MENG 411 - Capstone Team Project

Eastern Mediterranean University

Faculty of Engineering

Department of Mechanical Engineering

Design and Fabrication of Solar UAV

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Abstract

This report is about solar UAVs in general and the manufacturing of a small solar UAV as Capstone team project in Eastern Mediterranean University. Engineers design solar UAVs for many different purposes, and they have different classifications. The purpose of this report is to give information about solar UAVs and the method used to make the design intended for the project. There are three main sections in this report introduction, literature review including information about solar energy, UAVs, solar UAVs, history and classifications of UAVs, and the design and configuration of the solar UAV required for the project.

Key words: Solar powered UAV, Solar Energy, Solar Airplane

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Aspect Ratio	AR
Area of solar cell	A_{sc}
Wingspan	b
Wing Drag Coefficient	C_D
Wing Lift Coefficient	C_L
Chord Length	c
Propeller Diameter	D_p
BEC (Step-down) Efficiency	η_{bec}
Efficiency of Cambered	η_{cbr}
Efficiency of Battery Charging	η_{chrg}
Efficiency of Motor Controller	η_{ctrl}
Efficiency of Battery Discharging	η_{dchrg}
Efficiency of Gearbox	η_{grb}
Efficiency of Motor	η_{mot}
Efficiency of Maximum Power Point Tracker	η_{mppt}
Efficiency of Propeller	η_{plr}
Efficiency of Solar Cell	η_{sc}
Efficiency of Weather	η_{wthr}
Fuselage Length	F_L
Acceleration due to Gravity	g
Energy Density of Battery	k_{bat}
Mass/Power Ratio of Propulsion Group	k_{prop}
Solar Cell Mass Density	k_{sc}
Airframe Constant	k_{af}
Total Mass of Aircraft	m
Total Mass of Airframe	m_{af}
Total Mass of Avionics	m_{avc}

Total Mass of Batteries	m_{bat}
Fixed Mass	m_{fixed}
Total Mass of Payload	m_{pld}
Total Mass of Propulsion Group	m_{prop}
Total Electrical Power Available	$P_{electot}$
Power Required for Steady Level Flight	P_{level}
Density of Air	p
Total Empennage Side Area	S_t
Tail Aperture	α
Total Day Time	T_{day}
Total Night Time	T_{night}
Aircraft Velocity	V

Chapter 1
Introduction

The aviation industries are continuously developing from the invention of the first plane till today. There are different types of aircraft present to which could include airplane, helicopters, unmanned aerial vehicles(UAV) etc. this various aircrafts have moved from the stage of being driven by a human inside them to the stage of being controlled by a controller device outside them, and in some cases by developed program to help them control themselves. They have also diversified to have more than one power source that includes solar energy and an electrical source; these kinds of aircrafts are called hybrids. This capstone project would be capitalizing on the modern development on the hybrid energy sources to develop a UAV.

1.1 Importance of Solar UAVs

The ability for an aircraft to fly for a long period of time has become an important issue and a target of research. The UAVs have been of important use for both civilian and military applications. The required endurance is in the range of a couple of hours in the case of law enforcement, border surveillance and forest fire fighting. However, other applications require high altitudes, such as communication platform for mobile devices, weather research and forecast, environmental monitoring, would require remaining airborne during, weeks or even months. The only way possible currently to reach such endurances is through solar powered UAVs.

1.2 Summary of the Problem

The ability of an UAV to fly for long periods of time has become an important issue and target of research. These researches are increasingly taking importance in our society and world, for civilian and military applications. In case of military application the required endurance is just a couple of hours where it ca be used for border surveillance, forest fire fighting or power line inspection. However, other applications at high altitudes, such as communication platform for mobile devices, weather research and forecast, environmental monitoring, would require remaining airborne during days, weeks or even months. Until this moment, the only possible way to reach these kind of goals is using solar powered UAVs. Solar cells which are integrated into one panel is used to collect energy from the sun and power the propulsion unit and other instruments, the other part being stored for the night time. In order to reach the target endurance, the design of the airplane has to be thought very carefully, as a system composed of many subsystems that are continuously exchanging energy. Due to these relationships, each part has to be sized accordingly to all the others.

1.3 Objectives

The objective of this project is to develop an RC unmanned aerial vehicle, which is powered by solar energy in conjunction with a battery system, using flexible solar photovoltaic cells as the main source of electric energy generation in the UAV and also with an aim of developing a cost efficient design of the hybrid unmanned aerial vehicle.

1.4 Report Organistaion

The report would give information about solar energy and unmanned aerial vehicle in the 2nd chapter and in the 3rd chapter; information such as dimensioned drawing, cost analysis, materials and manufacturing methodology would be discussed. In the 4th chapter a step by step manufacturing process and assembling will be explained and the testing process of the final model would be discussed. The 5th chapter includes the results of testing and discussion of the project and will contain ideas to make the project more efficient of sustainable. The last chapter includes the conclusion and future work. In conclusion the project would be achieved with the theoretical knowledge and basic skills obtained by the students all through their educational life in the field of mechanical engineering.

Chapter 2

Literature Review

2.1 Solar Power

Solar power is energy from the sun that is converted into thermal or electrical energy. Solar energy is the cleanest and most abundant renewable energy source available. Using the technology present this energy can be harnessed for many uses such as generating electricity, providing light and heating water for domestic, commercial or industrial use. Solar energy can be harnessed using photovoltaic, solar heating and cooling, concentrating solar power and passive solar. The first three forms are called active solar systems and they use mechanical or electrical devices to convert the sun light into other useful forms. Passive solar buildings are designed and oriented to collect, store, and distribute the heat energy from sunlight to maintain the comfort of the occupants without the use of moving parts or electronics. Solar power plants can be built as distributed generation located at or near the point of use, or as a central-station [2].

2.2 Photovoltaic Cell

Photovoltaic (PV) cells are made up of at least 2 semi-conductor layers. As shown in figure 2.1 the first layer contains the positive charge, and the second the negative charge. Sunlight contains little particles of solar energy called photons. As a photovoltaic cell comes in contact with sunlight, many of the photons are reflected, passes through, or immersed into the solar cell. When adequate amount of photons are absorbed into the negative layer of the photovoltaic cell, electrons are released from the negative semiconductor material. Owing to the manufacturing procedure of the positive layer, the released electrons migrate to the positive layer generating a voltage differential, similar to a household battery. When the two layers are connected to a load, the electrons flow through the circuit generating electricity. All individual solar energy cell produces only 1-2 watts. In other increase power output, cells are jointed in a weather-tight package called a solar module. These modules, from one to hundreds or thousands are then connected in series or parallel to one another, which are then called a solar array, to create the anticipated voltage and amperage output required by the given project [3].

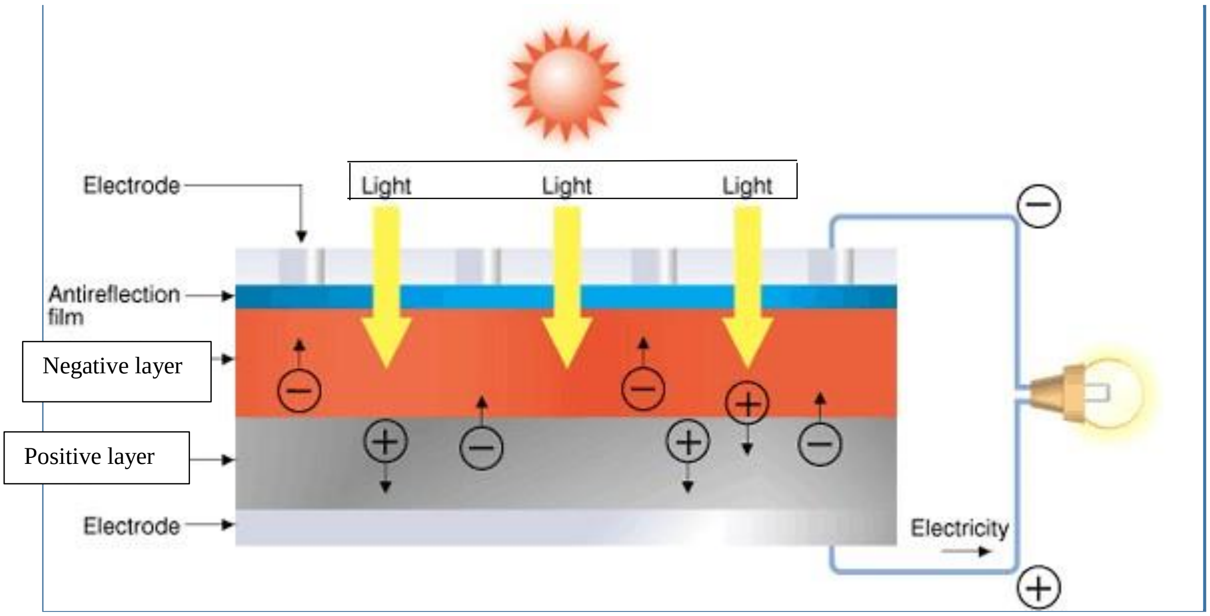


Figure 2.1: Photovoltaic cell solar panel adapted from [32]

2.3 UAV

The UAV is an abbreviation for Unmanned Aerial Vehicle, it is an aircraft without a pilot. UAVs are also remote controlled aircraft (e.g. usually flown by a pilot from a control station) or can fly by itself based on flight programmed plans or more autopilot systems [4]. Unmanned aerial vehicle have has been in existence since the early 1900s, the first unmanned aerial vehicles built were used by the military during wars to pick and drop bombs on targets, but the unmanned aerial vehicle made had flaws such and missing the target or in controlling them.

Modern day unmanned aerial vehicle have advanced to more sophisticated machines which are both used by military and civilian, they have become very important in areas such as surveillance, military defense, news broadcasting etc. and in the future they would become of more importance to the world.

2.4 History of UAV and Time line

Unmanned aerial vehicles (UAVs) were first used during the American Civil War, an inventor patented an unmanned balloon that carried explosives that could be dropped after a time-delay fuse mechanism triggered the basket to overturn its contents. Air currents and weather patterns made it difficult to estimate for how long to set the fuse, and the balloon was never successfully deployed. In 1883, the first aerial photograph was taken using a kite, a camera and a very long string attached to the shutter-release of the camera. In 1898, this technology was put to use in the Spanish-American War, resulting in the first military aerial reconnaissance photos.

World war I was when the first radio controlled unmanned aerial vehicle were developed but unfortunately where not used until the end of the war [5]. A time line of the various unmanned aerial vehicle developed from the table given below:

Table 2.1: UAV Time Line adapted from [6]

Time line	Description	Inventions
1910s	The first UAV took flight in the U.S. The success of UAVs in test flights was huge. Armistice arrived before the prototype UAVs could be deployed in earnest.	Sperry Aerial Torpedo (USA). Kettering Aerial Torpedo (USA).
1930s	For more than a decade after the end of World War I, development of pilotless aircraft in the U.S. and abroad declined sharply. By the mid-to-late 1930s, new UAVs emerged as an important combat training tool.	DH.82B Queen Bee (UK). Radio Planes (USA).
1940s	During World War II, Nazi Germany's innovative V-1 demonstrated the formidable threat a UAV could pose in combat. America's attempts to eliminate the V-1 laid the groundwork for post-war UAV programs in the U.S.	V-1 (Germany). PB4Y-1 and BQ-7 (USA).
1960s	From their early use as target drones and remotely piloted combat vehicles, UAVs took on a new role during the Vietnam War: stealth surveillance.	AQM-34 Ryan Firebee (USA) D-21 (USA)
1970s	The success of the Firebee continued through the end of the Vietnam War. In the 1970s, while other countries began to develop their own advanced UAV systems, the U.S. set its sights on other kinds of UAVs.	Ryan SPA 147 (USA)
1980s	During the late 1970s and throughout the 1980s, the Israeli Air Force, an aggressive UAV developer, pioneered several important new UAVs, versions of which were integrated into the UAV fleets of many other countries, including the U.S.	Scout (ISRAEL) Pioneer(ISRAEL)
1990s to Present day	UAVs command a permanent and critical position in high-tech military arsenals today, from the U.S. and Europe to Asia and the Middle East. They also play peaceful roles as monitors of our Earth's environment.	Darkstar (USA). Pathfinder (USA). Helios (USA). Etc.

2.5 Classifications of UAV

Several different organizations have proposed different specification for the reference standards the international UAV community should use. The European Association of Unmanned Vehicles System (EUROUVS) provides a classification of UAV system based on different parameter such as maximum takeoff weight (MTOW), flying altitudes, endurance, speed, size etc. [7].

Table 2.2: Classifications of UAVs adapted from [7]

	Category	Max. take-off weight (kg)	Max. flight altitude (m)	Endurance (hours)	Example	
					Mission	Systems
Micro/Mini UAVs	Micro	0.10	250	1	Scouting, surveillance inside buildings	Black widow, Homet
	Mini	<30	150-300	<2	Agriculture, pollution measurements	Tracker, Raven, Skorpio
Tactical UAVs	Close range	150	3000	2 - 4	Search & rescue, mine detection	Observer l, Phantom
	Short range	200	3000	3 - 6	RSTA, EW, BDA	Luna, Silver fox
	Medium range	150-500	3000-5000	6 – 10	NBC sampling, mine detection	Aerostar, Falco, Sniper
	Long range	-	5000	6 – 13	Communication relay, BDA, RSTA	Hunter, Vigilante 502

2.5.1 Micro and Mini UAVs

Small aircrafts include micro and mini UAVs that fly at a low altitude of 300m. These types of UAVs can be used for surveillance inside buildings or flying in small areas, they can also be used for recording and listening. Example of micro and mini UAVs are BlackWidow (figure 2.2), Carina-Mini ARF etc.

Figure 2.2: Black Widow Mini UAV obtained from [21]

2.5.2 Tactical UAVs

This kind of UAVs are more bigly compared to the micro and mini UAVs, they also fly at a higher altitude ranging for from 3,000 to 8,000 meters. They are used by the military in the following applications

- Border patrol
- Surveillance high value assets
- Target Acquisition

Examples of Tactical UAVs includes Bayraktar (figure2.3), Shadow, etc

Figure 2.3: Bayraktar Tactical UAV obtained from [22]

2.5.3 Strategic UAVs

They are UAVs with high endurance and maximum high altitudes of about 20,000 meters, they are usually fully automated which includes its landing and takeoff. This type of UAVs are usually controlled from the ground know as ground control station (GCS). They are you in different fields one of which is airport security, examples includes Global Hawk (figure2.4), Raptor etc.

Figure 2.4: Global Hawk Strategic UAV obtained from [23]

2.6 Solar Flight

The concept of the solar flight is flying the aircraft with solar energy as a source of generating power. From the first invention of a solar aircraft in 1974 many other solar aircrafts has been made, they vary is shapes and sizes but all having same concept. Based on their sizes we can categorize them into two

2.6.1 Large and medium solar aircraft

They are solar aircraft with very large wingspan and mass, they also operate on high altitude some examples are

a) Pathfinder

The pathfinder is a project of NASA which could produce a maximum of 8,000W from its solar cells, it weighed 286lb and had a wingspan of 98ft. In 1995 the pathfinder sets first altitude record for solar powered aircraft at 50,000ft during 12hours of flight. Its configuration is as that of a flying wing with six propellers, three on the right and on the left of the aircraft which uses an LA2573A airfoil [8].

Figure 2.5: Pathfinder solar UAV obtained from [23]

b) Helios

The Helios was the largest solar powered aircraft made by NASA it has a wing span of 247ft weight over 2,000lb and photovoltaic array capturing of about 42KW of solar power, it also had a maximum altitude of 96,500ft in 2001. But unfortunately for the project during its flight test in 2003 it crashed into the Pacific Ocean and was destroyed. It has a better version of the pathfinder with almost similar configuration but differed in the number of propellers, it had 10 propellers five on the right and on the left [9].

Figure 2.6: Helios solar UAV obtained from [24]

2.6.2 Small solar aircrafts

They differ from the large and medium UAV because of their small sizes and lower flying altitudes examples includes

a) Sky-Sailor

It is a small solar UAV designed by Andre Noth, it has a wing span of 3240mm and a width of 1818mm and a flying altitude of 500m. It has a configuration of a v-tail and its wings above the fuselage (high wing). The solar cell are placed on the wing because of its area, the aircraft is made up of balsa wood and some composite materials, the wing was designed while the tail uses an NACA0008 airfoil.

Figure 2.7: Sky-sailor small solar UAV obtained from [12]

b) Sun-Surfer:

The sun surfer MAV was designed with the purpose of carrying 20 grams of payload and be able of flying continuously in good weather conditions. The sun Surfer has a wing span of 0.8m and a total mass of 0.126kg. It has a T-tail configuration and an airfoil similar to that of the Sky-Sailor.

Figure 2.8: Sun Surfer small solar UAV obtained from [13]

CHAPTER 3

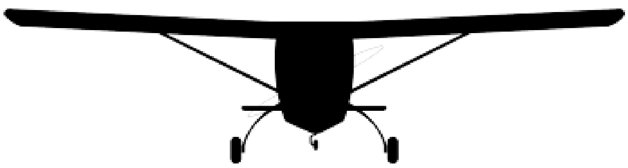
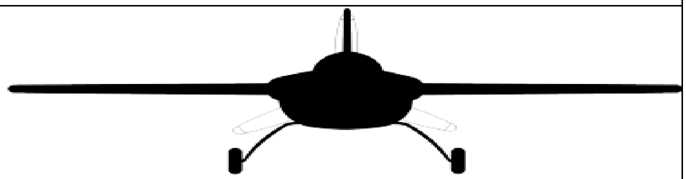
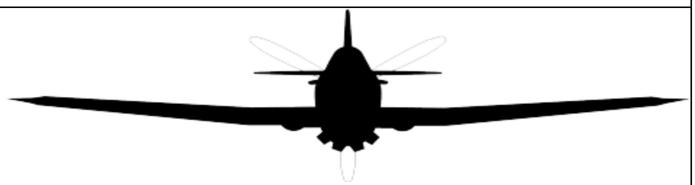
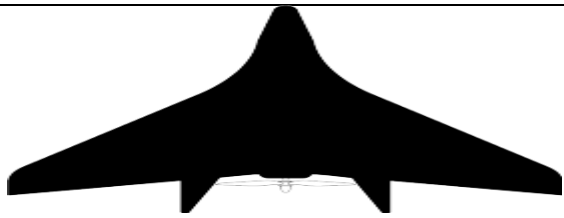
Design and Configuration

3.1 CONFIGURATION

3.1.1 Wing Configuration

The configurations of UAV's may differ from one to another, but choosing the best configuration would be based on some factors such as stability, robustness of the structure, design simplicity, weight, maximum lift. There are different types of wing configurations,

Table 3.1 Types of wing configuration adapted from [10]

Type of wing	Configuration
High wing A high wing is typically any plane that has the main wing mounted on the top of the fuselage. This configuration is favored for training purposes because it offers more stability at slower speeds and a tendency to right itself, allowing a beginner more room for error	 manufacturing difficulty: Easy
Mid wing Mid-wing planes are typically very well balanced and offer much bigger control surfaces makes them highly maneuverable and predictable in their flight characteristic	 manufacturing difficulty: medium
Low wing Generally the wing has a more pronounced dihedral to give it more stability in turns and help prevent stalling at slower speeds. They do show more of a tendency to want to lose altitude in a turn, requiring more coordinated elevator	 manufacturing difficulty: hard
Flying wing With the lack of a rear stabilizer, flying wings are very quick to change pitch and can also roll very fast. Not for the typical beginner	 manufacturing difficulty: hard

For the design of the solar UAV we would be selecting the high wing configuration because of its simplicity.

Evaluation Scale for Pugh's matrices

+ = strongly meets selection criteria

0 = neutrally meets selection criteria

- = does not meet selection criteria

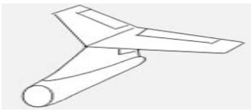
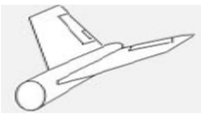
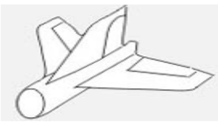
Table 3.2: Selection criteria for wing configuration

	High Wing	Mid Wing	Low Wing	Flying Wing
Stability	+	+	+	-
Manufacturing	+	0	-	-
Assembly	+	0	-	+
Sum +	3	1	1	1
Sum 0	0	0	0	0
Sum -	3	0	-2	-2
Net	3	1	-1	-1
Rank	T1	T2	T3	T3
Continue?	Yes	Yes	No	No

3.1.2 Tail Configuration

The tail is a vital part of the aircraft its selection is based on deferent parameters including stability, weigh etc. There are also different tail configurations which are

Table 3.3: Types of tail configuration adapted from [11]

Types of tails	Advantages	Disadvantages
T-tail 	• Allows for smaller vertical tail • Allows for smaller horizontal • Tail • Better glide ratio	• Deep Stall • Heavier as the vertical tail must support the trim forces of the horizontal tail
V-tail 	• NACA research shows that area required is about the same, however there is still reduced interference drag • Saving weight • Better stability	• Adverse roll-yaw effect: right rudder produces right raw +some left roll
Conventional Tail (inverted T) 	• No single point of failure • Simplistic control system	• More Drag than V-tail configuration • Not as much glide ratio as T-tail configuration

From the given table above we have selected the v-tail because of better stability of the aircraft and good weight.

Evaluation Scale for Pugh's matrices

+ = strongly meets selection criteria

0 = neutrally meets selection criteria

- = does not meet selection criteria

Table 3.4: Selection criteria for tail configuration

	T-tail	V-tail	Inverted T-tail
Stability	0	+	0
Glide ratio	+	-	0
Weight	-	+	-
Simplicity of control	+	0	+
Sum +	2	2	1
Sum 0	1	1	2
Sum -	-1	-1	-1
Net	1	1	0
Rank	T1	T2	T3
Continue?	Yes	Yes	No

3.2 Solar Irradiation

The irradiation horizontal global map of Cyprus is based on the data obtained from April 2004 to March 2010 on a year's average sunshine provided by solarGIS database [26] shown in figure 3.1.

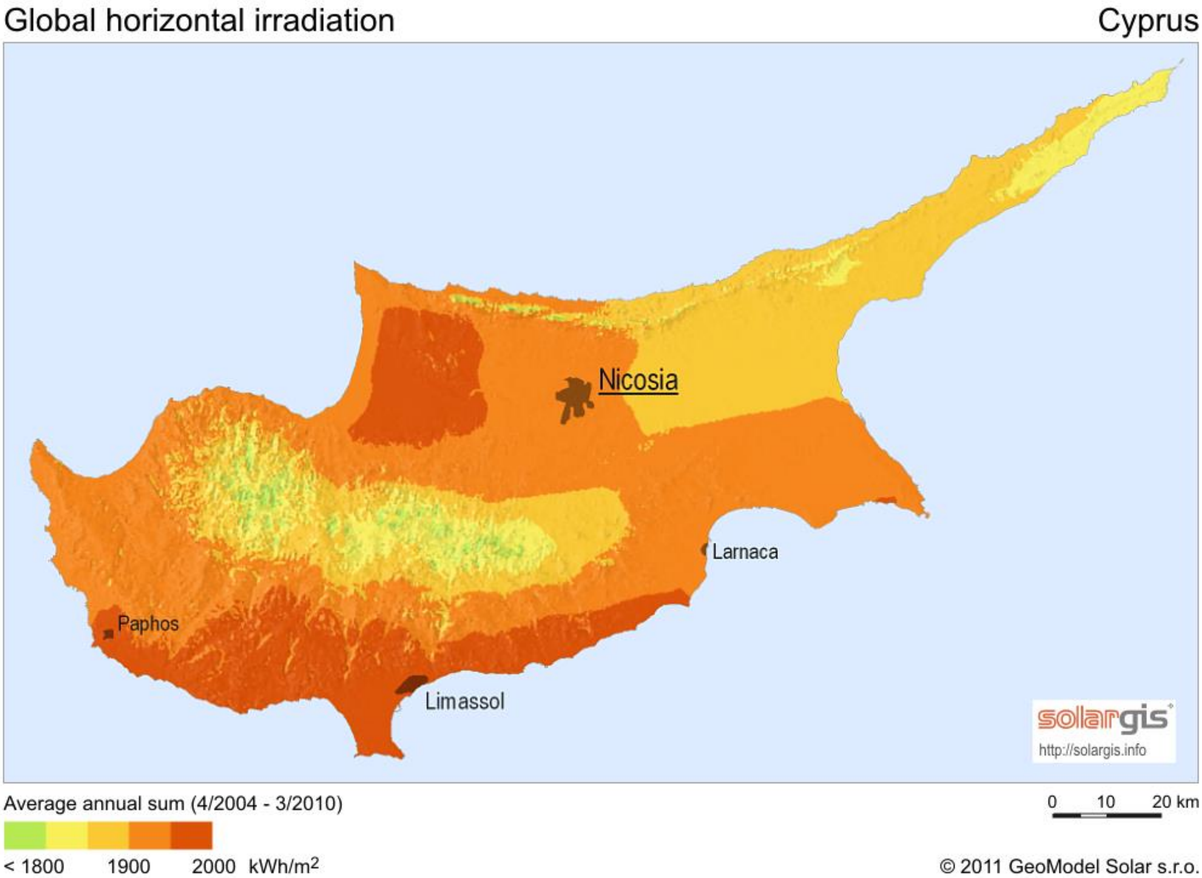


Figure 3.1: The irradiation horizontal global map of Cyprus is based on the data obtained from April 2004 to march 2010. Adapted from [26]

Solar radiation on the horizontal surface received annually in Cyprus is 1725KWh/m2 per year. About 69% direct solar radiation reaches the surface which give a value of 1188KWh/m2, and a diffuse radiation of 31% equaling the value of 537KWh/m^2 [27].

Cyprus global horizontal radiation weather data is shown in figure 3.2. It identifies the global radiation all through the year per hour of all days of the month. As shown in the figure, in the summer the global radiation peaks during midday with a radiation of 1000W/m^2 [25].

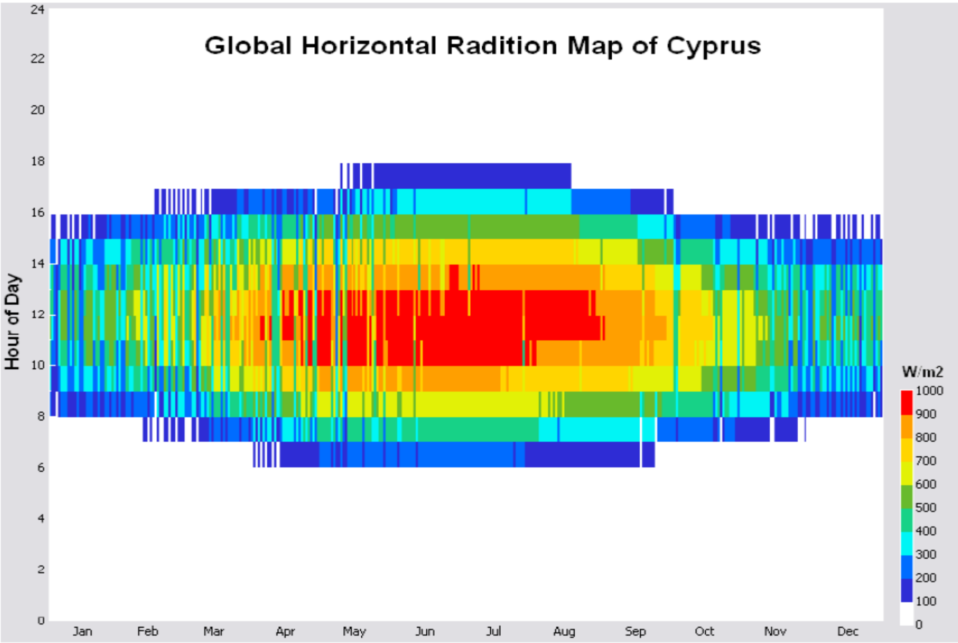


Figure 3.2: Global horizontal radiation map Cyprus obtained from [25]

From figure 3.3 we can notice the global horizontal radiation has its lowest values at the winter period of about 450W/m^2 and continuously increase towards the summer and reaches the maximum during June and July to about 950W/m^2. Also shown in figure 3.3 the drop in irradiance during the winter and autumn periods the sky becomes cloudier causing shadows which would lead to a drop of efficiencies of the solar cells. We are going to consider two parameters in the model, the maximum irradiance I_{max} and T_{day} the duration of the day. The area under the curve is the daily solar energy per square meter which would be calculated using the equation (3.0). ɳwthr is a constant for cloudy days with values 1 for a clear day and 0 for darkness [12].

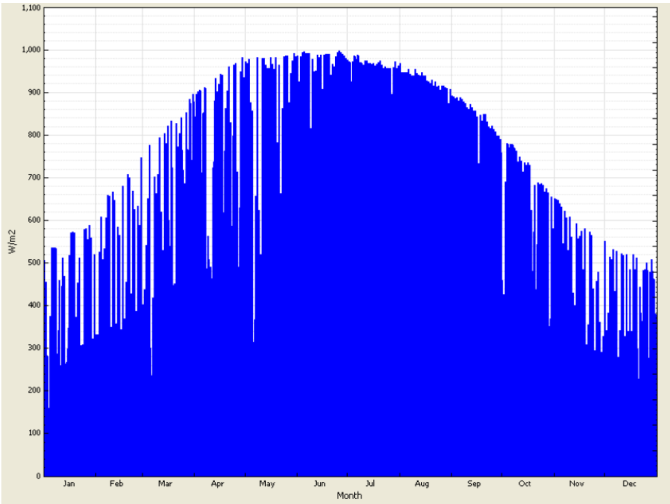


Figure 3.3: Continuous monthly global horizontal radiation map of Cyprus obtained from [25]

$$E_{day\ density} = \frac{I_{max} T_{day}}{\pi/2} \eta_{wthr} \qquad (3.0)$$

The values of I_{max} and T_{day} are obtained from the figures above, that gives information about our location which is Cyprus.

3.3 System Breakdown Structure

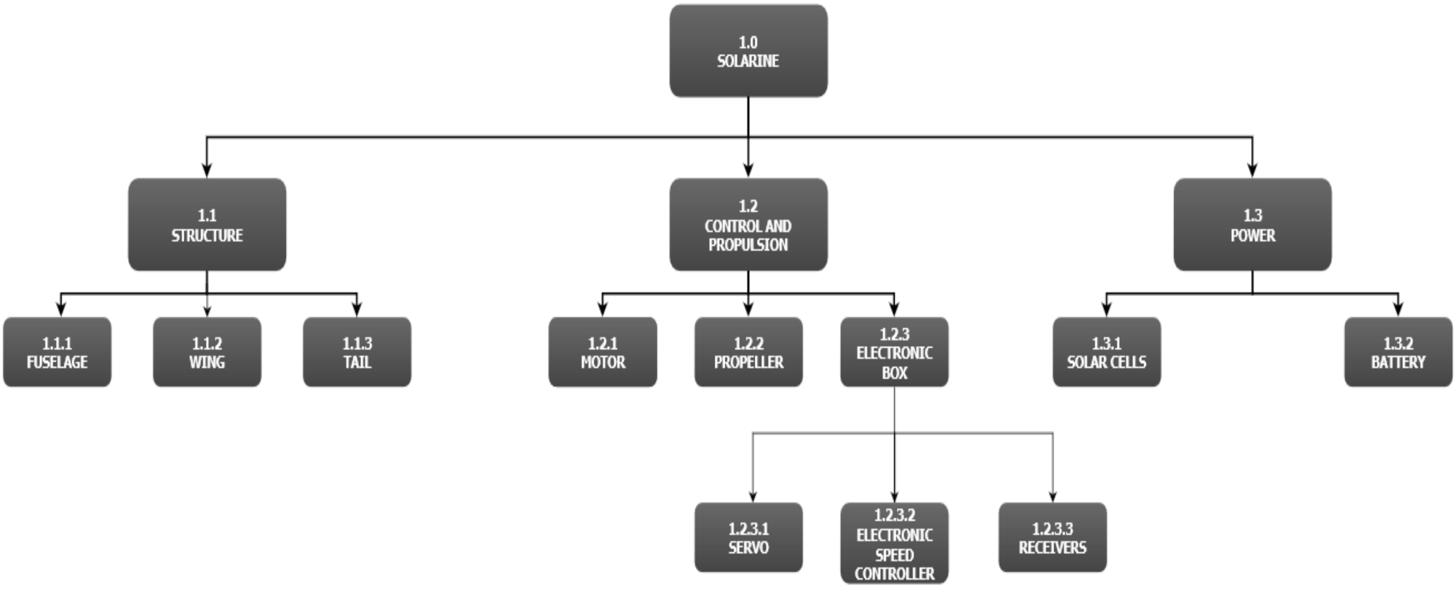


Figure 3.4: System breakdown structure

3.4 Power and Mass Estimation model

Mass model estimation is a good means to calculate the total mass m of the aircraft, we would also perform some calculations which would allow us obtain estimate of the power required for flight and finally achieve an estimate of the total area occupied by the solar cells on the aircraft the various equations need would be obtained from A. Noth's design of solar powered airplane for continuous flight [12].

3.4.1 Power Available

For the power available we have to consider the lift and drag force which are the most important forces for calculation we use the equation

$$L = C_L \frac{1}{2} p V^2 S \tag{3.1}$$

$$D = C_D \frac{1}{2} p V^2 S \tag{3.2}$$

The lift force is also equal to the weight and the drag to thrust. In a steady air flight the velocity can be then calculated using the equation

$$V = \sqrt{\frac{2mg}{pSC_l}} \tag{3.3}$$

For the power $P_{level} = TV$

$$P_{level} = \frac{C_D}{{C_L}^{3/2}} \sqrt{\frac{2AR g^3}{p}} \frac{m^{3/2}}{b} \tag{3.4}$$

3.4.2 Fixed Mass

From Noth's mass prediction model the fixed mass can be calculated

$$m_{fixed} = m_{av} + m_{pld} \tag{3.5}$$

3.4.3 Mass of Airframe

Noth uses a statistical analysis to show how the airframe mass depends on the aspect ratio and wingspan of the aircraft. He then chooses constants

$$m_{af} = k_{af} AR^{x2} b^{x1} \tag{3.6}$$

The constants x1 and x2 will remain the same as in Noth's models

3.4.4 Mass of Solar Cells

To obtain the mass of solar cells we first have to determine the area of the solar cells on the aircraft by using the Noth's equation below

$$A_{sc}=\frac{\pi}{2\eta_{sc}\eta_{cbr}\eta_{mppt}I_{max}\eta_{wthr}}\left(1+\frac{T_{night}}{T_{day}}\frac{1}{\eta_{chrg}\eta_{dchrg}}\right)P_{electot} \quad (3.7)$$

To calculate for

$$P_{electot}=\frac{1}{\eta_{ctrl}\eta_{mot}\eta_{grb}\eta_{pir}}P_{level}+\frac{1}{\eta_{bec}}(P_{av}+P_{pld}) \quad (3.8)$$

Then collecting the values of irradiation we can calculate the mass by

$$m_{sc}=A_{sc}(k_{sc}+k_{enc}) \quad (3.9)$$

3.4.5 Mass of Batteries

$$m_{bat}=\frac{T_{night}}{\eta_{dchrg}k_{bat}}P_{electot} \quad (3.10)$$

3.4.6 Mass of Propeller

It consists of various parts and could be obtained using the below equation

$$m_{prop}=k_{prop}P_{level} \quad (3.11)$$

3.5 Design Methodology and Application

The design methodology is completely based on A. Noth's design of solar powered airplane for continuous flight [13] which is a simulator made based on collected data from different UAVs to easily generate the data for a new design based on the initial parameters. After all the design parameters are defined from the above formulas, its applications are done by using a simulator on MATLAB, inserting some required parameters such as AR and b the program is able to provide you with some preliminary result which would guide you in the design of the aircraft as shown in figure 3.5.

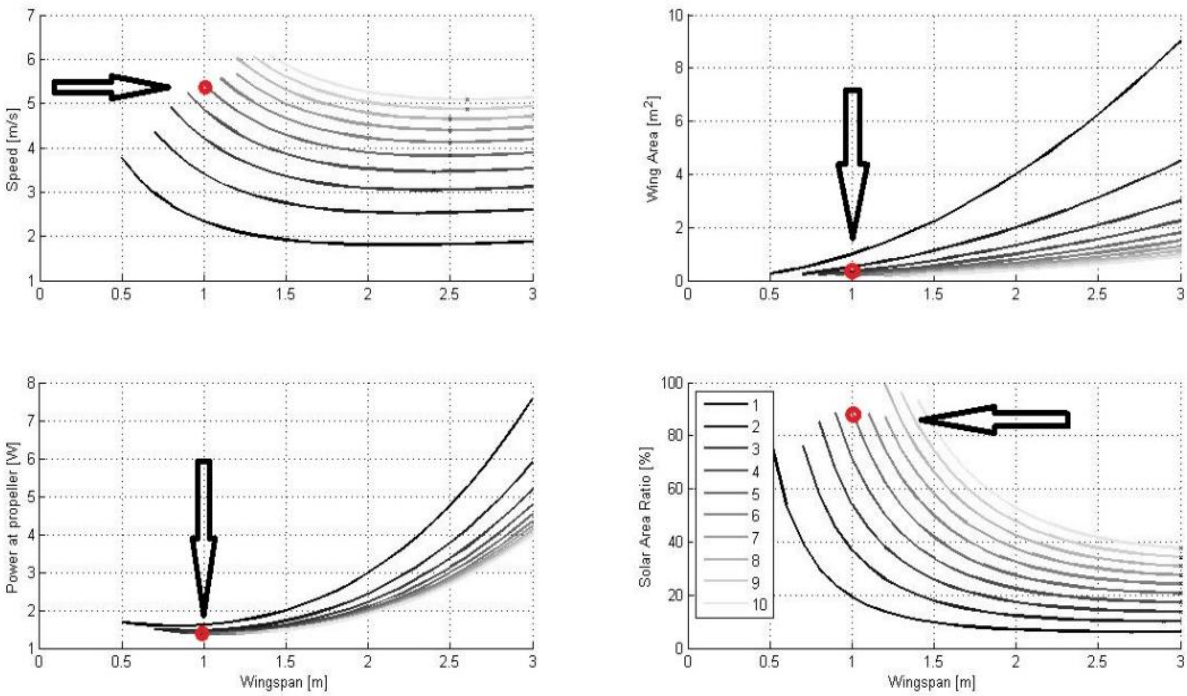


Figure 3.5: Conceptual design graphs for different aspect ratios

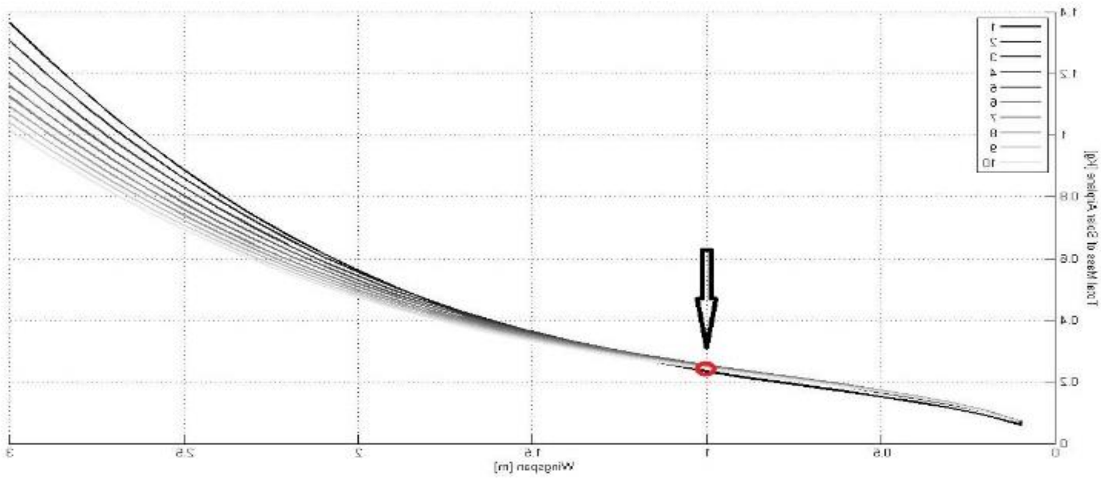


Figure 3.6: Total mass of solar aircraft against wingspan

The above graph results from the matlab software which was analyzed to determine the final design concept. From the combination of all the results which includes speed, wing area, power of propulsion etc. the most suitable wingspan ranges from 0.6m to 1.3m which is in the range of a small wing. A problem related to small wingspan is that the solar area ratio would be large, making it more complex compared to large wingspan aircraft. The most suitable aspect ratios lies between 5 and 8. Below 5 the wing area becomes significantly larger while above 12 it requires a high percentage of solar cell.

3.6 Air frame structure

3.6.1 Structural materials

The materials used for the fabrication of the UAV would depend on factors such as weight, strength, production possibilities etc. Some popular materials used in UAV manufacturing includes plastics, Styrofoam, balsa wood etc. this materials all have their various ups and downs but our selection would be based on the availability of this materials in north Cyprus and also on the cost. The table below shows the different characters of some materials which can be used

Table 3.5: Materials adapted from [13]

	Plastic	Balsa wood	Styrofoam	Carbon fiber
Strength	Good	Reasonable	Not good	Excellent
Specific weight	High	Low	Low	Low
Repairable	Yes	Yes	Yes	No
Attachable	Good	Good	Preferable in one piece	Bad
Cost	High	Low	Low	High

3.6.2 Structural mass

The structural mass of the aircraft in another important facture to consider in designing because we have to obtain a minimum weight which affects the lift of the aircraft and also the drag force which affects the thrust. From Noth R. siegwart's design of solar powered airplanes for continues flight which shows the weight of the airframe as a function of the wingspan and aspect ratio AR of the aircraft in the equation below [28].

$$m_{af} = K_{af}\ b^{3.1}\ AR^{-0.25} \qquad (3.5)$$

K_{af} is the structural weight constant. It was found that, in order to belong to the best 5% of sailplane structures worldwide, the airframe should have a K_{af} value below 0.44N/m^3. In this project we would be use the estimated value from obtained from the sun surfer design report which sets its K_{af} as 0.75N/m^3 [13].

3.7 Airfoil Selection

The wing is a very important part of the aircraft not just because of its aerodynamic characteristics in this case, but also for the placing of the solar panels on them which would generate power to the aircraft. We have selected a National Advisory Committee for Aeronautics (NACA) category of airfoil which is NACA0015, based on the Design and Fabrication of Solar R/C Model Aircraft by Prof. Alpesh Mehta, Chirag Joshi, Kuldeepsinh Solanki, Shreekant Yadav. It is a symmetric type of airfoil as shown in figure 3.7 with a thickness of 15% to chord length and 0% camber. The reason for this selection was the wing would be handmade so the development on cambers would be difficult.

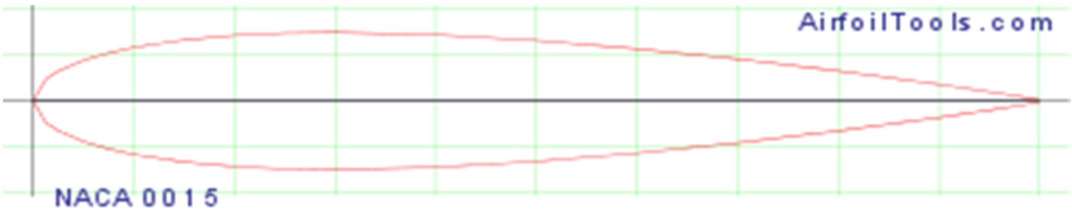


Figure 3.7: NACA0015 Airfoil obtained from [31]

XFLR5 software is used to calculate the aerodynamic properties of an airfoil. We downloaded the airfoil data in inserted it into the software. We were required to input a range of Reynolds number which was 30000 to 100000 and angle of attacks in which the analysis would be done. After providing the necessary information the simulator run and generate the graphs shown figure 3.8 to 3.12.

3.7.1 Airfoil Analysis with XFLR5

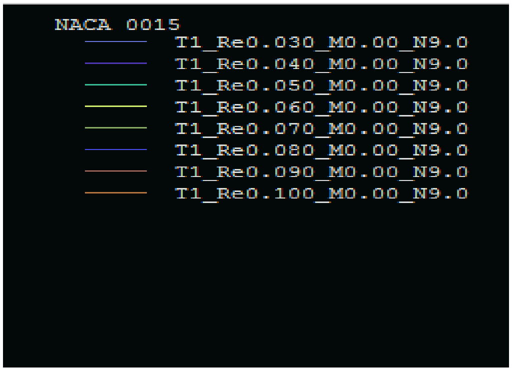


Figure 3.8: XFLR5 Reynolds numbers obtained using XFLR

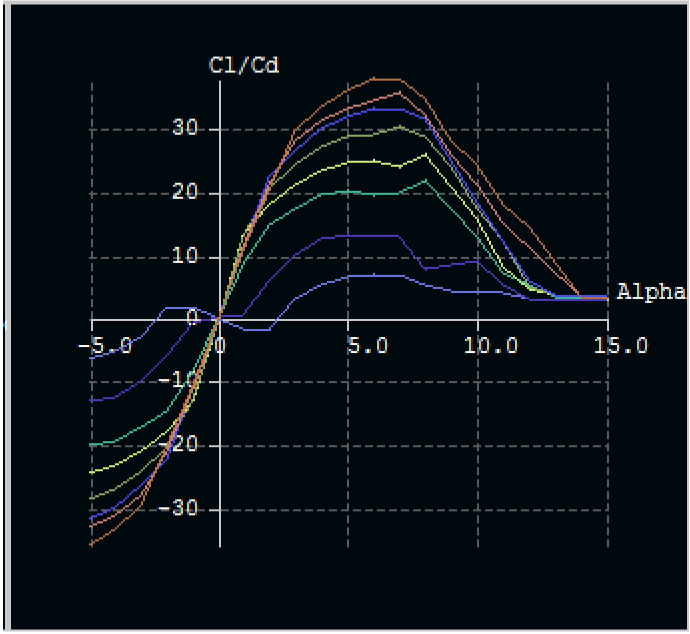


Figure 3.9: Lift-to-Drag Ratio against Angle of Attack for NACA0015 obtained using XFLR5

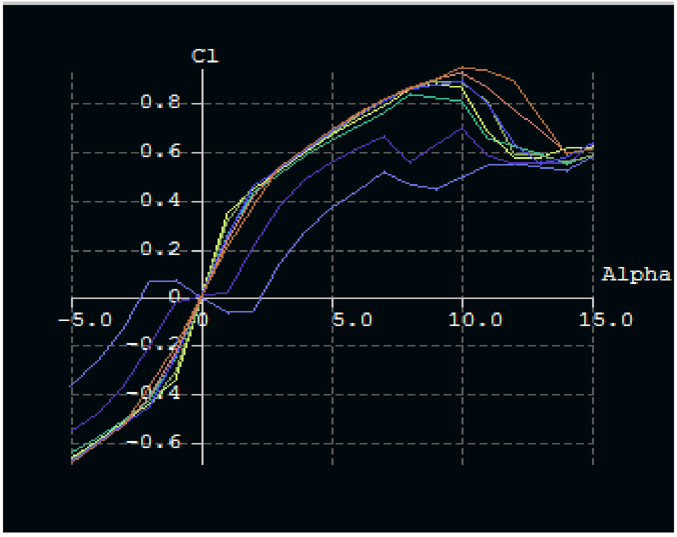


Figure 3.10: Lift Coefficient against Angle of Attack for NACA0015 obtained using XFLR5

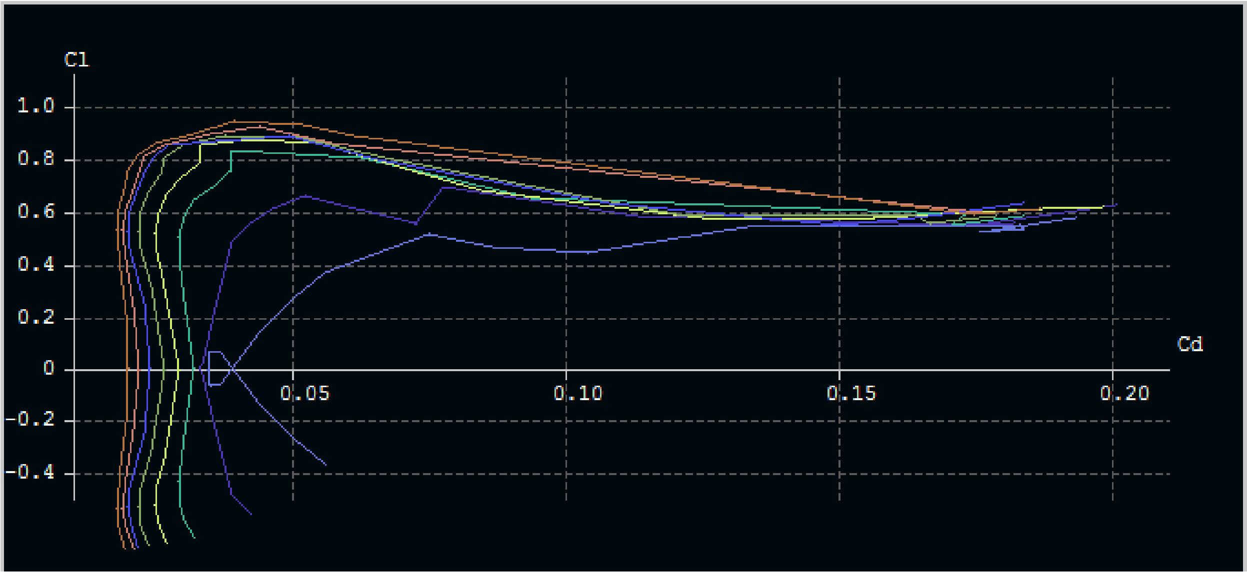


Figure 3.11: Lift Coefficient against Drag Coefficient for NACA0015 obtained using XFLR5

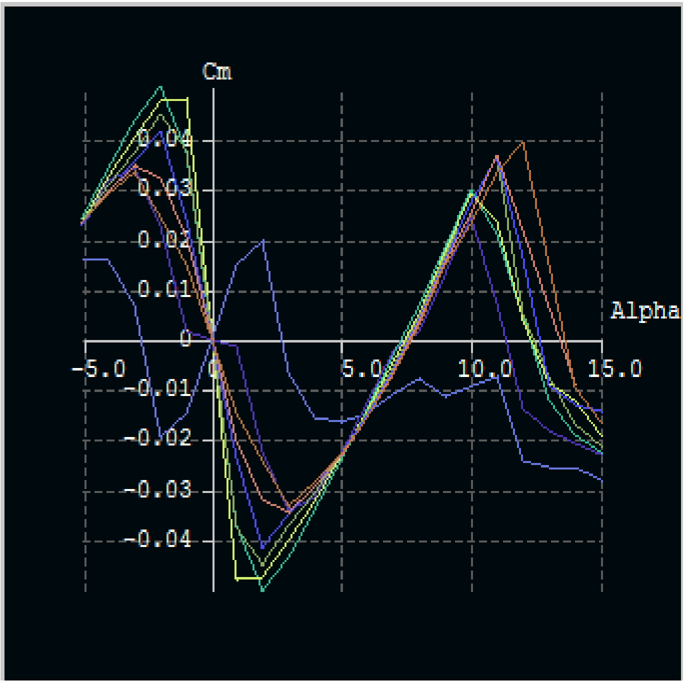


Figure 3.12: Moment Coefficient against Angle of Attack for NACA0015 obtained using XFLR5

3.8 Empennage Configuration

The tail configuration selected was a v-tail and would be using an NACA0007 airfoil, the airfoil selection was based on the manufacturing process, which would be easy since the NACA007 has 0% chamber and 7% thickness. For the tail calculation we use Raymer [14] suggestion that the tail arm should be 60% of the fuselage length

$$L_{vt} = L_{ht} = 0.6(67.5) = 40.5\text{cm} \tag{3.12}$$

To calculate the tail area, the total horizontal and vertical areas are calculated using. For the horizontal and vertical tail volume coefficients we will use that of Roskam for sailplanes [15]

$$S_{vt} = \frac{C_{vt} b S}{L_{vt}} \tag{3.13}$$

$$S_{ht} = \frac{C_{ht} c S}{L_{ht}} \tag{3.14}$$

We use Raymer's methods to determine the angle of the v-tail

$$\alpha = \arctan\left(\sqrt{\frac{S_{vt}}{S_{ht}}}\right) \tag{3.15}$$

For the calculation of the area of one side the v-tail

$$S_t = \frac{S_{ht}/2}{\cos(\alpha_{td})} \tag{3.16}$$

Therefore the calculations for the following equations are given below

$$S_{vt} = \frac{C_{vt} b S}{L_{vt}} = \frac{(0.02)(0.9)(0.135)}{0.405} = 0.006\text{m}^2$$

$$S_{ht} = \frac{C_{ht} c S}{L_{ht}} = \frac{(0.5)(0.15)(0.135)}{0.405} = 0.025\text{m}^2$$

$$\alpha = \arctan\left(\sqrt{\frac{S_{vt}}{S_{ht}}}\right) = \arctan\left(\sqrt{\frac{0.6}{2.5}}\right) = 26^{\circ}$$

$$S_t = \frac{S_{ht}/2}{\cos(\alpha_{td})} = \frac{0.025/2}{\cos(26)} = 0.0139\text{m}^2$$

From comparison with other similar UAVs the tail chord is said to be 60% of the wing chord.

C_t = 9cm

3.8.1 Empennage Airfoil Analysis

The v-tail empennage an NACA 0008 airfoil would be used for simplicity and controllability, its analysis would be done using XFLR5 and the results obtained are shown from figure 3.13 to3.17.

Airfoil analysis results XFLR5

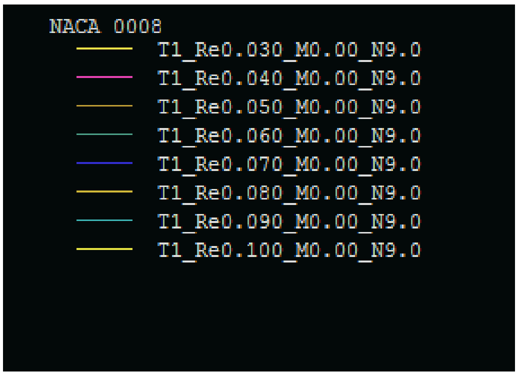


Figure 3.13: XFLR5 Reynolds numbers obtained using XFLR5

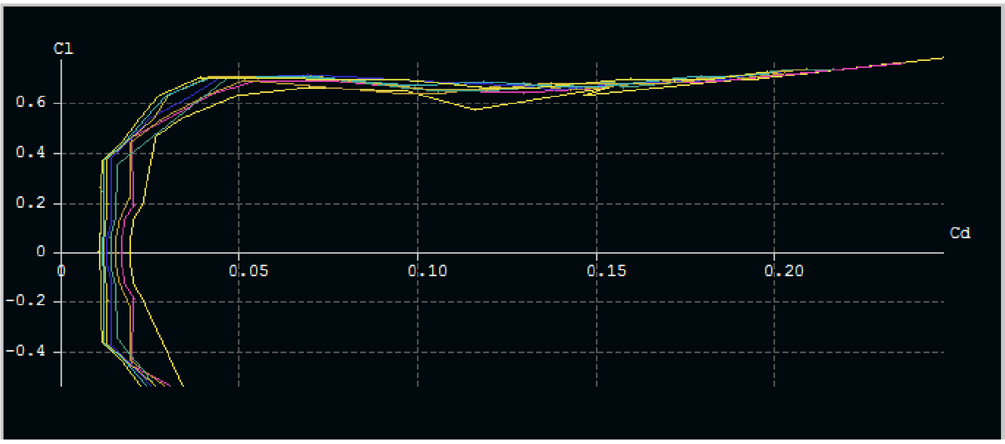


Figure 3.14: Lift Coefficient against Drag Coefficient for NACA0008 obtained using XFLR5

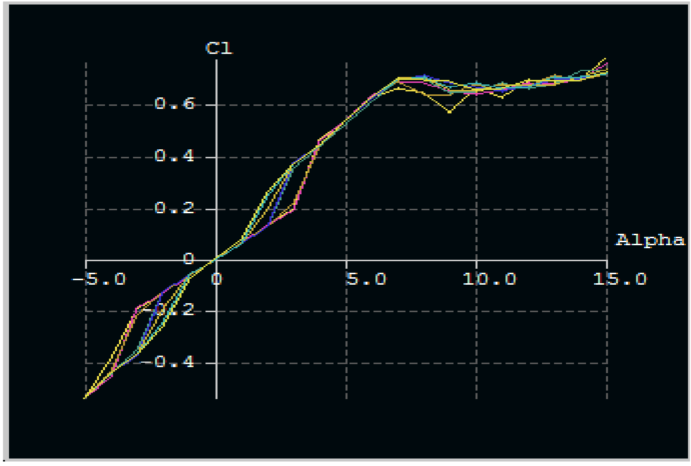


Figure 3.15: Lift Coefficient against Angle of Attack for NACA0008 obtained using XFLR5

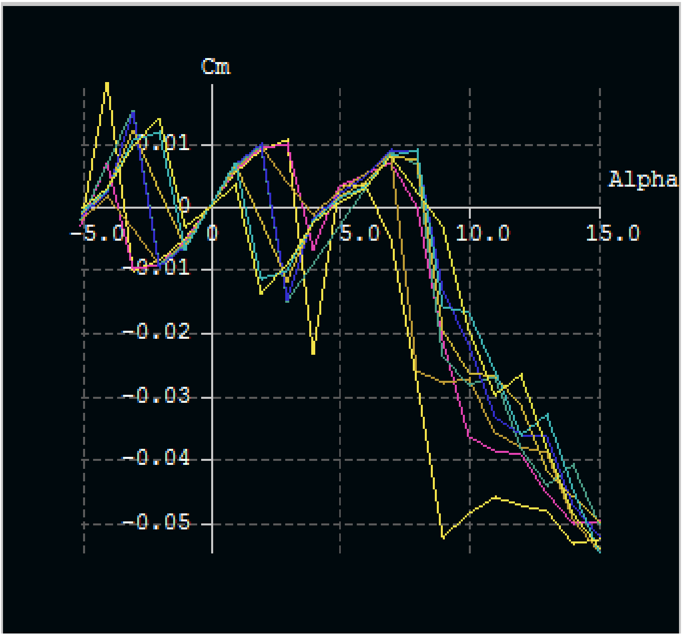


Figure 3.16: Moment Coefficient against Angle of Attack for NACA0008 obtained using XFLR5

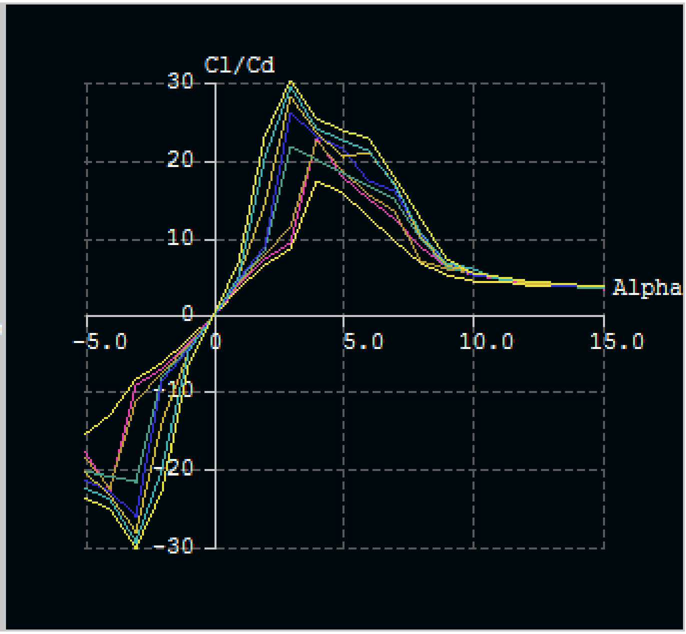


Figure 3.17: Lift-to-Drag Ratio against Angle of Attack for NACA0008 obtained using XFLR5

3.9 Fuselage Design

The main components that will be placed into the fuselage will be the autopilot computer, batteries, servos etc. For size the fuselage, comparing with similar aircraft such as the Sun-Sailor and Sky-Sailor designs were most appropriate for this assessment. A comparison of the fuselage length and wingspan was made for the two aircraft and the relationship that was found is shown below [16]

$$F_L = b^{0.5289} \tag{3.16}$$

The fuselage would be in a cylindrical shaped of two different diameters which would be specified in the CAD drawing.

3.10 Electrical Components

3.10.1 Propeller

For propeller selection, the size is the main factor to consider because it determines some important parameters such as speed and torque. For larger propellers they spin at a slower speed, produce more torque making it easier to take off, quieter, fly slower while for smaller propellers they spin at a higher speed, produce less torque making it harder to take off, louder, fly faster. To select the correct motor for the propeller we have to consider the voltage constant (kV), different motor will have a specific kV listed which could range from roughly 1,000 to 4,000. Without getting into all the specifics the lower the motor's kV the slower the motor is going to spin and the higher the motor's kV the faster it will spin [17]. In relation to the efficiency the larger the propeller the better the efficiency. Various blade sizes are available for selection the motor selected.

3.10.2 Motor

There are different elements to consider when selecting a motor for your aircraft. The first step in selecting a motor is to determine how the motor will be mounted. If the motor will be fixed in an enclosed area and cannot rotate, an in-runner should be used as all the moving parts of the aircraft except the propeller shaft are internal. An out-runner should be used, if the motor is intended to be placed in an area where it is free to turn [17]. We would be selecting brushless out-runner for the design because this arrangement gives much higher torque

3.10.3 Electric Speed Controllers (ESC)

Electric speed controllers are used to control the electric motor speed. An electronic speed controllers which is specially designed for the brushless motors, converts the battery's DC voltage into three pulsed voltage line that are out of phase by 120 degrees. The Electronic Speed Controller is based on Pulse Width Modulation (PWM) system, which means that the motor's rpm is regulated by varying the pulses' duty-cycle according to the throttle position of the transmitter's [18].

Figure 3.18: Electric speed controller [30]

The connection of the ESC is shown in (figure 3.18), it shows that it has three connections; the first one is to the battery or solar panel. The function of the electric speed controller is to distribute the required amount of current to the required needs of the other parts such as motors and receivers, the second connection is to the receiver which sends signal to the ESC and the third is to the motor. The ESC receives the signal from the receiver which is used to determine the power to be used by the motor to maintain a certain speed.

3.10.4 Servos

They are devices you to control certain parts of the aircraft, parts such as the elevators and ailerons. They receive pulse from the receiver on what direction to turn the elevators or aileron, the servos are able to control this parts by the connection of a push rod from the servos to the various parts.

All RC-servos have a three wire connector. One wire supplies positive DC voltage – usually 5 to 6 volts. The second wire is for voltage ground, and the third wire is the signal wire. The receiver “talks” to the servo through this wire by means of a simple on/off pulsed signal [19]

3.10.5 Batteries

To select a battery few characteristics should be taken into consideration, one of which is the mAh. It can be referred to as the fuel of a car, when the tank is full it makes the car drive for longer distances but it adds to weight to the car. Another characteristic is the discharge rate which is the maximum rate your battery is capable of discharging. The last of these characteristics would be the voltage, it is the most important part of the battery and if the selection is done wrongly the ESC and the motor might get damaged, and when a given voltage of the battery has been chosen it is recommended not to exceed it.

3.10.6 Solar Cells

They are used to convert solar energy into electrical energy. The type of solar cells chosen was manufactured by Lemo-solar, and they are Polycrystalline. The cells were soldered using copper wire. To be able charge the battery a voltage of 7.4V and an amperage of 1 amp was needed. This was achieved by connecting 2 arrays of 13 cells in series, then connecting them in parallel. The surface area of the panel was calculated to be 0.0703m^2. It was calculated by multiplying the surface area of each cell by the number of cells used which is 26. Since the surface area of the wing is 0.135m^2 the solar cells can be easily integrated into the wing.

3.10.7 Transmitters

They are used to control the aircraft through radio signals. It operates by sending signals to the receiver located in the aircraft. The transmitters are usually given abbreviation 'Tx', there are four different modes of control for the aircraft shown below in figures 3.19 to 3.22.

a) Tx Mode 1

Stick controls: right stick controls throttle and ailerons, left stick controls elevator and rudder.

Figure 3.19: Tx mode 1 obtained from [20]

b) Tx Mode 2

Stick controls: right stick operates elevator and ailerons, left stick operates throttle and rudder.

Figure 3.20: Tx mode 2 obtained from [20]

c) Tx Mode 3

Stick controls are: left stick operates elevator and ailerons, right stick operates throttle and rudder.

Figure 3.21: Tx mode 3 obtained from [20]

d) Tx Mode 4

Stick controls: right stick operates elevator and rudder, left stick controls throttle and ailerons.

Figure 3.22: Tx mode 4 obtained from [20]

All RC transmitter mode are equivalent, the various configuration depends on the controller [20]

3.10.8 Cost Analysis

1 = total material cost   2= shipping cost   3 = extra expenses   4 = transportation cost

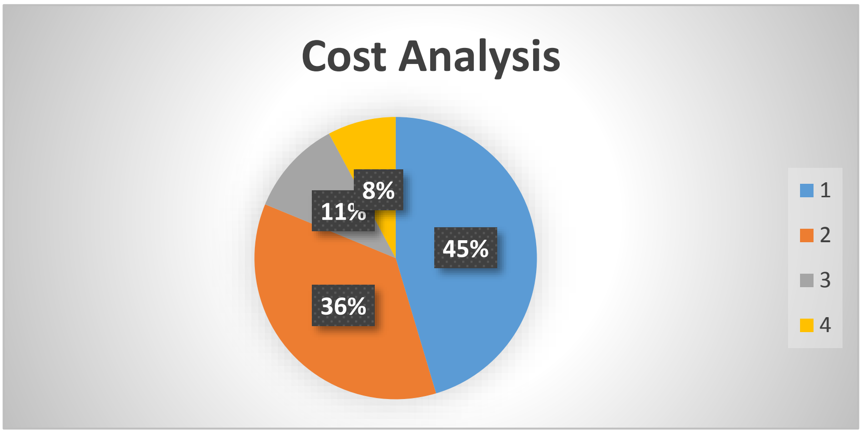


Figure 3.23: Cost analysis

CHAPTER 4

Manufacturing and Testing

4.1 Model 1 Manufacturing Process

4.1.1 The wing

The wing was fabricated from balsa wood. First the ribs of the wings where cut to the airfoil shape from flat sheet of balsa wood as shown in figure 4.1, holes are made on the ribs to reduce the weight of the wing and also add the spar.

Figure 4.1: Ribs from balsa wood

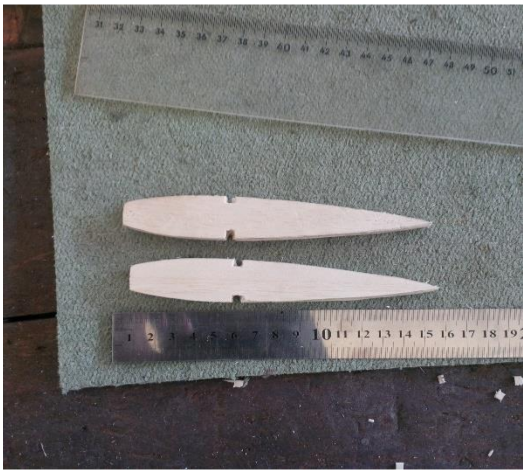


Figure 4.2: Cut ribs for placing spar

The top of the rib is cut as shown in figure 4.2 so the leading edge is attached to while the back is also cut to attach the trailing edge which are both made from balsa wood. The ribs are then places on a spar made of balsa with spacing of about 5 – 8cm apart as shown in figure 4.3.

Figure 4.3: Spacing of ribs

The leading edge is attached and sanded to have the shape of the airfoil and the trailing edge is attached to accommodate the ailerons of the unmanned vehicle shown in figure 4.4.

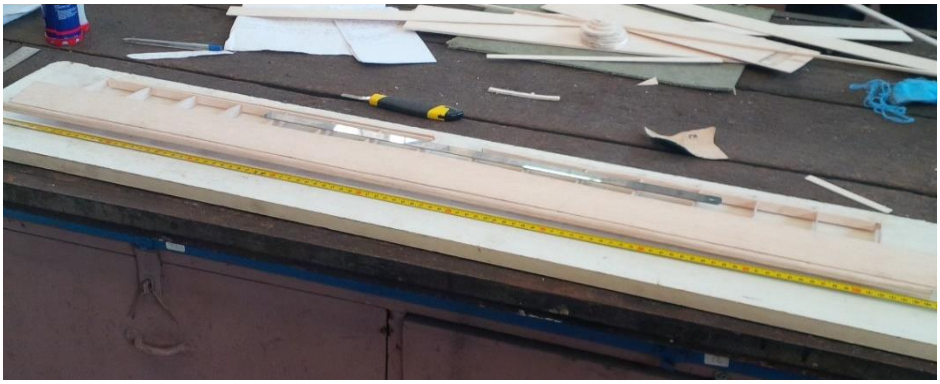


Figure 4.4: Leading edge

The ailerons are also made of balsa wood and are shaped in a triangular form in other for better control of the unmanned vehicle during takeoff. Hinges blocks are also made to place the servos in the wing which connects to the ailerons.

Figure 4.5: Installed ailerons

4.1.2 The fuselage

The fuselage was the second part of the unmanned vehicle to be made it is made of balsa wood with an integration of a carbon fiber pipe at the end to connect to the tail.

Circular shapes were cut out of the balsa sheet to get a guide in building the fuselage structure, hole were made through the circular shapes to create space for the components such as battery, servos, ESC etc. which would be placed in the fuselage.

Figure 4.6: Fuselage structure

After the structure was completed the bottom half was covered with balsa so the electrical components would be placed inside. Next a carbon fiber pipe was attached to the end of the fuselage, the pipe was used to connect the tail and the fuselage together shown in figure 4.7.

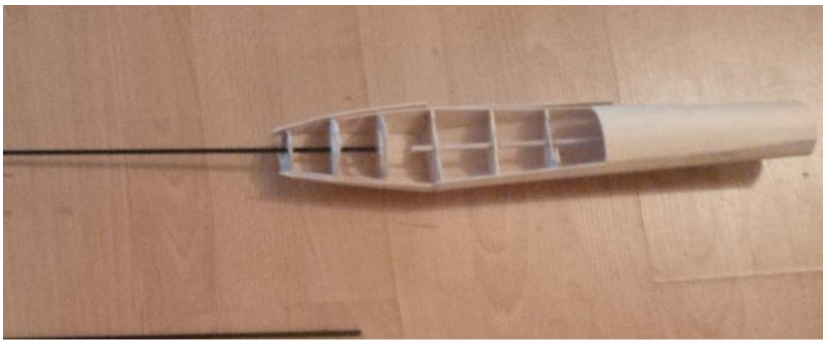


Figure 4.7: Fuselage and carbon fiber pipe

4.1.3 The Tail

The tail configuration was changed from the initial configuration from a v-tail to an inverted t-tail as it was easier to be produced and fixed on the carbon rod, since the circumference of the carbon rod is small the v-tail would not fit on to it. It is the last part needed to complete the structure of the unmanned aerial vehicle.

The stabilizer and fin was cut from balsa wood to the new dimensions, then they were attached using glue. A small space was provided to allow the carbon fiber pipe fit into the tail as shown in figure 4.8.

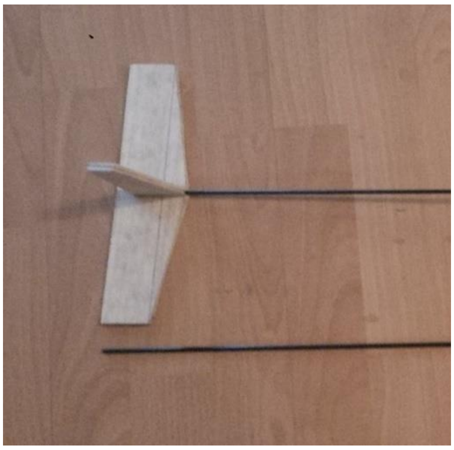


Figure 4.8: Stabilizer, fin and carbon fiber pipe

The rudder and the elevator where the next parts made which are installed in the end of the fin and stabilizer. The rudder and elevator where also made from balsa wood, the installation of this parts where done using a thin wire to connect the holes made on the stabilizer to elevator and fin to rudders as shown in figure 4.9.

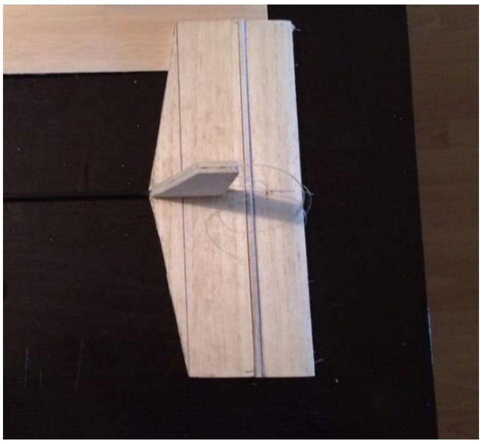


Figure 4.9: Installation of elevator and rudder

Finally all the structural part where assembled together to obtain the design of the solar unmanned aerial vehicle

4.2 Model 2 Manufacturing Process

During testing the first model crashed and was destroyed so a second model was needed. Due to the time constraints the model was made from Styrofoam because of ease of manufacturing.

The wing was built flat without an airfoil. The fuselage was rectangular instead of circular and the same tail configuration was used for the manufacturing of the model and it's shown below in figure 4.10.

Figure 4.10: Model 2

4.3 Solar Cells

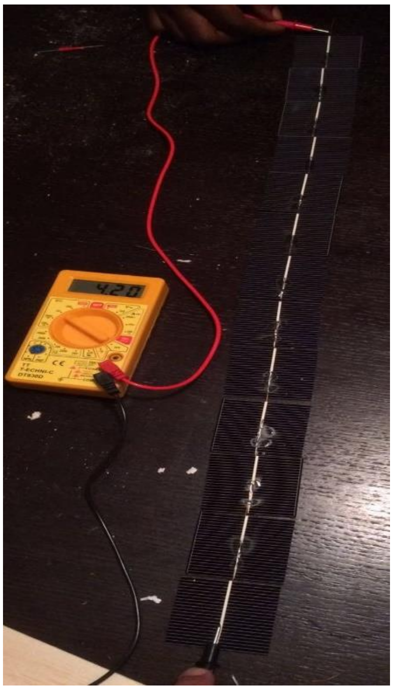


Figure 4.11: Connected solar cells

The solar cells procured had a voltage of and a current of per solar cell so we had to do some soldering of the solar cells to achieve our required voltage of 7.5volts and amperage of 1amp. The soldered cells are shown in figure 4.11.

So we connected 13 solar cells in series and another 13 cells to have two rolls to get a voltage of about 7.8volts, next we then connected the two 14 solar cells in parallel to increase the amperage from 0.89 to 1.78 amperes

4.4 Assembly of the Solar UAV

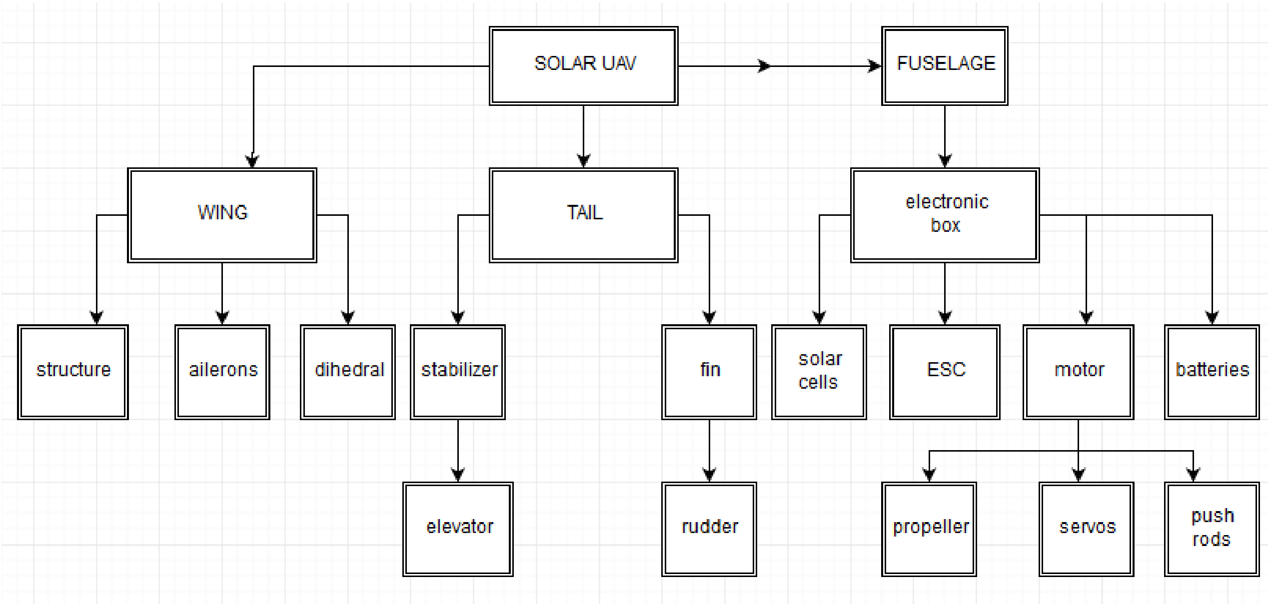


Figure 4.12: Assembly tree

Figure 4.12 shows the assembly tree. After the structural part was manufactured, the next step was the installation of all the electronical parts in the unmanned aerial vehicle.

The motor was the first electronic component to be installed, it was mounted in the front of the fuselage as shown in figure 4.13. First the motor mount was glued and then the motor was screwed to the motor mount, next the propellers were fixed to the motor while the motor wires was passed into the fuselage

Figure 4.13: Mounting of motor

The next electrical component installed was the ESC (electronic speed controller), it had a different head from that of the motor so we cut the different heads and connected the wires together. The ESC was also connected to the receiver and to the battery, while the receiver was connected to the transmitter. After all the connection the receiver, ESC and battery were all fitted into the fuselage as shown in figure 4.14.

Figure 4.14: Installation of electrical components in fuselage

The servos were the next electrical components installed on the wings and the fuselage, for the wings two servos were mounted close to the ailerons and was connected to the ailerons using short push rods. While two more servos were installed in the fuselage what connected to the elevator and rudder by long push rods, all the servos were then connected to the receiver which enables us control then with the use of the transmitter

The next installation done was connecting the solar cell, the solar cells were connected in parallel and series to achieve the required output for the battery. The solar cell were placed on the top of the wing using glue to hold them at some points to prevent them from falling, the solar cell were then connected to the batteries using a voltage step down to prevent the battery from blowing up.

Finally all the parts were jointed together using glue in some necessary places such as connecting the wing to the fuselage, before the gluing of the various components the parts were all wrapped with thin plastic sheets to ensure smoothness of the surface an also make the aircraft look good.

4.5 Testing

4.5.1 Electrical Components Testing

The electrical parts were tested outside the unmanned aerial vehicle. The first part tested was the motor, after connecting it to the ESC and the ESC to the receiver the motor was mounted on balsa wood to test if the was working properly. Figure 4.15 shows the connection and the motor rotating.

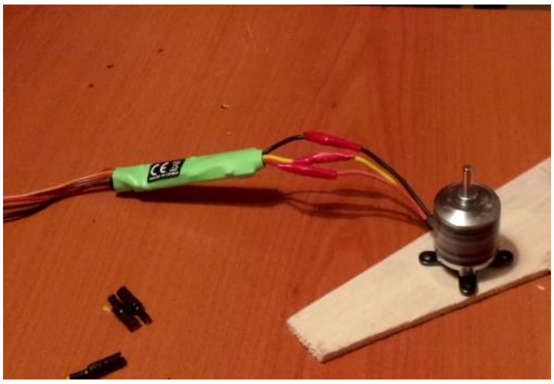


Figure 4.15: Motor testing

The servos where tested when they were all connected to the ailerons, rudder and elevator using the transmitter. They were connected to different channels of the receiver to check for oscillatory movement. The installed servos are shown in figure 4.16

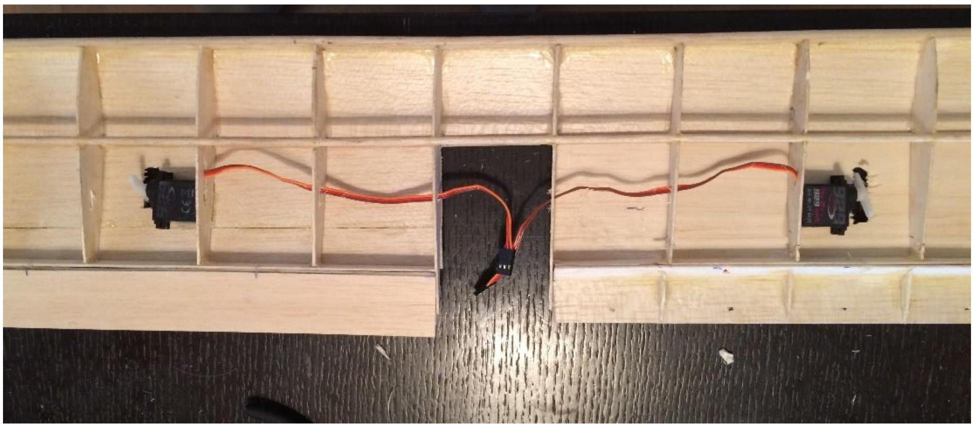


Figure 4.16: Servos to ailerons

Another component tested was the solar cells, after the connection a voltmeter was used to check the output voltage of the solar cells connected in series and then the amperage when connected in parallel. Figure 4.17 shows the solar panel produced and used to charge the battery.

Figure 4.17: Solar cells in series and parallel

Finally after all the parts were ready, a flight test was done for the solar unmanned aerial vehicle.

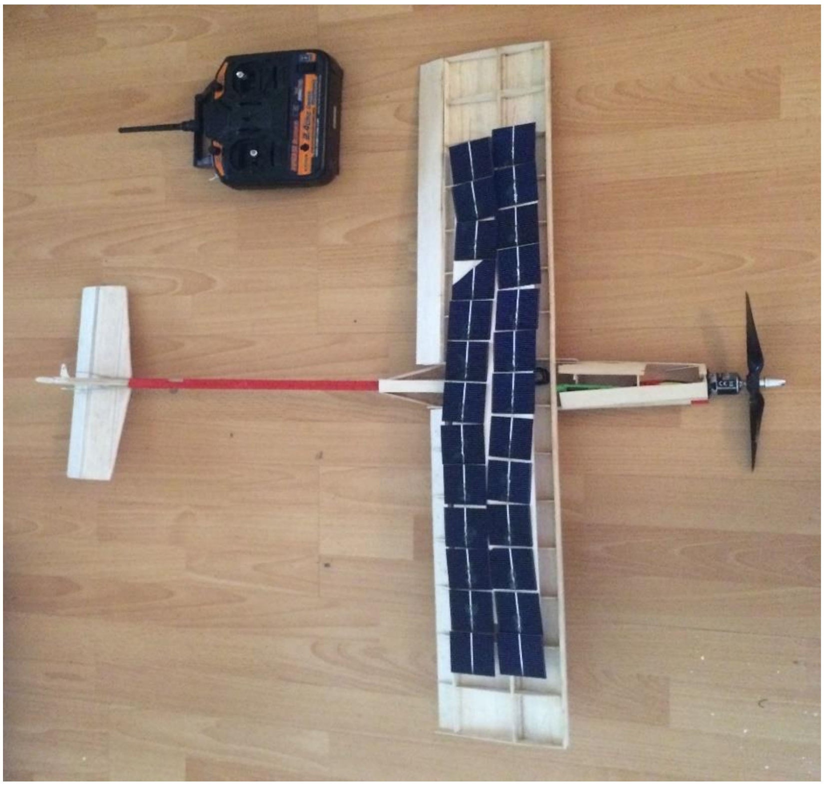


Figure 4.18: Solar unmanned vehicle

4.5.2 Flight Test for First Model

After the assembly of the various components of the first model, the flight test was carried out on the 15th of June 2016. The flight test was unsuccessful because of some reasons

One of the many problems we faced was that the aircraft was not statically stable. After inserting the batteries into the electronic box. The UAV became nose heavy which caused it to crash immediately after launching into the air, so we inserted the battery into the system and performed a balancing test which was placing the center of gravity of the UAV on a pointed surface. Another was that the servos and ESC where all placed into different channel on the receivers cause the control of the different component very difficult.

Also the mode of launch was also wrong due to inexperience with UAVs, we hand launched the UAV into the air without regarding the angle of attack on the wing structure, which causes the plane to immediately stall after takeoff. After all the trial on the first model as a result of the impacts it received when crashing the fuselage was destroyed and a second model was made to correct the flight mistakes from the first model.

Figure 4.19: Flight take-off

Figure 4.20: Failed take-off

4.5.3 Flight test for the Second Model

The second model was lighter in weight compared to the first model with the hope of the motor to generate sufficient thrust for flight, we also face difficulties in the control system of the model, and after researching about the different channels we were able to place the ESC and servos into the right channels. But a new problem occurred which was the reduction of the rpm of the motor as a result of much impact from the first model during failed flights, so we recalibrated the transmitter to increase the rpm which was sufficient for flight. Another error observed during the testing of the second model was that launching of the aircraft was done on full throttle instead of less than 50% throttle.

Some other changes were made which was the connection of both ailerons to a single servo for better control during flight. Unfortunately the second model could not also ascertain a stable flight but with the hope to obtain a steady flight some other factors would be considered such as the air speed, direction of the wind etc.

Figure 4.21: Model 2 flight take-off

Figure 4.22: Flight stall in the second model

CHAPTER 5

Discussion and Result

Table 5.1 shows the results we obtained using the Matlab code from Andre north. The value differed a bit from the actual values obtained during the manufacturing process

Table 5.1: Results from Matlab for estimate mass

A	NaN
AR	10
A_sc	NaN
C_D	0.0696
C_D_afl	0.0400
C_D_ind	0.0226
C_D_par	0.0070
C_L	0.8000
D	NaN
I_max	900
P_elect_tot	NaN
P_level	NaN
P_sc	NaN
Sol_A	0.9000
Sol_A_sc	0.1527
Sol_D	1.3849
Sol_P_elec_tot	4.7399
Sol_P_level	0.7092
Sol_P_sc	20.2787
Sol_m	1.6218
Sol_m_af	1.2956
Sol_m_bat	0.2836
Sol_m_mppt	0.0085
Sol_m_prop	0.0121
Sol_m_sc	0.0886
Sol_v	0.5121
T_day	47520
T_night	38880
a0	1.0302
a1	2.1278
a10	0.1936

The manufacturing of the Solarine was simple and it was made of widely available material which is balsa wood. It gave a good strength and was easy to shape, but it needed a little care of handling as its brittle when in sheets. The biggest problem faced in the project was the brittleness of the solar cells. It was intended to use flexible solar cells which are more efficient but it was costly. A more advanced transmitter and receiver was needed to know more information about the situation of the battery.

During the flight test we observed that the stability of the models where greatly affected by the battery in the UAV. Also we took note that to attain more stability in flight the ailerons should be connected to a single servo, because of our inexperience with the use of the transmitter in controlling the UAV.

CHAPTER 6

Conclusion

This report has discussed solar UAV's and the design and manufacturing methodology. This report has shown the different classification and types of UAV's with a history timeline of already made UAV's. The design and the methodology used was the most important challenge in this project. A high wing configuration was used as it is easier, it enhances stability and it gives some room for error for beginners. A V-tail configuration was used for its simplicity but was changed to a conventional tail because of stability problems in the unmanned vehicle. For the mass and power estimation of the RC plane various equations were used from A. Noth's design of solar powered airplane for continuous design. At the end there was the material selection where the most suitable and cost efficient motor, propeller, ESC and material used to make the airframe were selected. We think that our design is really suitable for a cost efficient solar powered UAV as it is simple to manufacture.

APPENDIX A

David Dangana 127342

11/10/2015	Meeting with the supervisor to talk about the selected capstone project
13/10/2015	Meeting with group members to gadder information about capstone project
13/11/2015	Preparing Chapter 1, the introduction of the project
18/11/2015	Meeting with supervisor to discuss the introduction and literature review
18/11/2015	Meeting with group members to select a design and name for the project
20/11/2015	Choosing and Airfoil for the wing configuration and selecting the length of the wing chord to calculate the dimensions for the wing,
25/11/2015	Performing the wing analysis on XFLR with group members
2/11/2015	Selecting the required formulas to calculate the mass and power estimate of the aircraft
7/12/2015	Meeting with supervisor to show our progress on the project
11/12/2015	Selecting the tail configuration and Airfoil and calculating the required dimensions. Also performing the tail analysis on XFLR software with group members

12/12/2015	Running MATLAB code from Andre Noth. And later inputting our initial parameters to obtain the mass and power estimates
13/12/2015	Designing of the wing, tail and fuselage on solidworks
15/12/2015	Meeting with supervisor to show progress and get more information about the project
15/12/2015	Selection of materials needed and preparation of bill of materials for the project with group members
15/12/2015	Preparing chapter 3 with all information obtained
1/1/2016	Meeting with group members to discuss manufacturing process
8/2/2016	Manufacturing of ribs and spar
15/3/2016	Assembly of wing
15/5/2016	Installation of servos and push rods

Mazen Abdulrazik 125534

5/10/2015	Choosing the project desired with the group
11/10/2015	Meeting with the supervisor to understand the requirements of the project
13/10/2015	Gathering information about solar energy and UAVs
15/10/2015	Writing the Solar Energy part in Chapter 1
18/10/2015	Meeting with the Supervisor to know our next step
18/10/2015-25/10/2015	Gathering information about different types of UAVs and their classification
26/10/2015-1/11/2015	Meeting with my group member on daily basis to finish Literature review chapter
2/11/2015	Meeting with group members to select a design and name for the project
5/11/2015	Performing the wing analysis on XFLR with group members
9/11/2015	Meeting with supervisor to show our progress on the project
11/11/2015	Performing the tail analysis on XFLR software with group members
13/11/2015-20/11/2015	CAD/CAM drawings
21/11/2015 30/11/2015	Selecting and ordering electrical components according to the results obtained from MATLAB
5/12/2015	Selecting the solar cells to be used and contacting the manufacturer
7/12/2015	Meeting with the supervisor to check our progress

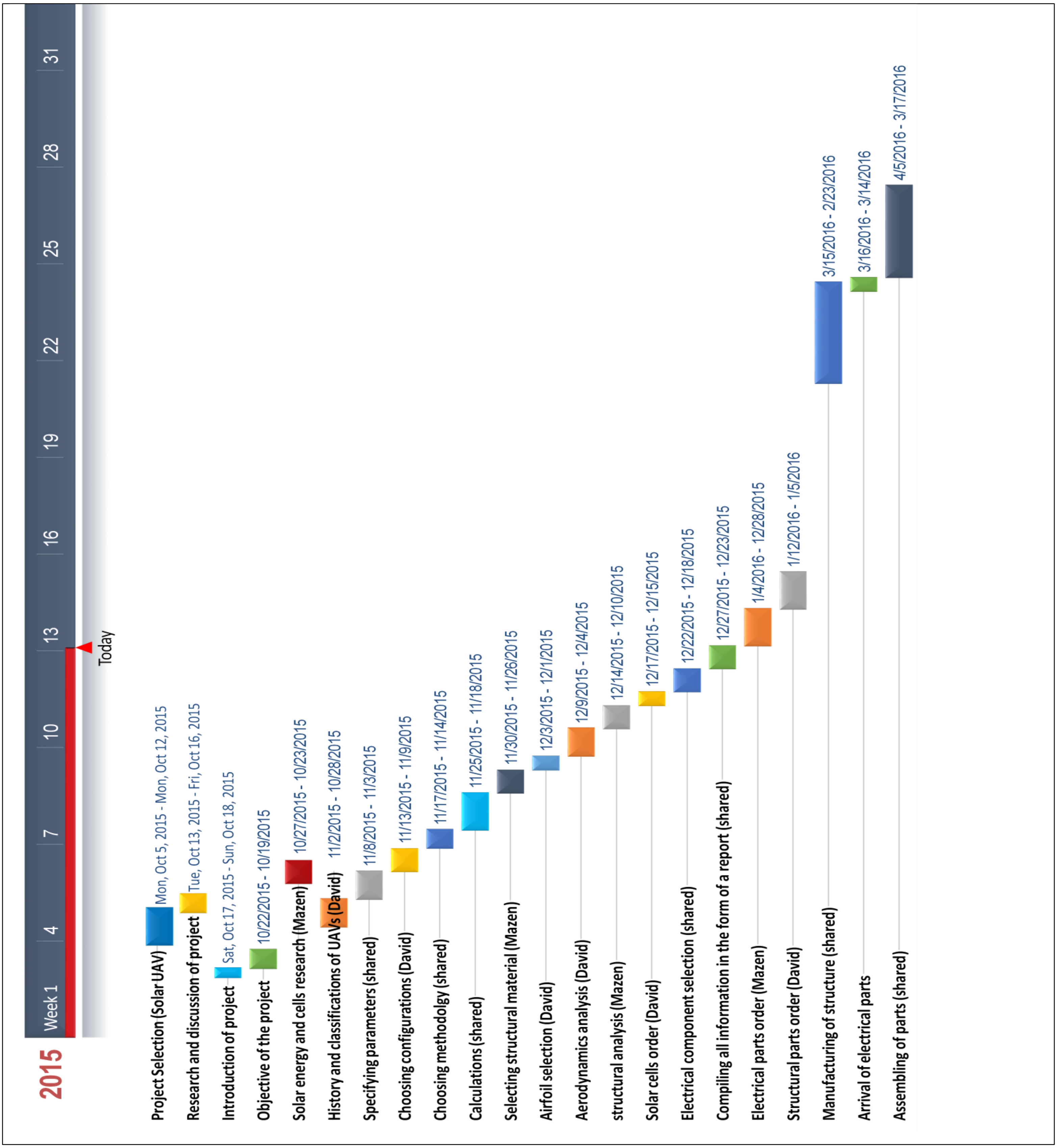
7/12/2015 15/12/2015	Meeting with the group member to start writing chapter 3
1/1/2016	Meeting with group members to discuss manufacturing process
8/1/2016	Working on the wing group members in the workshop
15/1/2016	Working on the fuselage with group members in the workshop
23/1/2016	Working on the tail with group members in the workshop

Yehia Jamaoui 138037

5/10/2015	Choosing the desired project with the group
11/10/2015	Meeting with the supervisor to discuss the selected capstone project
13/10/2015	Gathering information about solar energy and UAVs
15/10/2015	Preparing chapter 1, the introduction
18/10/2015	Meeting with the group to assign weights
18/10/2015-25/10/2015	Gathering information about different types of UAVs and their classification
26/10/2015-1/11/2015	Meeting with my group member on daily basis to finish Literature review chapter
2/11/2015	Meeting with the supervisor to discuss the next step
5/11/2015	Performing the wing analysis on XFLR with group members
11/11/2015	Performing the tail analysis on XFLR software with group members
13/11/2015-20/11/2015	CAD/CAM drawings
21/11/2015 30/11/2015	Selecting and ordering electrical components according to the results obtained from MATLAB
5/12/2015	Selecting the solar cells to be used and contacting the manufacturer
7/12/2015	Meeting with the supervisor to show our progress on the project

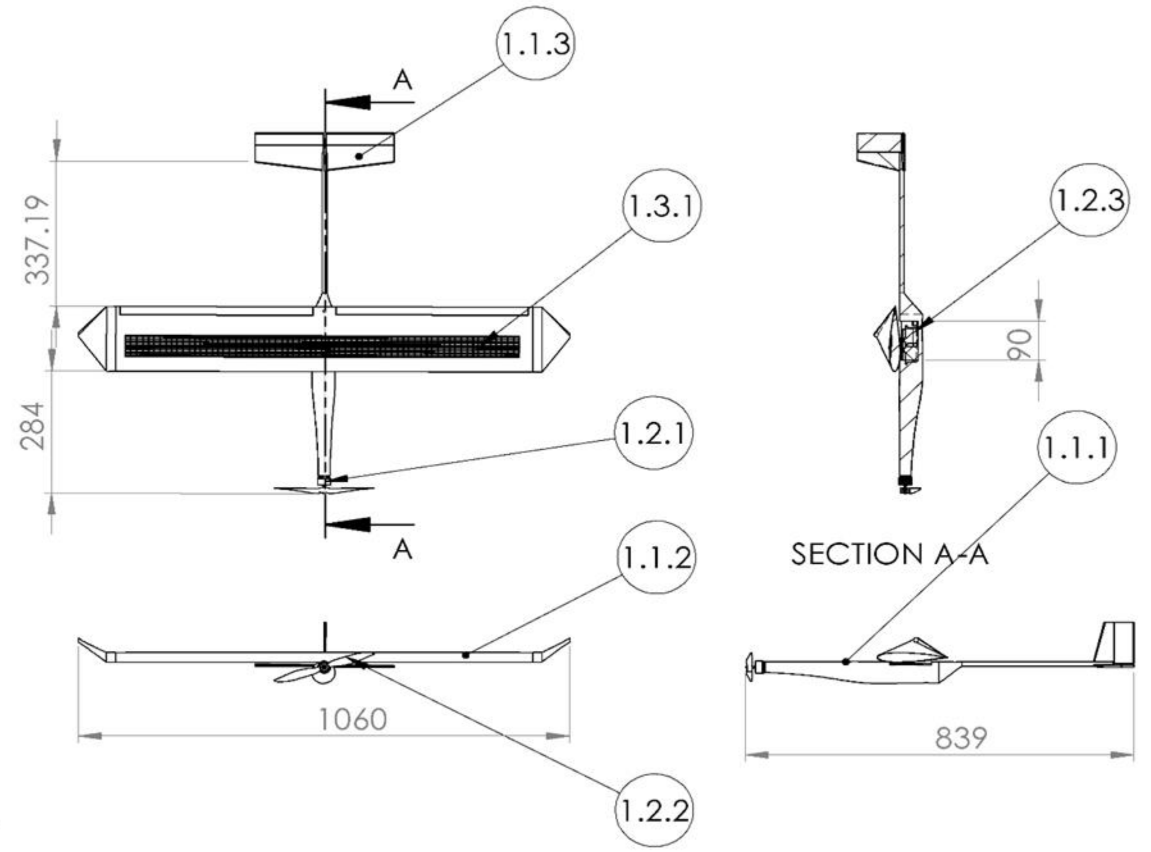
7/12/2015 15/12/2015	Discussing the project's progress among the group and putting plan for the next step
3/1/2016	Meeting with group members to discuss manufacturing process
8/1/2016	Working on the wing group members in the workshop
15/1/2016	Working on the fuselage with group members in the workshop
23/1/2016	Working on the tail with group members in the workshop

APPENDIX B



2015
Week 1
4
7
10
13
16
19
22
25
28
31
Today
Project Selection (Solar UAV)
Mon, Oct 5, 2015 - Mon, Oct 12, 2015
Research and discussion of project
Tue, Oct 13, 2015 - Fri, Oct 16, 2015
Introduction of project
Sat, Oct 17, 2015 - Sun, Oct 18, 2015
Objective of the project
10/22/2015 - 10/19/2015
Solar energy and cells research (Mazen)
10/27/2015 - 10/23/2015
History and classifications of UAVs (David)
11/2/2015 - 10/28/2015
Specifying parameters (shared)
11/8/2015 - 11/3/2015
Choosing configurations (David)
11/13/2015 - 11/9/2015
Choosing methodolgy (shared)
11/17/2015 - 11/14/2015
Calculations (shared)
11/25/2015 - 11/18/2015
Selecting structural material (Mazen)
11/30/2015 - 11/26/2015
Airfoil selection (David)
12/3/2015 - 12/1/2015
Aerodynamics analysis (David)
12/9/2015 - 12/4/2015
structural analysis (Mazen)
12/14/2015 - 12/10/2015
Solar cells order (David)
12/17/2015 - 12/15/2015
Electrical component selection (shared)
12/22/2015 - 12/18/2015
Compiling all information in the form of a report (shared)
12/27/2015 - 12/23/2015
Electrical parts order (Mazen)
1/4/2016 - 12/28/2015
Structural parts order (David)
1/12/2016 - 1/5/2016
Manufacturing of structure (shared)
3/15/2016 - 2/23/2016
Arrival of electrical parts
3/16/2016 - 3/14/2016
Assembling of parts (shared)
4/5/2016 - 3/17/2016

APPENDIX C



FABRICATION PROCESS

1. insert electrical parts into electrical box
2. join the fuselage to wing and tail using glue
3. joint the solar cells to the wing
4. mount the motor in front of fuselage

NUMBER	PART NAME	MATERIAL	MASS(kg)
1.3.1	SOLAR CELLS	CYSTALLINE SILICON	0.1
1.2.3	ELECTRONIC BOX	BALSA WOOD	0.13
1.2.2	PROPELLER	CARBON FIBER	0.016
1.2.1	MOTOR	STEEL	0.067
1.1.3	TAIL	BALSA WOOD	0.02
1.1.2	WING	BALSA WOOD	0.33
1.1.1	FUSELAGE	BALSA WOOD AND CARBON FIBER	0.08

	NAME	SIGNATURE	DATE
DRAWN	DD		1-6-16
CHK'D	MA		
APPV'D	Q.Z		
MFG			

GRIND

0.8/0.8

2.5 / RZ 4.0

TOLERANCE180-9001

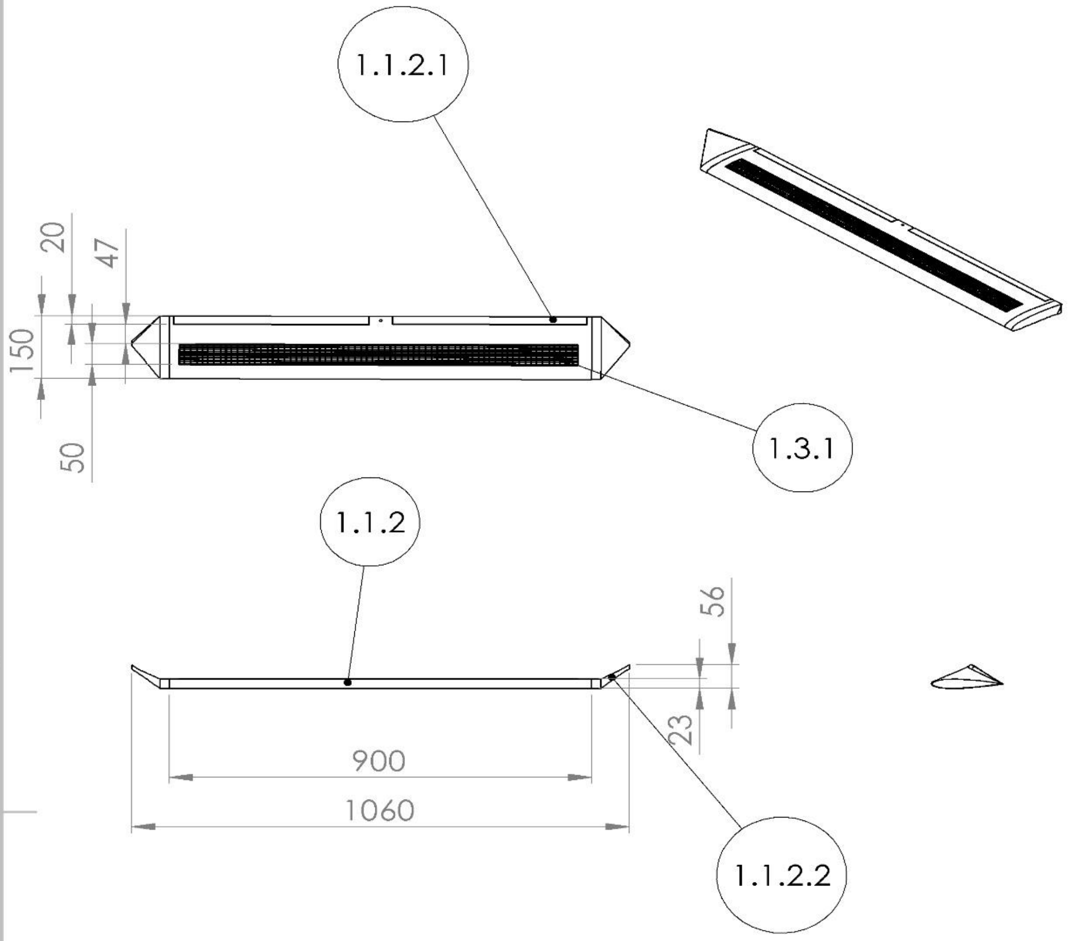
DWG NO.

full assembly

A4

SCALE:1:15

SHEET 1 OF 1



FABRICATION PROCESS

1.cutting the rib
2.joining the ribs, spar, leading edge, trailing edge
3. installing the ailerons and dihedrals
4. installing the solar cells

1.1.2.2	DIHEDRAL	BALSA WOOD	0.07
1.1.2.1	AILERONS	BALSA WOOD	0.05
1.3.1	SOLAR CELLS	CYSTALLINE SILICON	0.1
1.1.2	WING	BALSA WOOD	0.33
NUMBER	PART NAME	MATERIAL	MASS(kg)

	NAME	SIGNATURE	DATE
DRAWN	DD		1-6-16
CHK'D	MA		
APPV'D	Q.Z		
MFG			

TOLERANCE 180-9001

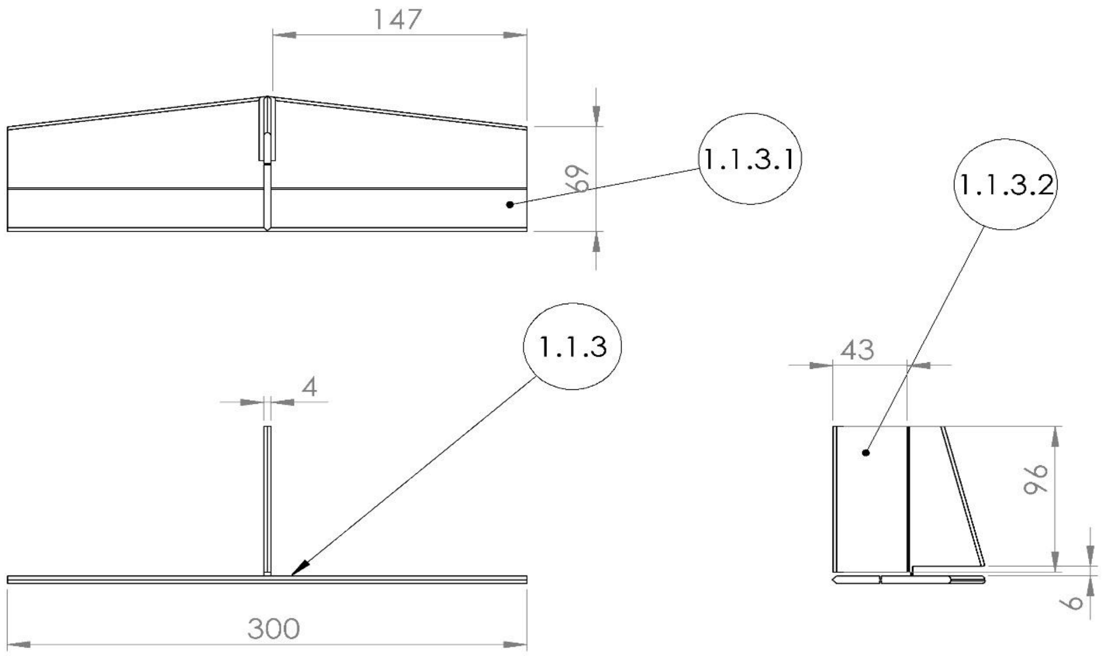
GRIND 0.8 / 0.8 ⊥ 2.5 / RZ 4.0

DWG NO.

FULL WING

A4

SCALE:1:15 SHEET 1 OF 1



FABRICATION PROCESS
1. tail shape was cut from balsa
2. installation of elevator
3. installation of rudder
4. complete assembly of tail using glue

1.1.3.2	RUDDER	BALSA WOOD	0.005
1.1.3.1	ELEVATOR	BALSA WOOD	0.005
1.1.3	TAIL	BALSA WOOD	0.01
NUMBER	PART NAME	MATERIAL	MASS(Kg)

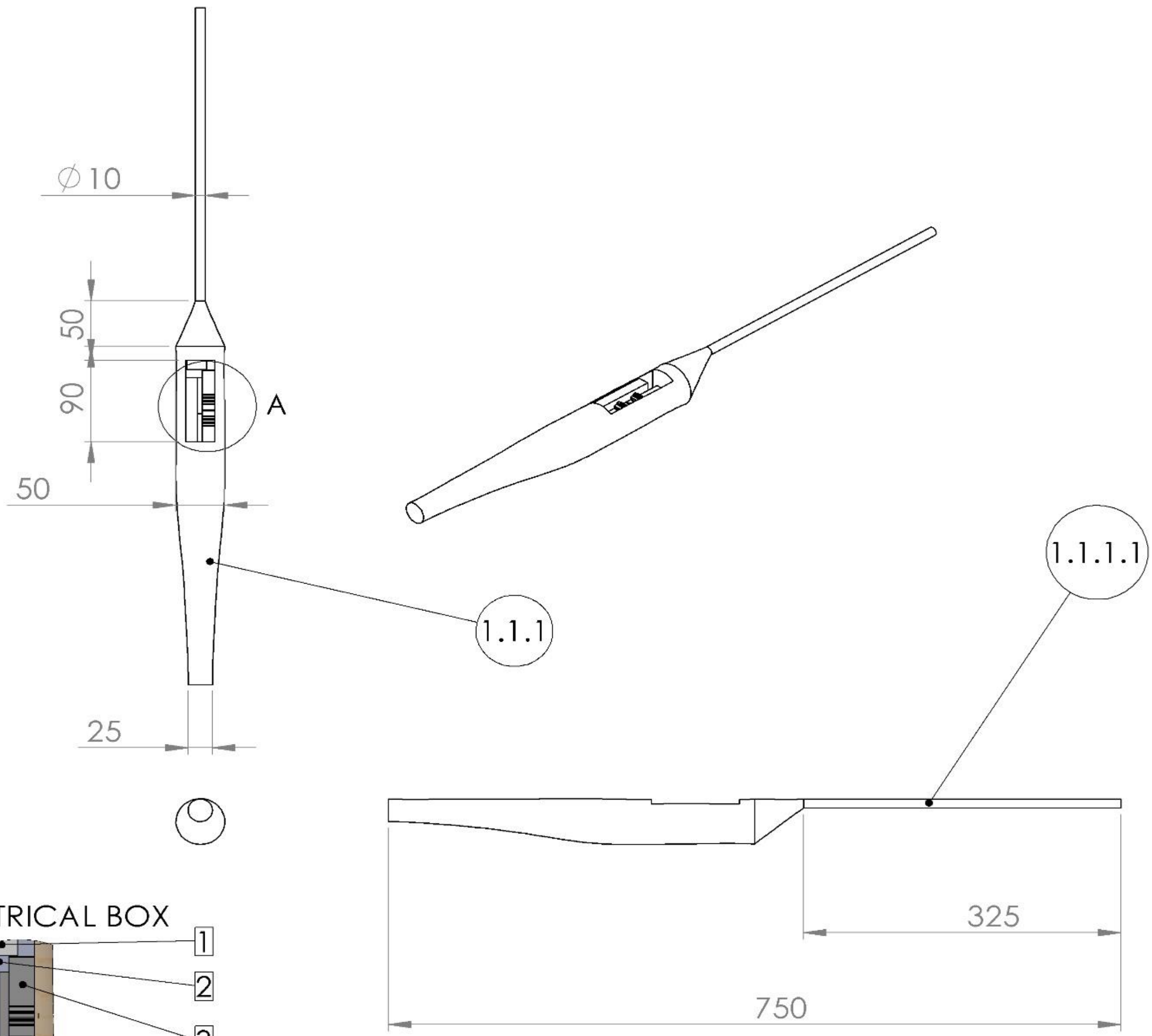
	NAME	SIGNATURE	DATE
DRAWN	DD		1-6-16
CHK'D	MA		
APPV'D	Q.Z		
MFG			

TOLERANCE 180-9001

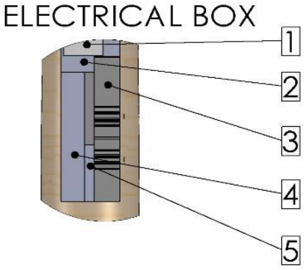
GRIND
0.8 / 0.8
⊥ 2.5 / RZ 4.0

DWG NO.
TAIL
A4

SCALE:1:4
SHEET 1 OF 1



ELECTRICAL BOX



DETAIL A
SCALE 2 : 7

ELECTRICAL PARTS
1. CHARGE CONTROLLER
2. SERVOS
3. BATTERY
4. ESC
5. RECEIVER

FABRICATION PROCESS
1. cutting the structure of the fuselage
2. attacting carbon fiber pipe
3. placing the electrical parts in fuselage

1.1.1.1	PIPE	CARBON FIBER	0.02
1.1.1	FUSELAGE	BALSA WOOD	0.08
NUMBER	PART NAME	MATERIAL	MASS

	NAME	SIGNATURE	DATE
DRAWN	DD		1-6-16
CHK'D	MA		
APPV'D	Q.Z		
MFG			

TOLERANCE 180-9001

GRIND
0.8 / 0.8
2.5 / RZ 4.0

DWG NO.
fuselage assembly A4

SCALE:1:7 SHEET 1 OF 1

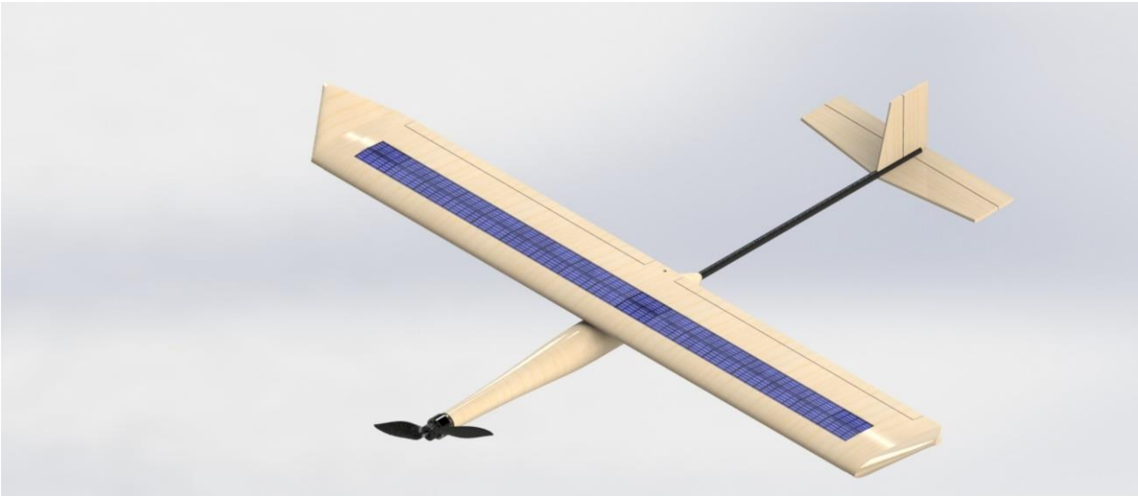


Figure C-1: Full assembled model

Figure C-2: Individual parts for assembly

APPENDIX D

Table D-1: Comparing the Solarine with other solar UAVs

	Solar Solitude	Solar Excel	Sun Sailor 1/2	The Solarine
Weight (kg)	2	0.72	3.6	0.723
Range (km)	38.84	48.31	139	10
Endurance (hrs)	-	11.5	-	1
Aspect ratio	13.3	12.8	13.15	6
Wing span (m)	2.7	2.1	4.2	0.9
Wing area (m^2)	0.55	0.35	1.35	0.135
Altitude (m)	1283	2065	200	400

TECHNICAL DATA

Typical Uncured Physical Properties

Color:	Clear and colorless
Appearance:	Liquid
Base:	Ethyl cyanoacrylate
Specific Gravity:	1.08
Viscosity:	80,000 to 100,000 cps
Flashpoint:	176°F to 200°F (80°C to 93.4°C)
VOC Content:	2% by weight (< 20 g/L)
Shelf Life:	From date of manufacture (unopened):
Stored at 2-8°C:	21 months
Stored at 20°C:	21 months
Lot Code Explanation:	YYDDD YY = Last two digits of year of manufacture DDD = Day of manufacture based on 365 days in a year
(Lot code imprinted on crimped end of tube)	For example: 13061 = 61st day of 2013 = March 2, 2013

Typical Application Properties

Application Temperature:	Do not apply below 50°F (10°C)
Odor:	Sharp,irritating (use in a well-ventilated area)
Fixture Time:	5 to 45 seconds (see Table 1)*
Handling Time:	Leave undisturbed for at least 5 minutes. For best results, leave undisturbed overnight to allow full bond strength to develop.
Full Cure Time:	12 to 24 hours*
	*Cure time is dependent upon the temperature, humidity and amount of adhesive used.

Table D-2: Results from Matlab for estimate mass and Power

Mass	0.2145kg
Total Electric Power	13.3W
Power for Level Flight	1.097W
Max. Solar Electric Power	4.6432W
Level flight speed	5.69m/s
Total Drag	0.1926
Wing surface Area	$0.1350m^2$

APPENDIX E

All information about the electrical parts a were obtained from hobbyking.com
Electrical Components Selection and specification

Motor

Name: Turnigy Park450 Brushless Outrunner 890kv

Figure E-1. Motor obtained from hobbyking.com

Specification

Battery: 2~3 Cell
Voltage: 7.4~11.1V
RPM: 890kv
Max current: 14A
No load current: 8V/0.7A
Current capacity: 18A/15sec
Internal resistance: 0.20 ohm
Weight: 67g (not including connectors)

Requirement

20A ESC
2S~3S Li-Po / 6 ~ 10-cell Ni-MH/Ni-Cd
9x6 ~ 11x3.8 prop
Suitable for sport and scale airplanes weighing 15 to 30 ounces (425g–850g).

Dimensions of motor

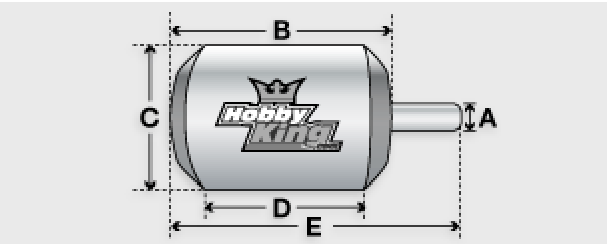


Figure E-2: Motor dimension

Table E-1: Dimensions of motor

Shaft A (mm)	4
Length B (mm)	38
Diameter C (mm)	28
Can Length D (mm)	19
Total Length E (mm)	51

3.8.2) Propeller

Name: Dynam Carbon Fiber Propeller

Figure E-3: Propeller

Specification

Type: Electric
Length: 9 inch
Pitch: 6 inch
Center Hole: 9mm
Hub Thickness: 11.5mm
Weight: 16g each
Material: Carbon
Rotation: Standard (Clockwise from rear)

Batteries

Name: Turnigy nano-tech

Figure E-4: Battery

Specification

Capacity: 1000mAh

Voltage: 2S1P / 2 Cell / 7.4V

Discharge: 25C Constant / 50C Burst

Weight: 60g (including wire, plug & case)

Dimensions: 71x35x12mm

Balance Plug: JST-XH

Discharge Plug: XT60

Battery Dimension

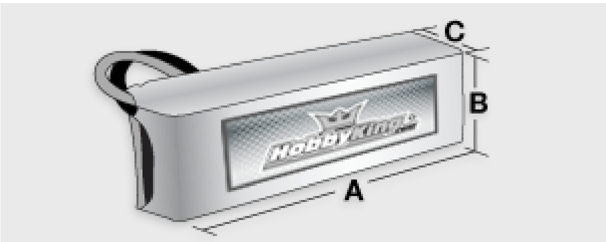


Figure E-5: Battery Dimension

Table E-2: Battery dimension

Length-A(mm)	71
Height-B(mm)	35
Width-C(mm)	12

Electronic speed controllers

Name: Turnigy Multistar 20A V2 Slim BLHeli Multi-Rotor Brushless ESC 2-6S

Figure E-6: Electronic speed controllers

Specifications

Constant Current: 20A

Input Voltage: 2-6 cell Lipoly

BEC: Yes (linear) [Remove middle wire to disable]
BEC Output: 5V/3A
PWM: 8 KHz
Max RPM: 240,000rpm for 2 Pole Brushless Motor
PCB Size: 62mm x 13mm
Discharge Plugs: Male 3mm Bullet Connector
Motor Plugs: Female 3mm Bullet Connector
Weight: 20.3g
A cable is required to connect the ESC to the batter since the have different connection types which are bullet and XT60

Servos
Two servos are selected one for the aileron and the other for the ruddervator
Servo 1 is for ruddervator and servo 2 for aileron

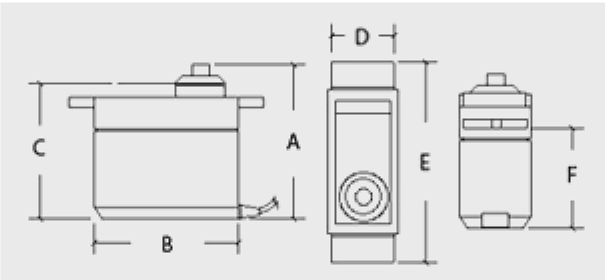


Figure E-7: Servo 1 dimension

Table E-3: Servo 1 dimension

A(mm)	33
B(mm)	36
C(mm)	30
D(mm)	15
E(mm)	50
F(mm)	20

Table E-4: Specification of servo 1

Weight (g)	8.4
Torque (kg)	1.5
Speed (Sec/60deg)	0.12

Servo 2

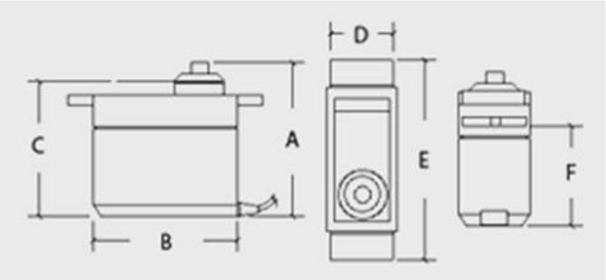


Figure E-8: Servo 2 dimension

Table E-5: Servo 2 dimension

A(mm)	30
B(mm)	25
C(mm)	26
D(mm)	12
E(mm)	34
F(mm)	15

Table E-6: specification of servo 2

Weight (g)	25
Torque (kg)	2.3
Speed (Sec/60deg)	0.08

Solar cells

Name: Polycrystalline solar panel 1 Wp 4 V

Figure E-9: Solar cell obtained from [29]

Specifications

Category: Polycrystalline solar panel

Power: 1 Wp

Nominal voltage: 4 V

Open circuit voltage (OCV): 4.4 V

Nominal current: 250 mA

Short-circuit current: 275 mA

Width: 82mm

Height: 3mm

Length: 120 mm

Weight: 45 g

Bill of materials

ITEM	PART NO	PART NAME	QUANTITY	WEIGHT (g)	PRICE (EU)	SHIPPING COST (EU)	SOURCE (Company)	CONTACT INFO.
1	1.2.1	Motor: Turnigy Park450 Brushless Outrunner 890kv	1	67	16.24	183	Hobby king	www.hobbyking.com
2	1.2.2	Propeller: Dynam Carbon Fiber	2	16	7.41	"	Hobby king	www.hobbyking.com
3	1.3.2	Batteries: Turnigy nano-tech	2	60	12.32	"	Hobby king	www.hobbyking.com
4	1.2.3.2	Electronic speed controllers: Turnigy Multistar 20A V2 Slim BLHeli Multi-Rotor Brushless ESC 2-6S	1	20.3	9.86	"	Hobby king	www.hobbyking.com
5	1.2.3.1	Servo 1 for ruddervator	1	8.4	7.73	"	Hobby king	www.hobbyking.com
6	1.2.3.1	Servo 2 for aileron	1	25	4.59	"	Hobby king	www.hobbyking.com
7	1.2.3.4	Push rods	2	15	1.63	"	Hobby king	www.hobbyking.com
8	1.2.4	Transmitter	1	1500	22	"	Hobby king	www.hobbyking.com
9	1.1.1	Carbon fiber rod	1	1000	7.5	24	Easy composite (UK)	http://www.easycomposites.co.uk sales@easycomposites.co.uk 00 44 1782 596868
10	1.1.2	Balsa wood		1000	30	-	Deniz Plaza(EMU)	
11	1.1	Glue	3		15	-	Deniz plaza(EMU)	
12	1.3.1	Solar cells	54	69	140	-	Lemo-solar (Germany)	http: //www.lemo- solar.de vertrieb@lemo-solar.de 07062/902 1579
13	1.3.3	Charge controller	1		5.3	22	Alibaba (China)	www.sunsunsolar.cn 86 1868 2003 877
		Total	70	2780.7	279.58	229		

DESIGN specifications

Wing chord (cm) = 15	Tail Aperture (α) = 26
Wingspan (cm) = 90	Tail span (cm) = 30
Wing Area (cm^2) = 1350	Ruddervator Chord (cm) = 3.2
Fuselage (cm) = 67.5	Total Ruddervator Surface Area (cm^2) = 96
Aileron (cm) = 1.9	Tail area (cm^2) = 270
Aspect ratio = 6	Ruddervator Length (cm) = 30

Matlab code by Andre North

```
%==========================================================================
%=== Global Design of Relay UAV
%=== - Initialization of Parameters -
%=== May, 2010
%===
%=== This code initialize parameters for the design program of Relay UAV
%=== (or other solar airplane in general)
%==========================================================================


%AR = 6;            % Aspect Ratio
g=9.81;             % Gravitational acceleration [m/s^2]
alt=200;            % Initial altitude [m]
alt_array=[0, 1000, 2000, 4000, 6000, 10000, 15000, 20000 ];
rho_array=[1.224, 1.11, 1.006, 0.819, 0.659, 0.413, 0.192, 0.087, 0.039,
0.017];
rho=spline(alt_array,rho_array,200);      % Airdensity at 500m [kg/m^3]


%=========== Irradiance conditions ==============
I_max=900;               % Maximum irradiance [W/m^2]
T_day=13.2*3600;         % Duration of the day [s]
n_wthr=0.7;              % Margin factor <1 take clouds into account [-]


%================ Aerodynamics ==================
C_L=0.8;                 % Airfoil lift coefficient [-]
C_D_afl=0.04;          % Airfoil drag coefficient [-]
C_D_par=0.007;          % Fuselage drag coefficient [-]
e=0.9;                   % Constant depending on wing shape [-]


%======= Wing & fuselage Structure ==============
k_af=0.75/9.81;          % Constant [~Kg/m3]
x1=3.1;                  % Scaling exponent for b [-]
x2=-0.25;                % Scaling exponent for AR [-]



%============= Propulsion group =================
n_ctrl=0.95;             % Efficiency of motor controller [-]
n_mot=0.85;              % Efficiency of motor [-]
n_grb=0.97;              % Efficiency of gearbox [-]
n_plr=0.60;              % Efficiency of propeller [-]
k_prop=0.008;            % Mass/Power ration of propulsion group [kg/W]


%======= Battery and Stepdown converter =========
n_chrg=0.95;          % Efficiency of charge process [-]
n_dschrg=0.95;      % Efficiency of discharge process [-]
n_bec=0.65;         % Efficiency of bec (5V stepdown) [-]
k_bat=190*3600;     % Energy density of LiPo [J/Kg]


%================ Solar cells ===================
k_sc=0.32;          % Mass density of solar cells [Kg/m2]
k_enc=0.26;         % Mass density of encapsulation [Kg/m2]
k_mppt=1/2386;      % Mass/Power ratio of mppt [kg/W]
n_sc=0.169;         % Efficiency of solar cells [-]
n_cbr=0.9;          % Efficiency of cambered configuration [-]
n_mppt=0.97;        % Efficiency of mppt [-]


%============== Avionics & Payload ==============
m_av=0.15;          % Mass of controler and electronics [kg]
```

```
m_pld=0.05;         % Mass of payload [kg]
p_av=1.5;           % Power required for control [W]
p_pld=0.6;          % Power required for payload [W]

%============== End of File ====================
```

```
%==========================================================================
%=== Global Design of Sky-Sailor Airplane
%=== - Evaluation of the solution -
%=== May 2010
%===
%=== This code evaluates, based on given parameters, the feasibility of a
%=== certain configuration of solar airplane. In one sentence, the main
%=== problem is to balance weight/lift and obtained/required power.
%==========================================================================
C_D_ind = C_L^2/(e*pi*AR);          % Induced drag coefficient [-]
C_D=C_D_afl+C_D_ind+C_D_par;        % Total drag coefficient [-]
C_D_afl= Airfoil drag coefficient


a0=C_D/(C_L^1.5)*sqrt(2*AR*(g^3)/rho);                      % Eq 3.5
a1=1/(n_ctrl*n_mot*n_grb*n_plr);                            % Eq 3.6
a2=1/(n_bec)*(p_av+p_pld);                                  % Eq 3.6
a3=m_av+m_pld;                                              % Eq 3.10
a4=k_af*AR^x2;                                              % Eq 3.25
a5=k_sc+k_enc;                                              % Eq 3.27
a6=k_mppt*I_max*n_sc*n_cbr*n_mppt;                          % Eq 3.28
a7=T_night/(n_dschrg*k_bat);                                % Eq 3.30
a8=k_prop;                                                  % Eq 3.32
a9=pi/(2*n_sc*n_cbr*n_mppt*n_wthr)*...                      % Eq 3.26
    (1+T_night/(T_day*n_chrg*n_dschrg))*1/I_max;
a10=a0*a1*(a7+a8+a9*(a5+a6));                               % Eq 3.34
a11=a2*(a7+a9*(a5+a6))+a3;                                  % Eq 3.34
a12=a10*1/b;                                                % Eq 3.35
a13=a11+a4*b^x1;                                            % Eq 3.35


z=roots([a12 -1: 0 a13]);                          % Solving equation to find
mass
Sol_m = min(z)^2;                                % It can be 2 masses, we take
the smallest one



if (isnan(Sol_m)==0)                     % If a solution is found, we compute
...
    Sol_P_level = a0*Sol_m^1.5/b;          % Eq 3.5 level flight power
    Sol_m_af = a4*b^x1;                    % Eq 3.25 airframe mass
    Sol_P_elec_tot = a1*Sol_P_level+a2;    % Eq 3.6 total electric power (level
flight)
    Sol_m_bat = a7*Sol_P_elec_tot;         % Eq 3.30 battery mass
    Sol_A_sc=a9*Sol_P_elec_tot;            % Eq 3.26 solar panels area
    Sol_m_sc = a5*Sol_A_sc;                % Eq 3.27 solar panels mass
    Sol_m_mppt = a6*Sol_A_sc;              % Eq 3.28 mppt mass
    Sol_P_sc = a6*Sol_A_sc/k_mppt;         % Eq 3.28 solar electrical power max
    Sol_m_prop = a8*a1*Sol_P_level;        % Eq 3.32 propulsion group mass
    Sol_v = sqrt(2*Sol_m*g/(C_L*rho*b*b/AR));      % Eq 3.3 level flight speed
    Sol_D = Sol_m*g/C_L*C_D;                       % Eq 3.1-2 total drag
    Sol_A = b^2/AR;                                % wing surface
end


if  ((isnan(Sol_m)==1 || (Sol_A_sc > b*b/AR)))       % If no solution, Nan is
returned


    Sol_P_level = NaN;
    Sol_m_af= NaN;
    Sol_P_elec_tot= NaN;
    Sol_m_bat= NaN;
    Sol_A_sc= NaN;
    Sol_m_sc= NaN;
    Sol_m_mppt= NaN;
```

```
    Sol_P_sc= NaN;
    Sol_m_prop= NaN;
    Sol_v= NaN;
    Sol_D=  NaN;
    Sol_A=  NaN;
end

%========================End of File==========================%
```

```
%==========================================================================
%=== Global Design of Sky-Sailor Airplane
%=== - Plot Example for Unmanned Aerial Vehicle -
%=== May 2010
%===
%=== This code tries different combinations of wingspan and aspect ratio
%=== and then evaluates the feasibility or not of the solution. It uses the
%=== technological & mission parameters from Initparameters. The results
%=== are plotted on graph where one can also see the mass distribution.
%==========================================================================
clc;clear;clf;
cmap=colormap(gray(100));
j=0;

InitParameters;             % Parameters are initialized
T_night=24*3600-T_day;      % Duration of the night [s]

for AR = [1,2,3,4,5,6,7,8,9,10]          % For different aspect ratios...
    j=j+1;
    col=cmap(floor(((100-10)-0)/(10-1)*(AR-1))+1,:);

%================================================
%===              CALCULATION               ====
%================================================

i=0;
b_max=3;
b_step=0.1;

for b=b_step:b_step:b_max               % And different wingspans...
    EvaluateSolution;                   % ... the solution feasibiliy is computed
    i=i+1;
    m(i)=Sol_m;
    P_level(i)=Sol_P_level;
    m_af(i)=Sol_m_af;
    P_elect_tot(i)=Sol_P_elec_tot;
    m_bat(i)=Sol_m_bat;
    A_sc(i)=Sol_A_sc;
    m_sc(i)=Sol_m_sc;
    m_mppt(i)=Sol_m_mppt;
    P_sc(i)=Sol_P_sc;
    m_prop(i)=Sol_m_prop;
    v(i)=Sol_v;
    D(i)=Sol_D;
    A(i)=Sol_A;
end

%================================================
%===                 PLOTS                  ===
%================================================

width=2;
b=b_step:b_step:b_max;

figure(1);

set(gcf,'Position',[1056 204 560 420]);
hold on;
    plot(b,m,'Color',col,'LineWidth',width);            % Plot total mass wrt to AR and
b
     [m_min.m(j),index]=min(m);
    m_min.b(j)=b(index);
    grid on;
xlabel('Wingspan [m]');
ylabel('Total Mass of Solar Airplane [Kg]');

figure(2);
```

```
set(gcf,'Position',[487 704 800 420]);

subplot (2,2,1);

hold on;
plot(b,v,'Color',col,'LineWidth',width);                    % Plot speed wrt to AR and b
[v_min.v(j),index]=min(v);
v_min.b(j)=b(index);
grid on;
ylabel('Speed [m/s]')

subplot(2,2,3);

hold on;
plot(b,P_level,'Color',col,'LineWidth',width)              % Plot the propeller power wrt
to AR and b
grid on;
ylabel('Power at propeller [W]');
xlabel('Wingspan [m]');



subplot(2,2,2);

hold on;
plot(b,A,'Color',col,'LineWidth',width); % Plot wing area wrt to AR and b
grid on;
ylabel('Wing Area [m^2]');
Subplot(2,2,4);
hold on;

plot(b,A_sc./A*100,'Color',col,'LineWidth',width);            % Plot solar area wrt to AR
and b

[ratio_area_min.ratio_area(j), index]=min(A_sc./(b.^2/AR)*100);
ratio_area_min.b(j)=b(index);
grid on;
xlabel('Wingspan [m]');
ylabel('Solar Area Ratio [%]');

if (AR == 13)
    figure(3);set(gcf,'Position',[487 204 560 420]);
    area(b,[m./m*m_pld;m./m*m_av;m_af;m_bat;m_sc;m_mppt;m_prop]');
    legend('Payload','Avionics','Airframe','Batteries','Solar Panels','Mppt',...
'Propulsion group','Location','NorthWest');
xlabel('Wingspan [m]');
ylabel('Mass [kg]');
    colormap(gray(100));
end
end
figure(1);

plot(m_min.b,m_min.m,'xk','MarkerSize',4);
legend('1','2','3','4','5','6','7','8','9','10','Location','NorthWest');

figure(2);

subplot(2,2,1);
plot(v_min.b,v_min.v,'xk','MarkerSize',4);
subplot(2,2,4);
plot(ratio_area_min.b,ratio_area_min.ratio_area,'xk','MarkerSize', 4);
legend('1','2','3','4','5','6','7','8','9','10','Location','NorthWest');
```

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