Final Report

TEAM SOL AVEM (T.S.A)

Mitchell Anderson
Joel Freedman
Gage King
Radley Rel
Fall 2021 – Spring 2022

Project Sponsor:

Faculty Advisor:

Sponsor Mentor: [Note: if any of these categories are the same person, delete the repeats]

Instructor:

DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

EXECUTIVE SUMMARY

[Provide a one-page summary of your project, including description, design, and results.]

It is the year 2022 and we are killing our planet. There needs to be a global shift towards renewable energy. This shift will affect every sector of innovation, including aerospace. Our team, Team Sol Avem was awarded to work on the Solar Powered Unmanned Aerial Vehicle for our senior capstone. This project is on the leading edge in integrating renewables with aerospace. The goal for our project is to be able to make sustained flight through the integration of solar voltaic panels in hopes to create a more sustainable aircraft. Our team along with the help of many faculty and industry advisors have incapsulate an in-depth report of the knowledge and our design within the specified constraints.

This report will begin with the background of this project and the importance of the overall scope of the solar powered aircraft. The background will include the major constraints and objectives Team Sol Avem must accomplish during the development of the aircraft. It will also include a listing of funding, advisors, clients, and mentors contributing to the project. Also, the background will include the original system created by Ultra-Light Solar Aircraft and Team Solis Fur. The report will include a brief description of how these teams approached the design of a solar powered aircraft and what components contributed to our design. After the background, the project description will be displayed in detail according to the customer and engineering requirements created by Team Sol Avem with the help from the main client, department of mechanical engineering. The customer needs include powered flight, affordability, and solar integration, payload capacity, and simplicity. The engineering needs include cost, thrust, aircraft mass, coefficient of lift, flight time, repairable/reusable, wing load, operating radius, solar energy harvest, cargo capacity, and safety. All these needs stem from an iterative design process of Sol Avem.

From there, the functional decomposition of Sol Avem will be described and broken down with a Black Box Model and a Work Process Diagram. The decomposition sub-assemblies include airfoil, flight control, on-board systems, solar panel selection, motor selection, and wing selection. After the functional decomposition, Standards, Codes, and Regulations are mentioned for the design of the aircraft. Most of the regulations come from the Federal Aviation Administration (FAA) which relates to the project for certain flight assembly, flight paths, and location of flight. Mentioned after the standards are the testing procedures used to determine the final design for Sol Avem and what routes the team is taking. The first test mentioned is the testing between the two concepts generated Design Test Sol Avem vs Single Wing, then airfoil test with Wind Tunnel on NACA 6412 vs Clark Y, and finally the Extended Flight Test.

The next step documented in the report is the Risk Analysis and Mitigation for the components aboard Sol Avem and how critical each one of them is. The components are listed in the bill of materials at the end of the report and described with a description for potential critical failure for those components. The potential critical failures include temperature deformation, fracture, connection interruption, impact fatigue, abrasive wear, cell deformation, buckling, electric failure, center of gravity misalignment, and radio transmitter. The Risks and Trade-offs Analysis is mentioned next taking each potential failure and describe which components our team will focus on to base the design around for the best possible outcome for the final assembly. The final two sections listed are Design Description and Implementation of Sol Avem. These sections are backed up in 2-D computations for each component supported with a database and equations to support the decisions made. Prototyping is then displayed to understand how the team decided on which concept would fulfill the customer and engineering requirements the best. Ultimately the single wing design was chosen and was designated the name Sol Avem to follow the team's name. Different programs such as MATLAB and SolidWorks were used to see results of the structure analysis and solve lift to drag ratio for a stable flight. The implementation also goes into how Sol Avem will go about manufacturing the design and what materials will be used. The CAD model will also be included in the view which was used in the different programs to get information that is useful for structure design.

Our team has broken down each portion of this project including the design process, full project description, background information and research, benchmarking, concept generation, selection and

finally our projects budget.

Enjoy the report,

Team Sol Avem

ACKNOWLEDGEMENTS

[Use this page for acknowledging those who have substantially supported or assisted you, such as faculty and staff members, fellow students, sponsor mentors, sponsors, companies that donated time or supplies, etc.]

Team Sol Avem would first and foremost like to thank W.L Gore and Northern Arizona University department of Mechanical Engineering for funding this project. We would also like to acknowledge all our teams' advisors such as Dr. Carson Pete, Professor David Willy, and Kelly Gallagher, Flagstaff Flyers, and SAE Micro Team; for guiding our team through the progression of ME 476C. With the help of all our senior advisors our team has been able to successfully begin the design process with a very strong start along with great potential to create a senior project that meets all our customers' needs. We would also like to thank the Teaching Assistant Matilda Nsunyameye Koa for aiding Dr. Pete in grading our assignments and reports. With their feedback and knowledge our team can accurately complete each assignment and improve as this semester progresses. Our team would also like to acknowledge the past capstone teams Solis Fur and Ultra-Light Weight Aircraft for aiding in background research and development.

TABLE OF CONTENTS

[Use Word to delete the following Table of Contents and insert a new TOC. Include front matter (except for the cover page), body of the report, and all appendices. The Table should include three levels of headings, e.g., down to 2.3.1, as illustrated below. Front matter should be in Roman numerials.]

Contents

1 BACKGROUND

1.1 Introduction

[Use this section to introduce the reader to your project. Describe what the project is, project objectives, why it is of interest to the sponsor (project relevance), and how the project benefits the sponsor and other stakeholders, upon completion. A large emphasis in the section should be on why this project is important. What contemporary issues does this project address?]

[You may use the same text from previous Reports here provided all issues have been edited/mitigated and any changes to the project reflected in this report. If comments from the previous Reports are not addressed, this may result in a grade of zero for this section.]

Team Sol Avem is a multidisciplinary capstone team comprised of four Mechanical Engineers and two Electrical Engineers studying out of Northern Arizona University. The goal of our project is to design and fabricate a Solar Powered Unmanned Aerial Vehicle (UAV). This aerial vehicle must fly a total of one and a half times the flight time with the integration of solar power. The sponsors for this capstone project are W.L Gore and the Mechanical Engineering Department here at Northern Arizona University. They have collectively awarded our team a total of $1500 for prototyping and fabrication. These two sponsors recognize the trend towards green energy and are investing a lot of time, money, and equipment in upcoming engineers. It is in both our best interests to design an aircraft that not only meets the needs of our customers but learn the material to implement in future projects. Our team began with researching not only the field of but also referenced previous capstone and club teams. We realized that learning from their successes and failures would guide us on a better path than any pre-requisite could. This will enable our team to not only make a feasible capstone project but also gain experience in the green energy sector before transferring into industry.

If the world continues polluting the earth with carbon emissions the world will continue to deteriorate and we will begin seeing destructive occurrences more frequent, eventually impacting our everyday lives. Some of these impacts will be more extreme weather, species extinction and climate change. The United States has been investing in renewable energy since the last couple IPCC reports have been published; however, this is not enough to combat climate change. As a human race we are already past the point of full recovery now its damage control. Sadly, the leaders of the world have disregarded climate change as a cultural issue and never paid the correct amount of attention to the issue. There has never been a direct incentive to do so when the repercussions were so futuristic. But the future is here. Now. It is now time to invest in green solutions and ideas in every section including aerospace. Our capstone is so important as it is relatively untouched even though it emits a large contribution to annual CO_2 emissions and greenhouse gases. This capstone project is important as there is a huge demand for green energy in every sector of engineering. Our team is on the leading edge of renewable energy being integrated in the aerodynamic industry. When we are successful, we can share our designs and data with other teams doing similar research. As stated in our previous literature review there are multitudes of people and industries doing similar projects to us. There is a global movement to move away from fossil fuels and other pollutants and continues investment in renewable energy.

There are multiple advisors and teams that our current team have been coordinating with to create the most viable capstone project. Our advisors consist of David Willy, Dr. Carson Pete, Kelly Gallagher, Flagstaff Flyers, and SAE Micro Team. David Willy is a professor at Northern Arizona who is very well versed in most disciplines of engineering and is our primary source of information for this project. Our team has meetings bi-weekly with Professor Willy, giving updates, gathering resources, and asking questions. Our capstone class mentor is Dr. Carson Pete. Dr. Pete meets up with our team every week to get similar updates on David Willy. Dr. Pete makes sure our team is on track and assigns various assignments to expand our scope and knowledge of the project. Kelly Gallagher is our industry advisor. Ms. Gallagher is a NAU alumni and a retiary of over 35 years a Northrup Grumman. Our team meets with her bi-weekly to discuss future testing protocols and industry experience. Lastly, both the Flagstaff Flyers and SAE teams are very helpful in responding to our questions on RC design and will be providing us with an airfield for flight testing when we hit that phase in our project. Throughout the entirety of our capstone, we will be in strict contact with each of these advisors to make sure we fabricate a complete capstone project.

1.2 Project Description

[Provide the sponsor's original project description, as presented at the beginning of fall term. To credit the source, precede the description with text, such as "Following is the original project description provided by the sponsor." Set the Description in a block quote (i.e., indented from the surrounding text). If the description has been changed, provide an explanation of what has changed and why.]

[You may use the same text from previous reports here provided all issues have been edited/mitigated and any changes to the project reflected in this report. If comments from previous Reports are not addressed, this may result in a grade of zero for this section.]

According to our client, W.L Gore and NAU Engineering Department the following is the original project description. 'In the lobby of the engineering building, you will find a solar PV powered aircraft that was built by mechanical engineering students back in 2018-2019. It does not fly nor does the solar PV system work. Your project, if you choose to accept it, is to iterate on this design or even start from scratch on the design – if necessary – to make a successful aircraft. You cannot use any existing parts on the first design, but successful design choices can be maintained if you like. You may even iterate on or even borrow ideas from any of the past SAE AERO projects at NAU. There are only three requirements for this project to be considered successful: The plane must fly by week 20, it must carry an agreed upon payload that you and the client determines, and lastly It must run off solar PV power for prolonged flight (by week 30) – defined here by at least 1.5 times longer than the capacity of any onboard batteries.'

2 REQUIREMENTS

[Use this section to describe to the reader what is required from the project. Provide an introduction here (describing what this chapter contains) before leading into section 2.1]

[You may use the same text from previous memos and reports here provided all issues have been edited/mitigated and any changes to the project reflected in this report. If comments from the past assignments are not addressed, this may result in a grade of zero for this section.]

For section two of this report, we will analyze the metrics used to measure performance. We will also examine what must be achieved by the design and operation of our product. Overall, for our project to be considered a success there are only three general requirements. According to the capstone proposal provided to us by Professor Willy [1], the first and most crucial requirement is that our plane sustains self-powered flight. The second is that the plane must carry an agreed upon payload. The final requirement is that the aircraft uses a PV cell(s) to prolong the original flight time by 50%. This means that if our aircraft has a runtime of two minutes off the batteries alone, the plane with the solar cells engaged should fly for 3 minutes. It should also be mentioned that this project is provided with a $1,500 budget sponsored by GORE [1].

2.1 Customer Requirements (CRs)

[List and discuss all Customer Requirements and weightings. Customer Requirements must fully incorporate all the project requirements provided by the sponsor. Additionally, the Customer Requirements should fully specify and clarify the overall project objectives. The discussion of each CR should elaborate on how they meet the project objectives.]

[You may use the same text from previous assignments here provided all issues have been edited/mitigated and any changes to the project reflected in this report. Clearly state what changes have been made, if any. If comments from previous assignments are not addressed, this may result in a grade of zero for this section.]

For our team to produce a functional product, it must meet the needs of our customers. These needs primarily include the 3 previously mentioned requirements of powered flight, payload capacity, and solar integration. Two more customer needs were derived from the 3 general requirements which include affordability and simplicity to bring the total customer needs to 5. We felt these qualified as CN’s because the customer only wants the product if it stays within the determined budget, and the product must be simple enough to operate with minimal training to increase the usability of the aircraft. Table 1 displays the full list of customer requirements listed in order from most important to least. These customer requirements have not changed since the first day and clearly define what a successful project will accomplish.

Table 1:RANKING OF CUSTOMER NEEDS

Customer Need	**Ranking of Importance**
Powered Flight	1
Affordability	2
Solar Integration	3
Payload Capacity	4
Simplicity	5

2.2 Engineering Requirements (ERs)

[Use this section to list and discuss the Engineering Requirements that have been developed. ER's must be verifiable, that is, specify objectively measurable parameters or conditions. **Each ER must have a target, or design-to, value with tolerance along with justification/rationale for the selected value and tolerance. Every project must include ERs relating to Reliability and Durability.**]

[You may use the same text from previous assignments here provided all issues have been edited/mitigated and any changes to the project reflected in this report. Clearly state what changes have been made, if any. If comments from previous assignments are not addressed, this may result in a grade of zero for this section.]

Using the customer needs as a baseline, our team evaluated them under an "engineering lens" to compile a list of Engineering Requirements that must be met to achieve the customer requirements discussed in the previous section. These technical requirements must be specific metrics with defined values of success. For example, one of the technical requirements derived from the customer need of powered flight is that of producing thrust. Based on our rough calculations, we will need at least 0.277 lbf of thrust produced by the motor to achieve powered flight. Table 2 will provide a ranked breakdown of the engineering requirements and the target goal of each one.

Table 2:ENGINEERING REQUIREMENTS

	Engineering Requirements	**Target Value (units)**
1	Cost	2,400 ($)
2	Thrust	0.277 (lbf)
3	Aircraft Mass	5.00 (lb.)
4	Coefficient of Lift	0.6 (unitless)
5	Flight Time	2.5 up to 5 (minutes)
6	Repairable and Reusable	1 (manhours)
7	Wing Load	22 (lb.)
8	Operating Radius	1.5 (km)
9	Solar Energy Harvest	142.1 (W/m^2)
10	Cargo Capacity	0.1 (m^3)
11	Safety	1.2 (N)

The 11 ER's that team Sol Avem developed all have defined scales on which to measure performance. Things like a factor of safety, cost, and a space for carrying cargo come directly from customer needs of the project description. The sixth ER of being repairable and reusable is another ER taken almost directly from the customer's need of a robust and durable design. Based on our scale we will measure this by the amount of time it takes working on the aircraft in-between flights. Our goal is to have an easily repairable design that takes at maximum an hour for one person working on the plane after a flight or broken part to get it flying again.

At the current stage of this project do have specific and attainable goals, but they are purely hypothetical based on customer needs and the research conducted to this point. These technical requirements will help the team in the next phase of the project which is prototyping. If we have a prototype that meets all 11 technical requirements it will be a fantastic start. We can use that model to conduct testing and then develop even more engineering requirements with more specific goals of performance. We will use these 11 ERs for our first prototype, however moving forward into the testing phase our team anticipates adding engineering requirements pertaining to take off distance, stalling velocity, turning radius, max velocity, and rate of climb.

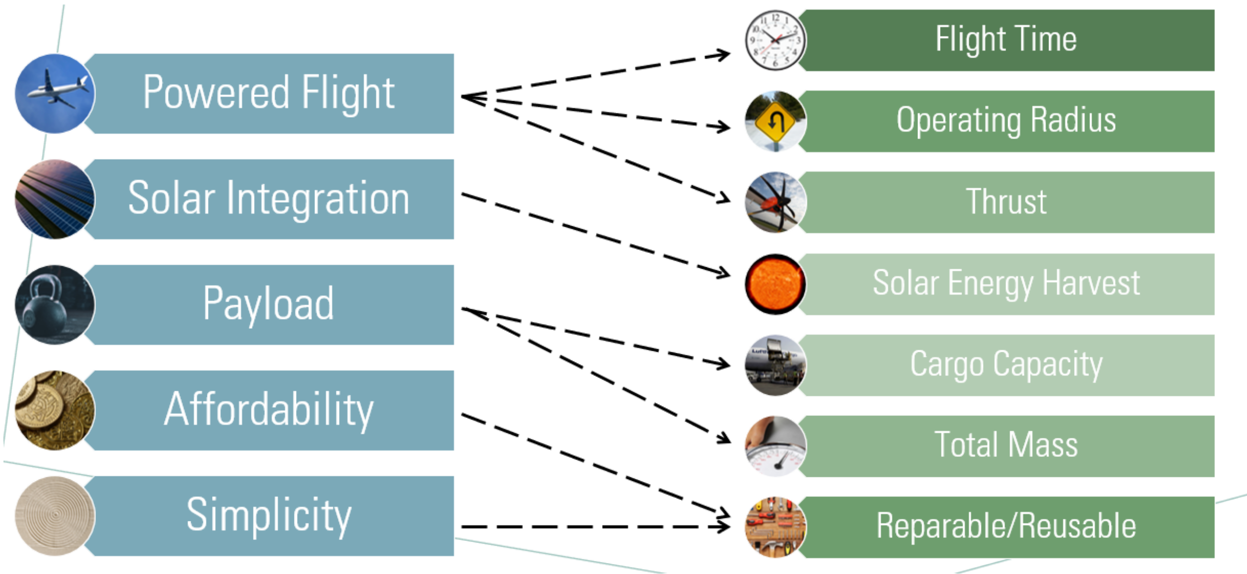


Figure 1: Customer Needs Relationship with Engineering Requirements

2.3 Functional Decomposition

[Use this section to update and describe a functional decomposition or system/process hierarchy of your system. Use this space to describe the main functions of the projects and elaborate on your functional decomposition process. Describe your functional decomposition in this section, including (at minimum): a Black Box Model and a Functional Model, Work-Process Diagram, or Hierarchical Task Analysis.]

[This Functional Decomposition should be updated based on progress in the project and reflect a more detailed plan regarding how the project problem was solved functionally. Clearly state what changes have been made.]

The Functional Decomposition model focuses on the major sub-functions of the Solar UAV design. That is to fully understand the scope of the aircraft design, six major sub-functions were created. The sub-functions include Airfoil, Flight Control, On-Board Systems, Solar Panel Selection, Motor Selection, and Wing Selection. After the sub-functions were identified, the functions were described in more detail. The Airfoil function focused on the lift and drag of the aircraft. Airfoil is an important reason to how the aircraft will perform in flight. It determines the most efficient way of how pressure is distributed around the wings of the aircraft. The next sub-function is flight control. Flight Control deals with different combinations of ailerons, rutters, and servo control. These allow the aircraft to roll, sway, and have different pitches for increase/decrease in elevation. The following sub-function is the on-board systems. This includes the type of battery powering the propeller, GPS to have direction awareness, and a receiver for controller connection. The Solar panel selection is another sub-function that includes the efficiency of energy generation ultimately powering the battery after a certain time to maintain flight at least 1.5 times more than the life of the battery. Next sub-function is motor selection. This function is a critical attribute to aircraft flight. The motor must have a reasonable thrust to payload ratio to ultimately have a stable flight for a specific amount of time. The last sub-function is wing selection. This function determines the layout of the aircraft and creates the uniqueness of each wing design. The full body wing selection is the heart of the aircraft to have a calm flight that's aerodynamic. Figure 16 displays the full layout of the

Decomposition model.

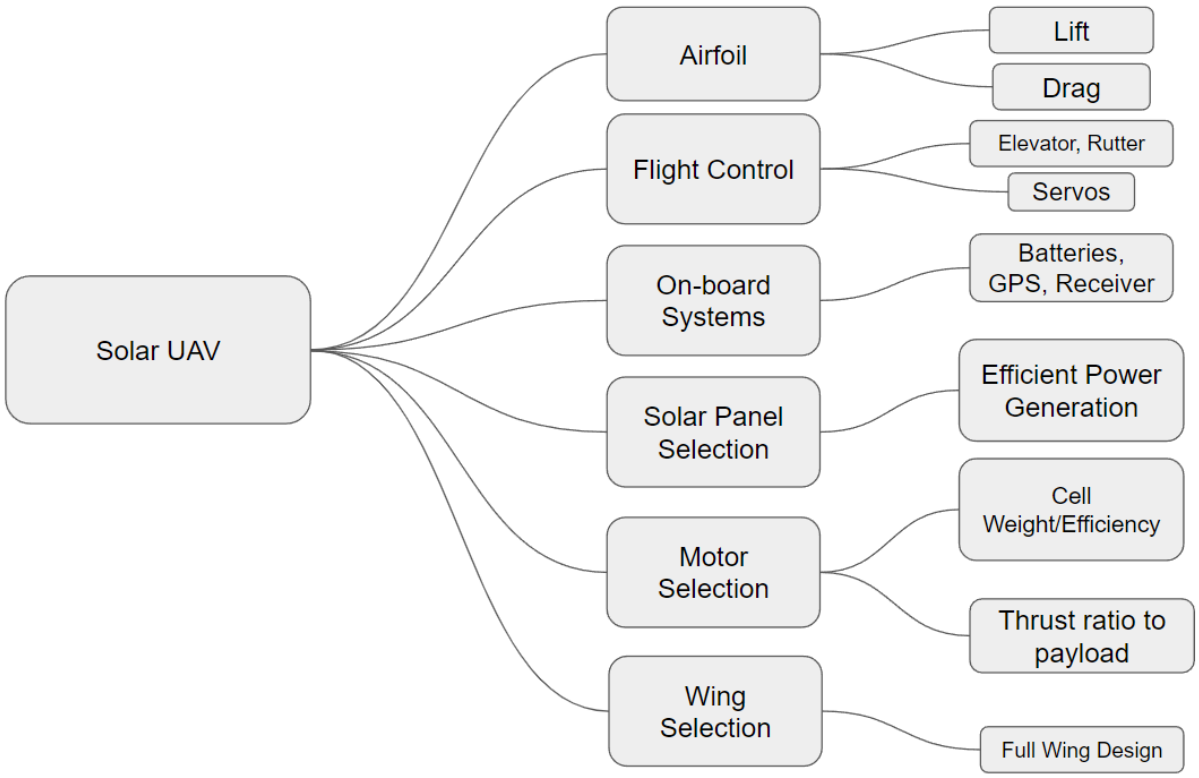


Figure 2: Sol Avem Components

2.3.1 Black Box Model

[Provide an introduction to this section before presenting the Black Box Model with appropriate inputs and outputs in the form of materials, energies, and signals. Include a discussion of how this model helps the team to visualize or clarify your project.]

[Updated to reflect detailed plan of project solution.]

The Black Box Model helped Team Sol Avem identify the material, energy, and signal input/outputs for the Solar Powered aircraft. The focus of the aircraft is to ensure that takeoff, stable flight, and landing are all successful when testing. On the left side of the Black Box model are the inputs into the solar powered flight aircraft and on the right are the outputs. The very top arrows are the material attributes to the aircraft. The middle arrows are the identifiable energy inputs and outputs of the airplane. Last, but not least, at the bottom of the model are the signals the aircraft will interact with for a successful flight. Starting with the material, the inputs are the hand and electric batteries. The hand represents the control of flight from a remote control and to use the controller, hands are required. Joel and Gage will be the primary pilots of the aircraft. Electric batteries are the other major material input for the aircraft to use some sort of fuel source to power the flight. The material outputs include the hand, airflow, and thrust. The hand will control the flight the whole time from takeoff to landing. From the electric batteries, the aircraft will experience thrust and airflow while traveling through the air, all powered by the electric batteries. Moving on to the energy inputs and outputs, the inputs include potential, solar, and battery energy. The built-up energy right before takeoff is the potential energy input into the aircraft. The solar energy from the UV rays from the sun keeps the batteries powered even after the battery's life wares. The batteries are the key component to the energy input which powers the aircraft. The outputs of energy include kinetic, power output, mechanical energy, energy storage, and heat. As the aircraft takes off, the potential energy from the input transitions into kinetic energy because of the output. Power output is generated from the batteries powering the motor and propeller. Mechanical energy is also a huge output for the aircraft. The solar panels do store energy into the battery and that causes the battery to extend its life for a longer run time. The last output is heat generated from all the energy inputs combined. The very bottom arrows represent the signal input/outputs of the aircraft. The major inputs include channel signal, on/off switches, and LEDs. The channel signal comes from the controller to the airplane to control the flight. The on/off switch operates the functionality of the plan to turn it on and off. The LED lights will help with orientation of the plane when flying in the air which allows the pilots to have a good in-depth perception of the aircraft in flight. The outputs include controlled flight and radio frequency. All Inputs and Outputs displayed in the Black Box model are key components to identify when attacking design alternatives for the airplane. The team must understand the importance of each component within the solar powered aircraft which was capitalized within the Black Box Model.

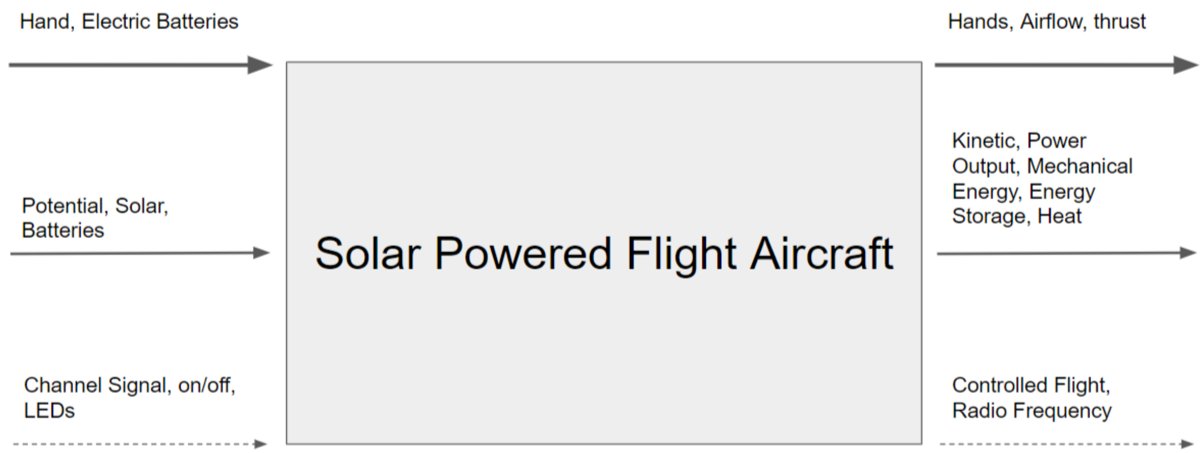


Figure 3: Black Box Model

2.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

[Provide an introduction to this section before presenting the team's selected model with appropriate form based on the process diagram/model/analysis. Include a discussion of how this model helps the team to visualize or clarify your project.]

[Updated to reflect detailed plan of project solution.]

Figure_ below displays the Work Process Diagram of the Sol Avem Design. The diagram has a combination of the functional decomposition model and black box model to describe the inputs/outputs of the Solar Powered Flight Aircraft with the guts of each function in between. Starting off with the inputs which include electric batteries, solar energy, channel signals, hand energy, and thrust power flow into each sub function of the aircraft. The electricity provided from the batteries will input power into all the components of the flight and ultimately maintain an efficient amount of power generation for the aircraft to have a stable flight. The solar pane ls work in unison with the electricity to generate another source of power to maintain battery life so the flight can last 1.5 times past the initial battery span. The power will operate all the components including the receiver, GPS, servos, and elevators/rutter. The channel signals will be the connection point between the components on the aircraft and the controller. The controller will provide a signal to the receiver which guides the function of the aircraft from the ground. The controller will be operated with hand energy provided by the test engineers (Joel and Gage). The controller will also provide an on/off function for the aircraft to be operated when needed. The controller will guide the flight and result in a stable flight. The final input is thrust power which will be operated off the motor selection which will be managed with 2D calculations to have a balanced thrust ratio to the payload of the aircraft. The thrust ratio to payload calculation will also work co-inside with the wing/airfoil selection to have an efficient lift to drag ratio for consistent airflow. All these inputs that flow through each function of the aircraft which lead to the outputs of the Solar Powered Flight aircraft which include energy storage, heat, hands, kinetic/ mechanical energy, radio frequency, controlled flight, stable thrust, and airflow. The batteries will store energy and produce some sort of heat with the generation of some sort of energy. Hands will flow through the whole process since the test engineers will control the aircraft through the whole process of the flight. Potential energy builds up from takeoff and turns into kinetic and mechanical energy during flight. The controlled flight will result from the signal inputs and how well the controller is handled. Stable thrust relies on motor selection and wind design. The lift and drag are crucial components to how the aircraft will fly. The final output is the airflow that results on the geometry of the aircraft and the airfoil selected. The combination of all these functions results in a successful solar powered flight aircraft.

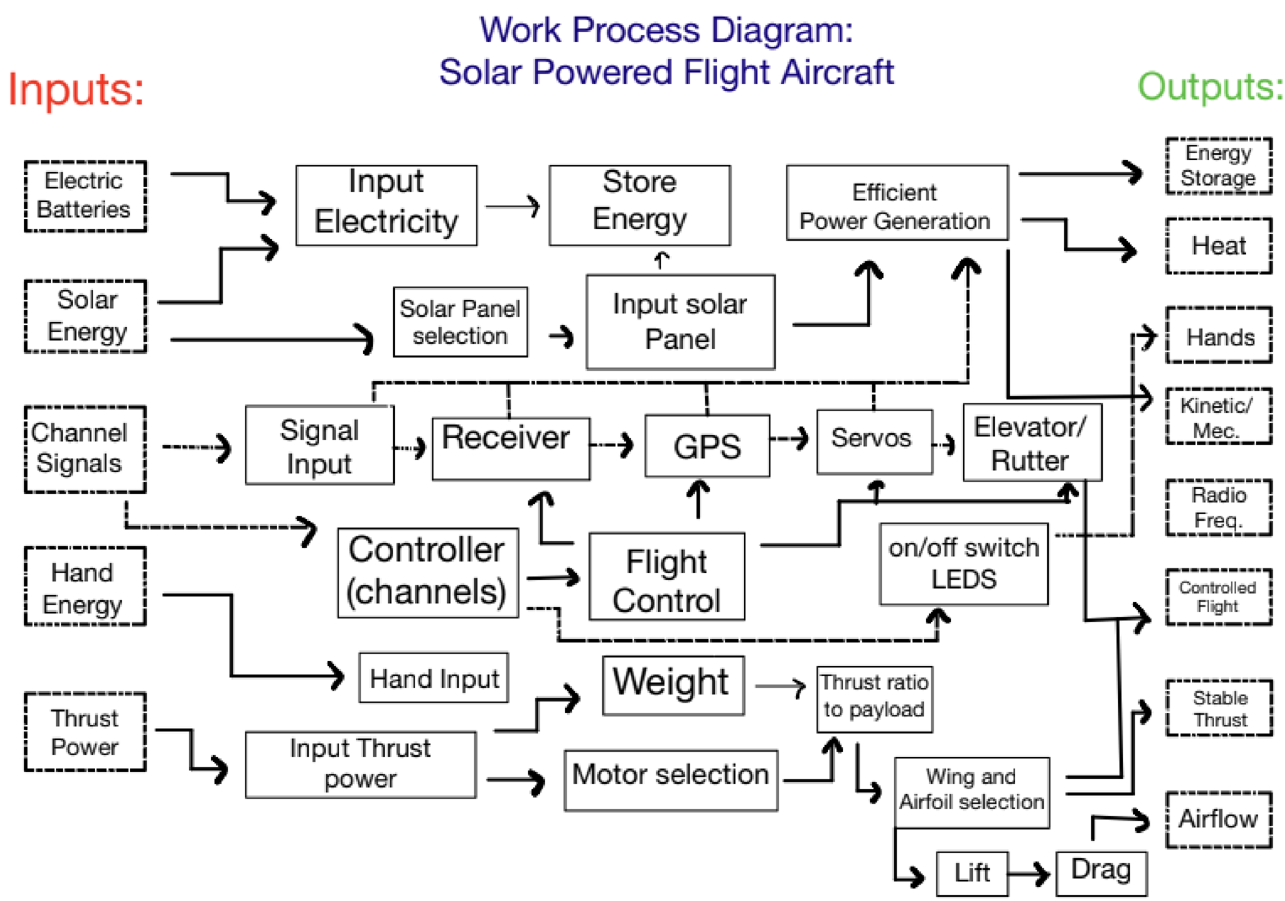


Figure 4: Sol Avem Functional Model

2.4 House of Quality (HoQ)

[Summarize project requirements in a House of Quality using the template provided on the course website. If the HoQ is small enough you may include it here as landscape or portrait. If it is too large, add the HoQ as an Appendix. Include a detailed introduction to the section and a discussion of how the HoQ has helped the team in the design process. Be specific and detailed (i.e. do not write any statements that could be applied to multiple projects besides your own). Ensure that every Engineering Requirement has a legitimate target value and tolerance to the target.]

[Include Testing Procedures in the House of Quality for this report. Each Testing procedure in Section 3 should have a distinct number that is used in the Testing Procedures row of the HOQ template. Some testing procedures may be used for multiple ERs, but every ER must have a Testing Procedure.]

The engineering process looks different for every single product to be designed. One thing they all have in common is the requirement to turn the need of a customer into a physical product. Our team is no different, we were given a project description with 5 separate customer needs that the product must address. To make the jump from a list of needs to an operational product, a "House of Quality" or "QFD" is utilized to make the job easier. This matrix relates the customer needs to physical parameter goals that will be needed to produce a successful prototype. Through the matrix calculations it is then determined the most important engineering requirements, and in what order to focus on them. When our team plugged in the 5 customer needs along with the determined engineering requirements, our result was the QFD shown in Figure 15.

1	Cost										
2	Thrust	-									
3	Aircraft Mass	-	-								
4	Coefficient of Lift	-	+	+							
5	Flight Time	-	0	-	+						
6	Repareable/Reusable	-	0	0	+	+					
7	Wing Load	-	-	+	+	-	-				
8	Operating Radius	-	0	-	+	+	-	-			
9	Solar Energy Harvest	-	+	-	0	+	-	+	+		
10	Cargo Capacity	-	-	-	+	-	0	-	-	+	
11	Saftey	0	-	-	0	-	+	-	-	0	0

	Customer Needs	Customer Weights	Cost	Thrust	Aircraft Mass	Coefficient of Lift	Flight Time	Repareable/Reusable	Wing Load	Operating Radius	Solar Energy Harvest	Cargo Capacity	Saftey
			Technical Requirements										
1	Powered Flight	9	7	8	8	9	4	5	4	4	7	6	5
2	Solar Integration	6	7	8	7	4	9	5	3	7	8	2	4
3	Payload	3	6	8	9	8	6	5	3	6	3	3	4
4	Affordable	8	9	5	5	4	7	9	5	7	3	4	5
5	Simplicity	5	7	5	4	4	6	7	6	6	6	5	7
	Technical Requirement Units		$	lbf	min.	unitless	min.	ManHrs	lbf	km^2	W/m^2	m^3	n
	Technical Requirement Targets		7.2	0.3	2.5	0.6	5	1	22	1	142.1	0.1	1
	Absolute Technical Importance		7.20	6.80	6.60	5.80	6.40	6.20	5.40	6.00	5.40	5.20	5.00
	Relative Technical Importance		1	2	3	7	4	6	8	5	9	10	11

Based on the House of Quality results, our team determined that the primary focus of our design should start with how we are going to achieve our goals of thrust output and aircraft weight. Our highest ranked technical requirement was meeting our budget goal. It is obvious that the most important thing to keep in mind throughout this project is that we do not go over budget because once the budget is gone, we will not be able to buy parts to progress the project. While staying within the budget, our first prototyping and testing phases will be focused on creating an aircraft that produces the maximum amount of thrust out of the lightest platform.

As seen in Figure 3, the 4th and 5th ranked technical requirements are flight time and operating radius. This demonstrates that once we have a light aircraft with sufficient thrust, we should then focus on designing it to fly for as long as possible over a large area. One of the significant customer requirements is that our plane flies 150% of the time in solar that it flies with batteries alone. Thus, maximizing the flight time for the batteries also maximizes the amount of solar energy that can be captured. All these results from Figure 3 give us a great starting place for testing and prototyping, however we will never stay in our budget if our aircraft isn't reusable and durable. We need a design that allows for many flights and one that does not catastrophically fail if there is a rough landing. Keeping the results from our QFD in mind, moving into the prototyping phase will facilitate the most efficient and cost-effective construction of our aircraft. Moving forward, the team will use the testing procedures outlined in this report to evaluate whether the UAV is meeting the engineering requirements.

2.5 Standards, Codes, and Regulations

[Provide a summary and table of any and all standards and codes of practice that apply to this project. A table of the standards should be similar to the table below. Provide a discussion of how these standards affect your project in general. You may reference the list you created last semester, but this section must be more detailed and thorough now that your team is nearly done with designing the system]

Table X: Standards of Practice as Applied to this Project

Standard Number or Code	**Title of Standard**	**How it applies to Project**
ASNI/AAMI HE 74:2001	Human Factors Design Process for Medical Devices	Helps in the design of how the device with interface with the user in a safe manner.

[delete example text from your table]

[Every team should adhere to ASTM dimensioning and tolerancing standards for their drawings unless otherwise specified by project client.]

Standards, Codes, and Regulations are very arbitrary for the Solar UAV project. A lot of the project is scaled for personal use and personal data. The aircraft will be designed to be a small remote-control airplane that can be flown for personal use. Now that being said, the FAA (Federal Aviation Administration) has some guidelines and regulations when flying recreational flyers or drones. The major standard code for RC Airplanes is AC 91-57B. The purpose of a recreational flyer is to fly only for recreational use only. If the aircraft flies more than 400 feet in the air, there must be a license or clearance for the aircraft to fly the desired height. For our purpose, team Sol Avem will not be flying near the 400' mark. We will be a lot closer to the ground when flying the aircraft. Another regulation mentioned in the code is that if the aircraft weighs more than 55 pounds, then the operator must comply with community guidelines and the aircraft is operated from a fixed site. The operator cannot lose sight of the aircraft while in flight so that the aircraft does not crash into any residential homes or hurt anybody in the process of flight.

Now with the construction of an aircraft, anything can potentially happen when in flight. If anything were to malfunction or the plane were to crash, the Declaration of Compliance is a way to certify that the aircraft is allowed to fly in the air in specific locations. The contents of the code do not have the force and effect of law and are not meant to bind the public in any way. The intention is only to provide clarity to the public regarding existing requirements under the law or agency policies. There is a compliance form listed at the end of the code that requires general information including address, name, phone number, and/or email. This compliance may apply to the project depending on the location of the flight and to be safe with common standards so the public understand the tests and procedures that will take place for a successful flight.

With the development of prototypes, sub-assemblies, and final assembly for Sol Avem, there will be a chance that the flights will take place over civilians. From the Code of Federal Regulations, Chapter 1, Sub-Chapter F Part 107, code 86 FR 4381 discusses the operation of unmanned aircraft over human beings. No operator can operate a small, unmanned aircraft over civilians unless the operator is directly participating in the operation of the unmanned aircraft, the operator is located under a covered structure/ inside a stationary vehicle that can provide reasonable protection from a falling aircraft, and the unmanned aircraft meets all safety specifications to fly. Part 107 goes into further detail of visual observers, visual line of sight of aircraft operation, operation at night, operating the aircraft on alcohol/drugs, in flight emergency, condition for safe operation, etc. Some of the points apply to Team Sol Avem and the aircraft will be under extensive testing and maintenance so that the aircraft operates in the most safety condition as possible. Since the aircraft will be powered by solar panels, Team Sol Avem will not be flying at night and only during the day. This will allow for visible flight and the location will be somewhere in flagstaff that is open and can see the whole flight path of the aircraft.

Location is a very important point to focus on when Team Sol Avem plans to test fly and operate for the final presentation of the final assembly. The FAA has a couple of rules on flying near certain locations that are prohibited. The FAA states that some airspace restrictions include stadiums/ sporting events, near airports, security sensitive airspace restrictions, restricted or special use airspace, and Washington D.C. (The White House). Code ENR 5.1 defines the areas that are restricted and puts the team on notice when going to fly the aircraft. With the different codes and standards, the FAA provides for unmanned aircraft, these are about the only standards Sol Avem must follow. This aircraft design will be a very arbitrary project that doesn't have too many restrictions. The size of the aircraft will not be a problem and with the use of recreational aircraft everywhere, Sol Avem will be no different than a RC plane bought at a hobby shop.

Standards and codes come from many organizations and societies. Examples of those that most directly apply to Mechanical Engineering projects include (but are not limited to):

- Federal Aviation Administration (FAA)
- Aluminum Association (AA)
- American Gear Manufacturers Association (AGMA)
- American Iron and Steel Institute (AISI)
- American National Standards Institute (ANSI)
- American Society of Mechanical Engineering (ASME)

- American Society of Testing and Materials (ASTM)
- American Welding Society (AWS)
- American Bearing Manufacturers Association (ABMA)
- Industrial Fasteners Institute (IFI)
- Institute of Electrical and Electronics Engineers (IEEE)
- International Standards Organization (ISO)
- National Institute for Standards and Technology (NIST)
- Society of Automotive Engineers (SAE)
- U.S. Department of Transportation (DOT)
- Code of Federal Regulations (CFR)

Table X: Standards of Practice as Applied to this Project

Standard Number or Code	**Title of Standard**	**How it applies to Project**
AC 91-57B	Exception for limited recreational operations of unmanned aircraft	This regulation applies to our Sol Avem design strictly to provide details on the acceptation to flying an aircraft for recreational purposes only. The regulation goes into detail on where it can fly, the size of the aircraft, and the height it can reach.
AC 89-2	This AC provides guidance on the Declaration of Compliance of the aircraft	This code applies to the project to make sure if anything were to happen with the aircraft (malfunction or potential crash) the aircraft has a certification for any compliance.
86 FR 4381	This code focuses on the operation of unmanned aircraft over civilians	Depending on the area of flight, Team Sol Avem may be flying over civilians during testing, final flights, and recreational flights.
ENR 5.1	Prohibited, Restricted, and Other Areas of Flight	This code applies to Team Sol AVem because it defines specific locations that the aircraft can and cannot fly around.

3 DESIGN SPACE RESEARCH

[Provide the sections of the Final Proposal from ME 476C here, mitigating any and all issues from the last report.]

3.1 Literature Review

[Provide a BRIEF summary of the literature review that all team members conducted in the first semester. You DO NOT need to break it into sections based on each student's work as you did last semester. Use this section to describe what sources were used for benchmarking and design research. This could have been done by examining similar systems, literature review, or web searches. Describe the TYPES of sources found.]

3.1.1 Mitch Anderson

[Explain what technical aspect of the project this student focused on and then list the 5+ relevant sources **with summaries and discussions**. Cite all textual information and figures.]

Chapter from Current Book Publication:

Summarizing chapter eight 'Design of a Propeller-Driven Airplane' [#,pp 397-486] of 'Aircraft Performance and Design' written by John D. Anderson details the classical design of a an aircraft starting from scratch. This book is written pertaining to actual aircraft design so our team will be taking some of the ideas with a grain of salt but will be using the process as it is the same for remote control aircraft as well. This process begins with highlighting the pivot points of concept design. The book stated the first step to concept designs is stating the engineering requirements. These requirements were crucial for flight as they provide the necessary parameters to go from theoretical ideas to physical aspects. These requirements range from max velocity, cost, weight, reliability to take off distance and more. Each of these requirements are meant for real aeronautics but can be tampered and sorted to fit our customer needs. The next highlight in the chapter was the estimating the initial weight [1]. This is a huge first step to aircraft design as you must know your weight to calculate lift and other dependent calculations. Anderson stated this will be a very rough estimate but will be become more conclusive the more iterations that occur down the line in the design process. After creating a weight estimate critical performance parameters can be calculated using equations seen in [] we can estimate parameters such as max lift, lift to drag ratio, wing loading and thrust to weight. The last two being the most important to the overall design.

$$W_0 = W_{\text{crew}} + W_{\text{payload}} + W_{\text{fuel}} + W_{\text{empty}}$$

Equation 1: Weight Estimation

$$\text{Average } (c_l)_{\max} = \frac{1.6 + 1.8}{2} = 1.7$$

Equation 2: Max Lift Coefficient

$$\frac{W}{S} = \frac{1}{2}\rho_\infty V_{\text{stall}}^2 (C_L)_{\max}$$

Equation 3: Wing Loading Estimate

$$s_g = \frac{1.21(W/S)}{g\rho_\infty (C_L)_{\max}(T/W)}$$

Equation 4: Thrust to Weight Ratio

Next would be the configuration layout. This design component layout how the aircraft will be controlled and function. The aspects that go into these criteria are aircraft propellor location, is the aircraft a pusher or tractor [], the wing configuration, fuselage configuration and an initial center of gravity location [1]. These initial parameters will be very irritative as changes are made to the design or weight these parameters will be changing. After the process is done a couple of times a more reasonable weight estimate will be calculated that should be close to final design. With each variation of parameters will also allow for a performance analysis which will give insight of which parameters effect the design the most either positively or negatively. Lastly is the optimization factor which is taking the performance analysis and choosing the most efficient design from the results and integrating them into the design.

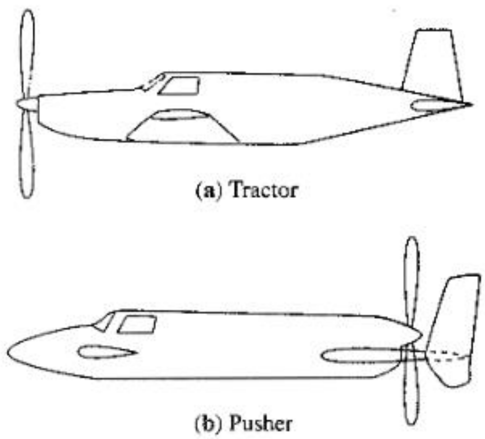


Figure 15 5: TRACTOR VS PUSHER

Peer-Reviewed Journal Article:

Reviewing journal article 'Basic Understanding of Airfoil Characteristics at Low Reynolds Numbers' written by Justin Winslow, Hikaru Otsuka, Bharath Govindarajan, and Inderjit Chopra from The University of Maryland, College Park, Maryland [2]. This article used computational fluid dynamics (CFD) to understand low-Reynolds-number aerodynamics over various surfaces. They conducted their research using a structured RANS solver called TURNS2D. This software allowed them to calculate lift, drag, pitching moment, and surface pressure data with available experimental data. Overall, the calculated values from TURNS2D agreed with experimental and analytical measurements at low Reynolds numbers/ The results from TURNS2D show that there is extreme sensitivity of airfoil performance when the Reynolds number is below 10^5. In the journal they concluded that as the Reynolds number decreases there is an increase in drag due to flow separation. There is also a large decrease in lift when the maximum lift coefficient is decreased by 46% between 10^5 and 10^4.

In low Reynolds number wing design to achieve lift to drag a 6% camber is optimum. However, a 9% camber can be used if a maximum lift is a stronger design factor. After experimentation NACA 4403 and NACA 6403 were showed to have the highest lift-to-drag at both 2 x 10^4 and 10^5 Reynolds numbers.

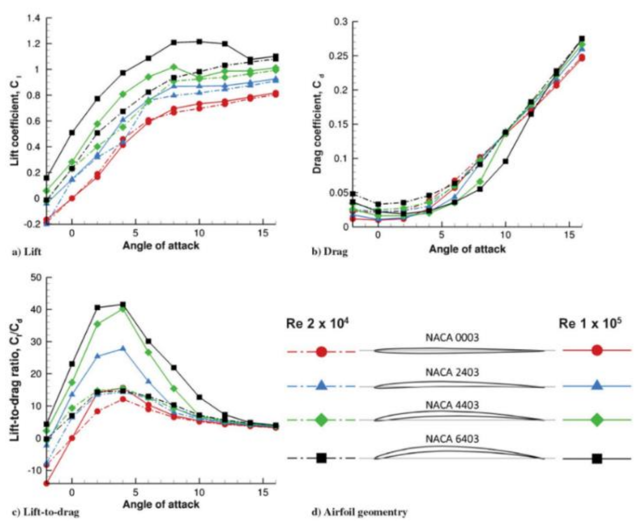


Figure 16 6: Effect of camber on lift, drag, and lift-to-drag ratio for naca airfoils

Peer-Reviewed Journal Article:

Reviewing peer reviewed article 'Study of NACA 4412 and Selig 1223 Airfoils Through Computational Fluid Dynamics' by Jaswinder Singh, Dr. Jaswinder Singh, Amritpal Singh, Abhishek Rana, Ajay Dahiya, School of Mechanical Engineering, Chikara University, Punjab, India [3]. Conducted studies over two airfoils NACA 4412 and S1223. These airfoils were subject to comparison of coefficient of lift and coefficient of drag. The angle of attack was varied, and the effect of velocity, pressure, lift, and drag were all measured. After running numerous tests on both airfoils, it was concluded that the NACA 4412 airfoil had lowest coefficient of lift and drag thus making it suitable for sport planes. Sport planes have high velocity compared to heavy lift cargo planes. In the case of S1223 airfoil the drag and lift coefficients are highest which would be useful in applications of heavy lift. Cargo planes travel at lower speeds which is ideal for this airfoil.

Table 3: COMPARISON OF NACA 4412 AND S1223 AIRFOILS

NACA 4412 airfoil				S1223 airfoil		
Angle of Attack (Degree)	**cl (coefficient of lift)**	**cd (coefficient of drag)**	**cl/cd**	**cl**	**cd**	**cl/cd**
0	0.22	0.05	4.4	0.82	0.09	8.28
5	0.67	0.07	9.57	1.26	0.15	8.07
10	0.88	0.13	6.47	1.70	0.25	6.84
15	1.25	0.22	5.58	2.13	0.38	5.61

Online Source:

A YouTube page by the name of RCTestFlight created a video called 'R/C Flying Solar Panel' [4]. This video is part of a series of remote-control aircraft design. The creator of these videos, Daniel Riley straps solar panels to various rc aircraft design and does numerous tests on each design. At the beginning Daniel goes through some of the process of fabricating the glider showing the construction of chassis, solar integration, and initial flight tests. Daniel used a software called ARDUPiolt. This software is an autopilot that allows for set parameter flight to do consistent testing. This software allows for multiple types of hardware which they list on their website. Daniel also included the vendor that he uses for solar panels. It is a company out of Vietnam that sells various custom solar panels designed specifically for UAV aircraft.

Figure 17 7: ARDUPIOLT RCTestFlight

Figure 8: U-Glider

Previous Capstone Team:

One of the sources that we will be referring heavily on is the 2018 a Mechanical Engineering team by the name of ‘Team Solis Fur’ [5]. This team took upon the Solar UAV project before the hit of Covid19. The team’s goal was to have an indefinite flight while the sun was out. The team consisted again of only mechanical engineers. This ended up being one of the team’s downfall as a large customer restraint is the need for solar integration. The Solis Fur designed to be a glider. They did complete flight after the fact but without solar integration. This flight went over 170 feet off the ground and lasted for 140 seconds.

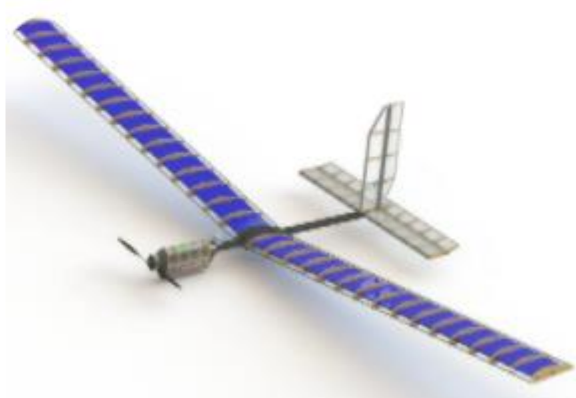


Figure 9: Solis Fur Design

3.1.2 Joel Freedman

For the purposes of this report, this student is focused on developing engineering requirements and the

QFD, as well as researching flight control methods for the team's aircraft. Pertaining to the technical requirements, these were derived using information from the book Mitch mentioned, 'Aircraft Performance and Design' [5]. Also assisting with selection/goals of ER's was our client Professor Willy, our professor Dr. Pete, and our industry advisor Kelly Gallagher. Meeting with these professionals to discuss our project helped shape what technical requirements should be focused on and what goals should be met first.

Research Paper:

One of the most recognizable airplanes in modern aviation is the B2 Stealth Bomber. This "Flying Wing" concept is an enticing one for team Sol Avem because it maximizes the planform area of the aircraft. With planform area being a crucial factor in the performance of the solar system. The research paper titled, "Analysing the "Northrop Grumman B2 spirit" aircraft's operational and design aspects to ascertain the issues related to flying wing concept in implementing as a commercial airliner" [6] proved to be a valuable source in not only some background of the B2 design, but also theory on how to apply those design methods to other aircraft. In the paper the author compares the lift coefficients of the B2 and an A320 Airbus with the calculations seen in Figure 8 [6].

Equation 5: calculations comparing Coefficient of Lift for A320

A. Basic Calculations for B2

1) Velocity Calculation

$$M = \frac{\text{Speed of free stream}}{\text{Speed of sound}} = \frac{V_s}{V}$$

$V_s = MV$ $\quad$ $V_s = 0.85*340.29$ m/s

$V_s = 289.2465$ m/s

2) General Lift Coefficient

Wing Loading= 329 kg/m^2

$$\text{Wing Loading} = \frac{\text{Gross weight}}{\text{Wing Area}}$$

$$\text{Wing Area} = \frac{152{,}634}{329} = 463.9331 \text{ m}^2$$

$$C_L = \frac{2mg}{\rho S V^2} = \frac{2*152{,}634*9.81}{1.225*464*(289.2465)^2} = 0.06297$$

Equation 6:calculations comparing Coefficient of Lift for B2

B. Basic Calculations for A320

1) Velocity

Maximum operating velocity: $V_s = 180.056$ m/s

2) General Lift Coefficient

Gravitational Acceleration: $g=9.81$ m/s^2

Wing Area: $S= 128$ m^2

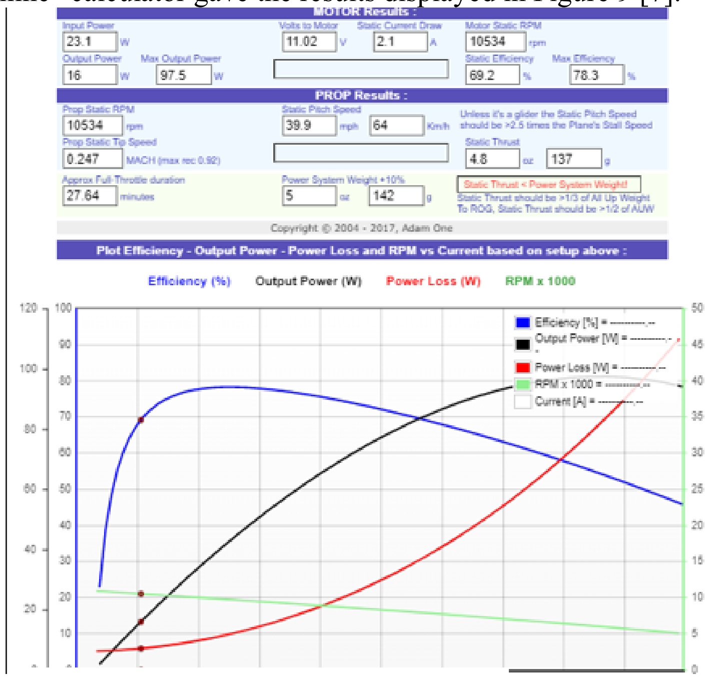
Air Density: $\rho= 1.225$ kg/m^3

$$C_L = \frac{2mg}{\rho S V^2} = \frac{2*73{,}500*9.81}{1.225*128*(180.056)^2} = 0.2837$$

The most significant takeaway is how much smaller the coefficient of lift is for the B2 than the A320. The numbers for our aircraft will be significantly different because of the scale difference, but it is helpful to keep in mind that going with a flying wing design will require our team to compensate for the smaller coefficient of lift compared to that of a classic aircraft with two wings and a tail.

Online Source:

The source used primarily for the QFD was a website called "rcplanes.online"[7]. After getting some background from the Aircraft Performance and Design book, we needed to figure out what the differences between full scale vs RC plane designs are. This website is a wealth of knowledge regarding model aircraft performance, design, and aerodynamics. The most helpful part was a motor calculation page for eclectically powered aircraft. This page had a program set up to accept motor, prop, ESC, and battery parameters, and then output efficiencies, power, thrust, and rpm performances that would be achieved with the configuration. Based on the components we have selected and the theoretical performances of those parts, the "rcplanes.online" calculator gave the results displayed in Figure 9 [7].



3.1.2.1

Figure 20 10: motor and prop performance from rcplanes.online

Based on the results from the website, our configuration provides the optimal performance at only a 2.1-amp draw. It is also predicted to produce 137g (0.302 lbf) of static thrust which is greater than our predicted goal of 0.277 lb. required in our QFD for the aircraft to fly. It should be mentioned that these are rough calculations and estimations.

Journal Article:

The next source considered is one used for guiding the selection of a flight control system for the aircraft. The journal article is titled, "Design, Build and Fly a Flying Wing" and was distributed by the Athens Journal of Technology and Engineering [8]. The most significant takeaway from this article is that a team of engineers had success flying an unmanned aircraft without a rudder, only elevators and ailerons as pictured in Figure 8.

Figure 1121: Flying wing with only ailerons and elevators

The presented flying wing design does not require a rudder to control flight. Instead, it utilizes classic elevators in tandem with ailerons to achieve elevation control and steering through roll. We want to emulate this style of flight control eliminating the need for a rudder and rudder servo, improving simplicity, and decreasing weight. Ideally, our team wants to have only two "Elevons" (hybrid elevator/aileron) controlled independently with a servo each to achieve controllable flight.

Industry Advisor Meeting:

For this project, team Sol Avem has been put in contact with an industry advisor by the name of Kelly Gallagher. Kelly did her undergraduate degree at NAU before receiving her master's in mechanical engineering from University of Utah. She has many years of experience in project managing, particularly for aerospace projects [9]. A reoccurring biweekly meeting has been established with Kelly to keep her updated on project status and obtain design advice. So far, our team has met with her on two occasions, the first on February 17th [10], and then again on March 2nd [11]. These two meetings were early in the project stages, so they were focused on how to get started designing a prototype. She gave us great advice about starting with the thrust source and then working out from there. She also stressed the importance of keeping track of mass. She suggested we have an excel spreadsheet with a detailed breakdown of each parts mass and summing up the total mass. We heeded her advice and have started to compile a spreadsheet tracking aircraft mass as shown in Table 4.

Table 4: Aircraft Mass

	Bill of Materials		
Part #	**Description**	**Quantity**	**Mass (g)**
1	Motor	1	189.1
2	Prop	1	22.96
3	Servo	2	13.4
4	Radio Reciever	1	27.22
5	Battery	1	57
6	Solar Cells	4	20
7	Speed Controller	1	14.8
8	Airfoil	2	22.1
10	Chasis (Fuselage)	1	40
11	Chasis (Wings)	1	40
13	Wiring harness	1	30
14	Hardware	1	15
		FINAL MASS=	587.08
			1.293lbs

It is important to keep in mind that these are estimated values based on the research and part selection up to this point. As the team begins prototyping the BOM will become more robust and detailed, which will probably increase our overall mass. This is helpful for giving us a target and making sure we have enough thrust to get our plane off the ground with the selected components.

Online Source:

The final noteworthy source is FLITETEST.com [12]. This website is perfect for the beginner RC plane hobbyist. They have over 6,000 articles covering topics from aircraft construction to flying tutorials. Another aspect of this website is the online forum. The forum is very active with lots of knowledgeable hobbyists and contains over 3,000 questions already answered about fixed wing electric aircraft [12]. This source has not been utilized to its full potential yet. Once we are in the prototyping phase, we will be consulting the guides on the website, as well as seeking answers to any specific questions we may have about component selection through the group forum.

3.1.3 Gage King

This solar aircraft design had a lot of different components to be fulfilled and researched to understand the full scope. The technical aspects that were focused on were the airfoil design of the wings, electric motor selection, optimal path planning for a solar powered aircraft, solar panel advantages/disadvantages, and performance/design. The customer requirements need to be fulfilled and the engineering requirements are the most important to focus on so detailed research allows for those peaks to be met. This student had to focus on the cad model of the aircraft and understand what kind of motor is suitable for the situation to match other components to work in unison.

Online Source:

Motor Selection is a very important aspect of how the RC airplane will fly efficiently through the air. RCplanes.com provides a breakdown of the options of motors for RC aircraft. [15] Electric powered motors operate based on electromagnetic principle. There are two main motors model aircraft typically use which are brushed and brushless motors. Brushed motors consist of a stator and a rotor all incased in a cylindrical metal case. The rotor has several coils that may be coreless or have an iron core. The stator usually consists of two permanent magnets that are placed close to the metal cylinder case. In figure __, the configuration of a brushless motor displays all components.

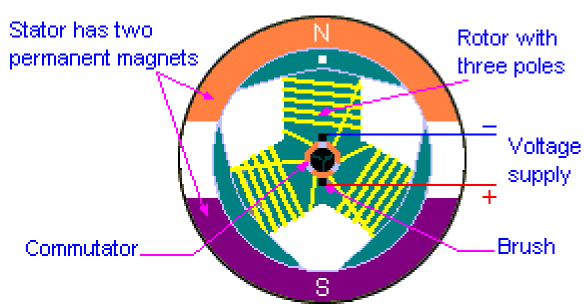


Figure 12: Motor Schematic

Now for a brushless motor, the rotor coils are not wrapped around an iron core. Since it doesn't have an iron core, this results in a lot less iron loss, which makes them more efficient than a cored motor. These motors are generally a lot smaller than a brushed motor and work ideally for small indoor planes because they cannot stand continuously high RPM and/or loads. This helped Team Sol Avem narrow down what motor should be used for the aircraft design which will be brushed.

Journal Entry

One major technical aspect that was taken into consideration was the most optimal path when flying for the solar panels to be the most efficient to generate energy. "Solar Powered Aircraft: Energy-Optimal Path Planning and Perpetual Endurance" [16] describes to most ideal paths for a UAV to take with solar panels attached to the aircraft. During perpetual flight, a positive total energy balance must happen when there is optimal sunlight. Translating that into the power ratio, for an optimal flight the power ratio must be greater than or equal to the reciprocal of the daylight cycle. Elevation is a huge factor in where the location is at when the flight takes place. Flagstaff is in a very high elevation compared to sea level and that will affect how the solar panels interact with energy generation for the batteries to operate at least 1.5 times past the original life. The figure below displays the total energy during the flight as a function of solar elevation.

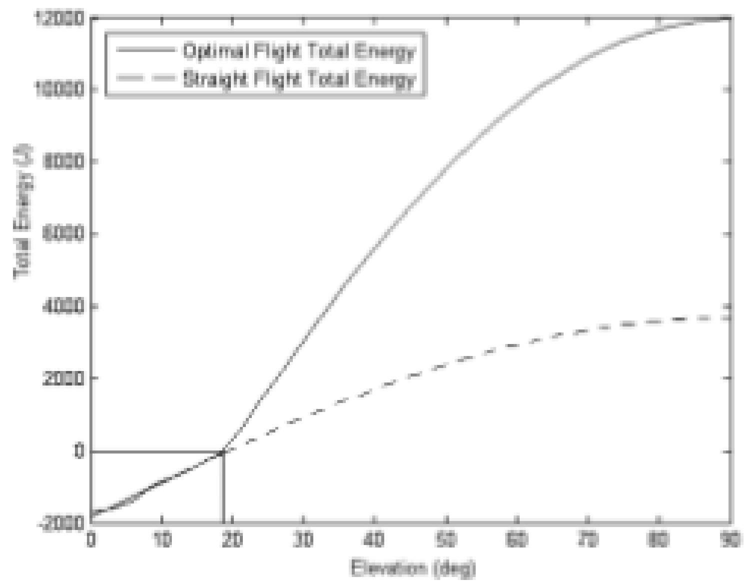


Figure 13: Energy

Depending on the degree of flight towards the sun, elevation has a huge factor on how the aircraft should fly. So, with the selection of solar panels and the efficiency it offers, the aircraft must fly in a specific fly pattern to optimize the best energy generation by solar panels.

Peer-Reviewed Journal Article:

Airfoil is a huge design feature that ultimately determines the amount of lift and drag the plane will have. It optimizes the flight and can affect the stability the aircraft has. This peer-reviewed journal article, "Investigation and Comparison of Airfoils" created by the New York Institute of Technology, discusses pros and cons of certain airfoils and gives feedback to the designs.[17] This article focused on the pros and cons for NACA65-415 and the NACA 2412. The NACA 65 had a coefficient of lift of CL=.6 and the coefficient of drag was CD=.0042. The max L/D at this point is 142.5. Now for the NACA 2412, CL=1.1 and CD=.009. The max L/D ratio at this point is 122.2. The Institution ran many speeds test to see the comparison between lift coefficient or reduction in drag coefficient. The table below shows the data they collected and explained that NACA 2412 was not an ideal airfoil compared to the NACA 65-415.

Table 5:Airfoil Performance

	NACA 65_2-415		NACA 2412	
	Cl	Cd	Cl	Cd
Cruise	0.152993	0.0042	0.130979	0.006
Best Glide	0.460479	0.0042	0.487863	0.0065
Stall	1.567728	0.02	1.328567	0.0125
TO Max	1.135479	0.011	0.922111	0.008
Land min	0.611972	0.0042	0.617665	0.0065
Land max	0.441698	0.0042	0.566871	0.0065

This provides valuable information to team Sol Avem to allow for testing to be done on the selection of airfoils and see what the ideal fit would be for the design that was created. The team must pay attention to the drag and lift of the wing and find the max L/D ratio to optimize a stable flight.

Chapter from Book Publication:

One source that was used to help with understanding the idea of aircraft design is a book called "Introduction to Aircraft Design" written by John P. Fielding.[18] Chapter one goes through step by step on how to attack a design concept for an aircraft. Since none of the team members have ever fully developed a design for an aircraft, this chapter was crucial to understand the see the scope of an aircraft design process. The phases of airplane design include conceptual design, preliminary design, and detail design. Conceptual Design focuses on the overall shape, size, weight, and performance of the design. The major technical requirements when in conceptual design are the aerodynamics of the aircraft, propulsion, and flight performance. The preliminary design is minor changes to the configuration to focus on the details of the design. The detail design is the "nuts and bolt" phase of the airplane design. It is the final step to the creation of the aircraft. Some of the specific requirements that must be noted when in the process of designing the airplane include range, take off distance, stalling velocity, endurance, maximum velocity, rate of climb, turn rate/radius, maximum load factor, service ceiling, cost, reliability, and maximum size. The focus of the whole design is the payload of the aircraft. The payload affects the power needed to fly the aircraft, the material used for a stable flight, and flight time. All these concepts and processes are key to how the team developed the components of the solar UAV.

Online Source:

Batteries are one key component of how the aircraft will fly. Now with the incredible amounts of different types of batteries, there are usually only two types of batteries that RC vehicles use. This online source is called "RC Plane Battery Guide" [19] and they cover the two major batteries used in RC planes. The two main batteries used in RC planes are Nickel Cadmium (Ni-Cd) and Nickel Metal Hydride (Ni-MH) One benefit to the Nickel Cadmium battery is that it has been around the longest and is obsolete to assemblies. One disadvantage these batteries have is that they suffer from memory effects and are toxic. They tend to lose energy quickly. Ni-HM batteries are cadmium free and don't suffer as bad as the Ni-Cd due to memory effect. They have a pretty good energy retention and are very efficient. Other than how they operate; they have a lot of similarities to each other when manufactured and built. The battery packs usually consist of cylinder-shaped cells which are easy to store within a cargo space. The cells are usually oriented in series to determine voltage. This entire article was very helpful to understand the benefits to the different types of batteries and helped team Sol Avem select the most efficient battery for our situation.

3.1.4 Radley Rel

The technical aspect this student worked on was the on-board systems. This includes all electronics and configurations within the aircraft design. This student provides detailed analysis of the advantages and disadvantages of the components needed to ensure all engineering and customer requirements are met. Below are 4 unique sources that aided in the facilitation of this student's technical focus. In addition to the 4 unique sources, this student conducted a faculty advisor meeting with David Willy. David Willy has in-depth experience in avionic design and aerodynamics.

Solis Fur Assembly Manual:

Although Solis Fur did not complete all their customer and engineering requirements within the allotted period, there is a lot of useful information that Sol Avem can learn and utilize in selection of the on-board components and configurations. The Solis Fur assembly manual contains a complete list of the team's bill of materials and assembly tools. It also contains instructions of the wing, fuselage, horizontal/vertical tail, and electronics construction. Page 14 and 15 of the assembly manuals are extremely valuable to Sol Avem because it has detailed instructions of the configuration of their on-board electrical components. As mentioned above, Solis Fur did not fully complete the requirements set in place by the customer and the team's engineering requirements, but there is useful information of how to get started and what to look for when configuring the electronics. Sol Avem will be utilizing this assembly manual to aid in the configurations of the on-board systems.

Online Source:

No one on Sol Avem has built a RC plane before, but luckily there are plenty of free online resources that the team can utilize to have successful communication throughout the onboard systems. The team decided it would be necessary to have a beginner's guide to RC components, their capabilities, and how to configure them. Within this online source called The Beginners Guide to Your Rc Plane Electronic Parts, the reader will find 11 separate steps detailing each specific component necessary to design a successful RC plane. This beginner guide is especially valuable because not only does it list the functions of each on-board component and mates them with pictures and description to aid in the design process, but the author also gives advice as to where to buy the components, and more importantly how to pick and pair components based on previous selections.

Servo motor used in RC Airplanes

The Beginners Guide to Your Rc Plane Electronic Parts

Online Source:

After exhausting the Beginners Guide to Your Rc Plane Electronic Parts, Sol Avem felt that it would be necessary to provide a more advanced guide for component selection and configuration. The Making of a

Radio-Controlled Plane contains valuable information about not only the functions of components and how to correctly pair them, but they also provide useful calculations to ensure the component selection will take account for Sol Avems specifications (weight, thrust, lift, and drag). Sol Avem is currently drafting up 2D calculations and will be ordering parts soon based on these calculations and useful equations provided by this guide.

Journal Article:

In 2007-2008 a mechanical engineering capstone team like Sol Avem at the University of Tennesse was tasked with creating a radio-controlled aircraft capable of carrying multiple payload configurations for the AIAA (American Institute of Aeronautics and Astronautics) design/build/fly 2007-2008 competition. Within this journal article Sol Avem is particularly interested in their component selection, configuration and manufacturing plan. Within this section of the journal article, the author/s go in depth as to why they picked the components they did, as well as including all hand calculations. This is extremely valuable to Sol Avem because the team is currently in this phase of capstone.

Faculty Advisor Meeting:

As previously mentioned, team Sol Avem has a faculty advisor assigned to them to ensure smooth transitions between initial benchmarking up to final design testing. Sol Avem's faculty advisor is Dr. David Willy. Dr. David Willy is an experienced mechanical engineer with industry experience in the renewable energy fields. Specifically performing wind and solar variability grid integration research for the institute for Sustainable Energy Solutions (ISES), as well as experience in manufacturing, design, and contract engineering. Team Sol Avem meets with David Willy once a week to present current and future progress on the team's solar UAV. In turn David Willy provides excellent feedback and advice on that current and future progress. David Willy also pushes the team to ensure they are meeting the customer and engineering requirements. Currently David Willy has asked team Sol Avem to compile a specifications table to aid in the selection and pairing of the team's components.

3.2 Benchmarking

[Provide the information from ME 476C final proposal report on the benchmarking done in the first semester. Mitigate any and all issues from the last report.]
[Use this section to describe the benchmarking process. Benchmarking involves on-site visits to organizations, observation, and interviews with employees to see how others have approached this type of design problem. Benchmarking can also be done online through extensive research. Based on your completed Original System analysis and the Project Description, identify relevant problems / issues / opportunities that would benefit from the Benchmarking Study. More than one area of the project should be identified for benchmarking. Include the findings of the Benchmarking Study in the remaining sections of this chapter.]

Benchmarking within Sol Avem was a crucial part of the team's concept generation. After crucial literature review, (page 28 and 29) the team discussed 3 existing designs and 3 subsystem designs relevant to Sol Avem's engineering requirements. In the existing design sections below, the reader will learn about two previous NAU capstone teams that were tasked with creating a solar UAV. These collegiate teams are Solis Fur and the ULSA or ultra-light solar aircraft. The third existing design the reader will learn about is the Solar Impulse model 2. This solar plane was the first completed flight around the globe, approximately 25,000 miles, using only solar energy to power the flight. The nine subsystem designs Sol Avem researched were the on-board components and construction (electrical systems and configurations) of the three existing designs. Sol Avem wants to ensure the success of the customer and engineering requirements. To achieve this goal, detailed analysis of the three existing designs and nine subsystems is necessary.

3.2.1 System Level Benchmarking

[Use this section to discuss existing designs that address requirements relevant to your project at the system level. For example, if you were designing a race car, one would use this section to describe entire race cars meeting similar or related requirements. List at least three system-level designs and add more as necessary. Cite the sources from which the designs were identified, including your own benchmarking results, if appropriate. Use this section to describe the rationale for your selection of the systems described in the following subsections.]

Below are the descriptions of the system level benchmarking for Solis Fur, ULSA, and Solar Impulse 2. The reader will find the general project description of each existing design, the relation to Sol Avem's engineering requirements, and a thorough analysis of the success and failures of each existing design. System level benchmarking is to be considered a necessity before taking the initial steps of concept generation. The system level benchmarking will allow Sol Avem to bypass previous failures, ensuring a smooth transition from concept generation to initial prototyping.

3.2.1.1 Existing Design #1: Solis Fur 2018 Capstone Team

[Describe this system-level existing design and explain how it relates to your requirements. Cite all textual information and figures.]

The Solis Fur collegiate capstone team was formed in august of 2018. The makeup team consisted of 5 mechanical engineers and David Trevas, a former mechanical engineering professor at NAU who Solis Fur's faculty advisor and project sponsor was. The teams project description and customer requirement via their website was to "design and build a solar powered aircraft capable of sustaining indefinite flight while the sun is out" [18] Their engineering requirements was to minimize UAV weight and drag, while maximizing lift. Their team placed a high importance on the UAV's aspect ratio. The aspect ratio (AR) is the ratio of the wingspan to the chord length. Higher aspect ratios mean the aircraft has wide short wings. The aspect ratio that team Solis Fur was aiming to achieve was on the low end (long wingspan with short width), as seen in their final design below. On Solis Fur's website there was no available house of quality, however on their front page under project description, they decided the variable that held the utmost importance was the weight. The customer and engineering requirements are homogenous to Sol Avem's. Sol Avem's faculty advisor expects to see the solar panels power 1.5 times the onboard battery capabilities, unlike Solis fur's requirement of having sustained flight while the sun is out. Unfortunately, Solis Fur was not able to achieve their goal in the allotted period given to them, however they continued to work on the project. The team was able to achieve flight times of 140 seconds (about 2 and a half minutes) gaining an elevation of 170 feet from the ground. The team was not able to integrate the solar to power the onboard battery, however. Below is a picture of the final design from Solis Fur.

Figure 14: Final Design of Solis Fur

3.2.1.2 Existing Design #2: ULSA 2016 SAE Aero Capstone Team

[Describe this system-level existing design and explain how it relates to your requirements. Cite all textual information and figures.]

The Ultra-Light Solar Aircraft (ULSA) capstone team was created in response to the inability to compete in the SAE Aero competition in August of 2016. The makeup team consisted of 6 mechanical engineers and David Trevas, a former NAU professor and the team's faculty advisor. The team, MACH6, set out to expand the preexisting requirements implemented for SAE Aero teams. MACH6 aimed to create a radio-controlled plane that was able to maintain a fully self-sustained flight harnessing solar thermal energy using photovoltaics (solar panels). MACH6's engineering and customer requirements via their website (provided in references) was to maximize the strength to weight ratio while still able to maintain a self-sustained flight. MACH6 also decided to place importance on the installation of a on board data logger and test flight camera which could record energy production, consumption data from solar cells, and record visual data. These engineering and customer requirements are dissimilar to Sol Avem's. Team Sol Avem places the highest importance on the powered flight aspect of the customer needs, due to the two previous teams either not being able to take flight or expend their allotted period. Due to the complexity of their design, shortcomings with onboard electronics, and the aircraft weight, MACH6 was not able to conduct a successful launch of the HELIOS after three failed flight tests. Sol Avem places a high importance on prototyping and test flights early and often to ensure the team achieves its goal of solar integrated flight. Below is a picture of MACH6's final design, HELIOS.

Figure 15: Final Design of ULSA Team MACH6. The HELIOS

3.2.1.3 Existing Design #3: Solar Impulse 2 – Solar Powered Aircraft

[Describe this system-level existing design and explain how it relates to your requirements. Cite all textual information and figures.]

The Solar Impulse 2 is a solar powered aircraft awarded the world's first flight around the globe (25,000 miles) using only solar energy. Solar Impulse 2, unlike the previous 2 existing aircraft designs, this design was mostly successful in completing its customer needs and engineering requirements. The makeup team consisted of about 90 people, including 30 engineers, 25 technicians, and 22 mission controllers. The Solar Impulse project was supported financially by over a hundred partners and advisors. The project description was to create an aircraft that could travel 40,000 kilometers without any fuel, using photovoltaics to power the flight. This was the first aircraft created to successfully achieve this goal. It is a staple benchmark in the solar powered aircraft community and should be recognized as such. This large aircraft was tasked with being able to efficiently harness the energy from the sun to power on board components indefinitely. To do this, the Solar Impulse team needed to create a design prototype that would have enough solar panels to achieve this goal. Aircraft design is linear in that if you change one variable, you will be affecting all other variables (thrust, lift, drag, and weight). To create a perfectly balanced system, the engineers needed to design an aircraft that could have enough planform area on the wings to hold the massive number of solar cells. Due to the efficiency of the thin film solar cells, an impressive 17,248 photovoltaic panels were installed across the 235-foot wingspan. The solar impulse 2 weighs 3,527 pounds, has a cruising speed of about 56 Mph and a top speed of 87 Mph. For reference, a Boeing 747 jumbo jet has a wingspan of 225-feet, weighs 404,600 pounds, has a cruising speed of 565 Mph and a top speed of 614 Mph. Sol Avem is not going to design anything nearly as large as this pilot operated solar aircraft, however the team can use this engineering accomplishment as a staple benchmark to achieve the customer and engineering requirements. Below are pictures of the final design of the Solar Impulse 2.

Figure:16 Solar Impulse Flight Leg 9 – Hawaii to San Francisco

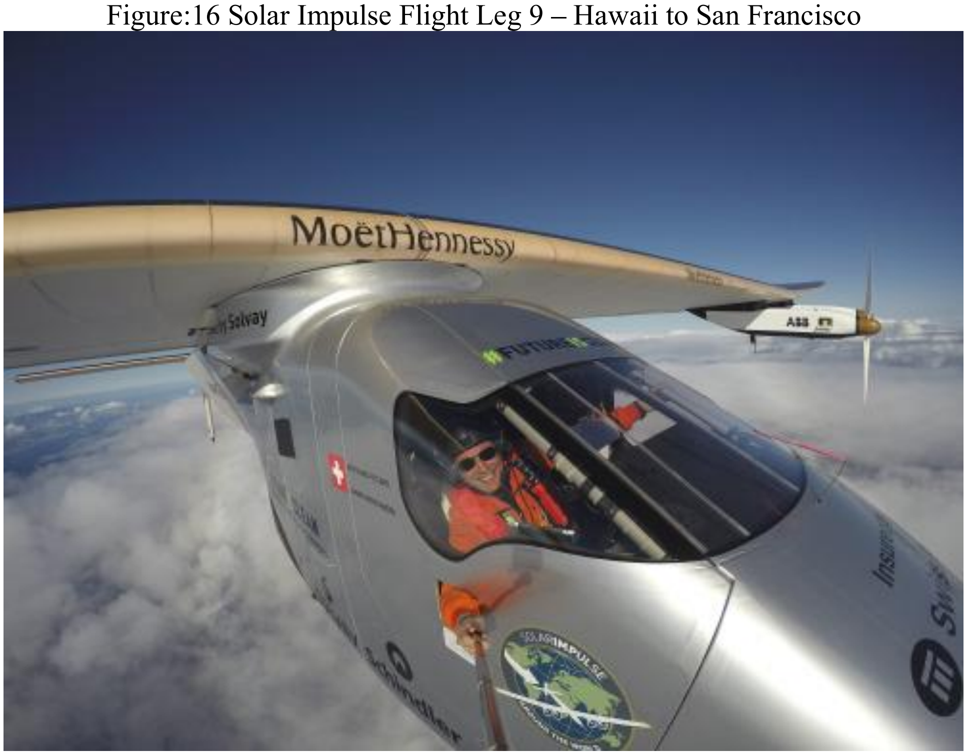


Figure 17: Bertrand Piccard over the Atlantic Ocean approximately 30,000 feet in elevation

Figure 18:Solar Impulse 2 Team including Engineers, Technicians, and mission controllers

3.2.2 Subsystem Level Benchmarking

[Use this section to discuss existing designs that address requirements relevant to your project at the subsystem level. Under each subsystem heading, list existing designs meeting similar or related requirements. There must be at least three existing designs described under each component/subsystem.]

In researching benchmark designs, Sol Avem placed greatest importance upon three subsystem designs within each of the existing designs. These are the onboard electrical components/configurations, the airfoil and wing design, and solar cell selection. Below the reader will learn about each of these subsystems implemented onto the Solis Fur, ULSA HELIOS, and the Solar Impulse 2.

3.2.2.1 Subsystem #1: Solis Fur Subsystems

[Describe this subsystem from your functional decomposition. Discuss why this subsystem is important to your overall project.]

3.2.2.1.1 Existing Design #1: Electrical Components and Cconfigurations

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

Solis Fur provided an assembly manual and complete bill of materials, in case another team wanted to replicate/improve upon their previous design. On pages 14 and 15 within the assembly manual, the reader will find the complete electronics configuration. Solis fur decided to go with a basic electronics setup with a data logger. The setup is as follows, (figure will be provided below for visual representation) a Hobby Sky 360 kv motor, wired to a Turnigy Plush 60-amp electronic speed controller (ESC). The ESC and motor were attached to an Eagle Tree RPM sensor which was relayed to the Eagle Tree Elogger V4 data logger. Solis fur decided to also attach a Eagle Tree GPS and an Eagle Tree pitot tube sensor (airspeed sensor). Solis Fur routed 2 Parkzone DSV-130 Servos to a FR Sky X8R Radio Receiver. This receiver is wired to the Turnigy 60A ESC. All these components wired to the data logger were connected to a Switching Relay. A Turnigy 2200mAh battery was also wired to this switching relay. The main power source was 30 thin film C60 solar cells connected by 45 C60 Solar Cell Dogbone connecters. These connecter ends were wired to the switching relay, in turn powering the battery. The onboard component configuration was almost successful however Solis Fur could not get the solar cells to charge their battery within their allotted period. Based on this information, Sol Avem has decided to use a charge controller, and play with the configurations once we have ordered all components.

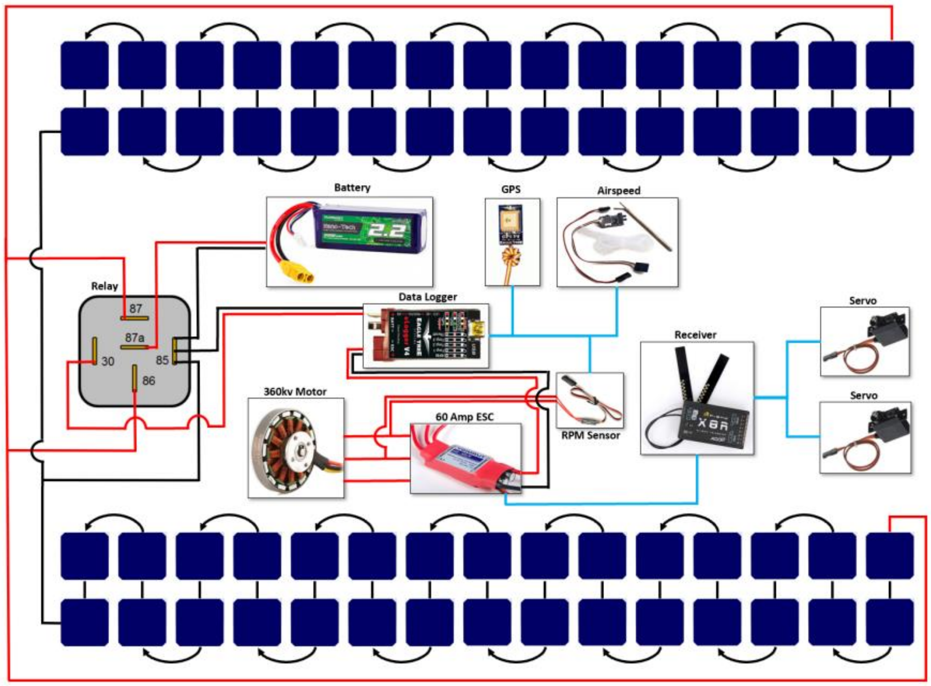


Figure 19:Solis Fur on Board Electronic Configuration

3.2.2.1.2 Existing Design #2: Solis Fur Air Foil and Wing Design

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

The air foil design that Solis Fur decided to use for their final design was the NACA 4412. Solis Fur used 16 total Balsa wood 4412 foils. Solis fur constructed the wing using 2 13mm (about 0.51 in) carbon fiber wing spars, and 4 5mm (about 0.2 in) carbon fiber support rods. These spars and rods were placed inside of the balsa wood to give the wing design the strength it needed to hold all 30 C60 solar cells. The reason for choosing NACA 4412 is that it is a mostly flat bottomed designed with a with a non-aggressive camber over the top of the wing. When an airfoil design is mostly flat, it provides for easy construction of the wing itself. Flat bottomed airfoils are also easy to predict the stall characteristics, making it an ideal choice for radio-controlled aircraft. Sol Avem is still researching what airfoil design best suits our two aircraft designs we have decided to pursue. Seeing that NACA 4412 and Clark Y are both flat bottomed airfoil designs suitable for smaller radio-controlled planes, we will have to further investigate within the wind tunnel available at NAU’s Fluid Mechanics laboratory.

3.2.2.1.3 Existing Design #3: Solis Fur Solar Cell Selection

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

Solis Fur decided to implement 30 C60 solar cells. The C60 solar cell is a mono crystalline silicon panel. These have an efficiency rating of about 22.4%. The C60 solar cell has lower temperature coefficients and lower normal cell operating temperatures. This means that at higher temperatures they can generate more energy when compared to standard C type solar cells. These also have an anti-reflective coating to reduce voltage temperature coefficients. The C60 solar cell is considered a thin film solar cell. This is recommended for the wing design and airfoil choice for Solis Fur's NACA 4412. The camber on the top of the airfoil makes the use of thin film solar cells a great option because they can contour to the shape of the airfoil, maximizing efficiency and are also very lightweight. Sol Avem has decided to use thin film solar cells on both prototypes.

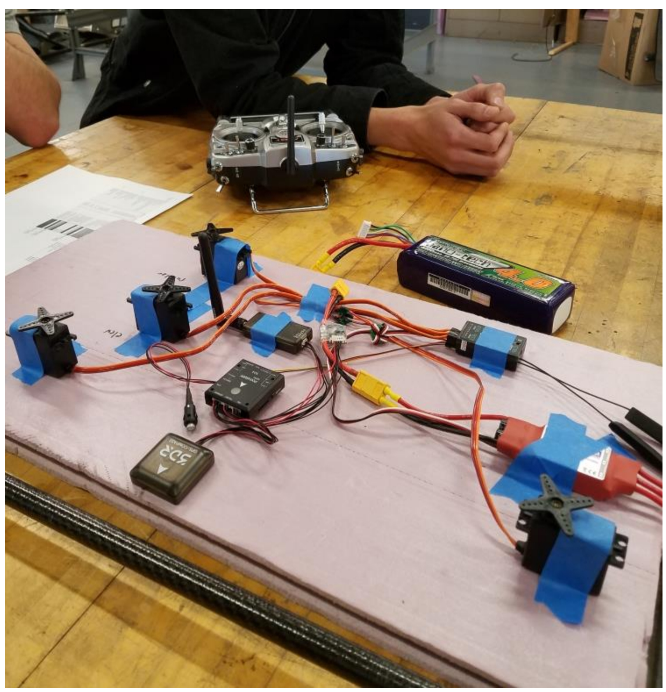
3.2.2.2 Subsystem #2: ULSA HELIOS Subsystems

[Describe this subsystem from your functional decomposition. Discuss why this subsystem is important to your overall project.]

3.2.2.2.1 Existing Design #1: ULSA HELIOS Electrical Components and Configurations

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

Unlike Solis Fur, the USLA HELIOS did not provide a bill of materials or assembly manual available to the public. However, I was able to find pictures in their photo gallery tab of their website of the onboard components and configurations which will be included below. The configurations are very similar to the Solis Fur configuration. The electronics are connected and powered the telemetry circuit board, the GPS unit, and the motor. HELIOS operated on a LiPo Battery and 36 solar cells. A switch controlled the power from the solar cells to the battery from the RC controller. From this switch, the electricity flows into the power module which funnels power to the control board and then into the electronic speed controller (ESC).



3.2.2.2.2 Existing Design #2: ULSA HELIOS Air foil and Wing Design

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

ULSA HELIOS decided to use the S1223 airfoil which has an angle of attack of 3 degrees for their RC aircraft. The HELIOS had a dihedral profile to the wing build. On their website, USLA MACH6 stated that during their test flights, the team tried to increase the dihedral profile hoping they would achieve a greater factor of lift. MACH6 stated that they lacked technological capabilities to accurately find optimal wing dimensions to finalize a design that could generate enough lift to get the plane off the ground. Unlike Solis Fur airfoil and wing construction, MACH6's HELIOS utilized carbon fiber instead of balsa wood (too brittle to endure flight) for their construction. They also made note that the carbon fiber design acted as a conductor with the team's non-insulated busbars connecting the solar cells. This is a hazardous situation because it creates a live circuit when connected to the battery. The wingspan of the HELIOS was 8 feet, chord length of 12.5 inches, and an aspect ratio of 8.35. Sol Avem will ensure that no live circuit is accidentally constructed when manufacturing is underway.

3.2.2.2.3 Existing Design #3: USLA HELIOS Solar Cell Selection

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

MACH6 decided to use thin film solar cells for the same reason as Solis Fur. They are lightweight and able to contour to the shape of the wing design and the foil. They did not state what kind of thin film solar cells they used however they closely resemble C60 solar cells. The 36 solar panels were connected in parallel with a Turnigy switch to open and close this circuit.

3.2.2.3 Subsystem #3: Solar Impulse Two Subsystems

[Describe this subsystem from your functional decomposition. Discuss why this subsystem is important to your overall project.]

3.2.2.3.1 Existing Design #1: Solar Impulse 2 Electrical Components and Configurations

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

For purposes of simplicity, the onboard components are beyond the scope of senior mechanical engineering students since this aircraft is in fact not radio controlled but needs two pilots in the cockpit. The battery operation powering the components was relayed to a lithium polymer battery.

3.2.2.3.2 Existing Design #2: Solar Impulse 2 Air Foil and Wing Design

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

The solar impulse 2 has a wingspan of 235 feet. As mentioned in the existing design description, this plane needed to generate enough lift while being lightweight. The wing construction of the Solar Impulse 2 was made from carbon fiber and honeycomb sandwich panels to ensure the weight variable was kept within the engineering parameters. The solar impulse 2 has an aspect ratio of 19.7. Sol Avem will utilize lightweight materials such as carbon fiber and Balsa wood for the final prototype.

3.2.2.3.3 Existing Design #3: Solar Impulse 2 Solar Cell Selection

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

The Solar Impulse 2 team decided that it would be best to utilize the true amorphous thin film solar cells due to their weight. Thin film solar cells are traditionally less efficient than monocrystalline and polycrystalline solar panels. This means that their planform area needed to be large enough to place these amorphous cells throughout the wingspan to generate enough power output for not only the 4 propellors located on the wings, but also power the onboard systems. That is why the Solar Impulse 2 team installed 17,248 amorphous solar cells across the entirety of the wingspan to ensure they could have a fully self-sustained indefinite flight. Sol Avem plans to design a large enough plan form area of the wing to where we can install enough amorphous cells to power the flight.

4 CONCEPT GENERATION

[Provide the section from the final proposal in ME 476C regarding the concepts that you generated for this project. Mitigate any and all issues from the previous iteration of this section.]

From the decomposition model, Team Sol Avem came up with different types of each sub-function in order to find which combination of each function would be the best design for the solar aircraft. Each function has 5 concepts that were created and took into consideration for the advantages and disadvantages of aircraft design.

Flight Control

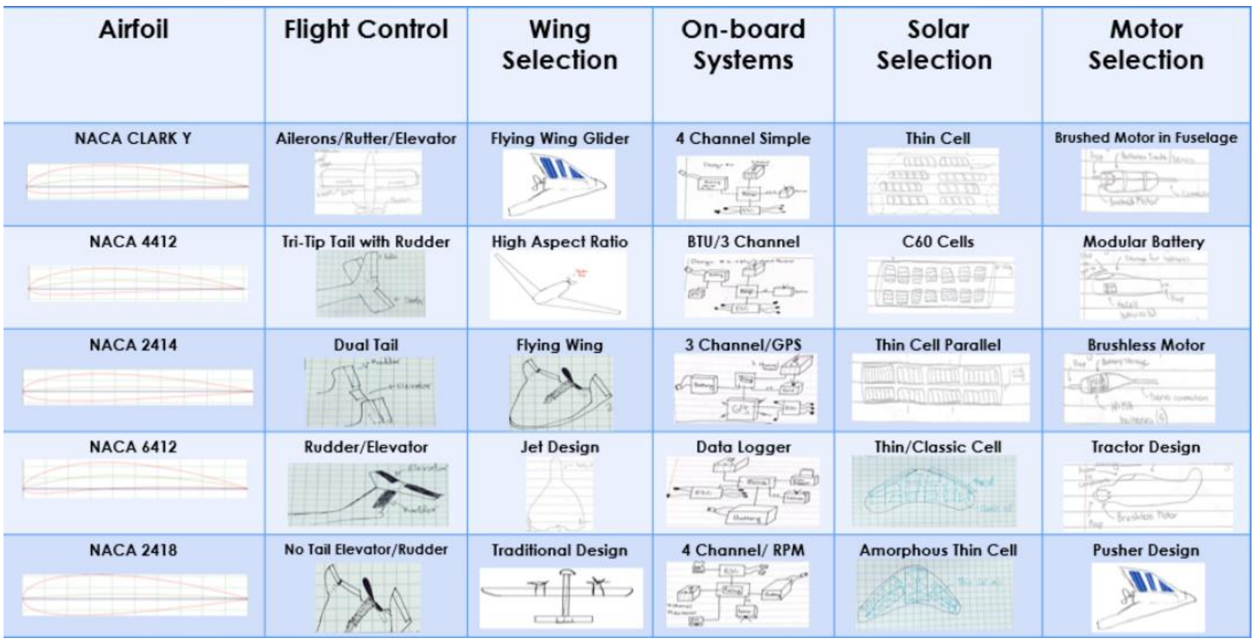
Wing Selection

On-Board Systems

Solar Selection

Motor Selection

Table 6:MORPHOLOGICAL MATRIX



Airfoil	Flight Control	Wing Selection	On-board Systems	Solar Selection	Motor Selection
NACA CLARK Y	Ailerons/Rutter/Elevator	Flying Wing Glider	4 Channel Simple	Thin Cell	Brushed Motor in Fuselage
NACA 4412	Tri-Tip Tail with Rudder	High Aspect Ratio	BTU/3 Channel	C60 Cells	Modular Battery
NACA 2414	Dual Tail	Flying Wing	3 Channel/GPS	Thin Cell Parallel	Brushless Motor
NACA 6412	Rudder/Elevator	Jet Design	Data Logger	Thin/Classic Cell	Tractor Design
NACA 2418	No Tail Elevator/Rudder	Traditional Design	4 Channel/ RPM	Amorphous Thin Cell	Pusher Design

4.1 Full System Concepts

4.1.1 Full System Design #1: Sol AVEM

The Sol Avem design was the first design generated and uses the high aspect ratio wing selection with motor being in the back of the airplane. It has a pusher design when it comes to motor selection. The main cargo area is used for batteries and other servos controlling the airplane.

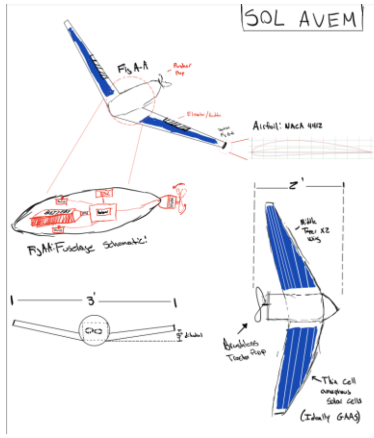


Figure 20: SOL AVEM Design

4.1.2 Full System Design #2: Flying Wing

Design #2 is that of a single airfoil "Flying Wing" design. Pulling inspiration from the B2 Bomber [88], this design maximizes the planform area of the aircraft. In theory the larger planform area available, the more solar energy that can be harvested. Not only does this design maximize the surface area available for solar cells, it is also the most simple design. The Flying Wing utilizes only a motor and two control surfaces, (independent elevators) to control flight. While this option provides a simple and theoretically solar efficient aircraft, it is not perfect. Compared to the previously described "Sol Avem" design #1, this one is not as aerodynamically efficient. The more refined aircraft designs #1 and #3 would have better flight control and higher lift coefficients, but they are both more complicated and could possibly be less efficient at solar energy capture.

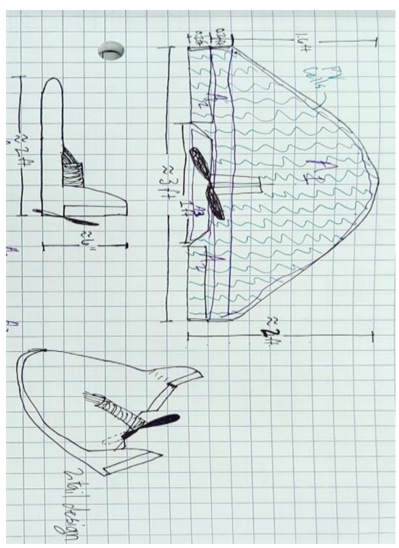


Figure 21:Flying Wing Design

4.1.3 Full System Design #3: Glider

Design #3 represents a more lightweight, durable design approach to the RC aircraft. The design approach's a "glider" assembly with different components to control the flight of the aircraft. The Glider includes one rudder and two elevators on the rear wings. The main wing design has ailerons on each wing to allow for roll and sharper turns while flying. The body of the aircraft is long and sleek with an aerodynamic design to allow for a smooth flight. The front of the body will have an open flap to allow access to the batteries, servos, and stabilizer. Wires will be managed within the body of the aircraft and the wires from the servos to the flight control components will feed through the back of the aircraft. The motor for this design will be a brushless motor with the propeller feeding out of the back of the aircraft. The solar panels will be attached to the surface area across the main wing design. The thin cell solar panels would be used within this design to keep it lightweight and efficient. This design would have a very usable lift and drag coefficient because of the common design of a glider.

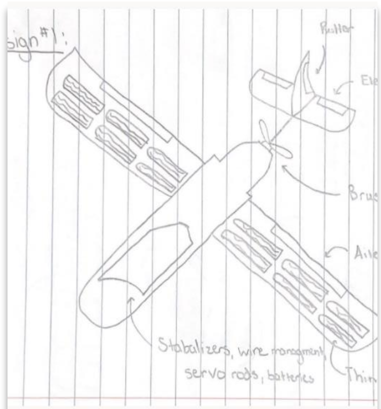


Figure 22:Glider Design

4.2 Subsystem Concepts

The following are the subsystem design concepts for the first stage of our project.

4.2.1 Subsystem #1: Airfoil

The airfoil designs that were created were the NACA Clark Y, NACA 4412, NACA 2414, NACA 6412, and NACA 2418.

4.2.1.1 Design #1: NACA Clark Y

The NACA Clark Y airfoil is a maximum camber of 3.4% at a 28% chord. This allows for a coefficient of lift compared to other airfoils on this list. The high camber however creates a lot of drag making the airfoil overall a high cargo capacity design. This airfoil is to be used in high weight or cargo design.

4.2.1.2 Design #2: NACA 4412

The NACA 4412 airfoil is known as being the most efficient airfoil that is out there. It has a very tapered finish causing its lift drag ratio to be very low. This type of airfoil is best for sports planes that move at very high Reynolds numbers and need fast reaction time.

4.2.1.3 Design #3: NACA 2414

The NACA 2414 airfoil has a max camber of 2% and is relatively symmetrical. This symmetrical design provides very low lift but has a low coefficient of drag. This type of airfoil is best for high maneuverability aircraft such as fighter jets.

Design #4: NACA 6412

The NACA 6412 airfoil is very cambered with a 6% camber at a chord length of 30.1%. This makes for high load capable aircraft at low Reynolds numbers. At an angle of attack of 5 degrees the boundary layer does become separated from the airfoil.

Design #5: NACA 2418

Lastly NACA 2418 is a very symmetric and standard airfoil for high performance. It is typically used in high g-force applications as the turn radius is very sharp. This airfoil has a very low lift to drag ratio resulting in low lift coefficients making the design very specific to light loads.

4.2.2 Subsystem #2: Flight Control

For an aircraft to go where the pilot wants it to go there must be a way to steer and control the flight. The three Flight Control systems that were most highly considered for this project were that of a traditional tail with elevator and rudder, one with only two elevator/aileron combo control surface, and finally one with two elevators and two rudders.

4.2.2.1 Design #1: Traditional Rudder/Elevator Tail

This system design takes inspiration from classic looking airplane tails found on the likes of commercial airliners and Piper Cubs. The advantage is this design is that it provides a high maneuverability with very accurate flight control. The problem is that it requires a whole separate assembly with multiple servos to operate. We want our design to be as simple and as light as possible so this approach might be challenging.

4.2.2.2 Design #2: Two Elevator/Aileron Combo Flaps

This proposed design is the most appealing to team Sol Avem. This design consists of a flying wing that utilizes two flaps in tandem to achieve elevator functions, and then the same two flaps independently to achieve roll and turning. The pro of this design is that it is light and integrated into our airfoil which reduces complication. It might be difficult, however, to program the two flaps to achieve all of the flight control processes required.

4.2.2.3 Design #3: Two Elevators + Two Rudders

This design proposal is a combination of the first two. Working with a flying wing design, this proposes two elevator flaps on the wing and one tail at each wingtip with a rudder. This design would also be a highly maneuverable one that works with the flying wing design. The issue is that it would be very complicated and require at least 3 servos which would add a lot of weight to the aircraft.

4.2.3 Subsystem #3: Wing Selection

The wing selection that was developed are the flying wing glider, high aspect ratio, flying wing, jet design, and the traditional design.

4.2.3.1 Design #1: Flying Wing Glider

The first design for the wing selection was the flying wing glider. The flying wing glider provides a wide surface area and is sleek enough for the L/D ratio to be stable for flight. Now that being said, it isn't the most optimal wing design when considering a heavier payload. For the design of the solar UAV, the payload will be lighter and easier to work with sense the only things accounted for are the material of the aircraft and fuel storage.

4.2.3.2 Design #2: High Aspect Ratio

The high aspect ratio was the second design included in the morph matrix. The high aspect ratio is a very reliable and stable wing design. It is very lightweight, durable, and has a very affective dihedral angle for stable flight. Some of the cons on the design is it not as easy to manufacture and can have major damage if interfered from an outside source because of the configuration of the body. It more fore stable straight flights rather than sudden movement.

4.2.3.3 Design #3: Flying Wing

The third design that was created was the flying wing design. This design is a more unique, rare design that creates a lot of surface area and may result in a more unstable flight. With the goal of having solar panels covering the surface of the aircraft, this design presents the best option for doing that. It has two side wings going up the side of the design. The front of the aircraft has a reversed parabolic figure and expands diagonally to the back of the aircraft.

Subsystem #4: On Board System

The on-board systems that were considered were the 4 Channel Simple, 3 Channel/Data logger, 4 Channel/Data Logger/GPS/Pitot Tube Sensor

4.2.3.4 Design #1: On-board Components- 4 Channel system

The first design considered for team Sol Avems on board components and configurations is a straightforward design consisting of a 4-channel receiver, connected to 4 servos, a 2200 mAh battery, and a 60-amp electronic speed controller all set to the switching relay. This design is the simplest concept which will make it easy to configure. A downside of this design is that it does not have any failure systems like a charge controller or a data logger to view the cause of failure.

4.2.3.5 Design #2: On-Board Components – 3 channel system with a data logger

The second design consists of a 3-channel receiver, connected to 3 servos, a 2200mAh battery, and a 60-amp ESC all set to a data logger which is connected to a switching relay. This design is more complicated than the design one due to the fact you must relay connections through the data logger. The advantage of this is that we will be able to accurately see the efficiencies of our on-board systems in real time. A disadvantage to this is the complexity of connection to the data logger, and making it match to our machines running the data logger open/closed source software.

4.2.3.6 Design #3: On-Board Components – 4 Channel Receiver with data logger, Pitot tube sensor and GPS

The third design is the most complex to configure, however it would be the most beneficial for purposes of flight testing and prototyping. The third design consists of a 4-channel receiver, connected to 4 servos, a 2200 mAh battery, and a 60amp ESC. Sol Avem plans to connect a pitot tube sensor and a GPS as well as all other components relays to the data logger. This design would give Sol Avem the most accurate variable data acquisition amongst the other 2 designs. The disadvantage to this configuration is the calibration with the pitot tube sensor and the GPS, as none of the team members have experience in dealing with these specific components. The Advantage would be that our prototypes (if components are configured and calibrated correctly) will be a true representation of our final design.

4.2.4 Subsystem #5: Solar Selection

Many different solar panels were taken into consideration, but Team Sol Avem narrowed it down to three different selections which include Thin Cell amorphous, C60 Monocrystalline Cells, and Polycrystalline cells.

4.2.4.1 Design #1: Thin Cell – Amorphous

Amorphous thin solar cells are extremely useful when applied to a surface that has contour. These amorphous cells due to their flexibility are also very light. These cells can also withstand higher temperatures without the power output being affected, unlike monocrystalline and polycrystalline cells. The disadvantage to using amorphous cells is that their efficiency is rated at roughly 6 to 7 percent with a theoretical limit of about 15 percent. Due to the low efficiency, the quantity of the amorphous cells needed to power on-board components is much higher than that of mono or polycrystalline

4.2.4.2 Design #2: C60 Cell – Monocrystalline

This solar cell was utilized in both USLA HELIOS and team Solis Fur. C60 monocrystalline cells have a higher efficiency rating at 15 to 20 percent. The C60 cell also has an output voltage of around 0.6 volts per cell. These cells are best utilized in warm weather, making their application in flagstaff during the winter months less than ideal for the team's solar cell selection. This cell is also not flexible, making the contour over a single wing design hard to implement.

4.2.4.3 Design #3: Polycrystalline

The last type of solar cell team Sol Avem considered was polycrystalline cells. Polycrystalline cells have a lower efficiency of around 15-17 percent when compared to monocrystalline cells peak of 20 percent. Like the thin cell amorphous cells this means that you will need to buy more cells to match the same amount of power output as fewer C60 cells. The advantage of Polycrystalline cells is that they are remarkably inexpensive compared to the C60 cells.

4.2.5 Subsystem #6: Motor Selection

The different types of motors that were considered were a brushed motor in fuselage, modular battery, brushless motor, tractor design and pusher design.

4.2.5.1 Design #1: Brushed Motor in Fuselage

The brushed motor in fuselage was the first design created for motor selection. This type of motor is the most used motor in RC airplanes. It can produce a lot of power and can push a lot of weight if need be. The problem with brushing is that the motor has a tough time running for long periods of time and isn't as efficient as other options. It can also produce a lot of heat if not maintained right.

4.2.5.2 Design #2: Brushless Motor

This design was the other option of the two main motor types. The brushless motor is a very efficient motor that is also used in RC airplanes. It does not have an iron core and doesn't really overheat. It can create a consistent amount of energy but doesn't produce a lot of it. It is a very small motor and cannot produce a lot of RPM's. It is usually used for indoor RC airplanes that don't require a lot of power to operate. The pay load of those airplanes is a lot less compared to the design of the solar UAV.

Design #3: Tractor Design

The tractor design is more of placement of the motor itself. The tractor design pulls the aircraft through the air with the propeller being at the front of the aircraft. This is a very efficient way of gaining power through the air. If any crash or mistake happens in flight, the tractor design is more prone to severe damage with the motor being in the front. The motor being in front of the plane does balance out the aerodynamic of the airplane but can have consequences based on the placement.

5 DESIGN SELECTED – First Semester

[Put introduction to this chapter here. Describe what is contained in the chapter before leading into Section 5.1. You may use the text from the Final Proposal from ME 476C provided any and all issues are mitigated.]

[Use this section, with additional subsections as appropriate, to fully describe your design. Include descriptions of how the design has changed since presented in the Preliminary Report and why those changes were made.

Show engineering calculations (or if lengthy, place them in an Appendix and refer readers to that part of the report) to justify the proposed design. Create, and refer to, detailed engineering drawings, 3D models, parts and materials used, simulations, facility layouts, or other appropriate tools to completely specify all aspects of the design. **Include pictures of the prototype constructed during Fall Semester with a description of what you learned by doing the prototype and what changes to the final design were made due to the construction of the prototype**.]

This chapter will focus on the iterative design process and testing results our team has performed to conclude our design choice. To justify our design selection our team wanted to have qualitative data from practical testing. To achieve this, our team began with creating a wide database of all the components necessary to achieve our customer needs. After, our team began the iterative process by formulating a flowchart of 2-D calculations that we referenced from *Journal of Guidance, Control, and Dynamic*s. These calculations are necessary to meet our customer needs. To be efficient our team automated these calculations by writing several MATLAB scripts that we could then use to evaluate the most practical components for our design. Our team used 2-D calculations and built several of the testing methods around each mentioned in **Error! Reference source not found.** along with performing several computer a ided simulations. Due to time constraints, we were only able to run the **Error! Reference source not found.** and the data will be referenced in this section. The other two testing methods **Error! Reference source not found.** and **Error! Reference source not found.**will be conducted shortly. To continue the design process our team decided to run several structural analyses in place of the other three testing methods. With the full analysis below. At the end of this section, we will conclude our results and explain how we will implement these changes in the future.

5.1 Design Description

5.1.1 Calculations:

From the beginning of this project both our faculty advisor, David Willy, and our industry advisor, Kelly Gallagher, have recommended that we complete 2-D calculations to get a sense of the weights, forces, and specifications that our plane will have to withstand. Initially we gathered all the components both mechanical and electrical. This consisted of the motor, battery, servo, receiver, esc, converter (either boost or buck), charge controller, solar cells, and the chassis material. From there we completed research on each component and created a collective database that formulated all the different components and their specifications. These tables had a range of components from the most expensive to cheapest, so our team had a wide range of choices when it came to decision making. Each table was tabulated based on the necessary information for each component. We did take constant measurements from each component regarding their weight, platform area, and price. These three constants were totaled and averaged and then used to begin our estimation process (Table 5: Motor Database).

Table 6: Motor Database Tabulate Specifications

Motor (Brushless)	Weight (g)	Input Watts	Input Voltage	Planform Area (mm^2)	Price($)	Application
Avian 4260-480Kv Outrunner Brushless Motor	**268**	810	18.5-22.2V (5-6S LiPo)	2623	99.99	Sport airplanes up to 9.5lbs (4310g) and 3D airplanes up to 6lbs (2720g)
Park 370 Brushless Outrunner, 1200Kv with 4mm Hollow Shaft: 3.5mm Bullet	**45.35**	120	7.2-12	1828.8	45.99	Excellent motor for small 3D airplanes 7–14 oz (200–400 g)
Power 360 Brushless Outrunner Motor, 180Kv, 6.5mm Bullet	**500**	6000	44.4	14630.4	413.99	For high-power airplanes weighing 15 to 25 pounds (6.8 to 11.0 kilograms)
Power 32 Brushless Outrunner Motor, 770Kv, 3.5mm Bullet	**150**	800	12-16.8	2880.36	86.99	airplanes weighing 3.5–6 lb (1.6–2.7 kg)
Avian 5065-450Kv Outrunner Brushless Motor	**400**	1200	18.5 - 22.2V / 5-6S LiPo	3366	139.99	Recommended Model Flying weight – 3D 4080 g (9 lbs) - Sport 6520 g (14.5 lbs)

Table 7: Total Weights

	Components	Max (g)	Min (g)	Avg (g)
	Motor	500	45.35	272.67
	Battery	230	16.9	91.6
	Servo (2X)	85	25.2	56.48
	Reciever	80	6	32.4
	ESC	68	5.5	45.7
	Material	1726	192.314	957.65
	Wire	89.13	89.13	89.13
Total w/o Solar (Grams)		2778.13	380.394	1545.63
Total w/o Solar (Grams)	Solar (40%)	3889.382	532.5516	2163.882
Total in Pounds (lbs)		**8.574609**	**1.174074**	**4.770538**

Initially we ran into an issue. We found during this process that each component was in some way a resultant of another. For example. If you want to calculate the overall lift that will be needed for your aircraft, you need the weight and surface area. However, to get the weight you need the overall surface area of the aircraft. Both are related throughout the area, so an executive decision had to be made to start with a rough estimate for the area to move forward.

Equation 7: Weight Summation

$$W_{TO} = \sum W_{ME} + W_{EE}$$

Assumptions had to be made to make the initial planform area estimations so get an exact the estimated area was sent to our CAD manager so he could model his designs around the initial specifications. This allowed us to get a better surface area estimation as SolidWorks can render the exact area based on the actual model of the system. We then took that area and reimplemented it into our flow chart to calculate the lift and drag components that would be acting on our aircraft. A visual aid of this iterative process is shown below.

Figure 23: Iterative Estimation Process

While the CAD manager was designing the model based on the initial area estimations, we designed a flowchart in parallel to continue moving forward. To represent all the separate calculations necessary to have a successful aircraft we used previous research to devise two specific flow charts that would aid in the analysis portion of this project. The first chart ran through the aerodynamic calculations starting with the initial weight then splitting off into lift and drag calculations. The second flow chart would be comprised of the structural components of the design. Each of these flowcharts would guide our design process so we could select the necessary components needed for our design.

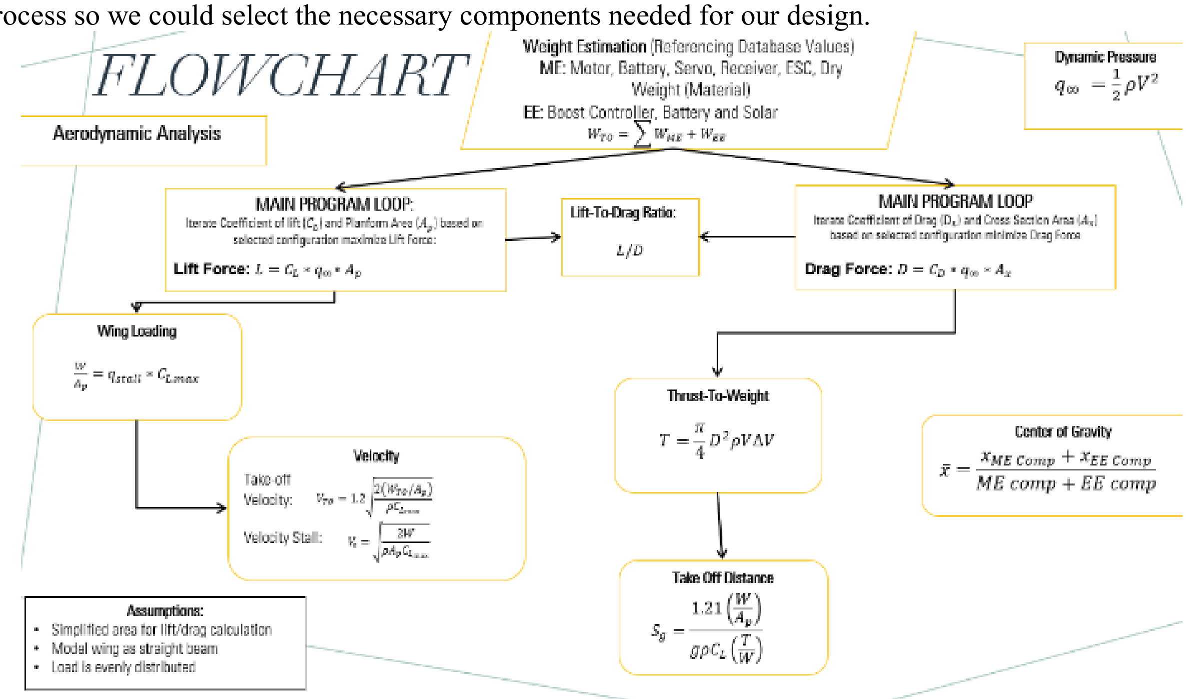


Figure 24: Aerodynamic Flowchart

For the left side of the flow chart, we knew we needed the planform area to gather an appropriate estimation. From there we calculated the wing loading which measures the amount of stress that the wing would be under at any moment during the flight taking the absolute values of coefficient of lift and stall velocity (Equations 2-6). From there the takeoff velocity and stall velocity would be calculated. As you might tell, how can we calculate the stall velocity if the wing loading was used in that calculation and how can we calculate wing loading without stall velocity. This is where assumptions and the iterative process were used to get around this hurdle.

Equation 8: Dynamic Pressure

$$q_\infty = \frac{1}{2}\rho V^2$$

Equation 9: Lift Force

$$L = C_L * q_\infty * A_p$$

Equation 10: Wing Loading

$$\frac{W}{A_p} = q_{stall} * C_{L,max}$$

Equation 11: Take-Off Velocity

$$V_{TO} = 1.2\sqrt{\frac{2(W_{TO}/A_p)}{\rho C_{L_{\max}}}}$$

Equation 12: Stall Velocity

$$V_s = \sqrt{\frac{2W}{\rho A_p C_{L_{\max}}}}$$

The second loop of the aerodynamic flowchart was the drag components. This started again with the weight estimation but uses the cross-section area instead of the platform area for the initial calculation (Equations 7-9). This result was then used to calculate the thrust to weight value. The thrust to weight is especially important as it dictates the amount of thrust that our selected motor will need to produce to get the plane off the ground and climbing (which is typically when the drag forces are greatest). From there we, with the help from the wing loading, would be able to determine the takeoff distance needed which would dictate where we flew the aircraft.

Equation 13: Force of Drag

$$D = C_D * q_\infty * A_x$$

Equation 14: Thrust

$$T = \frac{\pi}{4}D^2\rho V\Delta V$$

Equation 15: Thrust To Weight

$$S_g = \frac{1.21\left(\frac{W}{A_p}\right)}{g\rho C_L\left(\frac{T}{W}\right)}$$

The next flow chart focused on the structural components of the design. Several assumptions were made to make these calculations feasible. These assumptions consisted of modeling the wing as straight beam and loading the wings evenly across the whole span. These assumptions were necessary for the initial calculations to determine a starting point. Once we gathered the rest of the results, we will be able to go back and reduce the number of assumptions to gather a more exact estimate. For the structural analysis we focused on the loading, shear force and bending moment. Each of these approximations would be integrated into the bending stress estimation. Once we have the bending stress, we could evaluate materials and narrow down the search down based on the yield strength and necessary modulus of elasticity needed to support our values.

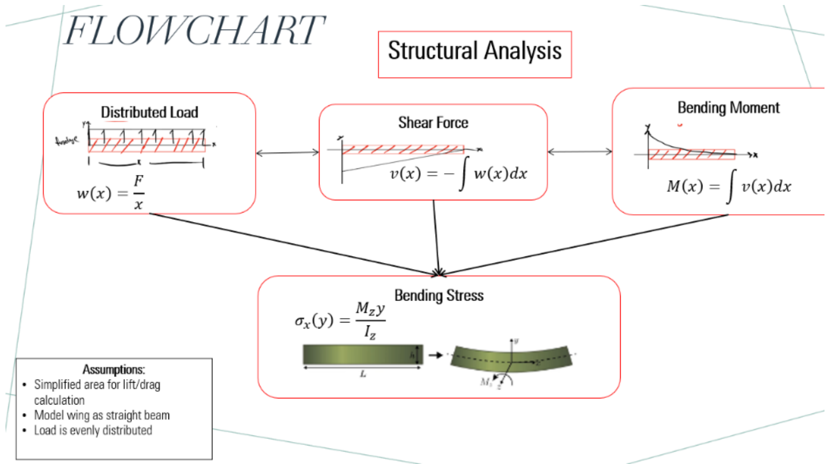


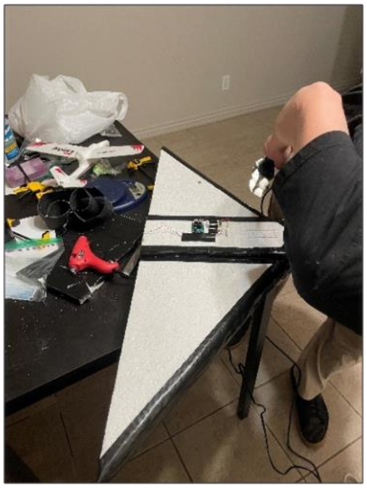
Figure 25: Structural Analysis Flowchart

5.1.2 Prototyping:

On March 29th, 2022, two engineers from W.L Gore came into our capstone section to discuss test methods and prototyping. They began with the discussion with the iterative process of prototyping and using what you learned from your first iteration and incorporating it into each version until all customer needs are satisfied. They mentioned having milestones throughout the process to evaluate the feasibility of the design to make sure you were on schedule. Our team took notes from this lecture and integrated it into our prototyping phase. We began by laying out exactly what we wanted to learn by this prototyping phase. Our team determined that the design selection was the first step towards the final design. So, we gathered materials from the local hardware store and began fabrication. We created both Sol Avem and Single Wing Design. We took both those models and used the testing procedures from **Error! Reference source not found.** to conclude our low fidelity prototyping phase.

Figure 26: Sol Avem Construction

Figure 27: Sol Avem Low Fidelity Prototype



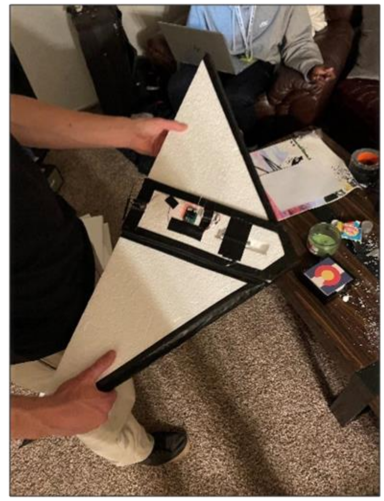


Figure 28: Single Wing Construction *Figure 29: Single Wing Low Fidelity Prototype*

5.1.3 Design Selection Results:

The first test that we ran was based off **Error! Reference source not found.** was to conclude which a ircraft design we wanted to move on with the Sol AVEM design or the Single Winged aircraft. The focus of this test was to prove which design would be more efficient. Our team made sure to keep the testing factors as constant as possible to avoid errors in the results. To do this we preformed the test inside the Rolle Center on campus, had the same trajectory, and take off velocity all which is recorded in **Error! R eference source not found.**. We conducted several trials from each design and used Logger Pro to solidify our results. According to our data the Single Wing design not only had an increase flight time and glide distance. It also had a more gradual Y velocity. This meant that the aircraft actually 'fell' slower. During the flight test the right wing on the Sol Avem became detached from the fuselage meaning there was high stress concentration at the fuselage. Our team took note of this failure and added it to the importance of the design. Also, during the fabrication process of both designs we came into various problems with constructing the Sol Avem. This was due to the more complex geometry such as the rounded fuselage and angled wings. We had initially thought this would make the aircraft more aerodynamic but according to our results we were wrong. Since this test was constrained by the above testing procedure our team is confident with our results and have collectively decided to move forward with the Single Wing design. From this point on we will be calling the Single Wing design 'Sol AVEM' to keep correlation with our team's name.

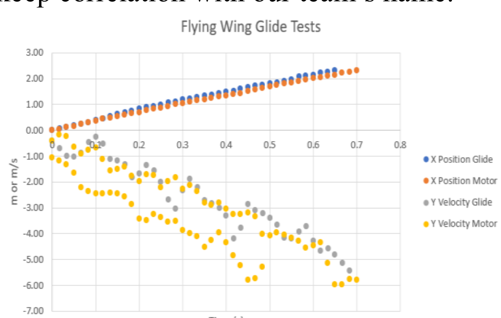


Figure 31: Flying Wing Logger Pro Results

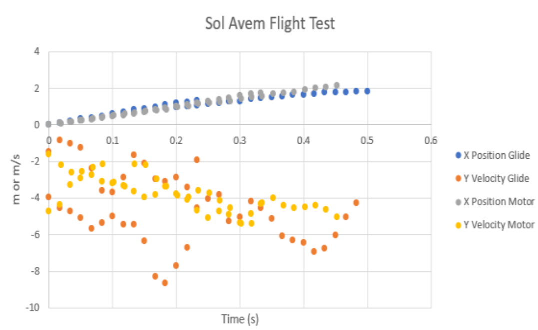


Figure 30: Sol Avem Logger Pro Results

5.2 Implementation Plan

Throughout the design of the solar UAV, we have learned just how iterative design from scratch can be.

Especially in aerospace. Since there are so many components that rely on each other every single component must be on a constant cycle until a design converges. To automate this our team has implemented several computer software's to aid in this cycle. We have implemented several MATLAB scripts to run our theoretical calculations. Also, until we can **Error! Reference source not found.**, REF _Ref100346236 \h **Error! Reference source not found.**, and **Error! Reference source not found.** our team has used SolidWorks simulations to get supportive data. From this data we will continue to adjust our design until all our customers' needs are satisfied. Our goal is to implement these design modifications into our end of semester prototype so that we will be able to be up and flying by the first couple weeks of next semester.

5.2.1 MATLAB:

Throughout this process we have come across multiple instances of components that overlap each other. Since so many systems directly correlated with one another our team had to make more of an educated guess as starting points using past teams. For example, if you found out that you needed a larger battery to support all your systems then that would end up changing your overall weight which then might need a larger motor to produce enough thrust to get off the ground. This process became very redundant and time consuming. To get around this issue we took advantage of our computers. Our team is well versed in MATALB, a multi-paradigm programming language that is very efficient at numeric computing. We wrote several MATLAB scripts that would take our theoretical calculations and allow us to input any type of constraints that were needed. For the lift script we took several NACA airfoils from the *Airfoil Tools* database. We were able to compare each airfoil against each other and found that the NACA 6412 and Clark Y airfoils produced the most lift with the least amount of drag at Reynolds numbers under 300,000. We concluded that we could max out about nine pounds of lift which is more than our max weight according to our component database. Taking advantage of MATLAB to automate the computational process saves our team hours of time that we can use to fabricate and test.

```
% ME 476C
% Mitch Anderson
% Capstone Inital Weight Estimation
%03/9/2022

clear; clc; close all;

%NACA data
xlsread('NACA.xlsx')
%Constants
V = input('Enter Flight Speed (m/s) = ');
Area = 0.2321;
Temp = 298.15;%Standard Temp in Kelvin
c = 0.1524; %in meters but equal to 1ft
c_l = input('Enter Lift Coefficent for specific NACA airfoil = ');
P_s = 105.68*10^3 %Static Pressure in Flagstaff kPa(kg/m*s^2)
R = 287.05 %Ideal Gas Law Constant of Air (J/kg*K)
d_visc = 1.738*10^-5 %Dynamic Viscosity of Air at 20 o C Ns/m^2
g = 9.81 %gravity in (m/s^2)

%Calculations
%Density in Flagstaff
rho = P_s/(R*Temp)
%Dynamic Viscosity
q_inf = .5*rho*V^2

%Reynolds Number
Re = rho*V*c/d_visc
if Re <= 5*10^5
    fprintf('Flow is Laminar')
else
    fprintf('Flow is Turbulent')
end
%Lift Calculation
L = c_l*q_inf*Area

%Weight
W = (L/g)*1000
W_l = W*0.00220462
```

Figure 32: MATLAB Lift Force Script

5.2.2 Structural Analysis Results:

In continuing the design process and meeting our customers' needs our team constructed a testing method to measure the reliability and durability of our design. Due to strict time constraints and other priorities such as electrical system testing and several presentations our team has not had the chance to implement **Error! Reference source not found.**. Instead, we decided to take advantage of SolidWorks highly a ccurate simulation features. We ran several computer aided tests on the design to predict the points of failure. This would enable our team to adjust our design accordingly before taking money out of our budget and purchasing supplies that might not be sufficient.

The first structural analysis conducted was a static analysis of the aircraft to determine where the highest points of stress, strain and displacement would occur. For this analysis material does not have a huge impact on the results. Yes, the magnitude of the resultant forces would be impacted however, the areas of concern would not, and the areas is what we were trying to determine with these tests. For this analysis we selected the material to be balsa wood uniform throughout the design. This is again not our design proposal, but balsa wood has similar properties that our team would like to use. We selected the sides of the fuselage to be the fixture place where the bending would occur. We then put wing loading equal to the maximum weight of our aircraft design, 8 and a half pounds uniformly across both the wings. As seen in figure (X and Y) the greatest amount of stress and strain occurs at the edge of the fuselage. This confirmed our initial guess from the failure of the initial sol avem in the design test. This test also produced great deflection points to consider as well. According to figure (X) at high amounts of strain the wing tips will be the first to deform. This is due to the lower amount of surface area found at the edge of the wings.

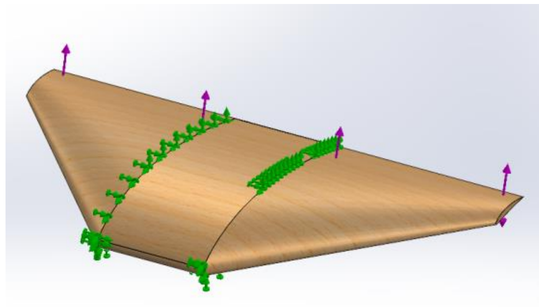


Figure 33: Sol Avem Loading and Fixtures

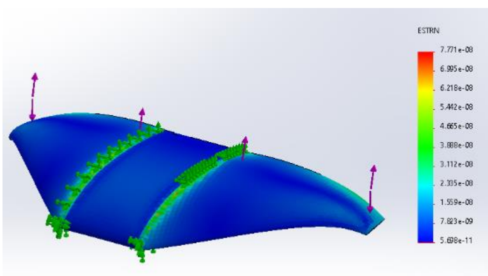


Figure 34: Sol Avem Strain Test

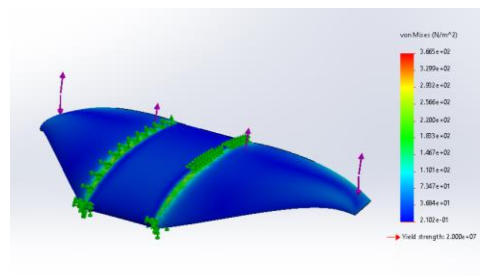


Figure 35: Sol Avem Stress Test

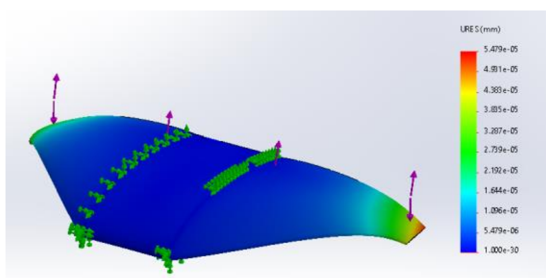


Figure 36: Sol Avem Wing Loading

The next structural analysis that our team conducted was the drop test. Again, we used balsa wood for this analysis as we were only focused on the area of failure. We assumed the only force acting on the body is gravity, and the surface area is constant so the drag force opposing gravity would be equal as our actual model. For the first drop test we chose to test from 10 feet above ground with gravity acting at the centroid of the aircraft. We chose this height after referencing the **Error! Reference source not found.** as w e determined this would be the maximum height our aircraft would reach if a system were to fail right after takeoff. Based on Figure 37: Sol Avem Drop Test (10 Feet) we concluded that most of damage would be caused on the rear end of the plane. This is due to the design being thinner and tapered off at the tail end. We will take this into consideration when redesigning the aircraft. We will aim to add more support towards the back end with either stronger material or by making the rear thicker. The only constraint that we will want to stay in is making sure the aircraft is still streamlined after making these changes. If the tail end is too rigid and cutoff the boundary layer will become detached at a lower angle of attack making the stall velocity lower. This would be detrimental to our design so we will find a happy medium between the two and test different designs during our next round of prototyping.

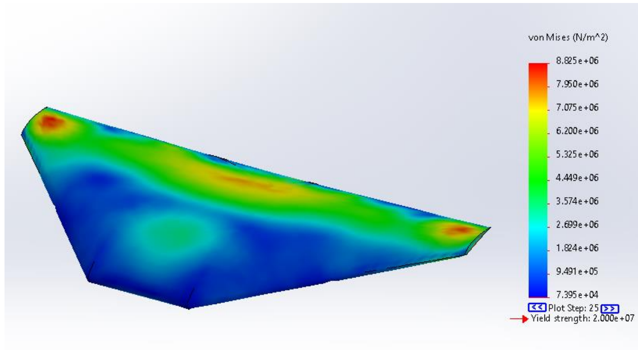


Figure 37: Sol Avem Drop Test (10 Feet)

The next drop test that was considered was mid-flight failure. Our team concluded based off past capstone team's flight data that a maximum height that our aircraft would reach 50 feet. We used the same method as the 10-foot drop test and found opposing results. At this height the strain and stress would be directed towards the center of the aircraft according to figure (X). This was a little daunting as we plan on housing all our electrical components in the fuselage. Our design team has taken this data and will be implementing the results into our next prototype. We plan on constructing the fuselage out of still a light-weight material but one with a higher yield strength such as carbon fiber.

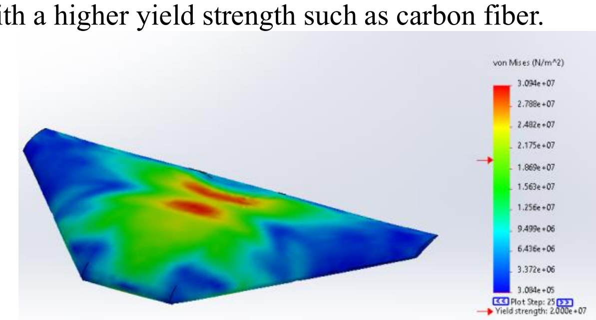


Figure 38: Sol Avem Drop Test (50 Feet)

5.2.3 Future Implementation:

Our team has methodically taken notes from each test and analysis and will use them to improve the overall design of our aircraft. So far, we have concluded that we need to protect our components on the trailing edge like alerions and motors. These components are subject to high stress if the aircraft is to fail after takeoff. We will also be implementing a more durable material for the fuselage like carbon fiber. Since these are subject to large amounts of strain and stress after a midflight fall, we want to protect all our on-board electronics as best as possible. The remaining components such as the solar panels are very light weight and relatively inexpensive. We would rather they take the blunt of the impact as they are replaceable. As mentioned in **Error! Reference source not found.** we want to mitigate issues with t emperature deformation, connection issues, and impact fatigue. We will consider each of these three failure sections separately and make sure they are all taken into consideration during our next prototyping phase. Currently our we have created two separate CAD models for our **Error! Reference source not f ound.**. We will be 3D printing both models and testing each model in the wind tunnel to determine which profile is more aerodynamic.

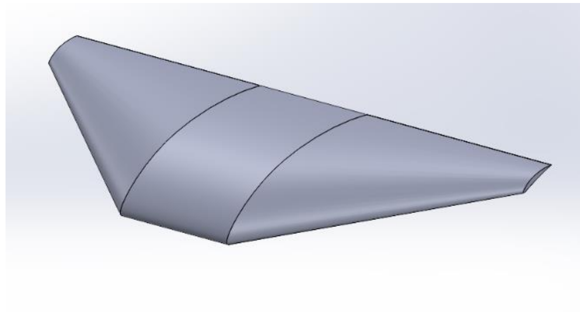


Figure 39: Wind Tunnel Testing CAD CLARK Y

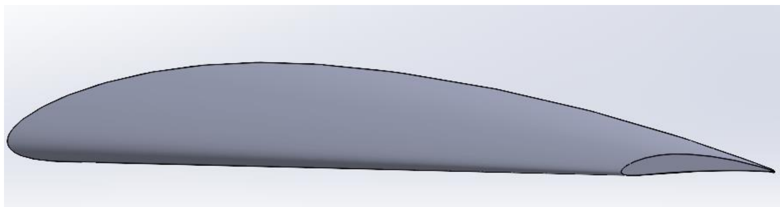


Figure 40: Wind Tunnel Testing NACA 6412

Once results have been analyzed and adjustments have been made, we will conduct physical load testing to our prototypes according to **Error! Reference source not found.** along **Error! Reference source not found.** to confirm these results. If data does not agree with these results our team will go back to the simulation and add more boundary conditions that may have been assumed in these tests such as materials and gravity. According to our schedule we have the next three weeks to implement our designs to complete our final fabrication. Next week we will be defining our materials according with the testing method to make sure our analysis is complete. Week two will be working on chassis and implementing the best stress control concluded from the simulation and testing methods. Week three will be testing our electrical components and completing a prolonged flight with the chosen components. Throughout this whole process our team will be directly communicating with our electrical counter parts to make sure our design achieves their constraints as well.

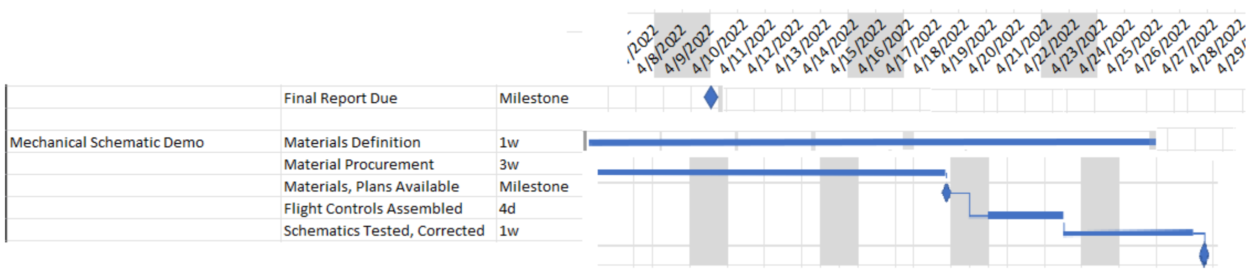


Figure 41: Implementation Schedule

Currently our team has spent about a third of our total budget. Our team has collectively decided that it is important to allot a fair amount of our budget into prototyping as if we do not answer all our questions while prototyping the odds that our final aircraft will function as expected drops significantly. Our total bill of materials is reported below. Only about half of our components have been purchased but the rest will be bought after testing.

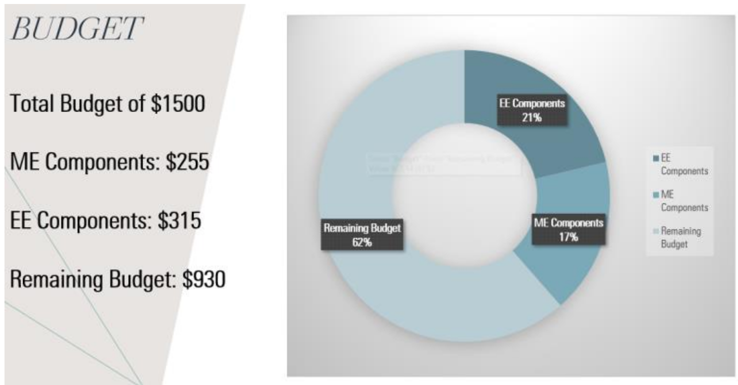


Figure 42: Running Budget

6 Project Management – Second Semester

6.1 Gantt Chart

Actual Gantt chart for the second semester. Describe everything and then reflect on how your actual is different from the original one that you created at the beginning of the semester. What could you have done better?

6.2 Purchasing Plan

Actual purchasing plan that was implemented. Place an image of your BOM purchased items with details (when, from where, how much, etc). Describe everything and then reflect on how your actual is different from the original one that you created at the beginning of the semester. What could you have done better?

6.3 Manufacturing Plan

Actual manufacturing plan that was implemented. Place an image of your BOM manufactured items with details (when, from where, how much, etc). Describe everything and then reflect on how your actual is different from the original one that you created at the beginning of the semester. What could you have done better?

6.4 Bonus/Substitution Sections – as needed

If you had a competition, analytical, or other self-identified “special project”. Detail how your deliverables were modified from the classic capstone sequence.

7 Final Hardware

7.1 Final Hardware Images and Descriptions

Provide images with detailed description of your final hardware for your project. Discuss functionality of your system.

7.2 Design Changes in Second Semester

[Teams may elect to organize the information in the following format, but are not required to.]

7.2.1 Design Iteration 1: Change in [subsystem/component] discussion

[Briefly describe what the original design was and the change made for this particular component or subsystem.]

[Provide pictorial evidence of the differences (through product photos, CAD iterations, etc.) and justification of the decisions behind the changes.]

7.3 Challenges Bested

Discuss the challenges that your team faces to get 100% hardware on time and how your team overcame/bested those challenges.

8 Testing

8.1 Testing Plan

Reference your QFD and ERs/CRs while your give a top-level summary of your testing plan. Reference your final testing document – no need to include all testing procedures unless you want to.

8.2 Testing Results

Show your finalizes Specification Sheet and describe how ERs/CRs were met or not met.

9 RISK ANALYSIS AND MITIGATION

[Use this section to discuss how the team mitigated potential failures in the system based on their design decisions. Provide an introduction to the section here.]

9.1 Potential Failures Identified First Semester

[Review your previous FMEA from last semester. Provide the shortened FMEA here, then include the full FMEA in the appendix. Include an introduction here then discuss the critical failures shown in the shortened FMEA.]

9.2 Potential Failures Identified This Semester

[Provide an introduction to how new failures were identified this semester and add any and all new potential failures that were brought about by the design changes this semester. Highlight these new/changed potential failures in the full FMEA in the appendix.]

9.3 Risk Mitigation

[Discuss how your team took the list of potential failures and designed their system to mitigate these failures. Provide design evidence that the major critical failures have a low likelihood of occurring. Also provide discussion regarding any trade-offs in risk mitigation that occurred (i.e. were any risks harder to mitigate when trying to mitigate another? Were any new risks created during the design process?).]

10 LOOKING FORWARD

[This section can also be used to provide detailed information to your client regarding how they can finish the project, improve upon it, etc. Include observations you may have on the overall project such as ways to improve the capstone experience for future teams or future clients. This section will be split into two sections –Future Testing Procedures and Future Work.]

10.1 Future Testing Procedures

Detail testing procedures yet to be accomplished or not included in the scope of your project.

10.2 Future Iterations

Make suggestions for iterations if this project was to move forward with another hypothetical team.

11 CONCLUSIONS

Provide a general conclusion here of the project, team goals, the results, etc. Then complete the following subsections.

11.1 Reflection

[Provide a commentary on how your team applied engineering design principles to produce a solution that meets specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. Your reflection does not need to address every category stated in the previous sentence but should provide details regarding those most relevant to your project. What were those factors that were most important to your project (public health? Cultural factors? Etc.)? How does your design address those factors? How did you ensure your design was safe? How did you ensure your design met certain environmental issues? etc.]

11.2 Resource Wishlist

If you were to do this project over again, what resources would have been helpful for the success of your project? More team members? Specialized equipment? Specialized training? Etc

11.3 Project Applicability

Provide commentary on how you think this project has prepared each of you for your future careers. Use this section to conclude your project formally.

12 REFERENCES

[Include here all references cited, following the reference style described in the syllabus. There should only be one Reference list in this report, so all individual section or subsection reference lists must be compiled here with the main report references. If you wish to include a bibliography, which lists not only references cited but other relevant literature, include it as an Appendix.]

13 APPENDICES

[Use Appendices to include lengthy technical details or other content that would otherwise break up the text of the main body of the report. These can contain engineering calculations, engineering drawings, bills of materials, current system analyses, and surveys or questionnaires. Letter the Appendices and provide descriptive titles. For example: Appendix A-House of Quality, Appendix B- Budget Analysis, etc. All Appendices should start on a new page.]

13.1 Appendix A: Descriptive Title

13.2 Appendix B: Descriptive Title