Solar Drone Version 2 Design Review

Real World Engineering | Solar Drone Design Team

Authored by *Grant Sherman, James Bautista, Garrett Leath, Braxton Eisel, Austin Thomas, Aaron Shumer, Agus Zurlo, Gage Pollard, Nick Famiglietti*

Funded by the University of Florida's Department of Mechanical and Aerospace Engineering

Table of Contents

Introduction

Overview

Real World Engineering (RWE) is a unique student-led engineering group at the University of Florida (UF), operating similarly to a design firm. Supported by the University's Department of Mechanical and Aerospace Engineering (MAE), RWE offers its members practical experience in the engineering design process, beginning with its initial project — a solar-powered drone.

The purpose of this document is to explore the second iteration of the Solar Powered Drone completed in the Fall 2023 Semester. We will first break down the use case of the project, and then examine the project goals and timelines. After that, we will dive into the design, manufacturing process, testing, project management, and team frameworks. From there we will review lessons learned from the V2 Iteration and detail initial plans for the V3.

Problem Statement

Florida's vulnerability to hurricanes, such as the devastating Hurricane Irma in 2017, underscores the urgent need for efficient post-disaster response. In the aftermath of such storms, communities are often left to sift through wreckage for weeks in search of lost pets, loved ones, and valuables. The task of assessing the scope of damage to towns is equally daunting.

Aerial search and rescue operations have become indispensable in these times of crisis, yet traditional methods involving manned aircraft are time-consuming and expensive, demanding considerable resources and specialized personnel. This reality presents an acute need for a more streamlined and economical solution to enhance the efficacy of these critical missions.

The Solar Drone offers a viable alternative to traditional aerial search and rescue methods. By leveraging inexpensive, autonomous drones equipped with solar charging capabilities, this innovative solution can search a larger area more efficiently, while maximizing flight time. This approach not only reduces the costs associated with traditional search and rescue operations but also increases the likelihood of successful outcomes by covering more ground in a shorter amount of time.

Project History

In its first semester in Fall 2022, RWE launched the solar drone project but faced execution challenges due to a lack of funding. The following spring, the club successfully obtained financial backing from the student government, although this came with its own set of hurdles related to design space and regulatory constraints. Additionally, the absence of a project management framework led to a disjointed workflow with little consideration for how individual tasks would come together.

Despite RWE's ambition to engage numerous students on a singular project, it became clear that such a collaborative effort demanded a robust infrastructure. Over the summer of 2023, the club delved into project management research and chose to implement a tailored agile Scrum framework for its design teams, details of which are elaborated later in this document. Coupled with its first leadership transition and acquisition of MAE funding, these developments equipped the Solar Drone Design team with a definitive direction for the Fall 2023 semester.

100,000ft Timeline

The adapted Scrum framework divides the project into "Sprints," allowing for focused iterations. Initially, the objective was to fully integrate solar capabilities by the beginning of the Spring 2024 semester, dedicating that term to enhancing the drone's electronics and features. However, this target was overly ambitious, as various team limitations became apparent during the Fall 2023 semester. These challenges and the insights gained are discussed in the "Lessons Learned" section of this document.

Following is an updated timeline, outlining the current progress and future milestones for the 100,000ft solar drone development:

Solar Drone 2023 - 2024 100,000ft Timeline			
Fall 2023 Semester		Spring 2024 Semester	
Version 1 (V1)	V2	V3	V4
-Basic electronic development. -Drone overall design determination. -Project Management framework integration.	-Develop proprietary drone structural design. -Develop a proprietary electronic framework.	-Integrate Solar into structural design. -Refine Structural design for aerodynamics. -Begin advanced solar-capable electronics development. -Begin software development.	-Weight reduction and aerodynamic structural refinement. -Full solar integration. -Advanced software features development.

Design

Overall

Version 1

The design for the V1 was based on a decision matrix conducted during the Spring of 2023. In February of that semester, the structures sub-team was split into five groups and tasked with researching their ideal structural design for the solar drone. After initial eliminations based on members' RC experience and consideration for the overall mission of a solar-powered flight across Florida, the final two designs remaining were the traditional glider and the delta wing. The decision matrix factored in cost, manufacturability, weight, flight efficiency, solar integration capabilities, and stability. By mid-February, it was decided that Real World Engineering's Solar Drone Team would create a delta wing due to its larger planform area and lower drag coefficient.

Following this decision, the electronics sub-team purchased and assembled a Matek packed-wing flight controller as well as other necessary components including a 14.8V LiPO Battery, brushless motor, servos, and micro receiver. In total, seven different components were soldered onto the flight controller to allow for the battery to power the controller, the propeller to spin, the RC Controller to communicate with the drone, and control surfaces to move properly. These features were then tested through thrust testing and using iNAV.

While the electronic components were being assembled and tested, the structures team conducted a deep dive into the necessary considerations for a delta-wing RC plane. These topics included CFD testing, manufacturing techniques, and wing design. However, as a result of the semester's time constraint and the available budget, plans for the wings were downloaded from Flite Test and a fuselage was generated in Fusion360. The drone was then assembled and electronics were incorporated to create the V1. The V1 test flight served as the final test for the electronics with all systems responding accurately to the RC controller.

Version 2

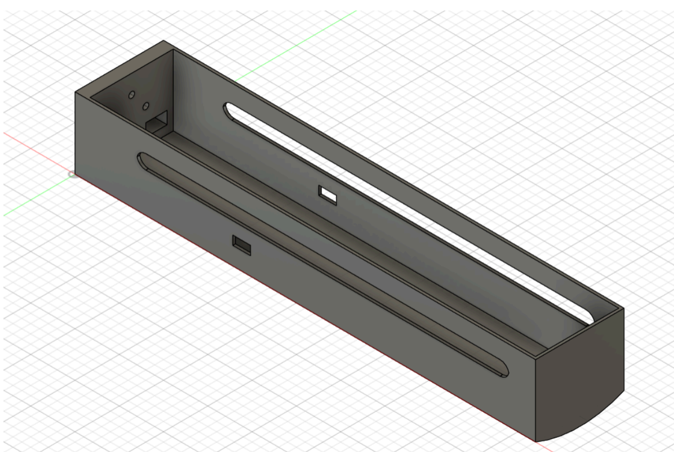
The V2 design is built upon the progress of the V1 but with all the structures developed internally. While this new version was still a delta wing, there were important changes made as a result of the first iteration. Some key lessons from the V1 and its test flight include the importance of mounting rods to connect the wings to the fuselage, the necessity of landing gear for a successful launch, and the secure mounting of electronics to prevent damage. While the V2 was also a delta wing, the internal design was completely different from the prior version. This difference was a result of utilizing additive manufacturing as the main manufacturing technique. A skeleton structure was employed to make the wings. Each wing was made up of seven ribs designed with spar clearance holes. By assembling with wooden dowels to connect the ribs and lightweight EPP foam to wrap, a wing with a Clark-Y airfoil shape, decreasing thickness, and 30° sweep was produced.

The electronic components are the same as the V1. One design change that relates to the electronics was the inclusion of a square cavity in each of the ribs and the fuselage. This gap allowed for easier management of the servo wires when connecting them to the flight controller. Additionally, the components in the fuselage were placed as far forward as possible with low tolerancing on either side to decrease movement and vibrations.

Structures

V1 Manufacturing and Testing

Last year the club manufactured wings made from foam poster board. Included in these designs were makeshift winglets and ailerons. The ailerons were designed with clearance and attachment points for servo motor movement. The servo motors were mounted to the wing with hot glue and the rod was attached to the aileron edge. Both V1 wings served as a proof of concept and prototype for the club. To start fresh and begin research for new designs, a test flight for the V1 was needed. In the past year, a fuselage and container for the electronic components were not designed. The structures team worked together to design a rough fuselage box in Fusion 360 that could adequately hold the battery and necessary components. The design was simple and limited to a shelled rectangular box with little aerodynamic consideration which is displayed below. The fuselage included space for the internal components, slots in the sides for wiring purposes, holes on the back panel for motor attachment, and a rounded nose. During assembly, both wings were attached to the fuselage using clear tape and adhesive. The final V1 assembly is pictured below.

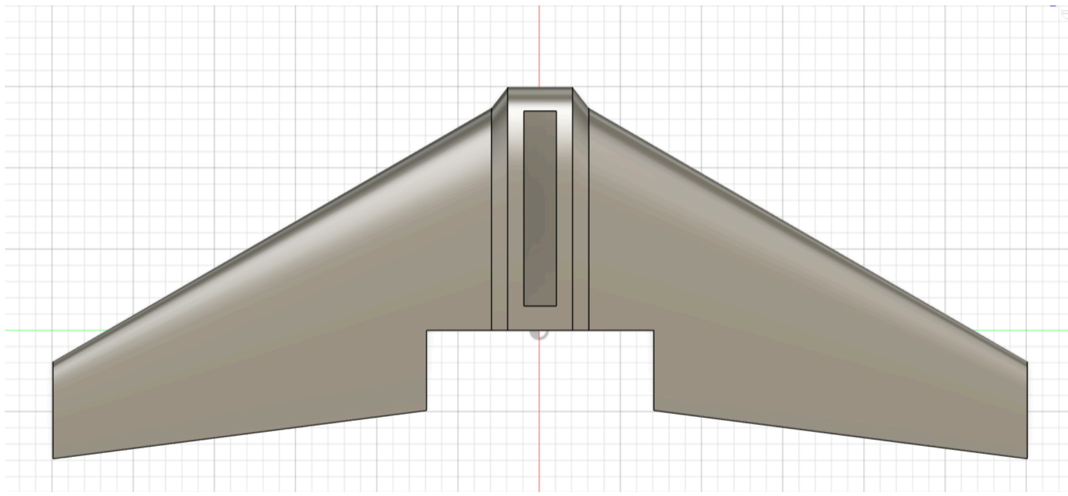


V1 Fuselage

V1 Prototype

V2 Design Process

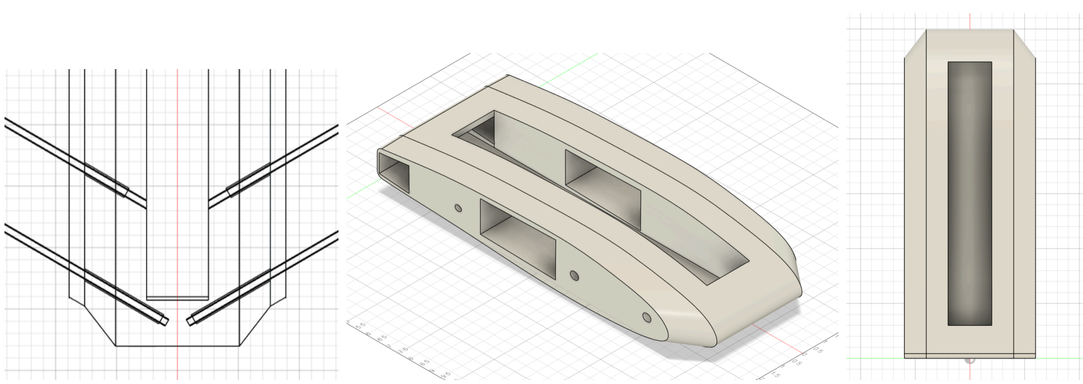
After V1 testing was completed and the past semester’s designs were put to rest, the structures team started research on V2 wing designs for the new year. Wing research concluded that a delta wing design could provide maximum surface area, increased lift, and a moderate sweep angle. Each member of the structures team researched integrated wing and body plane designs and posted their research in a designated folder for future use. In addition, team members researched winglet designs that would provide the best vertical stabilization. It was also noted that elliptical wings could provide similar advantages in future designs if the delta wings presented challenges. To visualize the delta wing assembly, a dimensionless model was developed in Fusion 360 as a single body and cut into its several wing segments, ailerons, winglets, and fuselage.



V2 Prototype Design

Fuselage Design

Starting the V2, the fuselage assembly and components were modeled in Fusion 360 and passed to the CAD team for refinement. The V1 model's dimensions were kept to account for the battery size and attachment points for the motor and wings. The fuselage design was refined to make it more sleek and integrated into the wings. Any discontinuities, gaps, or flat edges would impact its aerodynamics. Therefore, the rectangular V1 design was abandoned for a design with rounded edges that were flush with the wings. To check that the electronics still worked, they were tested and thrust values were obtained for rough aerodynamic restrictions. For attachment methods, it was decided that the wings would fasten to the fuselage core with long poles of a lightweight material using interference fits. The resulting upgraded fuselage design is shown below alongside an image depicting the pole interference fits.

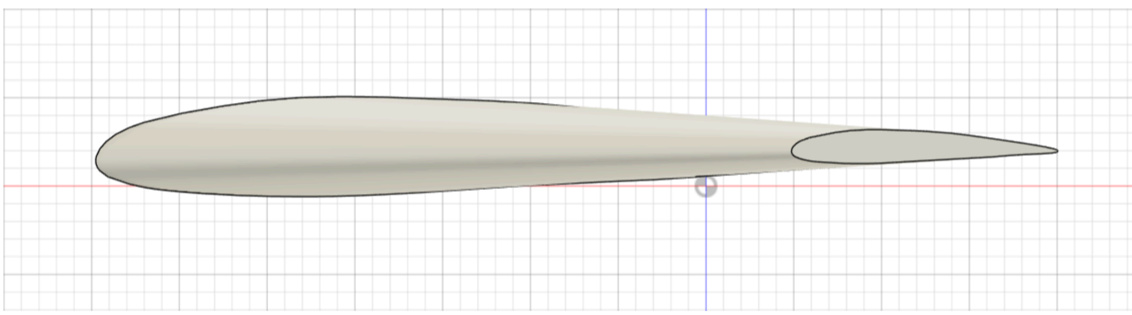


V2 Fuselage and Interference Fits

Wing Design and Airfoil Choice

Wing design and dimensioning were started by measuring the V1 wings and brainstorming ways to increase their manufacturability. During weekly meetings, a 30° sweep angle was decided, and the rough dimensions of the wing were set. In addition, it was concluded that several rods would be used to attach the wings to the fuselage. The rough lengths of the rods were discussed in meetings, and the material was narrowed down to carbon fiber or wooden dowels. Each would provide lightweight support and internal structure, but wooden dowels were the preferred option based on their price. The rod lengths were finalized and cut to achieve an exact fit. Each rod would attach to the thicker fuselage walls with a press-fit joint. Towards the back of the fuselage and wings, there was a required cutout for the propeller clearance set as 10 inches.

At the core of the wing design was the airfoil choice. After conducting research, our structures team decided on a Clark-Y airfoil which was suitable for models and full-scale aircraft with a thickness of 11.7% and a relatively flat bottom [6]. In addition, the airfoil provided a fair efficiency with its lift-to-drag ratio. The Clark-Y airfoil primarily offers high-speed, low-lift performance [7]. To design the wings, the airfoil was traced using a spline in Fusion 360 and lofted to an offset sketch. This resulted in a delta wing with a Clark-Y airfoil that was capable of stability under high speeds. The side profile of the wings depicts the airfoil shape which is pictured below.

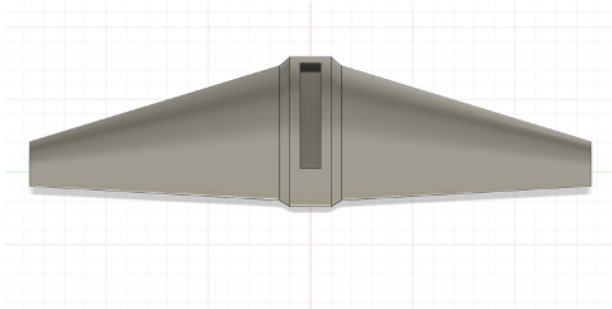


V2 Wing and Airfoil

Aerodynamic Considerations

The aerodynamics team was provided with a first-draft CAD model of the drone created by the structures team. This initial model was based on trade studies regarding the wing design and airfoil choice, which have been previously discussed. The model geometry was also based roughly on the V1 Design. The aerodynamics team was tasked with making necessary modifications to the design to ensure a successful and efficient flight.

The first advised modification was a change to the sweep of the trailing edge of the wing. In the initial model, the trailing edge swept forward while the leading edge swept backward, as shown in the image below. Preliminary research into delta-wing drones indicated that such geometry was not beneficial to the drone performance nor standard in aircraft design. Thus, the sweep angle of the trailing edge was changed to be more akin to traditional delta wing gliders. The final geometry is very reminiscent of the Delta Wing Streak 130 wing shape, also shown below.



Initial Drone Design

Delta Wing Streak 130 [1]

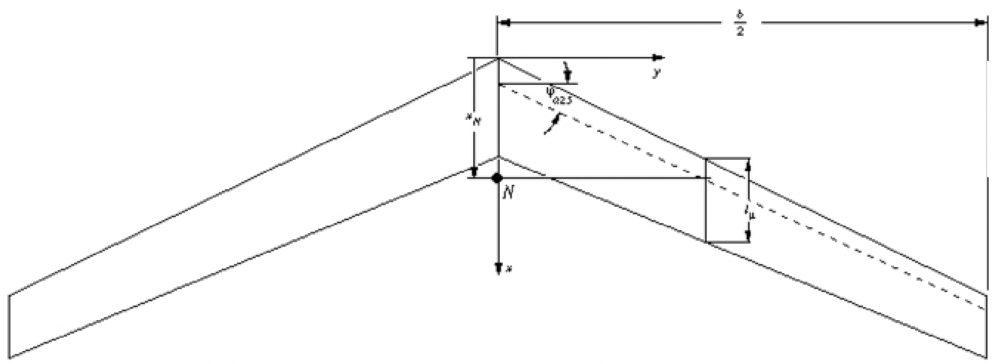
In making this change to wing geometry, we also considered the wing aspect ratio. From basic geometric calculations, we determined the aspect ratio to be ~4.03. Research showed that delta wing designs typically have very low aspect ratios, often below 3.0 [2]. Given the association between lift/drag ratio and aspect ratio, we considered an aspect ratio of ~4.0 to be acceptable for our purposes.

The trust-to-weight ratio was also considered. When the final aircraft weight was determined, we hoped to calculate the percent thrust required for level flight based on the T/W ratio. This would inform the drone pilot as to the proper throttle control during test flights. Research showed that a minimum T/W ratio of 0.5 is required for controlled flight, with a ratio closer to 1.0 being ideal for maneuvering and ascent/descent [3]. These values would be used to determine minimum/maximum throttle levels during flight based on an estimated drone weight of 1.4 kg, or 13.7 N.

A major consideration was the center of gravity location of the drone. It is commonly accepted that to produce stable flight, the center of gravity of an aircraft must be ahead of its center of lift. In the case of delta wing aircraft, one must further consider the consequences of a lack of horizontal stabilizer. Horizontal stabilizers traditionally function as inverse airfoils that provide a downforce at the rear of the plane, resulting in a net zero moment about the center of gravity. Delta wing aircraft, of course, do not have horizontal stabilizers, so this moment balance must be achieved with a constant upward deflection of the elevons, resulting in a downforce at the trailing edge of the wings. This was another important consideration for the drone pilot, and was also considered when installing the elevon servos: the range of motion of the elevons was preferential to upward deflection versus downward.

An attempt was made to calculate the stability coefficient of the aircraft: this parameter, which is calculated as the distance between the center of gravity and the center of lift divided by the mean chord length, ought to be between 0.02 and 0.05 for stable flight [4]. These boundary values were used to determine that the center of gravity and center of lift of the drone should be separated by no less than 0.68 cm and no more than 1.7 cm. Logically, however, these values are far too small and are beyond the tolerances of our manufacturing and measurement capabilities. Thus, we were forced to neglect the stability coefficient in our design and opt for a more logical and experience-based approach to defining the center of gravity location of the drone.

It should also be noted here that the center of lift was determined both analytically and computationally. The analytical approach involved the calculation of the neutral point of a tapered, swept wing such as ours. The formulae used in this approach are shown below [4]. This approach yielded a center of lift location 23.77 cm aft of the foremost leading edge.



$$l_\mu = \frac{2}{3}\,\frac{1+\lambda+\lambda^2}{1+\lambda}\cdot l_r$$

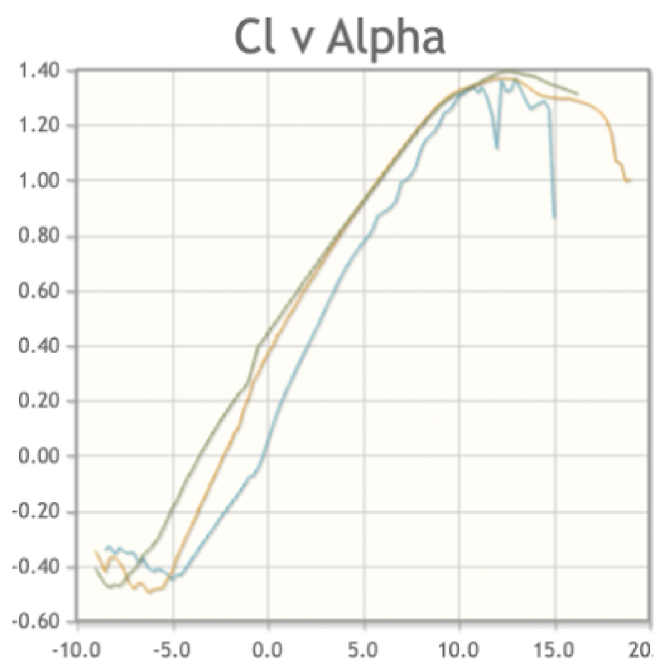
$$y = \frac{b}{2}\,\frac{l_r - l_\mu}{l_r - l_t}$$

Geometric parameters of a tapered, swept wing.

Analytical Formula for Neutral Point Calculations [4]

The computational approach is discussed in detail in the CFD SIMULATIONS section: the computational result was ~32.5 cm aft of the leading edge, which deviates significantly from the analytical result. We determined that the most likely cause of this discrepancy was that the analytical formulae were not derived specifically for delta-wing designs, which traditionally have centers of lift further aft than traditional aircraft.

For our flight conditions – that is, flight at ~0 km altitude – a linear relationship between Reynolds number and drone velocity was derived: $Re = 22744 \cdot U_{\infty}$. A software specific to Clark-Y airfoils was selected to generate plots of the lift coefficient versus angle of attack for various Reynolds numbers [5]. These plots are shown below for Re = 50,000 (blue), Re = 100,000 (brown), and Re = 200,000 (green):



Lift Coefficient Versus Angle of Attack for Various Reynolds Numbers [5]

A major goal for this design was to achieve steady level flight at an angle of attack of 0°. This limitation, coupled with an estimated aircraft weight of 13.7 N, allowed for the tabulation of lift force as a function of Reynolds number. The calculations behind this data are not shown, but are based upon the limitation that lift force equals weight force and the definition of lift coefficient.

Re	$c_l(\alpha = 0)$	$U_\infty\ [ms^{-1}]$	$L\ [N]$
50,000	~0.05	2.20	0.0296
100,000	~0.37	4.40	0.8762
200,000	~0.45	8.79	4.26
500,000	~0.39	22.0	23.1
1,000,000	~0.40	44.0	94.7

Tabulation of Lift Force as a Function of Reynolds Number, with Intermediate Parameters – Lift Coefficient and Flight Velocity – Included

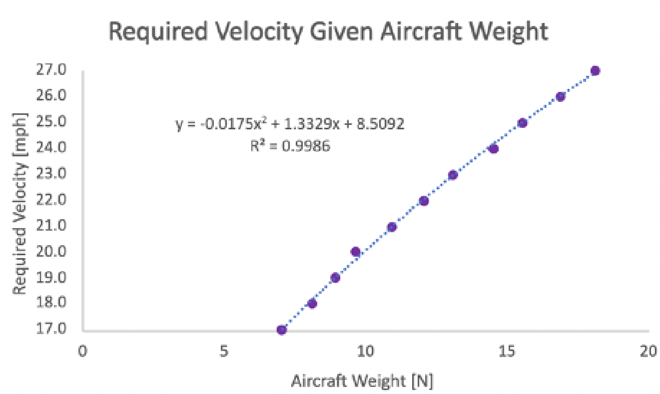
These lift values describe the lift per wing; thus, to achieve the desired lift force of 13.7 N, interpolation shows that a flight velocity of ~10.6 meters per second, or ~24 mph, must be maintained. This flight velocity formed the basis of CFD simulations, which are discussed in the following section.

CFD Simulations

While analytical approaches are important to gaining a fundamental understanding of the design, analytical results are often based on approximations and assumptions, leading to inaccuracy and uncertainty. Thus, computer-based simulations were used as well to gain a more accurate understanding of the drone design and flight parameters. These simulations were done using Autodesk CFD, allowing for virtual wind tunnel testing of our wing design. This testing provided important information about the lift force generated at given flight velocities, with computational results offering much more certainty than the previously discussed analytical results.

However, these analytical results – namely that steady-level flight occurs at ~24 mph – were used as a basis for CFD simulations. The left-wing was placed in a virtual wind tunnel in 11 distinct simulations, with integer values of flight velocity ranging between 17.0 mph and 27.0 mph. The results are tabulated and graphed below:

Free Stream Velocity [mph]	Lift Force [N]
17.0	3.51826
18.0	4.05071
19.0	4.45666
20.0	4.81565
21.0	5.46754
22.0	6.02248
23.0	6.53214
24.0	7.27222
25.0	7.77976
26.0	8.45401
27.0	9.05061



Simulation Results for Lift Force (per wing) as a Function of Flight Velocity

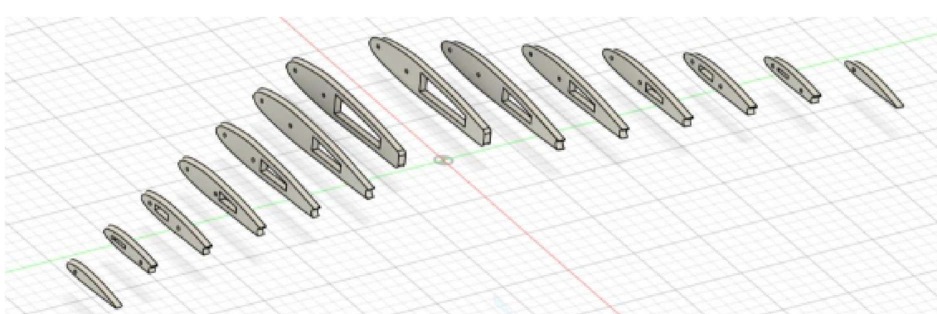
This data was used to determine the required flight velocity (and thus the required thrust/throttle levels) for steady-level flight. This provided practical data to the drone pilot and useful reference data for future iterations of the solar drone. It was noted during the design process that it would be beneficial to install a pitot tube in future iterations to allow for verification of both analytical and computational results for flight speed.

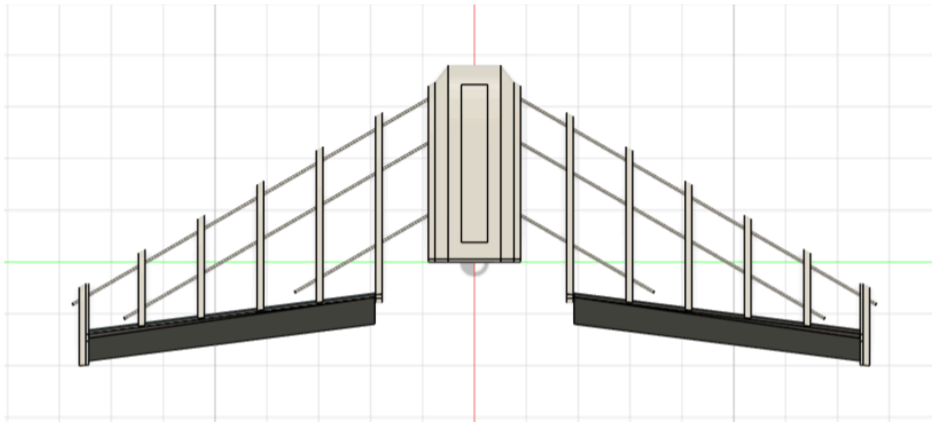
CFD Simulations also provided insight into the location of the center of lift of the drone. As was discussed previously in the AERODYNAMIC CONSIDERATIONS section, the center of lift was determined computationally to be ~32.5 cm aft of the foremost leading edge of the wing. This varied significantly from the analytical results for the center of lift. It was determined that the computation results were likely more accurate than the analytical results; when considering the center of gravity location of the drone, the computational center of lift location was used.

Our initial intent was to also use CFD simulations to determine the drag force experienced by the drone during steady-level flight. However, due to time constraints and a focus on manufacturing the drone, such simulations were not run. While these results for drag were not necessary for the test flight, they are important for reference in the design of future iterations. Thus, there may be merit in completing these simulations retroactively.

Wing Internal Structure

With the decided rod attachment, an internal structure was necessary within the wings to prevent collapse. In weekly structures meetings, the team decided that an internal structure would be designed using either a 3D printer slicing program or shelling and modeling in Fusion 360. These ideas were presented to the CAD team and a slicing program was used for the infill structure within the fuselage walls. After shelling and hollowing the wings, a truss or ribbed internal structure would be used to support the weight of the wooden dowels and electrical components. The research concluded that a ribbed internal structure would provide more stability and rigidity. In earlier stages, the rib material was set as PLA Aero, but it was changed later to ABS Plastic which provided a higher strength. Each rib within the wing was modeled with holes for the wooden dowels to create the drone's internal skeleton. Below are images of the CAD models for the individual ribs and overall skeleton.

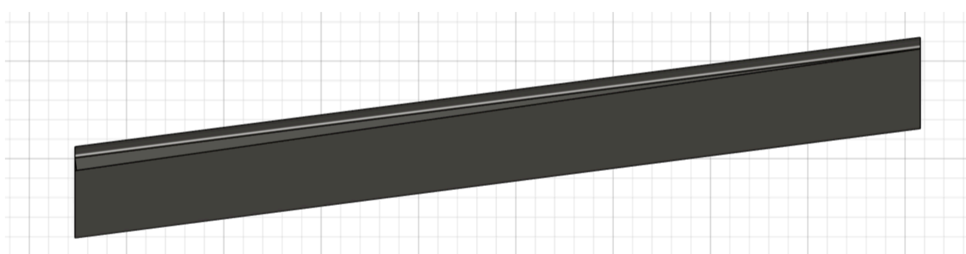




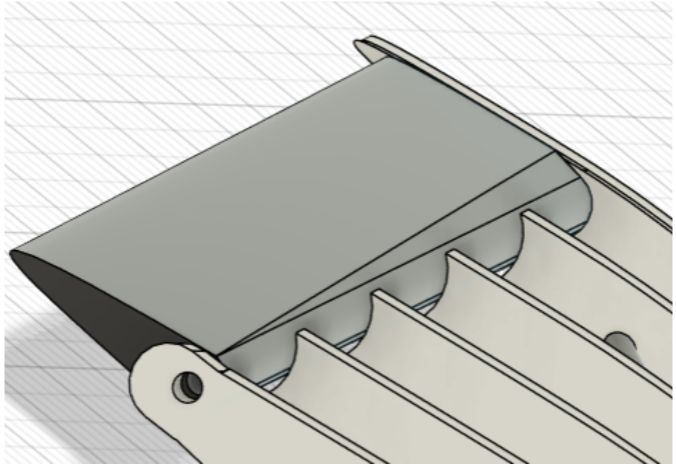
V2 Ribs and Skeleton

Aileron Design and Attachment

Moving on to the aileron design phase, research was started and an attachment method to each wing was required. Ailerons control the roll of a conventional aircraft, but with tailless delta wing designs, they control the roll and pitch in the absence of a tail rudder [8]. In the context of delta wings, ailerons are called elevons, and they are on the trailing edge of the wing. Elevons combine the features of elevators and ailerons [8]. As stated earlier, each aileron in the final assembly was controlled by its servo motor. The elevons were attached to the main assembly with a wooden dowel that slid through a clearance hole. In addition, crescent sections were cut from the ribs at an angle to allow the elevon to pivot and move with clearance. An image of this attachment method is pictured below. In the final assembly, the elevons were printed from ABS Plastic and the servo rod was glued to its surface. The elevon CAD drawings are shown below.



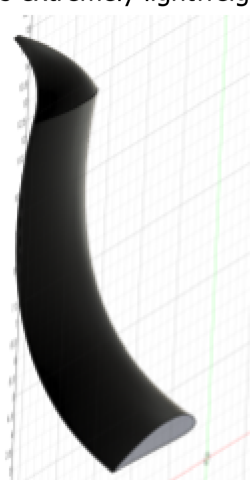
V2 Elevon



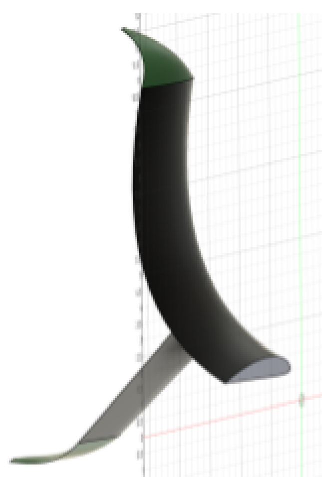
V2 Elevon Attachment

Winglet Design and Attachment

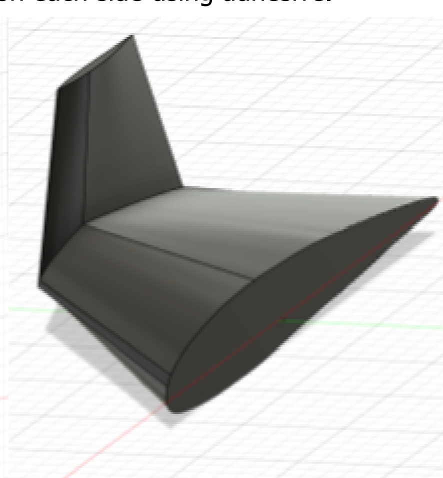
For delta wing designs, vertical stabilizers are necessary to prevent yaw and to ensure straight flight. Winglets increase the effective aspect ratio of a wing without adding to the span. In addition, winglets reduce drag by reducing wingtip vortices. Therefore, the shape of the winglet determines the aircraft's efficiency. For the purposes of experimentation and to run several CFD tests, three separate winglet designs were considered: Traditional, Blended, and Split Scimitar. Regarding the traditional winglet, the vertical or angled extension at the wing tip decreases vortices and drag which increases the wing's aspect ratio without impacting the wingspan. In the blended winglet, a smooth curve attaches the winglet to the wing instead of the traditional sharp angle which reduces interference drag where the two components meet. With the split scimitar, inspiration was drawn from the Boeing 737 and similar aircrafts that value the fuel saved using the winglet. The design involves an added tip cap and a ventral strake to a blended winglet. To determine our winglet weight restriction, calculations were performed. These calculations yielded that the winglet should be around 0.5-0.6% of our aircraft's total weight. Each winglet design was modeled in Fusion 360 and displayed below. For the final V2 assembly, the team decided to utilize the traditional winglet and set aside the others for future testing. The winglets were printed from ABS Plastic which was extremely lightweight and attached to the end rib on each side using adhesive.



Blended Winglet



Split Scimitar Winglet



Traditional Winglet

Electronics

Research & Trade Studies

After primary research, we concluded that our drone design would operate around a central flight controller. Controlled by this would primarily be servos and a propeller which would serve as the bare bones of the drone. The minimum requirements for this drone to fly included a flight board, controller, controller receiver, servo motors, a propellor motor, and a battery. Later implementations would additionally include solar panels, solar charge controllers, and GPS. The primary considerations when implementing our basic electronics were the weight of our battery, and what voltage our system should utilize. We opted for a ~12V system due to the balance between having a battery that was too heavy, and a system which would be underpowered. Additionally, our battery was specifically chosen to be the lightest choice which provided a reasonable output at 12V and included capabilities to be charged by a balance charger. The decision to use a 12V system allowed us to then choose our propellor, which ran optimally in the 11-14V range. Our flight controller was used due to it being a leftover item from previous experimentations and its compatibility with a 12V system. Our controller receiver was chosen to match our controller, which was obtained from the previous year's experimentations.

Prototyping

Our first prototype electronics system consisted of a borrowed, old battery, servo motors from Arduino kits, and a propellor. This was sufficient to complete a fully functional drone. The basic assembly of the system included soldering power leads from the flight controller to the battery. These power wires included plugs for easy removal when charging was necessary. Additionally, the servo motors were made for our flight board and were easily plugged into the board. The propeller motor had three wires that ran to the flight board, all to be soldered to the board itself. These three wires also included plugs for easy disassembly. The controller receiver was an additional three wires which were soldered onto the flight controller. This was the extent of all wiring completed.

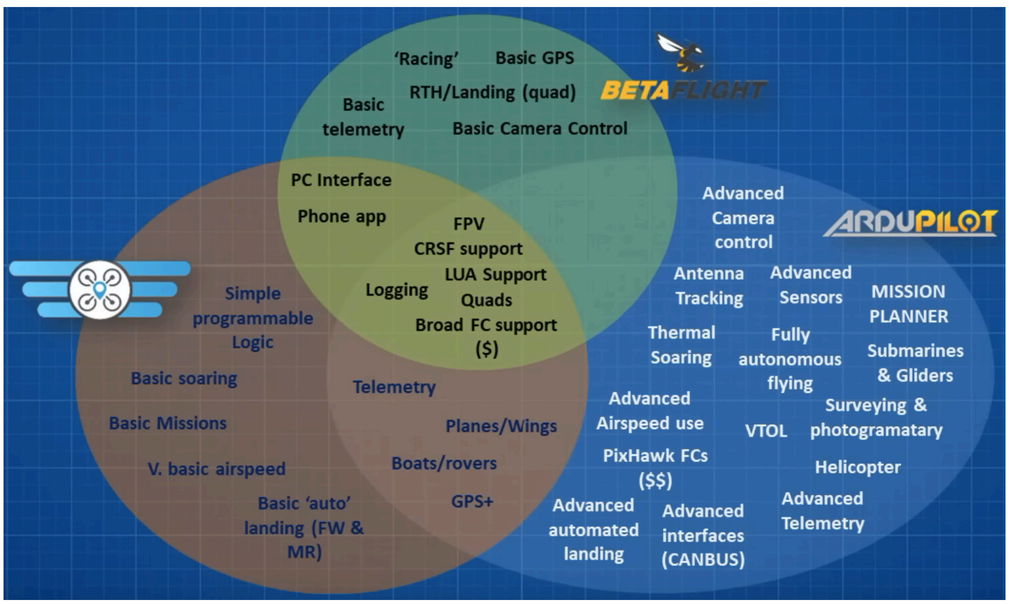
Final Design

In terms of the final design for our V2 drone, the electronics assembly remained fairly constant, as the primary goal of this version was simply to become airborne. Although the parts included in the final design remained the same, new servos were necessary due to an issue with poor responsiveness. The final design also noticed issues with the flight controller, a two-deck board design, which appeared to lose communication between its upper and lower boards during impacts. This loss of communication delayed our flight testing efforts as the system required a full restart, and plans were made to fully replace the flight controller in V3 because of this issue, as well as greater software capabilities with a more advanced flight controller. Additionally, there seemed to be a loose connection within the main ground wire running from the battery to the flight controller. This was fixed by resoldering the ground wire ends into their respective male and female plugs. Overall, the final electronics design of V2 was able to be fully functional, with all electronic components operating as intended and responding accurately to software commands. V2 additionally offered the team insight into what is best to consider when purchasing new servo motors and flight boards. (As aforementioned above).

Software

Choosing a Flight Control Software

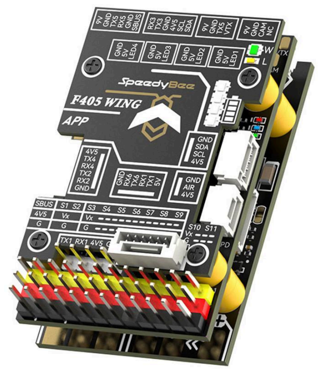
The three primary flight control software options for hobbyist drone flyers are Betaflight, iNAV, and ArduPilot. After evaluating each, our software team dismissed Betaflight due to its unsuitability for fixed-wing aircraft, leaving us to choose between iNAV and ArduPilot. iNAV, known for its simplicity, aligns well with our initial objective of achieving flight, whereas ArduPilot offers capabilities for extended missions and features like mission planning and automatic landings. Ultimately, we chose iNAV for our drone's early prototypes, planning to transition to ArduPilot once we achieve stable flight. Although learning and calibrating just one flight control software would have been ideal, beginning with iNAV and later adopting ArduPilot accelerates our primary goal of getting the drone airborne.



A Venn Diagram of the features supported by iNAV, Betaflight, and Ardupilot [9]

Choosing a Flight Controller

To fulfill our objectives, the drone necessitated a flight controller that was not only compatible with both iNAV and ArduPilot but also capable of enduring long-duration flights. Additionally, cost-effectiveness was a key consideration, as flight controllers can be quite expensive and vulnerable to damage in the event of a crash. With these factors in mind, our software team chose the SpeedyBee F405 WING APP. This flight controller not only meets all our requirements but also offers the convenience of wireless configuration and plug-and-play connectors. Additionally, its robust build quality and reliable performance make it an ideal choice for our project, balancing affordability with the necessary functionality for both initial testing and more complex future missions.



The SpeedyBee F405 WING APP Flight Controller [10]

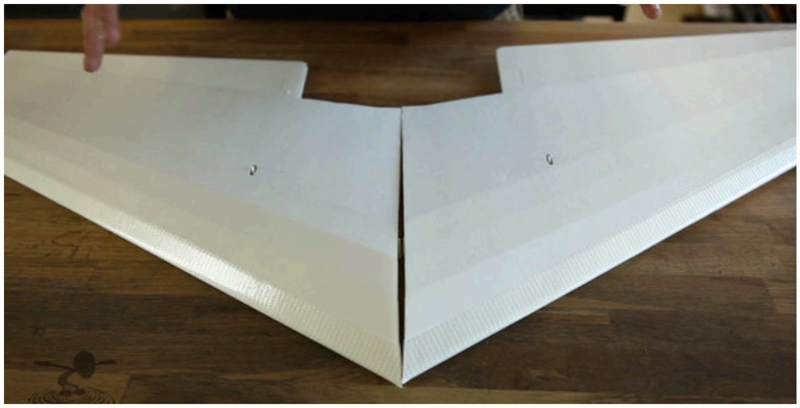
Manufacturing

Version 1

The V1 assembly began by printing the "FT Versa Wing MKR2" from Flite Test on a large paper sheet with a one-to-one scale [11]. Then, this sheet was placed on top of polystyrene foam and each part was cut out using an Exacto knife. Slits were cut in the front half of the top surface to allow the foam to curve when attaching to the lower surface. Below is an image of each of the wing portions. From top to bottom, the first is the bottom wing surface, the middle is the top wing surface, and the last is the spar support.

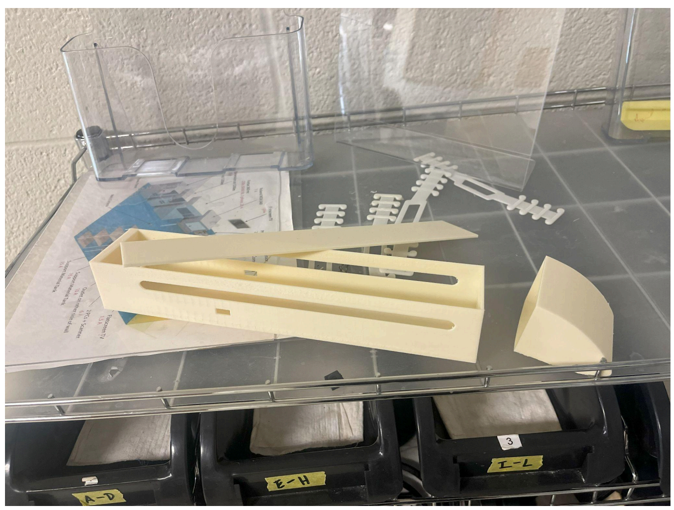
V1 Cut-Out Wing Sections [11]

The servos were mounted on small pieces of foam and glued on the inside of the bottom wing portion. Then, the two sections were attached and slots were cut into the top portion to allow a full range of motion for the servo arms. These slots and the complete wings are seen in the image below.



V1 Full Wings [11]

The last component is the fuselage. The Fusion 360 model was sent as a ".stl " file to the UF Rapid Prototyping Lab to be printed. ASA filament was selected for its balance of weight and strength properties. The entire assembly of three parts, the fuselage body, nose, and lid, is seen in the figure below.



3D Printed Fuselage Sub-Assembly

The nose was attached to the body utilizing clear Gorilla epoxy and sealed with clear tape to reduce the drag caused by the layer lines.

After the wings were manufactured from foam board and the fuselage printed in ASA, all three components were combined utilizing wooden dowels to support the wing bending moment and Gorilla Clear Adhesive. Finally, the electronics were integrated and the V1 was tested. The complete V1 is pictured below.

Completed V1 Solar Drone

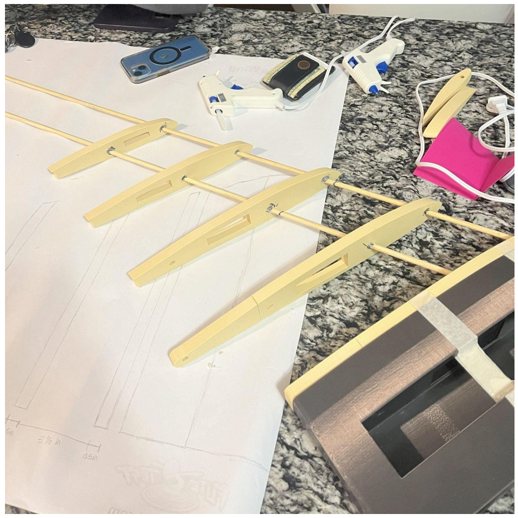
Version 2

14 ribs and the 2 portions of the fuselage were printed in ABS Plastic using a Bambu Lab Printer. An infill of 15% was chosen for the fuselage nose and the two ribs closest to the center. The larger portion of the fuselage had an infill of 10% in order to decrease weight and keep the center of gravity as far forward as possible. Similarly, the other 12 ribs had a decreased infill of 10% to decrease the weight and, as a result, the bending moment. Below is an image of the fuselage parts and the 10 ribs that could fit onto the 10x10x10 inch print bed without being cut.

3D Printed Ribs and Fuselage

The last four ribs were cut at two-thirds of their length from the leading edge and then later superglued together. This point was chosen as there were fewer forces close to the trailing edge and a decreased concern for breaking due to impact.

These ribs were then slid onto two wooden dowels with a spacing of 3.5 inches between the first and the second rib then 4 inches between each of the remaining ribs. Each rib was secured with hot glue. The skeleton wing assembly of the ribs and dowels is shown below.

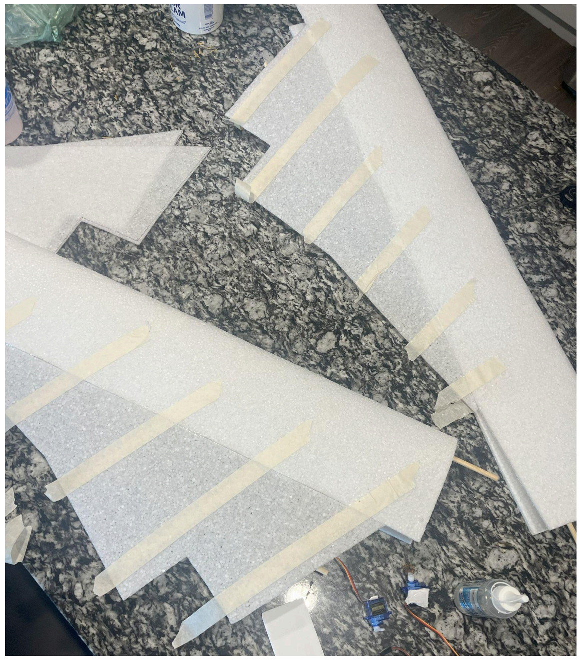


Wing Skeleton

After the wing skeleton was completed, a heat gun was utilized to bend the 6mm EPP foam over the leading edge of both wings. This technique proved to be the best method in ensuring that foam followed the shape of the ribs resulting in an accurate Clark-Y airfoil shape.

Heat Gun to Bend Foam

After being curved to the correct shape, EPP Foam Glue secured the sheet to the ribs. The 3mm EPP foam was cut to cover the back portion of the wing. As shown below, this thinner sheet was glued flush to the 6mm foam onto the ribs using the EPP Foam Glue.

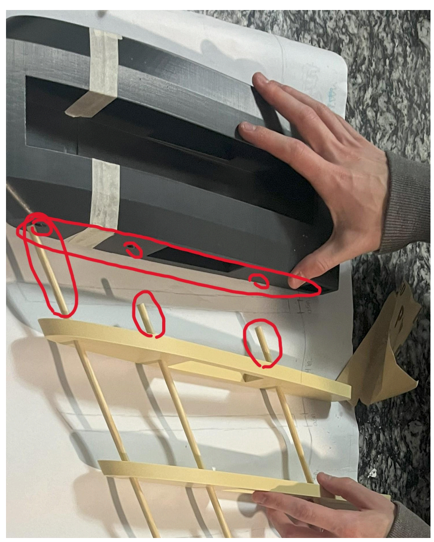


Foam-Covered Wings

The thinner foam sheet was selected for the trailing edge of the wing as flow separation would occur in this area, making the aerodynamic impact of the height disparity between the sheets negligible.
After curing for over 12 hours, the tape was removed. Then, a blade was heated with a lighter to trim any excess foam and make slots for the servo arms that control the ailerons. The servos were glued to thin pieces of foam and then attached to the top of the wooden dowel spars. The 3D printed, ABS ailerons were created with a free fit hole with a diameter of 0.3 inches. This hole provided clearance for a 0.25-inch dowel to mount the control surfaces without restricting the range of motion. As seen below, the slot at the top of the wing allowed the servo arm to move and a thin rod connected this arm to a mount hot glued to the aileron.

V2 Control Surfaces

The next task for the V2 was attaching the wings to the fuselage. After the individual wings were complete, clear Gorilla glue was applied to the wooden dowels, the spar holes of the fuselage, and the side of both the fuselage and the wings. The image below highlights where the adhesive was applied to attach the wings.

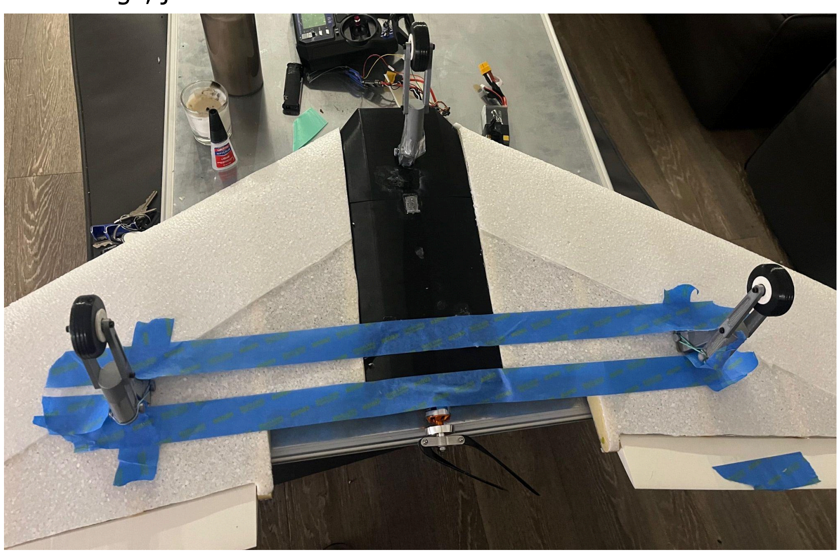


V2 Glue Application

To complete the wings, winglets were printed out of ABS Plastic. Due to the complex geometry, these wingtips were printed as two separate parts and then superglued together. After both winglet sub-assemblies were completed, they were super glued onto the last rib on either end of the drone.

V2 Winglets (mint green)

The final component for the V2 was the addition of landing gear. Each landing gear sub-assembly included ABS-printed joints, a TPU-printed wheel, and rubber bands for support. A small square slot, the length and width of the top of the landing gear, was cut into the foam beneath the third rib on each wing to expose the plastic of the rib. These slots were near the past the midpoint line, closer to the trailing edge. Super Glue was applied to both the rib and the top of the landing gear and then held for a minute to create a secure bond. This adhesion process was also utilized to attach the third and final landing gear to the bottom of the fuselage, just behind the nose.



V2 Landing Gear Location

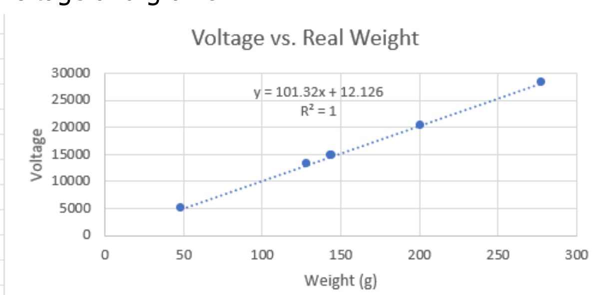
Below is an image of the finalized V2 Solar Drone ready for take-off.

Completed V2 Solar Drone

Testing

The main objective of the semester was to create a successful V2 drone. For this reason, the work done to complete the V1 and its attempted flight served the main role of testing before V2. At the beginning of the semester, the first goal was to test the electronic components from the prior semester. To do this, and to gain true numerical values for the aerodynamics team, a thrust test was conducted. Through this testing, it was discovered that the connections between the brushless motor and flight controller had to be resoldered. The thrust testing was conducted using an Arduino, load cell, weighing scale, and the Arduino IDE. First, objects were weighed with the scale and then placed onto the load cell which outputted a voltage value in the IDE. The Excel sheet shown below demonstrates the work done to determine the slope relationship between voltage and grams.

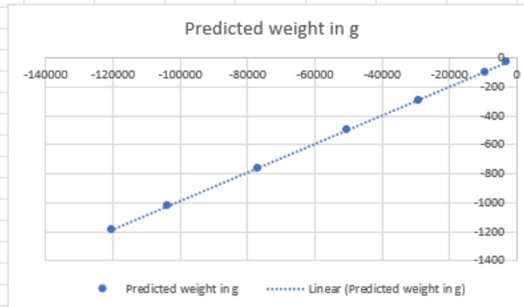
Item	Real Weight(x)	Voltage(y)
Box	144	14683
Watch	129	13064
Flight Board	49	4965
Box	145	14693
Phone #1	278	28190
Phone #2	201	20331
Slope:	101.3247847	



Thrust Test Calibration

Following this initial calibration and the correction to the flight controller soldering, the propeller was fastened onto a 3D-printed mount that connected to the load cell. Then, utilizing the INAV Configurator, the propeller weight was initially recorded then the motor power was increased by 10% until 70% of the maximum was attained. The voltage readings output into the Arduino IDE were then converted into grams through the calibration data acquired earlier. The data from this testing is shown below.

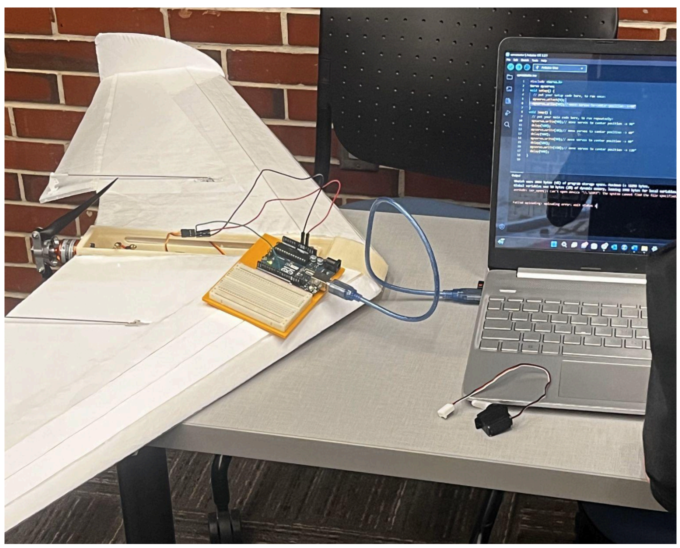
Avg Tare Weight	Percent of Power	Avg Voltage - Avg Tare Weight	Predicted weight in g
28116.36	0.05	-2949.171875	-29.21997005
	0.1	-9551.995739	-94.38288212
	0.2	-29325.64509	-289.5279595
	0.3	-50484.52604	-498.3438128
	0.4	-76808.05938	-757.5859203
	0.5	-103650.4844	-1022.381244
	0.61	-120439.9594	-1188.730206
	0.73	???	
		Predicted Max(g)	-2055.519959



Thrust Testing Resultant Data

This thrust test resulted in correction of flight controller connections through resoldering and useful calculations to estimate cruising speed of the drone.

Following the thrust test and prior to the V1 test flight, the flight controller was tested utilizing INAV. This work was to serve as a trial before the V1 launch. While the propeller spun, the servo motors meant to control the ailerons would not. After additional trials utilizing a simple Arduino circuit and two additional motors that were proven to be functional, it was discovered that the motors we had purchased the semester prior no longer worked. Attached below is an image of members of the electronics sub-team working to confirm that the issue was the old servo motors.



Servo Motor Testing

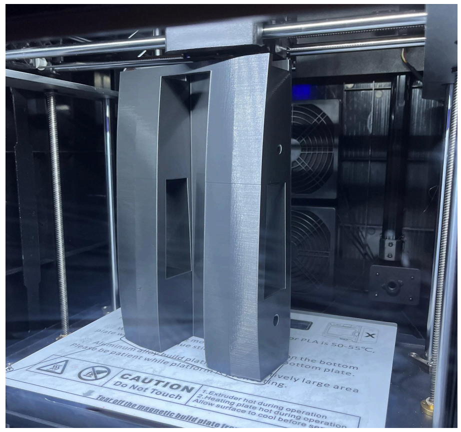
As a result of this servo motor testing, new motors were purchased prior to the V1 Solar Drone test flight. After they arrived, these servo motors were tested on both the Arduino and the flight controller and functioned properly.

The next test was from the first attempted launch of the V1. Two issues occurred during that day. The first was that while attached to the battery, only one half the flight controller received power preventing the remote from connecting to the receiver. After some trial and error, it was discovered that the pillars of the flight controller were too long and created a gap between the plug that connected the upper and lower boards. To fix this problem, two pillars were removed and a piece of wire with a non-conductive coating was utilized to keep the boards together. The second issue was that the remote was unable to power on the propeller motor. Unfortunately, this problem was not solved right away. The issue confused our team because the servos that moved the ailerons responded to the remote, but the motor would not spin. After additional research into the relationship between the flight controller, receiver, and the remote control, it was discovered that an arming procedure was necessary to validate the orientation of the drone prior to powering on the brushless motor. This first attempted launch not only led to electronics adjustments but also highlighted the importance of complete testing prior to flight day.

The next testing occurred on the actual launch of the V1. With the structures complete and electronic components now ready, all that was left was to fly the solar drone. Based on research into other delta wing RC planes with a push propeller, the expectation was to hand launch the drone. Two members held each wing, positioned on opposite sides of the drone to avoid the propeller. Then, a third member armed the motor and throttled it to full power. After a count of three, the two members lightly tossed the drone with the propeller already spinning at full speed. However, due to the heavier weight of our Solar Drone, a higher velocity was necessary to attain enough lift and this method proved unsuccessful after three different attempts. It was now clear that a new method of take off would be necessary for V2.

V1 Launch Method

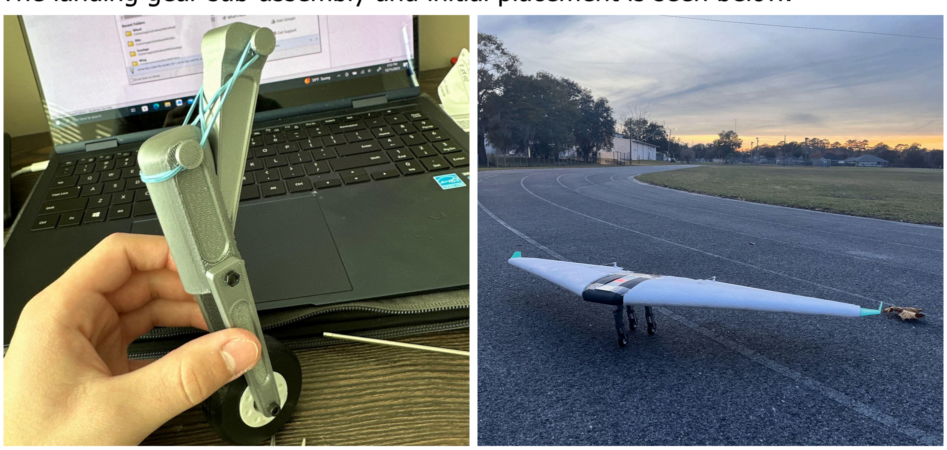
As the V2 would utilize the same electronic components as V1, there was less testing conducted. The main focus was prototyping the 3D printed components as this iteration had a higher stress on the use of additive manufacturing. For this reason, a complete fuselage was printed to test hole tolerances and internal structure design such as the number of walls and infill density.



Prototype of V2 Fuselage

This prototype proved that the close fit hole diameters for the 0.25” wing spars correctly accounted for the expansion properties of the ABS filament. Additionally, this prototype provided insight into methods to decrease weight. Less walls and decreased infill densities were employed and decreased the weight by over 200 grams. The information provided by this prototype also resulted in the decision of a maximum infill of 15% for the two closest wing ribs on either side then 10% for all others. This reduction decreased overall weight and the bending moment at the root.

The last test was the positioning of the landing gear. The easiest location to attach all three to the drone was underneath the fuselage as there was exposed plastic. However, this placement made it extremely difficult for the drone to reach the necessary speed as it would tip over due to imbalances. Furthermore, testing showed that the weight of the drone and forces endured during take off were too great for the rubber bands meant to hold the sub-assembly upright. For this reason, the landing gear were actually attached backwards which solved the issue of landing gear collapse while the drone was taking off. This initial V2 launch test was important for the orientation and wider placement of the landing gear found in the final V2. The landing gear sub-assembly and initial placement is seen below.

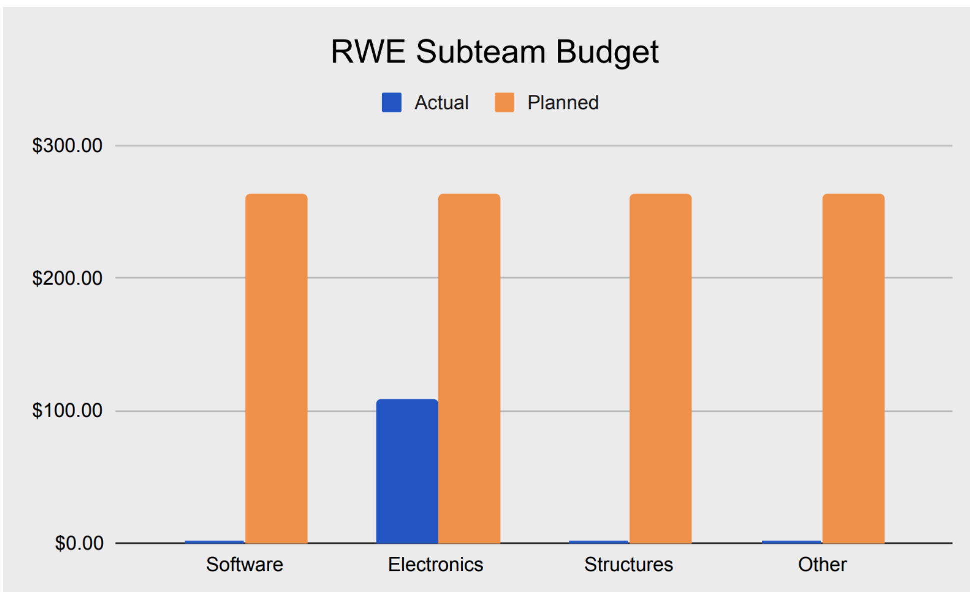


V2 First Landing Gear Attempt

Project Management & Team

Budget Utilization and Purchases

During the 2023-2024 school year, Real World Engineering allocated 75% of funding for the development of the solar drone. Structures and software teams optimized existing inventory, conserving budgets for future iterations. The electronics team utilized 41% of their budget for crucial V2 components, preserving 49% for upcoming versions. Efforts were done strategically, yet ambitious goals for third and fourth iterations necessitate further support. As we are anticipating near-full utilization of current funds by Spring 2024, the need for additional funding is crucial for sustained innovation. With increased support, we can accelerate our progress toward advancements in solar drone technology. Any additional support is pivotal in driving our mission forward.



Solar Drone 2023-2024 Budget

Team Members and Roles

Chief Engineer - James Bautista
Acted as the project's leader, overseeing component integration for cohesive functionality. Responsible for the overall design, development, and engineering quality of the product.

Product Owner - Grant Sherman
Set the product vision and scope, representing stakeholders' interests. Responsible for creating product value. Defined and prioritized features for the team to align with this vision. Also integrated and established the team's project management framework.

Scrum Master - Garrett Leath
Facilitated the Scrum process and removed obstacles encountered in development. Managed purchase orders, meeting spaces, and storage facilities. Organized team documentation, processes, and tools.

Structures Lead - Braxton Eisel
Led and developed deliverables for the structures subteam. Managed the project's structural elements, coordinating development and integration. Led the development of CAD models for all structural components.

Aerodynamics Lead - Austin Thomas
Developed various aerodynamic simulations and performed critical calculations, providing key feedback to subteams. This work was essential for optimizing aerodynamic performance and aiding in the project's overall development.

Electronics Lead - Gage Pollard and Matt Willard
Researched and developed the entirety of hardware implemented within the drone. Performed critical calculations in terms of circuitry voltage to maintain safety and maximize power output. Submitted purchase orders and proposals for all electronics system changes.

Software Lead - Aaron Shumer
Researched the flight control software and flight controller for the drone. Lead troubleshooting for software and hardware issues. Collaborated closely with Gage to conduct testing of the drone's thrust and accurately assess its power output. Oversaw electronics purchase orders.

Manufacturing Lead - Agus Zurlo
Served as an expert in the manufacturing discipline to aid in the development of the solar drone. Provided key design input and feedback to the structures team to ensure manufacturability. Facilitated 3D printing research and efforts for the team.

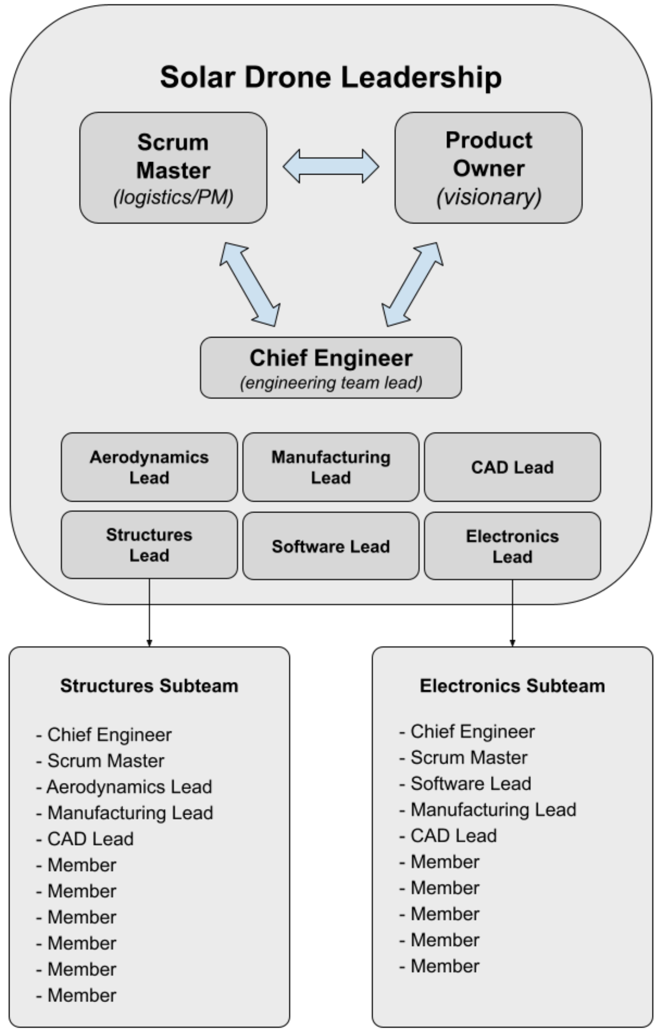
CAD Lead - Anthony (AJ) Sawmiller
Organized and streamlined the Fusion360 CAD system used by multiple subteams throughout the project. Responsible for onboarding new members within the system.

Agile Framework

Team Structure

Real World Engineering has tailored the Scrum framework to align with the unique challenges and dynamics of a student-led project. The team structure, depicted in the accompanying diagram, is designed with critical student-related constraints in mind:

1. Academic commitments take precedence, with team members prioritizing their studies.
2. The turnover of regular team members is anticipated due to the nature of student availability.
3. Assigning ownership of specific functions to team members increases their engagement and retention.
4. Some members will naturally exhibit significantly higher performance levels than others.
5. Team members can feasibly commit to two 1-hour meetings weekly.
6. The simpler, the better.



Artifacts

The Solar Drone Design Team employs monday.com for its project management needs, where it tracks high-level goals and manages deliverables. For day-to-day communication, general members and subteams use Slack, whereas the leadership team prefers the immediacy of an iMessage Group Chat. For CAD Modeling, the team uses Fusion360 which allows for seamless collaborative document editing. All design files are stored on a shared Fusion360 group. For file management and storage not related to CAD, the team relies on a Microsoft SharePoint drive. The file system is relatively straightforward, where each lead gets a folder. It is up to each lead to organize their folder as they see fit. The structure of the file system is organized as follows:

- /Solar Drone F23/
    - /Project Management/
        - /Purchase Orders/
        - /Templates/
    - /Aerodynamics/
    - /Electronics/
    - /Manufacturing/
    - /Software/
    - /Structures/

Meetings

The Solar Drone project employs a structured meeting schedule to facilitate efficient project management and development. The process begins with weekly 'lead meetings', akin to daily standups, where the leadership team sets strategic timelines, objectives, and outlines deliverables. These meetings are crucial for steering the project's direction and ensuring alignment with overarching goals.

On the same day as these lead meetings, a larger assembly involving the entire Solar Drone team takes place. This gathering is pivotal for translating the strategic plans set by the leadership into concrete actions. It provides a platform for general members to actively participate alongside the leads in the development and refinement of the drone, fostering a collaborative environment.

However, if the goals established during the lead meetings are not met within the stipulated timeframe, leads take proactive measures. They dedicate additional time outside the regular meeting hours to work with their respective subteams. This commitment is essential to keep the project on schedule and address any hurdles or delays promptly. This approach ensures consistent progress and adherence to the project timelines, vital for the success of the Solar Drone initiative.

Team Culture

A large focus this past semester was finding opportunities for members of the team to have complete ownership over the design and implementation of a component of the drone. Leads were meticulously selected as they were entrusted with running their teams and delegating tasks to each of their members. All of the assignments that members completed were then checked by the leads and shared with the chief engineer before being applied to the drone. All in all, the combination of independent, driven members with an organized project management structure resulted in an extremely productive team. The core team values that led to this success were trust, communication, collaboration, and innovation. These were all crucial in ensuring that all members felt valued, that the work being completed was pushing the project forward, and that as a team, everyone could be proud of the progress made.

Lessons Learned

Engineering Design Process

In the engineering design process of our solar drone project, we learned several valuable lessons. A primary insight was the critical importance of defining engineering requirements and constraints more clearly at the outset. This aspect turned out to be far more significant than initially expected, influencing various stages of the project.

We discovered a misstep in our approach to aerodynamics. Initially, the aerodynamics team was tasked with modifying an existing design. However, it became evident that a more effective strategy would have been for this team to select the initial design themselves, thereby setting the necessary constraints for the structures team. This realization underscores the need for a more integrated approach where different teams can influence design decisions from the beginning.

Another notable oversight was the lack of practical feedback regarding the flight characteristics of drones, particularly the takeoff procedure for remote-controlled aircraft. This gap in our understanding led to a lack of consideration for these critical aspects in the design process. Future projects will benefit from a deeper focus on practical flight dynamics and real-world testing scenarios.

Furthermore, the project highlighted the necessity of considering design for manufacturing from an early stage. For instance, the issue with the winglets not curving up, resulting in us having to slice off the end part and glue it, could have been avoided with earlier consultation with the manufacturing team. This incident and others like it stress the importance of developing concrete manufacturing constraints and regularly consulting with the manufacturing team at each step of the process.

From a physical standpoint, there were lessons to be learned as well. The control surfaces did not provide enough deflection for effective flight control, suggesting a need for greater motion in the servos. Additionally, complexities with the old flight board presented significant challenges, indicating a need for simplification in future designs.

The project also offered insights into the use of 3D printing. While PLA Aero was considered, it required a significant time investment, and we found that ABS was sufficiently light. We learned that large parts could still be effectively printed on small print beds by gluing parts together in a specific manner. This approach emphasizes the importance of prototyping in the engineering design process.

Prototyping proved to be a crucial step, particularly for systems with multiple interacting parts. A systematic approach to developing prototypes, especially for attachment systems, could prevent unforeseen issues. Acceptance testing during prototyping, such as printing a tiny section of the wing to foresee limited range of motion issues, is essential.

Finally, we recognized the value of simple research, such as consulting YouTube DIY videos on solar drones, and the importance of establishing feedback systems and basic flight telemetry for continuous improvement and learning.

Project Management

Sub-teams

At the onset of the Fall 2023 semester, the leadership established six main leads, each heading a distinct "subteam." However, this structure faced challenges due to a lack of sufficient deliverables to meet the retention criteria for all the subteams. Consequently, members from specific subteams, notably manufacturing and CAD, began shifting to the structures subteam or opted to leave the club altogether. This led to a significant reorganization within just four weeks, resulting in two primary subteams: structures and electronics.

It also became evident from a development perspective that integrating the manufacturing and aerodynamics aspects into the structures team was necessary. Keeping these elements as separate entities was leading to potential issues in designing for aerodynamics and manufacturing. This integration was crucial to streamline the development process and mitigate design conflicts.

Meetings

The design team's meeting structure proved effective in balancing member workload and flexibility. However, scheduling the leadership meetings on the same day as the general development meetings created logistical challenges. A critical issue was the brief four-hour interval between these meetings. If the leadership meeting revealed urgent matters, resolving them before the development meeting was often unfeasible.

This tight scheduling also hindered the ability to create quality deliverables in the time between the two meetings. When new tasks were identified in the leadership meeting, the rush to prepare them for the development meeting frequently resulted in substandard design specifications and requirements. This timing issue impacted the overall quality and efficiency of the team's output.

The development meeting's format, which involved conducting all activities in a single location, significantly enhanced collaboration among team members. However, the one-hour duration often proved insufficient, leading to meetings being prematurely concluded. To address this, it would be advantageous to book a room for a longer period, say 2-3 hours. This extended timeframe would allow members the flexibility to stay beyond the one-hour mark, especially if they are actively engaged in a task. Such an arrangement is likely to increase their inclination to remain at the meeting, consequently improving the rate of deliverable completion and overall productivity of the team.

Tools

Monday.com

For the upcoming V3 development cycle, it is essential that Monday.com, our central project management tool, is utilized to its full potential. In the previous iteration, the tool's primary benefit seemed limited to providing visual representation of processes and requirements. This limitation was evident in the team's challenges with meeting certain deadlines. Notably, the adoption of Monday.com occurred only midway through the development cycle, and that adoption was very limited in nature. Additionally, the V2 sprint backlog was overly ambitious, contributing to difficulties in meeting targets.

To improve, four key actions are necessary: Firstly, the team must fully commit to using Monday.com consistently throughout the project. Secondly, management should adopt a more realistic approach when prioritizing and selecting items for the sprint backlogs, ensuring they are achievable. Thirdly, there needs to be more detailed and careful planning of sprints to align better with realistic goals and timelines. Lastly, the sprint backlog items need to be more logical and feature-based with much clearer design requirements emulating a standard deliverable. This comprehensive approach will enhance project management and execution efficiency in the next development phase.

Sharepoint File System

Adopting a unified Sharepoint file system proved effective for the team. Looking ahead to the V3 development, two potential issues need addressing to maintain this efficiency. First, with each new phase bringing a surge of research documents and files, it's vital to organize these systematically. This can be achieved by creating specific folders labeled "V1", "V2", "V3", etc., within each lead's directory. Such a structure will maintain a clear and chronological separation of the work done in each design iteration, facilitating easier access and reference.

Secondly, it's important to exclude CAD files from this Sharepoint system. Since all CAD files are already managed within the Fusion 360 software, incorporating them into the Sharepoint system could lead to organizational complications. Keeping CAD files solely within Fusion 360 ensures a more streamlined and efficient management of these critical resources, avoiding redundancy and potential confusion.

Fusion 360

During the V2 development phase, Fusion360 emerged as a highly collaborative and effective tool for designing the drone's structure. Nonetheless, the prevalent use of Solidworks in the University of Florida's curriculum presented a notable challenge. Most club members are already proficient in Solidworks, leading to resistance in adapting to Fusion360. This reluctance to learn a new system resulted in a skewed distribution of workload, particularly in CAD file creation, burdening a small group of members with the majority of CAD-related tasks.

To mitigate this issue, the executive board should consider implementing a training program focused on Fusion 360. This program would not only teach members how to use Fusion 360 but also familiarize them with the specific ways it is used by the Solar Drone Design team, particularly regarding the team's file management system within Fusion 360. Such an initiative would help in evenly distributing the workload, enhancing team efficiency, and ensuring a smoother transition for members accustomed to Solidworks.

References

[1] National Air and Space Museum. (n.d.). Delta Wing Streak 130. Smithsonian Institution. Retrieved January 5, 2024, from https://airandspace.si.edu/collection-objects/delta-wing-streak-130/nasm_A19840716000
[2] Filippone, A. (2003). Aerodynamics of the Delta Wing. Retrieved January 5, 2024, from https://aerodyn.org/delta/
[3] mins. (2017, March 4). How does the aspect ratio of a wing impact its lift? [Online forum post]. Stack Exchange. Retrieved from https://aviation.stackexchange.com/questions/36009/how-does-the-aspect-ratio-of-a-wing-impact-its-lift
[4] Hepperle, M. (2018). Basic Design of Flying Wing Models. Retrieved January 5, 2024, from https://www.mh-aerotools.de/airfoils/flywing1.htm
[5] Airfoil Tools. (n.d.). CLARK Y AIRFOIL - CLARK Y airfoil. Retrieved January 5, 2024, from http://airfoiltools.com/airfoil/details?airfoil=clarky-il
[6] Airfoil Tools. (n.d.). CLARK Y AIRFOIL - CLARK Y airfoil. Retrieved January 5, 2024, from http://airfoiltools.com/airfoil/details?airfoil=clarky-il
[7] Heli-Air.net. (2016, February 9). Clark Y. Retrieved January 5, 2024, from http://heli-air.net/2016/02/09/clark-y/
[8] Brassaw, L. (2022, August 15). Ailerons – What are They, and How do They Work? Thrust Flight. Retrieved January 5, 2024, from https://www.thrustflight.com/ailerons/
[9] ThrustFlight. (2023, March 30). Private Pilot Ground School: Lift and Basic Aerodynamics [Video]. YouTube. https://www.youtube.com/watch?v=Y12tAXnGptY
[10] SpeedyBee. (n.d.). SpeedyBee F405 WING APP Fixed Wing Flight Controller. Retrieved January 5, 2024, from https://www.speedybee.com/speedybee-f405-wing-app-fixed-wing-flight-controller/
[11] Flite Test. (n.d.). FT Versa Wing MKR2. Retrieved January 5, 2024, from https://store.flitetest.com/ft-versa-wing-mkr2/