NAU
SOLAR FLYERS

EE Solar Flyers

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Subject Description: This document outlines all elements to the construction of a solar-powered unmanned aerial vehicle (Solar UAV).

NOTES:

- The deliverable lead editor is Gabriel Martin
- Substantial numerical values and measurements in the **Design** section are in **bold.**

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Introduction

The overall goal of the project is to construct an unmanned aerial vehicle (UAV), whose flight time can be extended by at least 50% from solar power. This can be achieved by recharging the battery that powers the plane with solar panels, to increase its capacity. This project is funded by W.L. Gore & Associates, along with the CEIAS department at NAU. The client for the product is David Willy, the Senior Lecturer of Mechanical Engineering at Northern Arizona University. Our team, the EE Solar Flyers, will be working closely with the Sol Avem mechanical engineering team to construct the solar-powered UAV. Our initial budget to construct the device is a total of $1500.00, split between the two teams. Our team of electrical engineers will attempt to operate within $500.00 of that budget. Building a solar-powered UAV is considered a multidisciplinary project. The construction of the UAV and ensuring its flight from a battery can be identified under a mechanical engineering skillset. Understanding the elements of a renewable power source like solar energy and using it to prolong the life of a mechanism can be identified under an electrical engineering skillset. Both teams will be using the knowledge, resources, and skillsets learned within the scope of their undergraduate program to adequately build this device. A UAV is essentially a drone. They are mainly built for military security and surveillance operations, or recreational use. The dreadful impact of global warming has raised a time-sensitive demand for alternative, renewable, clean energy sources. Solar energy aims to be one of the more practical and efficient options. Research is being developed to use solar energy as an indefinite supply of energy for numerous appliances. A traditional UAV will usually run on some type of battery to power the motor and is operated by a transmitter with a sensor of some sort. The battery type commonly used for UAVs is a lithium polymer (Li-Po). The goal of incorporating solar power is to recharge the li-po battery that operates the UAV to prolong its life, so its flight time is correspondingly extended by 50%. The main issue for achieving prolonged flight of a UAV is energy management while it is airborne. A challenge for us will be delivering the right amount of power from the solar panels, which will correspond with the rate of energy the motor is consuming from the battery. The irradiance of the sun, temperature, battery discharge rate, and the weight of the plane will all be factors to consider when assembling our PV system. However, the solar energy harvested cannot directly be delivered to the battery. The charge might exceed its capacity and destroy it. A charge controller will be used to regulate the charge from the solar panels to the battery. The client has an established background in avionics. When outlining his requirements for the product, he gave our team insight into the bigger picture of the project. To summarize, UAVs are an underappreciated tool. You will often see tech companies produce goods of the such under contract for the government. UAVs are used for top-level surveillance and can be weaponized as well. A substantial point to consider is that the construction of a military-grade UAV, depending on size and function, costs anywhere from $500,000 to $100,000,000. However, the total costs of the lives you are replacing with a UAV will exceed those amounts. On top of that, achieving prolonged or even indefinite flight from solar power could save companies lots of money on batteries, and could inspire other technologies to be ran or supported by solar energy. The document will outline every detail of the project reached so far, and provide insight into what will be achieved over the duration of the project.

Previous Work

UAVs hold a steady demand for military, industrial, and recreational use. New applications and functionalities of the technology increase every year. Before the use of solar energy came into play, the issue was powering UAVs long and effectively enough to keep them operational in the air. Batteries and fuels stood as the primary sources of energy for years (as they are for most technologies). Along with choosing a power source, many aerodynamic and performance-based factors such as a thrust/weight ratio, flight conditions, and frame material must be accounted for. The demand for renewable and sustainable energy sources has driven the increased use of solar energy applications. The sun is an everlasting source of energy, so the full optimization of power harvest has driven companies in the solar industry into a competition. The methodology of maximum power point tracking allows solar technologies to produce the maximum power output by using power conditioning methodologies and supporting electrical components to make up for any variance in the process. We can review a few previous works on these concepts to gauge how our project can be achieved.

In 2019, a mechanical engineering team from Northern Arizona University (Solis Fur) attempted to build and design a solar-powered aircraft capable of sustaining indefinite flight for their capstone project [1]. The plane they assembled held a wingspan of 4 meters, a weight of 7.6 lbs, and an operating voltage of 17.2 V from the solar cells. A model of their design can be seen in Figure 1.

Figure 1: Solis Fur's "The Sun Thief" Functional Model in 2019

The assembly manual describes their design in great detail. It includes a Bill of Materials sectioned by the elements of their design, and procedures for the construction of all the aircraft's parts [1]. It should be noted that the aircraft did not meet the advanced objectives/requirements asked by the client. The plane failed to run off of the solar panels, and flew far below the required time of a conventional UAV for its weight and build. Although the direct reasoning for their failures cannot be found on their website, a few speculations can be made. The team consists of 5 mechanical engineers. Photovoltaic energy is covered under an advanced elective course held in the electrical engineering undergraduate course requirements, so it can be assumed that the team probably had little-to-no prior knowledge of solar energy systems. To add, the team did not use a charge controller of any sort, so only estimations of the PV array's energy output could have been made to know what could adequately charge the battery. On top of that, only a minor amount of troubleshooting data was taken. Nevertheless, the team's endeavor to build the UAV is remarkable in its procedure, and they have provided some great sources to reference for building a functional device.

A helpful guide was provided to our team at the beginning of the project: "Photovoltaics: Design and Installation Manual". Photovoltaics (as mentioned earlier) is not a subject often touched on during our undergraduate program. A manual can only go so far depending on its content and relatability, but we have found it to be helpful in understanding the basic concepts to build any sort of solar system. To add, a standard manual itself holds the validation and accreditation of experts in the field of photovoltaics. This design and installation manual has served as the core reference material throughout this project. The first few chapters have given our team much background information on basic solar panel installation. Further chapters of the book cover advanced topics and photovoltaic applications. The manual has already provided us with an abundance of knowledge. First, the manual discusses how voltage and current are dissipated throughout the panels in series or parallel arrangements (Figure 2). This is followed by a review of solar radiation fundamentals, which includes the orientation of your panel to the sun, magnetic declination, climate considerations, and how to gather isolation data [2]. To summarize, this manual has helped us fill in gaps in knowledge, verify our thought processes, and will likely play a major role in troubleshooting.

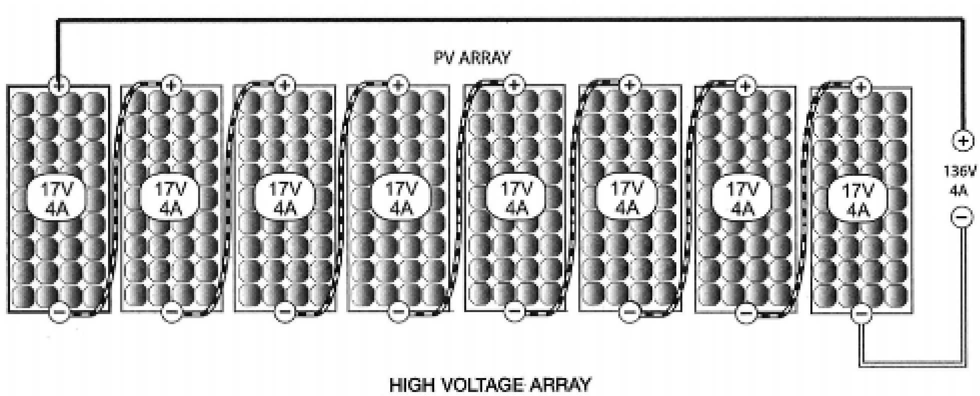

Figure 2: Photovoltaics: Design and Installation Manual Chapter 2: Series Connection Output

Our team came across an article reviewing a similar project developed in Thailand. In an attempt to help promote the development and use of renewable energy, the team built a solar-powered unmanned aerial vehicle used to monitor environmental tendencies in the area. The team aimed for a 6+ hour flight time using SunPower C60 mono-crystalline silicon PV cells [3]. These cells are the same ones that the NAU 2019 Solis Fur team used. The main difference between this UAV and our design is the lack of a charge controller. A critical issue discussed in the paper concerns the relationship between the energy the limited PV cells could produce on the device failing to account for the power requirement. Additionally, when their team was building the model, they were accounting for projected insolation levels during one season of the year in Thailand. The testing took part during another season of the year, where insolation levels showed minor spectrum changes from the preceding season Usually calculations and testing are simulated at STC (1000 W/m^2 and 25° C), but their test conditions deviated far from this. This will remind our team to execute a proper environmental analysis and prepare accordingly for our final testing. One element from the article that was helpful to our team was a testing procedure observing the power due to a change in the throttle of two motor configurations [3]. Figure 3 below provides a common trend of this relationship. Our team can use the single motor data to see how well it compares to how much power we will have to generate to lift our plane's weight. The UAV constructed in the article stands about 12.5 lbs / 5.7 kgs, but we are estimating ours to be **9lbs / 4.1kgs.**

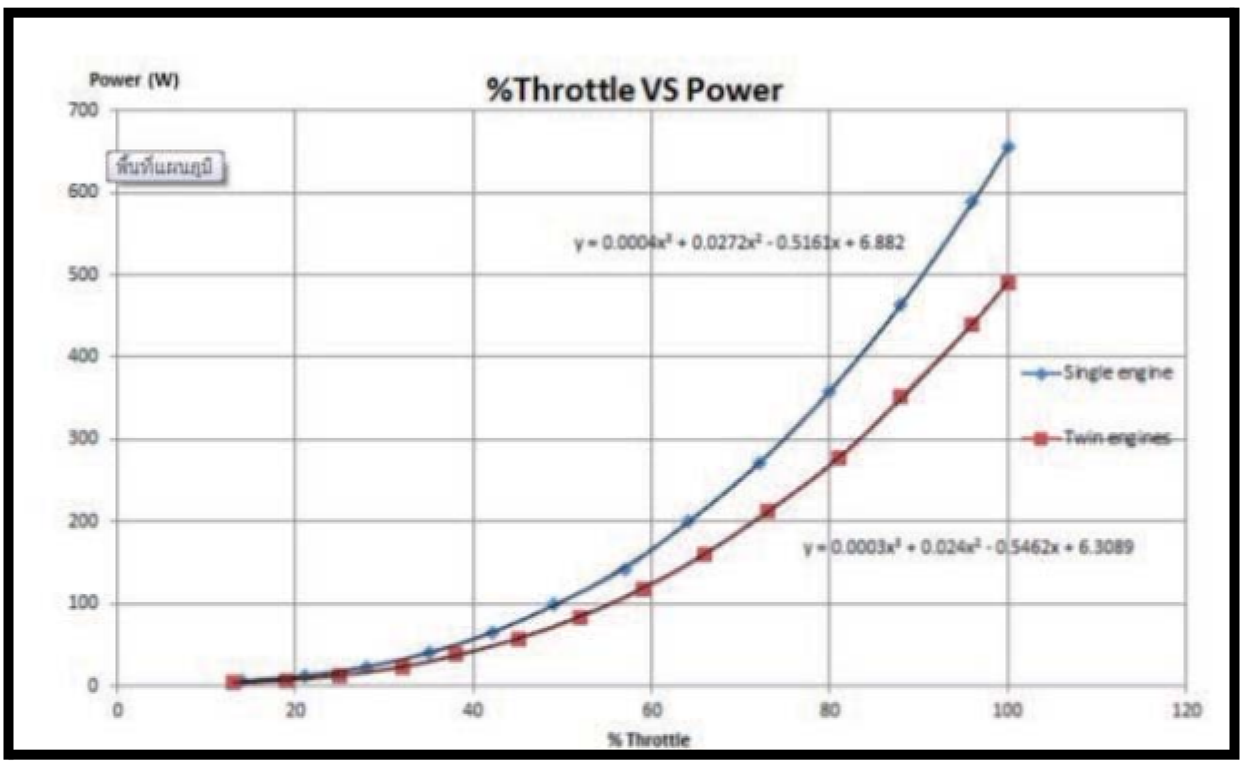

Figure 3: Power due to Change in Throttle

One of the most important elements of our project is understanding what to expect from our solar cells. This means we must understand the characteristics of a PV system, and how they might behave under certain conditions. Our team came across an article discussing the specifications and behaviors of a solar module, and how an improved Perturb & Observe algorithm may improve the efficiency of that standalone PV system [4]. A PV system's voltage, current, and power outputs under ideal conditions can be modeled as an IV and PV curve, shown in Figure 4. The paper explains the derivation and importance of a solar cell's open-circuit voltage (Voc), short circuit current (Isc), series resistance (Rs), and shunt resistance (Rsh) under partial shading conditions.

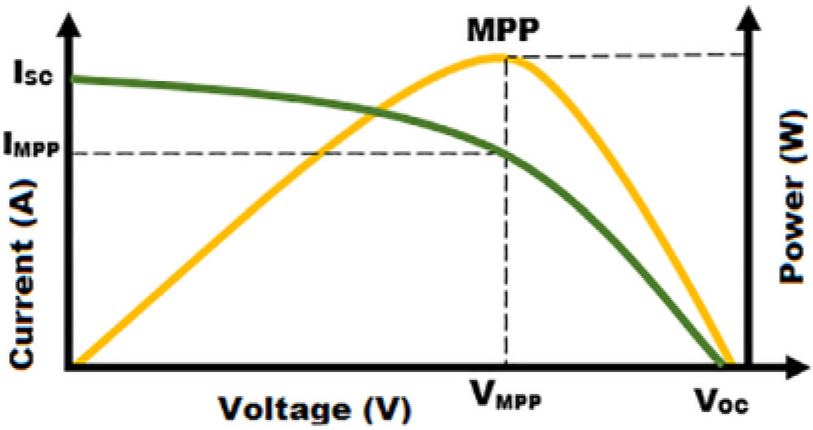

Figure 4: I-V and P-V curve of a solar cell

One of the last sources our team came across was an article detailing the implementation of a solar MPPT charge controller, for the purposes of battery protection and energy metering [5]. A charge controller is a major functional component for an independent PV system and will maintain an appropriate charging voltage to the battery. On top of that, it accepts a voltage from the PV array and conditions it to its maximum power output. In this article, a DC to DC controller is programmed via Arduino to implement a Perturb and Observe algorithm. This methodology is proven effective. However, to preserve time and materials, there are off-the-shelf MPPT charge controllers you can buy for your PV system. They operate in the interest of adequately charging the battery you are using, but it will be up to us to determine the size of the PV array and which MPPT charge controller can do the job.

Prototypes

After all elements of the project's demands were understood, each member of the EE team executed a prototype to help achieve some working parts of our system. Our level 1 system architecture can be broken down into two parts, which is perfect considering we are a team of two. The first element is the configuration of solar panels to achieve an output. Then, connect that output to a converter of some sort to see if you can condition the power coming from the panels. The second element is understanding the charge and discharge behaviors of the battery so that we can correctly size a PV system. Each of the prototypes will be explained in detail.

Gabriel's Prototype - Series & Parallel Solar Cell Connections with a Power Output Adjustment

Gabriel's prototyping directly modeled the setups of two Amorphous PV arrays, as well as their connection to a power converter. This is a critical component of system architecture because the panels' configuration will serve as the power supply needed to recharge our battery. Previous to conducting the prototype, Gabriel had no experience soldering wires to any electrical component. Bigger Polycrystalline and some Monocrystalline panels usually come with some type of connector. However, Amorphous cells are commonly connected via designated positive and negative solder terminals. Gabriel expected to learn how to correctly wire these panels in series and parallel, and how to properly connect the solar panels' output leads to a power converter. Our team was nervous beforehand, for we heard stories of people messing up their components because they were reckless or inexperienced in their soldering technique. To add, it concerned us that a power converter with an input range of 5 to 20 V was super low priced. For this prototype, the team purchased 6 JIANG Flexible Solar Panels and a DC to DC boost converter. The specifications for the panels and converter are listed below:

JIANG Flexible Solar Panel 1W		**DC-DC Breadboard Boost**	
- Voltage at Peak Conditions	6 V	- Input Voltage	3.7 - 18 V
- Current at Peak Conditions	160 mA	- Output Voltage	3.7 - 34 V
- Power at Peak Conditions	1 W	- Max Input Current	3 A
- Open Circuit Voltage	6 V	- Max Output Power	15 W
- Short Circuit Current	190 mA	- Efficiency	90%
- Weight	30 g	- Weight	3 g
- Dimensions (LxWxH) (mm)	200 x 100 x 1	- Dimensions (LxWxH) (mm)	32 x 34 x 20

Table 1: Specification for Solar Panel and DC-DC Boost Converter Used in Prototype

The panels had positive and negative solder terminals where connections could be made. 16 gauge wire, rosin core, and the soldering iron from the NAU A.M.P.E.R.E lab were used to connect the panels. Gabriel proceeded to connect a digital multimeter to the output wires from the boost converter to perform an open circuit voltage and a short circuit current test. The boost converter utilizes a potentiometer adjustment feature to adjust the voltages. Once the connections were established, Gabriel proceeded to get some initial reads from the solar panels. Multiple reads were taken to ensure continuity during testing. The data from these reads can be shown in Table 2. The setup of the procedure can be seen in Figure 5.

		Measurement	Trial 1	Trial 2	Trial 3	Avg
Desc:	One Panel / 4 Cells	Voltage (V)	8.45	8.37	8.34	8.39
		Current (A)	0.167	0.165	0.162	0.16
		Power (W)	1.41115	1.38105	1.35108	1.38
Vpv / Ipv	6V / 160mA	Tempertaure (C)	15.5	15.5	15.5	15.50
Voc / Isc	6V / 190mA					
		Measurement	Trial 1	Trial 2	Trial 3	Avg
Desc	Two Panels / 8 Cells / 2 in Series	Voltage (V)	16.42	16.16	16.83	16.47
		Current (A)	0.105	0.13	0.188	0.14
		Power (W)	1.7241	2.1008	3.16404	2.33
Vpv / Ipv	12V / 160mA	Tempertaure (C)	15.55	15.55	15.55	15.55
Voc / Isc	12V/ 190mA					
		Measurement	Trial 1	Trial 2	Trial 3	Avg
Desc	Two Panels / 8 Cells / 2 in Parallel	Voltage (V)	7.9	8.17	8.3	8.12
		Current (A)	0.27	0.338	0.276	0.29
		Power (W)	2.133	2.76146	2.2908	2.40
Vpv / Ipv	6V / 320mA	Tempertaure (C)	15.55	15.55	15.55	15.55
Voc / Isc	6V / 380mA					

Table 2: Initial Reads from JIANG Flexible Solar Panels 1W, 6V, 160mA

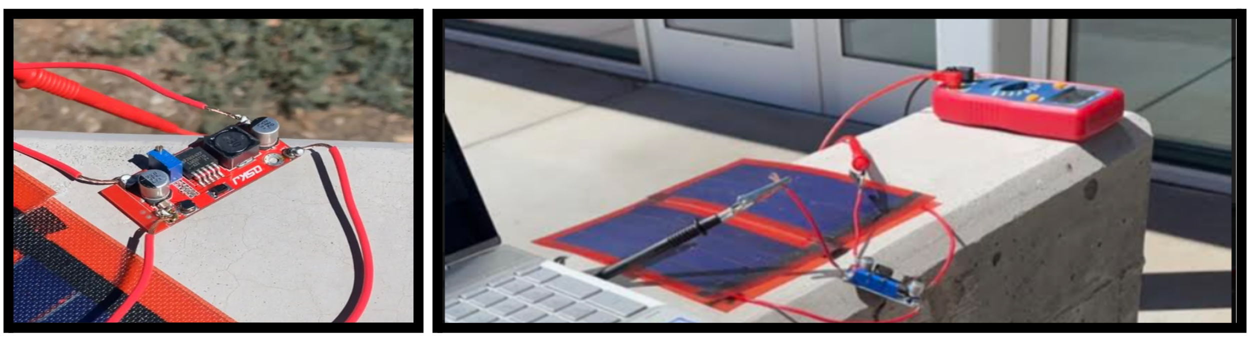

Figure 5: Gabriel's Prototype Setup

At first, Gabriel had trouble soldering on the wires smoothly. Luckily, one of the members of the ME team had some experience and was able to provide some pointers. The goal of the prototype was to produce an ideal IV and PV Curve to find a maximum power point (MPP), which is created by tracking the current's behavior over multiple voltages. The "knee" of the IV curve can be identified as the MPP. The data for the series connection came out great. In Figure 6 below, the MPP is located around **29.5 V** and **189 A** using the boost converter. The PV curve in Figure 7 corresponds with the data from the IV curve as well. The top of the PV curve is the MPP, around **29.5 V** and **5.45 W**. We expected a smoother curve from our data. This probably could have been achieved if Gabriel tracked the current by a voltage step-up of .1, rather than .5. The same procedure was executed with the parallel connection. Overall, the prototype was a success.

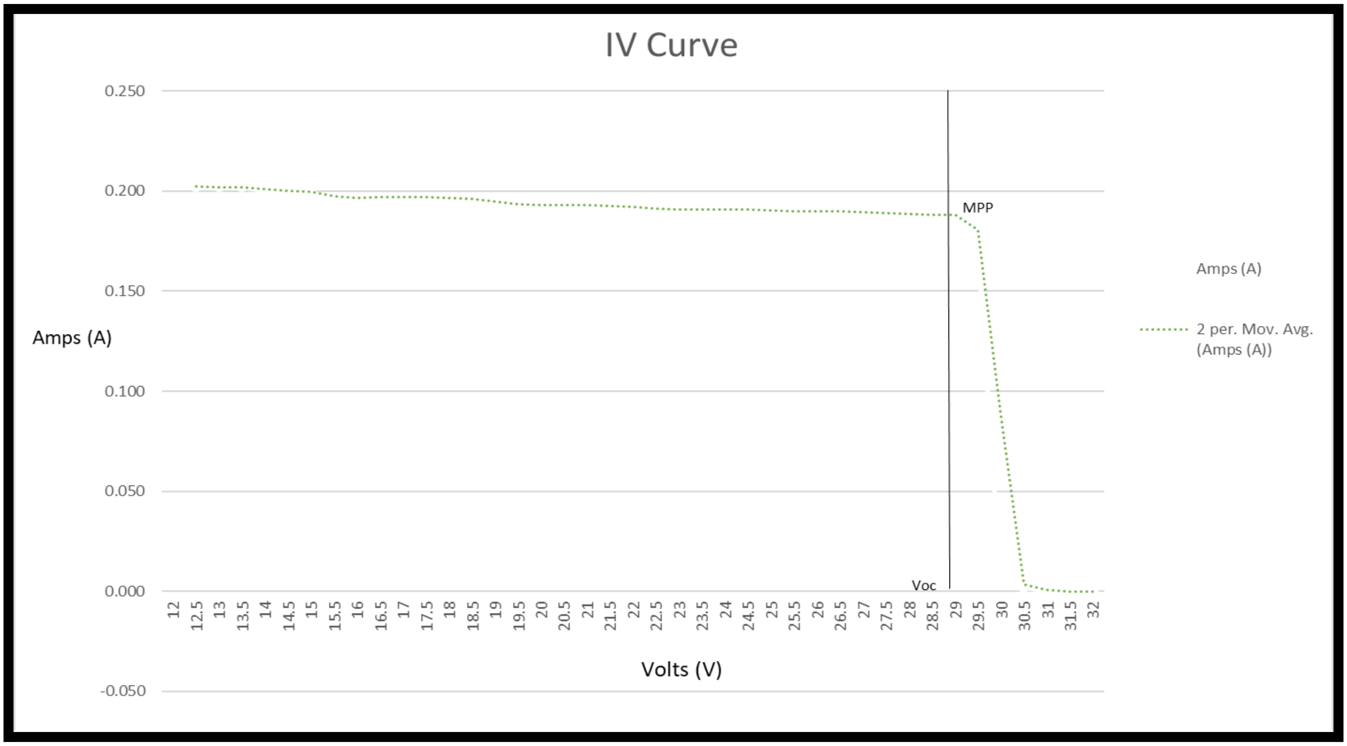

Figure 6: I-V Relationship Curve of a Series Connection with a Boost Converter

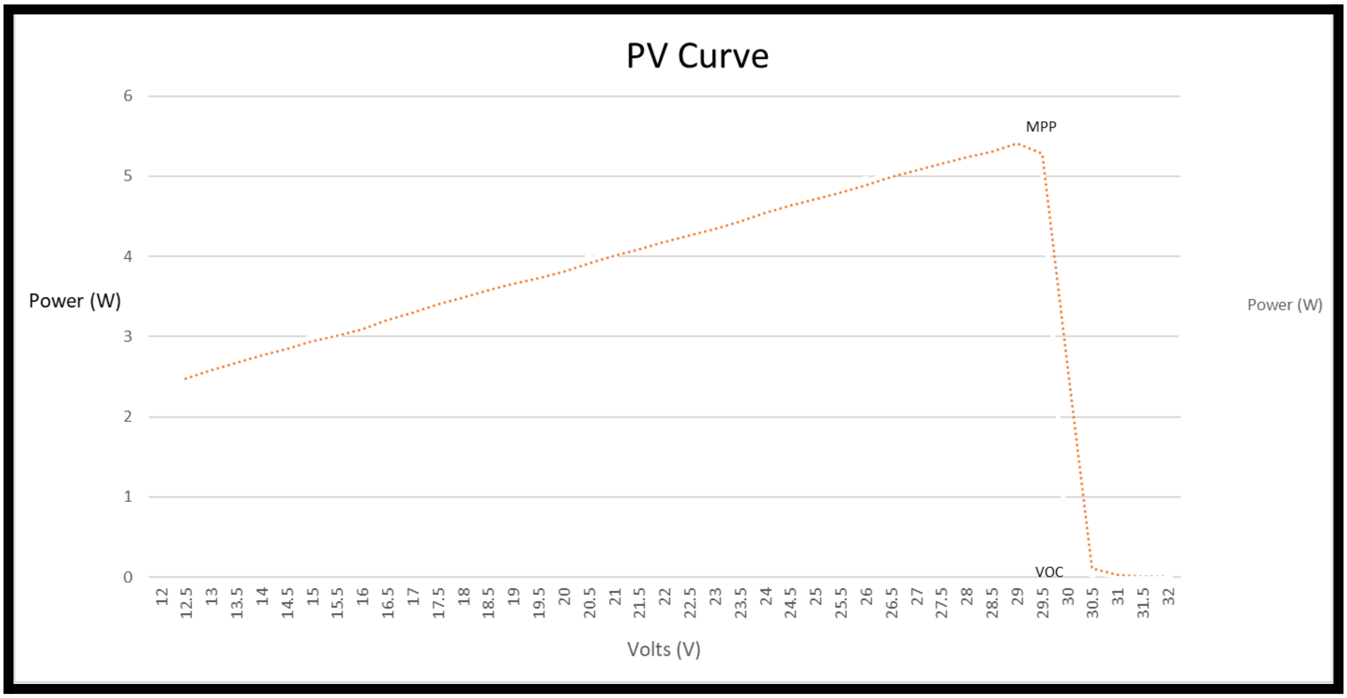

Figure 7: P-V Relationship Curve of a Series Connection with a Boost Converter

Sultan's Prototype - Charging a Battery using a Manual MPPT Charge Controller

- **Components Used**
    - LIPO Battery (11.1V, 2200mAH)
    - MPPT Solar Panel Controller Charge Module (Model: SD30CRMA)
    - [I/P DC: 7~28V & O/P DC: 1.2 ~ 18V Adjustable]
    - No. Solar Panel (Rated: 12-14V)
- **Tools:**
    - Digital Multimeter- DMM
    - Crimping Tool (i.e., Wire Stripper)
    - Alligator Clips
    - Sticky Tapes
    - Soldering Iron
    - Soldering Wire

Sultan's prototyping conducted an experiment about charging a LIPO Battery (11.1V, 2200mAH) using the MPPT controller charger module powered by Solar Panel (12V). The controller that Sultan used has a vast range of Voltages to accept and deliver at its input and output respectively. As per controller module design specification Input DC Voltage range: is 7~28V and the Output DC Voltage Range: is 1.2~18V (Adjustable: 3.6V, 4.2V, 4.35V, 8.4V, 12V, 16V & 18V Flexible) by varying the knob on a potentiometer already installed on the module as shown the Fig. 1

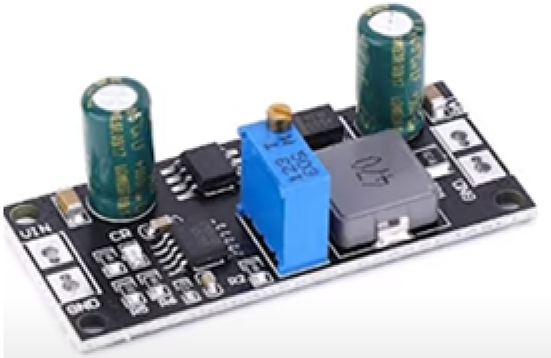

Figure 8: MPPT Solar Panel Controller Charger Module,

First of all, Sultan starts from the wiring side to connect the solar panel with the controller charger module by soldering jumper wires at respective connector points. Then to avoid any short circuit upon powering up the circuit, Sultan inspected the continuity of the whole circuit using DMM by setting its knob on the continuity point. Next, using DMM Sultan checked the functionality/working of a solar panel whether either it is providing the required range of voltages (i.e., 12V) at the input of the controller module or not depending on the Light (Lumens) directly striking the surface of the solar panel. In this case, when the light of the LED in the room strikes the solar panel surface it was providing a few mV at the input of the controller module. Since the light is dispersing in the room, therefore, to make LED Light efficient and effective Sultan brought the solar panel surfaces as close as possible to the led panel in order to accumulate the whole light directly on the solar panel surface. Surprisingly it worked and the solar panel was then producing almost 12V to 13.1V.

Since the input DC Voltage requirement was completed, Then Sultan calibrated the controller module by adjusting the potentiometer to get the desired DC Voltage at the controller charger output to charge the LIPO battery. Therefore, Sultan adjusted the potentiometer by rotating the screw at its top using a screwdriver such that we have got 12V at the output of the solar panel controller charger (*Note: Sultan measures Readings using a Digital Multimeter*).

After all the preparation (i.e., settings & calibrations) and cross-examination of the circuit now, Sultan is ready to charge his LIPO battery at its optimum level. Thus, Sultan placed the solar panel on the room window face towards the outside to use the direct sunlight as needed. At first in the morning around *07:00 AM* the solar panel was just providing a few mV but with the passage of time as the sun rises the voltages of the solar panel increased and, in the noon, *12:30 PM* solar panel voltages reached the optimum level, thus leaving the setup there for few hours so that the battery got fully charged. Almost at *02:00 PM* again checked his LIPO battery voltages using DMM, and the results were quite fruitful as the battery voltages shown recorded on the DMM were *11.3V~12V. See the circuit diagram in Figure 9.*

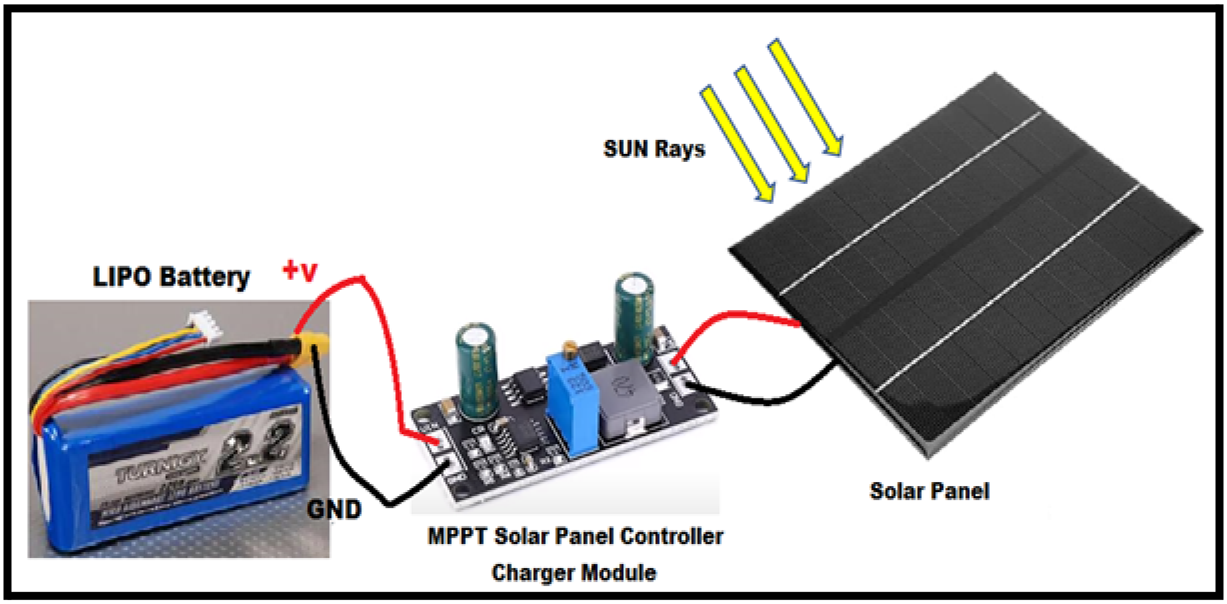

Figure 9: Sultan’s Prototype

Design

System Architecture

When defining the system architecture, it is important to learn what your roles and responsibilities are within the project. This is a multidisciplinary project, meaning that it will take the skill sets encompassed by multiple majors to successfully execute the project's demands. Although having knowledge of the whole project to an extent is necessary, it is critical to focus mainly on what you are held accountable for. Our team is responsible for adequately charging the battery based on the motor's power consumption rate from the battery. To simplify, our team is responsible for configuring a solar array to produce a determined amount of power, as well as regulating the charge to the battery using a DC to DC charge controller. We are not responsible for constructing and flying the UAV in any form, with the exception of a consult concerning the surface area of the UAV.

An array of solar panels can be made to deliver a precise range of power. This configuration is based on the type of solar panels used, the surface area, and the weight requirements of the UAV. The power output of the panel is also dependent on a trust factor. The thrust factor can be gauged as a percentage of power the motor is running on. The motor's thrust factor will be relatively high to get the plane off of the ground. When it starts to glide in the air, the thrust factor will decrease significantly to simply keep the plane airborne. This directly determines how much power is being drawn from the battery, which our team will correspondingly provide to keep the battery charged.

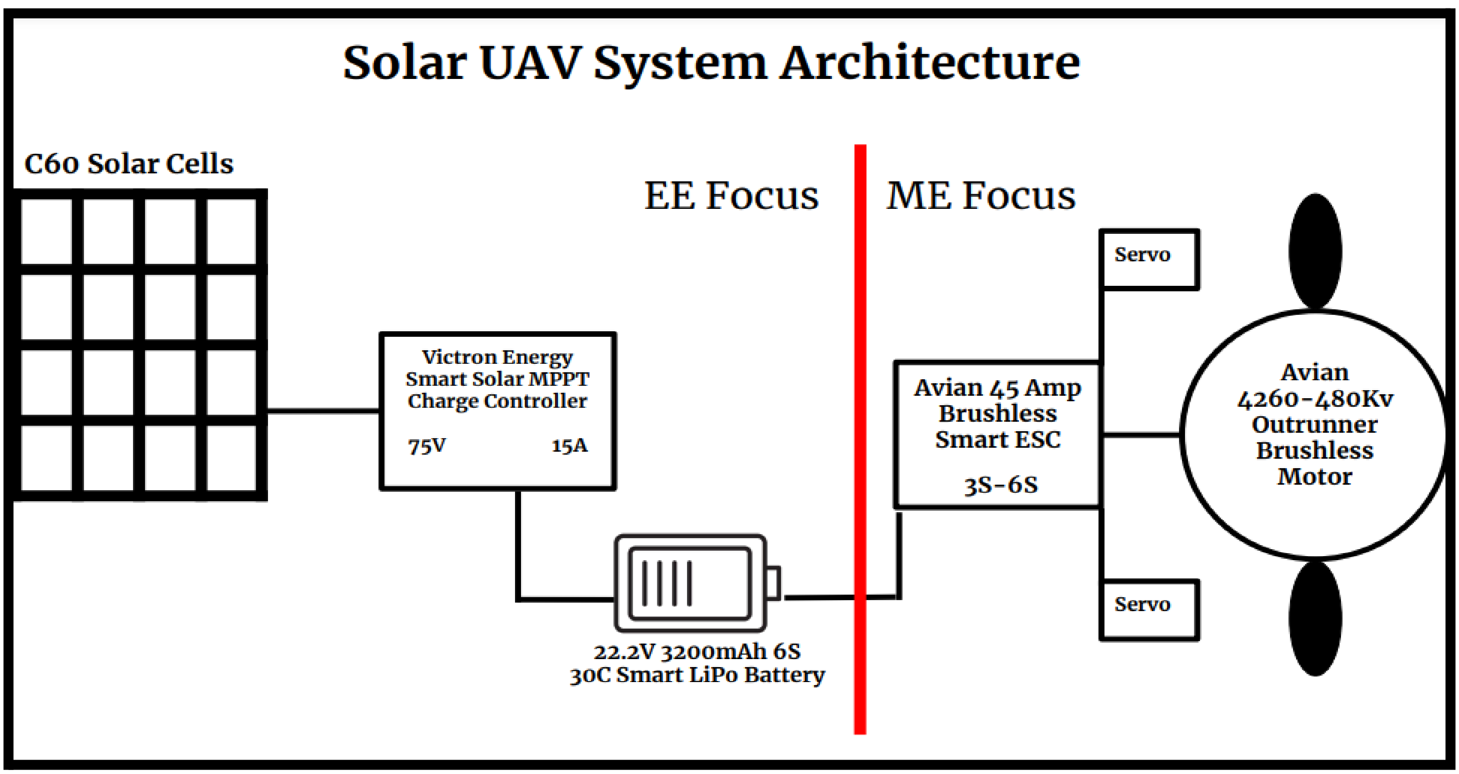

Figure 10: System Architecture of the Solar Powered Unmanned Aerial Vehicle (UAV)

Functional Decomposition

1) Load Specification

When building a PV system of any sort, it is important to understand everything about what you are trying to power. As mentioned before, traditional UAVs are usually run by a lithium-ion or a lithium-polymer (Li-Po) battery. Our goal is to recharge the battery while the UAV is airborne to increase its capacity. As a result, we want to provide as much detail about the charge and discharge relationship of the battery to the motor system. The Avian 4260-480 Kv Outrunner Brushless Motor was chosen for the UAV by the Solv Avem ME team. The main factor in their motor choice was its ability to support our total estimated weight of the plane: **9lbs**. A DC brushless motor is considered lightweight, compared to a conventional brush motor but can produce the same power output. The permanent magnets on the rotor allow the stator coil to energize, and the opposite poles of the rotor and stator become attracted to each other. Once the poles get close, the next coil becomes energized and the process continues to allow a constant rotation at the mercy of the DC power that is given [6]. A sensor on the motor will provide feedback to the speed control. This motor will run without wearing down over a period of time, for as long as it's provided power. Below are its specifications in Table 3, a brushless motor's anatomy in Figure 10, and a picture of the motor chosen are shown in Figure 12.

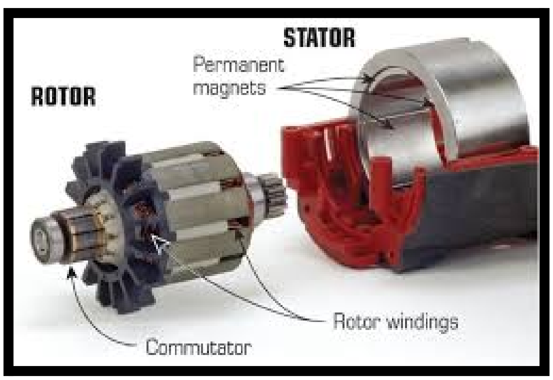

Figure 11: Anatomy of a Brushless Motor

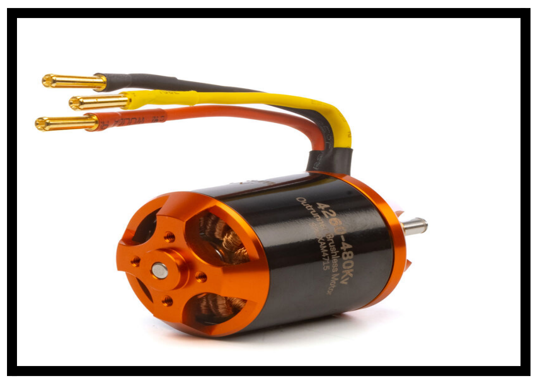

Figure 12: 4260-480Kv Brushless Motor

<u>**Avian 4260-480Kv Brushless Motor**</u>	
- Voltage Input Range	18.5-22.2V (5-6S LiPo)
- Propeller Range	13x10 to 15x8 Electric
- Max Cont. Power / Current	810 W / 36.5 A
- Max Burst. Power / Current	1350 W / 60.8 A
- RPM/Volt	480 Kv
- Weight	268 g
- Connector	4mm Bullet

Table 3: Brushless Motor Specifications

The brushless motor has three connection ports to an electronic speed controller (ESC). The ESC's job is to control how many of the motor's coils are energized, which determines the overall speed of the motor. This is where a thrust factor can be gauged. The ESC voltage and frequency control will determine the rotations per minute (RPM) of the motor. The higher your Kv rating is on the motor, the higher RPM you can correspondingly achieve. The thrust factor will be a measurement outlining how much power is used of the battery, so we can size the power and amperage we deliver from our solar panels. Our ESC is equipped to handle the two supporting servos on the wings of the plane. The ESC will also be connected to a receiver, so that a transmitter (remote control) may control the motor speed and corresponding thrust factor from the ground. This whole configuration will be referred to as the motor system. See Figure 13 below for a schematic of the motor system.

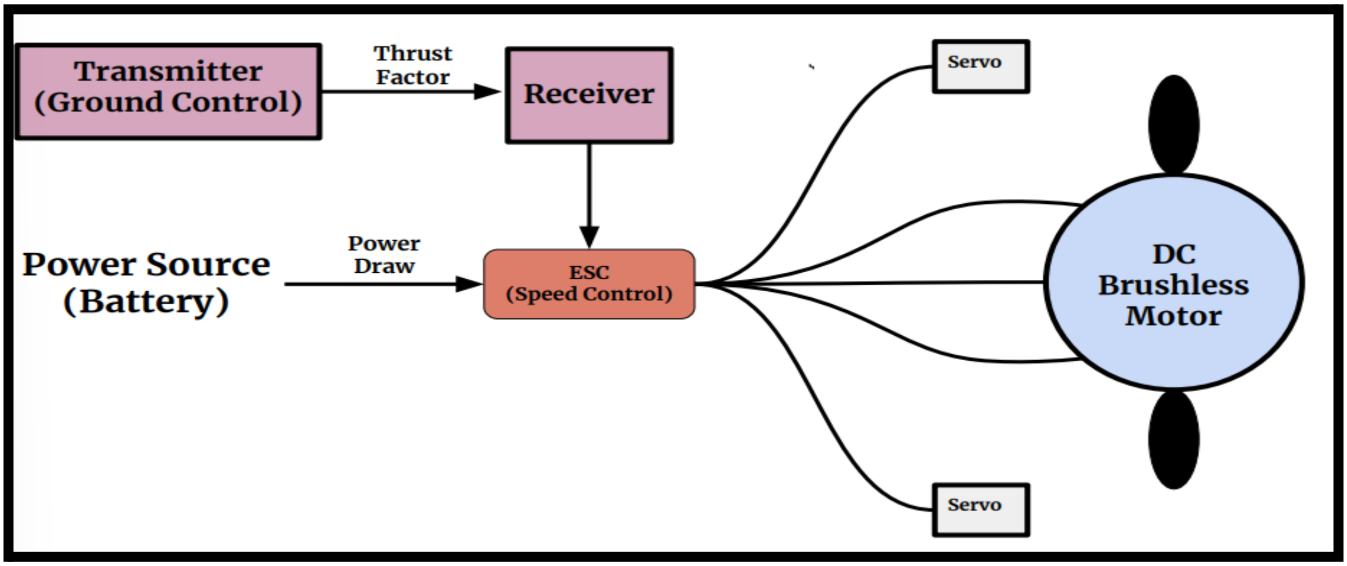

Figure 13: Setup of Motor System

The ESC and the DC Brushless Motor are matched. The continuous amperage required to run the motor is **36.5 A**, which our **45 A** ESC will be able to provide. The **3.2Ah** battery will provide power to the ESC for a certain duration of time The specifications for the ESC are listed below in Table 4.

Avian 45 Amp Brushless Smart ESC	
- Voltage Input Range	11.1-22.2V (3-6S LiPo)
- Max Cont./ Burst Current	45 A / 60A
- Weight	50 g
- Dimensions (LxWxH) (mm)	62 x 38 x 13
- Key Features	Programmable, BEC, Auto Cut Off

Table 4: Electronic Speed Control Specifications

2) PV Array

The solar panels used for this project will be C60 monocrystalline cells. As mentioned before, these cells are commonly used for solar-powered UAVs because of their weight of 7 **grams** each and their ease to connect to one another. These cells are commonly placed in series because of the high amperage a single cell carries. A schematic of each cell can be seen below in Figure 14 and the C60 cell's specifications can be seen in Table 6.

C60 Monocrystalline Silicon Solar Cell	
- Pmpp at STC	3.4 W
- Vmpp at STC	.582 V
- Impp at STC	5.93 A
- Voc at STC	.687 V
- Isc at STC	6.28 A
- Efficiency	22.5 %
- Dimensions (LxWxH) (mm)	125 x 125 x 1.65
- Weight	7 g

Table 6: C60 Solar Cell Specifications

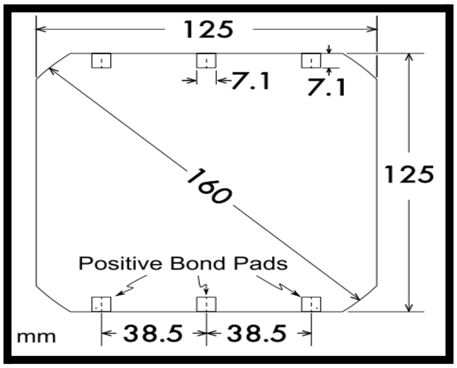

Figure 14: Schematic of Solar Cell

We created a decision matrix to help solidify our choice-making of the C60 solar cell. The weight served as a determining factor. The next problem was figuring out how to produce an adequate amount of solar power to charge the Li-Po battery. Our PV sizing depends on the motor's thrust factor (X_T) and its relationship with the battery's capacity. A new battery capacity is used to consider a 10% loss factor: **2.88Ah**. Thrust is a factor of motor speed, and we will rate it as a percent value from 0% to 100%.

- X_T(Initial) = **75%** **Thrust estimated to lift UAV off-ground (30-45 sec)**
- X_T(New) = **30%** **Cont. thrust estimated to maintain flight**

Practically, we can use both thrust factors to get a range of PV output by taking the power of the motor and multiplying it by the thrust factor. Then we can divide that by the battery's nominal voltage of **22.2V** to get the current draw by the ESC. Taking the battery's capacity, and dividing it by the current will give us an estimate of flight time. We calculated flight time for both thrust factors, which resulted in 9 ½ and 23 ½ minutes. We want to add 50% more capacity to the battery during the flight:

- 2.88 Ah / 2 = 1.44 Ah more capacity within 9 ½ and 23 ½ minutes.
  - 1.44 Ah / 9.45 min = **9.14 A**
  - 1.44 Ah / 23.55 min = **3.67 A**

Our power output range can now be calculated using the currents above:

- P_{max} = I * V = (9.14) (22.2) = **202.9 W**
- P_{min} = I * V = (3.67) (22.2) = **81.5 W**

Our solar output should be in the range of **80 and 200 W.** To narrow down our output, we can take another approach. Generally, a PV output should be 20% higher than the battery's voltage. The minimum current we should output is **3.64 A.** Power output can now be calculated, and we can check if it fits within the range of 80 and 200W.

- 22.2 * 1.2 = 26.64 V
    - 26.64 V * 3.64 A = **96.96 W** (minimum power from solar)

We can take 96.96 W as our goal. The next issue is configuring the solar panels to get as close to this power output as possible. The surface area of the UAV is curved, so our placement must be particular. The best setup we could build off of the surface area we were given is a configuration of **22** C60 panels spread across the plane, connected in series. The connections are made with **3840 mm** of 14 gauge wire, **7** dogbone connectors, and **1** DC bus connector. The cumulative weight of the panels is **.33 lbs / 154 g**. The total weight of the wire, dogbone, and bus connectors is estimated to be **.23 lbs / 104.7 g.** The total weight of the solder used will be under **4g**. These weights fit well within our weight requirement, and the panel's dimensions also fit within our surface area requirement. A schematic of this setup can be seen in Figure 15**.** The expected output of our PV array can be seen in Table 7.

PV Array for Solar UAV	
- Ppv	75.9 W
- Vpv	12.8 V
- Ipv	5.93 A
- Voc	.687 V
- Isc	15.1 A
- # of cells	22
- Weight	g

Table 7: PV Array Specifications

Before they are mounted on the UAV, we would like to perform an open circuit voltage and a short circuit current test, like the one Gabriel did in his prototype. This will show us that all connections are correct and that our solar panels will provide power. Once we know its output, the charge controller will be able to take its current from our PV array and distribute it accordingly to the cells of the battery. The output wire leads will go inside the fuselage, where the charge controller and battery will be kept.

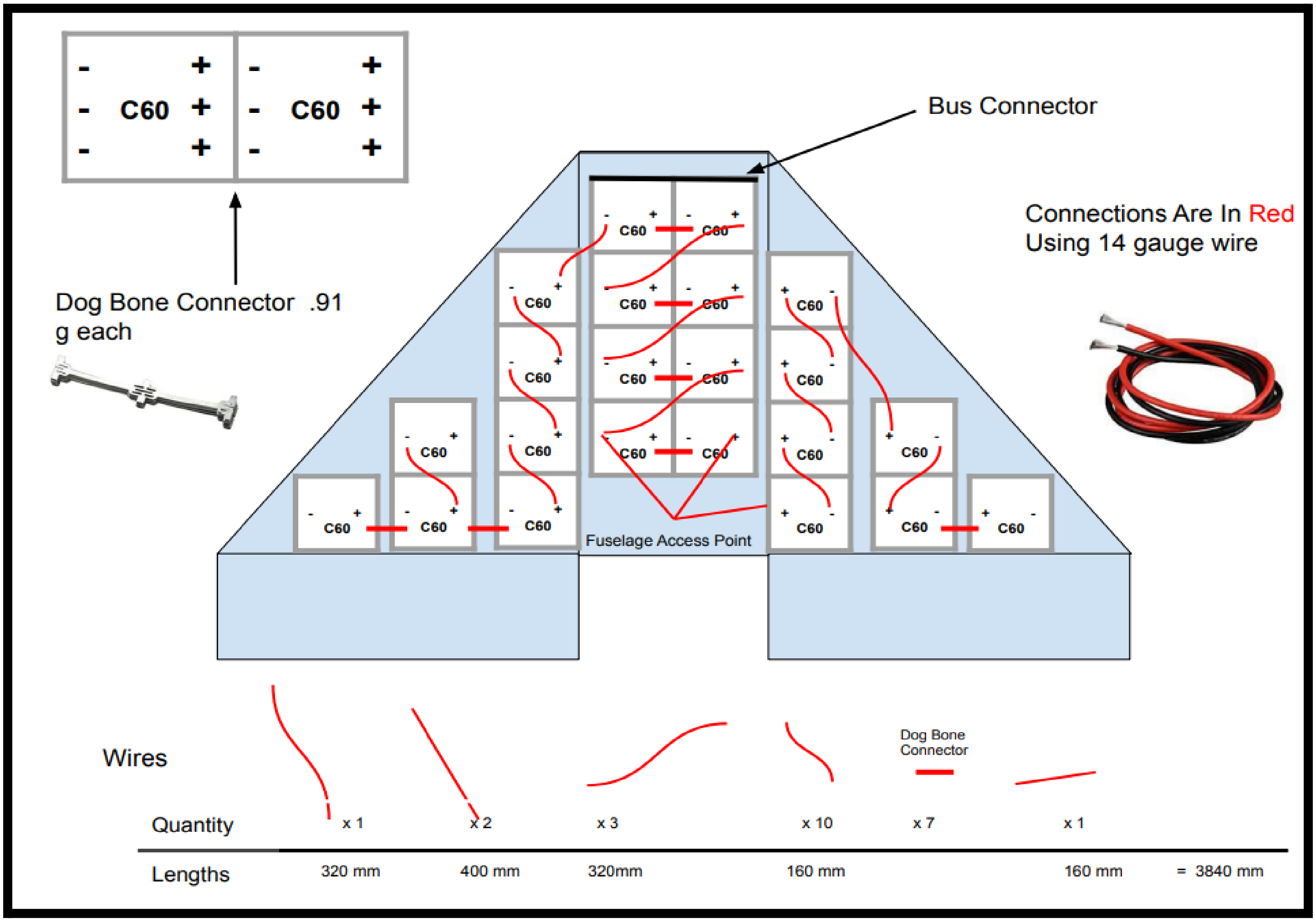

Figure 15: Schematic of Solar Panels on UAV

With any solar cell, there will be positive and negative terminals (See Figure 14). As you can see in Figure 13, each connection is from a positive to a negative pad (or visa-versa). This is how you achieve a series connection. The connection allows the voltage to increase throughout the system, while the current remains the same. This is why the voltage of our configuration is over 20 times the value of the initial Vmpp, and the current is still the same. C60 cells are commonly placed in series for small-scale UAVs, given that most fly off of less than 10 Amps, but may need to output a certain voltage. If necessary, a parallel or same-terminal connection will allow the current to increase, while the voltage remains the same [2].

3) Charge Controller

We are using a Victron Energy Smart Mppt Charge Controller, a charge regulator that controls the progression of the Electricity from the Solar System or PV framework. A charge regulator or battery controller or can say charge controller restricts the rate at which current is added or removed from the batteries to safeguard the framework from over-burdening, cheating, or now and again might be overvoltage. The charge regulator is one of the fundamental pieces of the PV framework. PV charge regulator deals with the ongoing coming from sunlight-based exhibits or PV plates. It ensures that PV plates don't overcharge profound cycle batteries during the day so that power doesn't stream in reverse to PV plates and channel out during the evening.

Function

Charge regulator for the most part comprises 4 stages in it. Charge regulators' four stages are over-burden, undercharge low battery, and profound release conditions. Out from the sunlight-based charger is associated with the switch and at the charge regulator out is taken care for the battery to charge it. Furthermore, the setting on it goes toward the heap switch and which goes toward the heap. A Charge regulator's prime capacity is to control over-burdening conditions, overcome undercharge and low battery conditions and forestall profound release conditions`

How a charge controller works

A charge regulator screens in-stream and out the progression of power and manages it, this is the principal reason for which the charge regulators are utilized. A PV charge regulator controls the current and voltage. It recognizes and screens or has checks and equilibrium over battery voltage. It decreases the ongoing stream to the battery when the battery is completely charged. The PV regulator keeps up with the float charge to keep the battery in the condition where it is prepared to utilize. Without a charge regulator if PV plates are straightforwardly joined to the battery it might charge the battery and not stop the harm. To forestall any kind of harm to the gear we use a Charge regulator. It has 3 associations fundamentally on normally used charge regulators. One is input, one is the result and one is the setting. At input, the result of PV plates is given which is considered as a contribution to the charge regulator. Yield is associated with the battery which will resultantly charge the battery and direct it and assuming the battery is full it will diminish the inflow of the current to forestall any hardware harm. The setting is used to set the charge regulator on various settings.

MPPT of charge controllers

This type of charge regulator is for the most part used in the PV framework to check equilibrium over the inflow of power toward batteries and forestall the surge toward PV plates. The fundamental center is to further develop execution and increment charging productivity. MPPT represents the greatest PowerPoint and is extremely cutting-edge than PWM charge regulators. It works at the most extreme PowerPoint and to be more exact and ideal voltage for the greatest power yield. MPPT charge regulators can be 30% more proficient than customary charge regulators relying upon the battery voltage and working voltage of the PV board. A greatest power point tracker, or MPPT, is essentially an effective DC to DC converter used to augment the power result of a nearby planet group. The picture underneath makes sense of the greatest point tracker all the more obviously and shows how the MPPT charge regulator functions.[7]

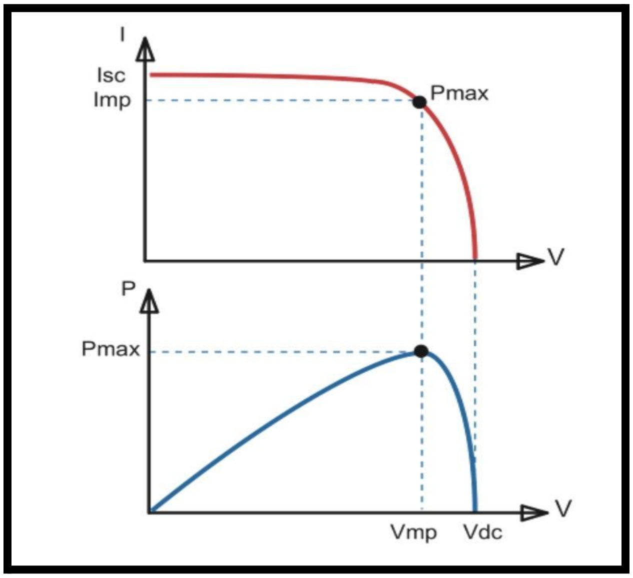

Figure 16: IV & PV Curve at MPPT

Figure 17: MPPT Smart Charge Controller

Victron MPPT 75V / 15A Charge Controller	
- Battery Voltage	12V/24V Auto Select
- Rated Charging Current	15A
- Maximum PV Short Circuit Current	15A
- Maximum PV Open Circuit Voltage	75V
- Nominal PV Power (12V / 24V System)	220W / 440W
- Maximum Efficiency	98%
- Self-Consumption	10mA
- Charging Voltage (Absorption)	14.4V / 28.8V (adjustable
- Charging Voltage (Float)	13.8V / 27.6V (adjustable)
- Terminal Connection Size	10AWG (6mm²)
- Dimensions (L x W x H)	113 x 100 x 40
- Weight	1.1 lbs

Table 8: Specifications for Victron MPPT 75V / 15A Charge Controller

So, we have to satisfy the following relation: *Voc of ch arge controller* > *Voc of PV arra*y. In order to select the PV charge controller. In the market, it is available in terms Of Amperes so you need to find how much ampere charge controller is required which is given by.

- Controller Current = P max / Voltage

Connection

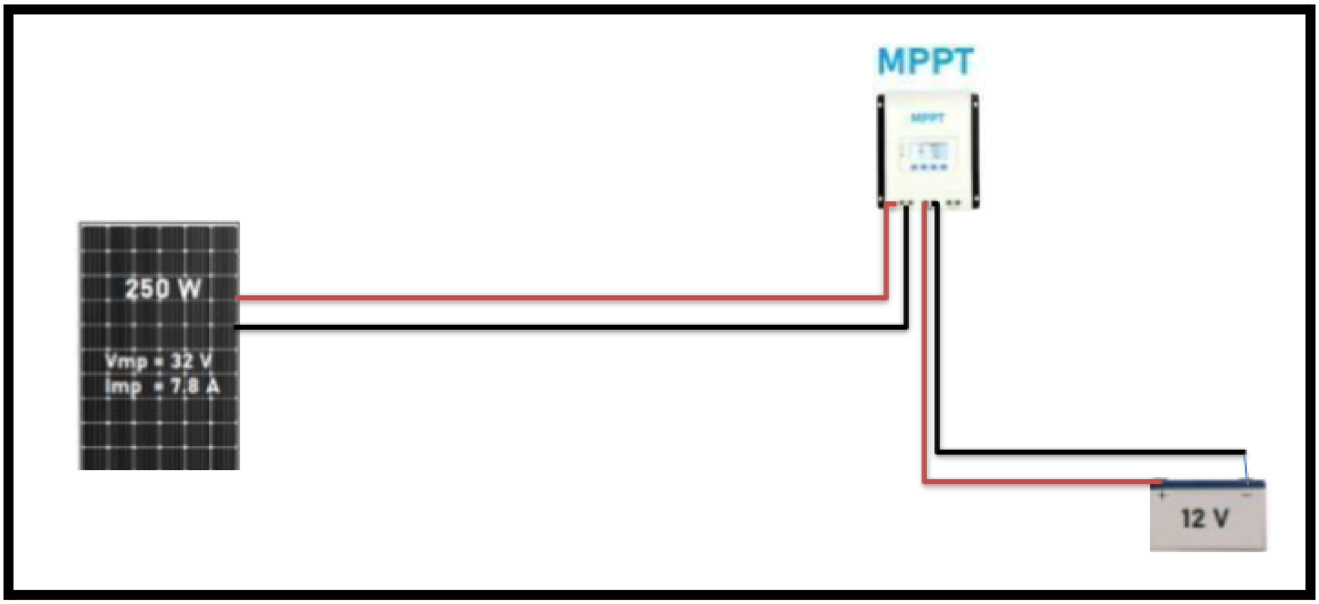

Figure 18: Connection Inputs and Outputs of an MPPT Charge Controller

Wiring grouping: to begin with interfacing the battery to the charge controller, set the working mode of the load via MPPT solar charge controller, then connect it to the solar panel.

4) Battery

A lithium-ion polymer battery or more accurately lithium-polymer battery also known as Li-Po, LIP , Li-poly, or Lithium Poly. It is a rechargeable battery of lithium-ion technology. It uses polymer electrolytes and does not use liquid electrolytes like other batteries. It is a High conductivity gel(semisolid) polymer from the electrolyte. Li-Po batteries do not have expiry dates but with time performance is reduced because of excessive use or passed time to 18 months. Li-Po batteries are suitable for robust and high-power use. Li-Po batteries work on the principle of de-intercalation and intercalation of lithium ions from a positive electrode material and a negative electrode material. Polymer semisolid (gel) works as an electrolyte which is the conducting medium here in these types of batteries. To prevent electrodes from touching each other directly, a microporous is in between them, which allows the ion, not the electrode particles to migrate from one side to the other. The voltage of a single Li-Po cell all depends on the chemistry of these batteries. It varies from fully charged (4.2V) to fully discharged (2.7-3 V) where the normal voltage is between 3.6 to 3.7V. The exact Voltage rating and other specifications can be sin or specified on the datasheets. Li-Po battery cells should be protected by an electronic circuit in order to prevent them from overcharging or over-discharge.[8]

22.2V 3200mAh 6S 30C Smart LiPo Battery	
- Capacity	3200 Ah
- Battery Voltage	22.2V
- Maximum Continuous Discharge Rate	30C
- Number of Cells	6
- Battery Type	LiPo (3.7V per cell)
- Connector Type	IC5
- Dimensions (L x W x H) (mm)	142 x 42 x 38
- Weight	484g

Table 9: Specifications for 22.2V 3200mAh Smart LiPo Battery

Figure 19: Li-Po BatteryVA

C-rate may be a degree of the normalization of the release current of a battery against its greatest capacity. One C rate implies that the release current will discharge 12 of the whole battery in 1 hour. The release current breaks even with the C-rate times the maximum capacity of the battery. The higher the C-rate, the shorter the discharge time. Generally, LIPO batteries can supply more cycles than lead-acid, making them great for delivering ancillary services to the grid. One energy-saving trait of lithium-ion, which makes it a good option for a solar system, is its high charge and discharge efficiencies.

5) Component selection and Construction

Aside from product functionality, weight might play the biggest role in our component selection. Our motor is suited to support 9lbs of weight total, so all elements of the UAV must be weighed. Between the solar array, charge controller, battery, and connection tools, we are looking to stay under 40% of the plane's total weight. **40%** of the plane's total weight is 3.6 lbs / 1633 g. The electrical components size up to just under **2.75 lbs / 1250 g**, so our weight requirement is met. The surface area of our UAV permits less space for our solar panels than we would have hoped for. The delta shape of the UAV also permits challenges. We were able to manage 22 C60 monocrystalline solar panels within the UAV's surface area. Each of the panels has an area of 125mm x 125mm. Refer to Figure 14 for details. We must ensure all onboard components can fit within the volume of the fuselage. See Figure 20 for a 2D model and dimensions of the UAV, and Figure 21 for confirmation that our charge controller and the battery will fit well within the fuselage's volume.

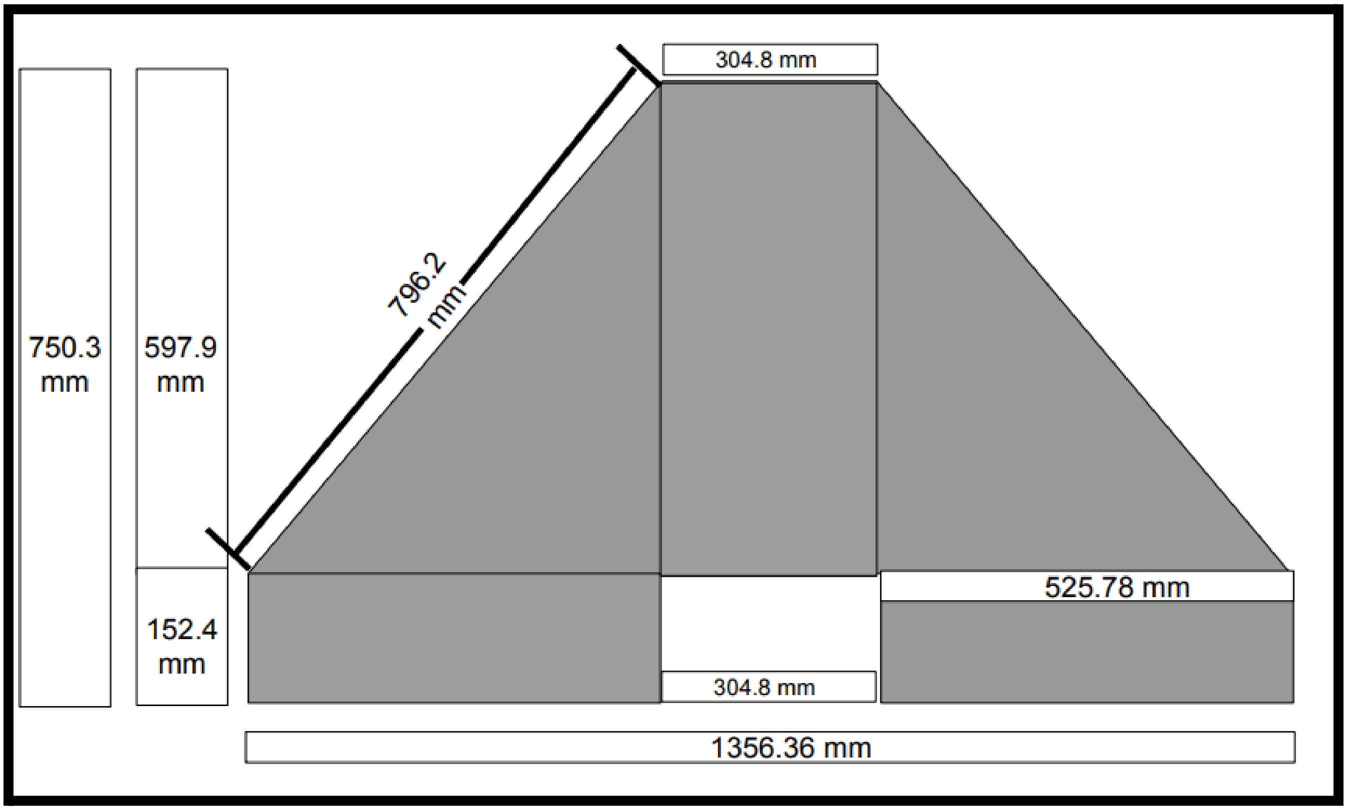

Figure 20: 2D Model of UAV

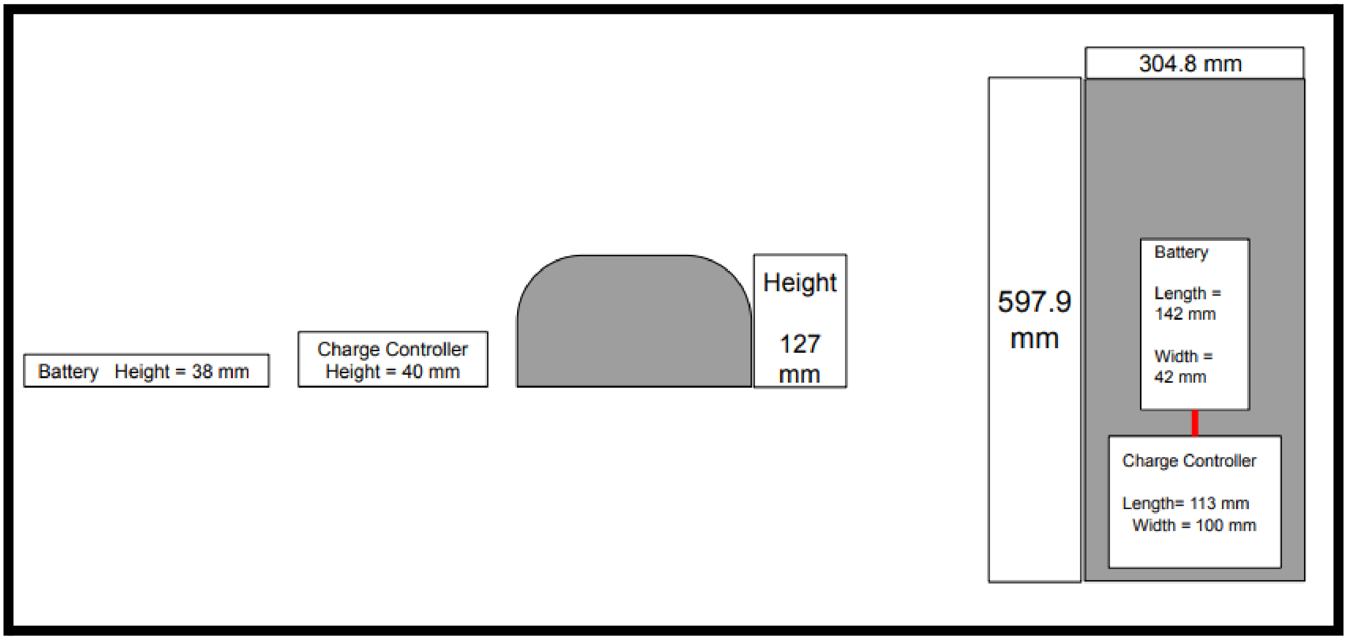

Figure 21: Volume of Fuselage

Below is a list of tools we will be using to assemble our components together.

- Soldering Tool
- Soldering Rosin
- Wire Strippers & Cutters
- Various Screw Drivers
- Hobby Knife & Utility Knife
- Digital Multimeter
- Super Glue
- 14 and 16 gauge wires
- Dogbone / Bus Connectors

Planning Ahead

- **Immediate next steps: Purchase materials and update website**

For our planning ahead. Firstly, In the summer we will be making a list of materials that we will purchase for our project and will get a couple of different types of each material and work with all of them to see which one gives us the best results in their efficiency for our project. Also, we will be adding them to our EE purchase table which we already have, so we don't exceed our EE team budget which is 500$, and try our best to work it within this amount. Secondly, over the summer we will be working on improving our website, which will have to make the website contain more pages and major elements. Also, we will be uploading our project documents, presentations, and meetings by organizing them in each section, then we will be adding more photos of our project that we're building

- **Flight of battery alone with the ME team**

Build Mathematical Model to Estimate Flight Time

By using this model, we'll be able to calculate the flight time of any battery. All we ought to do is to put the information of that battery within the exceeded expectations spreadsheet. So it seems to give us an unpleasant thought about what battery to go for and spares us from investing as well as much cash and time to undertake all types. First of all, will be utilizing the batteries we have and collecting information utilizing it. Fundamentally the information we require is flight times beneath distinctive loads. We will of course collect a few other information as well to assist us to distinguish what is the max stack our multi-copter can take, for case, the throttle esteem, current, etc.

- **Incorporating solar panels to perform flight**

We'll be working on how to cover most locales of the plane with solar cells, on both wings. We need to create beyond any doubt when uncovered to the rays of the sun, the photovoltaic panels change over it into electrical energy, and the amount of vitality created is decided by components just like the orientation of the panels to the sun, and the intensity of sunlight.

- **Functional demonstration**

Through Summer and next semester both EE&ME teams will be doing functional demonstrations and our job as EE is to demonstrate our part of the project and make sure that everything is working perfectly and giving us the best results before the due date of the demonstration.

- **Final design document and board presentation**

Also one of our most important plans for next semester is to start gathering all of our documents about our project and organize them for the final design document. Also, we will be preparing for our board presentation by demonstrating many times so we can meet all the requirements and make it perfect before the final presentation due date.

- **Gantt chart outline due dates**

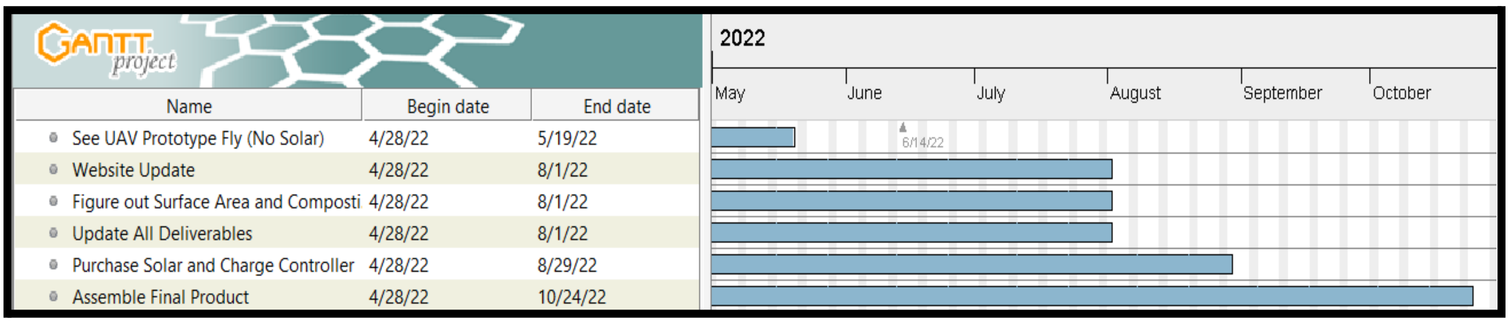

Figure 22: Gantt Chart

Conclusion

The thought behind UAV aircraft is exceptionally straightforward; the aircraft's wings are prepared with solar panels. These solar panels offer assistance in catching the sun-oriented vitality from the sun and hence offer assistance in changing over this warm vitality into electric vitality which can offer assistance in moving the framework moreover in control of gadgets and overflow can be put away in batteries. The vitality put away within the batteries can be utilized amid the night and in places where there's a shortage of sun's sun-oriented vitality. With profound investigation and examination of the aces and cons of sun-oriented fueled airplanes, it can be concluded that the vitality created by sun-based boards is distant less than the vitality created by generators and batteries and there's moreover a part of misfortune of vitality. The essential objective of adding a sun-based control framework into a UAV is to increase (duration of flight) the run by giving an additional control source amid flight. In expansion to the power system components in ordinary [17] UAVs, additional components are required. (PV) cells and Greatest Control Point Tracker (MPPT) are required for the solar control framework. The PV cells collect sun-based vitality and change over it into electric vitality; the MPPT tracks the most extreme control point of the PV cells and extricates the most extreme control Point Tracker (MPPT) required for the solar control framework. The PV cells collect sun-oriented vitality and change over it into electric vitality; the MPPT tracks the greatest control point of the PV cells and extricates the most extreme control from the PV cell.
David Willy is going to be the client of this project, the Senior Lecturer of Mechanical Designing at Northern Arizona College. Our team, the EE Solar Flyers, will be working closely with the Sol Avem mechanical engineering team to develop the solar-powered UAV. Our introductory budget to build the UAV aircraft may be an add-up of $1500.00, the part between the two groups. Our team of electrical engineers will endeavor to function inside $500.00 of that budget.

<u>Appendices</u>

- None to List

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