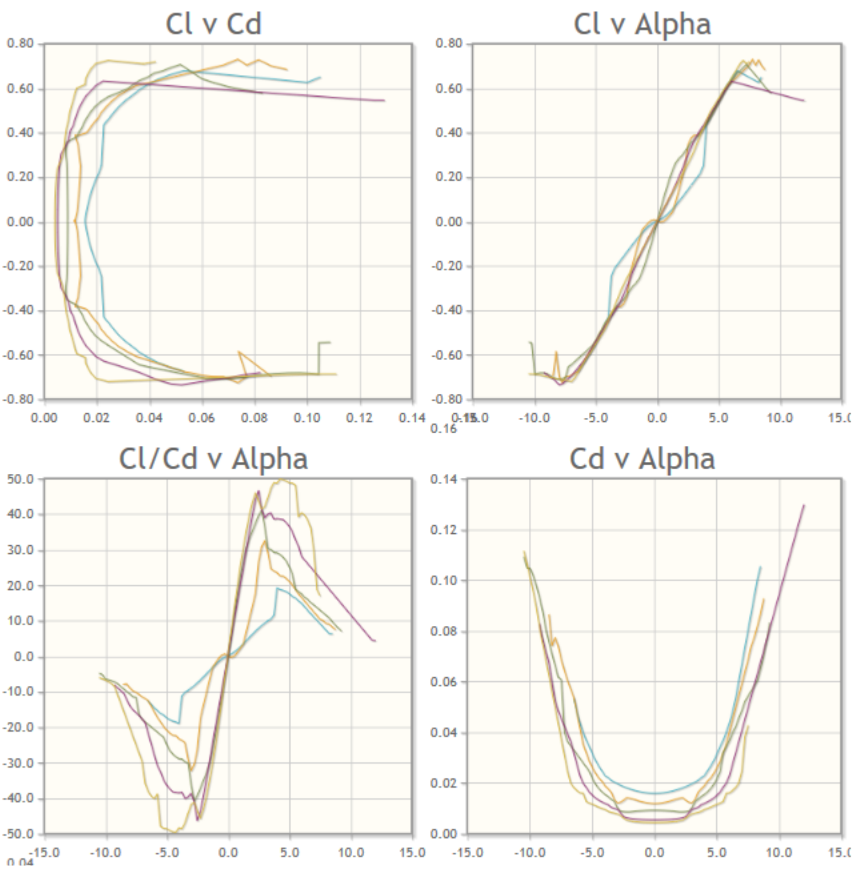


Figure 2.3.- Airfoil Graphics [39].

With the parameters obtained before, is decided to select the N.A.C.A. 64-008A with a thickness about 8% being a symmetric airfoil, so, with no angle of attack it would generate zero lift. This airfoil has the following parameters:

This graphics gives important information about the airfoil as the airfoil lift curve slope which is 6.3 rad^{-1}. A symmetric airfoil is perfect for a horizontal airfoil since changing the shape with the elevator It can generate lift force upwards or downwards depending in the real-time requirements.

Once the airfoil is selected is needed to choose the following parameters: Sweep and dihedral angle, which in this case, for this aircraft I would be 0 deg. for both due to simplicity and not need to include this kind of angles in the horizontal tail. Tail aspect ratio which it would be two thirds of the wing aspect ratio and the taper ratio which is chosen to be the same as the wing taper ratio and it is 0.75.

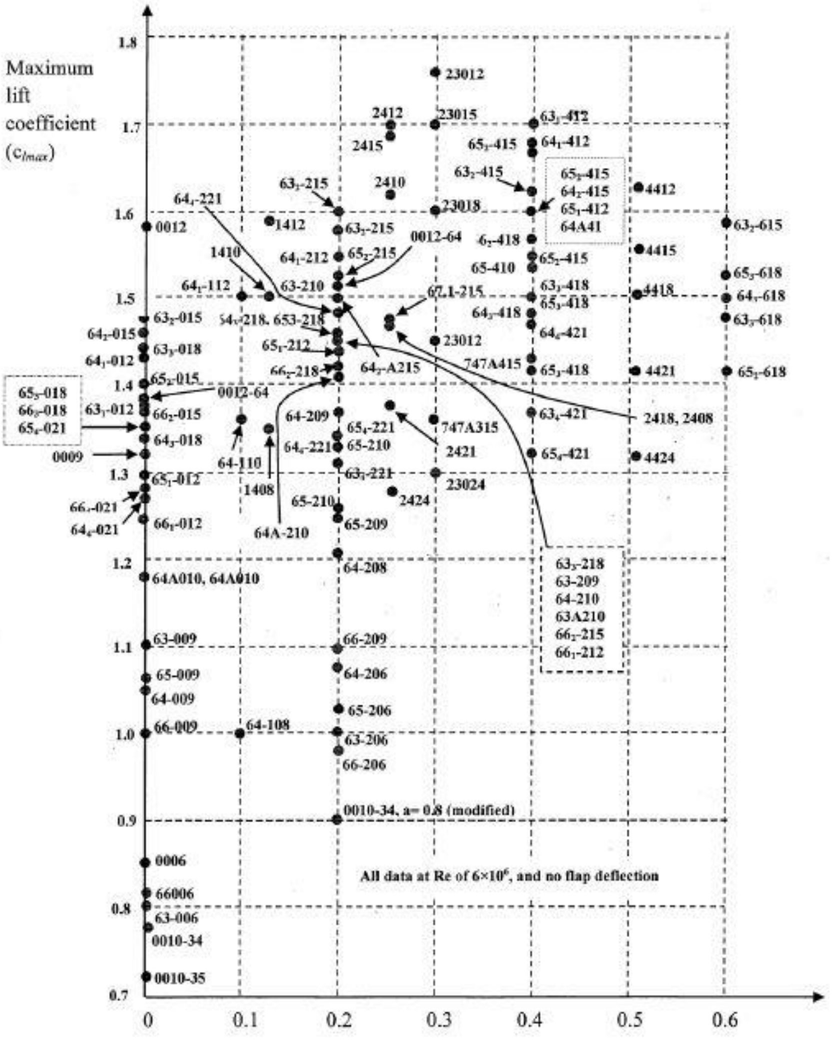


Figure 2.4.- N.A.C.A. airfoils [29].

With the all the parameters of the horizontal tail could be calculated the horizontal tail lift curve slope which will help to calculate the needed fix angle for the horizontal tail. In this case, the lift curve slope result in 5.37 rad^{-1}.

Knowing the cruise parameters can be calculated the angle of attack of the horizontal airfoil during the cruise operation due this part of the flight is the main part. Furthermore, in this case, being a T-tail, and being out of the wing downwash region, this angle will be the fix angle too. For this aircraft, the value would be -0.06 deg. The way to calculate it is by this equation:

$$C_{L_{\alpha_h}} = \frac{C_{L_h}}{\alpha_h} \Rightarrow \alpha_h = \frac{C_{L_h}}{C_{L_{\alpha_h}}}$$

Equation 2.6

It is usual that the longitudinal trim required a negative angle at the horizontal tail, so is possible to see that the parameters that are appearing have sense. Nevertheless, this valor is not the result of just one operation, is the result of an iteration until the lift coefficient resulting of calculate the result backwards is similar to the desired one.

The final step to determine in the main horizontal surface are the geometrical parameters, to calculate them is necessary to resolve a non-linear system of 4 equations with 4 roots:

$$AR_h = \frac{b_h}{\overline{C}_h}$$

Equation 2.10

$$\lambda_h = \frac{C_{h_{tip}}}{C_{h_{root}}}$$

Equation 2.9

$$\overline{C}_h = \frac{2}{3} C_{h_{root}} \left(\frac{1 + \lambda_h + \lambda_h^{\ 2}}{1 + \lambda_h} \right)$$

Equation 2.7

$$S_h = b_h \cdot \overline{C}_h$$

Equation 2.8

Solving this system with a mathematical program the following value are reached: the horizontal wing span should be 8.09 m long; the main chords is 0.70 m while the chords at the root is 0.79 m and at the tip is 0.59 m long.

What remains to be done in this surface is to check if the horizontal static stability and the horizontal wing optimization. To perform the first one the result of the following operation should be negative:

$$C_{m_\alpha} = C_{L_{\alpha_{wf}}}\left(h - h_o\right) - C_{L_{\alpha_h}} \eta_h \frac{S_h}{S}\left(\frac{l}{\bar{C}} - h\right)\left(1 - \frac{d\varepsilon}{d\alpha}\right)$$

Equation 2.11

In the present case, the resulting value is -3.29 that means that the aircraft is strongly stable at cruise operation. Must be mentioned that in more advance design stage, with other aircraft parameters obtained such inertias or aerodynamic derivates, it would be necessary to perform a dynamic stability study based on one dumped oscillatory mode and two exponentials models to control the *Dutch Roll mode*, the *Rolling mode* and the *Spiral mode*. For this very early stage at the design process and with such raw objective is obviate this study and assumed as this model is dynamic stable as it is static stable.

The optimization at the initial values from the other parts has been done meanwhile the calculations has been resolved. To do some better optimization about all the parts is necessary an iterative process between all the parts and years of work so, once again, in this early stage of the process there is no point to do something like that.

In the case that some of the requirements are not satisfied, is necessary to go backwards in earlier steps of the design and change some parameters until the requirements are satisfied.

2.2. Vertical tail design

As seen in the previous headland once the tail configuration is chosen, is necessary to select the vertical tail volume coefficient, which for this UAV is selected to be 0.03 in this early study based in other aircrafts, as well, due to the same reason, the vertical optimum arm is designated to be the same as the horizontal optimum arm.

Once that values are known is easy to calculate the necessary vertical tail surface:

$$S_V = \frac{b \cdot S \cdot \overline{V}_V}{l_V}$$

Equation 2.12

Which result for the aircraft in this project is 4.90 m^2 which means a really big vertical tail but is normal if the tail arm is reduced from the optimal one due to longitudinal constrains, so for the same spin with less arm is need a greater force supply with a greater surface.

The following parameters for an early concept of an aircraft are based on other similar planes. There is no information about HALE or solar-powered aircrafts by this reason the parameters are selected similar to gliders, light air-crafting and aircrafts that prioritize management than stability. Then the values acquired are as following:

Same airfoil section as the horizontal tail for simplicity since the horizontal airfoil is symmetrical and such that is required for a symmetrical aircraft about the xz plane due the plane is already trimmed and it do not need any lateral force. The vertical lift is needed in case of non-symmetrical aircraft or twin vertical tails used on stealth air-crafting.

Vertical aspect ratio $AR_v = 1.33$. The value of the vertical aspect ratio should be high to improve the directional control and reduce the vertical chord needed, but a high vertical aspect ratio for a T-tail derives in structural problems and heavier tail, also deteriorate the lateral control due to the inertia in the y axis is greater. High value makes the aircraft longitudinally unstable due to the greater weight origin on the aircraft a nose-up pitching. If the aircraft has a T-tail configuration, the horizontal tail location and efficiency are functions of vertical tail aspect ratio. Then, if the deep stall is critical, the vertical aspect ratio must be large enough to keep the horizontal tail out of the wing wake when the wing stalls. Finally, as greater the aspect ratio is, better is the aerodynamic efficiency and better is the dictional stability due to bigger yawing arm. For a starting point and based on similar light aircrafts with T-tail configuration the value above is selected.

Vertical taper ratio $\lambda_v = 0.9$. The main purpose to have a bigger chord at the root respect the tip is to have a more stable structure reducing the bending stress at the root and this allow the vertical tail to have sweep angle, but the things that brings are mainly bad parameters; an increment in the taper ratio reduce the directional control due to the reduction of the yawing moment arm and, also, reduces the lateral stability.

Vertical sweep angle Λ_v = 10º. When the sweep angle is increased the directional control of the aircraft is improved but the directional stability is deteriorated and is decided to have a bit of more control of the aircraft because there are just two control surfaces, even when the stability is the primary factor. The sweep angle in a T-tail configuration improves the longitudinal stability and control thanks to an increase of the horizontal tail moment arm.

The incidence angle and the dihedral angle are both 0º because this UAV have a symmetrical airfoil with just one vertical tail configuration that do not allow the vertical tail to have any lift force at cruise operations for do not compromise the directional stability.

Once these parameters are chosen, the following step is to calculate four geometrical parameters at the same time to enable the construction. These parameters are calculated as following:

$$AR_V = \frac{b_V}{\overline{C_V}} = \frac{b_V^2}{S_V}$$

Equation 2.14

$$\lambda_V = \frac{C_{V_{tip}}}{C_{V_{root}}}$$

Equation 2.13

$$\overline{C_V} = \frac{2}{3} C_{V_{root}} \left(\frac{1 + \lambda_V + \lambda_V{}^2}{1 + \lambda_V} \right)$$

Equation 2.15

$$S_V = b_V \cdot \overline{C_V}$$

Equation 2.16

With the values of this parameters it can be designed the vertical tail. Solving these equations yields the following results: vertical tail spam (b_V): 2.55 m; Vertical Main Aerodynamic Chord ($\overline{C_v}$): 1.92 m; Root chord (C_{VRoot}): 2.02 m; Tip chord (C_{VTip}): 1.82m. This shows that a big vertical tail is needed as we show with the area, and we can ascertain that it is not a rectangular wing.

As in the horizontal tail, the last step in the vertical tail is to check the lateral stability in case it generates lift forces that can untrimmed the lateral stability of the aircraft; and to optimize the surface and the structure of the vertical tail.

Also, as was presented in the horizontal tail design explanation, this is a very early stage of aircraft design and this is the result of just few iterations with the other parts. A better improvement is possible changing the values chosen at the beginning and obtaining the best with try and failure optimization.

As well, in the case that some of the requirements are not satisfied, is necessary to go backwards in earlier steps of the vertical tail design, or even wing or fuselage design, and change some parameters until the requirements are satisfied.

2.3. Tail control surfaces

2.3.1. Elevator design

With the basic horizontal tail geometry known is possible to start the concept of the elevator design. Due to the needed of the aircraft to climb or to dive or even to maintain the longitudinal stability this surface is needed. Thus, the elevator is the primary control surface and it is considered as the pitch control device.

There are two types of elevator design. One in which there are a trailing edge part of the horizontal tail deflects, and other where the whole horizontal tail turn and deflect giving a different attack angle and changing the lift force generated by the airfoil.

As well, there are two required responses or requirements to the deflection for this type of aircrafts: The motor power or torque. This tiny motor would make a torque and by a gearbox the torque will be incremented as needed. The other requirement is the time of response, in other words, the deflection velocity, which means that the quickest the earlier the stability or the desired conditions are reached. This two responses are opposed and the power condition is primary for this type of aircraft with low cruise speed due the constrains will not change fast enough to need that speed in the deflection of the aircraft.

Is necessary to denote in this part that, as a convention, the up deflection of the elevator is denoted as negative angle while the down deflection is denote with a positive angle. This is this way due to a negative elevator deflection create a negative horizontal tail lift and vice versa.

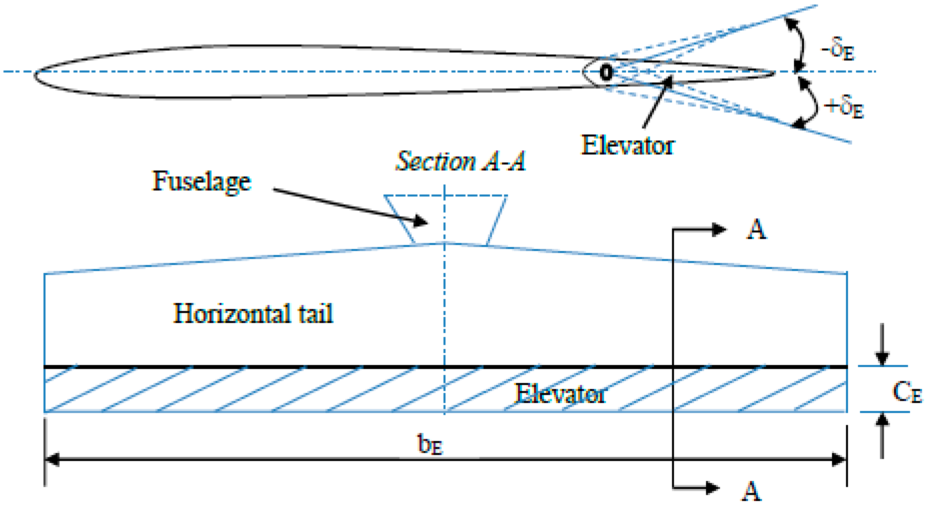


Figure 2.5.- Horizontal tail and elevator geometry [29].

The geometrical parameters needed to be determined for this part are the followings ones:

- Elevator chord to tail chord ratio (C_E/C_h).
- Elevator span to tail span ratio (b_E/b_h).
- Maximum up elevator deflection ($-\delta_{Emax}$).
- Maximum down elevator deflection ($+\delta_{Emax}$).
- Aerodynamic balance of the elevator.
- Mass balance of the elevator.

The first four parameters are related and when one of them are increased, the other parameters change. But each of them have unique constrains and for example the elevator maximum deflection should be less than the value that causes flow separation and, that way, making the horizontal tail to stall.

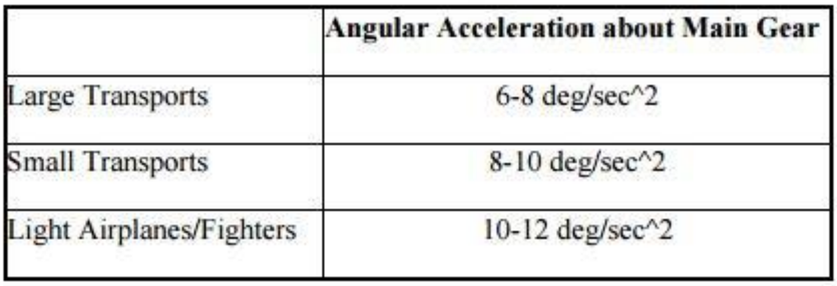
For an early concept is chosen that the horizontal tail and the elevator have the same span, that gives the design more simplicity both in elevator calculations and in the structure design. So, the first parameter determined is elevator span to tail span ratio $b_E/b_h=1$.

Also, due to different researches, is known that, about a 20-25 degrees of deflection, the flow around the horizontal tail starts to occur and thus, the elevator would lose its effectiveness. Close to this point, any flow perturbation can make the flow separation to become critical and make the horizontal tail to stall. To prevent this situation is recommended to consider the elevator maximum deflection to be less than 25 degrees in both ways and if it results more than this deflection, to increase the elevator area.

Furthermore, if the required area or chord for the elevator is more than the 50% of the total horizontal chord is recommended an all moving horizontal tail.

Is necessary to say, as well, the most critical flight condition for pitch control is when the aircraft is flying slowly due to the elevator effectiveness is very low. When the aircraft goes at these low speeds is at take-off and landing operations and between of them, the taking off is much harder than the landing control.

With all these statements, the design can start and as first step, is needed to select the suitable pitch angular acceleration based on similar aircrafts:



	Angular Acceleration about Main Gear
Large Transports	6-8 deg/sec^2
Small Transports	8-10 deg/sec^2
Light Airplanes/Fighters	10-12 deg/sec^2

Table 2.2.-Angular Acceleration about main gear for different types of aircrafts.

Looking at the table above, a value of 11 deg/sec^2 is tentatively selected.

The next step is to calculate the wing-fuselage lift and plane drag. These parameters are calculated in the *Design of the wing for UAV-HALE,* but they are calculated separately in this text and comparing the results to certain both are correct.

What follow is to calculate the linear acceleration during the take-off rotation using the following equations; first one is the ground friction and the second the line acceleration:

$$F_f = \mu(W - L_{TO});$$ *Equation 2.17*

$$a = \frac{T - D_{TO} - F_R}{m};$$ *Equation 2.18*

Where µ is the ground friction and for roadway is selected a value of 0.04. The linear acceleration result to be 3.4 m/s.

The following step is to calculate the contributing pitching moments in take-off rotation control. This moments are: aircraft weight moment (M_W), aircraft drag moment (M_D), engine thrust moment (M_T), wing-fuselage lift moment (M_{Lwf}), wing-fuselage aerodynamic pitching moment (M_{ACwf}), horizontal tail lift moment (M_{Lh}), and linear acceleration moment (M_a). The equations for those moments are:

$$M_W = W\left(x_{mg} - x_{cg}\right)$$

Equation 2.19

$$M_D = D\left(z_D - z_{mg}\right)$$

Equation 2.23

$$M_T = T\left(z_T - z_{mg}\right)$$

Equation 2.24

$$M_{L_{wf}} = L_{wf}\left(x_{mg} - x_{ac_{wf}}\right)$$

Equation 2.21

$$M_{L_h} = L_h\left(x_{ac_h} - x_{mg}\right)$$

Equation 2.22

$$M_a = ma\left(z_{cg} - z_{mg}\right)$$

Equation 2.20

Some of these moments helps the plane to climb and other ones make the plane to fall so, with the elevator we should fight against those moments. This is represented by:

$$L_h = \frac{L_{wf}\left(x_{mg} - x_{ac_{wf}}\right) + M_{ac_{wf}} + ma\left(z_{cg} - z_{mg}\right) - W\left(x_{mg} - x_{cg}\right) + D\left(z_D - z_{mg}\right) - T\left(z_T - z_{mg}\right) - I_{yy_{mg}}\ddot{\theta}}{x_{ac_h} - x_{mg}}$$

Equation 2.25

Where the I_{yy} inertia is needed to be estimated. This estimation is as follows:

$$I_{xx} = b^2 W(\bar{R}_x)^2/4g$$

Equation 2.27

$$I_{yy} = L^2 W(\bar{R}_y)^2/4g$$

Equation 2.28

$$I_{zz} = e^2 W(\bar{R}_z)^2/4g$$

Equation 2.26

Is just needed the I_{yy} estimation where L is the aircraft length, W the aircraft weight and g the gravity acceleration. Ry is an estimation parameter which is selected with the following table:

TYPE OF AIRCRAFT -	ROLL,Rx	PITCH,Ry	YAW,Rz
Single Low Wing	.248	.338	.393
Single High Wing(C182R)	.242	.397	.393
Light Twin	.373	.269	.461
Biz Jet, Light	.293	.312	.420
Biz Jet, Heavy	.370	.356	.503
Twin Turbo- Prop	.235	.363	.416
Jet Airliner 4 eng.	.322	.339	.464
Jet Airliner 3 aft eng	.249	.375	.452
Jet Airliner 2 eng wing	.246	.382	.456
Prop Airliner 4 eng	.322	.324	.456
Prop Airliner 2 eng	.308	.345	.497
Jet Fighter	.266	.346	.400
Prop Fighter 1 eng	.268	.360	.420
Prop Fighter 2 eng	.330	.299	.447
Prop Bomber 2 eng	.270	.320	.410
Prop Bomber 4 eng	.316	.320	.376
Concorde Delta Wing	.253	.380	.390

Table 2.3.- Estimation parameters for Inertia estimation

Where the value of 0.397 is selected due to our aircraft is a single high wing aircraft. Is noticed to know that the result of this formula is on slug·ft^2 where 1 slug·ft^2 = 0.13826 kg·m·s^2.

So, the desired tail lift coefficient should be big enough to satisfy the needed pitch moment:

$$C_{L_h} = \frac{2L_h}{\rho V_R^2 S_h}$$

Equation 2.29

The result for this aircraft is -0.32 which means that a down force is needed.

The maximum up deflection is for the take-off operation meanwhile the maximum down deflection is for the longitudinal stability trim.

The elevator design for the take-off rotation is crucial and is needed to determinate the tail chord to elevator chord ratio with is calculated based on the parameter τ_e which is 0.28; so as shows the following graphic:

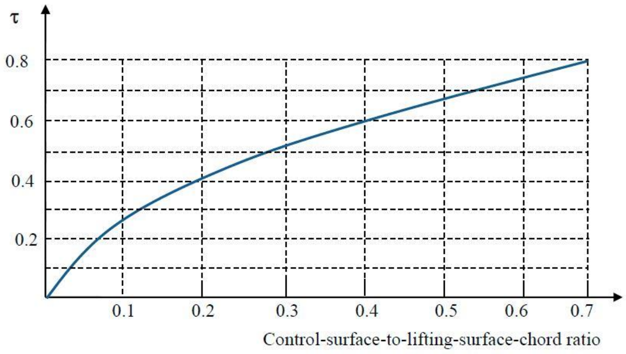
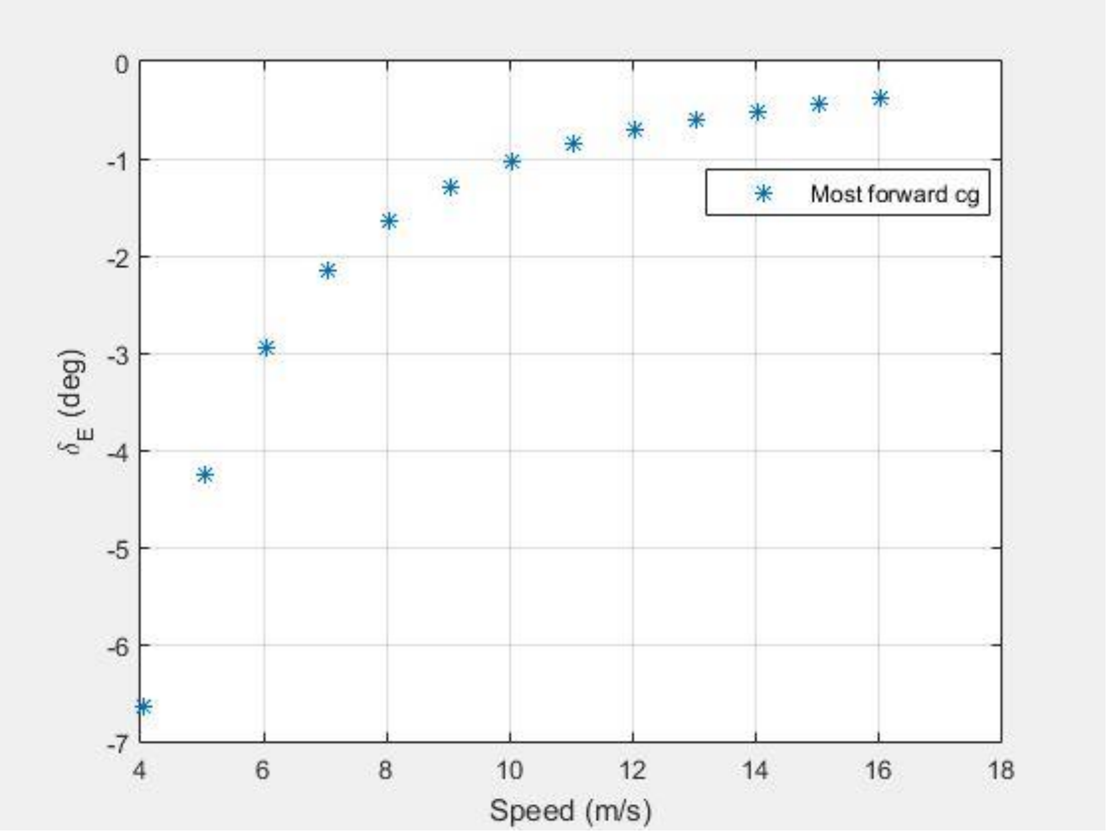


Figure 2.6.- control surface to control chord ratio

This figure shows that for a value of 0.28 the result for the TC-EC is 0.1.

The following parameters are acquired as the longitudinal trim on cruise flight denote. The pitching moments for the cruise flight are calculated as the calculations for the pitching moments for the take-off operations due to this aircraft's gravity center do not change during the flight.



Graphic 2.1.-Deflection need - Aircraft Speed.

Due to an optimal design, the perfect situation is where no deflection is needed at cruise flight. Due to this plane is designed for this proposal, as the following graph shows, it has been achieved:

However, in any case, a calculation for the most adverse case is done through the calculation of some longitudinal stability derivates and the equation 2.30.

The result for this operation is 17.65º needed which means that is not needed a full wing deflector or to change the tail arm.

$$\delta_E = -\frac{\left(\frac{T \cdot z_T}{q \cdot S \cdot C} + C_{m_o}\right) C_{L_\alpha} + \left(C_{L_1} - C_{L_o}\right) C_{m_\alpha}}{C_{L_\alpha} C_{m_{\delta_E}} - C_{m_\alpha} C_{L_{\delta_E}}}$$

Equation 2.30

It becomes necessary to say that if the knowledge about the process to get that value and the aircraft longitudinal stability derivates is required, is encouraged that follow the steps and the equations on the elevator m file program for MATLAB, due to this process is long and pointless for this section.

Finally, the last steps for the elevator calculation is the geometrical parameters defined by:

$$\frac{C_e}{C_h} = 0.1$$

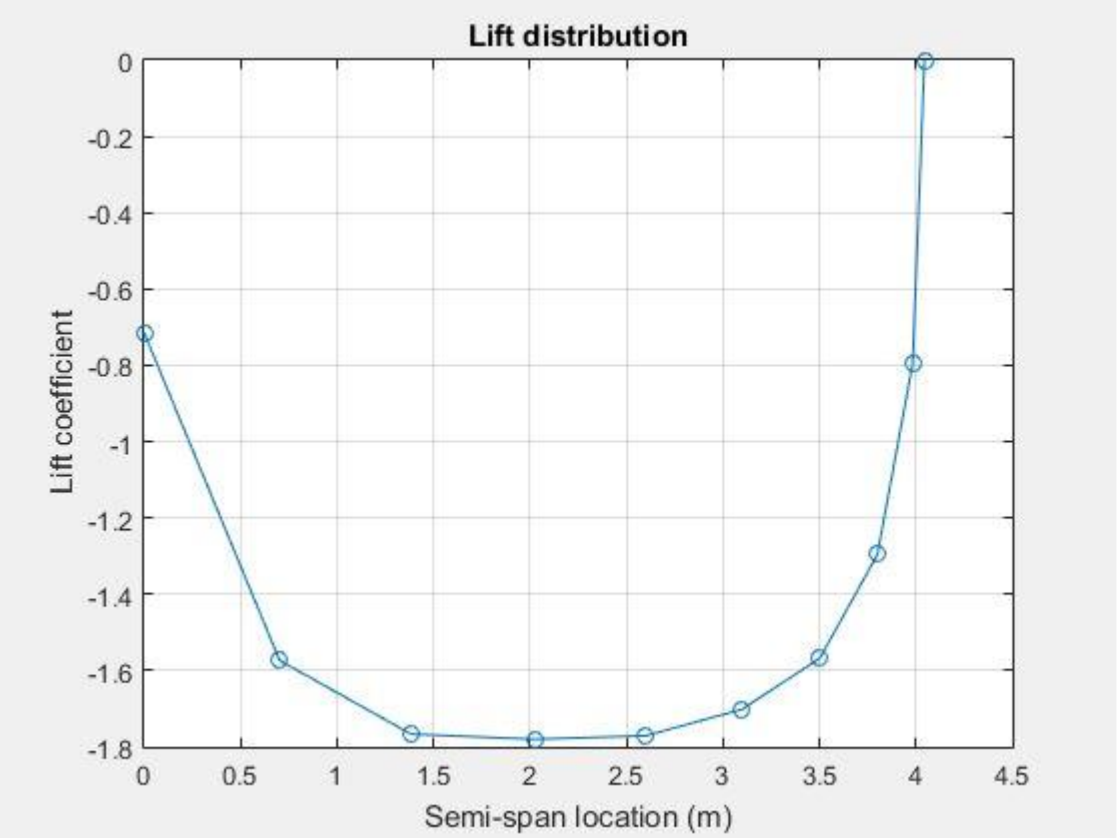
Equation 2.31

$$S_E = b_E C_E$$

Equation 2.32

Which results on C_e = 0.07m and S_e = 0.56m^2, what means that the 10% of the aircraft is elevator. It seems like a small elevator but it is because the horizontal tail is not that big.

The last thing to show is the horizontal tail lift distribution which shows that it has a close elliptical lift distribution which are the most wanted or the desired lift distributions due to the root handle more moment and force than the tip.

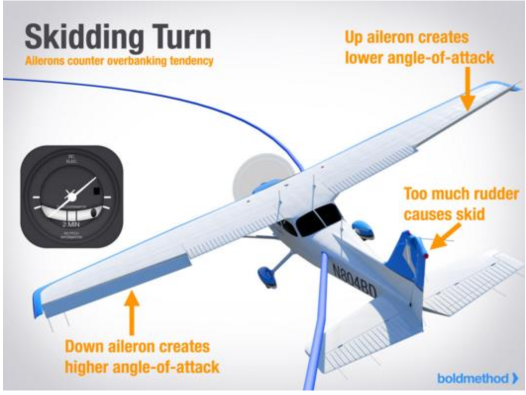


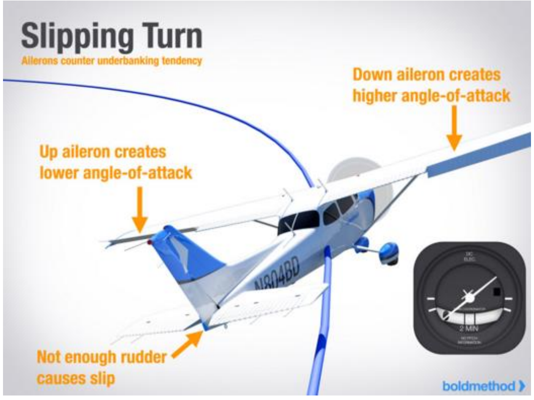
Graphic 2.2.- Lift distribution for the UAV horizontal tail.

What happen for this aircraft at the root is the effect of the vertical tail effect in the middle.

2.3.2. Rudder design

The last device to design is the rudder. This control surface is the responsible for the aircraft directional control. It is located on the railing edge of the vertical tail. When the rudder is deflected, a lift force is created what origins a yawing moment about the gravity center of the aircraft. The two fundamental roles of rudder are directional control and directional trim but, for and this aircraft that do not have alerions, the directional control is critical due to it cannot do a baking or a combination turn. The positive point is without this kind of combination turn the aircraft is less likely to sideslip. But the negative is that the directional control is poorer and lies all of it on this surface. This means that the required rotation would be very more slowly. Is supposed that the baking trim is fixed. As the elevator, the rudder control power must be sufficient to guarantee both requirements.





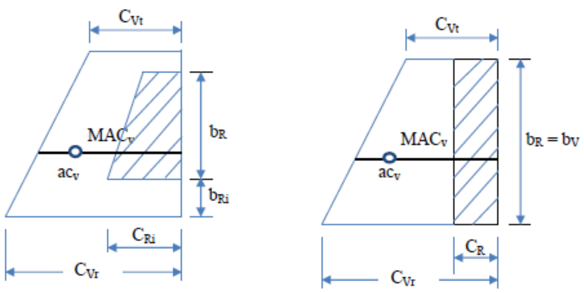


Figure 2.8.- Vertical tail and rudder geometry for a swept rudder (left) and for a rectangular rudder (right) [29].

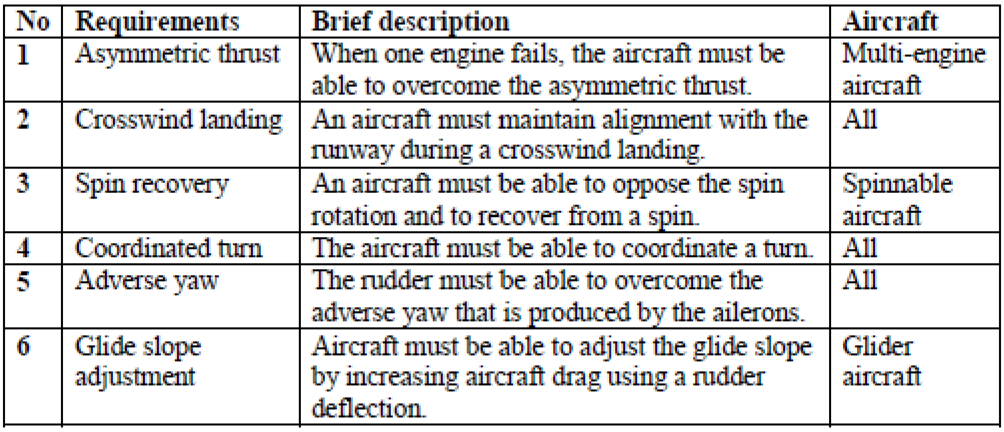
Like the elevator, the span of the rudder can be as long as the tail or less than it but this time the full moving vertical tail is not allowed by the time that this tail is a T-tail and is needed to own the required structure to hold the horizontal tail. The main parameters for the rudder are rudder area (S_R), rudder chord (C_R), rudder span (b_R), maximum rudder deflection ($\pm\delta_{Rmax}$), location of in board edge of the rudder (b_{Ri}).

In a symmetrical aircraft with a zero-sideslip angle, and without aileron, the yawing moment is determined by multiplying the vertical tail lift by the vertical tail arm:

$$N_A = l_v \cdot L_V$$

Equation 2.34

In this section, the rudder design depends on what is the main requirement. These requirements are asymmetric thrust, crosswind landing, spin recovery, coordinated turn, adverse yaw and glide slope.



No	Requirements	Brief description	Aircraft
1	Asymmetric thrust	When one engine fails, the aircraft must be able to overcome the asymmetric thrust.	Multi-engine aircraft
2	Crosswind landing	An aircraft must maintain alignment with the runway during a crosswind landing.	All
3	Spin recovery	An aircraft must be able to oppose the spin rotation and to recover from a spin.	Spinnable aircraft
4	Coordinated turn	The aircraft must be able to coordinate a turn.	All
5	Adverse yaw	The rudder must be able to overcome the adverse yaw that is produced by the ailerons.	All
6	Glide slope adjustment	Aircraft must be able to adjust the glide slope by increasing aircraft drag using a rudder deflection.	Glider aircraft

Table 2.4.- Design requirements.

The rudder plays different roles depending in which is the main requirement. For the aircraft in this text, the 4th requirement is not contemplated. The main requirements Asymmetric thrust, crosswind landing and glide slope adjustment and if the rudder is strong enough for these requirements would secure to fix other parameters.

Due to this decision, the first thing to determinate is the aircraft approach speed and the aircraft total speed at landing. For this design, the air speed is selected to be 40 knots or 20 m/s, that is a typical value for a safety landing, and the total aircraft speed at landing would be 21.03 m/s.

The following step would be to calculate the aircraft moments around the gravity center approaching the aircraft lateral area and it aerodynamic center and after that balancing that moment with the vertical tail.

The side force the vertical tail must generate is 2059.19 N that is not a big force for the huge vertical tail that this UAV has.

As happened with the elevator, the following steps it to calculate the different aircraft lateral stability derivates which is a long process and pointless to relate it here; due to that is encourage for those readers that want to know such process to look at the Rudder program.

Finally, with all those calculations done is possible to enter in the following system of 2 equations with 2 unknowns:

$$\frac{1}{2}\rho V_T^2 Sb\left(C_{n_o}+C_{n_\beta}(\beta-\sigma)+C_{n_{\delta_R}}\delta_R\right)+F_w\cdot d_c\cos\sigma=0$$ Equation 2.35

$$\frac{1}{2}\rho V_W^2 S_S C_{D_y}=\frac{1}{2}\rho V_T^2 S\left(C_{y_o}+C_{y_\beta}(\beta-\sigma)+C_{y_{\delta_R}}\delta_R\right)$$ Equation 2.36

Where δ_R is the rudder deflection.

Solving these equations is obtained a maximum deflection needed of 6.15º, which is totally allowable for this vertical tail structure.

Due to check the safety for the other requirements the following step is to check if the deflection obtained before is enough for meet those other requirements.

The deflection is enough for the asymmetric thrust and for the glide slope adjustment so any other deflection calculation is required

As in the other sections, the final part is to calculate the rudder geometrical parameters.

$$\frac{C_R}{C_v}=0.4$$ Equation 2.38

$$S_R=b_R C_R$$ Equation 2.37

Which parameters result to be a chord of 0.77m long and a surface of 1.96m^2. This means that the rudder is the 39.18% of the vertical tail. Which such surface is needed a very small deflection angle which means that is possible to optimize the rudder surface for future work; any way this small deflection is good due to generate less drag, less power at the motor is needed and there is no flow separation that can cause the tail to stall.

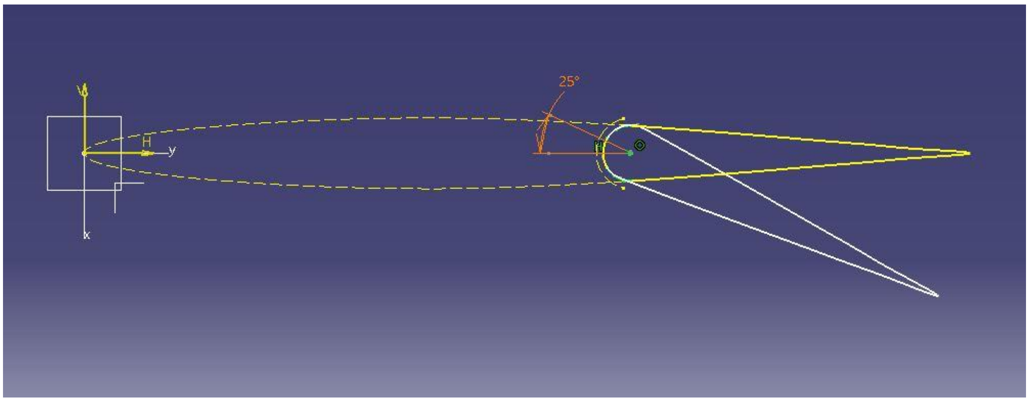


Figure 2.9.- Rudder deflection representation.

3. Operations, results and analysis

In this section are exposed the different calculus, the 3D design which result and the structure analysis.

3.1. Calculations (MATLAB programing)

Here is showed the various programs developing for the calculation of the parameters and the geometrical constrains.

3.1.1. Programs

Horizontal_Airfoiil.m

```
%    Horizontal Tail Airfoil Selection


function [] = Horizontal_Airfoil()
%Calculates de parameters for the horizontal tail airfoil selection


%Global parameters
global ARw
global Sh
global Clh
global Lopt
global h
global ho
global Sw
global Cmw
global p
global Cw
global vc
global vs
global bw
global Vv


%Variables


Vh = 0.6; %Vol. coefficient for the horizontal stabilizer.
Vv = 0.03; %Vol. coefficient for the vertical stabilizer.
p = 0.10439; %Aprox. air density at cruise altitude.
ho = 0.25; %non-dimensional wing-fuselage aerodynamic center.
```

```
nh = 1; %Tail efficiency of a T-tail.
vs = 4.04; %Stall speed calculated at Wing design (m/s).
vc = 16.7; %Cruise velocity parameter (m/s).


    %Needed variables from the wings to do the calculates
    Cw = input('Input the average chord of the wing: ');
    Sw = input('Input the surface of the wing (m^2): ');
    Df = input('Input the maximum diameter of the fuselage (m): ');
    Cmw = input('Input the wing pitch coefficient: ');
    ARw = input('Input the wing Aspect Ratio: ');
    SAw = input('Input the wing Sweep Angle (°): ');
    TAw = input('Input the wing Twist Angle (°): ');
    Wavg = input('Input the average aircraft weight during the flight (kg): ');
    Clw = input('Input the cruise Lift Coefficient of the wings (at the most unfavorable Re at cruising flight): ');
    Xcg = input('Input the location of the c.g. from the beginning of the wing (m): ');
    bw = input('input the wing span(m): ');


%Calculation of parameters
Lopt = sqrt((4*Vh*Sw*Cw)/(pi*Df)); %Optimum tail moment arm to minimize the aircraft drag and weight.
%Lopt = 5.5; %Changing the Lopt we change the rest of the parameters to improve the different parameters (3rd iteration).
Sh = ((Vh*Cw*Sw)/Lopt); %Calculate horizontal tail planform area.
Cmwf = (((Cmw*ARw*cos(SAw)^2)/(ARw+2*cos(SAw)))+0.01*TAw);%Calculate wing-fuselage aerodynamic pitching moment coefficient.
h = (Xcg/Cw); %non-dimensional aircraft center of gravity position.
Clh = ((Cmwf+Clw*(ho-h))/(nh*Vh)); %Calculate horizontal tail desired lift coefficient at cruise.
Clhm = ((2*Wavg)/(1.2*vs^2*Sh)); %Calculate the aircraft maximum tail lift coefficient.


%Print the parameters
disp ('1.- T-tail')
disp ('2.- aft')
```

```
disp ('3.- Vh = 0.6; Vv = 0.03 from tables')
fprintf(1,'4.- Lopt = %10.2f m \n',Lopt);
fprintf(1,'5.- Sh = %10.2f m^2 \n',Sh);
fprintf(1,'6.- Cmwf = %10.2f \n',Cmwf);
fprintf(1,'7.- Clw = %10.2f \n',Clw);
fprintf(1,'8.- Clh = %10.2f \n',Clh);
fprintf(1,'9.- Clhm = %10.2f \n',Clhm);

%Show the picture to Select the NACA Airfoil
Airfoil = imread('NacaAirfoilSelection.jpg');
figure('Name','NACA Airfoils','NumberTitle','off');
hold on
image(Airfoil);
end
```

Horizontal_Tail.m

```
%     Horizontal Tail

function [] = Horizontal_Tail()
%Calculates de parameters for the horizontal tail airfoil selection

%Variables
global ARw
global Sh
global Clh
global ARh
global h
global ho
global Sw
global Lopt
global Clah
global i_h
global Cla
global TRh
global a_h
global bh
global MACh

nh = 1; %Tail efficiency of a T-tail.



    %Warning box
        if ARw == true
        h = warndlg('Run Horizontal_Airfoil.m first');
        end

    %Needed variables from the wings to do the calculates
    TRh = input('Input the Taper Ratio of the wing: '); %In early design
the Tail TR is the same or aprox. the same as Wing TR.
    Cla = input('Input the Lift Curve Slope from the selected airfoil
(1/rad): ');
    a_w = input('Input the cruise wing attack angle(deg): ');

ARh = ((2/3)*ARw); %Aspect Ratio of the horizontal tail.
```

```
Clah = (Cla/(1+(Cla/(pi*ARh)))); %Lift Curve Slope for the horizontal tail
(2D).
a_h = Clh/Clah; %Angle of attack in cruise.

fun = @root2dh; %System of 2 nonlinear eq.
x0 = [5,5];
x = fsolve(fun,x0);
bh = x(1); %Tail Span
MACh = x(2); %Tail Main Aerodynamic Chord
Ch_root = ((MACh*3)/(2*((1+TRh+TRh^2)/(1+TRh)))); %Chord when the Tail is
close to the fuselage.
Ch_tip = (TRh*Ch_root); %Chord at the end of the tail.

        %With the angle of attack calculated is needed to know the real
tail lift coefficient
        %Applying the lifting line theory:
        Error = 10;
        cont = 1;
        N = 9; % (number of segments-1)
        alpha_0 = 0.000001; % zero-lift angle of attack (deg) (symmetric)
        alpha_twist = 0.0000001; %twist angle

      while Error > 0.001 %Bucle to obtain the desire angle of attack
      if cont == 0

       if CL_tail < Clh
            a_h = a_h-0.01;
       elseif CL_tail > Clh
            a_h = a_h+0.01;
       end


      end

        bh = sqrt(ARh*Sh); % tail span
        MAC = Sh/bh; % Mean Aerodynamic Chord
        Croot = (1.5*(1+TRh)*MAC)/(1+TRh+TRh^2); % root chord
        theta = pi/(2*N):pi/(2*N):pi/2;
        alpha = (a_h+alpha_twist):(-alpha_twist/(N-1)):(a_h); % segment's
angle of attack
        z = (bh/2)*cos(theta);
```

```
        c = Croot * (1 - (1-TRh)*cos(theta)); % Mean Aerodynamics chord at each segment
        mu = (c * Clah) / (4 * bh);
        LHS = (mu .* (alpha-alpha_0)) /57.3; % Left Hand Side
        % Solving N equations to find coefficients A(i):
        for i=1:N
            for j=1:N
            B(i,j) = (sin((2*j-1)*theta(i))*(1+(mu(i)*(2*j-1))/sin(theta(i))));
            end
        end
        A = (B\transpose(LHS));
        for i = 1:N
            sum1(i) = 0;
            sum2(i) = 0;
            for j = 1:N
               sum1(i) = (sum1(i)+(2*j-1)*A(j)*sin((2*j-1)*theta(i)));
               sum2(i) = (sum2(i)+A(j)*sin((2*j-1)*theta(i)));
            end
        end
        CL_tail = (pi*ARh*A(1));

        Error = (CL_tail/Cla)*100;
        cont = 0;
      end

      %Calculation of parameters

epsilon = (1+0.3*(a_w/57.3)); %Downwash angle.
i_h = a_h + epsilon - 0; % (0 = fuselage angle of attack at cruise) Horizontal tail incidence angle.



%Calculate the stability
Claw = ((0.3*pi*ARw)/2); %Approximate wing lift curve.

Cma = ((Claw*(h-ho))-(Clah*nh*(Sh/Sw)*((Lopt/MACh)-h)*(1-0.3))); %Must be negative to static horizontal stability
```

```
%Print the parameters
disp ('10.- Tail sweep = 0°; Dihedral angle = 0°')
fprintf(1,'11.- ARh = %10.2f; TRh = %10.2f  \n',ARh, TRh);
fprintf(1,'12.- Clah = %10.2f 1/rad \n',Clah); %Lift curve slope
fprintf(1,'13.- a_h = %10.2f ° \n',a_h); %attack angle
fprintf(1,'14.- epsilon = %10.2f ° \n',epsilon); %Downwash angle
fprintf(1,'15.- i_h = %10.2f ° \n',i_h); %incidence angle
fprintf(1,'16.- bh = %10.2f m; MACh = %10.2f m; Ch_root = %10.2f m; Ch_tip
= %10.2f m\n',bh,MACh,Ch_root,Ch_tip);
fprintf(1,'17.- Cma = %10.2f 1/rad; this must be negative to static
horizontal stability \n',Cma);

end
```

➔ Where root2dh.m is the following function:

```
function F = root2dh(x)
global Sh
global ARh


        F = [((x(1)*x(2)-Sh));
            (((x(1))/x(2))-ARh)];



end
```

Vertical_Tail.m

```
%       Vertical Tail

function [] = Vertical_Tail()
%Calculate de parameters for the vertical tail

%Global parameters
global Lopt
global Sw
global ARv
global Sv
global bv
global MACv

%Variables

Vh = 0.6; %Vol. coefficient for the horizontal stabilizer.
Vv = 0.03; %Vol. coefficient for the vertical stabilizer.
p = 0.10439; %Aprox. air density at cruise altitude.
ho = 0.25; %non-dimensional wing-fuselage aerodynamic center.
nh = 1; %Tail efficiency of a T-tail.
vs = 4.24; %Stall speed calculated at Wing design (m/s).
vc = 14; %Cruise velocity parameter (m/s).
ARv = 1.33; %Vertical aspect ratio.
TRv = 0.9; %Vertical taper ratio.
incidence_angle = 0; %Vertical incidence.
Sweep_angle = 10; %Vertical sweep.
Diedral_angle = 0; %Vertical Dihedral. (not allowed with one vertical tail).

 %Warning box
        if Sw == true
        h = warndlg('Run Horizontal_Airfoil.m first');
        end

    %Needed variables from the wings to do the calculates
    b = input('Input the wing span (m): ');

%Calculation of parameters
Sv = ((Sw*b*Vv)/Lopt); %Vertical Surface (m^2)
```

```
bv = (sqrt(ARv*Sv)); %Vertical span.
MACv = (bv/ARv); %Vertical main chord.
Cv_root = ((MACv*3*(1+TRv))/(2*(1+TRv+TRv^2)));
Cv_tip = (TRv*Cv_root);



%Print the parameters
disp ('1.- T-tail')
disp ('2.- aft')
disp ('3.- Vv = 0.03 from tables')
fprintf(1,'4.- Lopt = %10.2f m \n',Lopt);%For the design is supposed to be
the same as the horizontal one.
fprintf(1,'5.- Sv = %10.2f m^2 \n',Sv);
disp ('6.- Airfoil section selected for the Vertical Tail is NACA-64-
008')%Due to symmetric, no compress effects and good lift curve.
disp ('7.- The selected ARv = 1.33 based on other similar aircrafts')
disp ('8.- The selected TRv = 0.9 based on other similar aircrafts')
disp ('9.- The selected Incidence angle = 0° based on other similar
aircrafts')
disp ('10.- The selected Sweep angle = 10° based on other similar
aircrafts')
disp ('11.- The selected Dihedral angle = 0° based on other similar
aircrafts')
fprintf(1,'12.- bv = %10.2f m, MACv = %10.2f m, Cv_root = %10.2f m, Cv_tip
= %10.2f m  \n',bv,MACv,Cv_root,Cv_tip);



end
```

Elevator_Design.m

```
%                                Elevator Design


function [] = Elevator_Design()
%Provides the parameters to design de Elevator


%Global parameters
global ARw
global ARh
global Sh
global h
global ho
global Sw
global Cmw
global Cw
global vs
global Clah
global i_h
global Cla
global p
global vc
global bh
global Xfcg
global Tmax
global MACh
global TRh


%Variables
bebh = 1;
VR = (12*2*pi)/360; %Take off pitch angular acceleration for this kind of
aircrafts.(rad/s^2)
po = 1.21; %Average air density.
Tmax = 168.80; %Motor Thrust.
Zmg  = 0; %Landing gear high.
delta_up = (-20*2*pi)/360; %Maximum elevator deflection
alpha_hs = 10; %Horizontal airfoil stall angle (deg)



    %Needed variables from the wings to do the calculates
     Cdto = input('input the drag wing-fuselage coefficient at take-off:
');
```

```
     Clto = input('input the lift wing-fuselage coefficient at take-off: ');
     Xmg = input('input the distance from the nose to the main landing gear(m): ');
     Xfcg = input('input the distance from the nose to the most forward gravity center(m): ');
     Zd = input('input the altitude of the wings from the ground(m): ');
     Zt = input('input the altitude of the propeller from the ground(m): ');
     Xacwf = input('input the distance of the aerodynamic center of the wing from the nose(m): ');
     Zcg = input('input the altitude of gravity center from the ground(m): ');
     Xach = input('input the distance from the nose to the aerodynamic center of the horizontal tail(m): ');
     a_wto = input('input the take off attack angle(deg): ');
     Iyy = input('input the Inertia about y axis(kg*m^2): ');

%Calculation of parameters
Dto = 0.5*po*vs^2*Sw*Cdto; %Drag at take off
Lto = 0.5*po*vs^2*Sw*Clto; %Lift at take off
Cwf = 0.5*po*vs^2*Cmw*Sw*Cw; %Pitch wing-fuselage
FR = 0.04*(50*9.81 - Lto);
a = ((Tmax-Dto-FR)/50); %Acceleration at take off

    %Calculation of pitching moments
    Mw = -50*9.81*(Xmg-Xfcg);
    Md = Dto*(Zd-Zmg);
    Mt = -Tmax*(Zt-Zmg);
    Mlwf = Lto*(Xmg-Xacwf);
    Ma = 50*a*(Zcg-Zmg);

Lhto = ((Mlwf+Cwf+Ma+Mw+Md+Mt-Iyy*VR)/(Xach-Xmg)) ; %Desired horizontal tail lift at take off
Clhto = ((2*Lhto)/(po*vs^2*Sh)); %Desired tail lift coefficient

    %Calculation of the ideal angle of attack at take-off
    epsilon_o = ((2*Clhto)/(pi*ARw)); %Downwash effect.
    D_epsilon = ((2*Cla)/(pi*ARw)); %Downwash effect.
    epsilon = epsilon_o+(D_epsilon*(a_wto/57.3)); %Downwash angle.
    a_hto = a_wto+i_h-epsilon;
```

```
    Tao_e = abs((((a_hto/57.3)+(Clhto/Clah))/delta_up)); %angle of attack effectiveness of the elevator



%Print the parameters
disp ('1.- Take-off rotation. \n Longitudinal trim requirements. \n Low cost. \n Manufactural.')
disp ('2.- VR = 12 deg/seg^2 based on similar aircrafts.') %take-off pitch angular acceleration
disp ('3.- be/bh = 1 based on similar aircrafts.') %elevator-span-to-tail-span ratio
disp ('4.- delta_up = -20 °.') %elevator maximum deflection
fprintf(1,'5.- Drag-at-take-off = %10.2f N, Lift-at-take-off = %10.2f N, Pitch = %10.2f N*m \n',Dto,Lto,Cwf); %Forces
fprintf(1,'6.- a = %10.2f m/s^2 \n', a);
fprintf(1,'7.- Lhto = %10.2f N \n', Lhto);
fprintf(1,'8.- Clhto = %10.2f \n', Clhto);
fprintf(1,'9.- a_hto = %10.2f rad, Tao_e = %10.2f \n',a_hto,Tao_e);



%Show the picture to Select the NACA Airfoil
Airfoil = imread('Effectiveness to Cs-Ls area ratio.jpg');
figure('Name', 'Selection of the Ce/Ch ratio','NumberTitle','off');
hold on
image(Airfoil);



%%%%%%%%%%%%%%%%%%%%%%%%%%Second part of the program



CeCh = input('Select the correct number of the Elevator-chord-to-tail-chord ratio based on the picture and on the Tao_e valor: ');

 if CeCh > 0.5
 disp ('suggested to select an all moving tail');
 end

 if Tao_e > 1
 disp ('There is no elevator which can satisfy the take-off rotation requirement by the current tail/landing gear specifications.');
```

```
 end

%calculation of parameters
Delta_alpha_oe = -1.15*CeCh*(delta_up*(360/2*pi)); %change in the tail lift
coefficient when the elevator is deflected

        %Lifting line theory optimization

        N = 9; % (number of segments - 1)
        alpha_twist = 0.000001; % Twist angle (deg)
        alpha_0 = 0.000001 + Delta_alpha_oe; % zero-lift angle of attack
(deg)
        a_0 = Delta_alpha_oe; % flap up zero-lift angle of attack (deg)
        bh = sqrt(ARh*Sh); % wing span (m)
        a_0_fd = 0.00001; % flap down zero-lift angle of attack (deg)
        MAC = Sh/bh; % Mean Aerodynamic Chord
        Croot = (1.5*(1+TRh)*MAC)/(1+TRh+TRh^2); % root chord
        theta = pi/(2*N):pi/(2*N):pi/2;
        alpha=i_h+alpha_twist:-alpha_twist/(N-1):i_h; % segment's angle of
attack

        for i=1:N
            if (i/N)>(1-CeCh)
                alpha_0(i)=a_0_fd; %flap down zero lift AOA
            else
                alpha_0(i)=a_0; %flap up zero lift AOA
            end
        end

        z = (bh/2)*cos(theta);
        c = Croot * (1 - (1-TRh)*cos(theta)); % MAC at each segment
        mu = c * Clah / (4 * bh);
        LHS = mu .* (alpha-alpha_0)/57.3; % Left Hand Side

        % Solving N equations to find coefficients A(i)

        for i=1:N
            for j=1:N
                B(i,j) = sin((2*j-1) * theta(i)) * (1 + (mu(i) * (2*j-1)) /
sin(theta(i)));
            end
```

```
        end

        A=B\transpose(LHS);

        for i = 1:N
            sum1(i) = 0;
            sum2(i) = 0;
            for j = 1 : N
                sum1(i) = sum1(i) + (2*j-1) * A(j)*sin((2*j-1)*theta(i));
                sum2(i) = sum2(i) + A(j)*sin((2*j-1)*theta(i));
            end
        end

        CL = 4*bh*sum2 ./ c;
        CL1=[0 CL(1) CL(2) CL(3) CL(4) CL(5) CL(6) CL(7) CL(8) CL(9)];
        y_s=[bh/2 z(1) z(2) z(3) z(4) z(5) z(6) z(7) z(8) z(9)];
        plot(y_s,CL1,'-o')
        grid
        title('Lift distribution')
        xlabel('Semi-span location (m)')
        ylabel ('Lift coefficient')

        CL_TO = pi * ARh * A(1);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

xlh = input('input the distance from the tail to the most aft cg(m): ');
Clo = input('input the zero lift angle of attack for the wing(°): ');

Vh = ((xlh+Sh)/(Sw*Cw));
Cm_d = -Clah*1*Vh*bebh*Tao_e; %-0.2/-4
Cl_d = Clah*1*(Sh/Sw)*bebh*Tao_e;
Clh_d = Clah+Tao_e;

%Calculation of the most down deflection
Cm_a = Cla*(h-ho)-Clah*1*(Sh/Sw)*(xlh/Cw)*(1-D_epsilon);
q = 0.5*vc^2*p;
C_Ll = ((2*50*9.81)/(p*vc^2*Sw));
delta_down = (((((Tmax)*(Zcg-Zt))/(q*Sw*Cw))*Cla+((C_Ll-
(Clo/57.3))*(Cm_a/57.3)))/((Cla)*Cm_d-(Cm_a/57.3)*Cl_d));
```

```
delta_down_deg = delta_down*(180/pi);



%Display more results
fprintf(1,'10.- Delta_alpha_oe = %10.2f °\n', Delta_alpha_oe);
fprintf(1,'11.- CL_OT = %10.2f calculated and Clhto = %10.2f desired; If
the first is bigger than the desired one, in absolute value, the elevator
is acceptable.\n', CL_TO,Clhto);
fprintf(1,'12.- delta_down = %10.2f °\n', delta_down_deg);



%%%%%% Ploting the variations of the deflection


    Cmo = 0;
    CLa_wf = Cla;
    g = 9.81; %m/s^2
    m = 50; % kg
    etha_h = 1;
    xlh = Xach-Xmg; % m from main landing gear
    CLdE=-Clah*etha_h*Sh*Tao_e/Sw;

    % Most forward cg
    xcg = input('input the most forward cg position from main landing
gear(m): ');
    h_to_ho = -0.3/Cw; % m
    l_h2 = xlh+xcg; % m
    VH2 = (l_h2*Sh)/(Sw*Cw);
    CmdE2 = -Clah*etha_h*VH2*Tao_e;
    Cma2 = CLa_wf*h_to_ho-Clah*etha_h*Sh*(l_h2/Cw)*(1-D_epsilon)/Sw;
    i =1;


    for U1=vs:vc;
        qbar=0.5*p*U1^2;
        CL1= (m*g)/(qbar*Sw);
        f1=((Tmax*(Zt))/(qbar*Sw*Cw))+Cmo;
        dE1(i)=0;
        dE2(i)=-((f1*Clah)+(CL1-Clo/57.3)*Cma2)/(Clah*CmdE2-Cma2*CLdE);
        V(i)=U1;
        i=i+1;
    end
```

```
    plot(V,dE2,'*')
    grid
    xlabel ('Speed (m/s)')
    ylabel ('\delta_E (deg)')
    legend('Most forward cg')

    disp('Check if the delta_down and delta_up is between the values in the
graph')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

alpha_s = input('input the wing stall angle(deg): ');
alpha_to = alpha_s - 2; %For security we set the maximum angle at take-off
under 2 deg of the wing stall angle
alpha_hto = alpha_to*(1-D_epsilon)+i_h-epsilon_o;

if alpha_hto < (alpha_hs-2)
    disp('The horizontal tail do not stall during take-off rotation')
else
    disp('The horizontal tail stall during take-off rotation; check
parameters[reduce elevator deflection and/or elevator chord]')
end

 %Final parameters

 Ce = CeCh*MACh; %Elevator length.
 Se = bh*Ce; %Elevator surface.

 fprintf(1,'13.- Ch = %10.2f m, Ce = %10.2f m, Se = %10.2f m^2\n', MACh,
Ce, Se);



end
```

Rudder_Design.m

```
%           Rudder Design

function [] = Rudder_Design()
%Provides the parameters to design the rudder.

%Global parameters
global Lopt
global Sw
global ARv
global Sv
global bv
global Xfcg
global vs
global Cla
global bw
global Vv
global Vt
global Cy_beta
global beta
global Cy_delta
global wind
global Ss
global Cn_beta
global Cn_delta
global SideF
global Dd
global Tmax
global MACv

%Variables
bebh = 1;
wind = 40 * 0.514; %(m/s)Safe crosswind velocity to land
Va = 1.1*vs; %Typical approach speed
brbv = 1; %rudder-span-to-vertical-tail-span ratio
CrCv = 0.4; %rudder-to-vertical-tail-chord ratio selected in similar
aircrafts.
Tao_v = 0.55; %Effectiveness extracted for similar aircrafts.

    %Needed variables from the wings to do the calculates
     Ss = input('Input the side surface of the aircraft (m^2): ');
```

```
    Dm = input('Input the distance between the motors(m): ');

%Calculation of parameters
Vt = sqrt(Va^2+wind^2); %Drag at take off
%%%%For the calculation of the side projected area we must add the
%%%%fuselage area to the vertical wing planform area and the landing gear
%%%%area, due to a very first approach the landing gear would be a 2% of
%%%%the whole area.
SsT = 1.02*(Ss+Sv);
Xca = (Ss*Xfcg+Sv*Lopt)/(Ss+Sv); %Approximate.
Dd = Xfcg - Xca; %Difference distance between the gravity center and the
center of the aircraft area.
%%%%%Due to simplicity, a crosswind from the right is assumed; which is
generating a positive sideslip angle
%%Typical values for aircraft side drag coefficient for conventional
%%aircraft are 0.5 to 0.8, so a value of 0.75 is used.
SideF = 0.5*1.225*wind^2*SsT*0.75;

beta = atan (wind/Va); %side slip angle

%aircraft sideslip derivatives
Cn_beta = 0.75 * Cla * (1-0) * 0.95 * ((Lopt*Sv)/(bw*Sw));  %The typical
value of Kf1 for a conventional aircraft is about 0.65 to 0.85 so 0.75 is
selected.
Cy_beta = -1.35 * Cla * (1-0) * 0.95 * (Sv/Sw); %The typical value of Kf2
for a conventional aircraft is about 1.3 to 1.4 so 1.35 is selected.

%aircraft control derivative
Cn_delta = Cla * 0.95 * Tao_v * brbv * (Sv/Sw);
Cy_delta = -Cla * 0.95 * Tao_v * brbv * Vv;

%Calculate de rudder deflection
fun = @root2defl; %System of 2 nonlinear eq.
x0 = [0,0];
x = fsolve(fun,x0);
defl = x(1); %(rad)
crab = x(2); %(rad)

%%%%%%%%%% Now is considered to evaluate the tail for the requirement of
%%%%%%%%%% asymmetric thrust since the rudder geometry and derivates are
%%%%%%%%%% known.
```

```
% Minimum controllable speed is considered to be the 10% greater than the
stall speed for this
% aircraft for the most safety conditions.

%Deflection needed:
defl_asy = (((Tmax/2)*Dm/2)/(-0.5*1.225*Va^2*Sw*bw*Cn_delta));%(rad)



%Print the parameters
disp ('1.- Due to have a multiengine aircrafts the most critical rudder
design requirements are crosswind landing at 40 knots and asymmetric
thrust.\n')
disp ('2.- Vwind = 40 knot is a typical requirement for safety landings.')
fprintf(1,'3.- Vtotal = %10.2f m/s, \n',Vt);
fprintf(1,'4.- Side Force = %10.2f N \n', SideF);
fprintf(1,'5.- Cn_beta = %10.2f; Cy_beta = %10.2f  \n',Cn_beta, Cy_beta);

if defl > (pi/6)
    disp ('The rudder do not fix the safety deflection of 30° for crosswind
landing.')
elseif defl_asy > (pi/6)
    disp ('The rudder do not fix the safety deflection of 30° for
asymmetric thrust.')
elseif defl_asy > defl
    defl = defl_asy;
end

% 30deg is de most allowable deflection due to safety standards.

%Calculate the rest of rudder parameters.

Cr = CrCv*MACv; %Rudder chord.
br = bv; %Rudder span.
Sr = br*Cr; %Rudder Area.

defl_deg = defl*(180/pi);

fprintf(1,'6.- Deflection = %10.2f °  \n',defl_deg);
```

```
fprintf(1,'7.- Cr = %10.2f m, br = %10.2f m, Sr = %10.2f m^2 \n', Cr, br,
Sr);



end
```

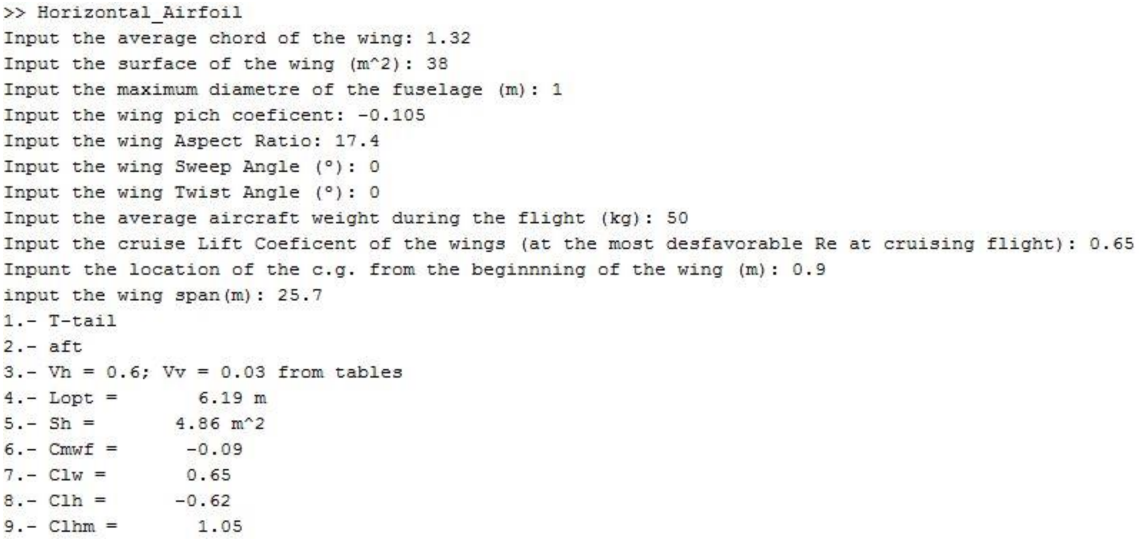
➔ Where root2defl.m is the following function:

```
function F = root2defl(x)

global Vt
global S
global Cy_beta
global beta
global Cy_delta
global wind
global Ss
global Sw
global bw
global Cn_beta
global Cn_delta
global SideF
global Dd

F = [((0.5*1.225*Vt^2*S*(Cy_beta*(beta-
x(2))+Cy_delta*x(1)))/(0.5*1.225*wind^2*Ss*0.75));
        (0.5*1.225*Vt^2*Sw*bw*(Cn_beta*(beta-
x(2))+Cn_delta*x(1))+SideF*Dd*cos(x(2)))];

end
```

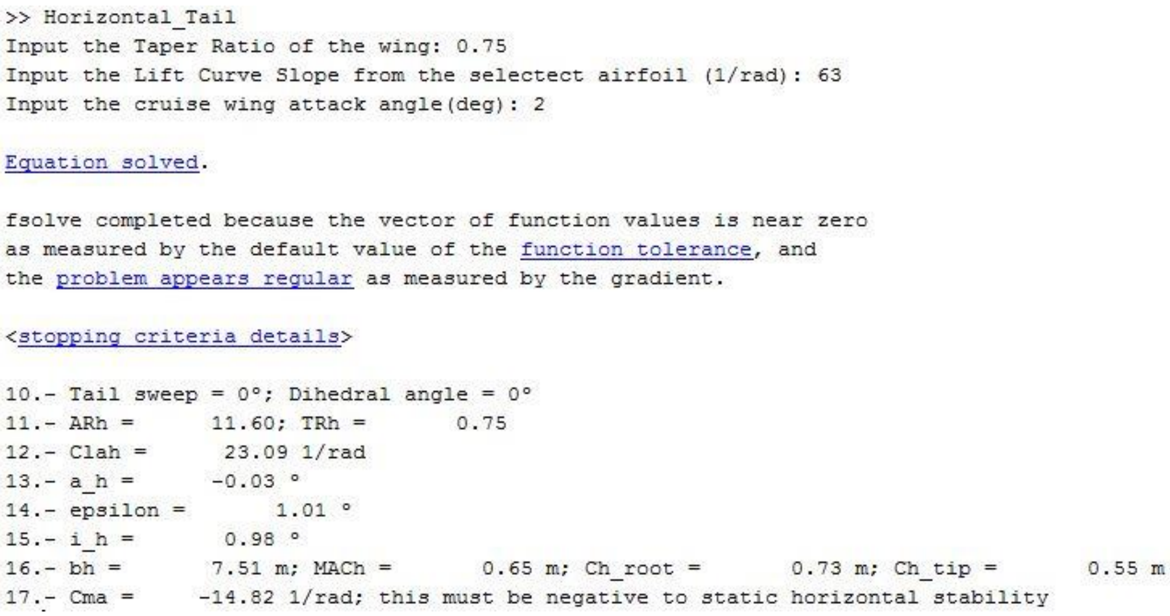
3.1.2. Solutions

In this section are showed the result of the last 3 iterations with the other components leaders and is showed how the factors change. The elevator and the rudder are calculated with the last iteration of the main geometrical part.

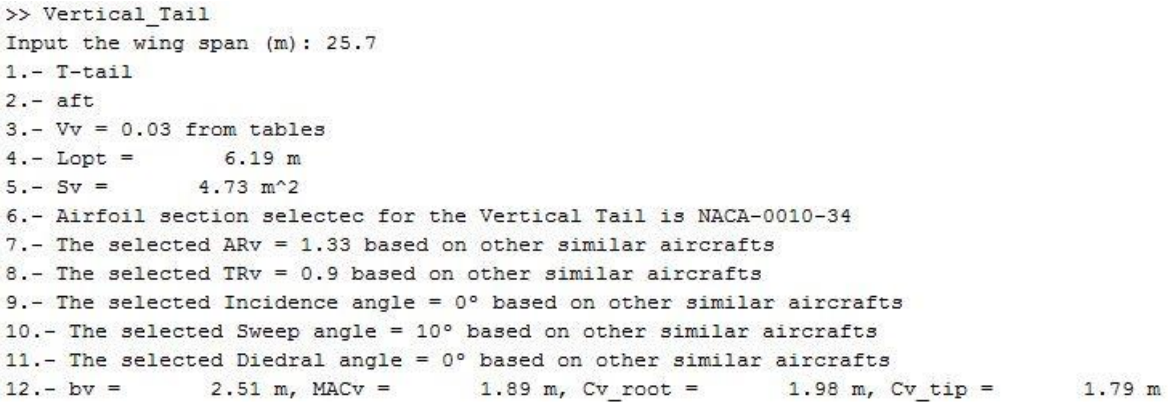
1st iteration



```
>> Horizontal_Airfoil
Input the average chord of the wing: 1.32
Input the surface of the wing (m^2): 38
Input the maximum diametre of the fuselage (m): 1
Input the wing pich coeficent: -0.105
Input the wing Aspect Ratio: 17.4
Input the wing Sweep Angle (°): 0
Input the wing Twist Angle (°): 0
Input the average aircraft weight during the flight (kg): 50
Input the cruise Lift Coeficent of the wings (at the most desfavorable Re at cruising flight): 0.65
Inpunt the location of the c.g. from the beginnning of the wing (m): 0.9
input the wing span(m): 25.7
1.- T-tail
2.- aft
3.- Vh = 0.6; Vv = 0.03 from tables
4.- Lopt =       6.19 m
5.- Sh =       4.86 m^2
6.- Cmwf =      -0.09
7.- Clw =       0.65
8.- Clh =      -0.62
9.- Clhm =       1.05
```

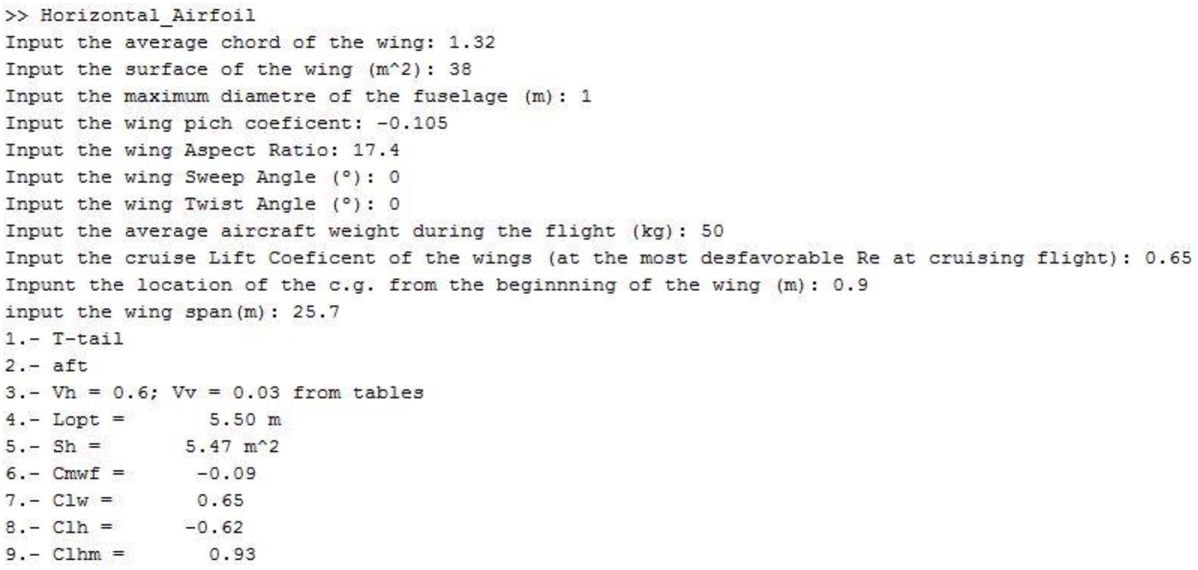


```
>> Horizontal_Tail
Input the Taper Ratio of the wing: 0.75
Input the Lift Curve Slope from the selectect airfoil (1/rad): 63
Input the cruise wing attack angle(deg): 2

Equation solved.

fsolve completed because the vector of function values is near zero
as measured by the default value of the function tolerance, and
the problem appears regular as measured by the gradient.

<stopping criteria details>

10.- Tail sweep = 0°; Dihedral angle = 0°
11.- ARh =      11.60; TRh =       0.75
12.- Clah =      23.09 1/rad
13.- a_h =      -0.03 °
14.- epsilon =       1.01 °
15.- i_h =       0.98 °
16.- bh =       7.51 m; MACh =       0.65 m; Ch_root =       0.73 m; Ch_tip =       0.55 m
17.- Cma =     -14.82 1/rad; this must be negative to static horizontal stability
```

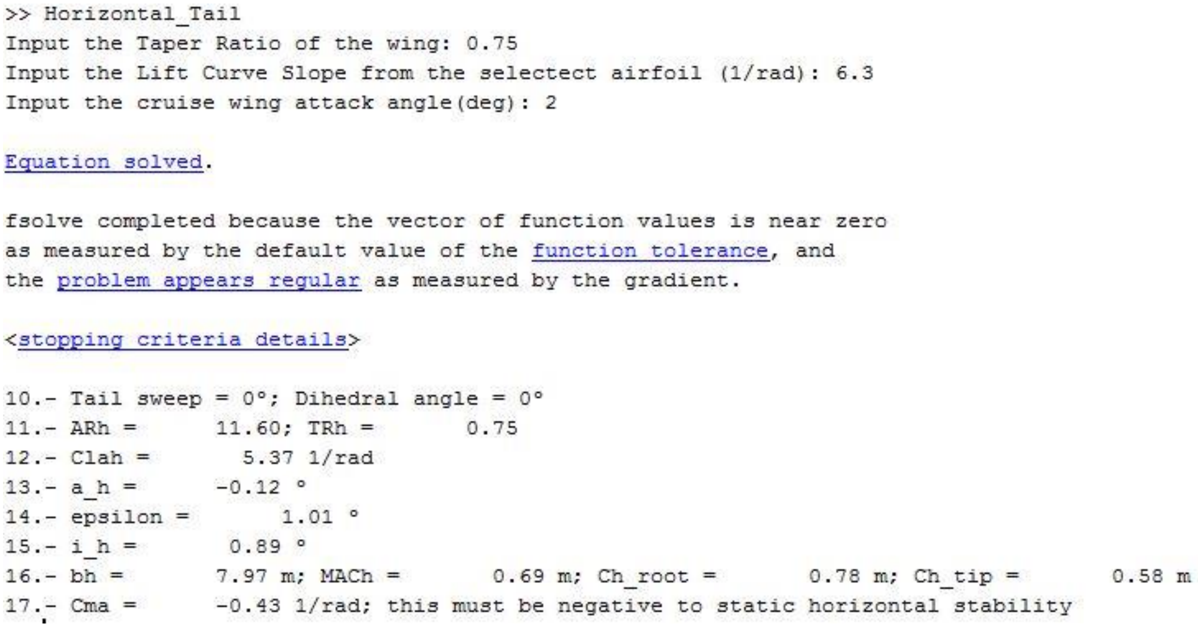


```
>> Vertical_Tail
Input the wing span (m): 25.7
1.- T-tail
2.- aft
3.- Vv = 0.03 from tables
4.- Lopt =       6.19 m
5.- Sv =       4.73 m^2
6.- Airfoil section selectec for the Vertical Tail is NACA-0010-34
7.- The selected ARv = 1.33 based on other similar aircrafts
8.- The selected TRv = 0.9 based on other similar aircrafts
9.- The selected Incidence angle = 0° based on other similar aircrafts
10.- The selected Sweep angle = 10° based on other similar aircrafts
11.- The selected Diedral angle = 0° based on other similar aircrafts
12.- bv =       2.51 m, MACv =       1.89 m, Cv_root =       1.98 m, Cv_tip =       1.79 m
```

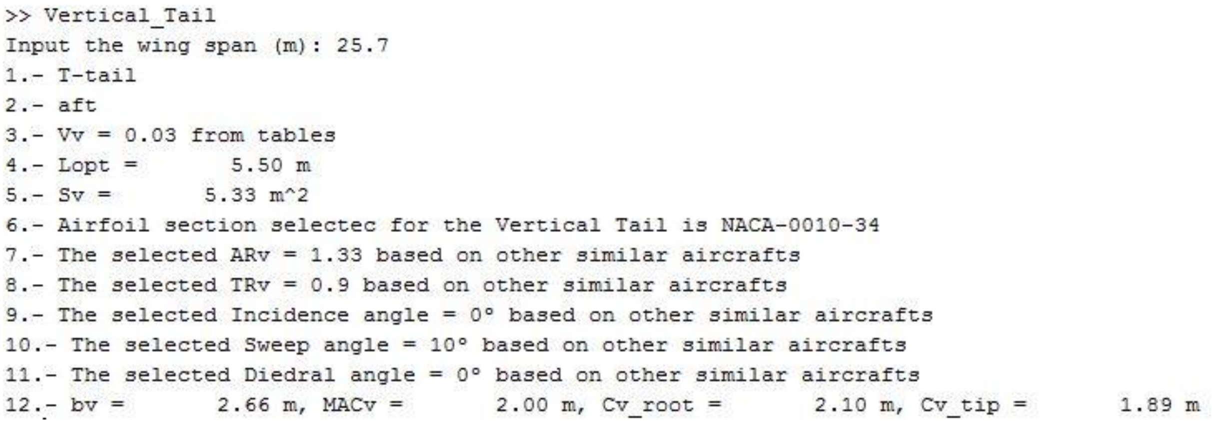
2nd iteration



```
>> Horizontal_Airfoil
Input the average chord of the wing: 1.32
Input the surface of the wing (m^2): 38
Input the maximum diametre of the fuselage (m): 1
Input the wing pich coeficent: -0.105
Input the wing Aspect Ratio: 17.4
Input the wing Sweep Angle (°): 0
Input the wing Twist Angle (°): 0
Input the average aircraft weight during the flight (kg): 50
Input the cruise Lift Coeficent of the wings (at the most desfavorable Re at cruising flight): 0.65
Inpunt the location of the c.g. from the beginnning of the wing (m): 0.9
input the wing span(m): 25.7
1.- T-tail
2.- aft
3.- Vh = 0.6; Vv = 0.03 from tables
4.- Lopt =       5.50 m
5.- Sh =       5.47 m^2
6.- Cmwf =      -0.09
7.- Clw =       0.65
8.- Clh =      -0.62
9.- Clhm =       0.93
```

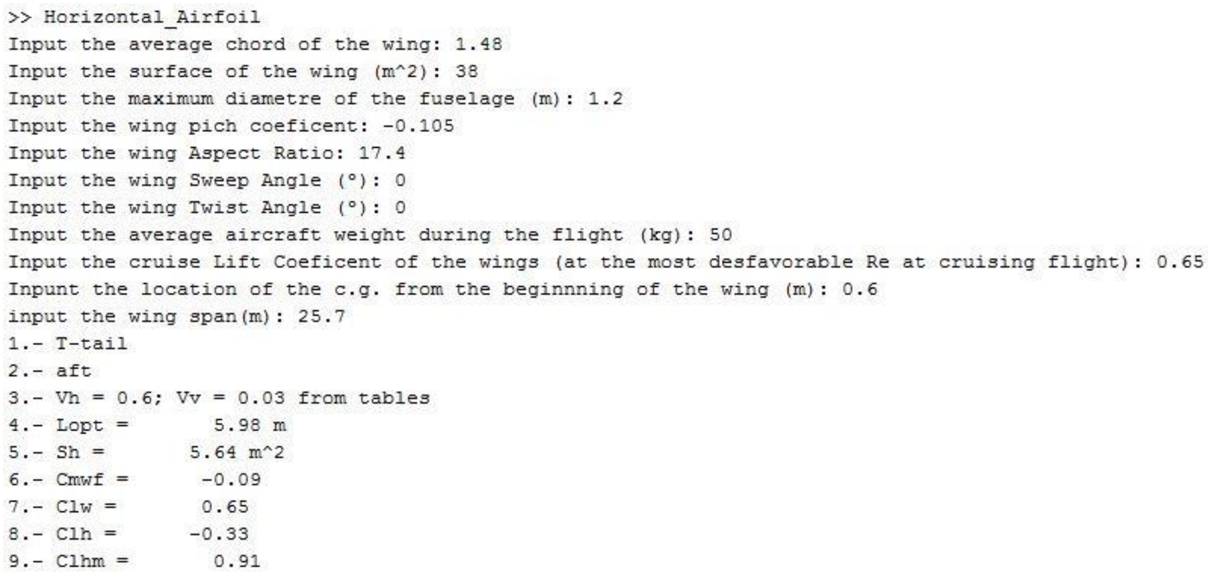


```
>> Horizontal_Tail
Input the Taper Ratio of the wing: 0.75
Input the Lift Curve Slope from the selectect airfoil (1/rad): 6.3
Input the cruise wing attack angle(deg): 2

Equation solved.

fsolve completed because the vector of function values is near zero
as measured by the default value of the function tolerance, and
the problem appears regular as measured by the gradient.

<stopping criteria details>

10.- Tail sweep = 0°; Dihedral angle = 0°
11.- ARh =      11.60; TRh =       0.75
12.- Clah =       5.37 1/rad
13.- a_h =      -0.12 °
14.- epsilon =       1.01 °
15.- i_h =       0.89 °
16.- bh =       7.97 m; MACh =       0.69 m; Ch_root =       0.78 m; Ch_tip =       0.58 m
17.- Cma =      -0.43 1/rad; this must be negative to static horizontal stability
```

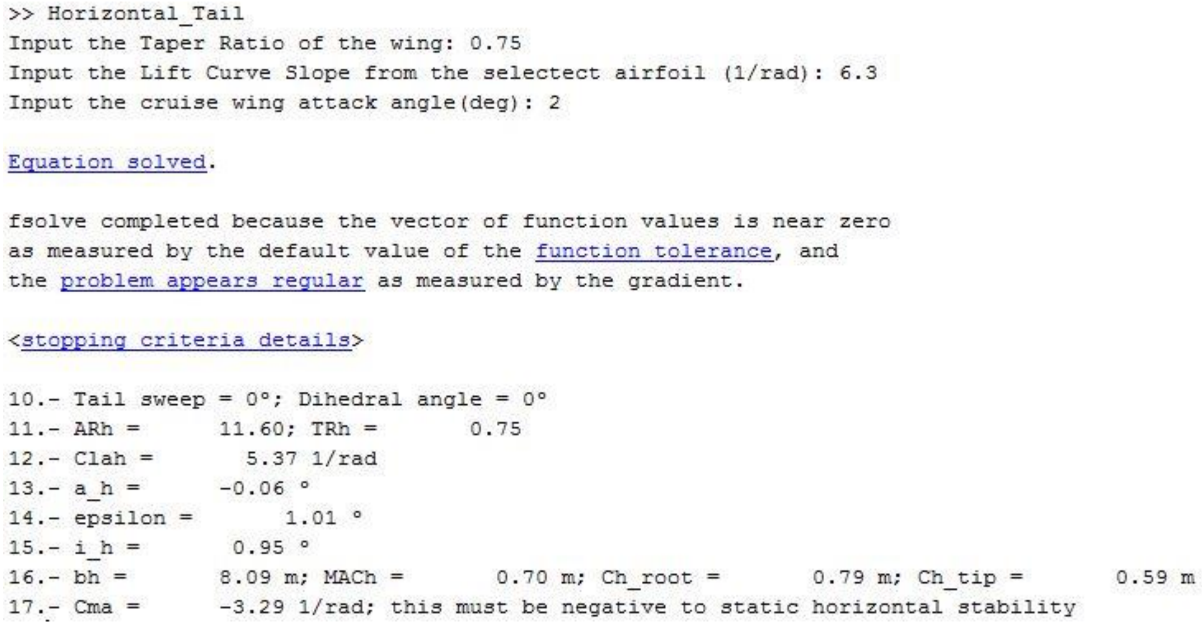


```
>> Vertical_Tail
Input the wing span (m): 25.7
1.- T-tail
2.- aft
3.- Vv = 0.03 from tables
4.- Lopt =       5.50 m
5.- Sv =       5.33 m^2
6.- Airfoil section selectec for the Vertical Tail is NACA-0010-34
7.- The selected ARv = 1.33 based on other similar aircrafts
8.- The selected TRv = 0.9 based on other similar aircrafts
9.- The selected Incidence angle = 0° based on other similar aircrafts
10.- The selected Sweep angle = 10° based on other similar aircrafts
11.- The selected Diedral angle = 0° based on other similar aircrafts
12.- bv =       2.66 m, MACv =       2.00 m, Cv_root =       2.10 m, Cv_tip =       1.89 m
```

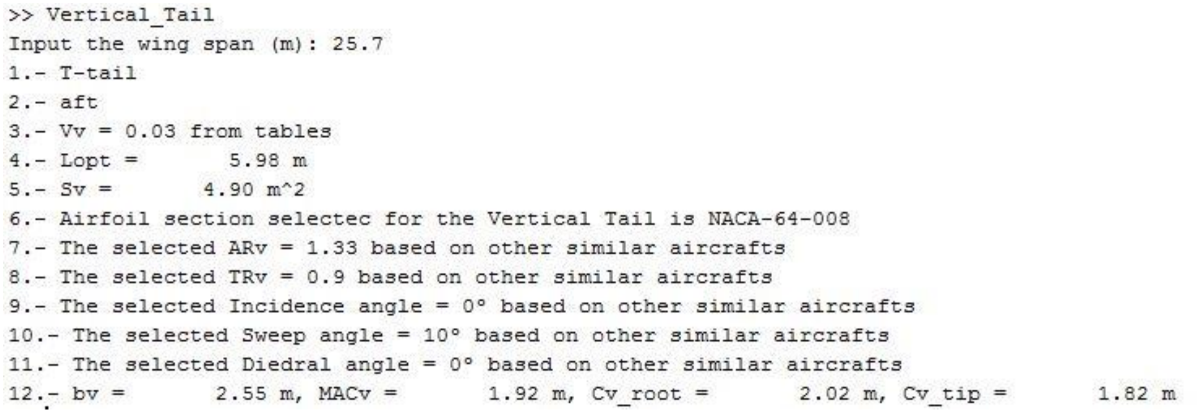
Final iteration



```
>> Horizontal_Airfoil
Input the average chord of the wing: 1.48
Input the surface of the wing (m^2): 38
Input the maximum diametre of the fuselage (m): 1.2
Input the wing pich coeficent: -0.105
Input the wing Aspect Ratio: 17.4
Input the wing Sweep Angle (°): 0
Input the wing Twist Angle (°): 0
Input the average aircraft weight during the flight (kg): 50
Input the cruise Lift Coeficent of the wings (at the most desfavorable Re at cruising flight): 0.65
Inpunt the location of the c.g. from the beginnning of the wing (m): 0.6
input the wing span(m): 25.7
1.- T-tail
2.- aft
3.- Vh = 0.6; Vv = 0.03 from tables
4.- Lopt =       5.98 m
5.- Sh =       5.64 m^2
6.- Cmwf =      -0.09
7.- Clw =       0.65
8.- Clh =      -0.33
9.- Clhm =       0.91
```

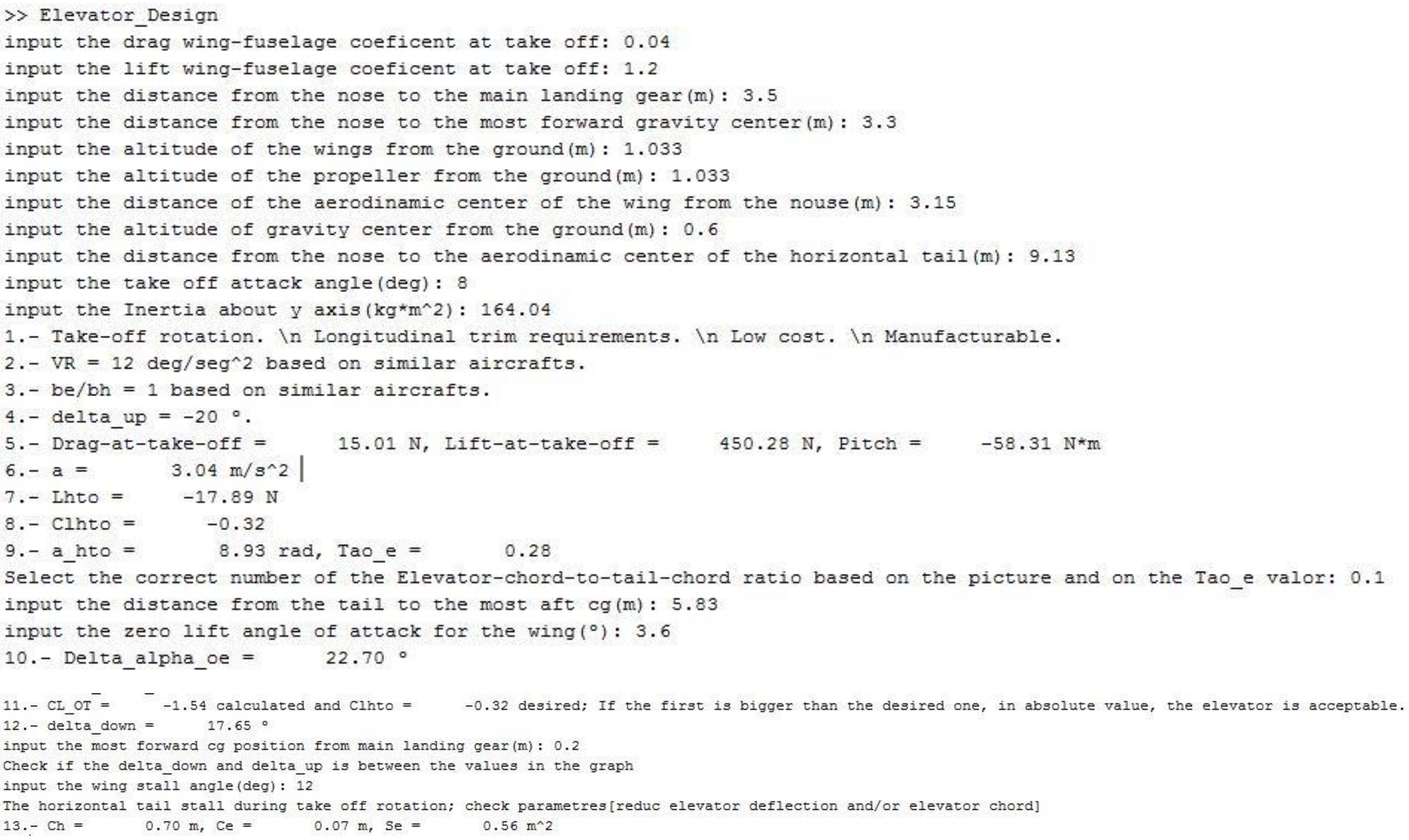


```
>> Horizontal_Tail
Input the Taper Ratio of the wing: 0.75
Input the Lift Curve Slope from the selectect airfoil (1/rad): 6.3
Input the cruise wing attack angle(deg): 2

Equation solved.

fsolve completed because the vector of function values is near zero
as measured by the default value of the function tolerance, and
the problem appears regular as measured by the gradient.

<stopping criteria details>

10.- Tail sweep = 0°; Dihedral angle = 0°
11.- ARh =      11.60; TRh =       0.75
12.- Clah =       5.37 1/rad
13.- a_h =      -0.06 °
14.- epsilon =       1.01 °
15.- i_h =       0.95 °
16.- bh =       8.09 m; MACh =       0.70 m; Ch_root =       0.79 m; Ch_tip =       0.59 m
17.- Cma =      -3.29 1/rad; this must be negative to static horizontal stability
```

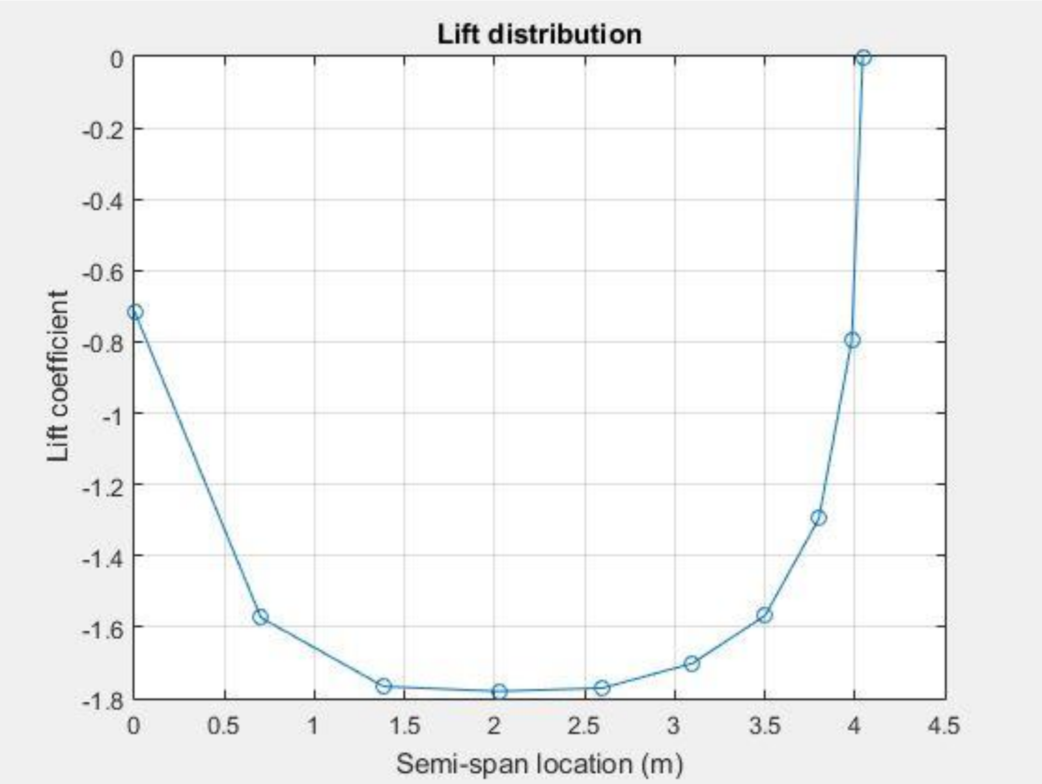


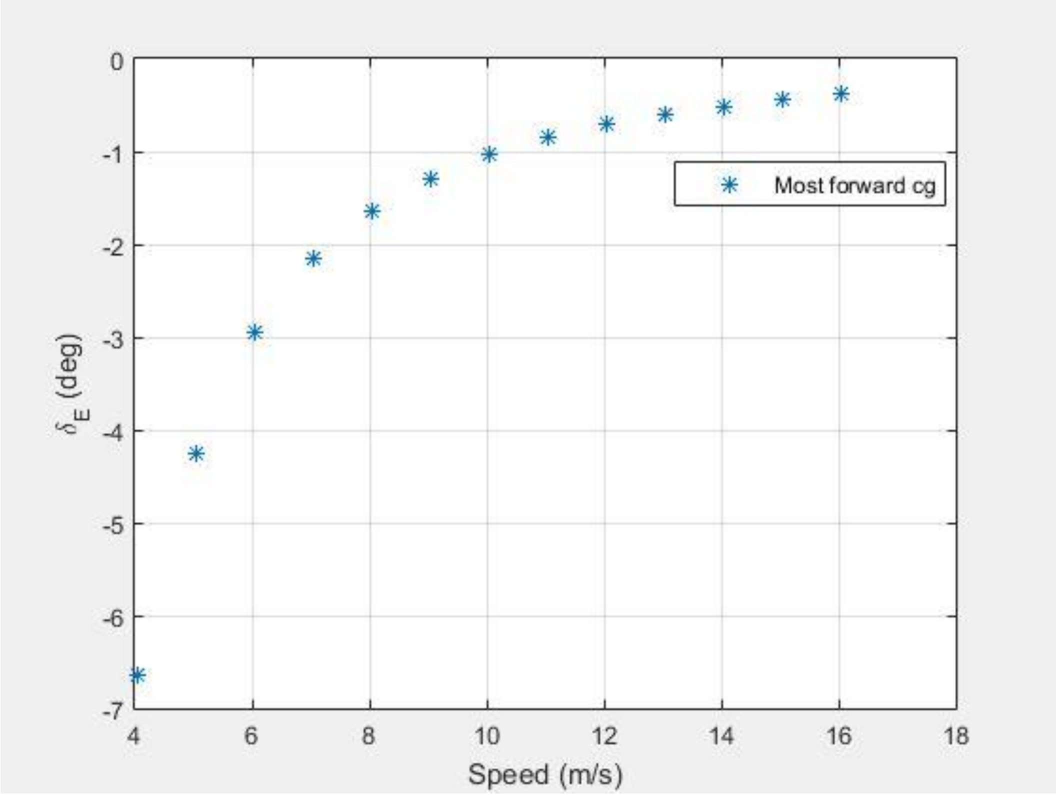
```
>> Vertical_Tail
Input the wing span (m): 25.7
1.- T-tail
2.- aft
3.- Vv = 0.03 from tables
4.- Lopt =       5.98 m
5.- Sv =       4.90 m^2
6.- Airfoil section selectec for the Vertical Tail is NACA-64-008
7.- The selected ARv = 1.33 based on other similar aircrafts
8.- The selected TRv = 0.9 based on other similar aircrafts
9.- The selected Incidence angle = 0° based on other similar aircrafts
10.- The selected Sweep angle = 10° based on other similar aircrafts
11.- The selected Diedral angle = 0° based on other similar aircrafts
12.- bv =       2.55 m, MACv =       1.92 m, Cv_root =       2.02 m, Cv_tip =       1.82 m
```

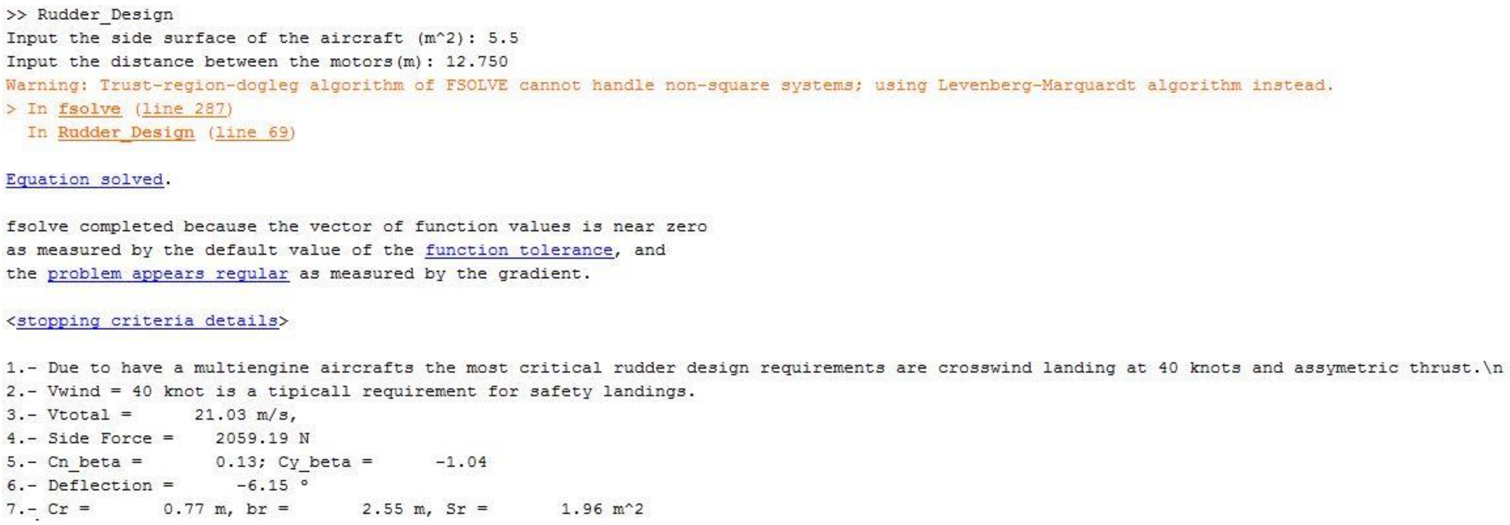
Elevator and Rudder



```
>> Elevator_Design
input the drag wing-fuselage coeficent at take off: 0.04
input the lift wing-fuselage coeficent at take off: 1.2
input the distance from the nose to the main landing gear(m): 3.5
input the distance from the nose to the most forward gravity center(m): 3.3
input the altitude of the wings from the ground(m): 1.033
input the altitude of the propeller from the ground(m): 1.033
input the distance of the aerodinamic center of the wing from the nouse(m): 3.15
input the altitude of gravity center from the ground(m): 0.6
input the distance from the nose to the aerodinamic center of the horizontal tail(m): 9.13
input the take off attack angle(deg): 8
input the Inertia about y axis(kg*m^2): 164.04
1.- Take-off rotation. \n Longitudinal trim requirements. \n Low cost. \n Manufacturable.
2.- VR = 12 deg/seg^2 based on similar aircrafts.
3.- be/bh = 1 based on similar aircrafts.
4.- delta_up = -20 °.
5.- Drag-at-take-off =      15.01 N, Lift-at-take-off =     450.28 N, Pitch =     -58.31 N*m
6.- a =        3.04 m/s^2
7.- Lhto =     -17.89 N
8.- Clhto =      -0.32
9.- a_hto =       8.93 rad, Tao_e =       0.28
Select the correct number of the Elevator-chord-to-tail-chord ratio based on the picture and on the Tao_e valor: 0.1
input the distance from the tail to the most aft cg(m): 5.83
input the zero lift angle of attack for the wing(°): 3.6
10.- Delta_alpha_oe =      22.70 °

11.- CL_OT =      -1.54 calculated and Clhto =      -0.32 desired; If the first is bigger than the desired one, in absolute value, the elevator is acceptable.
12.- delta_down =      17.65 °
input the most forward cg position from main landing gear(m): 0.2
Check if the delta_down and delta_up is between the values in the graph
input the wing stall angle(deg): 12
The horizontal tail stall during take off rotation; check parametres[reduc elevator deflection and/or elevator chord]
13.- Ch =       0.70 m, Ce =       0.07 m, Se =       0.56 m^2
```







```
>> Rudder_Design
Input the side surface of the aircraft (m^2): 5.5
Input the distance between the motors(m): 12.750
Warning: Trust-region-dogleg algorithm of FSOLVE cannot handle non-square systems; using Levenberg-Marquardt algorithm instead.
> In fsolve (line 287)
  In Rudder_Design (line 69)

Equation solved.

fsolve completed because the vector of function values is near zero
as measured by the default value of the function tolerance, and
the problem appears regular as measured by the gradient.

<stopping criteria details>

1.- Due to have a multiengine aircrafts the most critical rudder design requirements are crosswind landing at 40 knots and assymetric thrust.\n
2.- Vwind = 40 knot is a tipicall requirement for safety landings.
3.- Vtotal =      21.03 m/s,
4.- Side Force =    2059.19 N
5.- Cn_beta =       0.13; Cy_beta =      -1.04
6.- Deflection =      -6.15 °
7.- Cr =        0.77 m, br =        2.55 m, Sr =       1.96 m^2
```

3.2. 3D design (CATIA)

This section just shows the aspect of the surface and the different pieces and are commented why are chosen some construction solutions.

In this section are commented the different structural solution adopted for this UAV.

The first thing is to see the chosen design for the tail:

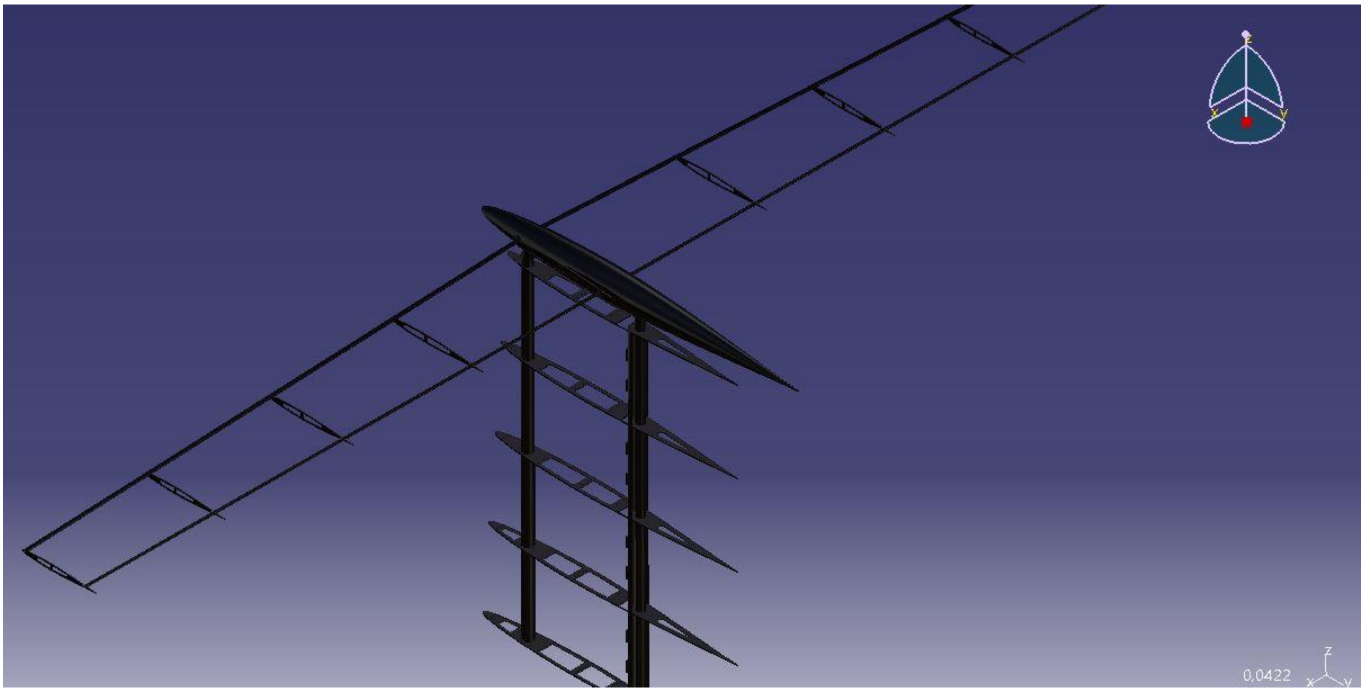


Figure 3.2.- Tail structure

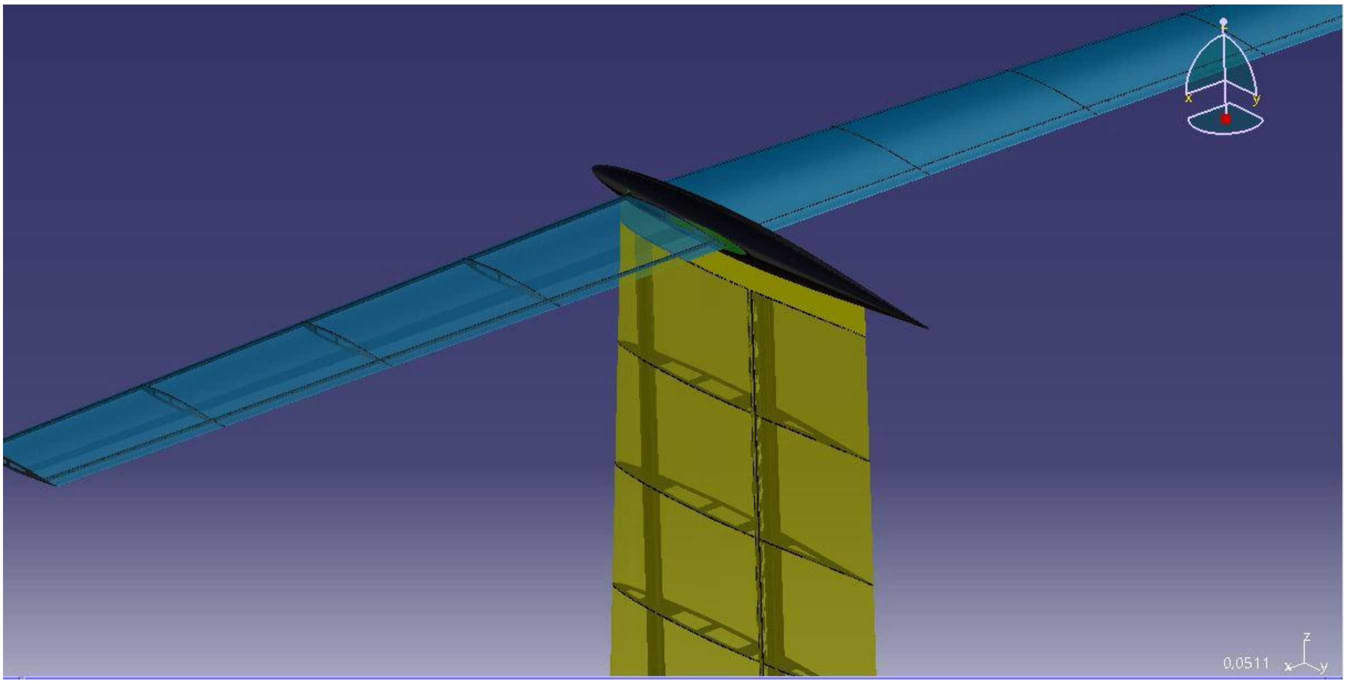


Figure 3.1.- Tail structure.

As can be seen in the images for each tail, horizontal and vertical, there are 2 longerons. The first one or the leading one is the longeron which must resist the forces and make sure everything is still together and in its place. Is selected for this proposal tubular profiles that withstand very well the forces and the twist.

For the horizontal longeron is designed a alveolate lateral to improve the weight due to the length it would weight too much.

The Vertical longeron is not on the leading edge as the horizontal one, due to this longeron is the structure that must to bear with the horizontal tail structure and force. Because of this a column structure is selected and the join between both is a tube so the upwards forces can be handle by the same column. This join should be bored to enable the wires to go through.

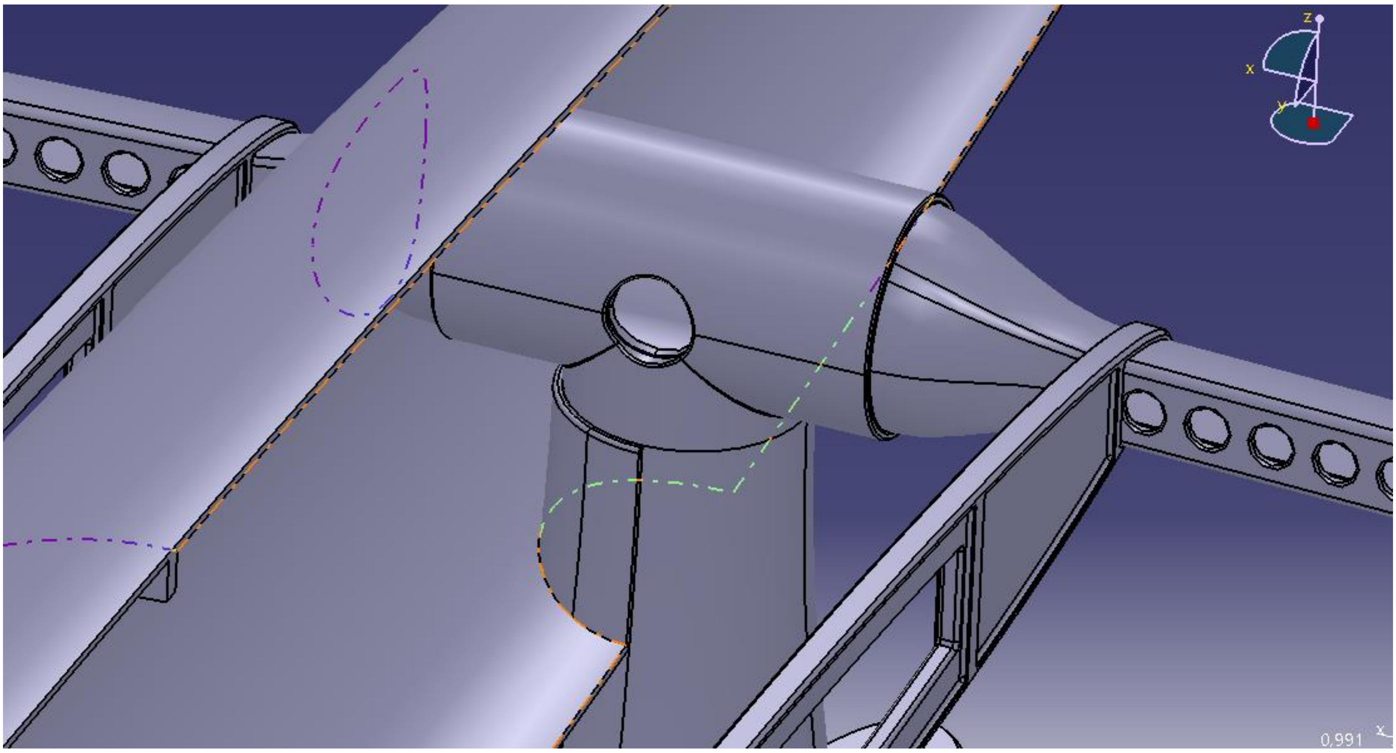


Figure 3.3.- join between vertical and horizontal longeron and the tear shape

The coupling is one of the main points of the structure. The vertical longeron is fixed with the fuselage join and then introduce the horizontal longeron fixing with the vertical coupling through a forced adjustment and adhesive. Then one side of the tear shape is placed and on it all the devices as motor, gear box, pitot tube, wires… and finally the other tear shape to close the surface. Finally, the ribs are introduced into the longeron and placed in their position.

In the rear part of the ribs, the hitch is placed by adhesive merging all the ribs together and enable the hinge mechanism. That hitch gives the rear part of the ribs resistance too.

The rear longeron is not a supporting structure. Is a combination 3 pieces. Is the hitch, where the elevators hook and the motor shaft.

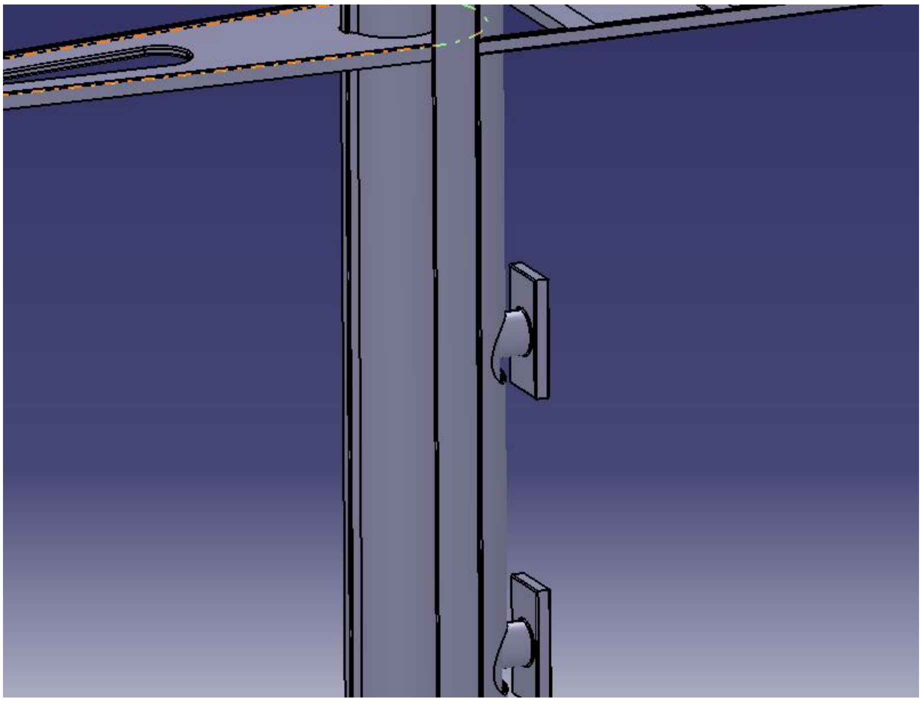


Figure 3.4.- Rear longeron

The mobility is solved by a hinge through holes as the image shows.

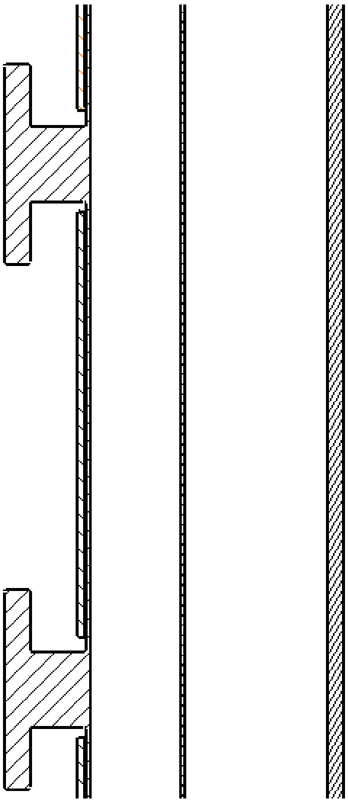


Figure 3.5.- Hinge and rear longeron detail.

The constructing of the hinge is coupling the cylinders into the holes of the other piece and then "welding" the stops on the cylinders to make the structure impossible to decouple.

The las part is to denote the aerodynamic shape at the top where the motors and some instrument as pitot tube are located. This shape is adopted to be the same as the airfoils sections because the airfoils are selected to not generate drag.

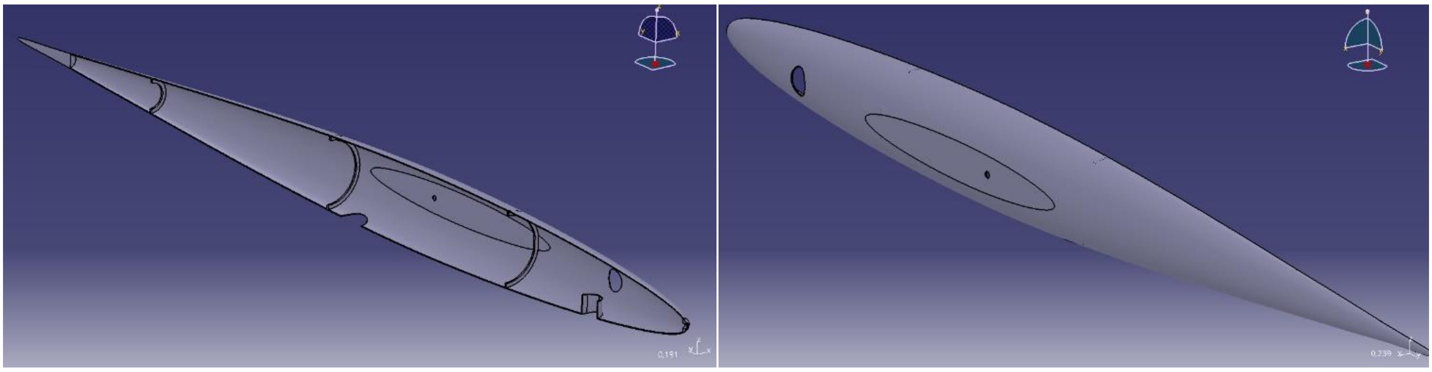
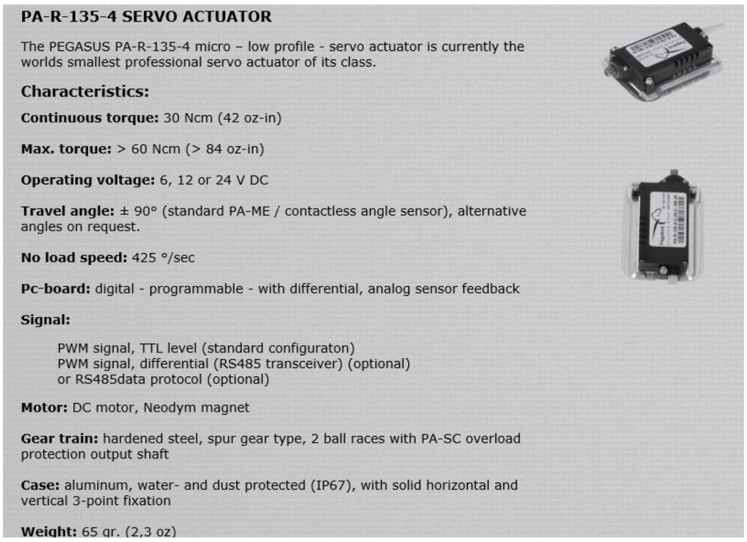


Figure 3.6.- Interior and exterior of the tear shape

All the pieces are made of superlight carbon fiber and they join by especial thermo-adhesive. This superlight carbon fiber is developed by the technology TeXtreme®. In general, this technology can reduce weight by 20-30% for other types of carbon fiber, with no change or even increased levels of stiffness or strength. It was thought to made some pieces from aluminum or lithium or magnesium-aluminum alloy or from fiberglass but they were rejected since those materials are heavier and the strength properties are similar to the carbon fiber ones.

The join with the fuselage part is with adhesive and a pressure adjustment.

The motor selected are the following ones used on other UAVs as *Qinetiq Zephyr:*



PA-R-135-4 SERVO ACTUATOR

The PEGASUS PA-R-135-4 micro – low profile - servo actuator is currently the worlds smallest professional servo actuator of its class.

Characteristics:

Continuous torque: 30 Ncm (42 oz-in)

Max. torque: > 60 Ncm (> 84 oz-in)

Operating voltage: 6, 12 or 24 V DC

Travel angle: ± 90° (standard PA-ME / contactless angle sensor), alternative angles on request.

No load speed: 425 °/sec

Pc-board: digital - programmable - with differential, analog sensor feedback

Signal:

PWM signal, TTL level (standard configuraton)
PWM signal, differential (RS485 transceiver) (optional)
or RS485data protocol (optional)

Motor: DC motor, Neodym magnet

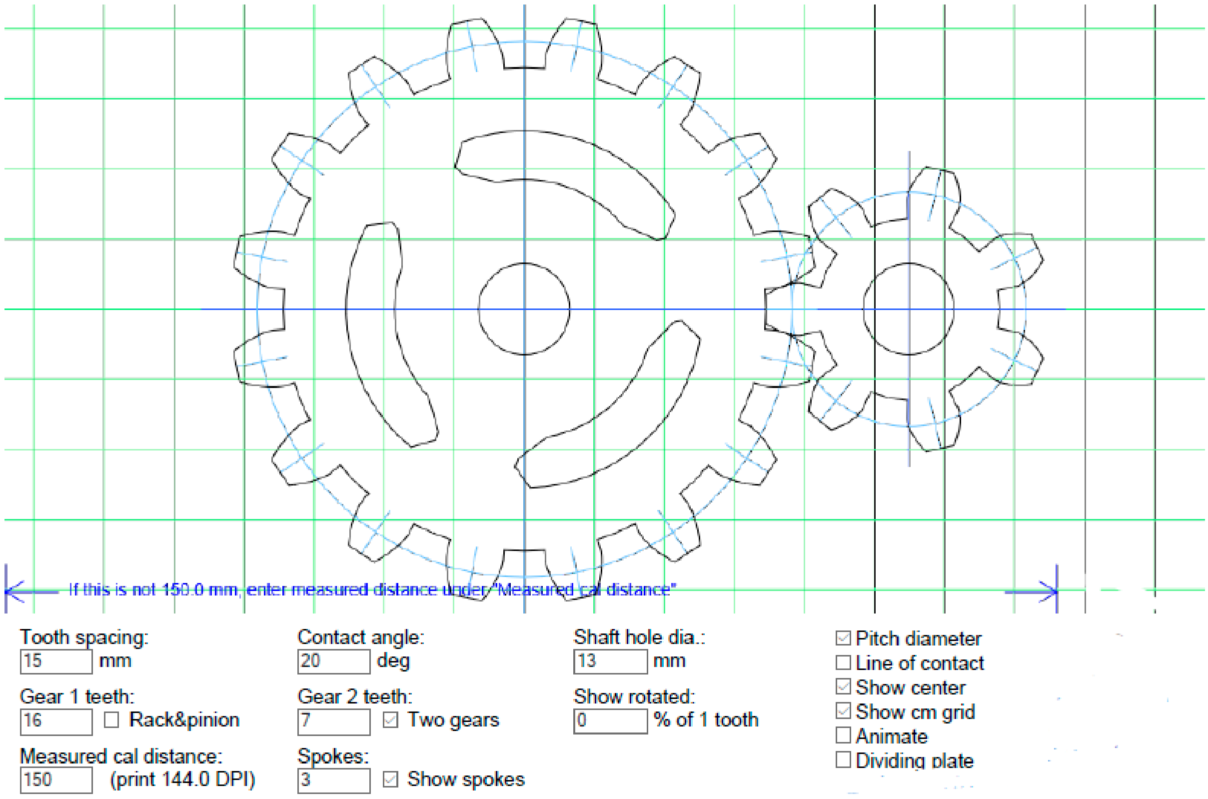
Gear train: hardened steel, spur gear type, 2 ball races with PA-SC overload protection output shaft

Case: aluminum, water- and dust protected (IP67), with solid horizontal and vertical 3-point fixation

Weight: 65 gr. (2,3 oz)

Figure 3.7.-Selected motor [59].

The join between motor and drive shaft are through a gear box that makes the motor develop a greater torque losing a bit of speed in the movement.



If this is not 150.0 mm, enter measured distance under "Measured cal distance"

Tooth spacing: 15 mm

Gear 1 teeth: 16 ☐ Rack&pinion

Measured cal distance: 150 (print 144.0 DPI)

Contact angle: 20 deg

Gear 2 teeth: 7 ☑ Two gears

Spokes: 3 ☑ Show spokes

Shaft hole dia.: 13 mm

Show rotated: 0 % of 1 tooth

☑ Pitch diameter
☐ Line of contact
☑ Show center
☑ Show cm grid
☐ Animate
☐ Dividing plate

Figure 3.8.- Designed gears.

The final torque developed by the mechanism is: 137.15Ncm while the angular speed is: 185.95º/sec.

The total weight for this part would be approximately 18kg that is a great weight for the rear tail but it could be reduced and optimized in future work.

3.3. Flow analysis (SolidWorks)

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

First think to create here is the mesh which, for this rough analysis, is not one accurate mesh but ideal one for optimize the operations and get valid results.

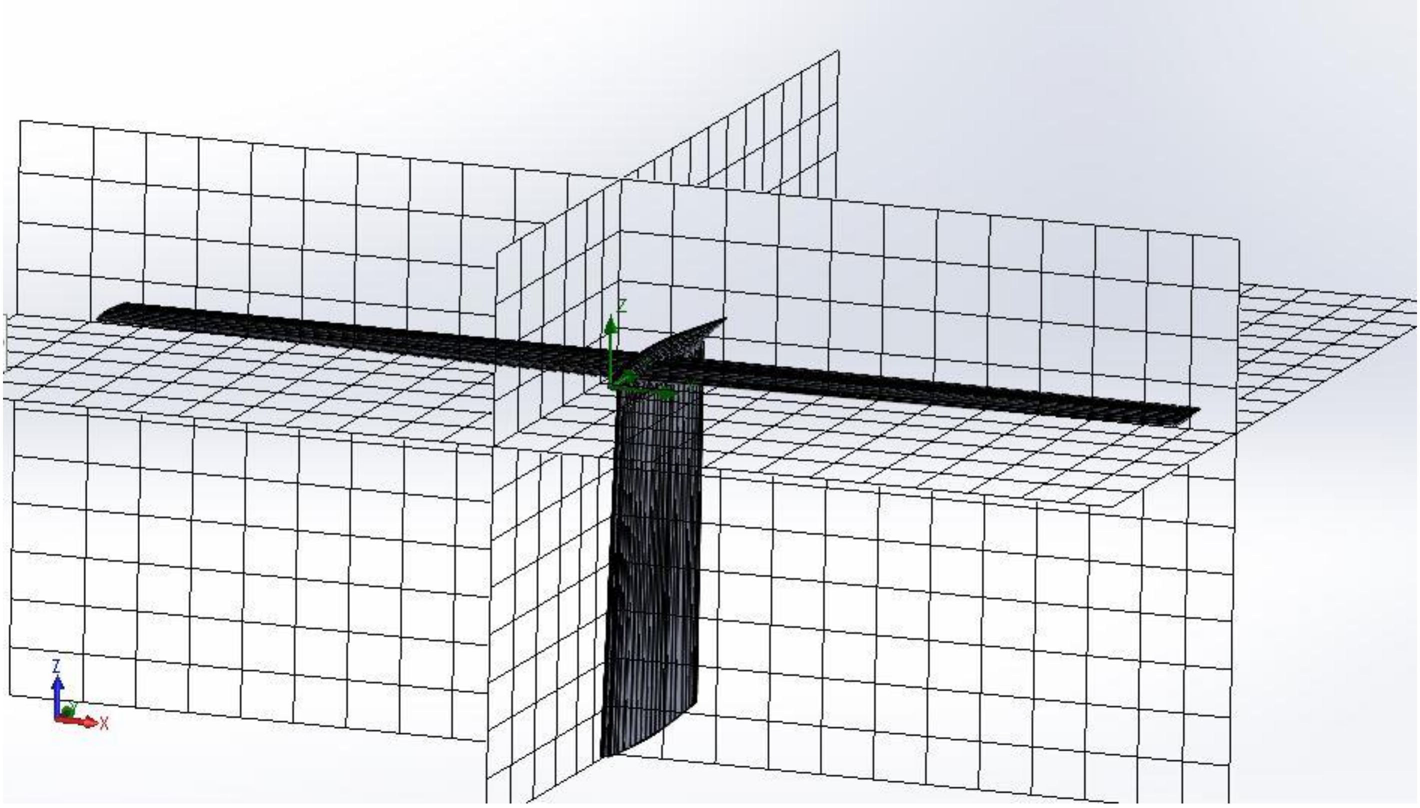


Figure 3.9.- Flow mesh.

Once the mesh is created and the boundary conditions are applied such as low density and freezing air or the air speed, the result interpretation begin.

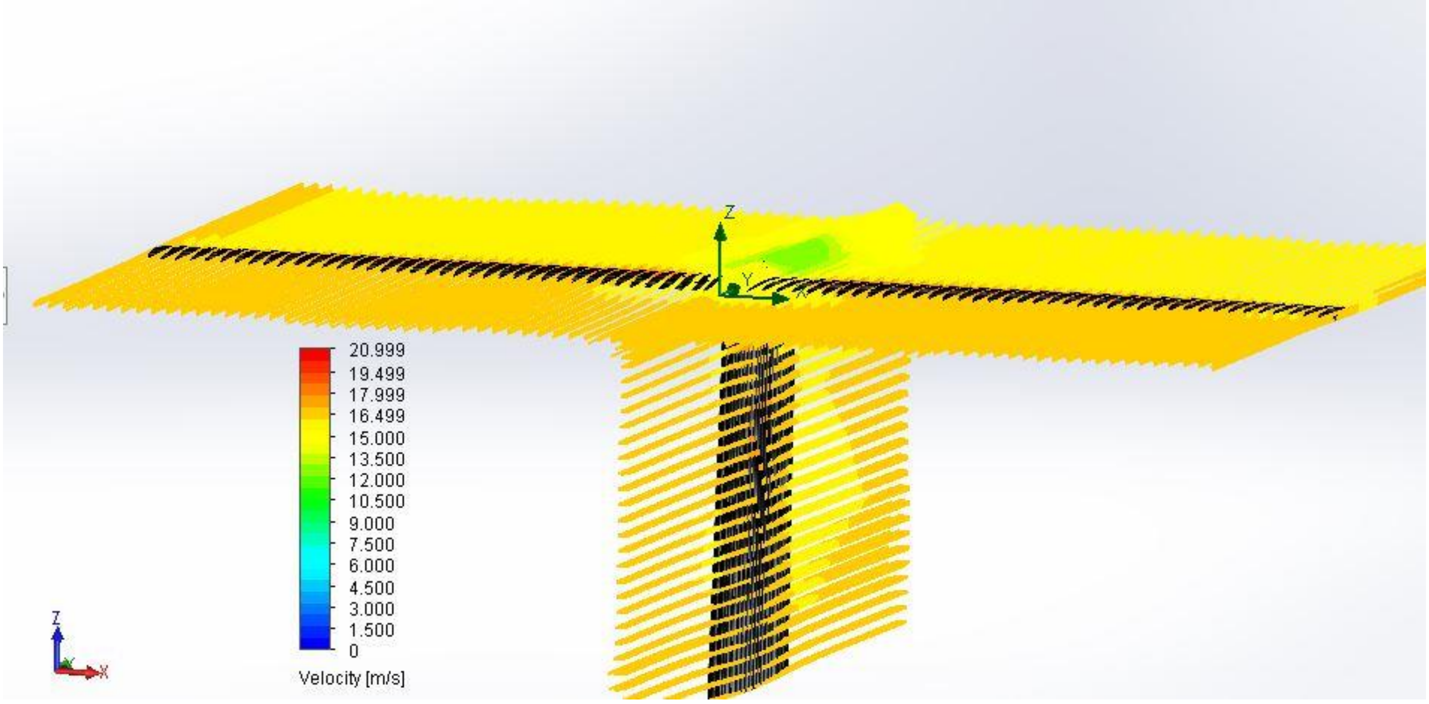


Figure 3.11.- Steam flow lines.

Is possible to see the air flow around the tail and how the air stops where there are more joins. Is interesting to see that zone in detail:

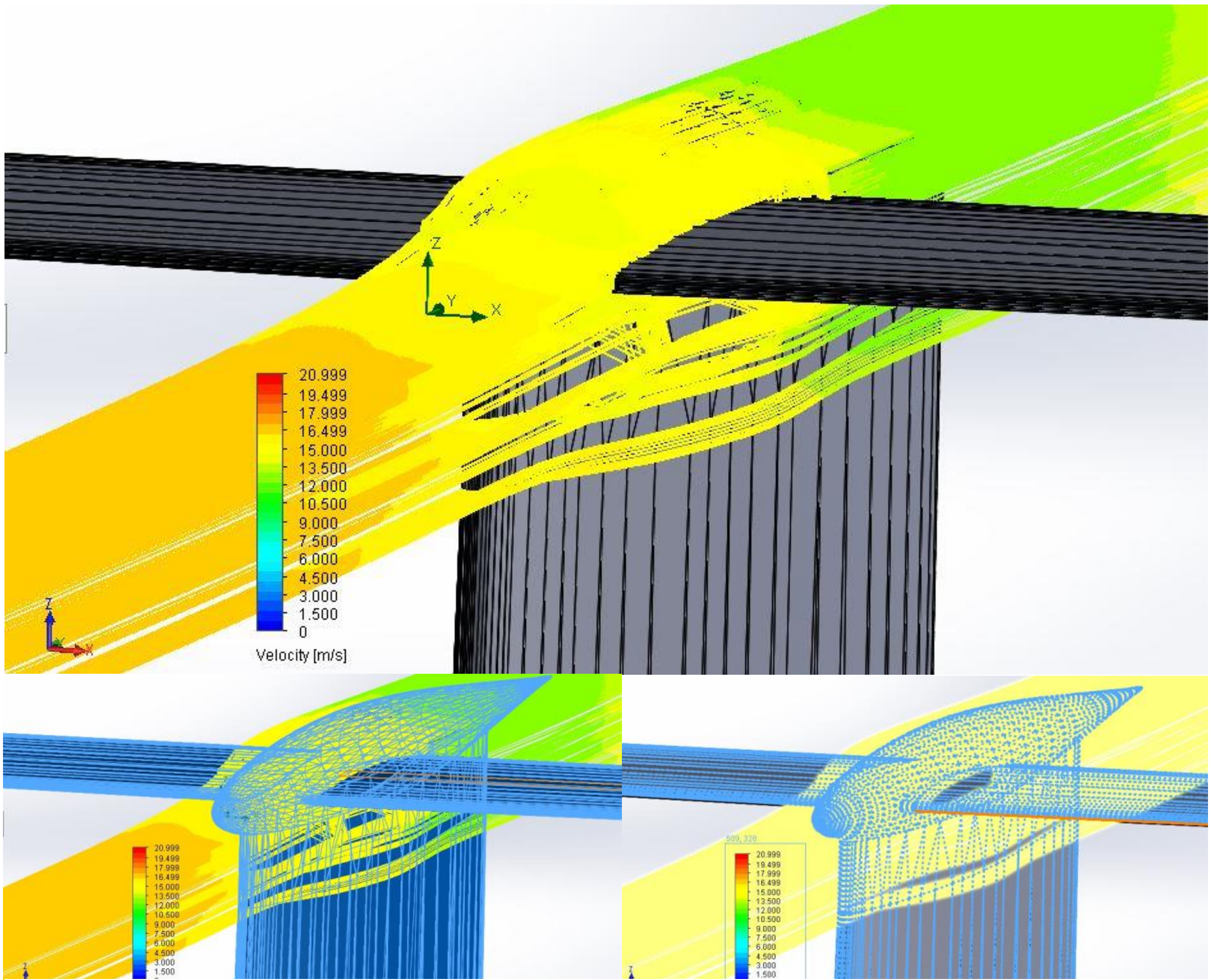


Figure 3.10.- Tear shape flow definition.

This flow is not greatly disturbed and the speed decreased from 16 m/s to 12 m/s, then the drag is not really big for this shape. Any way this shape could be improved changing the shape to reduce the disturbance.

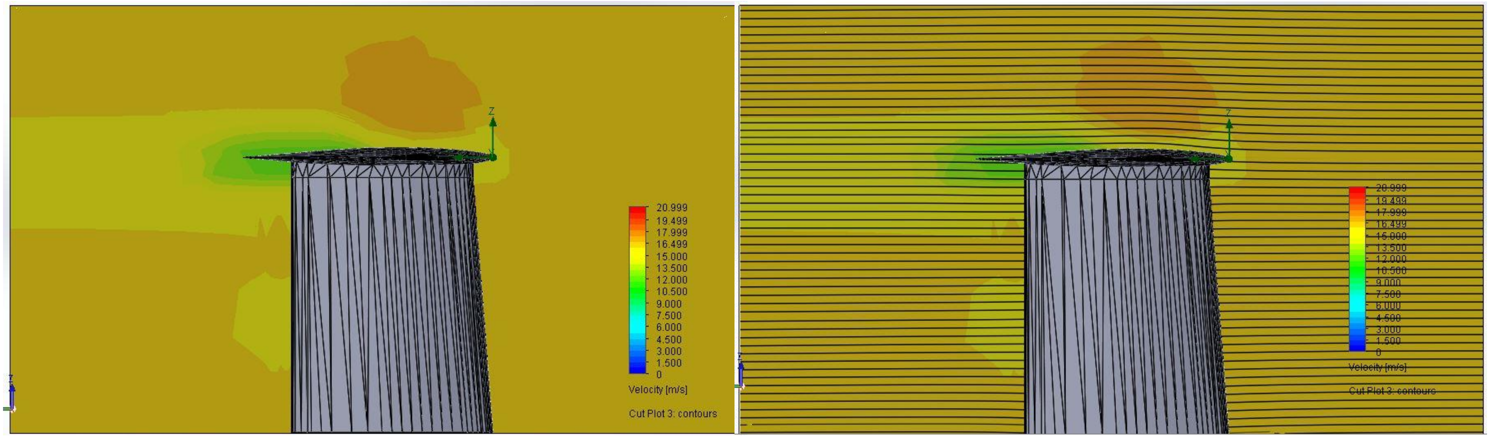


Figure 3.12.- XY Plane speed diagram.

In this section is possible to see the wake zone for the tear shape which is the main point of improvement for this design trying to reduce that drag.

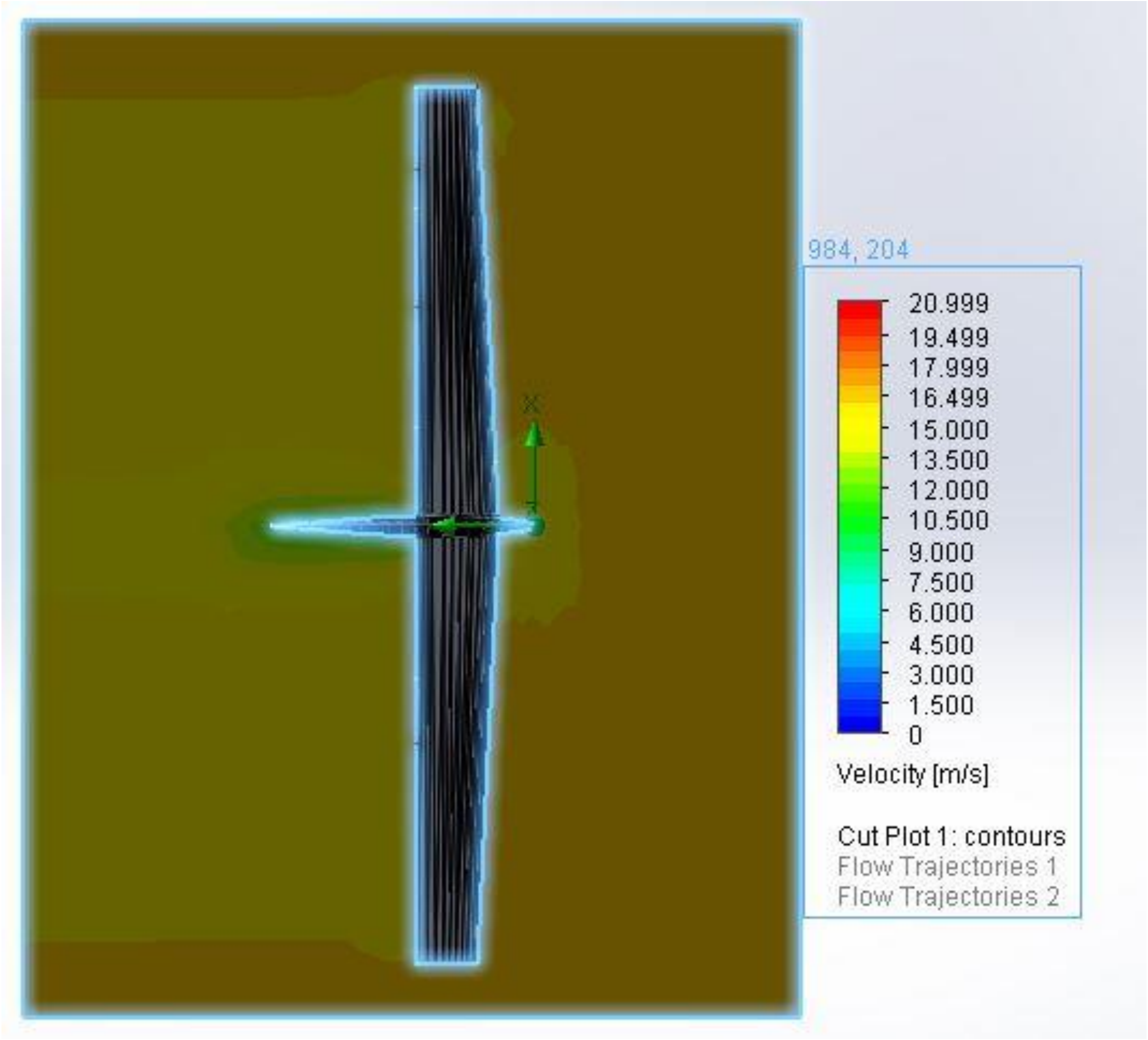


Figure 3.13.- XY plane speed diagram.

Once more is possible to see the wake region for the tear shape and here the wake zone for the horizontal tail, which makes that velocity reduce due to the inclination to generate lift force.

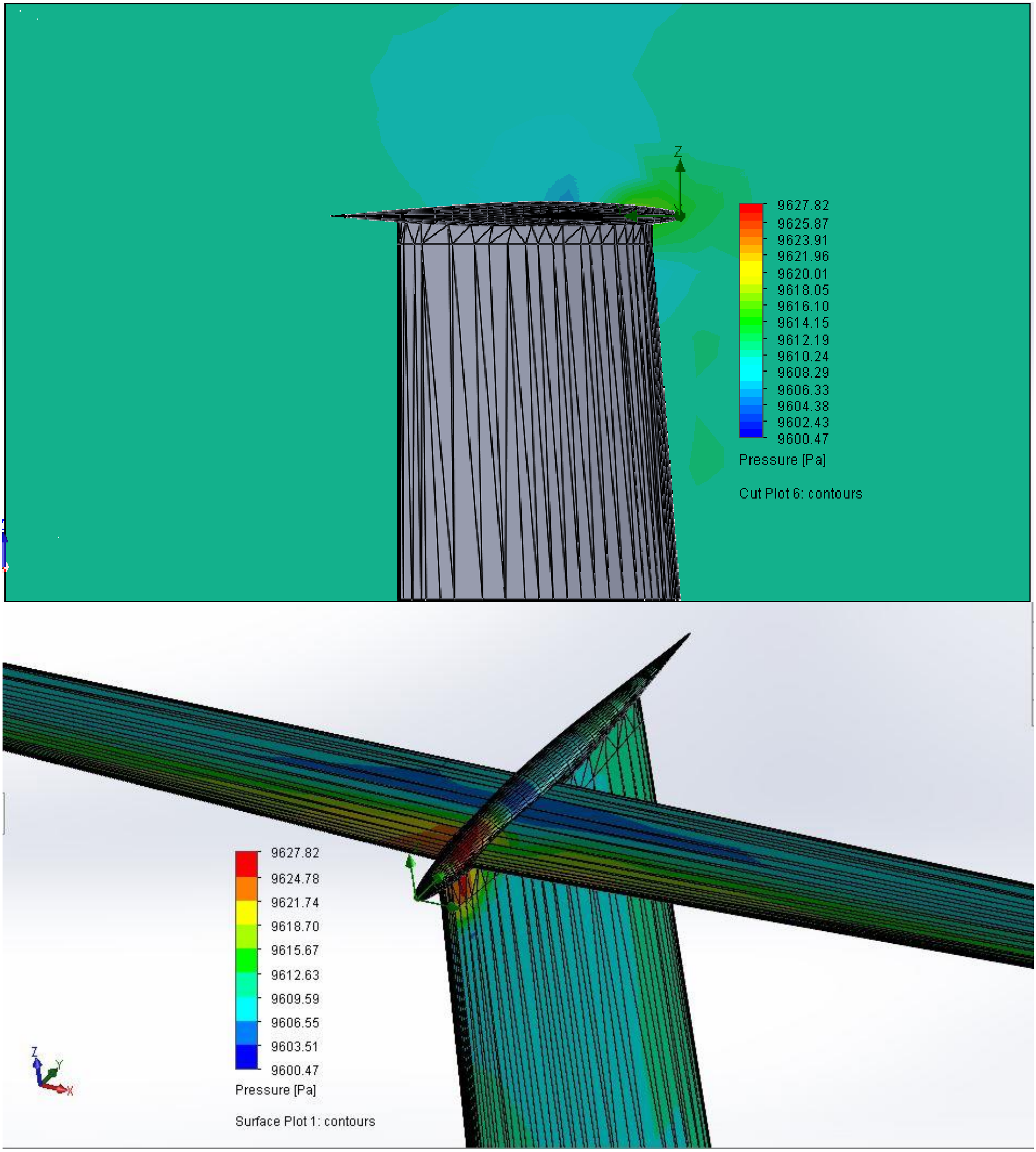


Figure 3.14.- the top one is the flow pressure around the tail and the bottom one is the pressure on the tail surfaces.

As is said before the horizontal tail generates a lift force in order to trim longitudinally the aircraft and it can be seen looking at the depression zone above the horizontal tail.

Another thing to say about is the pressure zone on the location of the pitot tube. The difference is not too big but it means that the said zone should be stronger.

With the vorticity analysis could see even better the wake region:

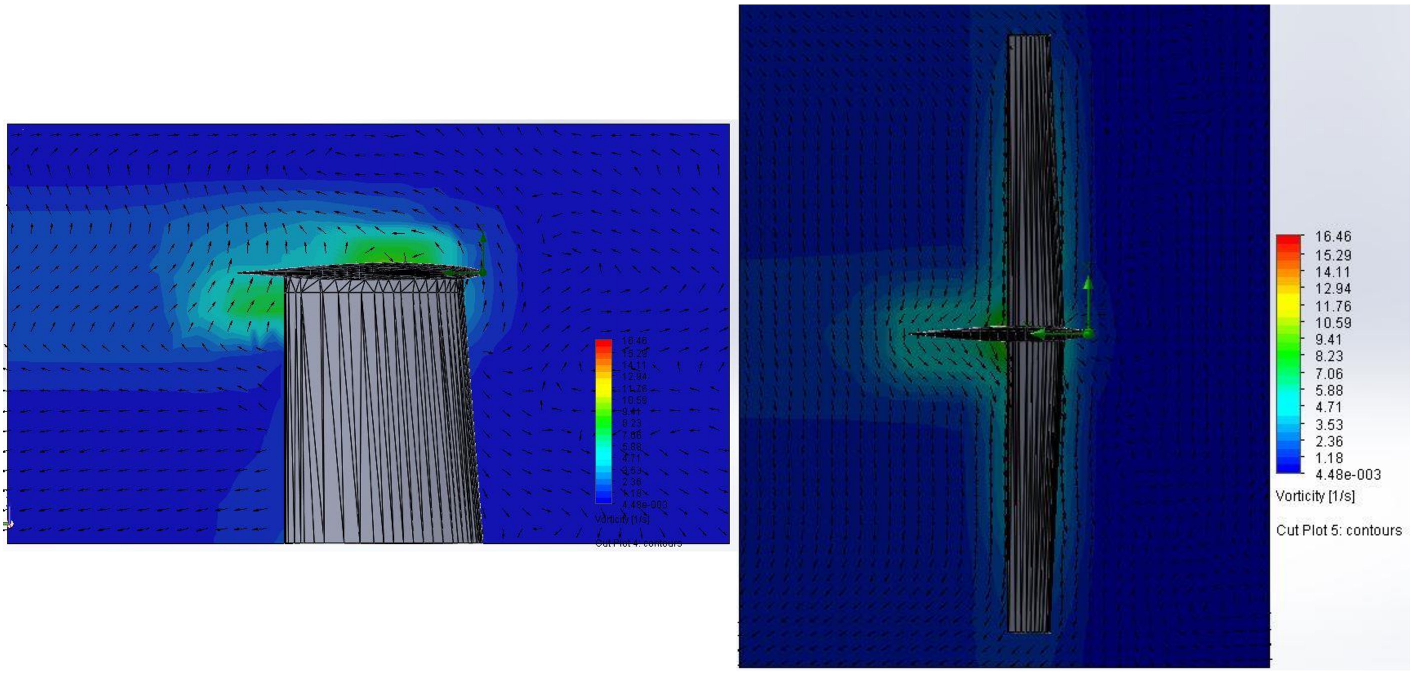
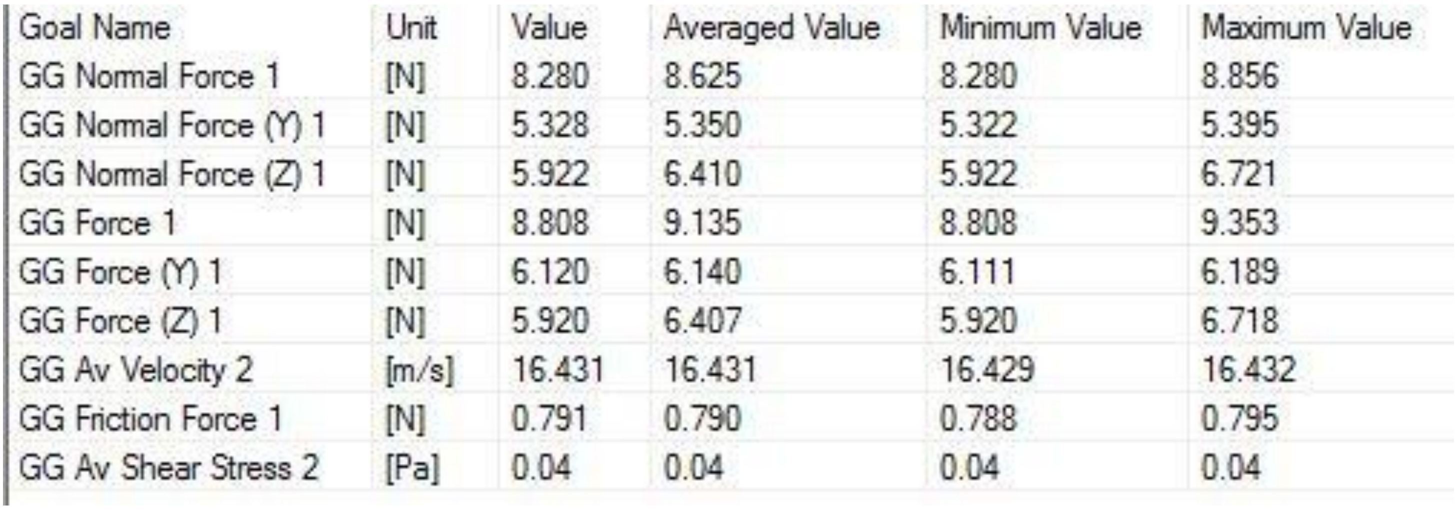


Figure 3.15.- vorticity diagrams.

The las thing to see is the forces for the tail in cruise flight:



Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
GG Normal Force 1	[N]	8.280	8.625	8.280	8.856
GG Normal Force (Y) 1	[N]	5.328	5.350	5.322	5.395
GG Normal Force (Z) 1	[N]	5.922	6.410	5.922	6.721
GG Force 1	[N]	8.808	9.135	8.808	9.353
GG Force (Y) 1	[N]	6.120	6.140	6.111	6.189
GG Force (Z) 1	[N]	5.920	6.407	5.920	6.718
GG Av Velocity 2	[m/s]	16.431	16.431	16.429	16.432
GG Friction Force 1	[N]	0.791	0.790	0.788	0.795
GG Av Shear Stress 2	[Pa]	0.04	0.04	0.04	0.04

Figure 3.16.- analysis solutions.

Looking at these values is obviously that the drag force (force (Y)), even with that problem at the tear shape is not too big so the improvement is not really needed.

The other thing is that the lift force (force (Z)) needed to trim the aircraft longitudinally is not really big so the most request flight stage is the take-off or the landing.

3.4. Structural analysis (SolidWorks)

Here is commented how strong is the structure and if it would bear the required loads. In addition will be discussed the way to improve the design in future work.

3.4.1. Horizontal ribs

Boundary conditions

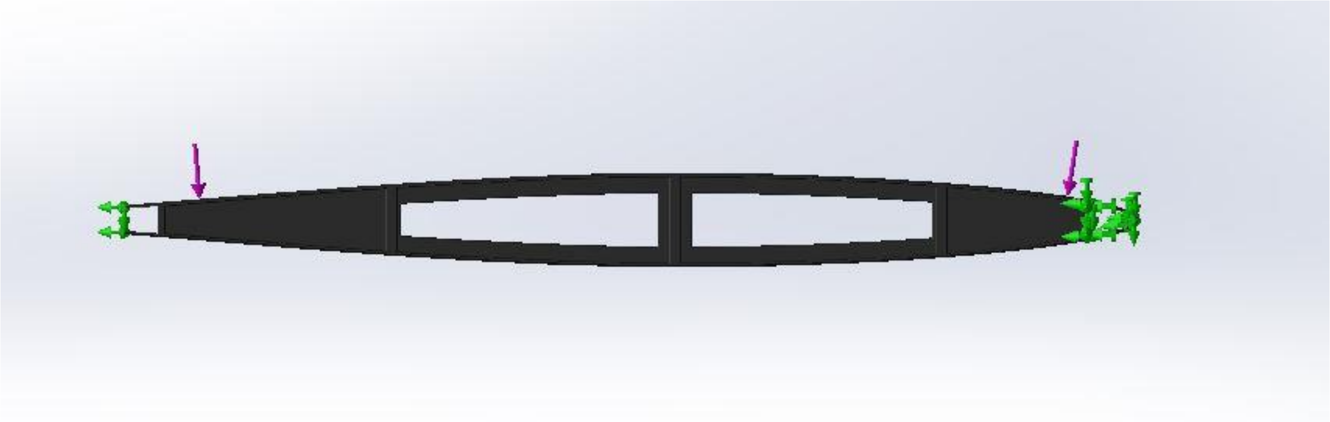


Figure 3.17.- Horizontal rib bonundary condition.

The loads are applied on the top side meanwhile the fix constrains are where the longeron are placed.

Stress analysis

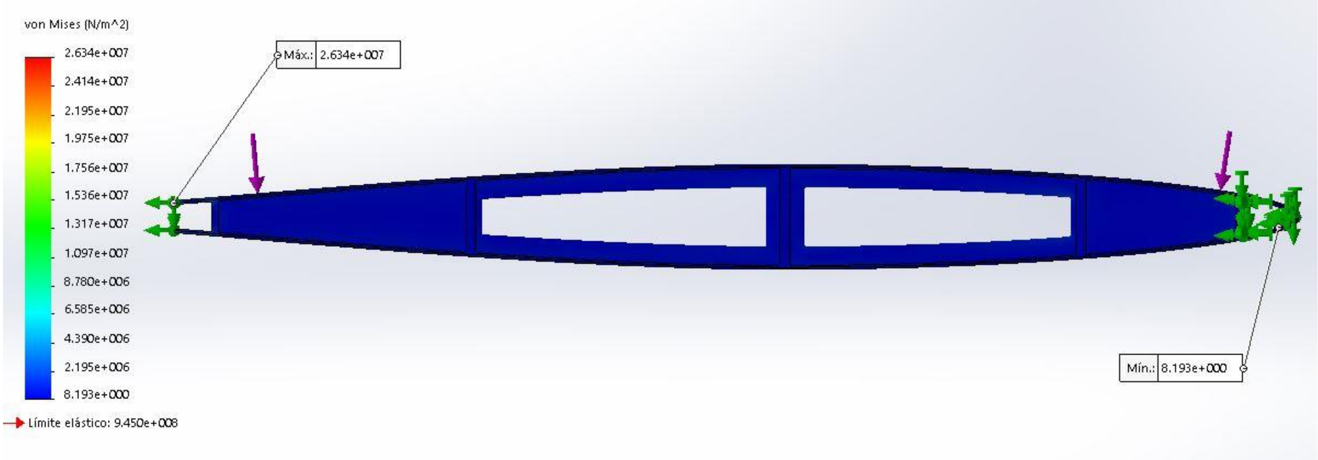


Figure 3.18.- Horizontal rib stress analysis.

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, which means that the material is working little. To fix this and improve the design, the material from the blue part must be removed, upgrading the weight and the cost at the same time. To finally improve this design, the part where the rib is more required, should be made bigger in order to resist that stress.

Deformation analysis

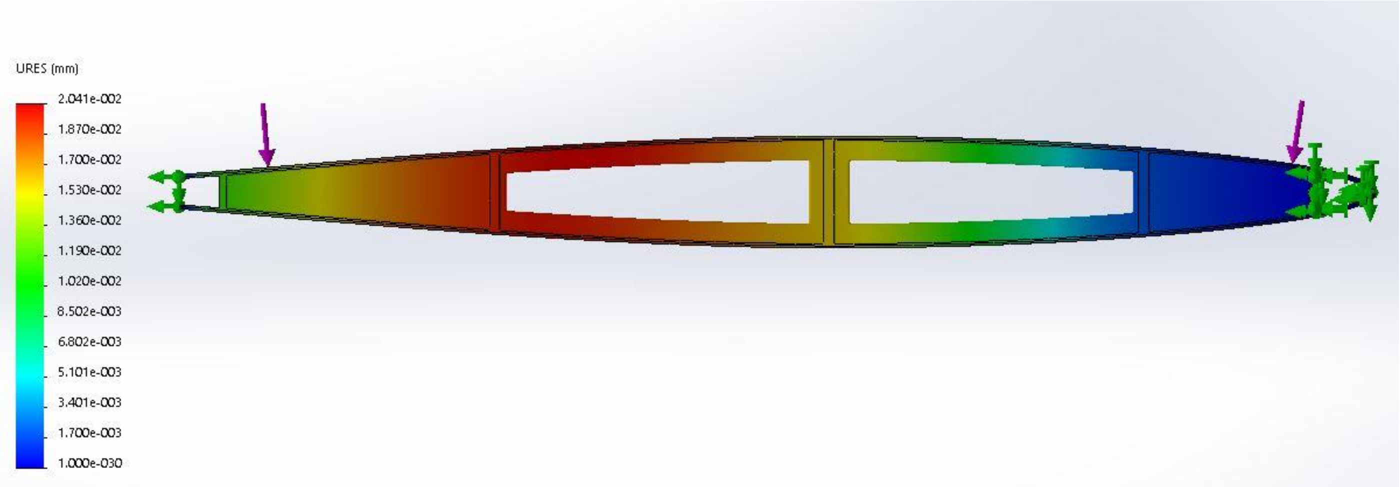


Figure 3.19.- Horizontal rib deformation analysis.

In this analysis can be showed up the displacements which not exceed the millimeter. 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.

3.4.2. Horizontal longeron

Boundary conditions

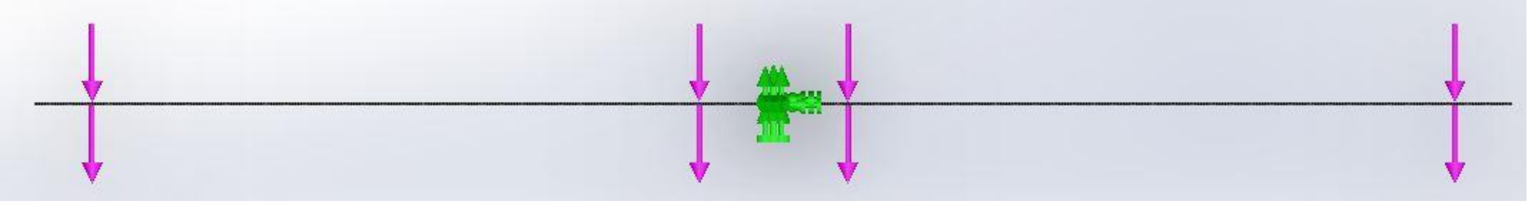


Figure 3.20.- Horizontal longeron bonundray conditions.

This image shows the loads and the holders for the horizontal longeron piece. The forces are where the airfoils should be placed and the fix where the join between horizontal longeron and vertical longeron.

Stress analysis

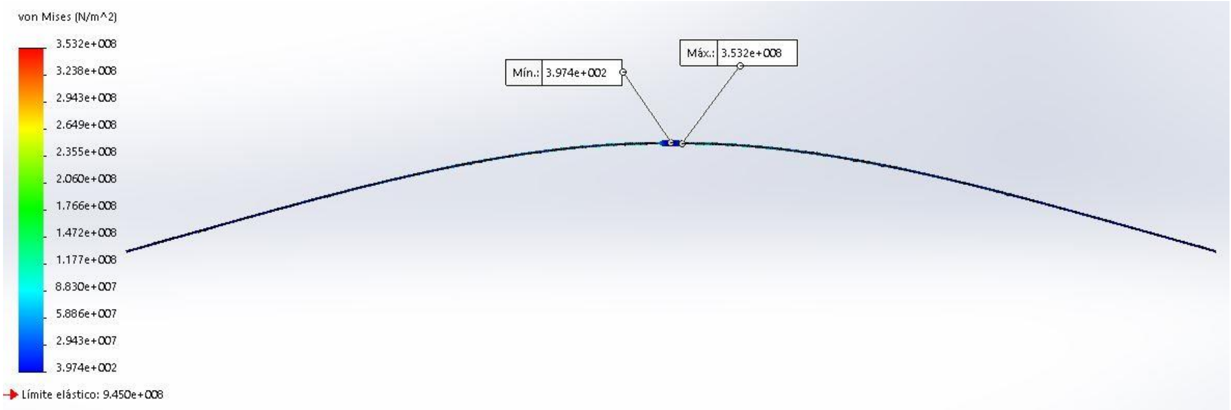


Figure 3.21.- Horizontal longron stress analysis.

In this section is possible to see that, according to Von Misses rule, the horizontal longeron do not exceed the elastic limit which means that the horizontal longeron do not break if the stress resistance is looked.

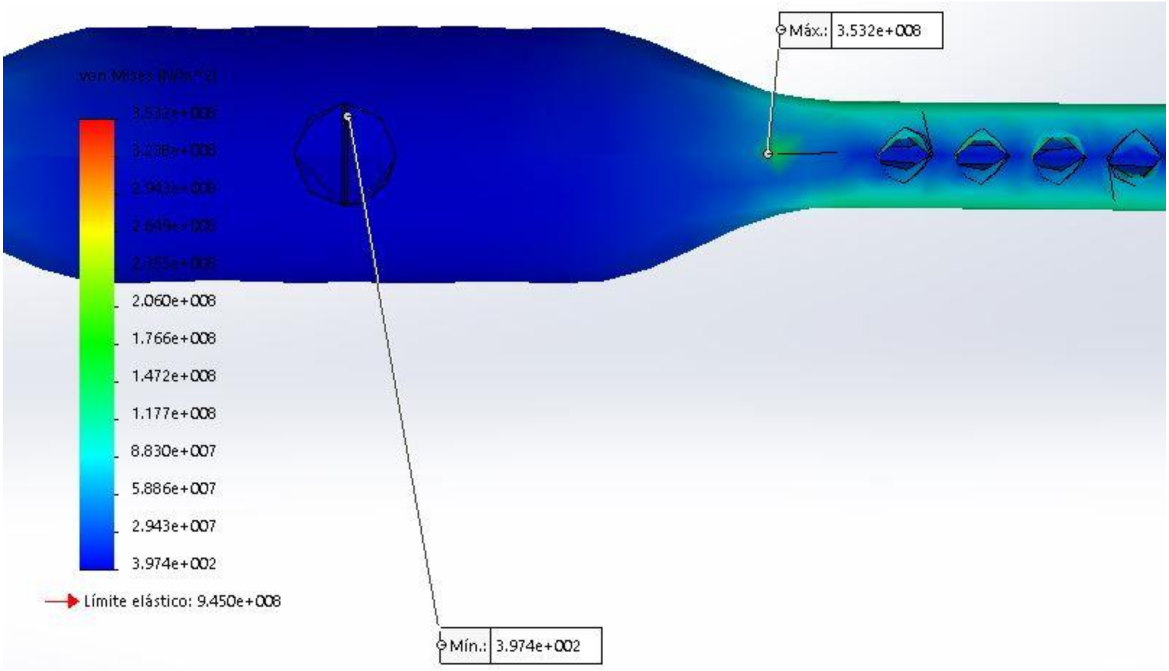


Figure 3.22.- Detailed horizontal longeron stress analysis.

Looking at the detailed image, is possible to see where the piece is required by stress. So, to optimize this part, the material from the union part could be removed decreasing the thickness and reducing the weight. As well is possible to see that the alveolate face works good reducing the weight and not compromising the endurance of the piece.

In the other hand, where the piece is more required, is needed to apply more material or to change the profile. For this case, changing that transition or union profile, “opening” it or making it bigger where the stressed point is located it would help to reduce that requirement and make the piece more optimum.

Deformation analysis

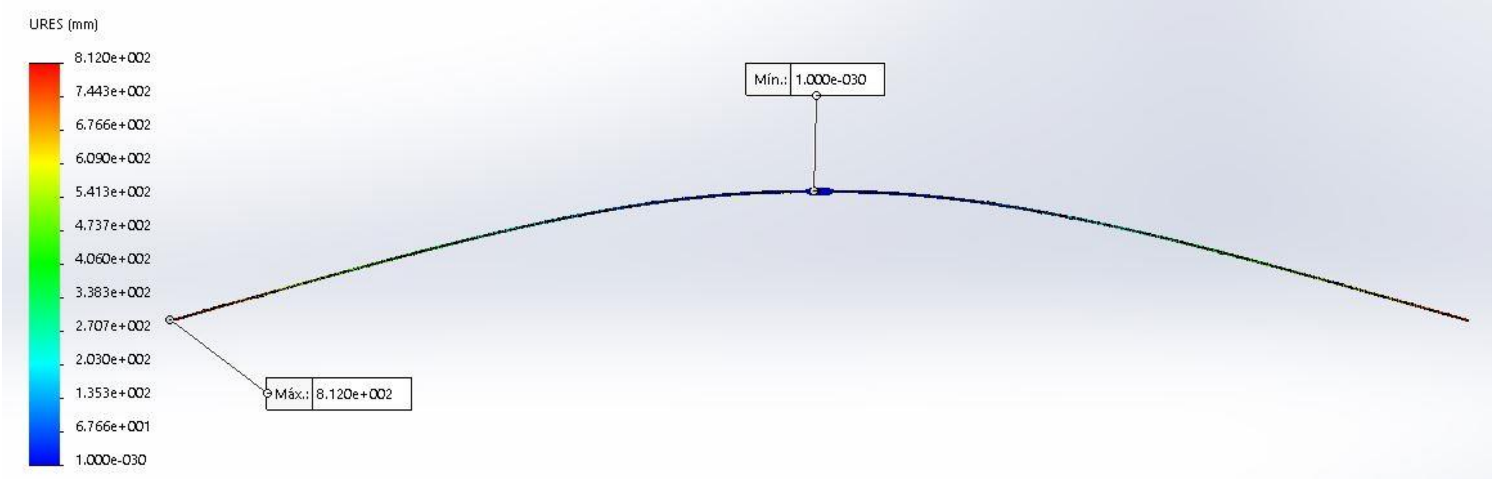


Figure 3.23.- Horizontal longeron deformation analysis.

In this analysis is possible to see the maximum deformation of this piece. It is a big dimension for this load so, is possible to decline this piece. Due to this problem, a more rigid piece is required, creating a bigger piece diameter to increase it inertia or change the longeron profile to improve the longeron in the same way.

3.4.3. Vertical ribs

Boundary conditions

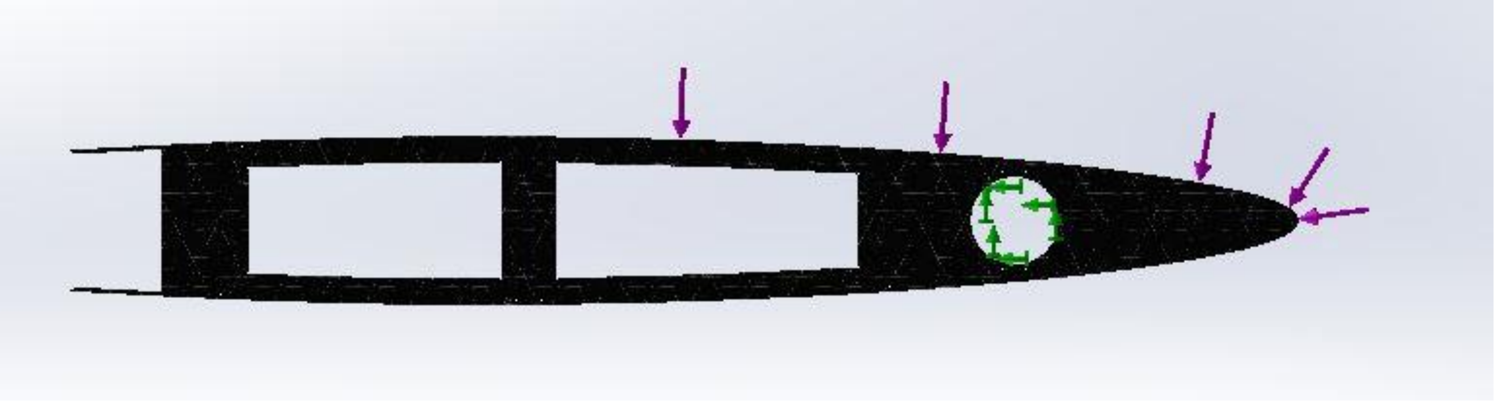


Figure 3.24.- Vertical rib boundary conditions.

As in the horizontal pieces, here is showed the loads on one of the sides and where the longeron is placed.

This section is similar as the homonym for the horizontal one.

Stress analysis

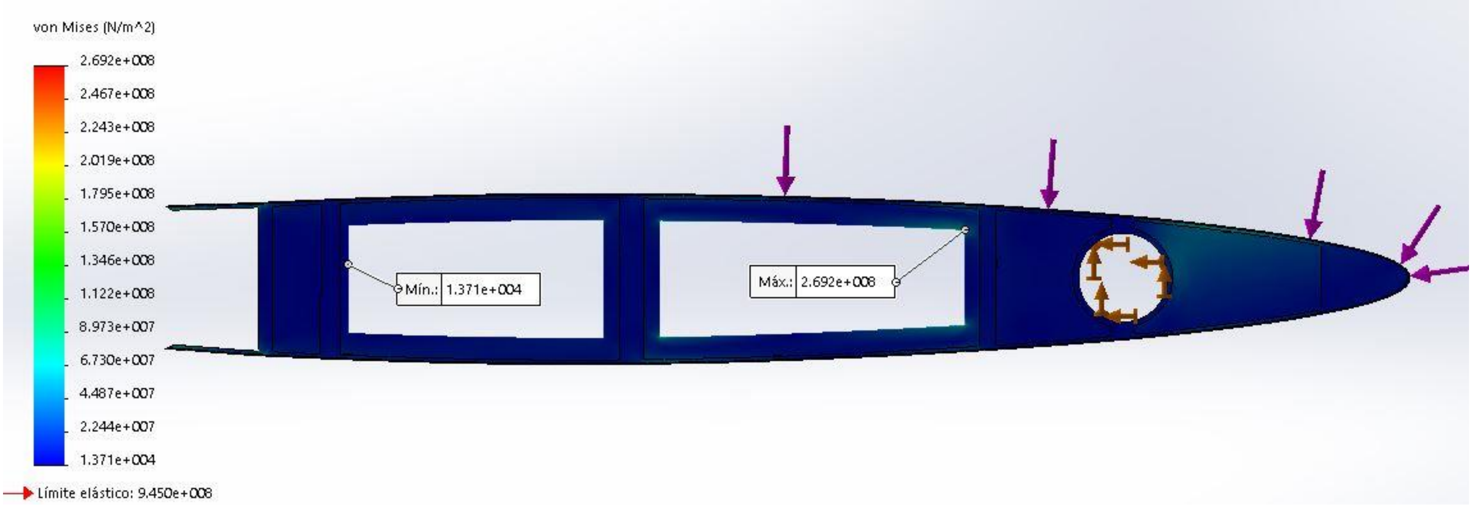


Figure 3.25.- Vertical rib stress analysis.

The analysis for this vertical rib is similar for the horizontal rib, is possible to reduce the material from the blue parts while the red parts is needed to improve. In this case, the red part is a very small fillet so the solution is to increase the radius of said fillet.

So, the ways to optimize this rib is making the pockets bigger and make new pockets and making the fillet radius bigger too.

Deformation analysis

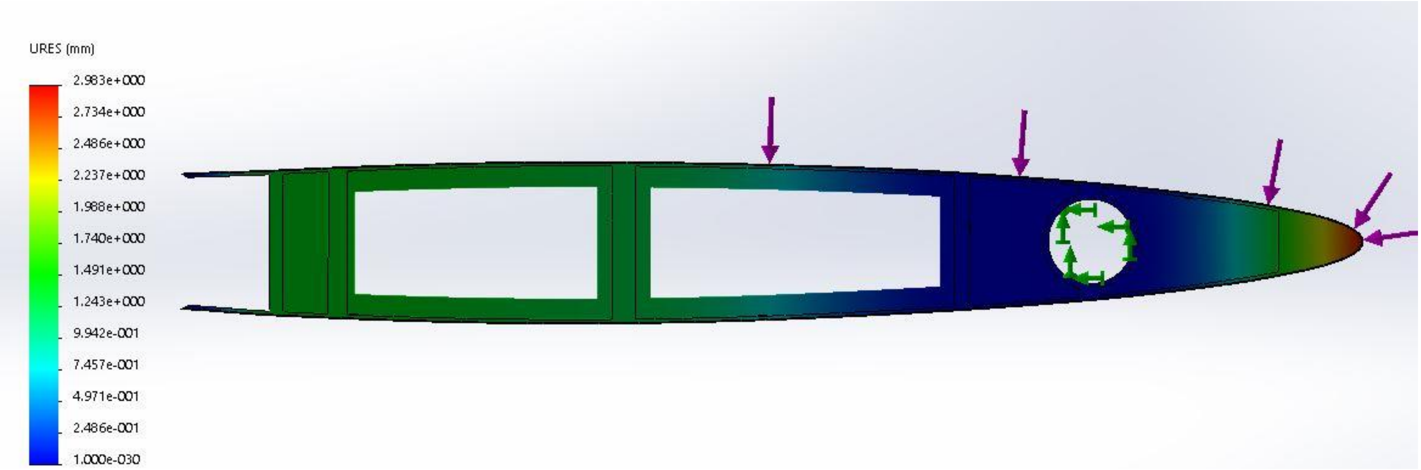


Figure 3.26.- Vertical rib deformation analysis.

As can be seen the critical deformation is when the airfoil receives the wing from the side and the front at the same time and it causes a deformation of 3 millimeters, then, is needed to make stronger this part and reduce the material used on the others. Other options are to increase the inertia of that part using another design or to place the longeron more forward to give more stability to that part.

3.4.4. Vertical longeron

Boundary conditions

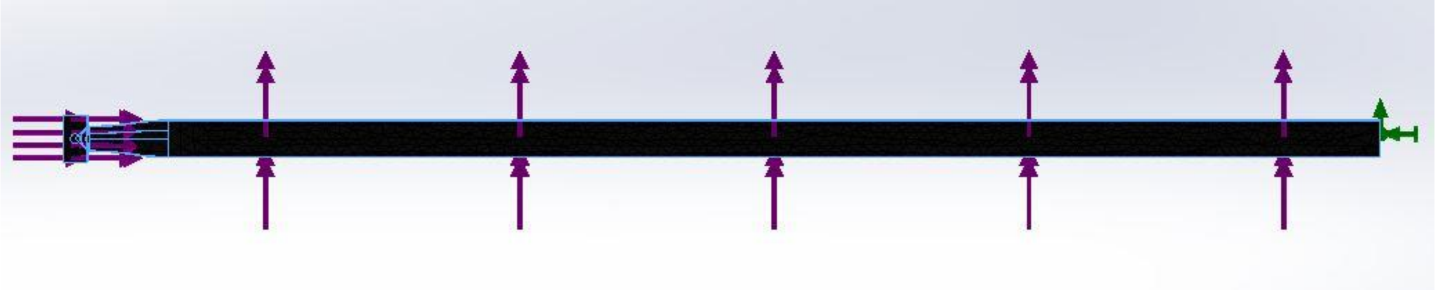


Figure 3.27.- Vertical longeron boundary condition.

Once more the loads and the fix points are showed in the image. Is necessary to say that for this part the real fixing mechanism it cannot be simulated or created then the results will not be the exactly expected one but them gives an approximation to optimize the piece.

Stress analysis

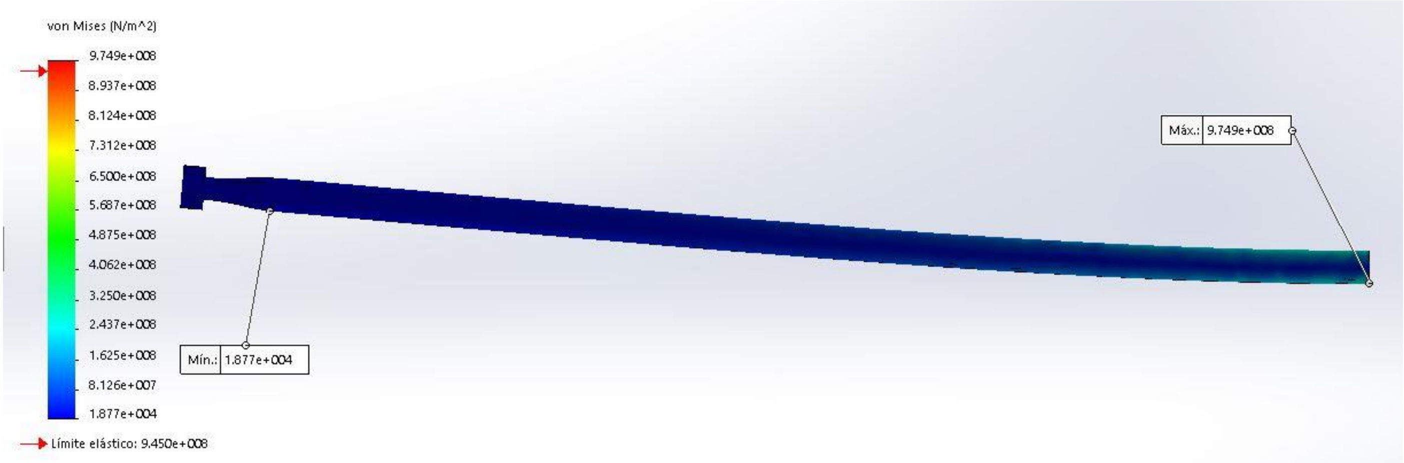


Figure 3.28.- Vertical longeron stress analysis.

In this picture can be seen that the elastic limit is reached, but that point is in a fixed point which is not the real fixing way, then for the real mechanism would be an area and the elastic limit is supposed not the be reached with that solution.

Taking this with care, the piece could be improved reducing the thickness due to whole piece is on dark blue. That is traduced in a reduced weight and cost.

Deformation analysis

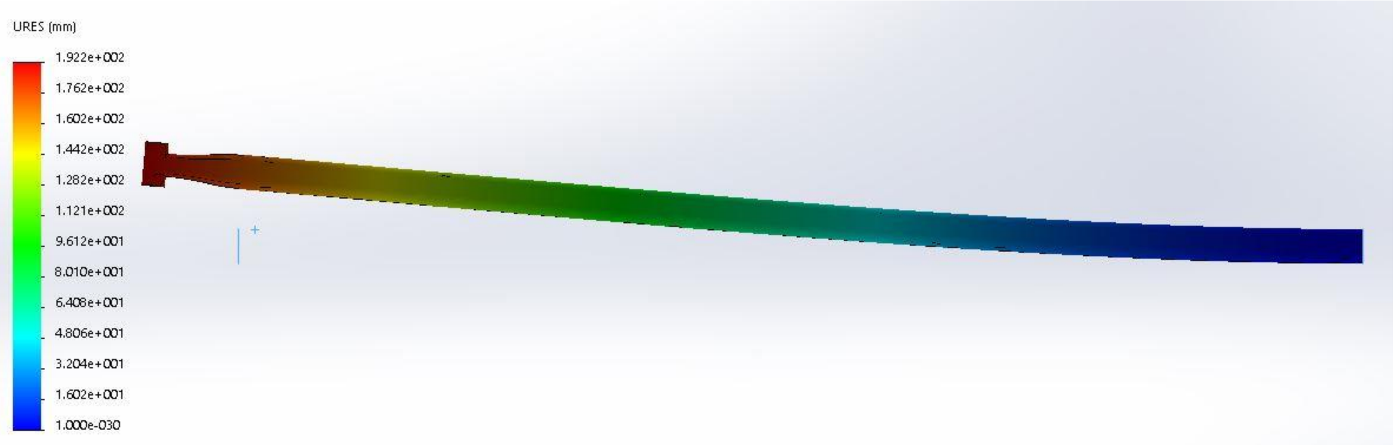


Figure 3.29.- Vertical longeron deformation analysis.

In this image is can be seen the maximum deflection which is 192 mm that is not a very big deformation but if more rigidity is needed the design should be improved doing other profile, making the tube bigger or using more longerons.

4. Description of control system

The following flow chart shows the global control:

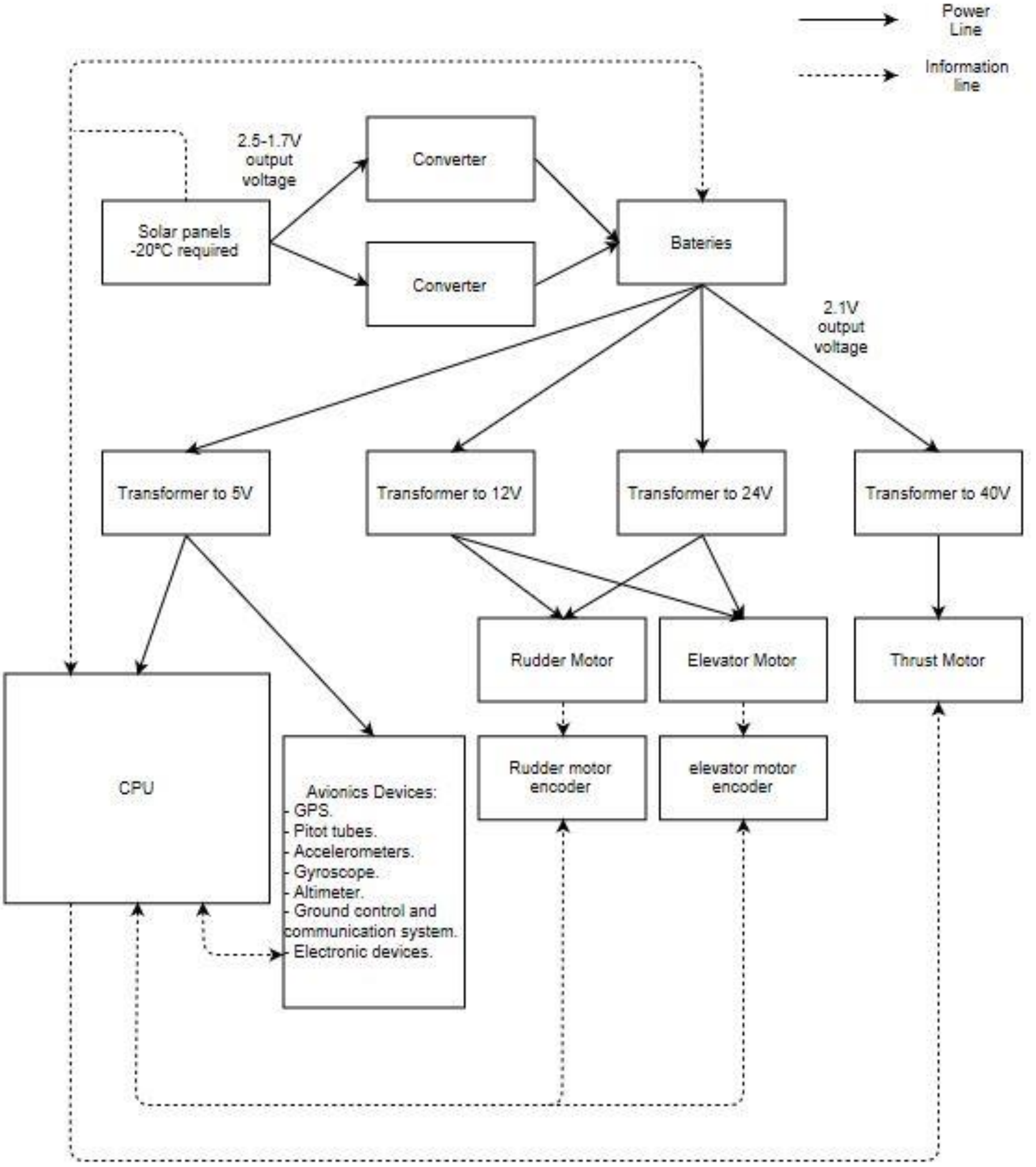


Figure 4.1.- Control scheme

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

To a safety work and workplace firstly is needed a recognition of all possible risk and accident could happen.

Once the risks are identified, the second step is to evaluate to plan corrections actions to control them.

The risks criteria are 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, etc.

Medium: the risk might occasionally occur, damage will happen at times.

For example: burns, minor fractures, sprains, etc.

Low: the injuries aren´t disabling, or the loss of material is slight.

For example: minor impacts, eyes irritations, cut, etc.

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 5.1.- Table of risk level depending in severity and probability

RISK AND SAFETY EVALUATION					Page nº 1
Company:	HALE UAV builder.				
Position:	**Head of Unit**	Date:			
Nº Ref	1.1	Nº of workers:			
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: Nº of workers:
Position:	**Maintenance technician**	
Nº Ref	1.2	

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.	Date:	
Position:	**Forklift operator**		
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

This study was done with the help of software SERAP.

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 the develop 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 can be destroyed some unknown features or archaeological importance so a geological study is needed.

As well the vibration can cause some collapses.

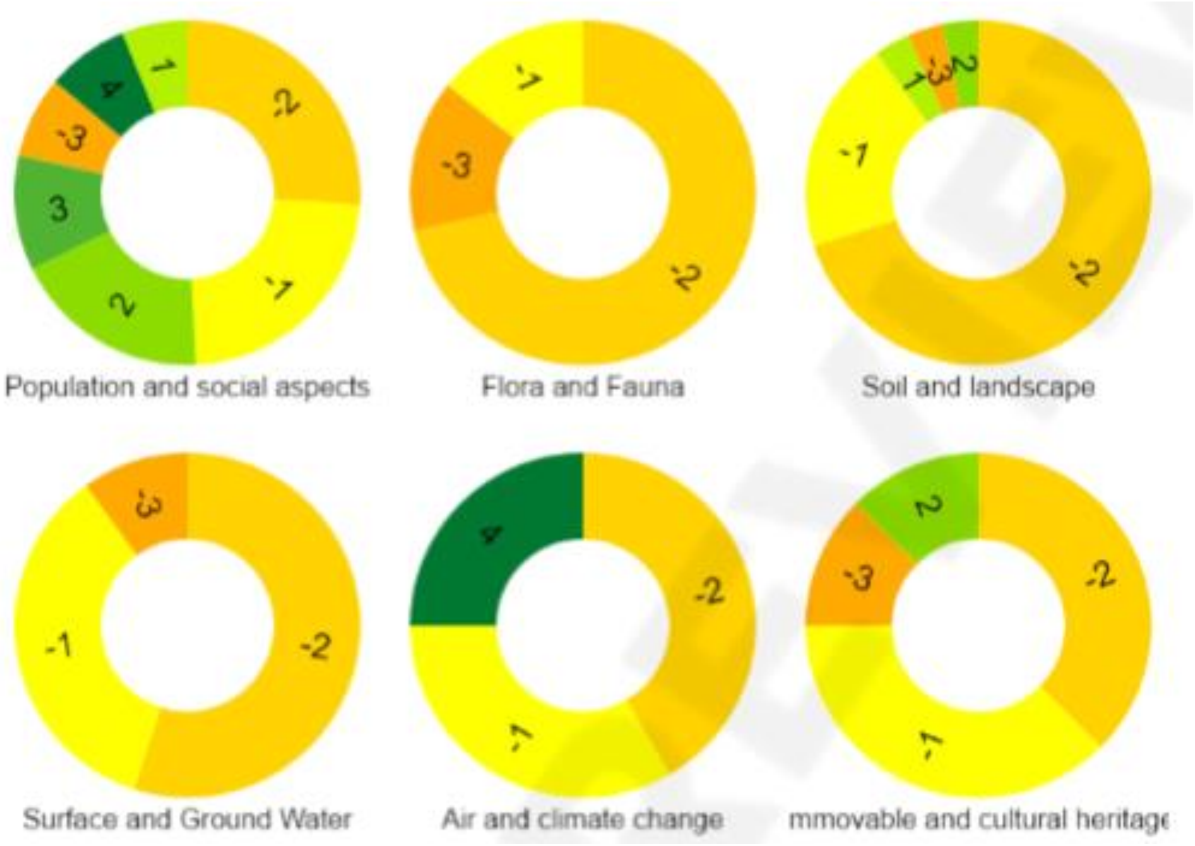


Figure 6.1.- Punctuation of all section about projects according to [6]

7. Economical calculations

In manufacture planning is important to know the potential sales and profits and know if the project is available or, on the other hand, it is not. The procedure consists in analyzing and calculating fixed and variable costs, carrying out a market research and calculate the break-even point where the profits began.

Calculating the break-even point is a financial analysis method used by businesses. Once is known the fixed and variable expenses for the product the business produces or a good approximation of them, is possible to use such information to calculate company's break-even point.

Estimating the price of all the elements of the HALE-UAV is the first task to do; this labor would consist on differentiating fixed and variables costs:

Fixed costs are those does not change with an increase or decrease in the number of units or services produced; in the case of the airplane at hand, the fixed costs are the price of the office employees, molds or the industrial plant building for example.

A variable cost is a company expense that varies with production output. Variable costs are those exes 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, or raw materials as carbon fiber are example for this type of cost.

Prices List

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

STRUCTURAL		
Carbon Fiber	300	€/kg
TOTAL	**15000**	**€/tot**
Solar panels	850	€/m^2
TOTAL	**31450**	**€ - 37 m^2 aprox.**
Batteries	312.5	€/kg
TOTAL	**2500**	**€ - 8 kg aprox.**
Flax Fiber covering	77.5	€/m^2
TOTAL	**9300**	**€ - 120m^2 aprox.**

Table 7.1.-Structural raw material cost.

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 7.2.- Devices cost.

These devices conform the part called as Avionics system, and the prices are easily found in companies' websites and asking for budget to them.

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

Table 7.3.- Molds cost.

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 7.4.- Employees cost.

The last thing to approximate is the employees' salary but this approximation does not include the business employees and is a rude approach.

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

PARTS		
	cover	elements (€)
	WING	
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 7.5.- Cost splitted by parts.

Break-even point calculation

As the HALE UAV market does not 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:

$$\text{Breakeven point [UNITS]} = \frac{\text{Fixed Cost}}{\text{Sales Price per Unit} - \text{Variable Cost per Unit}}$$

Equation 7.1

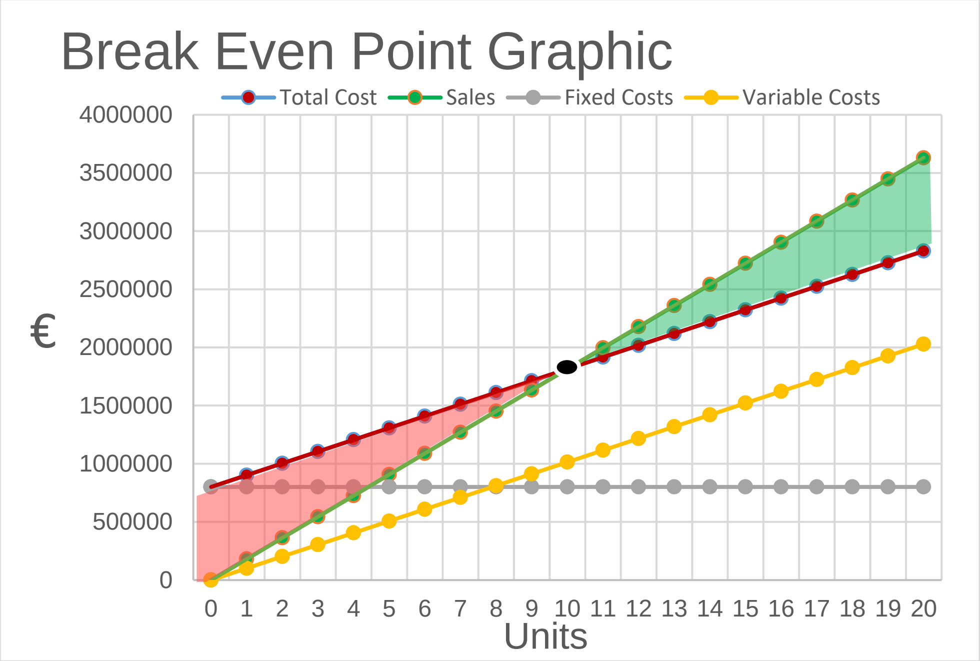
As number of units will be 10, and Fixed Cost and Variable Cost per Unit has been calculated, it is easy to solve equation (7.1), obtaining Sale Price per Unit.

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

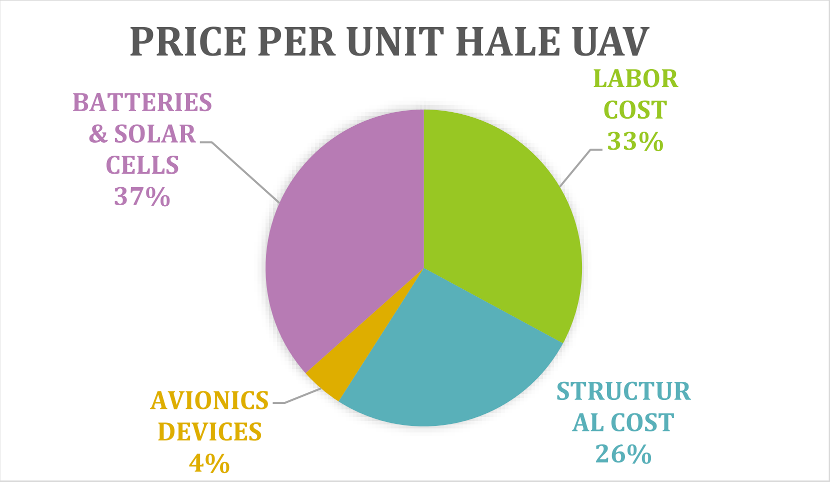
PRICE PER UNIT	**181495**	**€**

Table 7.6.- Final cost.

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



Graphic 7.2.- Break-Even point graphic.



Graphic 7.1.- Percentage of cost for a unit.

8. Conclusions

What left to say is what would happen with the UAV-HALE project in the future.

In terms of problems that can occur 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:

- Ice on the wing can change the shape of the wing and make the UAV to stall and fall.
- Ice on the thrust motors can break them up and leave the UAV without propulsion.
- 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 makes the plane to get heavier and, with many ice, make the plane collapse because of that extra weight and fall.
- Frozen components as batteries, GPS, CPU or any other, may 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 fiberglass for the volumes where the electronic components are. The fiberglass has a small coefficient of conductivity (around $0.044 {}^{W}/_{m^{\circ}C}$) 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.
- Install 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.
- 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 but it is worthy if they work and makes the aircraft not to be broken by ice.

Another problem that could happen is the deep stall of the vehicle which cannot be solved. The program which control the aircraft can above this situation not to get in deep stall but get into that situation is a possibility and the automatism cannot solve it.

In terms of future work to do is optimize the parameters of the aircraft working all parts of the UAV together in order to get the best values possible. Another thing to do is optimize the design to reduce the weight. As is said before, this project is an early stage of UAV design and some of the goals are not reached then the airplane should be improved.

Finally, what left to do is a strong programming and testing the device and how it works with some test flights before its use. The program should be good enough to enable the auto-pilot the most time possible with a path entered.

List of references

1.- NASA page for stabilators analysis. - *https://www.grc.nasa.gov/WWW/K-12/airplane/stablator.html*

2.- NASA page for airplane information. - *https://www.grc.nasa.gov/WWW/K-12/airplane/cp.html*

3.- Page of Wikipedia giving information about aircraft elevator. - *https://es.wikipedia.org/wiki/Tim%C3%B3n_de_profundidad*

4.- Page about how planes works. - *http://www.asifunciona.com/aviacion/af_avion/af_avion12.htm*

5.- Envigo (environmental impact assessment) powered by eon+ page for the environmental impact optimization and testing. - *http://envigo.eon-plus.com/account/projects/uticajis/438* by *http://www.envigo.software/*

6.- Information about Canard configuration. - *https://es.wikipedia.org/wiki/Canard*

7.- NASA research about inclination effects on the airplane. - *https://www.grc.nasa.gov/WWW/K-12/airplane/incline.html*

8.- NASA research about rochet aerodynamic. - *https://www.grc.nasa.gov/WWW/K-12/rocket/shortr.html*

9.- NASA index about aerodynamics topics. - *https://www.grc.nasa.gov/WWW/K-12/airplane/short.html*

10.- Information about longeron structure. - *https://es.wikipedia.org/wiki/Larguerillo*

11.- Information about how the aerodynamic chord works. - *https://es.wikipedia.org/wiki/Cuerda_(aeron%C3%A1utica)*

12.- Page about how the wings for an aircraft works. - *https://es.wikipedia.org/wiki/Ala_(aeron%C3%A1utica)*

13.- Information about MAC. - *http://www.aviationcorner.net/view_topic.asp?topic_id=10031*

14.- Aerodynamic principles explanation. - *http://juanzitnik1.tripod.com/sitebuildercontent/sitebuilderfiles/4_aerodinamica.pdf*

15.- Parameters for wing. - *http://www.oni.escuelas.edu.ar/2003/buenos_aires/62/tecnolog/alas.htm*

16.- Dassault Systemes solar powered aircraft project. - *https://www.3ds.com/industries/aerospace-defense/solar-impulse/*

17.- Materials used in aircrafting. - *http://www.sandglasspatrol.com/IIGM-12oclockhigh/Materiales%20Aeronauticos.htm*

18.- Wing construction. - *https://es.slideshare.net/klawmere/construccin-del-ala-de-un-avin*

19.- Aircrafting concepts. - *http://es.avia.pro/blog/obshivka-samoleta*

20.- Aircraft structure. - *http://www.aero.ing.unlp.edu.ar/catedras/archivos/Estructuras%20Aeronauticas%20Rev%20001.pdf*

21.- Aircraft design. - *https://gatovolante.wordpress.com/2015/02/05/estabilidad-lateral-el-diedro-ii/*

22.- RA glider wing design. - *https://gatovolante.wordpress.com/2014/07/06/disena-tu-velero-clase-2m/*

23.- RA glider tail design. - *https://gatovolante.wordpress.com/2014/07/11/diseno-de-un-velero-clase-2m-los-estabilizadores/*

24.- RA glider fuselage design. - *https://gatovolante.wordpress.com/2014/07/08/diseno-de-un-velero-clase-2m-el-fuselaje/*

25.- Important aspect for glider design. - *http://www.academia.edu/8520351/ASPECTOS_RELEVANTES_DEL_DISE%C3%91O_DE_PLANEADORES_DE_ALTA_PERFORMANCE*

26.- Guide for glider pilot "Manual del piloto de vuelo sin Motor" – author: Guido Enrico Bergomi and Francesco Padovano. Edition: Bibliotheka Edizioni, 15 may. 2015.

27.- Structure design project "Diseño estructural y construcción de un avión no tripulado: El Proyecto Céfiro" – author: Daniel Pérez Alcaraz and Sergio Esteban Roncero.

28.- Dynamical stability research "A theoretical analysis of longitudinal dynamic stability in gliding flight" – author: H. M. Lyon, P. M. Truscott, E. I. Auterson and J. Whatham.

29.- Aircrafting design "Aircraft Design: A Systems Engineering Approach" – Author: Mohammad H. Sadraey. Edition: John Wiley & Sons, 20 nov. 2012.

30.- Glider design. - *http://students.iitk.ac.in/aeromodelling/downloads/glider.pdf*

31.- Aerodynamics on flight. - *https://www.faa.gov/regulations_policies/handbooks_manuals/aircraft/glider_handbook/media/gfh_ch03.pdf*

32.- Aircraft design approach "Systems Engineering Approach in Aircraft Design Education; Techniques and Challenges" – Author: Mohammad H. Sadraey and Nicholas Bertozzi, Daniel. Edition: 122nd ASEE Annual Conference and Exposition; June 14-17, 2015.

33.- How a stall system works. - *https://aviation.stackexchange.com/questions/14727/how-do-aircraft-stall-warning-systems-work*

34.- NASA research for calculating de gravity center of an aircraft. - *https://www.grc.nasa.gov/www/k-12/airplane/acg.html*

35.- Page for calculate the gravity center of an aircraft. - *https://en.wikipedia.org/wiki/Center_of_gravity_of_an_aircraft*

36.- Aircraft weights. - *https://www.ivao.aero/training/documentation/books/SPP_aircraft_weight.pdf*

37.- MATLAB courses. - *http://www.caminos.upm.es/default.asp*

38.- MATLAB wiki. - *https://es.wikibooks.org/wiki/Matlab*

39.- Airfoil selection and information. - *http://airfoiltools.com/*

40.- MATLAB information. - *https://es.slideshare.net/morones.om/guia-rapida-de-matlab-comandos-basicos-graficacion-y-programacion*

41.- NASA technical note "Longitudinal aerodynamic characteristics of flight, twin-engine, propeller-driven airplanes". – Author: Chester H. Wolowicz. Edition: Flight research center; national aeronautics and space administration · Washington D.C., June 1972.

42.- AE 430 - Stability and Control of Aerospace Vehicle. - *http://people.clarkson.edu/~pmarzocc/AE430/AE-430-6.pdf*

43.- Temperature change. - *http://hyperphysics.phy-astr.gsu.edu/hbasees/Kinetic/barfor.html*

44.- Gravity change. - *http://intercentres.edu.gva.es/iesleonardodavinci/Fisica/Campo_gravitatorio/Campo_gravitatorio08.htm*

45.- General Description of the Atmosphere “Atmospheric Physics”. – Author: J. V. Iribarne and H.-R. Cho. Edition: D. Reidel Publishing Company 1980.

46.- HALE information. - *https://en.wikipedia.org/wiki/High-Altitude_Long_Endurance*

47.- UAV information. - *https://en.wikipedia.org/wiki/Unmanned_aerial_vehicle*

48.- HALE report. - *https://defensesystems.com/articles/2015/05/27/uas-male-vs-hale-debate.aspx*

49.- HALE-UAV information. - *http://defenseupdate.com/events/2007/summary/auvsi07_5hale.htm*

50.- Zephyr information. - *http://newatlas.com/zephyr-uav-civil-test-flight/34010/*

51.- Zephyr report. - *http://www.airforce-technology.com/projects/zephyr/*

52.- Phantom report. - *http://www.airforcetechnology.com/projects/phantomeyeunmannedae/*

53.- Economical calculation. - *https://www.thebalance.com/how-to-calculate-breakeven-point-393469*

54.- Break-Even point. - *https://www.accountingcoach.com/break-even-point/explanation*

55.- 3D design – CATIA - *https://www.3ds.com/es/productos-y-servicios/catia/*

56.- Programming – MATLAB - *https://www.mathworks.com/products/matlab.html*

57.- Analysis – SolidWorks - *http://www.solidworks.es/*

58.- Risk evaluation – SERAP - *https://prevencion.asepeyo.es/aplicaciones/evaluacion-riesgos/*

59.- Servo motor. - *http://www.pegasus-actuators.com/products/industrial-actuators/pa-r-135-4/*

60.- Climate in Vilnius. - *https://es.climate-data.org/location/431/*

61.- Magnetic field calculator. - *https://www.ngdc.noaa.gov/geomag-web/?model=WMM&lon1=25%C2%B017%E2%80%B200%E2%80%B3&startYear=2017&startDay=10&lat1Hemisphere=N&resultFormat=pdf&browserRequest=true&startMonth=3&lat1=54%C2%B041%E2%80%B200%E2%80%B3&lon1Hemisphere=E&fragment=declination#declination*