Escola d'Enginyeria de Telecomunicació i Aeroespacial de Castelldefels

UNIVERSITAT POLITÈCNICA DE CATALUNYA

Solar UAV for long endurance flights

by:
Llibert Chamizo Cuni
Marc Olmo Criado

Directed by:
Darius Rudinskas

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SAPERE AUDE

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Title: Solar UAV for Long Endurance Flight

Author: Marc Olmo Criado; Llibert Chamizo Cuni

Director: Dr. Darius Rudinskas

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Overview

The project have been done during the four months stay in Lithuania by Marc Olmo and LLibert Chamizo.
The aim of the project was to obtain an Unmanned Aerial Vehicle powered by solar energy that was able to flight for as long as possible it within the limitations which are the budget, the time and the technological limitations.
During the limited time, the team have been working in all the necessary phases to build a real scale and fully functional Solar UAV. This phases were the following; Theoretical Calculations, Design, Simulation, Building, Tests of the Airframe, Solar Energy Circuit Design and Building 2nd phase tests and Conclusion Obtaining.
Through all the process several technical and engineering decisions have been made leading the team to obtain a fully functional 4,4m wingspan fixed wing UAV with a TOW of 5,5 Kg which is perfectly pilotable

The final achievements have been a UAV capable of long endurance flight within daytime. The model achieved was able to maintain level, climb and turn perfectly using just the power gathered by the solar cells in its wing. During the development of the project the possibility of the multiday flight have been discussed leading to the conclusion that it's viable but not within the frame of this project.
There have been done several tests under actual mission parameters loading the plane with the weight it would be carried during the missions that are most likely solar uav related such as mapping or surveillance.
The final result have been correct and lead to an optimistic opinion about the whole Solar UAV paradigm and about the prototype modification and improvement in the near future to achieve even better results (which have been overviewed and planned in the actual report).
A fatal error drove the airplane to a nosedive fall with disastrous consequences, the whole project feels and success though it's undoubtable.

Greetings

In one hand we have to appreciate the help and leadership of our tutor DR. Darius Rudinskas who helped us determining this final project and advised us in the choice of the thesis, which have turn out to be the correct one. The attention payed by him in the project while not in the best timings deserves a mention by the team.

In the other hand this project would have not been in any way possible without the inestimable help and support given altruistically by our mentor and teacher Aleksandr Lapušinskij. Any kind of greetings our team give to him would not be enough to compensate the amount of knowledge, skills and time he have inverted in this project, we can just wish for him the best of the lucks in his, for sure successful, future projects.

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INTRODUCTION

In the current times the UAV industry or commonly known Drone industry is growing faster than ever getting its field of work far away from the military field which was its unique application in the past. The huge number of applications that they are being able to perform is pushing companies and researches to work with them and improve them day by day and the forecast for those unmanned aerial vehicles is giving reasons for the optimism.

Anyway there are major limitations in its use and application such as the low endurance or the safety which hopefully are going to be surpassed in the near future.

This project want to give answer and solution to one of those limitations for once and forever and this is the endurance problem.

The endurance for professional multi-copters UAV goes from several minutes to 1 hour in the available market and can have from minutes to several hours in the fixed wing options (by fuel powering them). For some missions this times of flight are not enough and that is where our idea would take place.

The main idea of the project is to design, check the viability and build the DAC SOLAR DRONE a solar powered UAV to achieve the greatest flight time possible, even though it will have to be taken into account the team limitations in terms of money and time.

It’s been already proved the viability of the project in multiple occasions but always with bigger budgets and technical capacities that in this case, in this case it’s wanted to achieve results in the same level quality by using cheaper and easier building methods.

During the following sections each phase of the project from the first sketches and designs to the final result will be explained step by step.

The first sections of the paper will deal with the aim of the project as well as with the theoretical framework or state of art that the engineering team have to cope nowadays for a project of this characteristics.

In the next section the Design and Simulations will be explained and detailed.

On one hand during the third chapter electronic part and the component choosing will be explained and on the other hand in the fourth chapter the Tests once the model will be build will be explained and the results obtained listed.

To finish with the document in the fifth chapter there is the conclusions section summing up everything what will have been seen in the whole project.

CHAPTER 1.

1.1. Aim and motivation

Nowadays limitation in terms of UAV missions is basically the time of flight, which in some cases is just not enough to achieve good results, in missions like 24/7 surveillance or big areas mapping a 30 min flight is just not enough. The development of the industry is going towards this direction working more and more in achieving the same level of quality along with a higher endurance and performances.

From the electrically powered to the engine based UAVs all devices will have from time to time to land and recharge its powering interrupting that way the mission they are developing (being not a problem in some applications and a huge inconvenience in another kind of applications).

That’s where the solar energy takes place and offers a reliable form of powering that it’s not necessarily placed on the ground, by powering an airplane with solar cells while its flying we can achieve the wanted perpetual flight (just having to land for maintenance and another mission parameters such as data download or sensors recalibration etc.).

Needless to say that during the night there is no sun but with nowadays solar cell efficiency and batteries capacity it’s perfectly possible to gather enough energy during the day in order to use it while the sun is not up to power the model the team is working with.

What 20 years ago would have been just a dream is now possible thanks to the late years technology advances regarding the solar energy gathering capacity and the motors and avionics consumption which together have got to a point where a mission as the one this project is aiming its possible. (Always talking about fixed wings models that offer the correct combination of aerodynamic efficiency with room for fitting the solar cells which are not easy to find right now in the multi-copter models).

The aim so in this project is to prove the viability of a solar UAV and achieve a fully functional solar powered UAV (as the viability is already proven in several previous projects the center of the group efforts in the design, construction and test of the model). The project would be about trying to achieve the perpetual flight but the limited budget and time will make the project be organized in the following way:
First it’s going to be tried to achieve the full day flight. To do so the start will be the theoretical calculation of the viability of the project followed by the design necessary to achieve it.

This first design will be simulated and tested before the construction phase which will be the immediately one after the simulation. Once obtaining a fully functional RC plane the test of its behavior and its consumption/aerodynamic efficiency will come. After will be moment for introducing the solar cell circuit to power the airplane and then test the whole model.

Once the solar flight is achieved the second main phase of the project will start. It will be the gathering of all the information obtained during the development of the previous phase and the conclusions obtained in order to rethink, remodel and redesign the plane and its components to achieve the multi-day flight.

All of this phases and steps will be explained in detail in following sections.

1.2 Theoretical Framework

1.2.1 UAV

UAV is the acronym for Unmanned Aerial Vehicle which is an aircraft with no pilot nor crew on it. The main difference by definition between an UAV and a Missile is that this first one is meant to be used more than once. In this category we can gather both, aircraft remotely controlled by a pilot on ground and vehicles with preprogramed trajectories and behaviors.

There are also other accepted acronyms that in terms of the project that we are working on are perfectly acceptable such as UAVS (Unmanned Aircraft Vehicle System) or UAS (Unmanned Aerial System) from now on just UAV will be used to avoid confusion.

In technological terms almost every type of UAV can be found, they can go from milimetrical quadcopters to 60 meter wingspan fixed wing UAVs, with all the different kind of technologies and capabilities which are going to be discussed in further sections.

1.2.2 History

By the early days of the UAV concept the first tests with unmanned balloons developed by the Montgolfier brothers in France at 1782 which can be understood as a really primitive form of UAV that was soon applied in different war actions when in 1861 some of the same kind of balloons where filled with incendiary devices in order to attack the opponents during the American Civil War. After several more intends in elementary Unmanned Vehicles the start of the actual UAV technology happened in the late 50's still using balloons but correctly manageable and with data connection to the ground.

The development of the missiles and of the UAV came together because as they are inherently almost the same and the development of their technologies are highly dependent. During the 50s 70s years the US UAV Program started to take off by improving in a really notable way the flight parameters such as endurance, propulsion and guidance systems. The Navy and the Airforce started converting surplus aircrafts in UAV and they were in majority applied for surveillance applications.

The huge evolvement of this systems came with the Modern Warfare era giving place to extremely large investments and with the subsequence improvement in the systems.

Lately the tendency to go cheaper of the systems along with the easiness of obtaining an UAV and the high end products the market is giving, is what is making the Civil/Entertainment application UAVs market to grow exponentially.

1.2.3 Applications

The main application they had on the early days were military and surveillance applications but they are growing unstoppably and taking its field of action in civil and recreational applications. The previously stated dynamic is forecasted to keep on his exponential growth during the following years. Such a tendency can be seen in several studies such as “Business Insider Global Aerial Drone Market Forecast”[1] where the Civilian and Defense are supposed to grow (Civil having a larger proportional increase in the market even being in a much lower market share) until reach a total market movement of over 3 Billion Dollars in the case of the Civilian and over 12 Billion Dollars in the case of the Defense.
Some examples of the actual applications where they are being used are (they are nowadays evolving constantly):

Military Application: Target and Decoy, Reconnaissance, Combat, Research and Development. [2]

Civil Application: Security and Control, Search and Rescue, Monitoring, Disaster Management, Crop Management, Communications, Survey, Photography and Video.

1.2.4 Fixed Wing UAV

A fixed-wing aircraft has both advantages and disadvantages in comparison with rotor-craft. Fixed-wing aircraft tend to be more forgiving in the air in the face of both piloting and technical errors, as they have natural gliding capabilities with no power. Fixed-wing aircraft also are able to carry greater payloads for longer distances on less power.

There is a huge variety of fixed wing aircraft from electric battery powered small foam planes to large scale wooden replicas with multi liquid fuel engines and everything in between. You are bound to find a plane that suits your flying style and needs.

When precision missions are required, fixed-wing aircraft are at a disadvantage, as they must have air moving over their wings to generate lift. This means they must stay in forward motion, which means they can't hover in one spot the way a copter can and as a result cannot provide the same level of precise camera positioning.

So for longer missions and more payload, a fixed-wing is the best choice. But for keeping a camera in one place, switching to a copter instead may be the smart choice. The same APM autopilot can control that equally well by simply loading the Copter code.

The use of Fixed Wing UAV in this project was almost mandatory as it offers a much larger area where to place the solar cells and also because of the lower consumption. It will be the chosen option also because of the applications, being really useful to be able to fly unstopped by using solar energy. That is because of the limitation that the taking off and landing of a fixed-wing represents, which are not as easy as in a multi-copter.

1.2.5 Solar Energy

The use of photovoltaic cells is way known and vastly implemented nowadays, this device work by converting solar energy into electricity. One solar cell is composed by semiconductors and its characteristics and efficiency will be directly related to the material of those semiconductors.

The photovoltaic effect is when photons of light excite electrons into a higher state of energy. Photovoltaic power generation employs solar panels, which are not more than a certain amount of solar cells connected in series or in parallel depending on the application. The full installation requires of the cells the copper cables arrays and a non-reflective environmental protection (commonly used a glass sheet just above the cells).

So, it's easily understandable that if the electrical energy obtained by our solar cells depends on the sun it won't be the same to be using them at the Ecuador that using them in Norway for instance.

The energy from the sun depends on its irradiance. The wavelength and other parameters affect the total power that it have. In the next figure the average solar irradiance at the top of the earth's atmosphere and at the surface is shown [3]:

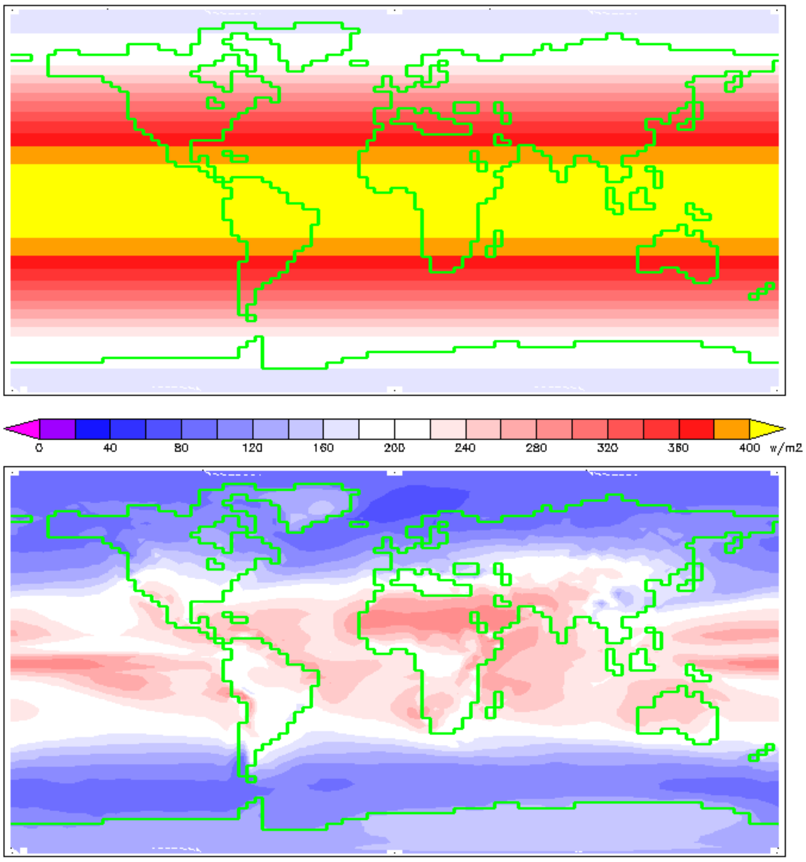

Fig. 1.1 Irradiance Worldwide

It’s plain to see that in both places where the investigation will be placed there are different irradiances and so, different conditions for the solar cells behavior (more detailed graphics on the annex introduced for the thesis).

In the next figure the average solar irradiance that we have in both of the cities is shown [4]:

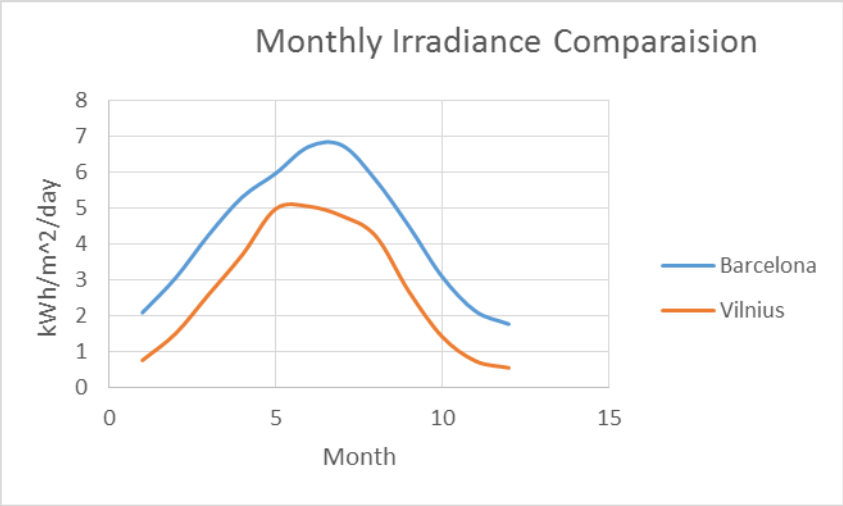

Fig. 1.2 Monthly Irradiance Comparaision

In terms of irradiance the Barcelona option is better any month. But there are more parameters to take into account such as the weather or the different kinds of irradiance. There are 3 main kind of irradiance: Direct, Diffuse (thought clouds or fog) and the reflected (highly dependent on the environment) and in situations such in a cold winter day both in Vilnius and in Barcelona the Reflected solar energy could even be beneficial for the Vilnius case that is more likely to be covered in snow in the mountains for example.

Chapter 2

2.1 Theoretical Calculations

First of all, it has to be taken into account that these are approximated calculations and the final model can vary. After saying that, the first thing to be done is to think about what have to be taken into account to make the calculations. There are three main objects to analyze:

·Drone's weight
·Propulsion available
·Amount of solar cells

Every one of the objects listed above are interconnected between them. The amount of solar cells that can be placed depends on how big is the drone, and that is related with the weight. More weight will require more propulsion available, and that will increase the power and with that the amount of solar cells.

So, it had to be decided which object fix first to then calculate approximately the other ones and do some iterations if it is required. Since the project is developed with the lowest possible money, the propulsion available was fixed with the motors that were already available and provided by the university.

These motors are the MT3506 from RC tiger motor company. The datasheet is the one showed now:

Item No.	Volts (V)	Prop	Throttle	Amps (A)	Watts (W)	Thrust (G)	RPM	Efficiency (G/W)	Operating temperature(℃)
MT3506 KV650	11.1	T-MOTOR 11*3.7CF	50%	1.4	15.54	195	3500	12.55	42
			65%	2.6	28.86	285	4500	9.88	
			75%	3.6	39.96	380	5000	9.51	
			85%	5	55.50	472	5650	8.50	
			100%	5.9	65.49	540	6000	8.25	
		T-MOTOR 12*4CF	50%	1.6	17.76	230	3300	12.95	45
			65%	3.2	35.52	334	4200	9.40	
			75%	4.5	49.95	439	4800	8.79	
			85%	6.1	67.71	540	5350	7.98	
			100%	7.3	81.03	645	5700	7.96	
		T-MOTOR 13*4.4CF	50%	1.9	21.09	260	3200	12.33	47
			65%	3.5	38.85	400	4100	10.30	
			75%	5.3	58.83	520	4600	8.84	
			85%	7	77.70	636	5100	8.19	
			100%	8.3	92.13	723	5400	7.85	
		T-MOTOR 14*4.8CF	50%	2.5	27.75	340	2950	12.25	54
			65%	5.1	56.61	499	3700	8.81	
			75%	7.1	78.81	626	4150	7.94	
			85%	9.3	103.23	736	4550	7.13	
			100%	11	122.10	848	4700	6.95	
	14.8	T-MOTOR 11*3.7CF	50%	2	29.60	290	4400	9.80	46
			65%	3.9	57.72	451	5600	7.81	
			75%	5.5	81.40	570	6400	7.00	
			85%	7.4	109.52	720	7100	6.57	
			100%	8.7	128.76	800	7450	6.21	
		T-MOTOR 12*4CF	50%	2.5	37.00	350	4100	9.46	52
			65%	4.9	72.52	570	5300	7.86	
			75%	6.9	102.12	720	6000	7.05	
			85%	9.2	136.16	880	6600	6.46	
			100%	10.8	159.84	1000	6900	6.26	
		T-MOTOR 13*4.4CF	50%	2.7	39.96	386	4000	9.66	60
			65%	5.6	82.88	651	5100	7.85	
			75%	7.8	115.44	822	5800	7.12	
			85%	10.3	152.44	970	6300	6.36	
			100%	12	177.60	1053	6600	5.93	

Notes:The test condition of temperature is motor surface temperature in 100% throttle while the motor run 10 min.

Fig. 2.1 Motor Datasheet [4]

At 14.8V and with the biggest propeller, these motors are providing a maximum 970 grams of thrust at 85% (a little bit more at 100%, but it is not recommended to work at maximum speed for the motor integrity) and as two of them will be placed for a better amount of thrust, this is a total of 1940 grams of thrust.
So, now that value it is fixed, the other ones can follow.

For the amount of solar cells, the power consumption by the motors at max rate (85%) is 152.44 W each one, making a total of 304.88 W. Since the c60 cells are giving a max power of 3.34 W:

$$\frac{P_1}{P_2} = \frac{304.88}{3.34} = 91. \qquad [1]$$

*P1 = Power consumption; P2 = Power provided per cell

92 cells are the amount to be placed into the airframe.

For the weight, it is recommended to have a 1/3 of the weight as a thrust, so the maximum weight is:

$$T \cdot 3 = 1949 \cdot 3 = 5820 \approx 6 \text{ kg} \qquad [2]$$

This is the values of the approximated weights of each part of the aircraft.

	Weight (Kg)
Propulsion	**0.2**
Batteries	**2**
Avionics	**0.5**
Solar Cells	**0.8**
Airframe	**2.5**

Propulsion is gotten by the datasheet. Batteries are taken into account as four of them with an approximated weight of half a kilogram each one. Avionics (autopilot, servos, wires, compass…) are counted as half a kilogram as much. Solar cells are about 8 grams each one, so that makes a total of 800 grams as much. So resting all of that, the maximum weight of the airframe of 2.5 kilograms. We will have to think carefully in the drone's design, especially the materials, to achieve this objectives.

2.2 Design

In this chapter, will be given the explanation of how the different parts of our solar plane have been designed taking into account the calculations that we have previously introduced.

The typical aspect ratios for the different surfaces for RC aircrafts have been looked upon, to make sure that the model stays inside the standards and the aircraft is going to fly.

2.2.1 Airframe design

The airframe will be characterized for having a big area to place the 96 cells finally chosen to place in our aircraft. The simplicity was a must , for an easier construction that would make it faster, and suitable for the team skills and available tools and industrial equipment.

2.2.1.1 Wing design

Chord design

The wing have been designed to place 3 rows of solar cells along all the wingspan. Taking into account the cells dimensions that are 12.5 centimeters wide,that would make a minimum of 37.5 centimeters plus the distance between each cells and the distances to the trailing edge and leading edge. Also have to be taken into account that the leading edge of the wing will be curved because of the airfoil, so even though the cells are semi-flexible, it is better to evade putting the solar cells in that zone to don't damage them and to have an angle of incidence of the sun more constant along the solar cell. To sum up, it was decided that the wing's chord would be 45 centimeters to accomplish all the details specified.

That makes the chord constant, making the leading and trailing edges parallel. That is simple and cheap to achieve, but outer section generates less lift while add weight and drag. However, it is necessary to place the solar cells, so it is the best solution after all. The weight will be reduced by selecting the material carefully and the drag will not be that high because the low speed of the drone.

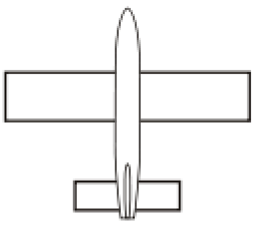

Fig. 2.2 Layout

Wingspan design

The wingspan have to be chosen according to the solar cells that have to be placed as did with the chord. So to make 3 rows of 32 cells each one was decided, making a total length of 4 meters. Leaving a distance of 5 milimeters between each cell, increase the length to 4.16 meter, rounding it to 4.4 meters to have also some more space in the wing tips and central connection, so that is the final wingspan's size.

With these values of chord and wingspan, the obtained aspect ratio is:

$$A.R = \frac{S^2}{S \cdot C} = \frac{4.4}{0.45} = 9{,}78 \qquad [3]$$

A.R = Aspect Ratio

It is a high aspect ratio that gives the model a long and slender wing more efficient aerodynamically, creating less induced drag. The worst disadvantage between a short wing are structurally, having a greater torque. That implies that the wing have to be really strong to handle the solar cells on the top.

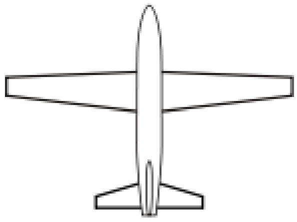

Fig. 2.3 Wingspan Design Layout

Wing sweep

The swing sweep chosen will be straight, since it is the simplest way and the most common for low-speed aircrafts. It is also the best structurally.

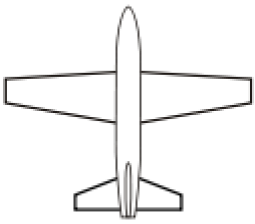

Fig. 2.4 Wing Sweep Layout

Dihedral angle

Dihedral angle has important stabilizing effects on flying bodies because it has a strong influence on the dihedral effect which is a rolling moment resulting from the vehicle having a non-zero angle of sideslip. So would be good to have a dihedral angle along the wing. Since the wingspan is 4.4 meters, it have been divided in 3 parts, one central part of 2 meters, with no dihedral angle to make the construction easier, especially in the central part where the connection with the fuselage will be, and the outer parts of the wing, that will have a small dihedral angle to increase the stability of the aircraft. That angle will be about 17.5 degrees respect to the ground. So the aircraft will be polyhedral, with upward cranked tips.

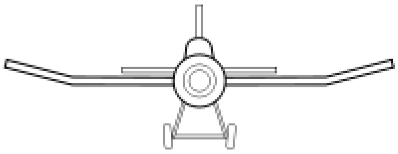

Fig. 2.5 Dihedral Angle Layout

2.2.1.2 Tail design

The aircraft will have a T-tail configuration for one main reason: to avoid the shadow of the vertical stabilizer on the horizontal stabilizer in case it’s decided to put some extra solar cells on the horizontal stabilizer surface. That have some advantages:

Not having disturbed flow on the horizontal from the wing, and increasing the pitch control.

This configuration also allows high performance aerodynamics and an excellent glide ratio as the empennage is less affected by wing and fuselage slipstream.

T-tail has a better effective aspect ratio (better lift slope), less interaction drag than a cruciform tail, and a more efficient vertical tail.
And some disadvantages:

High angles of attack can hide the elevator from the airflow, losing the pitch control.

It requires a stronger vertical stabilizer to support the forces generated by the tail. If the vertical stabilizer vibrates, horizontal stabilizer also begins to oscillate, not being appropriate for controlling the aircraft. It also increase the weight.

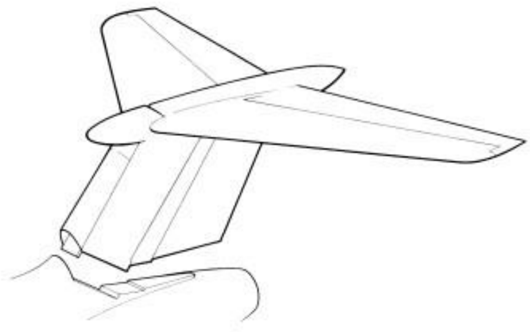

Fig. 2.6 Tail Design T Configuration

Horizontal stabilizer design

The horizontal stabilizer it is recommended to be between a fifth part and a fourth part of the entire wing and to have an aspect ratio between 3 and 6. So the decision was that the best option would be to have a chord of 30 cm, suitable for placing 2 rows of cells, and a length of 1.2 meters to place 8 cells in each row, making an aspect ratio of 4, almost a fourth part of the wing and a total of 16 cells to place in case we need them.

Vertical stabilizer design

The vertical stabilizer it is recommended to have an aspect ratio between 1 and 2. So, the width will be the same as the horizontal, decreasing a little bit from the upper part to the top part, from 30 cm to 25 cm, and the height will be 45 cm, making an aspect ratio of 1.5.

2.2.1.3 Fuselage

The fuselage will be very narrow to have less drag, with a rounded head in the front. The distance between the trailing edge of the wing and the front part of the tail it is recommended to be about 2 or 2.5 times the chord of the wing. The used wing is 45 centimeters, so it was decided to have a distance of 1.1 meters. The wide of the fuselage will be done in the construction phase, since it will be adapted to the wide of the electronics that will be placed there and to place the center of gravity where needed (3th of the wing). Batteries will be placed on the head to move the center of gravity forward, since it always have to be forward than the aerodynamic point to keep the stability.

2.2.2 Control surfaces

In this chapter, the dimensions of our control surfaces and how they are going to be moved will be specified.

2.2.2.1 Ailerons

Ailerons will be placed on the outer wing parts, and since there will be some solar cells on top of them, the width will have to be at least the same as a solar cell width. So, the aileron is going to be about 15 cm with, and 95 cm long, to place 7 solar cells on top of them, and 2 more in the rest of the outer wing on that row.

They will be moved with 2 servomotors each one (HobbyKing™ Digital Coreless Servo MG/BB 1.4kg/ 0.05sec / 15.3g [5]). The first approach was to place 2 of the same type, small servos, but was tested that the aileron was not moving properly because a lack of strength in the servos, so one of them have been changed (the closest one to the center to have a less torque) for a bigger one to make the movement better since it is the main control surface.

2.2.2.2 Rudder

The rudder will be a third part of the vertical stabilizer, about 10 cm long. It was decided to make some holes into the surface to reduce meaningful weight from the tail worrying about the momentum and the effect of it to the center of gravity. It will be moved by one small servo placed in the vertical stabilizer since it is a light and small surface. The upper part will be cut with an angle to avoid colliding with the elevator.

2.2.2.3 Elevator

It was decided that the elevator would be the whole horizontal stabilizer because it was easier in technical matters. It works the same way taking into account that the angle of attack of the elevator cannot be so big or it would enter a stall mode in the pitch control. It will be moved by the big servo placed in a vertical stabilizer, since it is a big surface with a great weight, so the strength have to be enough to enhance a fluent movement.

2.2.3 Airfoil design

There were 2 airfoils suitable for aircraft: one for the whole wing, and one for the horizontal and vertical stabilizer, they are up for different applications so different airfoils where the best thing.

2.2.3.1 Wing airfoil

The chosen airfoil for the wing is the famous CLARK-Y, widely used in general purpose aircraft designs, and very studied in aerodynamics over the years. The airfoil has a thickness of 11.7 percent and is flat on the lower surface from 30 percent of chord back. The flat bottom simplifies angle measurements on propellers, and makes the construction of wings on a flat surface easier. For many applications the Clark Y has been adequate. It gives reasonable overall performance in respect of its lift-to-drag ratio, and has gentle and relatively benign stall characteristics. It is true that the flat lower surface is sub-optimal from an aerodynamic perspective, and it is rarely used in new designs. However, it works really well on a low-speed aircraft and the construction simplifies a lot with the flat bottom.

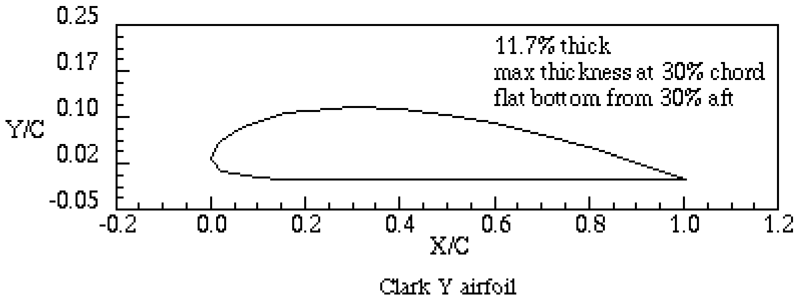

Fig. 2.7 Airfoil Clark Y

2.2.3.2 Tail airfoil

The chosen airfoil for the wing is the NACA0009. It is a common and symmetrical airfoil used for the rudder and the elevator. It is also quite thick (more than the famous NACA 0012) making it suitable for the project since it will reduce the weight of the tail. Contrary to the wing, that will be constructed with wing ribs, the tail will be filled with the material chosen, so each millimeter of thickness is determinant for the project.

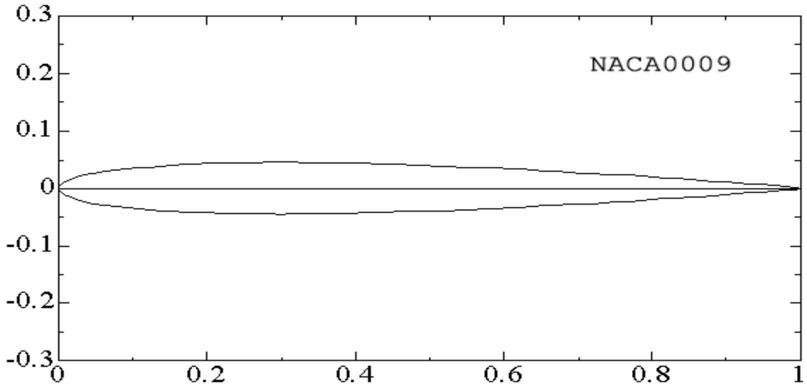

Fig 2.8 NACA0009 Airfoil

2.2.4 Material Selection

This is one of the most important point of the project, since each gram of weight it can be determinant, but at the same time, the aircraft have to be strong enough to fly.

The main materials used for the whole construction are the followings:

Compacted Styrofoam: Main material used along the airframe, being really light, and really strong combined with tape, working as a kind of composite. The main idea was to make some layers of Styrofoam and tape, but it was finally used only one layer of tape in the outer part of the wing and tested to be enough resistant.

Tape: It really gives the Styrofoam more tenacity, making it really hard to break.

Wood: Used to strengthen the wing, along the wing spar and horizontal and vertical stabilizer spar.

Balsa wood: used for strengthen the wing with small structures like in the central part, or some ribs in the outer of the central wing. Also used for making the trailing edge, for placing some screws...

Styrofoam: used to make the leading edge and ribs in the wing tips and central part. Softer material than the compacted one, but lighter.

Fishing rod: used as a connection of the fuselage and the tail. Really light, strong enough, and the most important thing, cheap.

Kleiberit glue: used for the most important connections between Styrofoam, wood, etc. 24 hours till it is dry, giving a strong connections between components.

Hot glue: solid glue that turns liquid with heat. It dries really fast giving you a decent connection. Less strength than kleiberit, so it has been used for gluing pieces that are not that important or that required a fast work.

Super glue: gives you a good connection, but it cannot be used on Styrofoam. It has been used only between some wood connections.

Steel tubs: used to connect the outer wing parts with the central part.

Carbon tubs: placed inside the steel tubs to strengthen them. They are really light.

These are the materials used in the construction of the aircraft. The resulting aircraft is really strong and it is less than 3 kilograms.

2.2.5 Propulsion

The first approach was to put one electric motor on the head of the aircraft. After some calculations it was determined that it would not be enough, or at least it would have to work at maximum capacity to make the aircraft fly, getting heated and being not good for the integrity of the motor itself and the aircraft. So the second approach was to put two electrical motors in central part of the wing, in the most external part, close to the connections with outer parts. The hypothesis was that if one of the motors stops working, the other one would create a big torque making the aircraft difficult to control. So the third and last approach was placing two motors in the middle between the head and the end of the central part of the wing (about 50 centimeters each side of the head).

2.2.6 Motor selection

The selection of the motor have been done by looking into the ones provided by RC tiger motors. The one that was suitable for the project is the MT3506. In the 3.1 section of the annex the specifications and drawings on the motors can be found. [6]

The idea is that the motor will be working with 14.8 volts with the biggest propeller that will give the greatest amount of thrust. It should be working at less than 50% for steady flight, so that is a power less than 100W, which solar cells can achieve it.

[4] For datasheet.

2.2.6.1 Motor box

The two motor boxes used will be placed in the wing, to keep some distance between them, and keep the wing protected in case of a failure. The motors are placed in a piece of wood that works as a fire wall. They also have a little window than can be opened to connect the wires and also works for cooling the motor since the air can go inside.

2.2.7 Auto cad design

This is the final design that contains all the real dimensions and solar cells placed into the airframe. Take into account that solar cells in the tail may not be placed and motors should be placed closer to the head. The painting process was done with photo shop.

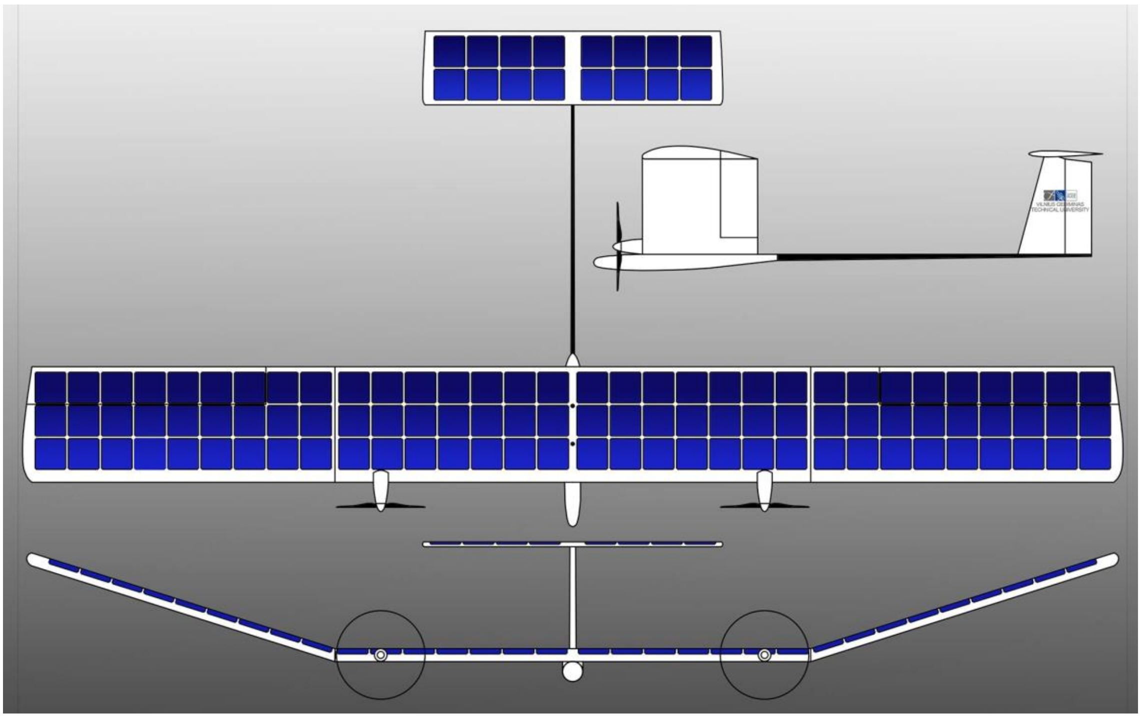

Fig. 2.9 Preliminary Design

So now all the dimensions are already known, the next step will be to proceed with the simulation part where we it will be calculated how the aircraft will be working in terms of aerodynamics.

2.3 Simulation

After the preliminary design the next step was to start testing them via simulation. For this matter the software SolidWorks and XFLR5 were used.
The 3D model was introduced in them following all the measures that have been previously determined and taken into account a first approximation of the total weight that the airframe plus all the components would have.

This first approximation lead to a value of weight of 5,5 Kg for all the TOW.

Taking this into account the simulations were about the lift generated in the wing to compensate the weight. The first approach was to give a go to the 1/3 Lift to Weight ratio for level flight.

Later on it will be seen that it's a really more than enough consideration and that the flight will be level with less lift than this first approximation but this will work as security margin.

In the following figures some of the results obtained can be seen (which can be also found in the Annex section where the complete logs will be gathered):

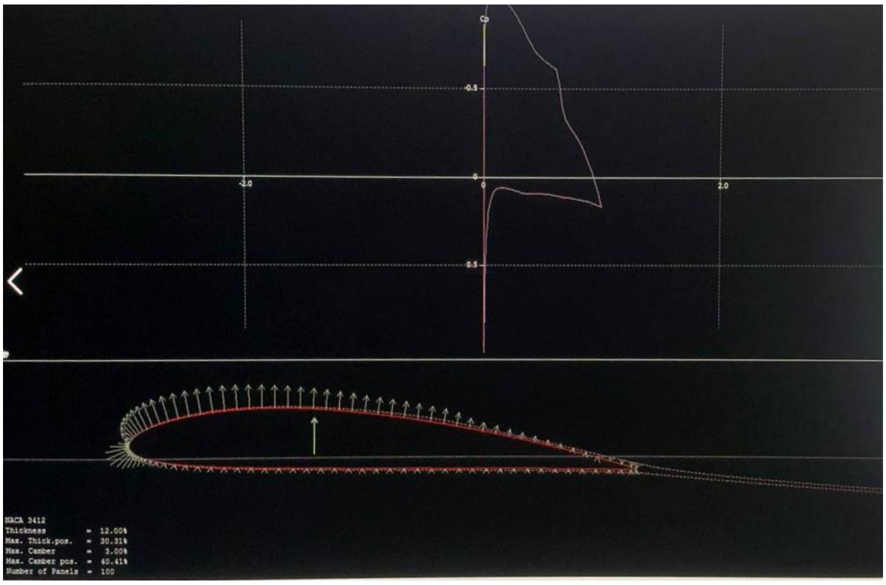

Fig. 2.10 Main Wing Airfoil Lift Generation XFRL5

By simulating the lift generation of the main wing the desired results are obtained what is normal as the CLARK Y profile is widely used and multiple times tested.

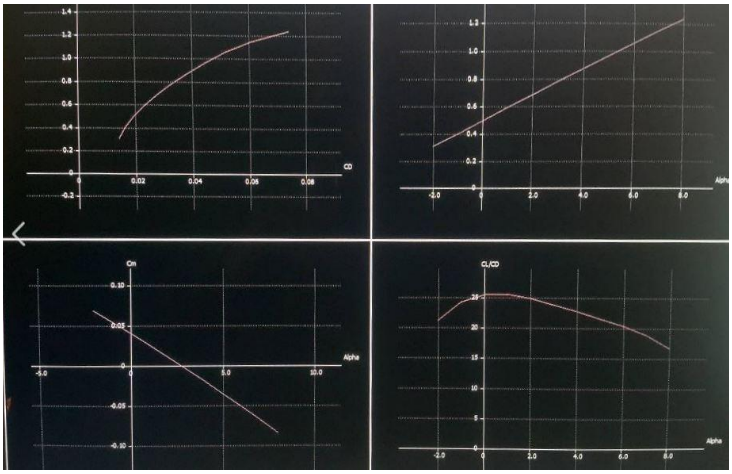

Fig. 2.11 Coefficients Results XFLR5

The coefficients were as supposed and fine for the model, it’s usual that they are like this by using airfoils and a composition that are more than tested.

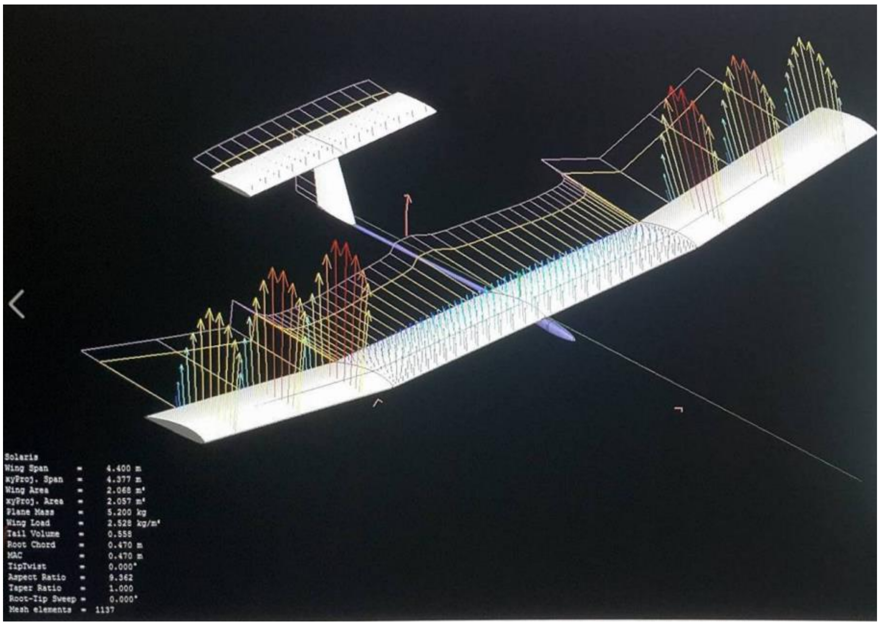

Fig. 2.12 Lift Simulation XFLR5

It can be seen that the major values of lift are generated in the wingtips from the angle to the end of the wing. It that’s why special care will be taken with the connection between the central part of the wing and the wingtips.

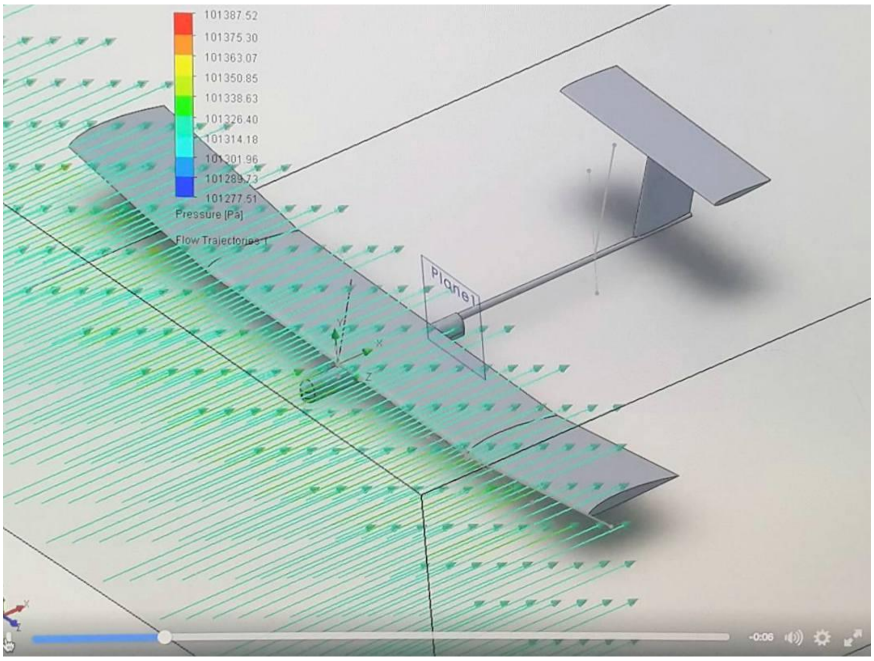

Fig. 2.13 Velocity Vectors Simulation SolidWorks

Even though the simulations in SolidWorks have been more visual and graphic it’s found that the more interesting values and results using XFLR5 but still by using SolidWorks it can be shown that the speed vectors behavior along the airframe is smooth and nice.
After all the test it’s known that the speed that the aircraft should have in order to maintain level flight will be around 9 m/s (which will have to be tested once built) which is a more than achievable speed for the model.
After this preliminary simulations the practical part of the project can be started. The next step will be building the model, in the following sections the process is going to be explained step by step.

Chapter 3

3.1 Solar Powered UAV

Once all the test have been done (which will be explained in the test section, chapter 4) the situation is suitable for begin designing the solar cells distribution and the electronic circuit.

It’s now know that the approximate consumption during the level flight is about 6-8 Amps and 15 Volts. To obtain so remembering the characteristics of the solar cells already stated 2 different configurations came to mind, 1 of them by using 3 equal cells groups and the other one by using 4 of them (groups of cells connected on series groups connected on parallel).

By using the configuration 1 larger voltages are obtained (remember that the current is not dependent of the number of cells but directly of the irradiance) that the ones that are needed, that's why the use the four groups configuration was more optimal.

By using so theoretically 6 amperes are obtained (in optimal situation) and 0,573X23= 13 Volts.

In the following figures how the groups are distributed along the wing and how is every cell connected in its group is shown:

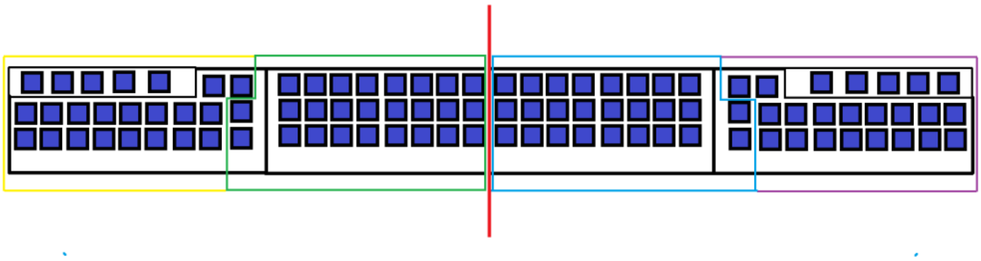

Fig. 3.1 Groups Configuration

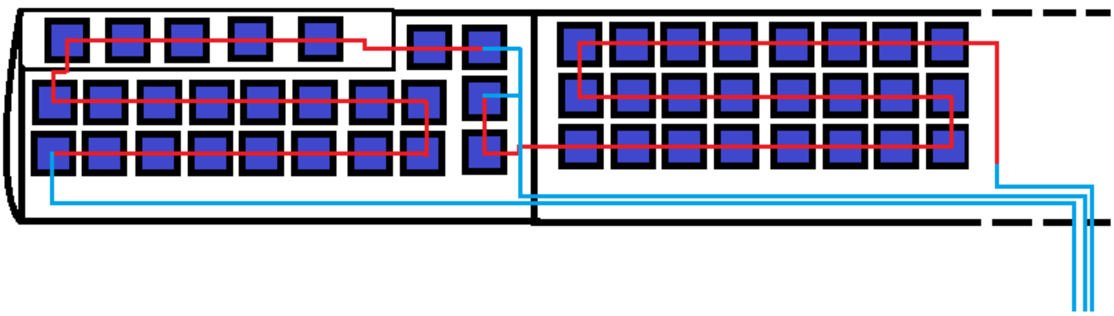

Fig 3.2 Connection Layout

Blue= Inside wing Connections   Red = Outer Connections

The main idea here is to be able to first power the motors directly by solar cells and then the leftover energy will go to charge the batteries. The problem here is to asset the priorities for the current to go to the motor from the cells and not to the battery or the other way around.

By connecting everything directly that problem would be found as the batteries are loaded with a higher voltage than the solar cells and that would make the motors to take the energy from the batteries. To achieve that a certain circuit of diodes have been used as we can see in the following figure:

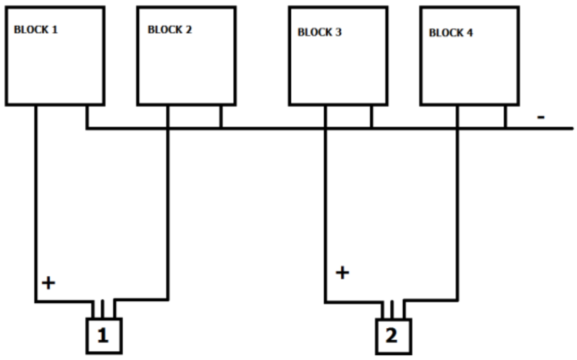

Fig. 3.3 Diode Connection

That circuit copes with the problem of the diodes sending the energy to the cell but makes us unable to charge that way, it's a temporally solution which will be changed in the final version by using a switcher or a charger along with an MPPT.

3.2 Avionic Equipment

In the following section all the electronic equipment will be pointed out. Every component will be explained along with his working principle and with the explanation about why it was chosen. It have to be taken into account that for every single selection the price the availability and the gravimetric efficiency have been the principal decision making elements.

3.2.1 Telemetry

The concept telemetry refers to the system that allows the aircraft and the ground based team to have a communication process. It is the group of elements that makes possible to the aircraft to send and receive all the necessary data in order to fulfill a mission and performance within the desired level of accuracy safety and security.

Obviously the data connection will have to be wireless and will be using radio systems.

The telemetry system used will be the following:

3DR Radio v2 (which is a consumer implementation of a SiKRadio).

It is small light and inexpensive (which make it perfect for the project) and offers rangers of better than 300m and can be as long as kilometers by using antenna on the ground. This device works with open source firmware and will work perfectly with the Mission Planner software that will be used for the tests. [12]

Features:

Small
Light
Sensitivity -121 dBm
Built-in error correcting code
Range of several kilometers.
Open Source.

For the correct use it will be connected to the Pixhawk autopilot as main and only telemetry system.

Fig. 3.4 Telemetry

3.2.2 Servos

It's understood as servo the kind of motors controlled by the signals send by the controller that are used to move or displace different surfaces or actuators. In this case the servos are going to be used for acting in the control surfaces moving them and deflecting the angles they are creating with the main surface they are attached to (Ailerons to the wing, Rudder to vertical stabilizer and Elevator in the horizontal stabilizer).

For doing so there are going to be used 6 different servos, 2 in each aileron (1 big and 1 smaller) and one in rudder and elevator.

In the following image the position of each of them is revealed:

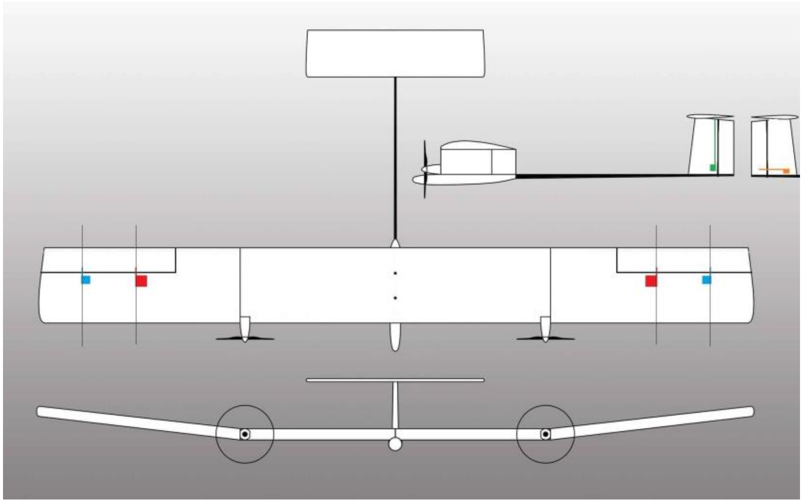

Fig. 3.5 Servo Location

Every one of the servos have to be connected to one output of the Autopilot. For the ailerons they are going to be both of the same wing connected together and each wing will get a contrary signal while working. The rudder and elevator also have to get connected to the autopilot. The connection is done by using a tri-wire with the positive/negative/signal signals. The connections are drawn in the following figure:

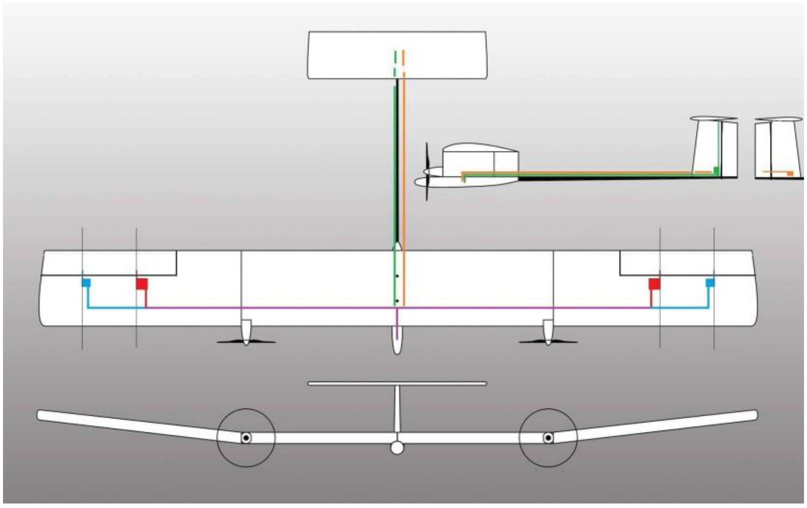

Fig. 3.6 Servo Connections

3.2.3 Wirings

As wiring we understand the electronic connections between different devices and modules. The amount of connections and wires will be explained in another section. The fact that it's one of the main joule effect creators they will have to be chosen carefully. There are 2 main type of connection used in the project.

Copper wiring for long connections and connection between devices and aluminum flat connections for the cell to cell connection.
Both of them have advantages and inconvenient such as the small flexibility of the flat connections or the problem of the wires not being volumetrically optimal for placing in the surface.

The wiring selection (apart from the flat connections that have been used just in the cell to cell connection) have been done taking into account the Joule Effect, so in the longer connections (where the Joule could have been a huge problem) the wire have been chosen to be thicker (∅4 mm) and in the connections that had to be over the surface or not that long the 1 mm option or the 2 mm options have been chose. The weight problem of using thinker wires have been handled by avoiding that way to have a voltage loss of more than 4 V (testing the wires such a lost was found).

3.2.4 RC Controller

A radio transmitter is an electronic device which produces radio signals (in a wave form) which are used to generate and broadcast information. The transmitter generates radio frequency by alternating current. For do so the use of an antenna is mandatory. The use of the radio transmitter in the case that occupies the project is for control reasons. The commands of the controller are bind to the main actions for the control surfaces in the aircraft. The control of all the surfaces in the model, when not using the autopilot, are controlled manually by the pilot on the ground by using the different controller buttons and joysticks. The thrust can also be controlled and the flight modes can be switch within the flight by changing the radio channel in the controller.
[7]

Fig. 3.7 RC Controller

3.2.5 Autopilot

Used to control the trajectory without constant human control making the decision making process by itself and easing the pilot’s task in a big part. The modern autopilot principle of working are the feedback between the sensors of the aircraft and the desired path data. By using GPS pressure sensors and gyros systems the aircraft is able to know the path is following the speed it’s flying and other necessary information that by checking with the planned data can make the aircraft to make decisions and control automatically the different parameters and control surfaces to perform the desired mission.

In the test developed by the team the autopilot will be also important as it will record and generate logs with all the necessary data to analyze the flights.
The modes used in the tests and flights will be explained in future sections (3.3 Flight Modes)

The autopilot that have been used in the project have been the Pixhawk Autopilot. Its and open-hardware project providing high-end autopilot hardware for academic, hobby and industrial communities (as said in the manufacturer website). One of the advantages of this device is the low cost and the high availability which have make it the most suitable device for the project matters.
The software runs a very efficient real-time operating system (RTOS) which works perfectly along with the Mission Planner Software. Its hardware characteristics are summed up hereby.

Features:

Sensors 3D ACC/ Gyros/MAG/ Baro
256 KB RAM
MicroSD slot, SPI
Integrated backup, override and failsafe processor with mixing
[8,9,10]

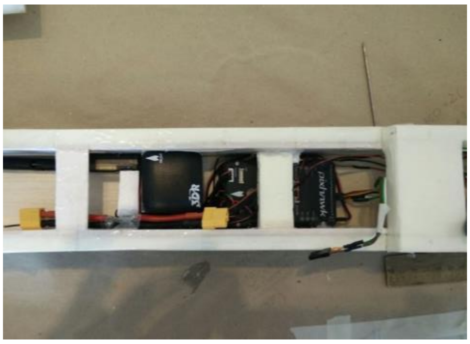

Fig. 3.8 Autopilot in fuselage

3.2.6 Batteries

Lithium Polymer Battery is the kind of batteries that will be used. They are rechargeable batteries that come in soft packages which make them lighter. They are widespread among users of radio-controlled models and that's because it is the best option for such applications.

The work principle for those batteries is the intercalation and de-intercalation of lithium ions from electrode material and the negative electrode. To prevent the electrodes from touching directly a microporous separator is used.

The first approach for the batteries was to use two unities of four cells lipo-batteries. After the first several test was stated that that much of voltage would not be necessary for the system in any case, this along with the fact this kind of voltage was troublesome had the team change its mind for using two three cells lipo-batteries.

The problem with the 4 cells was that the voltage was so much higher than the one obtained by the solar energy group and that could cause that the energy would go in the wrong way within the circuit.

That is why finally 3 cells lipo were used. In any case the circuit was protected from the problem of wrong way current by using one direction diodes avoiding such a problem.

The batteries in the first solar flight test were used for assuring a save take off and first climbing minutes, once in a save altitude they would be turn off until further need.
[11]

3.2.7 Propulsion

3.2.7.1 Motors

During the material selection the motors have been already named and presented so the depth of the explanation in this section will be lower.

An electric motor is meant to convert electrical energy into mechanical energy, the motors this project are using convert the electrical energy into circular a rotting motion. As most of the electric motors it operates through the interaction between the magnetic field and the winding currents to generate the force.

In our case the motors used are the MT3506 of the RCTigerMotors company.

The price in this case was not the case for selecting them as they are not the cheaper findable but there were two of them available in the lab and the characteristics furtherly explained were good for the project (there were other options in the lab but with this the full throttle would not need to be necessary which is highly convenient to avoid):

Features:

Stator Diameter 35 mm
Stator Length 6 mm
Shaft Diameter 4 mm
Dimensions 41.5X23.2 mm
Weight 70 g
Max Current 14.5 A
Max Power 260 W
Internal Resistance 155 mΩ

Fig. 3.9 MT3506 Motor

3.2.7.2 Propellers

A propeller is basically a fan that can convert rotational power (which is obtained by an electric motor in this case) into thrust. The working principle is easy and is based on the pressure difference between the front and rear surfaces of the blades. The kind of propellers used in the aircrafts can work both by Bernoulli’s or Newton’s third law.

In the project there are going to be used two propellers one for each motor and both of them will have to be the same to avoid the imbalance in flight. In the propulsion is highly important the combination between the motor and the propeller generating a massive amount of different combinations that will mean different types of consumptions for the thrust obtained and so one.

In the decision making process it will have to be taken into account the following parameters:

The maximum thrust that can be obtained.

The consumption for the necessary thrust for the project.
The percentage of throttle for the necessary amount of thrust (not being recommendable to work near the 100% throttle).
The propellers chosen for the project have been the following ones: T-Motor 12º4CF.

The synergy between them and the motors can be seen also in the section 3.1 MT3506 Datasheet, as the characteristics for them is stated.

The features are hereby collected:

Features:

570 Thrust (G): 72.5 W; 65% Throttle; 5300 RPM.
720 Thrust (G); 102.2 W; 75% Throttle; 6000 RPM.

3.2.7.3 Electronic Speed Controller

An electronic speed controller or ESC works in a way that may vary the motor speed at will (also direction). They are highly used in RC models and it's useful by providing a three-phase electric power for a motor.

In the case of the remotely controlled airplanes the ESC is designed with few safety features and it controls rotation of the motor such as the fact that even with not enough battery for powering the motors it will still be able to perform electronical driven actions such as powering servos for be able to manage the control surface in case of accident. That is highly favorable as it may make possible for the pilot to manage a safe gliding and landing even without any motor power. [13]

The device used in the project is the EMAX Simon Series 30A (initially thought for multi-copters).

As usual is a high end device with a low cost and one of the lighter in the market (28g). The main features that it have are summed up:

Features:

Over-heat protection and self-check functions.
Magnetic interference eliminated
Parameters programed by transmitter
Throttle range compatible with receiver
Max speed 210000 rpm for 2-pole

The over-heating and the magnetic interference protection are highly convenient as the motor boxes can get really warm while flying in full sun conditions with 75% throttle conditions that why the device have proven to be highly recommendable.

[14]

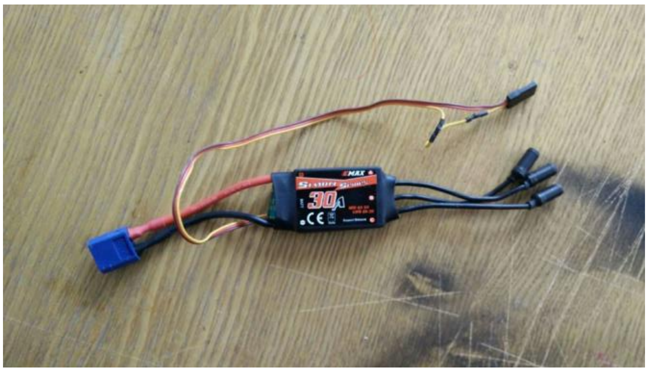

Fig. 3.10 Electronic Speed Controller

3.2.8 Cooler

While testing the switch, transistors were getting extremely heated in a short period of time, so if the flight was intended to be a long, a solution was needed for this problem. The easiest way to do it was to place a thermoelectric cooler.

A cooler is a device that conducts the heat from the devices that are connected from side to the other side of the device by the Peltier effect. That side was then placed outer the fuselage, so the air was cooling it.

This is the cooler used in our aircraft:

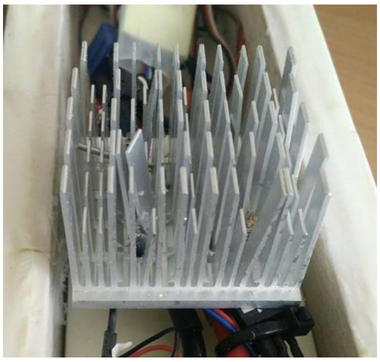

Fig. 3.11 Cooler

3.2.9 Switch

The first approach was to connect solar cells and batteries, so the motors were getting the power from solar cells and the rest of energy if they needed from the batteries.

But that system was not working since the motors were taking the energy from batteries instead of the solar cells, making them useless. So it was decided to place a switch to solve that problem.

The switch is an electronic device that only let one of the energy sources work at the same time, in the way that if solar energy is working, batteries are not providing energy and vice versa. So, since the solar cells are providing enough energy to enhance a steady flight, the idea is to perform the take off with the energy provided by batteries, and once in the level flight, switch to the solar cells. The switch was connected to an output of the autopilot, so it could be used at any time in the flight with the radio transmitter.

This is the built device where each transistor is connected to one of the sources and one extra wire for the ground:

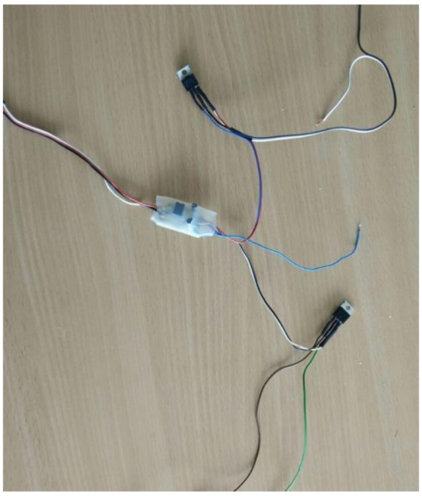

Fig. 3.12 Switch

3.2.10 Maximum Power Point Tracker (MPPT)

Solar cells provided a characteristic voltage-current curve where the current depends on how much sunlight are receiving. This curve can be seen in the next picture for the Sunpower c60, our solar cells:

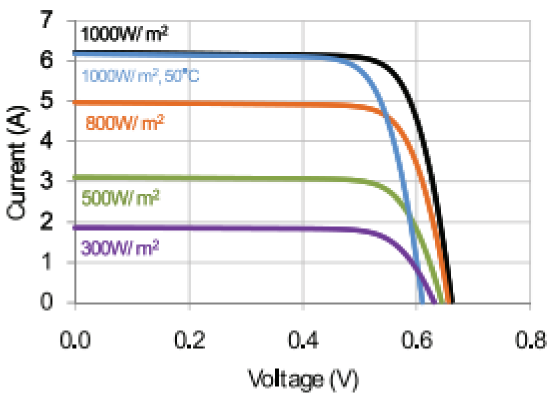

Fig. 3.13 Affect of the Voltage to the Current

Notice that after a certain level of voltage the currents drops to 0. So without a mechanism that tries to optimize the power, we can be in that drop of the current, obtaining less power than the best one that can be obtained (just before the drop).
The next picture represents where we can find the maximum power and therefore where the MPPT is:

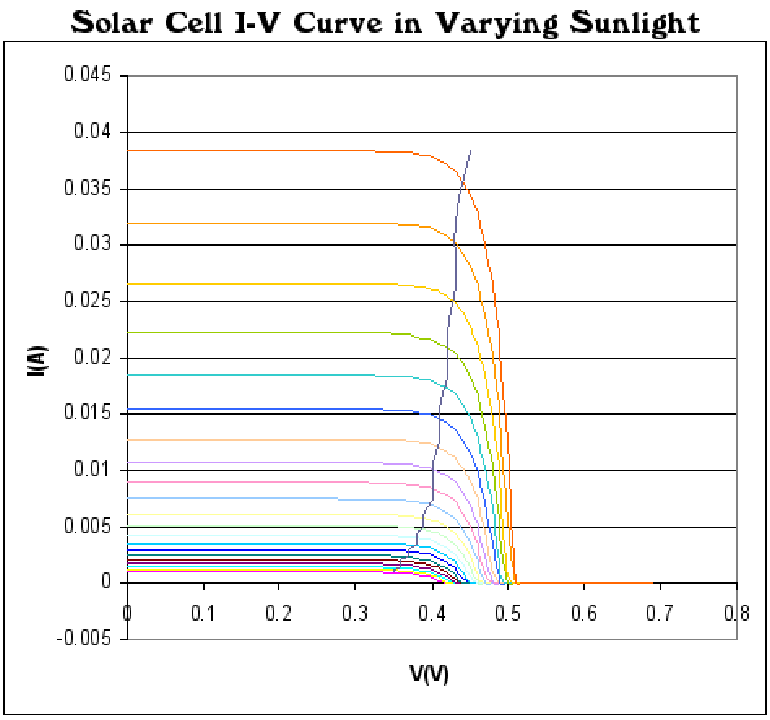

Fig. 3.14 MPPT Function

This is what an MPPT is doing, giving the optimal output power for every moment with an algorithm.

However, it could have not been placed because the lack of the time, so the system was working greatly but not with the best performance, making it harder to achieve the solar flight but still possible.

3.3 Mission Planner

Mission Planner is a ground control station for Plane, Copter and Rover and it can be used as a configuration utility or as a dynamic control supplement for your autonomous vehicle. Here are the main things that you can do with mission planner:

- Load the firmware (the software) into the autopilot (APM, PX4...) that controls your vehicle.

- Setup, configure, and tune your vehicle for optimum performance.
- Plan, save and load autonomous missions into you autopilot with simple point-and-click way-point entry on Google or other maps.
- Download and analyze mission logs created by your autopilot.
- Interface with a PC flight simulator to create a full hardware-in-the-loop UAV simulator.
- With appropriate telemetry hardware you can:
    - Monitor your vehicle's status while in operation.
    - Record telemetry logs which contain much more information the on-board autopilot logs.
    - View and analyze the telemetry logs.
    - Operate your vehicle in FPV (first person view)

3.3.1 Flight data

One of the main advantages of using mission planner is that you can get important information about the aircraft conditions in real time. This information is sent by the telemetry installed in the aircraft and received in our laptop. That contains values of yaw, roll and pitch, position in a map, altitude, groundspeed, battery left… So it is a really useful information that cannot be avoided.

All that data is saved in the autopilot, and it can be seen with the log reader that mission planner includes, being really useful to check our aircraft performance after flight and being able to improve them. The log includes data like current and voltage provided making it really useful for the calculations of the solar energy needed. So checking the altitude and these values, we can see the energy consumed in a level flight.

3.3.2 Flight plan

In mission planner, it is possible to plan a route to be followed by the aircraft using the autopilot. It is really useful for long flights as we intended to do with the solar plane, and very intuitive to use.

By clicking on the map you add waypoints, and afterwards, you can modify which action will be executed on them like take off, landing, holding… and also the altitude. It is very important to set the radius of the waypoint, so at smaller it is, the more accurate will be our aircraft in the performance of the planned flight. The flight plan mode was not finally used because of the lack of time, but it was intended to create a closed route to keep the aircraft in the same area for some hours. It is also really easy to create this type of routes since mission planner have an option that is called predefined routes, where you can set up routes like circles, known polygons and also scanning an area.

In the next photo can be seen how the interface looks:

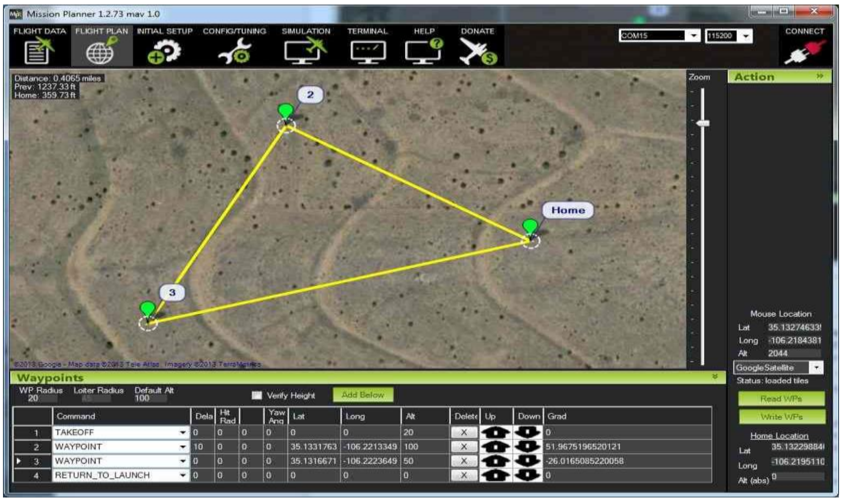

Fig. 3.15 Interface

3.3.3 Initial setup

In this mode you can mainly calibrate the autopilot to be used for a particular vehicle. There are three main calibrations that have been used for this project:

- Accelerometer calibration: mission planner indicates you different positions to place the aircraft that you have to follow. That positions are shown in the next picture:

Fig. 3.16 Calibration Positions

It is important to make level position correctly as this will be the attitude that your controller considers level while flying.

- Compass calibration: in this calibration you have to hold the vehicle in the air and rotate it slowly so that each side (front, back, left, right, top and bottom) points down towards the earth for a few seconds in turn, while the compass is saving that points as can be seen in the next picture:
-

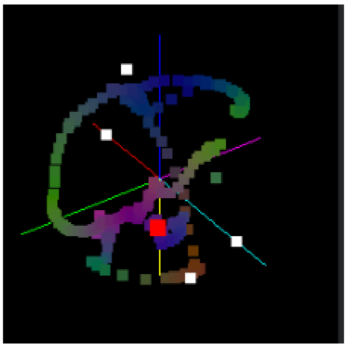

Fig. 3.17 Compass Calibration Points

The calibration ends automatically when the compass have acquired all the needed points.

- Radio calibration: this calibration is used to set the maximum and minimums of our controller on our autopilot, so the maximum and minimums of our controller (sticks) corresponds to the ones of the autopilot (main surfaces, throttle and extra channels). In the next picture is shown how it is done:

Fig. 3.18 Sticks and Channels Configuration

In initial setup is also configured the flight modes that are going to be used. In our case, it was mainly used the manual mod, where the pilot have the total control of the aircraft and the stabilize mode, where the aircraft returns to the neutral position if the sticks are released.

3.3.4 Config/tuning

In that mode it is possible to modify the parameters that controls our autopilot since every aircraft performance is different. So for us, few parameters were modified, as the main surfaces maximum and minimum or setting the pin functions (extra channel for the switch for example).

This parameters are easy to find, since are named RCX being X the number of the pin where the surface is connected and then followed by _MAX or _MIN to set the maximum and the minimum. There is also _FUNCTION to change the function of the pin for 30 different modes.

3.4 Flight Modes

In the hereby section the flight modes used for the test are going to be explained.
The flight mode refers to the kind of behavior the autopilot is going to follow under given circumstances and the kind of relation between the pilot and the model there is going to be.

As was stated the autopilot used for the project is the Pixhawk 4 which have 14 different modes which 10 of them are regularly used. All of them have advantages and disadvantages which are optimal for different level/types of flight stabilization.

3.4.1 Stabilize

Pilot’s roll and pitch input control the lean angle of the copter. The aircraft will always tend to stay in level flight and move control surfaces by itself. Pilots work will be to regularly input roll and pitch to keep the vehicle in place. Pilot’s throttle input control the average motor speed and its control is needed to maintain the altitude.

During the tests it will be used for matters of easiness for the pilot and will be the main flight mode while the RC model test as not a long flight is needed nor a flight waypoint guided.

Is also used to check the correct behavior of the control surface while the ground tests. This tests are performed by moving the aircraft into not leveled positions and checking that the control surfaces are moving accordingly. (The reversed control surfaces are the number 1 cause of accident).

3.4.2 Auto

During a mission using the Auto mode of flight the aircraft will follow a pre-programmed mission script stored in the autopilot which is made up of navigation commands and do commands.

The auto mode incorporates the altitude control and the position control (from another modes like AltHold mode and Loiter mode). For the use of such a mode is necessary to assure that the vibration levels and the compass interference levels are acceptable along with the GPS is functioning well.

Some of the considerations for the use of the Auto mode are the following:

If starting the mission while on the ground it have to be ensured that the throttle is down then start the Auto flight mode and then raise the throttle. When starting from the air (as in the test cases as the model does not have a landing gear) the mission will begin by first commanding the UAV by the pilot commands and once in flight switched to Auto.

The Auto mode for the project mission will be applied when trying to achieve the longer the better flight.

During the mission planning it will have to be taken into account the thermals and for trying to achieve the greater endurance different behaviors during the flight. The main idea is to try to flight 100% solar powered but if it’s not achievable the autopilot will be programed to climb during the battery usage and slowly gliding during the solar cells powering phase. The mission plan will be analyzed in a further section.

Chapter 4

4.1 RC Model Tests

The first flight test was held on the outlands of Vilnius, Lithuania on the 5^{th} of May of 2016 with a favorable weather of sun and 20º along with less than 5 m/s winds.

For the first flight the autopilot Pixhawk was attach to model to keep a log of all the necessary parameters during the flight (such as consumptions speeds and trajectories) but the manual mode was used during most of the flight.

First of all a range radio coverage test was done obtaining a range higher than 700m where the controls worked perfectly which was more than enough for the flight test purposes.

The take-off was done by hand as seen in the following image:

Fig. 4.1 Take Off

For the next 14’36’’ of flight the pilot performed a circular circuit flight while testing all the control surfaces and the general tendencies of the airframe and components.

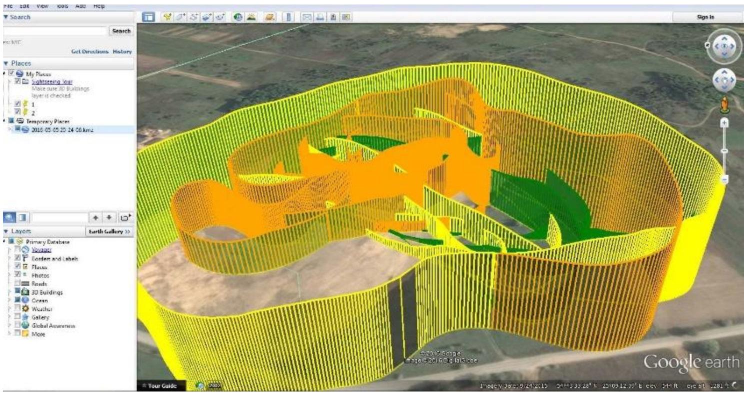

Fig. 4.2 Flight Pattern View in Google Maps

4.1.2 Piloting and Maneuverability

After calibrating correctly the controller and trimming the surfaces the piloting and maneuverability of the airplane were defined by the pilot as it follows:
The plane have shown to be really stable during flight and capable of performing a level flight in a really slow speed.

The control surfaces work perfectly and make the model easily maneuverable and controllable being the Ailerons the main control surface and making the rudder and stabilizer necessary just in determined situations.

The slow speeds and maneuverability make possible the safe landing directly on the ground without damaging in any way the surface of the plane.

4.1.3 Troubleshooting and Possible errors

Some of the first fears fade away while flying such as the following:
-The low rigidness of the tail that could have been a problem have proven not to be an obstacle once in the airflow.

Fig. 4.3 Snapshot taken by GoPro in Payload

-The apparent dysfunctional motor speed controller during the motor test have not been a problem during the flight even not doing any unidentified noise during it.

-The connections were as strong as supposed and performed perfectly during the whole flight not showing at any time any sign of failure.

Also during the flight some things that can be improved were found such as a slight tendency of the aircraft to turn to left when trimmed (which will be solved mechanically in the following building steps).

4.1.4 Consumption and performance

Using the Autopilot system to keep a log on the performance of the airplane we obtained the following data:

Speed for level flight: 12 m/s
Current for level flight: 10.5 A
Voltage for level flight: 14.2 A

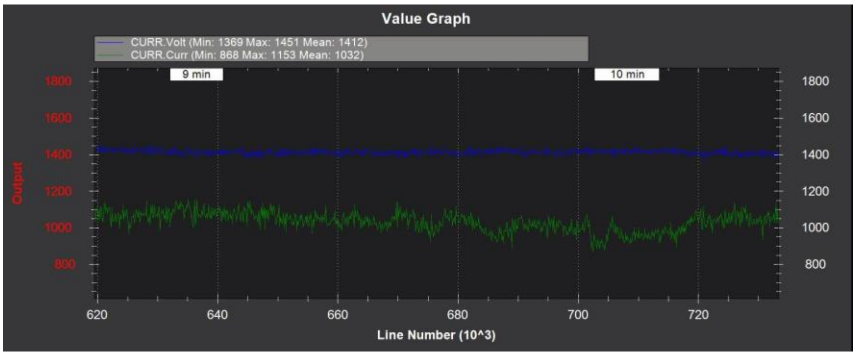

Fig. 4.4 Voltage and Current Log

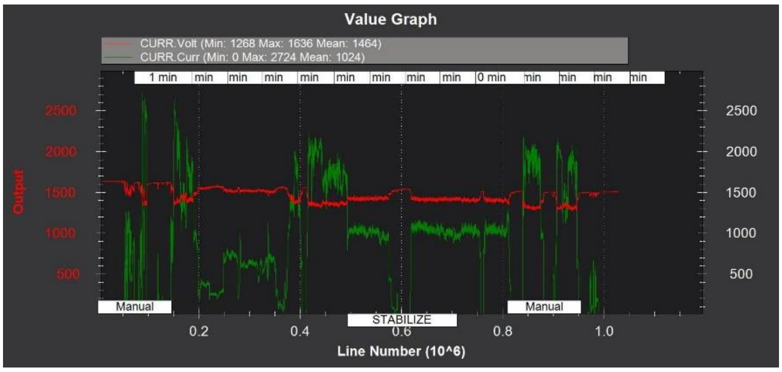

Fig. 4.5 Current Voltage Log 7-8 min

The flight shown that by using the motors in a 45% of full throttle the level flight is achievable and under this conditions the mean consumption is about 150W which was a relieve taking into account that we were expecting a much higher consumption (of about 250W), that we believe is achieved thanks to the nice aerodynamic efficiency we have achieved proven once again the good selection done in terms of components and materials.

4.2 Cells Configuration test

During the 17th and 18th of May of the current year (2016) several test have been done within the spring (cloudy) situation in Vilnius.

The tests have been performed both with groups of 32 cells and 23 to cross check the advantages and disadvantages of both configurations.

With the 32 cells configuration the voltage achieved was way too heavy for the electronic speed controller to handle and was unnecessary to cope with the voltage needs of our aircraft, that’s why the 23 cells configuration was applied.

Within the 23 cells configuration tests the following conclusions and facts have been obtained:

·The amperage of the group is highly dependent on the number of cells and on the irradiance being way more optimal in this matter to use just one cell than using a large group of them (because of the cumulative resistance on the connections).

·The shadow cast in one single cell of a large group generates a huge decay in the overall performance of the group.

·The angle of incident is affecting in a serious way the current generation being the best angle the one that faces the sun directly (vertical during noon).

·The covering of the solar cells with transparent tape is affecting its effectiveness but in a low per cent being so recommended to use it despite this fact.

Fig. 4.6 Solar Cells Testing

4.3 Battery/ Solar Cells synergy

As have been explained before a system of diodes have been applied in order to avoid the motors consuming battery energy instead of pure solar cell.

Once built and correctly connected the system have been tested in the following way:

The whole wing with the full solar cell system connected have been placed in the sun and with the energy the motors have been powered.

By using a wattmeter in both directions (from battery and from solar cells) it have been checked that the system was not working as smoothly as it was supposed to. The problem found was that while increasing the power given to the system the voltage was decreasing (first hypothesis because of the long and thin wires connecting the wingtips to the center creating a huge Joule's effect). Once the voltage decreased the motor started getting energy directly from the batteries which is not convenient at all.

To solve the problem the following solutions have been applied:

-Install a switch system which will make us able to choose whether we use batteries or solar cells (which will be applied smartly during the flight to try to enlarge the endurance as much as possible).

-Change the currently 1 mm thick wires for both 2 mm wires and 4 mm in the double connections.

The estimated increase of effectiveness here have been calculated taking into account the following calculations:

MARC PON CALCULOS DE PERDIDA EFECT JOULE CABRON

4.4 Solar UAV Flight test

During the 9th of June of 2016 the final model was proven and tested. The weather for the day was forecasted to be sunny in intervals and windy (5 m/s winds with 10 m/s gusts of wind).

Fig.4.7 Weather Forecast

As in the RC Model test the necessary previous test were done: Control surfaces checked, Stabilize and Auto modes correct function checked, throttle and motors response checked and center of gravity fixed.

The first idea of the flight was to start develop a circular pattern route while flying and getting altitude.

The start of the flight was troublesome as the final model is big and heavy enough to be difficult to carry and But it was manageable enough to start the climbing phase.

During the first 1:01 minutes the flight was powered by the lipo-batteries to ensure the correct climb and to test if the model was still aerodynamically efficient and maneuverable.

Once it was checked that the model was still perfectly controllable the switch was activated, giving all the powering responsibility to the solar cells.

The change in the behavior of the motors is just perceptible by the sound they emitted while. The flying capabilities though were not affected in any way and during the following 3:30 minutes the flight was performed just by using solar energy.

During this 3:30 minutes the plane was able not only to perform every maneuver necessary for the mission (turns, controlled climb and descent). As it will be seen in the conclusions the test for the team have been a total success despite of the finale of it.

In the following figure the Altitude/Time plot can be seen:

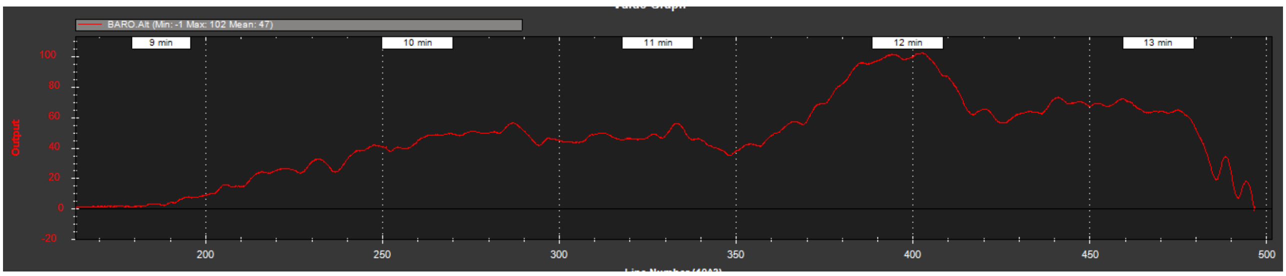

Fig. 4.8 Altitude/Time Plot

The first climbing phase untill the minute 11 is the one done with batteries, the next high climb was achieved just with solar panels, it's seen that it climbed from 40 m to 100 m in 50 seconds. It means that the climbing speed was in average a 1.2 m/s which is a nice climbing speed, better than the expected.

In the figure also can be seen the fast descent at the end that was caused because of a lost in the controll in the surfaces as it will be seen in the following section.

In the following section the consumptions and voltages for the flight are screened:

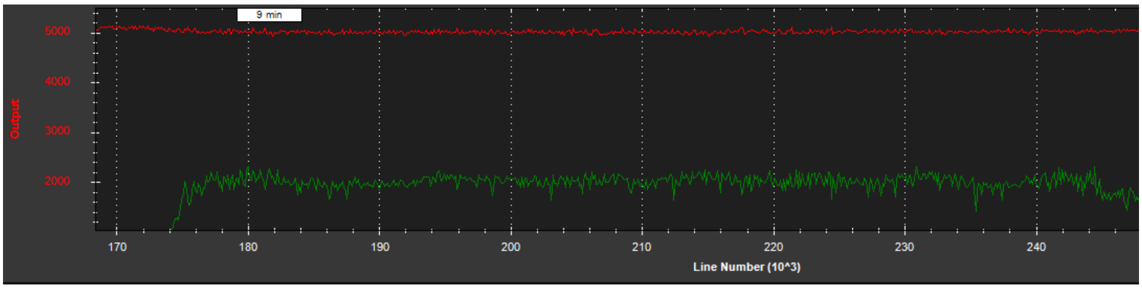

Fig. 4.9 Consumption

The information in the capture is the consumption during the level flight while using batteries, that is like this because of the configuration during the flight where just the information from the batteries was getting loged because of the switch that made the log of the solar energy consumption was not possible. In the log can be seen how in the minute 10 the consumtion is decreasing again to zero and that is because it was in that moment when the solar powering was switched on.

4.3.2 UAV Uncontrollability and Crash

During the flight an unadvised problem happened with the control surfaces control. The control surfaces stopped working all of a sudden and the pilot was not able to assure a proper landing for the model.

After some first hypothesis the log of the flight was checked and the problem was found.

The Speed controller that was in charge of powering with constant 5 Volts the Servo connections overheated and became overcame by the current.

The current along the Electronic Speed Controller was higher than expected and that caused that it stopped working, making the pilot unable to manage any control surface and leading the aircraft to a nosedive with catastrophic consequences.

In the following figure can be seen the probe of the electronic speed controller hypothesis:

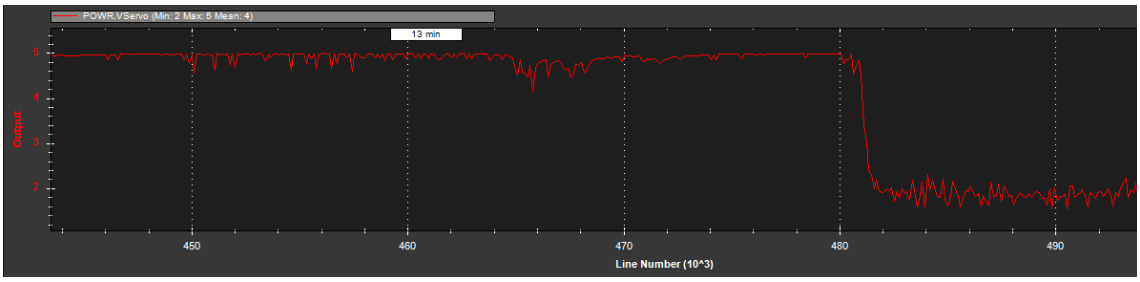

Fig. 4.10 Servo Current Intake

The Voltage given to the servos is shown in the figure and its plain to see that in a moment there is a drop in it.

The problem came after the block for powering during the RC model test had to be changed because of technical issues.

The solution for powering the servos was chosen without the proper time or calculations because of the proximity of the limit time (which would have lead the team to discard this option) and that's where the teams responsibility is.

Chapter 5

5.1 Scaling Considerations

After obtaining the prototype the team is ready to make some conclusions about the possibility of rescaling the UAV and to know if it would be able to perform his desired mission applying the same design methodology and building process but in another kind of measures.

It's understood that the model the team is working with can be placed in the medium average category (despite being really light) so in the following sections both the scaling up and scaling down will be discussed.

5.2 Scaling Down

Small or micro solar UAV applications can go from espionage to obstacle avoidance UAVs. We understand as micro UAV the drones that are shorter than 15 cm and lighter than 100g (which nowadays is possible because of the improvements in electronics and avionics).

It's plain to see that it's not a viable application for using the same methodology nor material used. A single solar cell would be bigger than the measures just stated.

5.2.2 Advantages

In the airplane structure matters the scaling down is advantageous as a lighter and more rigid structure with the same material could be achieved. It's calculated that dividing by 2 the wingspan the consequences are that the surface is obviously reduced and with it the solar power is reduced by a factor of 4 but it's compensated as the weight is reduced by a factor of 8.

Also the rigidness of the building would be highly increased avoiding long areas of Styrofoam alone.

5.2.3 Disadvantages

Unfortunately with the scaling down some disadvantages come through because of the viscosity giving a lower lift to drag ratio. The effectiveness then would be lower.

In terms of propulsion the efficiency of a motor for such an application have been proven to decrease dramatically when below 5 W working power.

And also in terms of viability of solar cells fitting would be troublesome to achieve the necessary power.

The limitations that just have been outlook along with the difficulties to build a prototype with such conditions would make a micro UAV unviable with the methodology followed for the DAC SOLAR POWERED UAV but what would be viable though it's to try different airfoils to fit just 1 row or 2 (making the aircraft smaller) which would be perfectly achievable.

5.3 Scaling Up

Once the feasibility of a really small solar uav have been discussed now it's time to discuss the feasibility of a big scale solar UAV. Considering big UAV a model with a weight higher than 60 KG. The applications for such a big aircraft would go from the payload transportation to the connection enhancement (Google project actually working on it).

5.3.1 Advantages

In aerodynamic matters the growing up of the airframe would be beneficial in many aspects. The lift to drag ratio would be better the bigger the airframe and the propulsion efficiency would be noticeably increased (and a gear box use would be applied).

More advantages come with the freedom in the solar cells fitting along the airframe. Being so easier to adapt all the solar cell groups in a way that all of them get the same irradiance which makes the whole system more efficient.

5.3.2 Disadvantages

The materials used in the DAC SOLAR POWERED UAV are good and viable for the measures that have been used but lack the necessary mechanic capabilities for a bigger prototype such as the one considered big (60Kg).The main problem would come in the skin and fuselage where the materials used are not capable of handle the increasing weights and torques. The change in the material would be a must and with it probably the wing design and tail as well would change accordingly with the new paradigm (hypothetically working with carbon fiber or another high end material the decision making that have been done during this project would have been dramatically different).

Chapter 6

6.1 Main Achievements

A fully functional solar powered UAV have been achieved. The following list sums up the main features that characterize the model.

High end despite cheap and affordable model.
High controllability and maneuverability.
High lift generation for slow speeds.
Auto flight and fly by wire flights enabled.
UAV able to flight both in solar power regime and with lipo-batteries.
Level Flight and climb phases achieved in solar powered regime.
Theoretically and proven long endurance flight during daylight.

6.2 General Conclusions

After every step in the process along the project have been done and revised the situation is ready to obtain the necessary conclusions, being this conclusions really important in this phase of the project for the system as it will be useful for an hypothetical future improving phase.

On one hand the main objective of the project have been fulfilled as the level flight and climb with solar power have been achieved (with no need of any energy from battery).

On the other hand it have been corroborated that as that was a first design and approach it can be improved in several ways that are going to be stated in 5.3 Improvements for future projects.

During the construction process the conclusions obtained are that when working with not high technology and while building the pieces from scratch the precision in the work is a must. Even using affordable material it was proven that the quality of the work can be truly semi-professional by using the correct building techniques and by taking the necessary time for calculations and decision making phases (in the material selection for example).

While working with the autopilot and mission planner hardware and software the team's conclusions are that the actual technologies available in the market for affordable prices are a great option and some of their advantages are the open source condition they have and the intuitive working principle. It have not been a huge problem to learn how to use them and configure them. In the vast majority of cases all the necessary options or modes for typical missions are already introduced in the software which was such a relieve for the team.

The overall conclusion about the whole project could not be better. For the team it have been a huge success. The principal objective for this project have been achieved even though some conditions where against the success of the project it all went as expected.

The potential of the solar UAV's have been checked by the team in first person seeing that it's perfectly viable and highly advantageous. The future of this kid of technology is bright and prosper. If a team of 2 students and 1 mentor can build such a nice working model that can help making an idea of what could be achievable by teams with more budget/time and engineering quality.
By terms of the future of this project concretely some improvements and redesigns are planned to take place in the near future by new engineering teams that want to follow the path opened by this first project try and by all the possibilities for improving that are now open. In the following section the possible improvements will be listed:

6.3 Improvements for future versions

In this section the possible improvements that were not done in this version will be listed. If with the current configuration and kind of building the whole day flight could have been achieved the engineering team truly believes that with the application of this improvements the multiday flight can be achieved easily.

Tail configuration:

As it have been stated in previous sections the T configuration that this project is using was perfect for placing more solar cells and avoid the shadows in them but as they were not finally needed a more traditional configuration could have been used.

By using the conventional configuration a big amount of weight could have been avoided. (The extra weight comes from the need of making the fin stronger and from the connections).

Also the control of the surface would be easier as the connection would not create as much torque.

MPPT:

As it was stated by using an MPPT the gathering and collection of solar energy would have been much more efficient as it would guarantee always the higher power from every situation. The current market options for MPPT's are for house applications (really big) or for research and investigation (really expensive) The only option so was to build one from electronic components but the lack of time and technical knowledge made the team chose to avoid using it.

Charger:

To achieve the multiday flight a charger is a must. In the project a system of diodes and a switch were used for the energy distribution matter. With the design and construction of a charger the principle of work of the whole UAV would change and it would fit the first approach the team wanted to take. The idea of making the energy coming from the solar cells go direct to the motor all the time and the energy from the batteries would have 2 ways of work. On one hand when there would be some energy leftover (or not consumed in the throttle generation) the energy would go from the solar cells to the batteries charging them through the charger. In the other situation if there was not enough energy from the solar cells (imagine during dusk or dawn) the energy supplement would be taken from the batteries).

It's plain to see how would a charger affect drastically in the project and how better would it be in order to achieve the desired multiday flight.

For future projects also it would be nice to avoid the empty spaces in the wings by adjusting in a more proper way the arrangement of the cells and the wing shape. A more difficult improvement would be to try to use carbon fiver instead of Styrofoam which would lead to a much lighter wing.

6.4 Environmental Study

The use of solar energy like any other renewable font of energy is highly advantageous for the environment in many ways. For sure for avoiding the use of fuels or another contaminant products for the propulsion but also for acoustic contamination for example.

By making use of solar UAV's instead of fuel powered ones we reduce the greenhouse effect and the consumption of fossil fuels. Within the current usage of UAV's and the number of them it may seem unimportant but as it have been already stated the potential of the UAV industry is leading towards a huge increase in the number of flights of UAV's and missions. So it makes sense to start taking them into account and look for more environmentalist options.

In the acoustic contamination the main advantage of the solar UAV in front of traditional fuel UAV's would be that the solar one does not need to land as much (or not need at all) as the fuel powered. It's the same situation as in the first case, it may seem unnecessary but it may not be in the near future.

To sum up, the team do believe that if you have the option of using a renewable font of energy so be it even in the smallest case, every drop counts.Also in this case being as advantageous as it is to sue solar energy it should be more the number of devices that started using it.

6.5 Future of the technology

In this section a forecast of the future of the Solar Powered UAV after our study on them and our experience will be presented.

As was said the main advantage of the solar UAV is the long endurance and the limitation is the same that in every fixed wing model and it's in the type of operations. In comparison with fuel engine UAV's the handicap would be the lowest payload for the same tow in the solar powered one.

It is plain to see that the world's need of greener solutions for some missions will make the technologies involved in the solar UAV's development. Not taking into account a huge development or improvement in the current solar gathering technologies the measure this UAV are going to have for concrete missions the believing is that will be from 4 to 8 meters as it is the big enough to fit enough solar cells to be able to carry substantial payload as the necessary equipment for the missions already stated (payloads in the 1 Kg range). The miniaturizing of electronics and avionics will be for sure a huge advantage especially in the weight saving. The development that the technology will have to follow in order to surpass the current limitations (related with the consumption and also with the low Reynolds) will be especially on the propulsion and energy storage (making the propulsion consumption lower and the energy storage higher) and also in the solar energy efficiency.

In a larger scale the problems are similar but with a fragility problem added, it's been seen during the project that the big area parts using light materials (such as in the wing) turn out to be fragile and difficult to work with. As engineers the team don't believe in the near mid future to be plausible to see solar powered

UAV's or airplanes carrying passengers but it do believe in high scale UAV's developing high precision missions solar powered capable of carrying heavy payload and equipment.

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ANNEX

For Solar UAV thesis

Useful additional information for the Thesis: Solar UAV for long endurance flights (by the same authors)

Llibert Chamizo; Marc Olmo

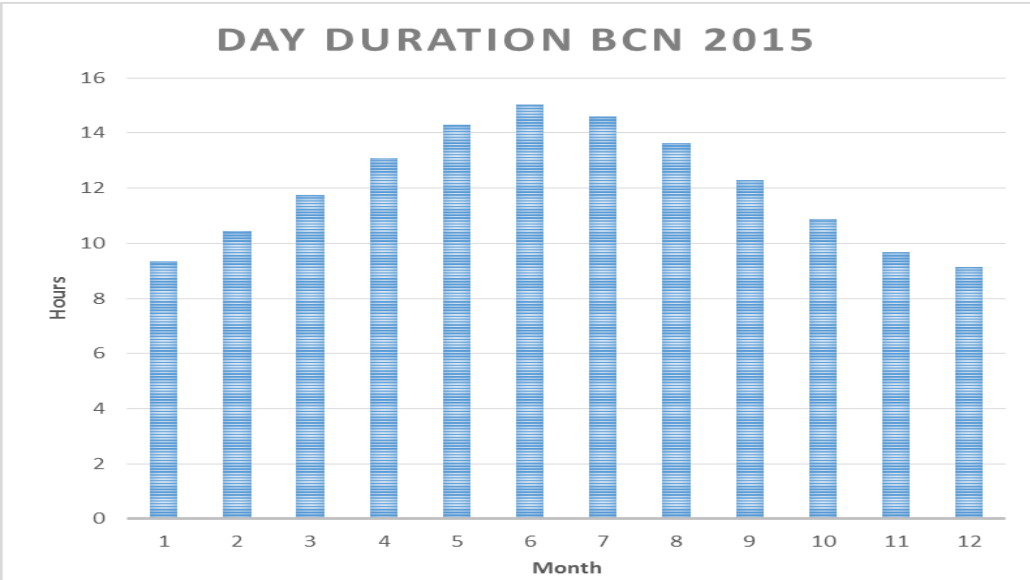
CONTENTS

Annex

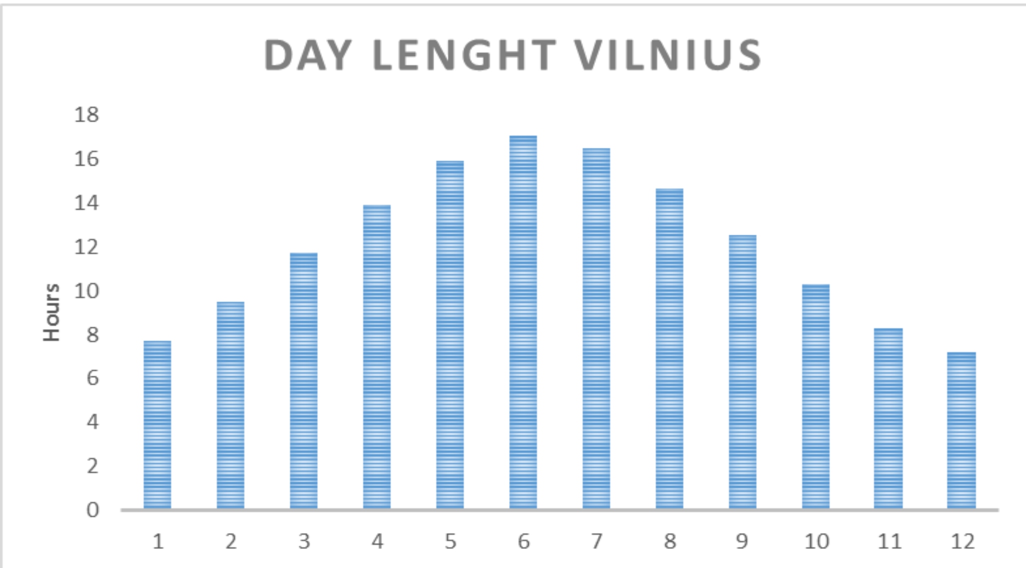
1.1. Solar Energy Data

1.1.1 Day Duration

1.1.1.1 Barcelona

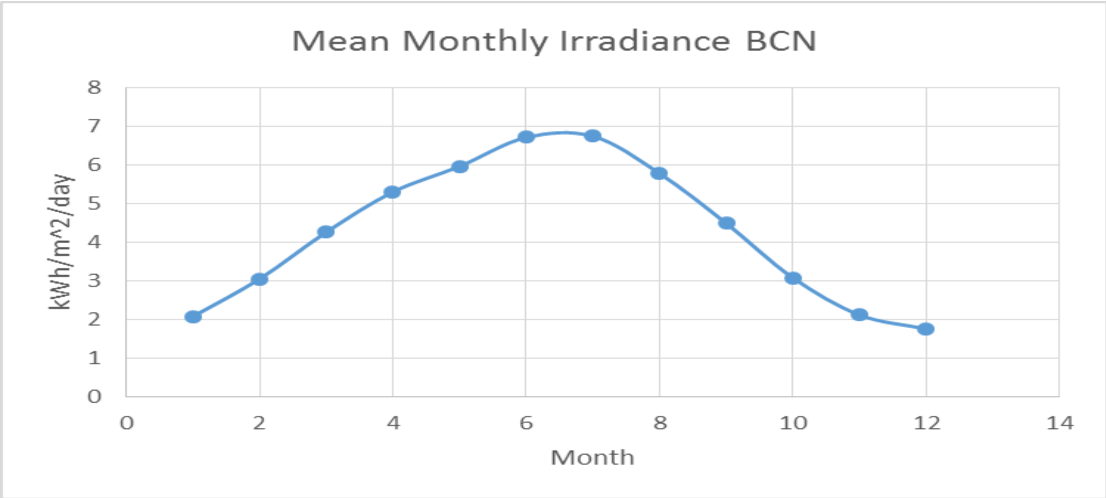


1.1.1.2 Vilnius

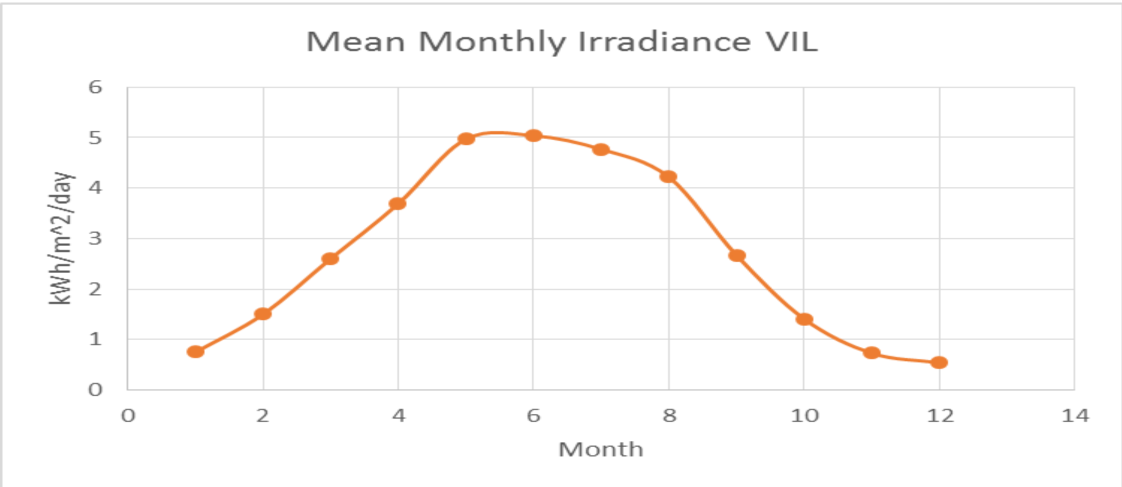


1.1.2 Irradiance

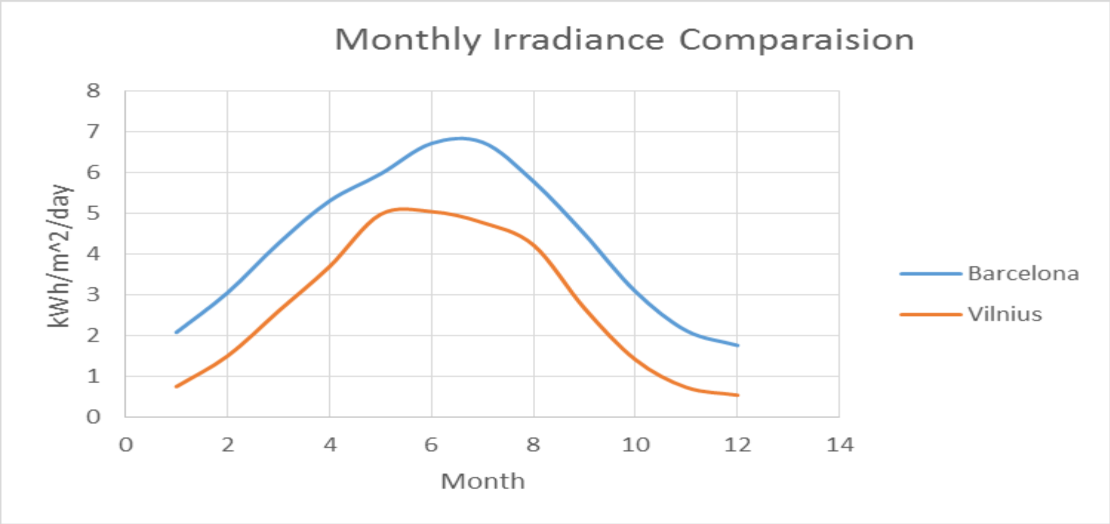
1.1.2.1 Barcelona



1.1.2.2 Vilnius



1.1.2.3 General



2.1 Construction Process

2.1.1 Building Process

During this section an explanation in a detailed way of the whole building process followed to build the plane from scratch. Every single particular piece was design build and attached by team team and little were bought.

2.1.2 Wing

The main work done is in the wing as it is the main part of the aircraft and where all the lift is generated, it have been chosen the design very carefully in order to fulfill all the requirements.

Different ways of building were planed rather than the optimal one because of transportation possibilities. The use of a traditional van for transportation with less than 3 m baggage made impossible to fit the whole wing in it.

To split the wing in 3 parts was the solution chosen. 2 wing extremes (1.2 m each) and one central part which is 2 m, this solution is perfect for transportation but carries several problems in the building process that will be explained later on.

The beginning of the job was so in the wing and more concretely in the Wing Ribs:

2.1.2.2 Wing Ribs

The wing ribs are the airfoil replicas that go along the wing attached to the airframe giving it the proper internal structure rigidness, they are along with the wingspan the main structural parts. The main idea of them is to give the proper shape for the wing which's skin will go attached to them.

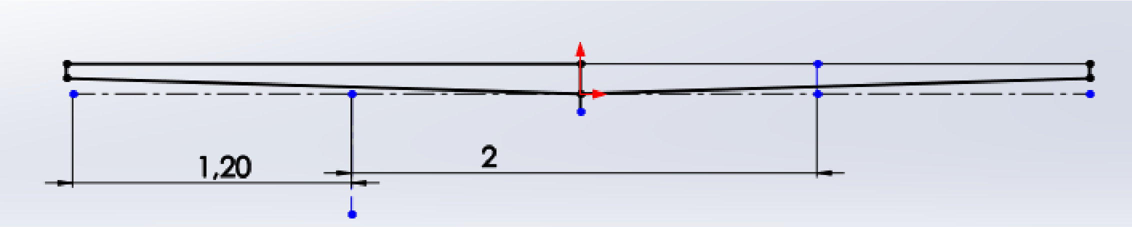
First of all some images of the airfoil chosen (CLARK-Y) where drawn and print and then cut 46 of them. To cut them first had to be obtained the correctly thick parts of Styrofoam which was performed by cutting several slices using hot wire. The ribs are meant to be placed equidistantly along the wing both in the wing tips and the central part of it. Taking into account that in 1/3 of the airfoil there is supposed to be the center of gravity the team had to cut the airfoil replicas consequently to fit the wing span in it. Here the whole stack of them:

Each rib have 2 holes in it, those were done in order to be able to put the wires through them easily once the wing is fully built.

2.1.2.3 Wing Spar

The wing spar is the vertebral column of the wing and it is meant to handle the fuselage weight and all the aerodynamic forces during the flight. Its main purpose is to give the wing the necessary strength and rigidness that's why the material used here is not Styrofoam nor balsa wood. For the building of the wings spar it was used a combination of strong Styrofoam with wood. The main characteristic here was the sandwich like combination and the tendency of the wing spar to be thinner and thinner the farer from the center. It was done like this to have the lower weight possible and by doing so a reduction on the wing spar weight in a third was achieved. The main form of the wing spar was as the following sketch shows:

And the final form was the one shown in the following image:



The image is not in scale*

This metallic part here will be explained in the following section as it's the connection part meant to keep the wingtips and the central part attached during the flight.

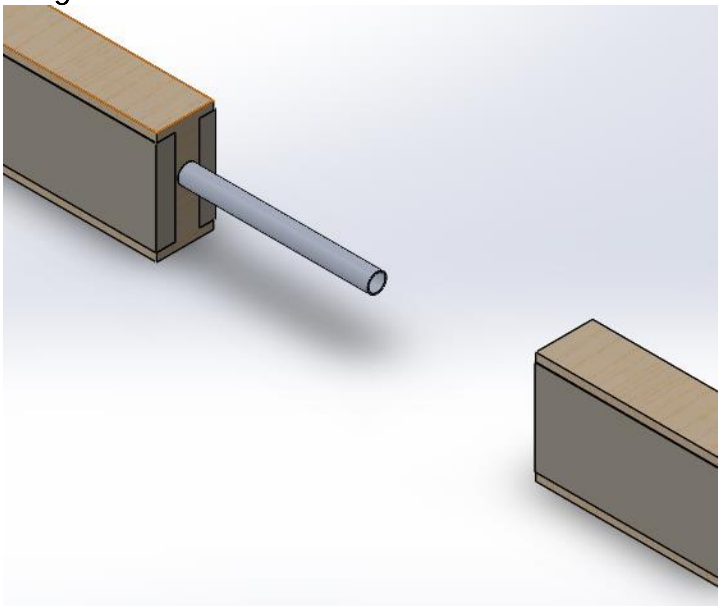
Once the wing tips are attached to the wing spar the airframe skeleton is achieved.

2.1.2.4 Connections

As stated before because of transportation limitations it was necessary to split the wing in 3 parts and also make other parts, like the tail or the fuselage, disassemblable. In this subsection how the connection problem was solved in order to have good, strong and relievable one will be explained.

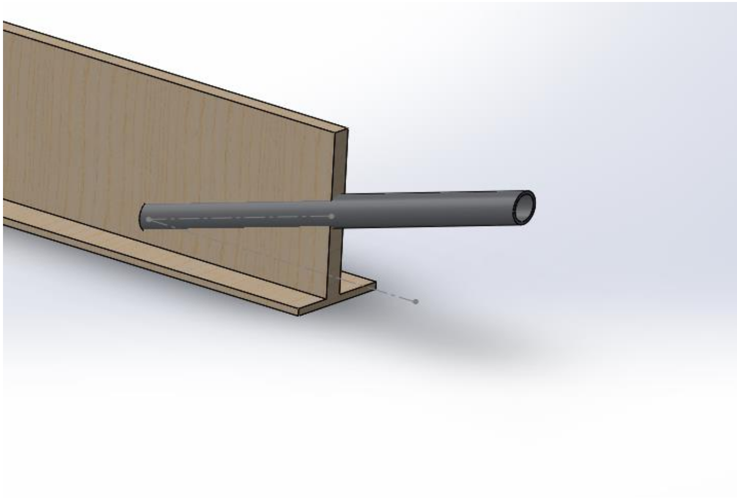
The connections will be the main structural junction between two different parts and in this case between both the wingtips with the central part.

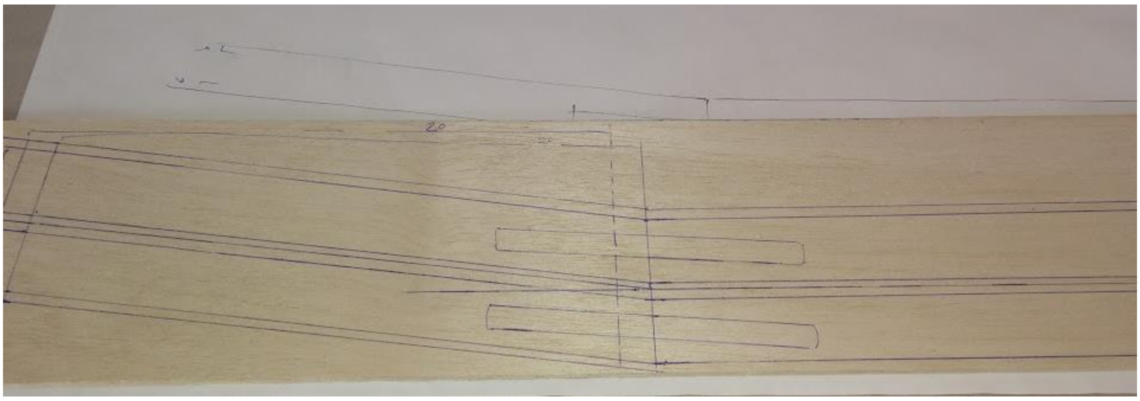
First building schematic:



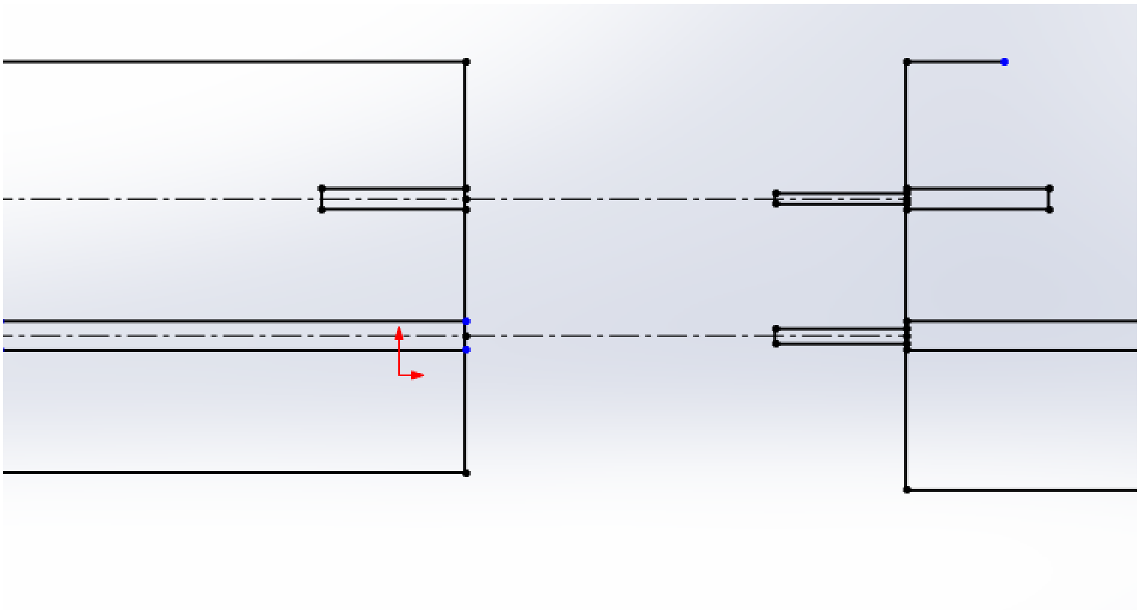
The central part will have one steel cylinder with a slightly bigger diameter than the one in the wing tips to make the second one able to fit inside the first.

It was really important to take into account the angle the wing tips have and it was a handicap in the building process but the desired degrees were achieved.



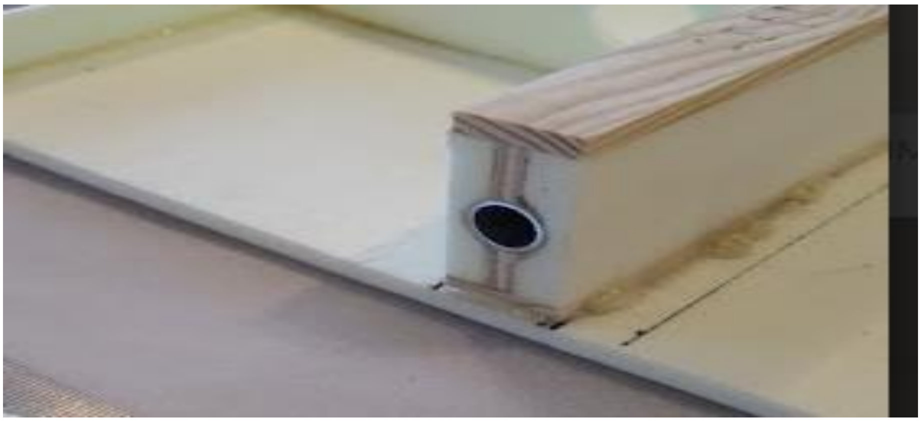


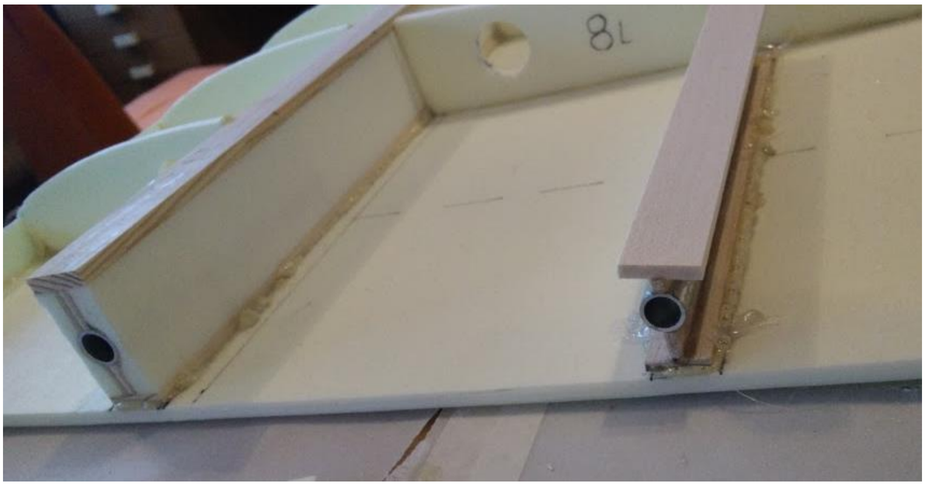
2 of this connections were used in each wing tip just to avoid all the forces generating torque along one single axis and also to avoid the circular rotation of the parts around one axis. The disposition of both connections can be seen in the following sketch (placed in each third of the chord):



For better strength and durability it was introduced a carbon fiber cylinder inside every smaller tube.

Here images of the procedure:





2.1.2.5 Leading Edge

The leading edge of the wing is the frontal part of it which is usually rounded that marks the limits between the extrados and the intrados. Is the part of the wing that first contacts the air.

In the wing all the parts of the wing ribs were cut and did all the leading edge from a long strong Styrofoam in order to avoid the technological problems that leaving the whole wing ribs would have carried. Those were the following:

It was not achievable to obtain perfect circular shapes for the part of the leading edge in the ribs.

The connection of the wing ribs and the wing skin would have been really troublesome in the Leading edge as they are 2 straight planes and would be impossible to achieve the correct roundness.

The process of achieving the correct roundness was by gluing the Styrofoam block in the leading edge position and then sanding it following a given pattern.

2.1.2.6 Trailing Edge

The trailing edge is the rear part of the wing where the airflow coming from the intrados and extrados converts into one, except when the angle attack is so big that we enter in stall. The main control surfaces are placed there, to redirect the airflow and creating momentums to control the aircraft.

Since the trailing edge is sharp, it is not a good idea to make it directly sanding the Styrofoam because it would be really soft. It was decided to glue 2 pieces of balsa wood along all the wing to make it strong enough and sharp by sanding it. Since it was not perfectly leveled with the Styrofoam edge it was decided to introduce more balsa where it was necessary until a perfectly aligned trailing edge was obtained.

2.1.2.7 Skin

The skin of the fuselage is the outer part of the wing and so the part that have to be more precisely glued and attached to the inner skeleton of the wing. Here it was wanted a skin strong enough to handle the solar cells and the wiring inside. The material used is as always the Styrofoam but once everything is correctly attached and placed it will be covered with tape providing the whole wing with a stronger skin and a neater look.

The building process was simple, 2 wide pieces of Styrofoam of 5 mm thickness using hot wire were sliced. The pieces were measured and cut in order to coincide with the intrados and extrados parts.

The gluing work was done carefully trying to maintain the perfect form and shape. The procedure started by gluing the intrados as in the CLARK Y is almost straight which is convenient. For the extrados gluing first attach the trailing edge was attached and maintaining it in its position and then fixing all the extrados. To avoid it from moving while drying it was convenient to fix everything in its position and after applying some weight in the top.

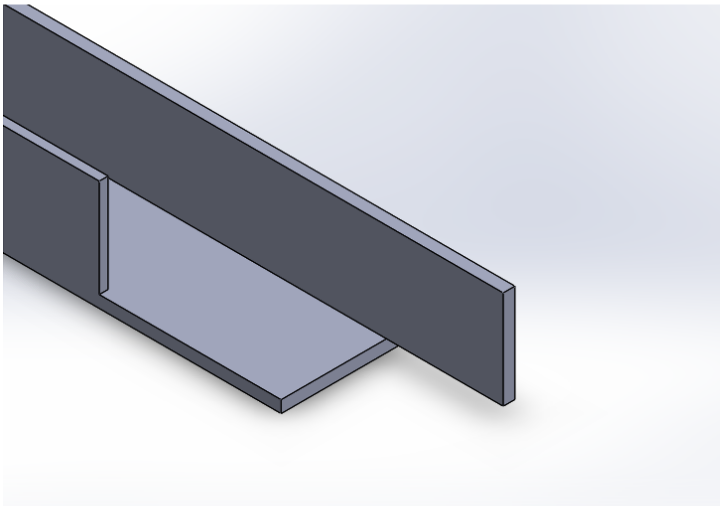
2.1.3 Fuselage

The fuselage is the main body of the aircraft and is meant to hold the cargo the payload and in our case the batteries and the major part of electronic components.

So that why it is supposed to handle all the weight of those components that are the heaviest in the model.

2.1.3.1 Body

The decision was to make the simplest model possible so the rectangular model was chosen. To make it from parts (for easiness) it was decided to build it like the following sketch:



By joining a piece like the previous one with the negative of it the team was able to build the long fuselage desired.

After that it was attach a second Styrofoam part in the lower part of the fuselage to be able to sand it and give the fuselage a rounded shape.

Until the center of gravity was measured a quite longer fuselage than the needed was built in order to be able to place the components in the more convenient place in order to create more or less moment as necessary.

Once the center of gravity was placed the leftover of the fuselage was cut and started cutting the frontal part of it.

To achieve the aerodynamic nose as in the image the Styrofoam was cut and sand:


Something similar was done to the back part of the fuselage which connects to the fishing rod that works as tail:

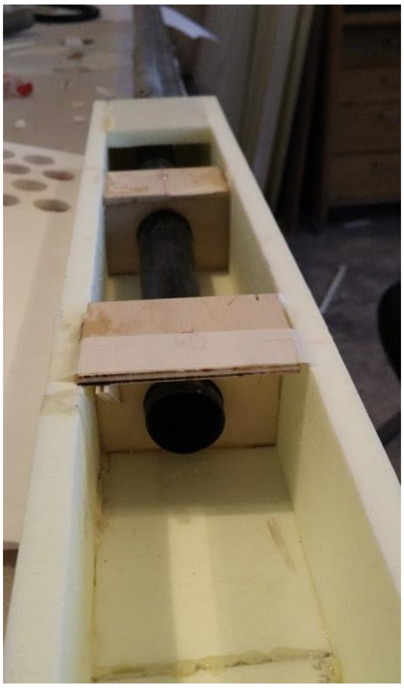

To provide the fuselage with enough strength to handle the weight to build an inner box with balsa wood was necessary. The reason was to introduce the autopilot and to handle the moments in the center of gravity.

2.1.3.2 Connections

A quite heavy tail was obtained that’s why a strong enough connection between the fuselage and the tail was mandatory. To do so they were built 3 pieces of wood with holes in order to fit the fishing rode in them. Those 3 pieces were attached in the fuselage making sure that the perpendicularity with the horizontal is perfect and that is perfectly parallel with the fuselage. In order to create strengthen nerves to apply to the connection tinny triangles were built, the complete connection building can be seen in the following image:


Where the big hole is where the tail goes and where the small screw holes is where the connection with the wing will go (which are 2 long screwst attach as the image below:


And images of the main tail connection:



2.1.4 Tail

2.1.4.1 Vertical Stabilizer

The vertical stabilizer is found at the end of the fuselage or body, and is intended to reduce the aerodynamic side slip and provide direction stability.
To construct it, first of all two pieces of wood were cut to place the NACA0009, the used airfoil for the tail. Then placing one of them each side of a Styrofoam block, it was cut following the outline of the airfoil with the hot wire.

The Styrofoam block was cut with the indicated inclination specified in the design in the trailing edge, and then after cutting with the hot wire, a vertical cut from the end of the bottom part was done, to make the upper part shorter.

After that, sand it to make the trailing edge sharp again. The final result is shown in the next picture:

2.1.4.2 Horizontal Stabilizer

A longitudinal stabilizer is used to maintain the aircraft in longitudinal balance, or trim: it exerts a vertical force at a distance so that the summation of pitch moments about the center of gravity is zero.

The construction procedure is really similar to the vertical stabilizer. Two rectangular Styrofoam block are cut (the hotwire is not that long to cut in one piece) and placing the NACA0009 on each side of the block, it was made the airfoil form with the hot wire.

After that, the pieces were cut in the 1/3 from the trailing edge to place the spar. The spar was made from wood in the central part, and two pieces of Styrofoam in the tips. After cutting all the pieces all was glued (two pieces of the horizontal and the spar) and sand it to make it a perfect surface. The final result is shown in the next picture:

2.1.4.3 Connections

For the connection between the horizontal and vertical stabilizer it was necessary to think carefully on what to use. The first approach was to use two support pieces since the horizontal stabilizer is quite heavy and that will do it more stable. That was making harder the construction, so finally it was choosen one strong piece in the middle.

It is made from a metal movable part acting as a hinge, and two pieces of wood on the top to keep a considerable distance from the vertical stabilizer to allow the movement. The subjection is done with two screws placed symmetrically on the wood. The result is shown in the next picture.

2.1.5 Final Result

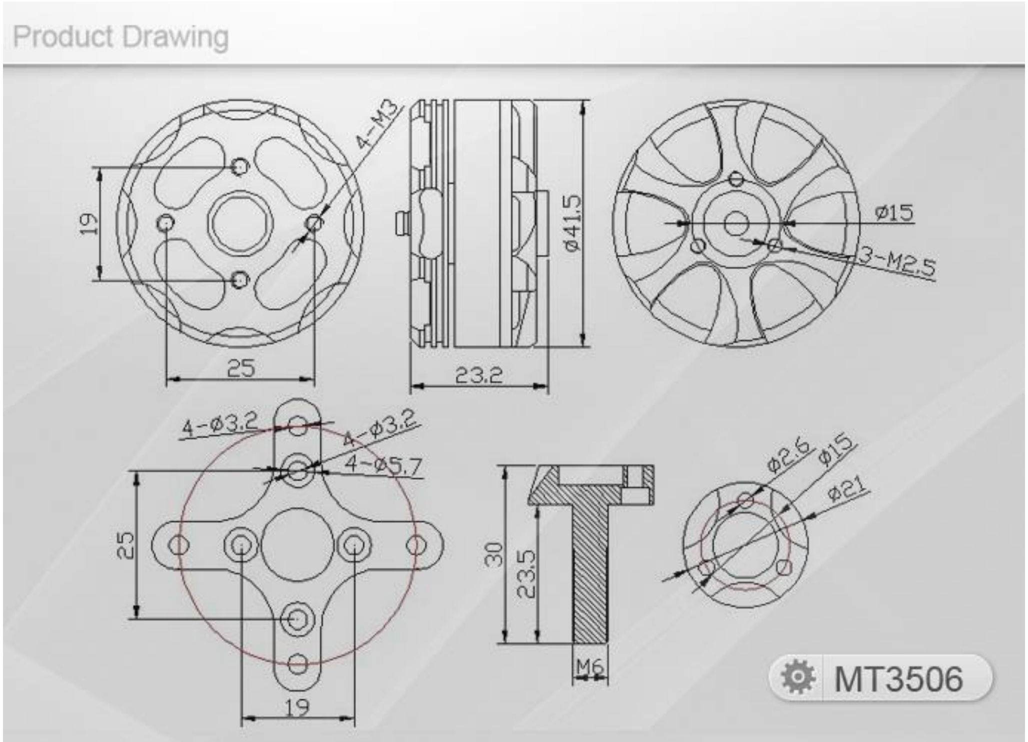
Image of the airframe result:

And Propulsion Final result:

Solar Powered UAV Final result

Foto of the solar powered Flight

3.1MT3506 Datasheet



Specifications:

KV	650
Configu ration	12N14P
Stator Diameter	35mm
Stator Length	6mm
Shaft Diameter	4mm
Motor Dimensions(Dia.*Len)	Φ41.5×23.2mm
Weight (g)	70g
Idle current(10)@10v(A)	0.2A
No.of Cells(Lipo)	3-4S
Max Continuous current(A)180S	14.5A
Max Continuous Power(W)180S	260W
Max. efficiency current	(4-9A)>84%
internal resistance	155mΩ

Item No.	Volts (V)	Prop	Throttle	Amps (A)	Watts (W)	Thrust (G)	RPM	Efficiency (G/W)	Operating temperature(℃)
MT3506 KV650	11.1	T-MOTOR 11*3.7CF	50%	1.4	15.54	195	3500	12.55	42
			65%	2.6	28.86	285	4500	9.88	
			75%	3.6	39.96	380	5000	9.51	
			85%	5	55.50	472	5650	8.50	
			100%	5.9	65.49	540	6000	8.25	
		T-MOTOR 12*4CF	50%	1.6	17.76	230	3300	12.95	45
			65%	3.2	35.52	334	4200	9.40	
			75%	4.5	49.95	439	4800	8.79	
			85%	6.1	67.71	540	5350	7.98	
			100%	7.3	81.03	645	5700	7.96	
		T-MOTOR 13*4.4CF	50%	1.9	21.09	260	3200	12.33	47
			65%	3.5	38.85	400	4100	10.30	
			75%	5.3	58.83	520	4600	8.84	
			85%	7	77.70	636	5100	8.19	
			100%	8.3	92.13	723	5400	7.85	
		T-MOTOR 14*4.8CF	50%	2.5	27.75	340	2950	12.25	54
			65%	5.1	56.61	499	3700	8.81	
			75%	7.1	78.81	626	4150	7.94	
			85%	9.3	103.23	736	4550	7.13	
			100%	11	122.10	848	4700	6.95	
	14.8	T-MOTOR 11*3.7CF	50%	2	29.60	290	4400	9.80	46
			65%	3.9	57.72	451	5600	7.81	
			75%	5.5	81.40	570	6400	7.00	
			85%	7.4	109.52	720	7100	6.57	
			100%	8.7	128.76	800	7450	6.21	
		T-MOTOR 12*4CF	50%	2.5	37.00	350	4100	9.46	52
			65%	4.9	72.52	570	5300	7.86	
			75%	6.9	102.12	720	6000	7.05	
			85%	9.2	136.16	880	6600	6.46	
			100%	10.8	159.84	1000	6900	6.26	
		T-MOTOR 13*4.4CF	50%	2.7	39.96	386	4000	9.66	60
			65%	5.6	82.88	651	5100	7.85	
			75%	7.8	115.44	822	5800	7.12	
			85%	10.3	152.44	970	6300	6.36	
			100%	12	177.60	1053	6600	5.93	

Notes:The test condition of temperature is motor surface temperature in 100% throttle while the motor run 10 min.