NAU NORTHERN ARIZONA UNIVERSITY

Mechanical Engineering

2021-2022 SAE Aero Micro

Final Proposal

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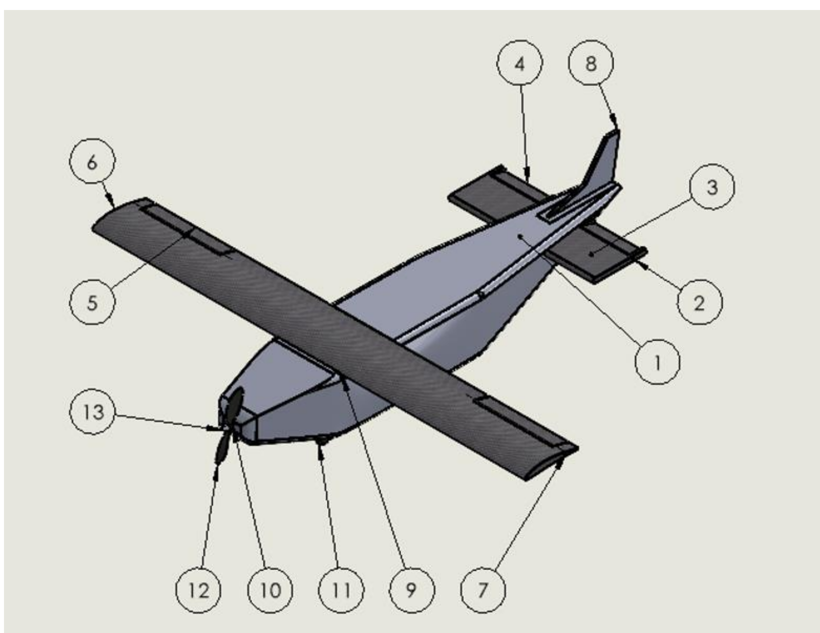
DISCLAIMER

EXECUTIVE SUMMARY

The SAE Micro Aero team is building an airplane that will be under 48” in wingspan and be capable of carrying a payload around the pattern at a competition in Van Nuys, California. The team broke up into different subgroups, each working on topics such as fuselage, airfoil/lift, composite materials, thrust, and electronics. As these groups narrowed down, select designs for the prototype began to assemble. The airfoil went through several iterations, as well as the entire empennage assembly. Different codes were run as well as CAD design modeling to ensure that the numbers matched the proposed design for calculations such as the coefficient of lift/drag and Reynolds numbers. The fuselage also went through a transition process from the beginning of its original CAD layout. It originally started out smaller and wider, then transitioned to more of a box, and is now the proper dimensions for the payloads that the team will need to fit inside. The new design is slightly more optimized to decrease drag and potentially give the aircraft an edge. The team decided that to reduce weight and simultaneously increase strength, carbon fiber would be the answer. In addition, this will also help the team have more parts available, due to the molds for the carbon to overlay, they can be easily replicated. The team got into touch with Novakinetics to receive assistance and guidance for the future carbon fiber projects. The customer requirements as well as the engineering requirements had a great influence on the design of the aircraft due to the fact that the very basis for the competition has to do with what they want. Being able to unload and load the aircraft in a timely manner, flying in a certain pattern around the mini “airport”, carrying a specific payload, and keeping the aircraft within the size parameters all influenced the design. The basis for the design of the aircraft is centered around the competition and how the aircraft is able to perform on that day.



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1 BACKGROUND

1.1 Introduction

SAE Micro Aero is a competition that requires teams of students to design and manufacture a RC airplane. The plane must be remote controlled and capable of carrying certain payloads provided by the competition. The NAU team is hoping to go to competition with a working product that adheres to the SAE guidelines. This project allows the team to analyze aircraft design and aerodynamics on a micro level in order to boost their understanding and apply it at a macro level. The stakeholders of this project are the NAU Engineering Department (CEIAS) and the SAE organization. CEIAS finds this project beneficial because the school will get advertising at the competition. Depending on how successful the project is, it can increase the school's reputation and draw potential students to the program. SAE is hosting the competition which is a notable competition to be a part of therefore they will also receive advertising through the participants.

1.2 Project Description

"The SAE Aero Design competition is intended to provide undergraduate and graduate engineering students with a real-world design challenge. These rules were developed by industry professionals with a focus on educational value and hands-on experience. These rules were designed to compress a typical aircraft development program into one calendar year, following the early development phase of system engineering and requirements derivation. This competition will expose participants to the nuances of conceptual design, manufacturing, system integration/test, and verification through demonstration. The Micro Class is an all-electric class designed to help students balance trades studies between multiple conflicting requirements. e.g. carrying the highest payload fraction possible, while simultaneously pursuing the lowest empty weight possible" [1].

2 REQUIREMENTS

The Society of Automotive Engineers provides an outline for participating teams to read and follow to properly compete in the competition. All of the customer needs can be found within this document and gives guidance to teams in designing their aircraft. These customer needs must be met for the aircraft to be used in competition and furthermore will help guide the design in a successful direction. From the customer needs, the team derived a list of engineering requirements that directly impact the design and will implemented into the design. The engineering requirements will be subject to change as testing and numerical verification happens.

2.1 Customer Requirements (CRs)

For the SAE Micro Aero competition, customer requirements were outlined by SAE in their rulebook for the competition. These requirements are specific to the SAE Micro Aero competition, and designs will be constrained in some respects by what is allowed for use in the design. The Micro class aircraft is being scored based on a flight score, where time is one of the heavier weights, along with the payload and a bonus score, seen in **(Eq. 1)**.

$$\text{Flight Score} = \text{FS} = 80 * \sqrt{\frac{\left(W_{payload} * \left(0.5_1 * N_{large}\right) + \left(0.4 * \left(N_{small}\right)\right)\right)}{T_{flight}}} \tag{1}$$

Also tying into the flight time, another customer requirement is the payload. The large boxes are 12x12x2 inches, with a weight of 5.5 oz, within a 0.25-inch tolerance and a 0.5-ounce tolerance. The small boxes are 6x6x4 inches plus or minus 0.25 inches and weigh 2.5 ounces plus or minus a half ounce. The more boxes that are carried, especially large boxes, the higher the flight score will be because these numbers are in the numerator. The SAE rulebook dictates that the aircraft must takeoff within 1 minute from its starting position on the runway and into its flight path as shown in **(Figure 1)**. It should fly along the pathway before making a 180-degree turn. After the turn, the airplane must fly its “downwind” leg 300 feet before making a second 180-degree turn. Finally, it must land within 200 ft of the same runway to complete the flight circuit. The aircraft will be remote-controlled for flight by a 2.4 GHz controller and receiver. Between trips, two team members are required to load and unload the payload within 1 minute to show the aircraft’s ease of access to the cargo bay. Furthermore, the team also will have spare parts in the competition in case of unexpected maintenance or changing of broken components of the aircraft.

The highest weighted customer requirements at a score of 9 are the flight time, payload carried, and unloading time. These factors are rated highest as they are what determines our final score in competition. The more we reduce flight time, the better our score will be. Similarly, carrying more weight will give the team a higher score. Lastly, unloading time must be completed within a 1-minute time limit. The next requirements are those weighted at a 3 which are: turning radius/ maneuverability, RC signal strength, takeoff, and landing. The aircraft must be maneuverable and able to be controlled in flight to be effective in competition. Likewise, signal must be constant in flight so the aircraft can be controlled, and not lose connection and likely crash. Takeoff and landing are also important in competition because the aircraft must be able to take off with the load and land as well to successfully complete a trial in competition, without these, the aircraft will not be able to compete. Lastly, the only customer requirement rated as a 1 is having spare parts, we are required to have spare parts in competition in the unlikely event of a part failure. The spare parts are important but also will not be useful if the aircraft does not fail, so it is not paramount to have spare parts necessarily.

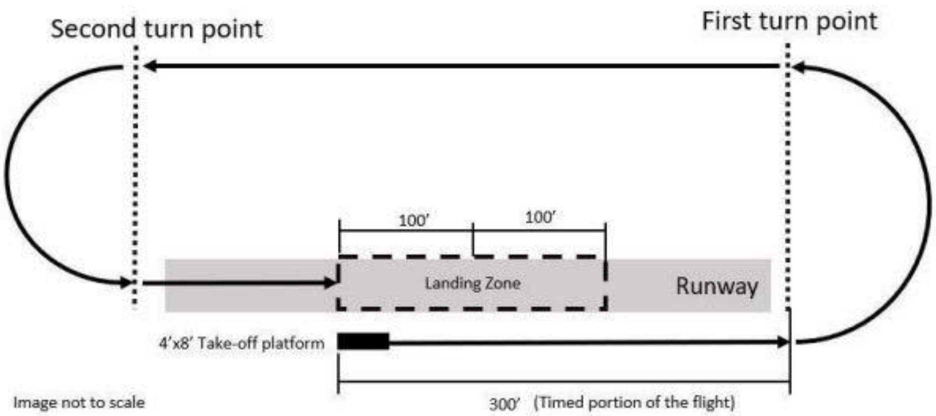

Figure 1: Designated flight pathway and runway for Micro-class competition [1]

2.2 Engineering Requirements (ERs)

After compiling customer needs from the rules and regulations, the team assessed what is required of the project and derived quantifiable engineering requirements to drive the design and set parameters for how the plane will perform. The engineering requirements will set the parameters of how the plane will compete and perform as a system. Engineering requirements include wingspan, cost, battery power, motor power, cargo bay volume, lift, drag, thrust, weight, and RC signal range.

For the aircraft to qualify for the Micro class competition, it must have a wingspan of 48", so the tolerancing on the wingspan is 2" less than 48" as the rules require the wingspan to be no longer than 48". The four fundamental forces acting on an airplane in flight are lift, drag, weight, and thrust. These four forces are engineering requirements crucial to the success of the airplane because the forces of lift and thrust must be able to overcome drag and weight. The calculated lift force of the aircraft is about 9 lbf with a tolerance of plus or minus 1 lbf, which can show up in errors in calculations or changing conditions. Opposing the lift force is the weight of the aircraft, which has a target of 2.5 lbs. plus or minus 0.5 lbs. which will account for the adding removing or change components. A key objective is to minimize the weight so the motor can be effective as possible, if the aircraft weighs too much the design will not operate as expected leading to a required design change. The target thrust force is 18 lbf plus or minus 2 lbf. This decision is based on the analysis of the set up and the estimated drag and wheel friction forces. The drag force is to be less than the thrust force for the aircraft to function, so a target of 10 lbf plus or minus 1 lbf is determined. To create a thrust vector, an effective powerplant must be utilized, with a 1000 mAh battery that will deliver 35000 mA plus or minus 1000 mA of current to the system. When taking off, it is important to optimize the flow over the airfoils. To optimize air flow, an engineering requirement of the optimal Reynold's Number of the flow during takeoff is 200000 plus or minus 100000. Per the competition guidelines, the airplane is required to carry a cargo. Therefore, a cargo bay is another important engineering requirement. The team must pilot the aircraft to demonstrate flight control whilst airborne then be able to land on the runway. During the flight, it is also important to maintain a constant RC connection, which drives an engineering requirement of RC signal range. The RC range is a critical component of the design and needs to be able to have a target range of 400 ft plus or minus 20 feet, to ensure connection when the plane is farthest away. While on the ground, the plane must also be able to steer effectively. Frame markings are required on the exterior surfaces to signify team identification as well as a center of gravity indicator. Durability and cost are also taken into account and are very important engineering requirements, as the plane must be within the budget and compete without falling apart. The plane should also be able to take rough landings as well as windy flight conditions, so a durability target for the landing gear has been set for 10 lbf plus or minus 3 lbf for the landing gear, further calculations will show if this target is feasible or an over design.

2.3 Functional Decomposition

Decomposing the aspects of a design and its functions is critical to decide what the key processes and components are, for the team's design, we constructed a Black Box Model and a Functional Model of our system. These two models are crucial to understanding what the system is supposed to do and will aid in troubleshooting when errors arise. The Black Box Model provides inputs and outputs of the system along with the overall functions of the system in the middle. The inputs and outputs will consist of material, energy and signals needed to operate the aircraft, and the Functional Model further decomposes the functions into processes and maps out all of the Black Box Model and Functional Model show how different subsystems interact to achieve the desired functions of the system.

2.3.1 Black Box Model

The Black Box model for the SAE Aero Micro airplane describes the overall function of the airplane, as well as the material, energy, and signal inputs and outputs of the system. The overall function of the aircraft is to maneuver the aircraft. The material input would be each of the individual components of the aircraft. These components include the wings, propeller, fuselage, landing gear, power plant, and the cargo box that will be provided at the competition. The overall material output is the complete airplane. The energy inputs are both electrical energy and human energy. The electrical energy comes from the batteries/motor as well as the RC remote. Human energy will come from the pilot using the controls of the RC remote. The energy outputs are rotational, thermal, and translational. The rotational energy will come from the propeller spinning on its axis. The thermal energy will come from the powerplant becoming hot during operation. Additionally, the translational energy will come from the servo motors moving in a straight line. In addition to material and energy inputs and outputs, there are also signal components. The signal inputs are human, RC, and on/off signals. The human signal comes from activating the remote control, and the RC signal comes from the remote control itself. The on/off input is the activation of the remote. The major signal output is the on/off signal for the powerplant and servo motors. The final black box model can be seen in **(Figure 2)**.

The Black Box Model is still up to date and changes have been made in the center function, transport cargo has been added because transporting cargo is a key task in the competition and was not reflected in the model. We anticipate making changes to it as testing and we get hands-on experience with the aircraft. We have mapped out how we believe the aircraft will operate best, and through flight testing will determine if any improvements to handling, operation and flight procedure can be made.

Figure 2: Black Box Model

2.3.2 Functional Model

The Functional Model seen in **(Figure 2)** for the aircraft builds off the Black Box Model, by taking the inputs of the Black Box Model and breaks them down into the functions of the aircrafts, showing what is required to operate the system, along with the outputs of the system. The three inputs of any Functional Model are energy, material, and signal, which will all be used in the operation of the system. Furthermore, the inputs can be used to function in other parts of the system.

Generating this Functional Model was a good first step for the team, and outlines what the aircraft is required to do, so concept generation and subsystem requirements can be determined, and simplifies the design process by breaking down each input to a desired output through some function of the airplane. The plane requires inputs of power to control and operate the aircraft, the plane as the material to be maneuvered, human input to control and fly the aircraft, and signal inputs from the controller so the human can operate the aircraft. From these inputs, the functions of the plane and outputs of the aircraft are formed and concepts for the plane can be generated based on these parameters. The Functional Model has aided the team thus far in conceptualizing what the plane needs to do and the best methods to achieve the desired outcome.

As the team progresses in the project, the functional model is being used for mapping out how the plane will function and aid in how different components are being designed and implemented into the system. This process is to ensure that all the components are put together properly and function as anticipated. Furthermore, the functional model will be extremely useful in the instance of improper functioning and bolster the troubleshooting process forward. Overall, creating the functional model serves several purposes and will be updated and changed if needed to map out the function of the system.

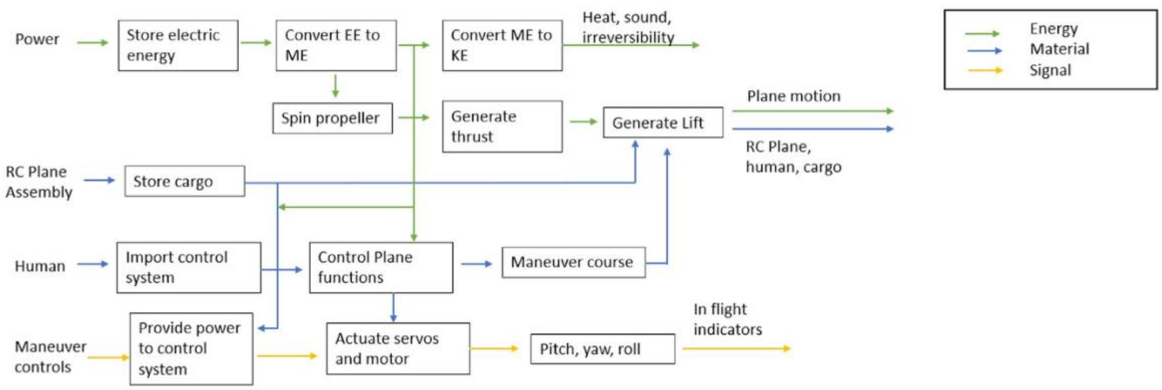

Figure 3: Functional Model

2.4 House of Quality (HoQ)

The House of Quality **(Appendix A)** is one of the first steps in generating what is required for the project. It takes the customer needs and the engineering requirements into consideration and gives an accurate representation of how the two are linked, providing the team with a good understanding of how the design applies to what the customer needs. Finally, the engineering requirement will be given an absolute technical importance which is a summation of the weight of the customer need multiplied by the rating associated with the engineering requirement, showing what is most important and least important. Relating the customer needs to the technical requirements gives an accurate depiction of how different sub systems will operate together and see the correlation between the two. This helps in driving the design process and gives the team the opportunity to design towards a target and ensure that all sub systems are accounted for in the system as a whole.

The team's HoQ provides a relative weight of the customer needs, and the engineering requirements are rated according to how they relate to the customer needs, 1 meaning a low relationship, and 9 meaning a strong relationship, while no number means there is no correlation between the specific customer need and engineering requirement, and is shown in the What vs. How room. Based on the absolute technical importance scores, the lift, motor/thrust, and wingspan are the highest scoring meaning that they have the highest correlation with the customer requirements, telling the team that those are the important requirements to design.

Customer Needs	Customer Weights	Wingspan	Cost	Battery	Thrust/Motor	Cargo Bay	Lift	Drag	Thrust	Weight	T/O Rey #	RC Signal Range	CG Marking	Ground Control	Flight Control	Durability
Flight Time	9	9	3	1	9	3	9	9	9	3	9	3		3	9	
Payload	9	3		3	9	9	9	1	3	9			9		3	9
Turning Radius/Maneuverability	3	3			3	1	1	1	9	1	9	3			3	
RC Signal Strenght (2.4 GHz)	3		1	3								9				
Spare Parts	1	1	3	1												9
Launch T/O	3	9	1		3	1	9	9	9	9	9			9	3	
Landing	3	9	1		1	1	3	3	3	3	3			9	3	
Unloading Time	9	1												3		

Figure 4: What vs. How Room

The top part of the HoQ is the How vs. How room, which assesses the impact of each engineering requirement upon the others. The purpose of this room is to show how the engineering requirements push others. For instance, if one engineering requirement pushes another towards the target value, the box will contain a plus sign, and if it pushes it away from the target value there will be a negative sign, but if there is no correlation between the two requirements there will be an o in the box, showing that neither are correlated in terms of meeting the goals.

1	Wingspan														
2	Cost	+													
3	Battery	-	+												
4	Thrust/Motor	+	+	+											
5	RC Signal Range	o	+	+	+	o	o	o	o	-					
6	CG Marking	+	o	o	+	+	o	o	+	-	o	o			
7	Durability	+	+	o	+	+	o	o	o	+	-	o	o	o	

Figure 5: How vs. How Room

The next room in the HoQ is the Now vs. What room, which finds competing products for benchmarking and rates them on how they meet the customer needs on a scale of 1, being poor, and 5 meaning excellent. This analysis rates products that are available to see how they can compete against the product we will design and show possible room for improvements. The analysis done for the benchmarking shows that the products analyzed meet the criteria at different levels, which is a good starting point for the team to start designing and comparing to.

Figure 6: Now vs. What Room

2.5 Standards, Codes, and Regulations

The table below, **(Table 1)**, shows the standards/codes, the title of the standard, and how it applies to the project. The codes are from the American Society for Testing and Materials, Society of Automotive Engineers, and Federal Aviation Administration. Standards and codes like these are incredibly important for practicing engineers because these standards have been put in place to keep engineers, users, and viewers safe. The codes chosen for this project pertain to the batteries used, design and construction, command and control systems, SAE Aero rules and regulations, and remote pilot licensing.

Table 1: Standards of Practice as Applied to this Project

Standard Number or Code	**Title of Standard**	**How it applies to Project**
ASTM F3005-14a [2]	Standard Specification for Batteries for Use in Small Unmanned Aircraft Systems (sUAS)	This applies to any sUAS system that uses batteries. Helps ensure there will not be overheating in wires. Additionally, ensures all electronic systems will not fail. This is to guarantee the safety of the aircraft.
ASTM F2910-14 [3]	Standard Specification for Design and Construction of	This is applicable for aircrafts 55 lbs or less. Give standards for landing gear, electrical system, construction/materials, propulsion,

	a Small Unmanned Aircraft System (sUAS)	propellers, etc… These will ensure the safety of those viewing the flight.
ASTM F3002-14a [4]	Standard Specification for Design of the Command and Control System for Small Unmanned Aircraft Systems (sUAS)	Application is for aircrafts that will have people viewing them that are under 55 lbs. This will help avoid collisions. This also discusses maximum range and altitudes.
SAE [1]	2022 SAE Aero Rules and Regulations	These are the competition rules and regulations. This is applicable because the team needs to follow these to avoid being disqualified. This also discusses power limitations, no use of metal, and
FAA Title 14, Chapter I, Subchapter F, Part 107.7.a.1 [5]	A remote pilot in command, owner, or person manipulating the flight controls of a small, unmanned aircraft system must have in that person's physical possession and readily accessible the remote pilot certificate with a small UAS rating and identification when exercising the privileges of that remote pilot certificate.	Our pilot will need to have a certification for flying a small, unmanned aircraft system.

3 Testing Procedures (TPs)

There will be two main testing procedures to ensure that all of the aspects of the design will come together and work as one. The wind tunnel will play a large role in the analyzation of the calculated numbers for the wing, tail, and control surfaces. The wind tunnel will provide the team with the ability to calculate scaled results for the lift coefficient, force of drag, provide a practical boundary layer analysis as well as understand how to optimize the design with different features. The second testing procedure will be the practical flight-testing application of the design. Naturally, once the airframe has been built and optimized though small-scale wind tunnel testing and software analysis, the design will need to be tested full scale. Testing the aircrafts flying characteristics will be integral for furthering the enhancement of its efficiency. For example, the control surfaces may not provide the correct amount of deflection for them to effectively provide authority, so certain factors need to be changed. The flight test will reveal all of these errors because any part of the aircraft that doesn't work right will be exposed very quickly.

3.1 Testing Procedure 1: Wind Tunnel

For this test procedure, a scaled down airfoil of our design will be 3D printed in the NAU MakerLab and tested in the wind tunnel at NAU. The airfoil will be tested at different wind speeds to analyze the total lift and drag forces on the airfoil, the Reynolds Number at the leading edge of the airfoil, the weight of the airfoil, and the durability of the airfoil. The test will be conducted on Monday, November 15th after the airfoil is 3D printed and sanded to a smooth finish.

The wind tunnel will be analyzing the main airfoil of the aircraft, as well as the components that make up the tail such as the horizontal and vertical stabilizers. The wind tunnel at NAU only has an area of about 12x12 inches, so all of the parts of the aircraft will need to be scaled down.

3.1.1 Testing Procedure 1: Objective

The objective of this testing procedure is to analyze and satisfy all the engineering requirements listed in section 3.2. The NACA6412 airfoil design being used by the SAE Aero Micro Team will be scaled down from a 48-inch span to a 9.6-inch span, which is a 0.12:1 scale ratio. Additionally, a 3-inch hollow cylinder was added to the trailing edge of the airfoil to make it compatible with the wind tunnel equipment. Once the airfoil is 3D printed from the NAU MakerLab, it will be sanded down to create a smooth edge without changing the geometry of the airfoil. The rough edges from the 3D printer would create a turbulent flow over the airfoil, which will be inaccurate in the final design. When in the wind tunnel, a pitot static tube will measure the static and stagnation pressures of the wind tunnel, while a mouse setup will be mounted to the top of the airfoil to measure boundary layer pressure. These readings will allow for the calculation of the Reynolds Number at the leading edge of the airfoil for takeoff speeds. Additionally, the lift and drag forces will be measured at different velocities on the wind tunnel. These measurements will satisfy the lift and drag ERs as stated in the QFD. The Reynolds Number combined with lift and drag measurements will tell us if the span is the correct length. It is important to note that the chord is scaled equivalently to the span, so the aspect ratio is unaffected. The durability of the airfoil will also be tested by subjecting it to much higher wind speeds than will be experienced during the competition.

3.1.2 Testing Procedure 1: Resources Required

There are a number of resources required in order to complete this testing procedure. The first resource needed is a 3D printer in order to make a scaled down version of the NACA6412 being used in the experiment. The 3D printers in the NAU MakerLab will satisfy this resource requirement. The next resource needed will be the sandpaper needed to finish the 3D printed airfoil. The sandpaper needed is readily available to the members of the team. The next resource needed is the wind tunnel in conjunction with the "AeroLab" software that control the wind tunnel. These two resources combine to be the main testing apparatus for this experiment. Another resource needed will be a manometer with 24 channels that can be mounted to the wind tunnel. This manometer will provide pressure readings throughout the experiment. Two pitot static tunes will be used in the wind tunnel and connected to the manometer to provide static and stagnation pressure in the wind tunnel. A mouse setup containing 10 channels will be mounted to the airfoil to provide boundary layer pressure readings through the manometer. Another resource needed will be a sting balance that communicates with the "AeroLab" software. The sting balance provides a lift force, drag force, and even the overall pitching moment of the airfoil. The final resource needed will be a smoke generator, in order to visualize the flow over the airfoil to better depict the vortices generated by the airfoil.

3.1.3 Testing Procedure 1: Schedule

The first iteration of this procedure will be completed in the NAU machine shop on November 15th, 2021, at 11:30 AM. The data from the test will be compiled and analyzed by November 19th, 2021. It can then be determined if additional testing is needed, or if the proposed airfoil needs additional adjustments to best serve the aircraft.

3.2 Testing Procedure 2: Practical Test Flight

The practical testing portion will be to physically fly the aircraft and discover how it feels and reacts to different inputs. This will be the final stage of the initial testing because all of the calculations, design, and measurements will all come together to see if the aircraft flies. The prototype will need to prove itself in various types of flying conditions to ensure that it is robust enough to withstand the forces of flight. The testing environment will be harsher than the competition environment because there will be wind, thermals, and other factors in an outside testing platform. However, this is an advantage because if the aircraft can handle challenging conditions, it will be able to withstand a smooth and controlled air mass at competition.

This part of the testing phase will prove the rest of the engineering requirements outlined in the QFD in **(Figure 4)**. Engineering requirements such as lift, drag, thrust, and weight will all be confirmed when the aircraft attempts to take flight. If there is not enough thrust to overcome the drag, the aircraft will not move. The lift required for flight will either be met, or it won't get off the ground, and changes will need to be made. The full-scale test will essentially validate all of the calculations for the engineering requirements thus far.

3.2.1 Testing Procedure 2: Objective

The primary objective is to ensure that the prototype is able to achieve lift-off, and subsequent steady state flight for a period of time. The testing procedure will vary for the different deliverables of engineering requirement. The main objective to test and validate the control surfaces will be to make sure that each surface provides adequate authority over each of the axis.

This testing procedure will occur in flight, and one axis will be focused on at a time. The rudder will be tested to ensure that the aircraft is capable of yawing, and whether or not that vertical stabilizer is effective. During the testing, the aircraft's rudder will be moved side to side to confirm that it performs as it should. The same idea will go for the ailerons on the wings for the control over the longitudinal axis. The ailerons should move opposite to each other, and not alter the angle of attack to the point where stability is lost. Too much roll rate will also cause instability, so the effectiveness of the ailerons will be determined as the aircraft is flying. The ailerons are also extremely important for directional stability because they are what make the airplane turn. If the airplane is unable to roll during the flight test, the ailerons will need to be reconstructed in a different fashion. The elevator effectiveness will also be a key objective when testing the prototype. The elevator must be strong enough to push the tail down in order to increase the angle of attack on takeoff. This will conclude the controllability portion of the flight test; however, there are more engineering requirements that will need examined during this test. The signal range is an engineering requirement that needs to be confirmed. The range will simply be tested first on the ground, and once the true limit of the receiver is found, that is when the flight test will take place. On that test, distances up to, but not past the previously determined line will be explored to confirm the signal range is adequate. The center of gravity marking, and the cargo bay/payload will tie together, as different loads are explored. Once the aircraft is flying on a regular basis, the payload capabilities will be tested, As the payload is added to the aircraft, the center of gravity will be offset. This test will allow the team to see and understand the different characteristics when the aircraft has aft center of gravity, and forward center of gravity. There is theory about handling characteristics in these flight regimes, but the flight test will give the team an idea of how it will perform. The flying will also be a proving ground for the undercarriage of the aircraft. If hard landings occur during the tests, another objective is to ensure that the airplane doesn't break. However, if it can't handle a hard landing, it may not have been strong enough after all.

The final objective of the flight test is to figure out what needs improved on the prototype and how to improve it. The flight tests will occur more and more as the airplane starts to take shape, and each time it is flown, there will be lessons learned and different ideas to make it perform better. Finding out what went wrong persuades the learning and creates a need for adapting to overcome the problem.

3.2.2 Testing Procedure 2: Resources Required

The required resources for testing the aircraft will be everything up to that point in the capstone so far. The assembled prototype, containing the airfoil, vertical and horizontal stabilizers, electric motor with the prop, battery, and wiring. There is a large quantity of assembled parts that go into the prototype. The environment for the testing will be an open field that doesn't contain many obstructions.

3.2.3 Testing Procedure 2: Schedule

The first day that the entire assembled prototype is built is the day that the team plans to begin the flight testing. This will allow any catastrophic failures that are due to inexperience to happen early and quickly, so that changes can be made and more effective solutions to problems can be drafted. Realistically late November to early December the prototype should be built in its initial stage and be ready to fly. These flight tests will continue throughout the next semester as this course has been a lot of calculations and measurements, while next semester will include all of the practical and physical testing where the plane will be flying and tested often.

4 Risk Analysis and Mitigation

While designing an airplane that meets all the performance targets is important, it is crucial to also focus on potential failures. An FMEA Analysis has been conducted to make note of these failures and identify methods of mitigating these failures. The analysis conducted covered all the sub-assemblies and parts associated with the design and evaluated how different failures can affect the functionality of the plane. Each failure is given a number rating of how important the failure is to the assembly. Some of the failures are minimal and can easily be fixed or mitigated on the spot, but others are more severe and may require an entire redesign. This analysis is especially helpful for designing, because from the failures, mitigation or redesign of the aircraft can be done and the assembly can be further improved as a result.

4.1 Critical Failures

4.1.1 Potential Critical Failure 1: Thermal Fatigue of the Battery (RPN: 140)

The top failure mode identified in the assembly is thermal fatigue of the battery. This failure mode can occur if it is not properly charged or overheats, which can cause a loss in maximum potential of the battery and weaken it over time. If this occurs, the battery may not be able to last the entire duration of the flights and potentially lead to the plane crashing if the battery dies midflight which would cause additional damage and failures. One method of mitigating this failure is by following proper charging techniques and making sure we do not overheat the battery in testing. Furthermore, if the battery does fail, we would need to purchase and implement a new battery.

4.1.2 Potential Critical Failure 2: Motor Seizing (RPN: 120)

The next mode of failure is motor seizing in flight. If the motor seizes, the plane will most likely go down and crash leading to further damage. Electrical motors seizing is a result of the motor being ran too much and the bearings inside of the motor failing. This failure is not very likely to occur but if it does occur, serious damage is expected. To mitigate this failure, the motor will only be running if it is in testing, and it is not to be used for non-testing or competing applications to elongate the life of the motor. As a result of the motor seizing, a replacement motor is needed and will eat into the budget and require more time of the team to replace.

4.1.3 Potential Critical Failure 3: Front Airfoil Disconnect (RPN: 96)

The front airfoil of the aircraft is needed to create lift and aids in the maneuverability of the plane, one critical failure is the airfoil connections to the fuselage failing and losing the airfoil in flight. This failure is critical because if it occurs, the plane will crash and cause more damage to the plane, making it very severe. To mitigate this failure, an enhanced connection to the fuselage will be implemented. Furthermore, the connection to the fuselage may need to be completely redesigned and other parameters may need to be recalculated, such as lift, and drive the design of the connection.

4.1.4 Potential Critical Failure 4: Landing Gear Buckling (RPN: 90)

The plane requires landing gear for takeoff and landing, and if the subsystem is to fail the plane will not be able to do either. One failure mode of the landing gear is buckling on landing. The force exerted on the landing gear during takeoff is only the weight of the aircraft, but when landing the force experienced in the landing gear will be the weight of the aircraft and the acceleration that happens when it touches down, which is where buckling may occur. To mitigate this failure, an analysis of the landing gear will be conducted, and designed for a factor of safety when landing as it will be able to withstand takeoff as well.

4.1.5 Potential Critical Failure 5: Front Airfoil Bending (RPN: 84)

Another critical failure will occur if the airfoil is bent, changing the geometry and producing different kinetic factors that will alter the performance of the aircraft. This failure is key to focus on because the geometry of the airfoil was chosen for desired outcomes, and if it is changed, the flight dynamics will change along with other aspects of the design not being as effective. This failure may come from extreme flying conditions or if it is dropped. To prevent this, the plane will only be tested in ideal conditions and will be transported and handled with care.

4.1.6 Potential Critical Failure 6: Rear Airfoil Bending (RPN: 84)

Like the previous failure, the rear airfoil may also be bent and change the geometry and flight dynamics. Bending may be caused by the same causes and have the same effects on the aircraft, but for the rear airfoil, the elevator may also fail if the airfoil is bent and lead to less flight control and potentially take off failure as a result.

4.1.7 Potential Critical Failure 7: Servo Connection Failure (RPN: 84)

Key components of the control system of the plane are controlled by servos moving parts of the plane, such as the ailerons and elevator so the failure of these components was analyzed. A critical failure of the servos is a connection failure between the servo and moving part, which would cause a loss of control. This failure may be a result of the connection between the servo and moving component disconnecting or the servo breaking off from the plane. To mitigate failure, a stronger adhesive or connection between the servo and the plane may be required or could be fixed by changing the placement of the servo. Currently, the servo placements seem to be logical and proper, but as the result of a failure, these may need to be redesigned.

4.1.8 Potential Critical Failure 8: Thermal Fatigue in Wires (RPN: 84)

The entire electric system of the aircraft relates to wires, and in analyzing the electrical system, a critical failure is thermal fatigue of the wires. Thermal fatigue may happen if the wires chosen are not capable of handling the current going through them, leading them to overheat and cause a short in the system. This failure will drive the wire selection as this failure can be mitigated if we chose the correct wires that can handle the anticipated current flow.

4.1.9 Potential Critical Failure 9: RC Signal Obstruction (RPN: 80)

The aircraft will be controlled by RC connection via a remote control and receiver in the aircraft, one mode of failure in this sub system is signal obstruction, which would cause the signal from the remote control to the receiver to not work properly. If this occurs, the plane will not be able to be controlled and this would cause the plane to potentially crash unless the connection is reestablished. This is a very likely failure to occur if we do not choose the proper receiver and controller that have enough range to stay connected for the whole flight, so to mitigate this failure, the components implemented will have to meet the required distances to ensure connection for the entire flight. If the connection distance does not meet the requirement, redesign and different components will need to be implemented.

4.1.10 Potential Critical Failure 10: Adhesive Failure of Fuselage (RPN: 72)

The last critical failure discussed is adhesive failure of the fuselage. With the current design, several panels will be used to make up the fuselage and will be held together with adhesive. In this set up, it is possible for the adhesive to fail if the drag and shear stresses acting on the fuselage are larger than the strength of the adhesive used. To mitigate this failure, the adhesive used will have to be strong enough to withstand the anticipated shearing and drag on the surfaces, if this analysis proves to be incorrect and the adhesive fails, a new adhesive will be used based on new calculations.

4.2 Risks and Trade-offs Analysis

The proposed potential critical failures all have a discussed method of mitigating each failure. The mitigation of the different failures is related to each other in different ways. For example, the mitigation of the front airfoil bending also protects the rear airfoil from bending. If the plane is cared for and only flown in ideal conditions, both failures can be prevented in this easy step. Another correlation in the failure modes is between the thermal fatigue of the batteries and the wires. It is possible that if a battery begins to experience thermal fatigue, the heat could break down the battery and cause it to have a greater outflow of current. Thus, the wires would then experience thermal fatigue because they would have too much current flowing as well. Therefore, it is crucial to ensure that the batteries are selected in a fashion to reduce the likelihood of thermal fatigue in order to prevent a multi-system cascading failure.

One potential area for an opportunity cost is in the mitigation of the airfoil disconnect failure. The current design of the aircraft features an airfoil that flips open, revealing the cargo bay of the aircraft. However, in order to mitigate the failure of an airfoil disconnect, a very strong connection is needed. There may be some necessary room for error in order to ensure that access to the cargo bay is intact. If a more secure connection between the fuselage and the airfoil is made, the airfoil disconnect failure is much less likely to take place, but the access to the cargo bay is impeded, which will cause another issue with the plane instead of fixing one.

5 Design Selected – First Semester

When designing the aircraft, several references were used to help provide details that influenced the design choices made by the SAE AERO Micro team. The primary source being the competition rules where specific criteria were given that were considered when designing. Another reference for the team was the aircraft produced by the capstone team of the previous year which provided a reference of ideas in consideration for adoption. Another reference was published books that helped provide conceptual context and understanding in how an aircraft is designed based on desired performance. The third and final reference was the literature review sources where the team conducted research on different topics crucial to designing the aircraft. The following sections describe the design developments of crucial subsystems of the aircraft: wings, tail, fuselage, Propeller, Landing Gear, and electrical system.

5.1 Design Description

The main factor towards determining the design of the main wings came from the given competition requirements of the aircraft having to achieve liftoff from an elevated platform having an area of 4 by 8 feet acting as the runway. An airfoil design was pursued by the team with the emphasis towards a high lift to drag ratio at low angles of attack as well as minimal to moderate drag. Through performance simulations and analyses, the airfoil NACA 6412 was chosen as the formatting of the aircraft's main wing. The format of the wings originated from the conditions of the air and the desired performance of the aircraft. A pair of straight wings with a high aspect ratio was determined towards the design of the wings due to the general circumstances of them being used for aircraft traveling at stable subsonic speeds. Ailerons is to be implemented into the trailing edge section of the wings to induce the desired angle of attack for the takeoff sequence of a flight. When it came to deciding the material of the wing, the team prioritized a material that is of affordable cost, reliable in the face of forces such as shear, pressure, moments, as well as feasible in manufacturing. Carbon fiber was determined as the ideal material for the wings due to its solid properties such as stiffness, its lightweight given its density, overall strength, and lastly ease of manufacturing. The material also allows the wings to be hollow which allows the team to implement designs into the interior of the wings such as braces and aileron rods inside. The chosen material of the braces is Balsa wood for its advantages in strength, light in weight, and ease of manufacturing. They are to be inserted into the edge of the wings interior to provide structural support against potential buckling from air induced pressure. The wings will be secured onto the fuselage in a high wing configuration by designing insert rods onto its bottom surface which would be secured into a plate through tight tolerances.

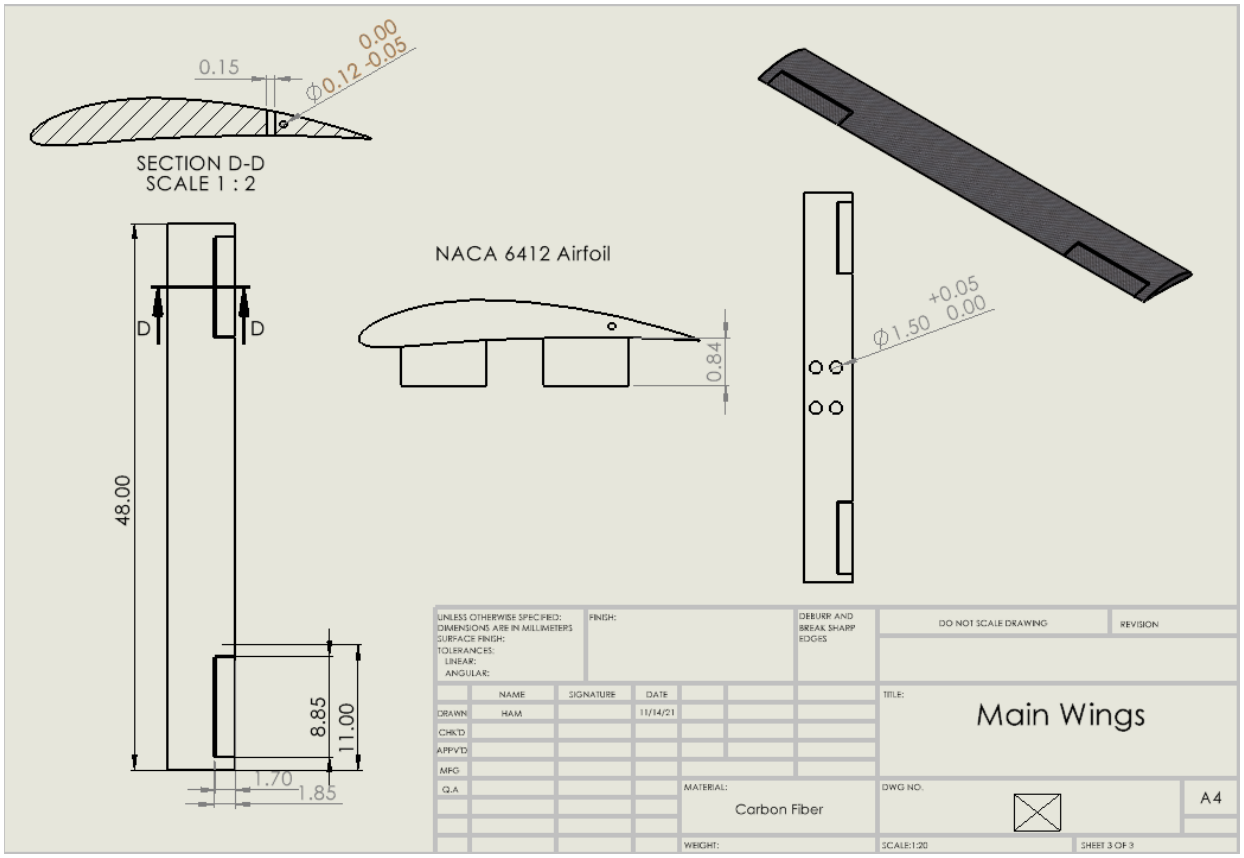

Figure 7: Main Wings Drawing

The design of the tail came in relation to the performance of the main wing where it would act as an elevator to the aircraft as well as provide longitudinal stabilizer against consequential moments from forces such as weight and lift. The orientation chosen for the main wings was also implemented for the horizontal tail being straight with a high aspect ratio except the cross-sectional design where no airfoil type is adopted. The horizontal tail will have the outline of a flat plate due to the emphasis of having a stable symmetric piece as shown in figure 8. For the material, the horizontal tail is to be made of carbon fiber for the same reasons given when it came to describing the favorability the material gives to the main wings. Like the main wings, ailerons are to be inserted into the trailing edge secured by internal rods with the structure being supported by interior Balsa Wood braces. The design of the vertical tail comes in stabilizing the directional trajectory of the aircraft which led to the rudder having symmetric geometry with similar support to its interior but without any ailerons. The horizontal and vertical components that make up the tail of the aircraft would be separately secured into the fuselage via tolerances and a centralized screw.

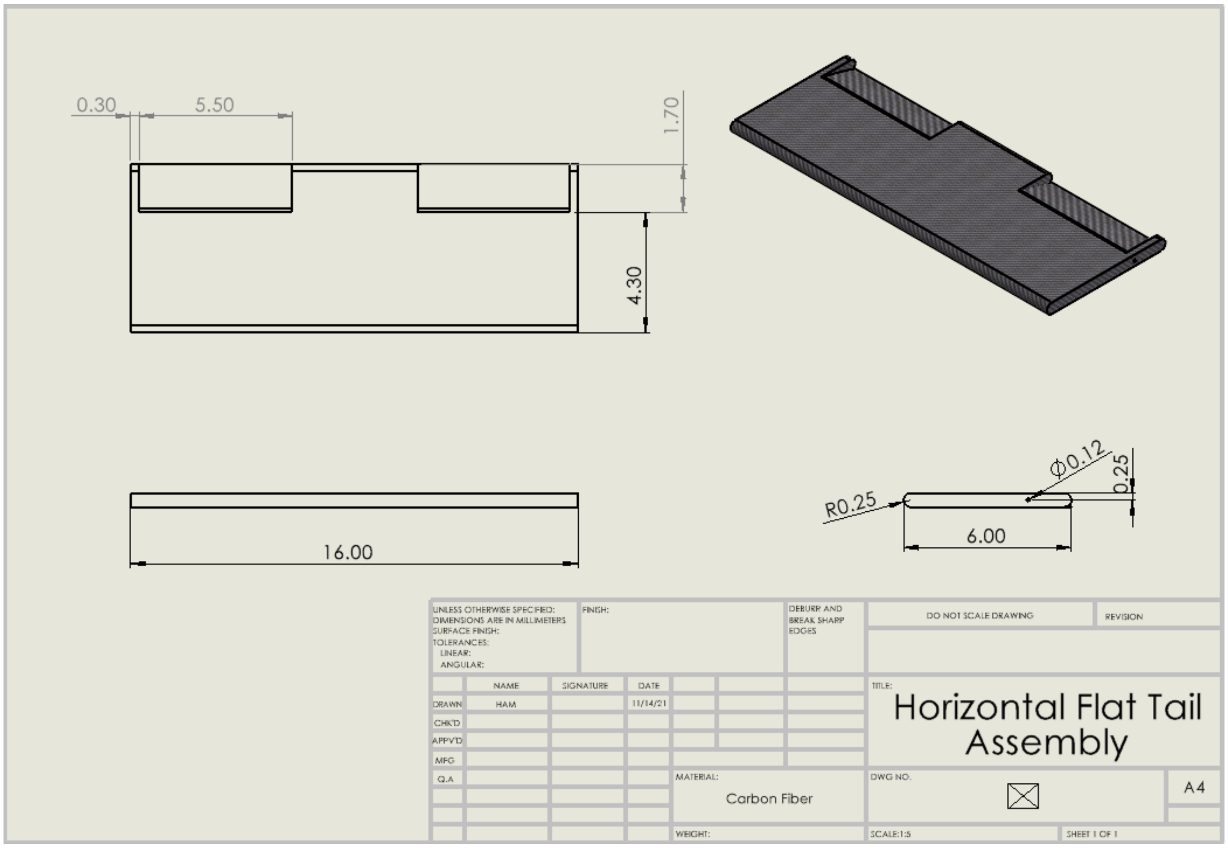

Figure 8: Aircraft Elevator Drawing

The design of the fuselage was a process influenced by multiple factors to consider that went through several adjustments leading to the final prototype. The general shaping of the main body of the aircraft was inspired by that made by last year's SAE AERO Micro Class team but also fulfilling the requirement of being an original design. The dimensions of the fuselage as depicted in Figure 9 were determined by the expectations and criteria of the team for the competition. The team decided to pursue carrying the small load of 6 x 6 x 4 inches plus or minus 0.25 inches so the height of the center section of the body would be at least 1-½ inches taller than the load. The length of the fuselage is confined to being distinctively shorter than that of the wingspan designed for the aircraft to improve the ability of takeoff. It is to be hollow with a thickness of 1/3 inches to fulfill the requirement of the load being enclosed when being transported and equally importantly provide spacing for the aircraft's electrical system. The exterior design of the fuselage has a general curvy and rounded profile with emphasis towards minimizing any potential drag induced onto the plane through the fuselage is minimized by providing a general curvy and rounded profile to the exterior design. It was also designed to be compatible with the different subsystems such as the wings, tail propeller, and others. The wings would be attached by an insert plate with slot holes for its insert rods which is then secured by screws going into the side of the fuselage. For securing the load plate, a separate base part would be placed inside which would be secured with patches of Velcro to enable adjustment to the positioning of the plate and the load. The material that would form the fuselage would be carbon fiber due to its potentially low surface roughness, strength, and light weight. Ideally the piece would be manufactured via a duo enclosed mold design utilizing sheets of carbon fiber.

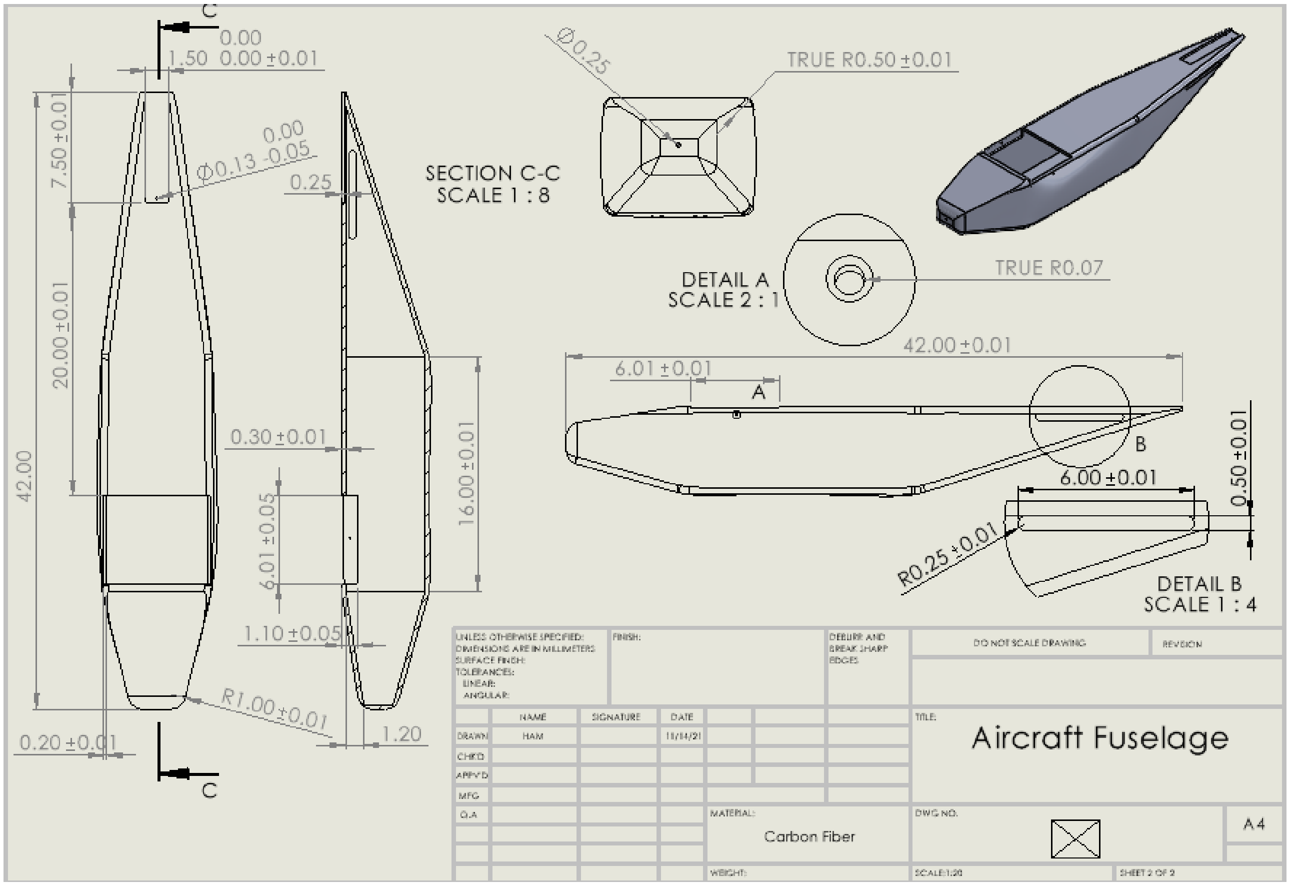

Figure 9: Aircraft Fuselage Drawing

The subsystems involving the landing gear and the propeller are those of which the team decided to purchase in minimizing the amount of effort the team would invest away from more critical subsystems as well as taking advantage of what is accessible to the team. The design of the propeller and the landing gear comes into their positioning on the fuselage and how they are secured. The landing gear will be secured onto the fuselage by utilizing screws where it will be in a tricycle orientation to achieve effective weight balance of the aircraft. The propeller will attach to the fuselage by a central rod to receive torque from the motor which would be improved by using a bearing joint whereas the propeller is secured by a nozzle.

The primary requirement for the team's design is that it be able to fly and do so while carrying a payload. The following technical analysis provides an estimate of the plane's ability to fly. To begin with, it is noted that lift must be greater than weight. This relationship can be stated mathematically as the following.

$$0.5C_LV^2A > W \qquad (2)$$

(Eq. 2) can be arranged to solve for a minimum coefficient of lift required for flight. However, at this point in the analysis, V and W are unknown. V can be estimated using knowledge of thrust data which is dependent on chosen electronics. Conveniently, W can also be estimated by choosing electronics. It is necessary to minimize weight and maximize thrust (thus increasing velocity, thus increasing lift). Determining thrust produced by an electric motor/propeller combination is inherently difficult due to the complexity of airflow through a propeller. However, some motor manufacturers post test stand data of their motors with specific battery and propeller setups. For the team's chosen design (Scorpion SII-3014-1040KV, 4S Li-Po battery, APC 9x4.5-E propeller) the motor manufacturer lists a thrust value of 1942.7 grams (19.05 N) with a power draw of 467.7 watts. The team is limited to 450 watts of power drawn by a power limiter as part of competition rules. This means the team can use roughly 96.21% of possible max power with this setup. Assuming a linear relationship between power drawn and thrust produced, the team can expect 18.33 N of thrust from this setup. Now that a sufficient estimate for thrust has been established, Bernoulli's equation can be applied to air in front of the propeller and air behind the propeller. Assuming the air in front of the propeller has zero velocity, which is reasonable considering the thrust value comes from a stationary test stand, the following equation can be applied.

$$F= 0.5*A*V^2 \tag{3}$$

Rearranging **(Eq. 3)** and solving for V_e, it is found that $V_e = 27$ m/s. It is important to note that this value describes the velocity of the air at the exit of the propeller. The velocity of the plane will be less than this due to drag effects and wheel friction while the plane is taking off. An estimate for the minimum velocity of the plane can be obtained by $V_{min} = 0.8V_e = 21.6$ m/s.
A weight estimate must now be made considering the choice of motor and propeller. However, there is one very important factor to be considered. In order to choose a proper battery for the system, all other electronics must be chosen first and then evaluated on their current draw. The following table is a breakdown of the current drawn by each electric component.

Table 4: Components and Current Draw

Component	Current Draw (mA)
Servos (x5)	3000
Receiver	30
Motor	30400
Total	**33430**

Building in a slight factor of safety, the team assumes that the system will draw 35000 mA. In order to reduce weight, it is important for the team to choose the smallest battery that will provide enough energy to the system. It is established that a 1000 mAh battery will provide energy to the system for almost two minutes. This should be sufficient as the plane only needs to fly about 800 feet per competition rules.

Now that all electric components have been chosen, a rough estimate for weight can be established. Weight estimates for fuselage and wings were made using rough geometric estimates and density of carbon fiber and balsa wood.

Table 5: Parts and Weight

Part	Weight (g)
Motor	130
Battery	125
Servos (x5)	49
Receiver	9
Propeller	15
Wings	150
Fuselage	750
ESC	45
SAE Package 1	85
SAE Package 2	170
Dry Weight	**1273**
Weight with Payload	**1528**

There is now only one unknown in **(Eq. 2)** being the coefficient of lift. Values for V_{min} and W can be plugged in to find that the minimum coefficient of lift required for flight with payload on board is 0.34. The NACA 6412 must be evaluated to ensure that it can provide the desired lift.

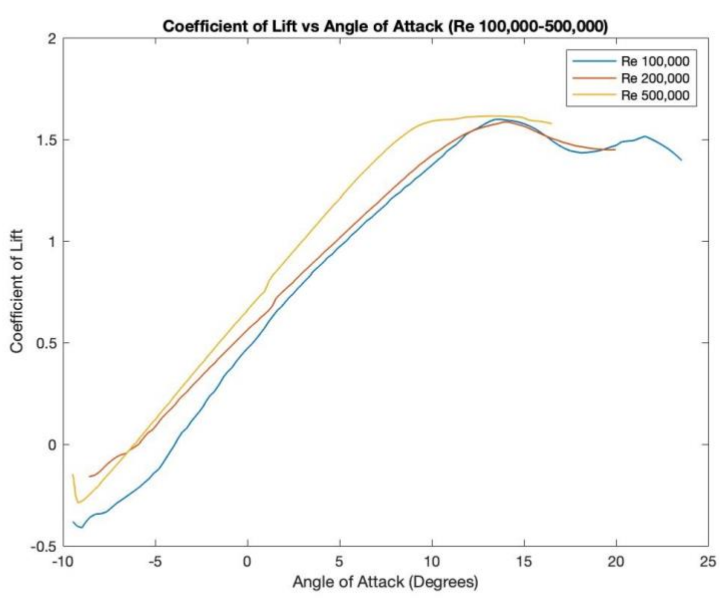

Figure 10: Coefficient of Lift vs Angle of Attack

(Figure 10) shows that even at zero angle of attack, the NACA 6412 airfoil will provide sufficient lift to achieve flight. At competition, the team can gather bonus points for additional payload carried. In order to establish a value for maximum weight that can be carried by the plane, an angle of attack must be chosen. An angle of attack of 5 degrees provides a coefficient of lift of about 1 at all Reynolds numbers of concern. Plugging in this value to **(Eq. 2)** it can be predicted that this plane will be capable of carrying a total maximum weight of 4500 grams. This is incredible and means the team should be able to carry almost four times the weight of the plane itself. More important than simply ensuring the coefficient of lift is high enough, is choosing an optimal angle of attack with high lift to drag ratio. **(Figure 14)** below shows the C_L/C_D ratio of the NACA 6412 at varying Reynolds numbers. This figure shows that the highest value of this ratio exists at an angle of attack of about 7.5 degrees. However, to avoid stall characteristics, the team would like to operate at an optimal angle of attack of around 5 degrees.

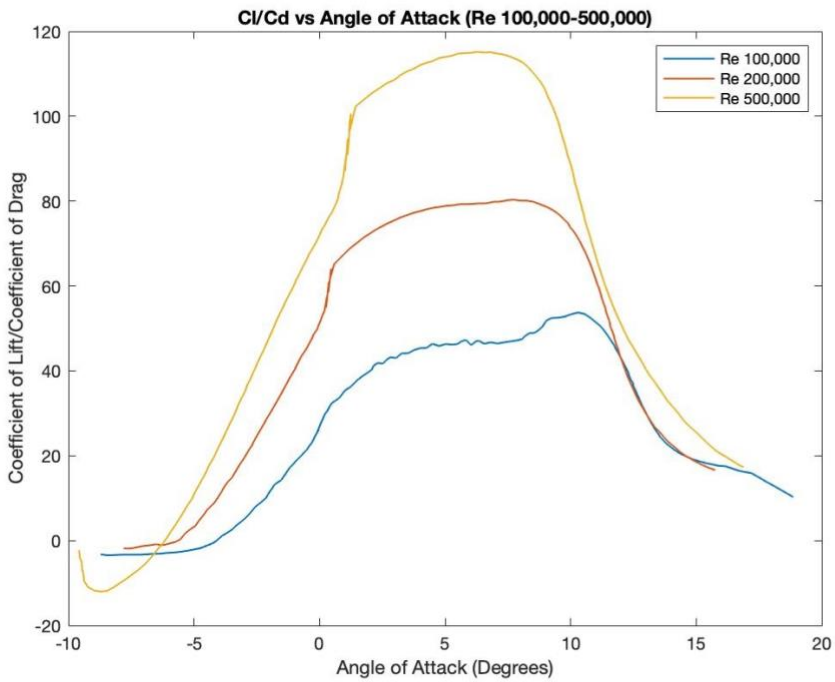

Figure 11: Cl/Cd vs Angle of Attack

Although the winner of the decision matrix listed a primary material of balsa wood, the team will likely tweak this and move forward with carbon fiber as it has desirable properties of both strength and weight.

Moving forward, the team will begin manufacturing and purchasing the critical subsystems of the prototype as depicted below. Trials and consequential adjustments are anticipated towards the prototype as time progresses closer to the competition.

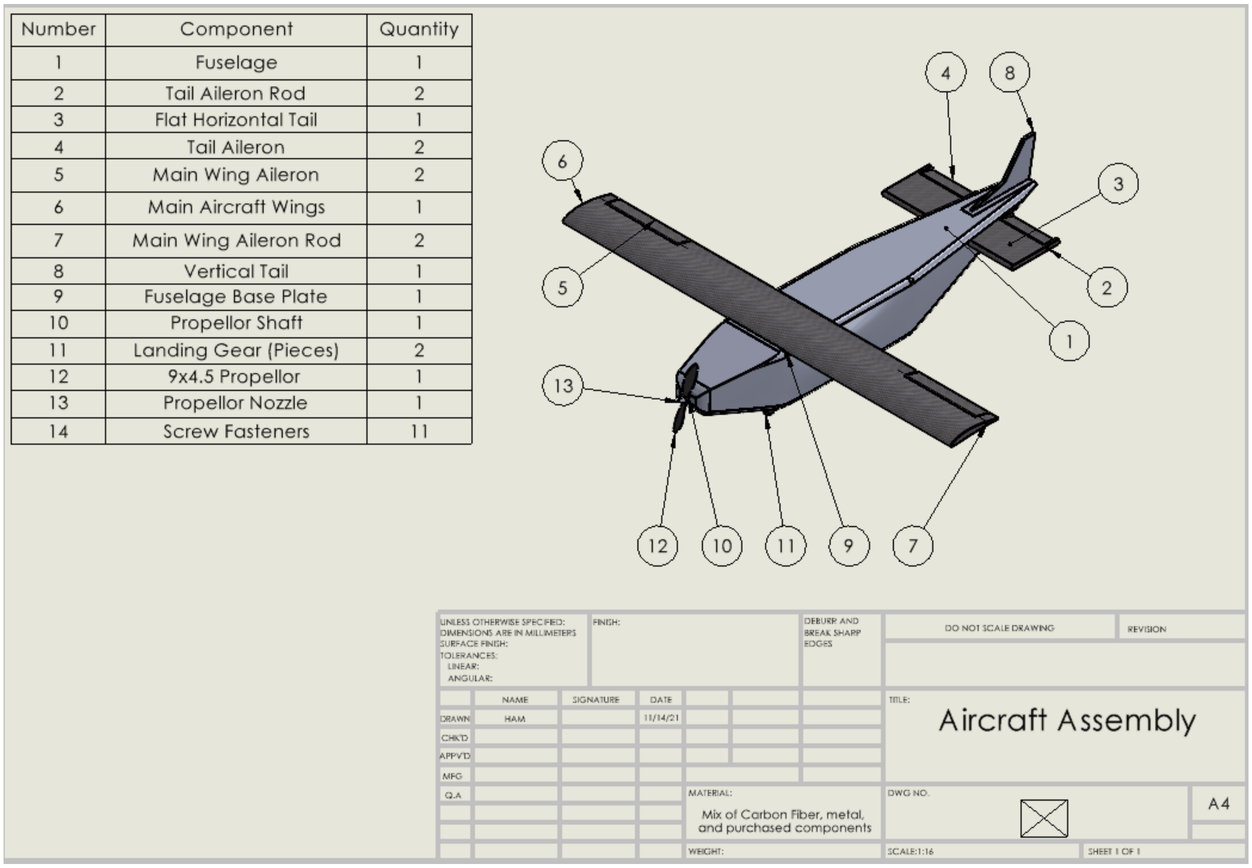

Figure 12: Aircraft Fuselage Drawing

5.2 Implementation Plan

The team was fortunate enough to have completed a design analysis early in the semester and was therefore able to start ordering parts early on. The team has received all the parts for our design except for the SAE power limiter. Regarding the airplane structure itself, a meeting with Novakinetics last week was largely beneficial in understanding what needs to be done for us to begin the manufacturing process. The team needs to finalize a CAD model built for making molds and maintain frequent contact with Novakinetics who is going to provide us with material and help us with the manufacturing process. The bill of materials which can be found in **(Appendix C)** lists all ordered parts and their costs. **(Table 6)** shows remaining tasks to be completed and their deadline for completion. Between the assembly of initial prototype and final design, the team will likely iterate many times and develop solutions to any problems the initial prototype may have.

Table 6: Remaining Deadlines

Task	Deadline
Manufacture airfoil with Novakinetics	December 10, 2021
Manufacture fuselage with Novakinetics	February 1, 2022

Assemble prototype and test	February 14, 2022
Finalize design	April 8, 2021

6 CONCLUSIONS

This report covers many topics that pertain to the SAE MicroAero team's design project. The first topic discussed was the background which explains the how this project allows the team to analyze aircraft design and aerodynamics on a micro level in order to boost their understanding and apply it at a macro level. Then the requirements for this project are discussed. In that section customer requirements, engineering requirements, a functional decomposition, a house of quality, and the standards, codes, and regulations were discussed. For the customer requirements the highest weighted customer requirements are the flight time, payload carried, and unloading time. For the engineering requirements a few are wingspan, lift, drag, weight, and thrust. All of these are compiled in the house of quality. The standards and codes discussed are to keep everyone using, or that will be around a device will be kept safe. The third item discussed was testing procedures. The main testing procedures will be a wind tunnel test of the airfoil and a practical flight test. Following this, the risk analysis and mitigation was discussed. The ten major potential critical failures are: thermal fatigue of the battery, motor seizing, front airfoil disconnect, landing gear buckling, front airfoil bending, rear airfoil bending, servo connection failure, thermal fatigue in wires, RC signal obstruction, and adhesive failure of fuselage. The final section was the design selection. The airfoil chosen is the NACA 6412, the fuselage is to be hollow with a thickness of 1/3 inches to fulfill the requirement of the load being enclosed when being transported and equally importantly provide spacing for the aircraft's electrical system. To implement this design the team will use the items ordered and work with Novakinetics to make the design.

7 REFERENCES

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8 APPENDICES

8.1 Appendix A: House of Quality

System QFD

Project: SAE Aero 2021-2022
Date: 9/16/21

		Wingspan	Cost	Battery	Thrust/Motor	Cargo Bay	Lift	Drag	Thrust	Weight	T/O Rey #	RC Signal Range	CG Marking	Ground Control
1	Wingspan													
2	Cost	+												
3	Battery	-	+											
4	Thrust/Motor	+	+	+										
5	RC Signal Range	o	+	+	+	o	o	o	o	-				
6	CG Marking	+	o	o	+	+	o	o	+	-	o	o		
7	Durability	+	+	o	+	+	o	o	o	+	-	o	o	o

Legend

A	Carbon Cub
B	Sport Cub
C	2019 SAE Micro Aero

Technical Requirements / **Customer Opinion Survey**

	Customer Needs	Customer Weights	Wingspan	Cost	Battery	Thrust/Motor	Cargo Bay	Lift	Drag	Thrust	Weight	T/O Rey #	RC Signal Range	CG Marking	Ground Control	Flight Control	Durability	1 Poor	2	3 Acceptable	4	5 Excellent
1	Flight Time	9	9	3	1	9	3	9	9	9	3	9	3		3	9			AB	C		AB
2	Payload	9	3		3	9	9	9	1	3	9			9		3	9	AB			C	
3	Turning Radius/Maneuverability	3	3			3	1	1	1	9	1	9	3			3				C		AB
	RC Signal Strenght (2.4 GHz)	3		1	3								9								ABC	
	Spare Parts	1	1	3	1												9					
4	Launch T/O	3	9	1		3	1	9	9	9	9	9			9	3			C	AB		
	Landing	3	9	1		1	1	3	3	3	3	3			9	3			C			AB
5	Unloading Time	9	1												3			AB			C	
6	**Technical Requirement Units**		in	$	#Cells	lbF/watts	in³	lbf	lbf	lbf	lbf		ft	in								
7	**Technical Requirement Targets**		10		4	450	144															
8	**Absolute Technical Importance**		181	39	46	183	117	201	129	171	147	144	63	81	108	135	82					
9	**Relative Technical Importance**		3	12	11	2	9	1	8	4	5	6	4	6	10	7	7					

8.2 Appendix B: FMEA Analysis

Product Name		2021-22 SAE Micro Aero Team				Page No.1of 1			
System Name						FMEA Number			
Subsystem Name						Date 1 November 2021			
Component Name									
Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
Transmitter	Signal Interference	Loss of control/crash	8	out of range	4	Test moving components	1	32	none
	Signal obstruction	spotty RC signal	8	transmission of signal is obstructed	5	test flight	2	80	ensure proper connections
Servos	High-cycle fatigue	limited control of rolling aircraft	7	overstressing	2	move ailerons	1	14	pair proper servo with function
	Connection Obstruction	loss of contol of components connected via servo	4	fracture of connection rod	3	visually inspect connections	2	24	enhance connection
	Connection failure	loss of in flight control of plane	7	adhesive connection less than drag force	3	pre flight test of moving components	4	84	use stronger adhesive
Power Limiter	Corrosion Fatigue	incorrect power supplied	4	over voltage/current input	2	test controls	2	16	redesign internal electronics
Receivers	Connection Error	no connection between remote and plane	9	no power	2	ensure connection	3	54	redesign for a longer range
Motor	High-cycle fatigue	bearnings in motor fail	8	over use /incorrect power supplied	3	ensure motor runs properly	1	24	consider replacing motor sooner
	disconnection	no thrust generated	8	motor mounts fail	3	tactice manipulation to ensure proper connection	3	72	connect motor mounts to fuselage with a plate
	motor seize	motor is inoperable	8	airplane is inoperable	3	test motor operation pre flight	5	120	replace motor
Propeller	deformation wear	incorrect thrust generated	7	impact, plastic strain	2	run motor and spin propeller	1	14	replace with more suitable propeller
	disconnection	no thrust generated	8	failure of fastener to motor	2	manually spin propeller before flight	3	48	use fastener that will not fail
Speed Controller	elecrical overstress	no control of speed	5	incorrect power supplied	3	run motor at varying speed	3	45	replace connections or device
Battery	thermal fatigue	decreased capacity	4	incorrect charging	5	test flight time	7	140	replace battery
	disconnected from fuselage	battery is not secured inside of fuselage	3	battery mounts fail	2	tactile inspection of mounts	2	12	improve mounting mechanism
	dehydration	over discharge of battery	4	incorrect use of battery	2	test battery operated components	4	32	ensure proper charging techniques
	dehydration	improper power sent	4	incorrect use of battery	2	test battery operated components	4	32	ensure proper charging techniques
Front Airfoil	fretting wear	deform airfoil shape, altering lift	3	assembly error	4	analyze structural integrity	2	24	use material with lower plastic deformation
	disconnected from assembly	plane will crash	8	connection to fuselage fails	4	ensure proper connection before flight	3	96	implement better connections with fuselage
	Displacement	angle of attack will change	4	extreme flying conditions	3	tactile test of connection	2	24	ensure proper security of airfoil
	Bending	manuverability/control will be lost	7	crash and not replaced	4	visually inspect airfoil before flight	3	84	do not drop air foil
Rear Airfoil	Bending	manuverability/control will be lost	7	crash and not replaced	4	visually inspect airfoil before flight	3	84	do not drop air foil
	Displacement	angle of attack will change	4	extreme flying conditions	3	tactile test of connection	2	24	ensure proper security of airfoil
	disconnected from assembly	plane will crash	8	connection to fuselage fails	2	ensure proper connection before flight	2	32	implement better connections with fuselage
Kill Switch	Galvanic Corrosion	inoperable kill switch	7	kill switch does not work in emergency	1	ensure connection between kill switch and wires is correct	4	28	use less corrosive conductive material
Landing Gear	Buckling	loss of landing functionality	5	impact with ground	6	put plane on ground	3	90	redesign with a more ductile material
	Disconnecting from fuselage	landing gear is detached and unusable	7	improper connection to fuselage or base plate	2	Analyze connection of landing gear to fuselage	3	42	enhance connection of landing gear to fuselage
	Wheels disconnect	landing gear is unusable	6	connection of wheels to landing gear fails	3	ensure proper connection before flight	2	36	design better connection
Wires	Thermal fatigue	failure of other components	7	constant prolonged use	3	test electrical components	4	84	use wires with higher thermal capacity
	Connection failure	no power delivered	8	wires disconnect from components	2	visually inspect connections	4	64	use wire connector for wired connections
Fuselage	Impact Fatigue	fuselage will fall apart, rendering unusable	9	impact with ground	3	test flights	1	27	redesign with stronger material
	Adhesive failure	fuselage will not stay connected at seams	9	shearing of fuselage destroys adhesive connections	2	tactile manipulation of fuselage pre and post flight	4	72	use strong adhesive to bond panels together
	Cargo hatch not connected	cargo catch can not be sealed	3	failure of locking connection	2	pre flight check	2	12	redesign hatch lock
Elevators	Connection Obstruction	no vertical control	4	servo is disconnected	3	visually inspect connections	2	24	enhance connection
	buckling of connecting rod	Elevator disconnected from wing	4	wear/shear stress	4	tactile test of connection	4	64	consider stronger sonncetion rod
	Drag force too large	elevator can not be operated	4	extreme flying conditions	4	ensure flight conditions are good enough	4	64	replace with stronger servo
	insuffienct power	limited control	4	poor connection	4	test controls pre flight	4	64	ensure proper connections
Ailerons	Connection Obstruction	loss of turning control	4	servo is disconnected	3	visually inspect connections	2	24	enhance connection
	insuffienct power	limited control	4	poor connection	4	test controls pre flight	4	64	ensure proper connections
	buckling of connecting rod	aileron disconnected from wing	4	wear/shear stress	4	tactile test of connection	4	64	consider stronger sonncetion rod
	Drag force too large	aileron can not be operated	4	extreme flying conditions	4	ensure flight conditions are good enough	4	64	replace with stronger servo

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Transmitter	Signal Interference	Loss of control/crash	out of range	32	none
	Signal obstruction	spotty RC signal	transmission of signal is obstructed	80	ensure proper connections
Servos	High-cycle fatigue	limited control of rolling aircraft	overstressing	14	pair proper servo with function
	Connection Obstruction	loss of contol of components connected via servo	fracture of connection rod	24	enhance connection
	Connection failure	connection between servo and component fails	adhesive connection less than drag force	84	use stronger adhesive
Power Limiter	Corrosion Fatigue	incorrect power supplied	over voltage/current input	16	redesign internal electronics
Receivers	Connection Error	no connection between remote and plane	no power	54	redesign for a longer range
Motor	High-cycle fatigue	bearnings in motor fail	over use /incorrect power supplied	24	consider replacing motor sooner
	disconnection	no thrust generated	motor mounts fail	72	connect motor mounts to fuselage with a plate
	motor seize	motor is inoperable	failure of bearings	120	replace motor
Propeller	deformation wear	incorrect thrust generated	impact, plastic strain	14	replace with more suitable propeller
	disconnection	no thrust generated	failure of fastener to motor	48	use fastener that will not fail
Speed Controller	elecrical overstress	no control of speed	incorrect power supplied	45	replace connections or device
Battery	thermal fatigue	decreased capacity	incorrect charging	140	replace battery
	disconnected from fuselage	battery is not secured inside of fuselage	battery mounts fail	12	improve mounting mechanism
	dehydration	over discharge of battery	incorrect use of battery	32	ensure proper charging techniques
	dehydration	improper power sent	incorrect use of battery	32	ensure proper charging techniques
Front Airfoil	fretting wear	deform airfoil shape, altering lift	assembly error	24	use material with lower plastic deformation
	disconnected from assemb	plane will crash	connection to fuselage fails	96	implement better connections with fuselage
	Displacement	angle of attack will change	extreme flying conditions	24	ensure proper security of airfoil
	Bending	manuverability/control will be lost	crash and not replaced	84	do not drop air foil
Rear Airfoil	Bending	manuverability/control will be lost	crash and not replaced	84	do not drop air foil
	Displacement	angle of attack will change	extreme flying conditions	24	ensure proper security of airfoil
	disconnected from assemb	plane will crash	connection to fuselage fails	32	implement better connections with fuselage
Kill Switch	Galvanic Corrosion	inoperable kill switch	kill switch does not work in emergency	28	use less corrosive conductive material
Landing Gear	Buckling	loss of landing functionality	impact with ground	90	redesign with a more ductile material
	Disconnecting from fuselag	landing gear is detached and unusable	improper connection to fuselage or base plate	42	enhance connection of landing gear to fuselage
	Wheels disconnect	landing gear is unusable	connection of wheels to landing gear fails	36	design better connection
Wires	Thermal fatigue	failure of other components	constant prolonged use	84	use wires with higher thermal capacity
	Connection failure	no power delivered	wires disconnect from components	64	use wire connector for wired connections
Fuselage	Impact Fatigue	fuselage will fall apart, rendering unusable	impact with ground	27	redesign with stronger material
	Adhesive failure	fuselage will not stay connected at seams	shearing of fuselage destroys adhesive connections	72	use strong adhesive to bond panels together
	Cargo hatch not connected	cargo catch can not be sealed	failure of locking connection	12	redesign hatch lock
Elevators	Connection Obstruction	no vertical control	servo is disconnected	24	enhance connection
	buckling of connecting rod	Elevator disconnected from wing	wear/shear stress	64	consider stronger sonncetion rod
	Drag force too large	elevator can not be operated	extreme flying conditions	64	replace with stronger servo
	insuffienct power	limited control	poor connection	64	ensure proper connections
Ailerons	Connection Obstruction	loss of turning control	servo is disconnected	24	enhance connection
	insuffienct power	limited control	poor connection	64	ensure proper connections
	buckling of connecting rod	aileron disconnected from wing	wear/shear stress	64	consider stronger sonncetion rod
	Drag force too large	aileron can not be operated	extreme flying conditions	64	replace with stronger servo

8.3 Appendix C: Bill of Materials

Bill Of Materials					
Item Number	Item Name	Where to Purchase	Quantity	Cost Approximation	Notes
1	Transmitter	https://scale-model-aircraft.com/reviews/best-rc-transmitter-for-planes	1	$ -	Used last years
2	Servos	https://hobbyking.com/en_us/hxt900-micro-servo-1-6kg-0-12sec-9-8g.html?queryID=ddf03f31299b33ef2bacabd17d1ee992&objectID=2962 3&indexName=hbk_live_products_analytics#qa[bW9kZT03JnBhZ2U9MSZxdWVzdGlvbl9zZWFyY2hfY29udGVudD0=]	7	$ 28.00	
3	Power Limiter	https://neumotors.cartloom.com/storefront/product/sae-2021-limiters	1	$ 75.00	
4	Receivers		1	$ -	Used last years
5	Motor	https://www.scorpionsystem.com/catalog/aeroplane/motors_1/s-30_v2/SII-3014-1040KV/	1	$ 100.00	
6	Propellers	https://www.apcprop.com/product/9x4-5e/	7	$ 21.00	
7	Speed Controller	https://hobbyking.com/en_us/turnigy-plush-32-40a-2-6s-brushless-speed-controller-w-bec-rev1-1-0.html	1	$ 22.00	
8	Battery	https://hobbyking.com/en_us/turnigy-nano-tech-1000mah-4s-70c-lipo-pack-xt60-hr-tech.html?queryID=8576f186bcf6b0a6ff30460e8cc1cd94&objectID =76048&indexName=hbk_live_products_analytics	3	$ 54.00	
9	Balsa Wood	ttps://www.hobbylobby.com/Crafts-Hobbies/Hobbies-Collecting/Balsa-Hobby-Wood/Balsa-Wood-Sheet---1-8%22-x-3%22-x-36%22/p/7202	5	$ 20.00	Used for wings
10	Material	https://www.michaels.com/elmers-foam-board-white/10110205.html	4	$ 12.00	
11	Kill Switch		1	$ -	Used last years
12	Landing Gear		1	$ -	Used last years
13	Material	https://www.horizonhobby.com/product/econokote-black-6/TOPQ2608.html	1	$ 13.00	
14	wires				
15	adapters				