SAE Aero Micro

Final Proposal

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Project Sponsor: Northern Arizona University Department of Mechanical Engineering, W.L. Gore

Faculty Advisor: David Willy

DISCLAIMER

EXECUTIVE SUMMARY

The Northern Arizona University Aero Micro team was created to participate in the SAE Aero Micro Design competition. The function of the team is to create a remote-controlled airplane that meets the design requirements of the competition. However, the main goal of the team itself is to create a remote-controlled airplane that can take-off and land safely. Customer Requirements (CR) and Engineering Requirements (ER) were taken from the competition rules and meetings with the client. From these CR's and ER's a House of Quality (Appendix A) was created to analyze the connections between them; they were then ranked to show which were most important to the project. It was then determined how to properly measure them and present the results. Which would be tested at a later date. After these steps the team created a Black Box Model and Functional Decomposition that broke down the main functions of the craft into 10 subsystems that could be further analyzed. From these 10 subsystems 30 different subsystem concept variants were made, all of which were combined into three final concept variants. From these three designs a final hybrid design was created.

The team began to analyze the hybrid design to see if it would be able to meet the requirements of the competition. After analytically analyzing the design, using volume, forces acting on the plane, overall weight, and the wingspan capabilities; it was discovered that while the design worked on paper, it couldn't be made to work in reality. The team began to create several iterations to find a design that would work analytically. Figure 1 is the final design the team was able to come up with. There is still a possibility that the design will change as the team progresses in the project, but for the present time, Figure 1 is the chosen design.

Leading into next semester, the team plans to fully build and test this design. The general analysis of this design, its validity and later tests are contained in the report below.

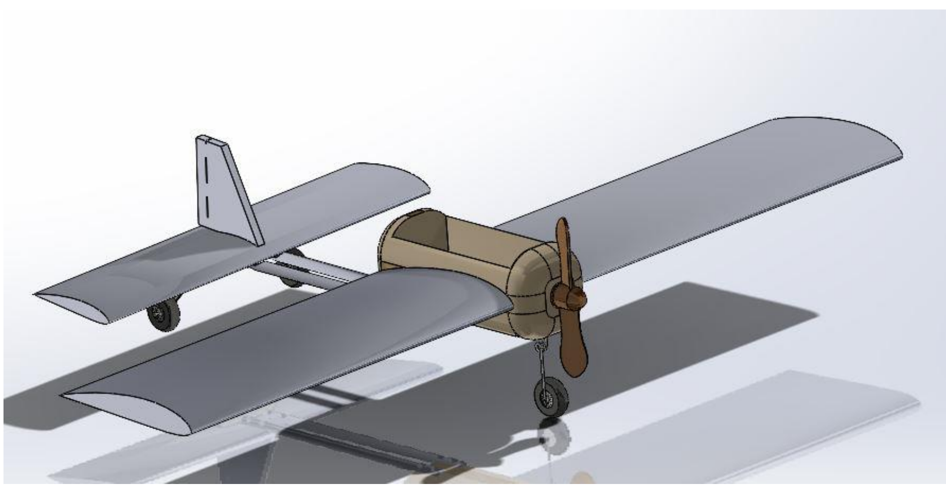

Figure 1: Final design

TABLE OF CONTENTS

Contents

1 BACKGROUND

1.1 Introduction

The SAE Aero Micro team was created as part of the SAE Aero international design competition. The design competition uses real world problems and constraints to challenge design teams to create a remote-controlled airplane. For this specific project the team is participating in the SAE Aero Micro class competition. The Micro portion of the competition limits the teams to create a micro airplane through dimension and weight restrictions. The focus of this team, however, is to create an aircraft that can take off and land safely. This project is particularly important, as it showcases real world design constraints and expectations in a small-scale competition. This not only challenges the teams to create unique and functional designs, but it also showcases the nuances of conceptual design in the real world.

1.2 Project Description

While the description of the project and the corresponding restraints were stated in the SAE Aero design competition rules and regulations, the main focus of this team is to create an aircraft that is able to take-off and land safely. This is done over the period of one academic school year. This time frame includes concept creation, evaluation, prototyping and final testing. This project was created to not only test the team and individual teammates' understanding of engineering, but also to promote real-world thinking and teamwork through real-world problems. The sponsors for this project are Northern Arizona Universities Department of Mechanical Engineering, W.L. Gore. and the SAE Aero design competition committee. These project clients are Dr. David Willy of Northern Arizona University, and the SAE Aero design competition committee. With advice for the team by Dr. Willy.

2 REQUIREMENTS

Section 2 showcases Customer requirements and the corresponding engineering requirements. Each of the requirements are listed and explained how they not only correspond with each other, but also how they are measured, weighted, and met through the final design. It is all combined in a visual aid called the House of Quality or the QFD.

2.1 Customer Requirements (CRs)

For this project the Customer requirements were taken from the SAE Aero Design Competition rules, with clarification from the team's academic advisor, Dr. Willy. The customer requirements were then weighed on how important they are to the final design and how the final design should be constructed; on a percentage scale of 1-10. One being the least important, but still needed, and 10 being critical to the design. All the weights add up to 100%.

1. Meets the requirements of the [SAE] rules (8%)
2. Safe design (5%)
3. Abel to take off and land (8%)
4. Innovative design (3%)
5. Manufacturable (3%)
6. Low cost (3%)
7. Modular compatibility (1%)
8. Static load capability (5%)
9. 60 second lift-off time limit (4%)
10. 200 feet landing distance (4%)
11. Payload extraction in 60 seconds or less (4%)
12. Use of lithium polymer batteries (4%)
13. Use of a 450-watt power limiter (4%)
14. Must have a cargo bay (4%)
15. Ability to make a turn in air (4%)
16. Ability to make a turn on the ground (4%)
17. Steering mechanism for landing gear (4%)
18. Must use an electric motor (4%)
19. Fixed wing (4%)
20. Functional failsafe for radio control systems (4%)
21. Must be equipped with a red arming plug (4%)
22. Must use model airplane safety nut (4%)
23. Appropriate center of gravity (4%)
24. Must have a radio control system (4%)

2.2 Engineering Requirements (ERs)

The Engineering Requirements for the project were found through the Customer Requirements from the SAE Aero Design competition rules. The CR's were analyzed, and measurable parameters were created from them. These measurable parameters give solid data for the team to follow and attempt to meet. Table 1 shows the ERs, their set parameters, tolerances, the target numbers, the relative and absolute importance of each requirement and justifications for said parameters.

Table 1: Engineering Requirements

Engineering Requirements	Technical units	Tolerances	Technical requirement targets	Absolute Technical importance	Relative technical importance	Justification
Lightweight	Pounds	Under 55lbs (- only)	55	181	11	Max weight from competition guidelines is 55 pounds
Increased Reliability	Percentage	N/A	100	151	13	Plane needs to flight multiple times successfully without catastrophic failure
Increased Durability	Percentage	N/A	100	124	18	Plane needs to withstand small crashes without catastrophic damage
Power limiter	Watts	Max 450 Watts (- only)	450	201	7	Power limiter required per competition guidelines
Cargo bay	Inches Cubed	+/- .5 inch	6*6*4	193	9	Cargo bay needs to hold substantial weight to score points in competition
Low cost	US dollars	Max 1500 (- only)	1500	153	12	Small budget, therefore, must keep costs to a minimum
Increase impact tolerance	Crashes before repair	N/A		114	20	Plane needs to withstand substantial impact without breaking, thereby preventing buying new parts
Wingspan of 48 inches or less	Inches	Max 48 (- only)	48	50	22	Wingspan limit required per competition guidelines
Lift force	Pounds	N/A		225	6	Lift force required to make airplane fly successfully
Drag force	Pounds	N/A		225	5	Drag force must be calculated to find proper components to overcome drag
Thrust	Pounds	N/A		285	3	Thrust force must be calculated to find proper components to accelerate plane
Ground turning radius	Inches	N/A		136	16	Must turn on ground per competition guidelines
Payload unloading time	Seconds	+/- 1 second	60	185	10	Unloading time must be under 60 seconds per competition rules
Low control surface slop	Degrees	N/A		196	8	Moving parts must have little to no play to prevent unwanted aerobatic movement
Must have 4 battery cells or less	Number of cells	Max 4 (- only)	4	131	17	Battery limit required per competition guidelines
Adequate servo size for aerodynamic forces	Ounces/inch	N/A		368	2	Servo torque must overcome aerodynamic forces
Must use 4.3GHz radio control system	GHz	Max 2.4 (- only)	2.4	146	14	Radio system limit required per competition guidelines
Landing within 200 feet	Feet	+/- 1 foot	200	121	19	Must land within certain distance per competition guidelines
Takeoff within 8 feet	Feet	Max 8 (- only)	8	136	15	Must take off within certain distance per competition guidelines

Cannot exceed 55 pounds	Pounds	Max 55 (-only)	55	112	21	Must not exceed weight limit per competition guidelines
Optimize safety factor	Factor of Safety	N/A		230	4	Must make plane components as strong as possible while keeping them lightweight
Meets SAE rules and regulations	Percentage	N/A	100	549	1	Must meet rules to compete in competition

2.3 Functional Decomposition

A Functional Decomposition is a breakdown of all the systems within a device and how they relate to one another. This also breaks down the overall systems into subsystems which can help the team members create accurate and detailed concepts that are able to meet the requirements of each subfunction. Figure 2 showcases the team's updated Functional Decomposition.

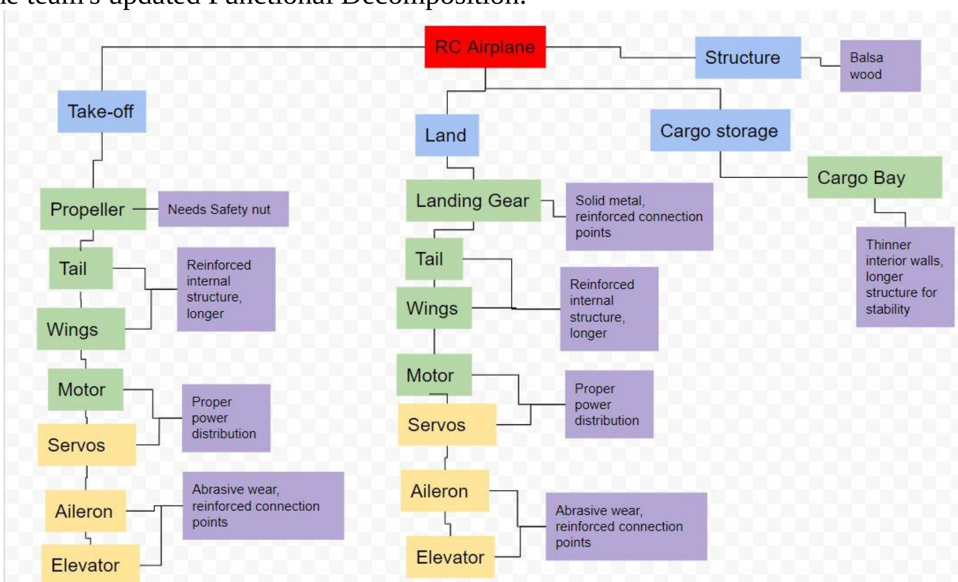

Figure 2: Functional Decomposition

The team was able to break down the aircraft into three main categories, with ten subsystems. The three main systems were the take-off, land, and cargo storage portion (blue portion). Take-off and landing are the main function of the aircraft, while the cargo storage is one of the main requirements of the competition. These systems were broken down into the ten subsystems (yellow, green), propeller, wings, motor, tail, landing gear, structure, aileron, servo, elevator, and cargo bay. Leading onto the designs, three different concept variants were made for each subsystem, and they were combined into three final complete designs. These designs were analyzed to ensure that each ER and CR would be met through the chosen design. The testing that occurred to showcase the validity of the design are outlined in Section 3.

Due to what the team has learned from analyzing the subsystems, three main things have changed within the design. These changes or realizations are boxed in purple. The first change made was to the structure, fuselage, and the resulting cargo hold. The fuselage and cargo hold were shortened, while two extending rods were added at the back for stability and weight reduction. Therefor the structure portion was changed into one of the main subsystems. The second change was made to the wings. Larger wings were needed in the front and back of the plane to ensure that the plane would be able to take-off and land. The third main change was the realization that the wings and tail will need reinforced interior structures to not only withstand general flight, but it also mitigates the potential damage caused by crash landing.

2.3.1 Black Box Model

A Black Box Model (BBM) is a visual representation of the inputs and outputs of energies, materials, and signals for the device as a whole. Figure 3 showcases the BBM for the Aero Micro team.

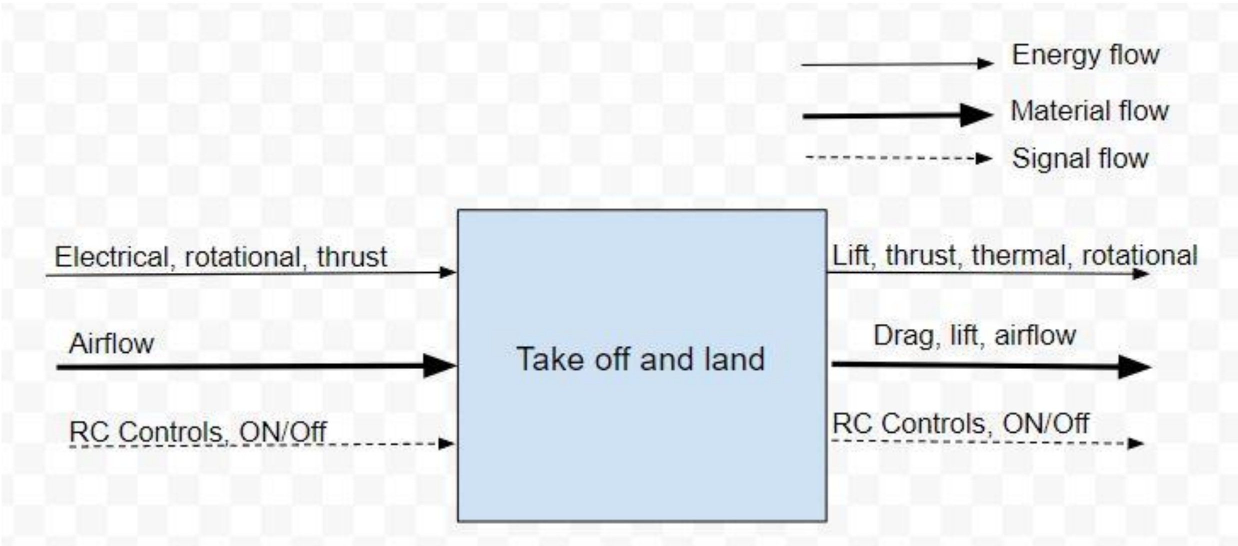

Figure 3: Black Box Model

This visual aid helps the team think about what needs to go into the device to ensure that it will meet its primary function. For this device the inputs of energy flow are electrical, rotational, and thrust, while the outputs are lift, thrust, thermal and rotational. The material inputs are airflow, and the outputs are drag, lift and airflow. The signal flows are the RC controllers and the ON/OFF switches, with the outputs the same.

2.3.2 Functional Model

A functional model is based off the BBM, it shows a detailed breakdown of how the inputs and outputs of the device flow through each other. Much like the BBM, the flows are outlined by the solid line being energy flow, the bolded line being material flow and the dotted line being the signal flow. Figure 4 shows the updated functional model for the Aero Micro team.

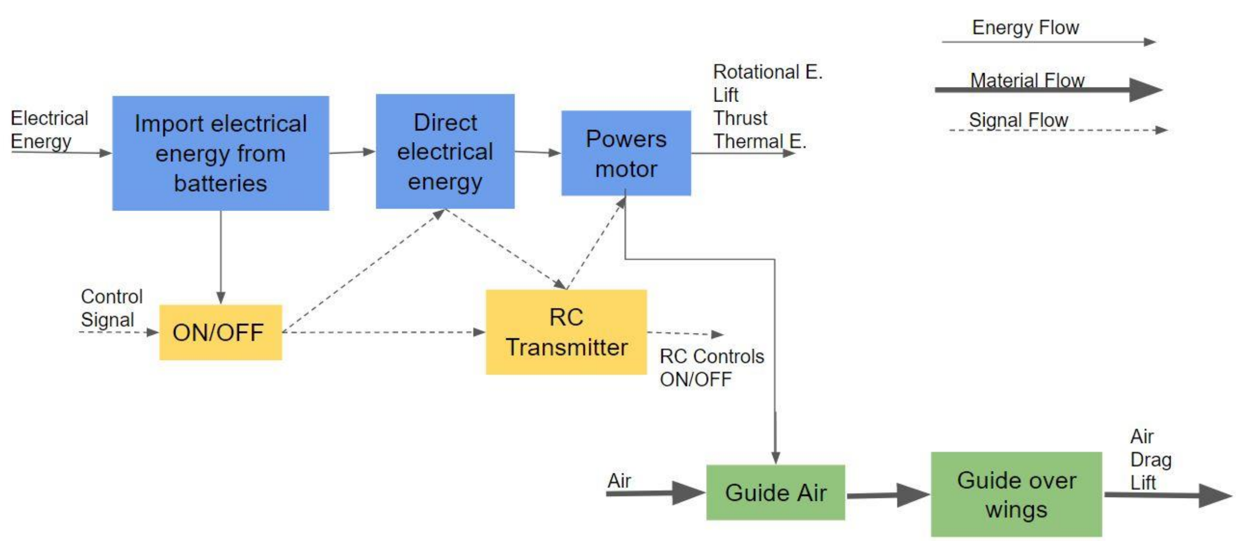

Figure 4: Functional Model

While creating the final design the team relied heavily on the functional model which helped create and analyze the Failure Mode Analysis in Section 4, enabling the team to focus on what failure modes are connected to each other. It also helped the team show how they needed to direct certain flows, such as energy and the control system. This led to the team creating a different structure, smaller fuselage with motor and servo pockets as well as having stronger batteries to make sure everything within the plane can get the power it needs.

2.4 House of Quality (HoQ)

The House of Quality or the QFD (Appendix A), is a process of comparing the Customer Requirements and the Engineering Requirements and ranking how each one compares to each other. This enabled the team to decide which CRs and ERs were most important and therefore needed to be focused on the most, while also showcasing which ERs would meet the requirements of the CRs. The sections were ranked using the 1-3-9 rule. 1 being they affect each other the least, 3 being medium affect, and 9 being that they highly affect each other. If a cell is left empty, there is no correlation. As the team went into the concept design process, the QFD was analyzed showing that the top three main focus areas of the concept variants should be:

1. Meeting the SAE rules and regulations
2. Adequate servo size for aerodynamic forces
3. Thrust

While the first one is the general goal of the overall project, it ensured that the team would focus their energy on meeting the requirements. While two and three are more technical requirements that the team must keep in mind to ensure that the device will be able to take off and land properly.
Looking at the QFD (Appendix A, Figure --) the top portion shows how the most important technical requirements relate to each other, again using the 1-3-9 method. The right half is the customer opinion survey, which showcases how three related projects relate to the team's current project. While the bottom of the QFD shows how the technical requirements are measured and the target weights for each. The weights were decided by the team, taking into account the SAE Aero competition rules.

After the QFD was created, the team came together to decide how to test each of the Engineering requirements (ER) to prove for one, that they could be tested and measured and two, that the requirements could be met through the design that the team created. These testing procedures will be discussed further in Section 3.

2.5 Standards, Codes, and Regulations

This section will provide a table of standards for specifications applicable to this project. Standards come from society, so we need to discuss why each standard is applicable to this project.

Table 2: Standards of Practice as Applied to this Project

Standard Number or Code	**Title of Standard**	**How it applies to Project**
AGMA 943-A22	Tolerances for Spur and Helical Racks	The latest standard document issued by AGMA ,helpful for the application of gears in design.
ANSI 105-2016	Hand Protection Classification	It helps to reduce the probability of personal injury during the production process and protect the producer.
ASME Y14.5-	Dimensioning and Tolerancing	It is used to read and drawings, which can increase the accuracy of manufacturing and drawing.

2018		
ASTM D7374-21	Standard Practice for Evaluating Elevated Temperature Performance of Adhesives Used in End-Jointed Lumber	Wood and glue are the main materials for the construction of the fuselage. This standard should be applied to prevent the cracking of the wood structure fuselage due to the high temperature of the engine.

3 Testing Procedures (TPs)

The testing procedures that will be used will determine the validity of a subsystem through various stresses and forces applied to each design as well as electronic setup and corrections. It will describe in detail what materials and equipment are needed for each test and how the team can acquire them. The testing procedures will be thorough so that each engineering requirement will be identified and tested and will then show how each requirement has been satisfied.

3.1 Testing Procedure 1: Wing Durability

This will test the durability of various wing designs that were designed by each member of the team. Each design will undergo various stress and torque tests on the wing to find how much deflection will occur. This test will also account for strength to weight ratios as well.

Satisfied engineering requirements:

- Lightweight
- Increase durability
- Increase impact tolerance
- Optimize safety factor
- Wing span of 48 inches or less

3.1.1 Testing Procedure 1: Objective

The test will use three different types of forces applied to each wing. The first will be both ends of the wing secured with weight placed on the middle and will be measured by the displacement of the wing. This will test the wings strength at the middle where it will be attached to the plane. The second test will be one end of the wing secured while another end of the wing has weight placed on it and will be measured by displacement. This will be testing the strength of the wings at the ends. The third test will have one end of the wing secured and the other end of the wing having applied torque on it where it will be measured in displacement. This will determine the wings strength during flight and account for aerodynamic forces.

3.1.2 Testing Procedure 1: Resources Required

All team members are required to do this test.

Materials:

- Torque wrench
- Balsa wood
- Hot glue
- Tape
- Foam
- Other miscellaneous materials made by members

3.1.3 Testing Procedure 1: Schedule

This test will take several hours due to setup time to test wings. It will be run on each team member's individual time and at their current location.

3.2 Testing Procedure 2: Fuselage volume

This test will determine if the fuselage is of adequate size for all electronic components and cargo bay. The fuselage will be manufactured and assembled for this test. The test will include fitting and sizing of components in the fuselage.

Satisfied engineering requirements:

- Meets SAE rules and regulations
- Payload unloading time
- Cargo bay

3.2.1 Testing Procedure 2: Objective

The objective of this test is to find a proper size of fuselage for our plane. It is critical that the fuselage has enough room for the electronics and a cargo bay otherwise the team will run into regulation problems in the competition. The test will include assembling the fuselage and organizing the interior area to fit all electrical components completely and securely. It will also assess the area for the cargo bay and how weights will be placed.

3.2.2 Testing Procedure 2: Resources Required

At least one team member is required to do this test. To assemble the fuselage basic hand tools are required to cut and manufacture individual parts.

Materials:

- Fuselage
- Battery
- ESC
- Servos
- Motor
- Receiver
- Cargo bay weights
- Adhesives

3.2.3 Testing Procedure 2: Schedule

This test will take several hours due to the meticulous work that is involved. The fuselage must be completely manufactured before this test can occur. This test should be run within the first weeks of the fall semester.

3.3 Testing Procedure 3: Electronics

This test will confirm that all electronics within the plane are working properly, and movement of components is in the correct direction. Each servo and motor will be monitored by a team member and adjusted with the transmitter to correct it.

Satisfied engineering requirements:

- Increased reliability
- Power limiter
- Must have 4 battery cells or less
- Must use 4.3 GHz radio control system

3.3.1 Testing Procedure 3: Objective

Successfully setup electronics including servos, motor, and transmitter-receiver communication. All electronics must communicate and work properly to provide a successful flight of the plane.

3.3.2 Testing Procedure 3: Resources Required

All electronic components will be required for this test.

3.3.3 Testing Procedure 3: Schedule

The test will take several hours to complete due to unforeseen errors in electronic setup and diagnosis of problems. It will take place when electronic components arrive (early August). Test will be done outside of school semester and therefore does not fit in semester schedule.

3.4 Testing Procedure 4: Fuselage to tail connection

This test will be conducted by each teammate to construct a design for the structure connecting the tail and fuselage together. Each design will be weighted based on cost and strength to weight ratio as well as subjected to various stress tests.

Satisfied engineering requirements:

- Lightweight
- Increase durability
- Increase impact tolerance
- Optimize safety factor
- Cannot exceed 55 pounds
- Low cost

3.4.1 Testing Procedure 4: Objective

The objective of this test is to determine a suitable structure and material to connect the tail and fuselage together. Each team member's design will be evaluated based on weight, cost, size, and strength. The test will measure deflection under load where one end of the structure is secured, and the other end is suspended. The second test will have the structure placed on the plane and measure deflection if applicable.

3.4.2 Testing Procedure 4: Resources Required

All team members are required to attend this test. Team-built structures are required to complete this test.

Materials:

- Adhesives (hot glue)
- Mounting points (nuts, bolts, rivets)

3.4.3 Testing Procedure 4: Schedule

This test will be completed within the first weeks of the second semester. The time to complete the test will be several hours due to tedious work mounting structures to plane and perform stress tests.

3.5 Testing Procedure 5: Flight and Performance

In this test we will take the fully assembled plane and fly it as well as observe its capabilities on the ground such as turning radius and rolling over rough terrain. It will also test the unloading time of the cargo. The team will test fly the plane and will observe the flight which will then lead to necessary changes and adjustments to the plane where applicable.

Satisfied engineering requirements:

- Increased reliability
- Increased durability
- Lift force
- Drag force
- Thrust
- Ground turning radius
- Payload unloading time
- Low control surface slop
- Adequate servo sizing for aerodynamic forces
- Landing within 200ft
- Takeoff within 8ft

3.5.1 Testing Procedure 5: Objective

The test will take place on NAU campus at various locations such as one of the soccer or football fields. A team member will control the plane and begin to fly it. All team members will observe it in flight and the member controlling the plane will pay close attention as to how it is flying. This will test the real-world application of our design. It will assess the planes turning radius, ground stability, and payload unloading time as well.

3.5.2 Testing Procedure 5: Resources Required

All team members must be in attendance for this test. An open field is required to fly the plane. The fully assembled plane, transmitter, and a charged battery are required to complete this test.

3.5.3 Testing Procedure 5: Schedule

This test should be completed at the end of the first month of next semester. The time to complete this test should be at least 3 hours due to recharging the battery, analyzing the plane during flight, and optimizing cargo bay unloading time.

4 Risk Analysis and Mitigation

For this project the team created a Failure Mode and Effects Analysis (FMEA). This is used to outline potential failures within the subsystems of the device, what the effects of it may be and how the team will then take this information and mitigate these potential failures as they construct the final design. A full FMEA was created with 40 total potential failures for the whole system, what it could be caused by, the lasting effects, and how the failure could be mitigated. Discussed in the following section are the top ten potential critical failures, with their effects and mitigation strategies.

4.1 Critical Failures

4.1.1 Potential Critical Failure 1: Aileron: Surface Fatigue

Ailerons are located on the wings and tail of the plane. Surface fatigue on the aileron could be created by crash landings or just general use of the device, due to adjusting, take-off and landing. The effect of this failure is not only a poor appearance, but it also could create extra drag and could lead to full failure of the subsystem if it is not monitored. To mitigate this failure layering of hardened materials over the surface paired with constant physical inspection will be conducted.

4.1.2 Potential Critical Failure 2: Aileron: Low-cycle Fatigue

The ailerons are controlled by servos, these servos in the wings create the lift and drag of the plane. Due to these forces, the ailerons are subject to low-cycle fatigue from raising up and down. This is caused by general use but can be elevated by crash landings. The effect of this failure is damage at main connection points and possible warping of the aileron itself. To mitigate this failure reinforced connection points could be made, along with proper lubrication.

4.1.3 Potential Critical Failure 3: Elevator: Abrasive Wear

The elevator is also located on the wings and tail of the plane. They are subject to forces not only through the aileron, but also general wind forces. The abrasive wear on the elevators could be due to general use of adjusting, take-off and landing or a crash landing. The effect of this failure is poor appearance, potential loss of control, creation of drag and/or complete subsystem failure. To mitigate this failure the elevators would need a layered, reinforced outer shell.

4.1.4 Potential Critical Failure 4: Motor: High-cycle Fatigue

The motor is the driving force of the plane, that being said the constant ON/OFF, throttling and holding of constant speeds and overloading creates high-cycle fatigue on the entire subsystem. The effects of these actions are loss of power, warping, smoke, and potential subsystem failure. To mitigate these effects, proper lubrication, proper power distribution and having a high torque motor would be used.

4.1.5 Potential Critical Failure 5: Servo: High-cycle Fatigue

Much like the motors the servos are the driving points of the ailerons and the elevators, this leads to high-cycle fatigue. The effects of this fatigue are noise, loss of power, smoke, and potential full subsystem failure. This can be mitigated by having proper lubrication, proper power distribution and having high torque, metal gear servos.

4.1.6 Potential Critical Failure 6: Aileron: Abrasive Wear

Much like the surface fatigue of the aileron, and the abrasive wear of the elevators, abrasive wear is caused by general use and crash landings. The effects of this failure could be poor appearance, possible warping, create unnecessary drag, and potential connection point failure. These can be mitigated by proper outer shell material layering that creates a strong outer surface to resist wear.

4.1.7 Potential Critical Failure 7: Landing Gear: Impact Fatigue

For this project the landing gear needs to withstand heavy forces, especially during landing. These forces could cause impact fatigue. This fatigue is characterized by deflection of the material, cracks, yielding and potential subsystem failure. To mitigate these potential failures the landing gear needs to be made of strong and heavy material, while reinforcing the connection points to ensure that the plane will land safely.

4.1.8 Potential Critical Failure 8: Elevator: Impact Deformation

With the amount of forces on the elevators and their construction, any impact deformation caused by a crash landing or an accident in transportation could lead directly to a complete subsystem failure. In order to attempt to mitigate this complete failure, each elevator needs to have reinforced internal and external structures, and reinforced connection points. However, it would benefit the team to have replacement parts made.

4.1.9 Potential Critical Failure 9: Motor: Impact Fatigue

Impact fatigue of the motor could be caused by crash landings, particularly hard landings, and overloading. It could be characterized by noise, loss of power, and potential failure of the motor. In order to mitigate this failure, the motor will have to have physical inspections after a crash or hard landing. With a particular focus on the connecting wires, ensuring that the power output has not changed.

4.1.10 Potential Critical Failure 10: Servo: Impact Fatigue

Impact fatigue of the servos could be caused by crash landings, and overloading. It could be characterized by noise, loss of power, and potential failure of the servos. In order to mitigate this failure, each servo will have to have physical inspections after a crash. With a particular focus on the connecting wires, ensuring that the power output has not changed and that the gears are not slipping.

4.2 Risks and Trade-offs Analysis

After careful analysis of the potential failure modes, there are a few risks and trade-offs that have surfaced. Many of the potential failures could be mitigated by adding internal reinforcements or adding layers to the outer subsystem shell. The trade-off for these fixes not only adds more weight, but also adds to the building materials budget. However, there are some subsystems that need this more than others, so the team could potentially cut costs by only focusing on what is vital to the success of the plane. This, however, could cause an unexpected failure. There are still risks after that as well, especially when adding more layers to the ailerons and elevators could cause connection breaks, abrasive wear and added weight. While the weight of a few layers might not seem like much, when it is all added together it makes a difference. This was a main reason for the team changing the fuselage and outer structure. After analyzing the FMEA, the team has decided that the elevators will have more protective layers added to them to ensure that they are properly protected due to them being such critical subsystems. During the building process the subsystems will be fully evaluated to see if there is a portion that needs to be adjusted more than others and the risks connected with those adjustments will be evaluated.

5 DESIGN SELECTED – First Semester

This part contains a comprehensive description of the team's design and an overview of the changes in the existing design compared to the previous design. This part will explain the changes and why we made them. In addition, this part will also specifically explain how we will put design into practice and give a plan on how to implement the design.

5.1 Design Description

This section will describe our designs in a comprehensive way, and clarify the changes of these designs compared with the previous ones, as well as the reasons for these changes.

5.1.1 Improved Design

As shown in the drawing, the existing design applies the following design: flat wing, large capacity fuselage and cargo tank, double blade propeller, and retractable landing gear. Compared with the previous design, this design has added many details and made modifications on the previous basis to meet the needs of customers and reduce the construction cost as much as possible.

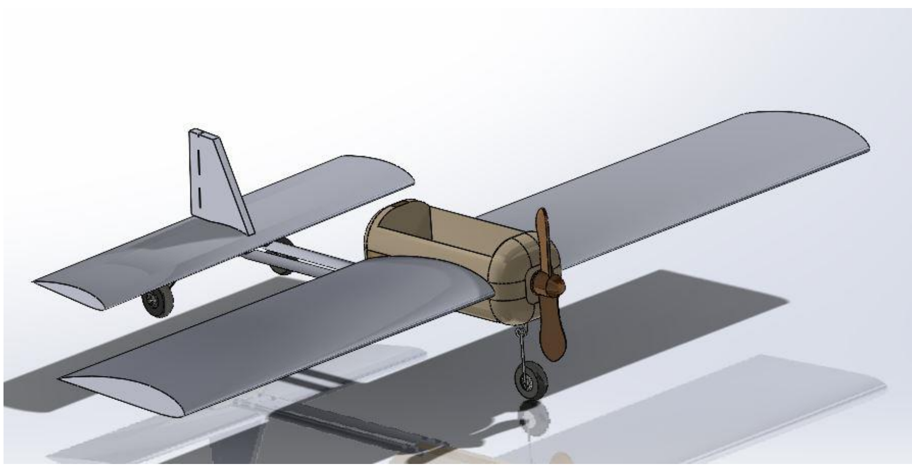

Figure 5: Improved Design

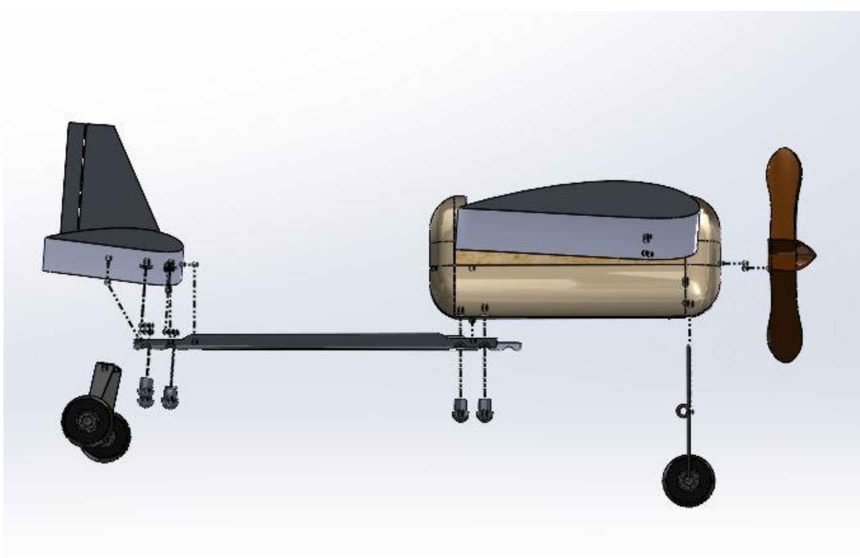

Figure 6: Exploded view

5.1.2 Engineering Calculations

Wings

Lift coefficient needed

$C_y = 2Y/(\rho V^2 S) = 2*55lbf/(1.225kg/m^3)(20m/s)^2(100in^2)$
$=15.478$

Maximum Shear Stress $\tau = F/A = 55lbf/2.19in^2 = 244.651\ N/1.413*10^{-3}\ m^2$
$=173.155$ KPa

Fuselage

Cargo Bay Volume
L x W x H = V
9 in∗4 in∗3.82 in=137.52 in^3
Impact Force
$F = (m*g*h)/d = (3.27\ lb*384\ in/s*5\ in)/(.1\ in) = 62,784\ lb\ in/s$

Electronics

Thrust
Thrust = weight * thrust/weight ratio
Thrust = 1800g * 0.7 = 1260g
Power = thrust * power/thrust ratio
Power = 1260 g * 0.226 W/g = 284.76 W

Landing gears

Maximum force:
$F=M*a=3.9N$
Maximum deflection:
$\Delta_{max} = (FL^3)/48EI = 0.0096m = 0.96cm$

5.1.3 Reasons for the changes

Base the preliminary report, after calculation and testing, we have found some unreasonable points of the previous design. First of all, we must ensure the reliability and applicability of the design, that is, we must meet the needs of customers. Secondly, the constructability of the design and the construction cost are also need to be considered. Through calculation and testing, we can remove some redundant designs, so as to save the use of materials and achieve a balance between reliability and cost. In addition, the testing and calculation work also provides a reliable assessment of the risks of the project, which enables us to find the risks in time and correct them. Therefore, modifying the design can also reduce the use and construction risks of the design. In conclusion, it has a lot of positive significance for the modification of the design.

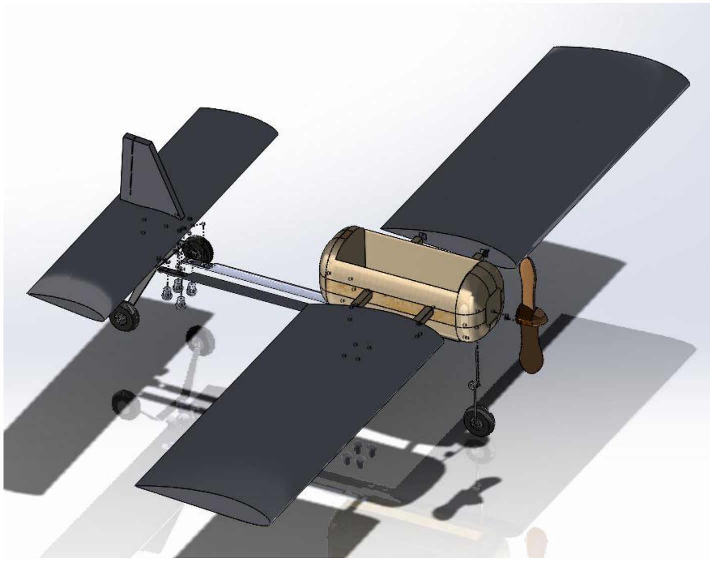

Figure 7: Exploded view 2

5.2 Implementation Plan

This section will describe how we will implement our design. This section will also clarify what resources we need to complete our work, including materials, grounds, personnel, etc. , as well as a schedule on how we will complete the work.

5.2.1 Resources needed

As for the implementation of construction, we need many resources, including manpower, information, materials, and ground. In order to visually show the needs of these resources, we have made a Budget Analysis table and resource table. The tables can be seen in the appendix C and D.

5.2.1 Schedule for next semester

For the tasks of next semester, we can divide them into the following parts in detail: project determination, material preparation, product manufacturing, project adjustment, testing, and final report. in order to visually display the time periods applied to these tasks, we have made the following chart.

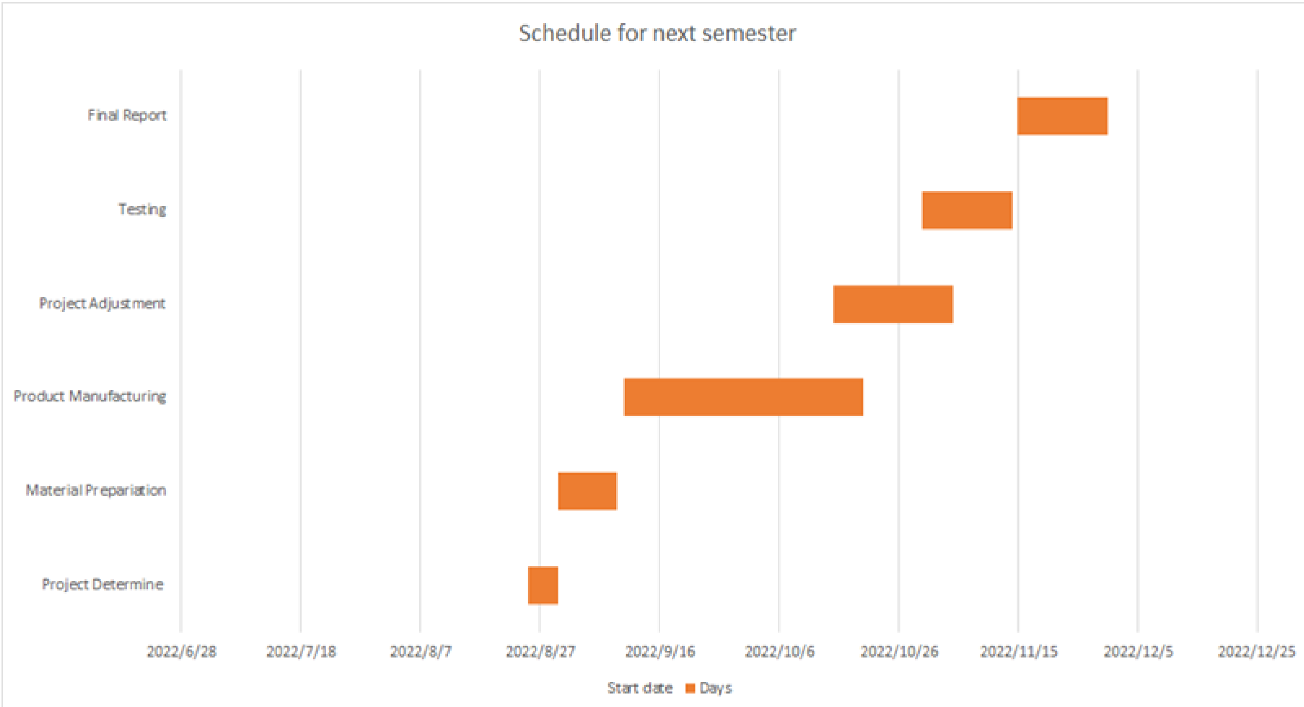

Figure 8: Next semester Schedule

6 CONCLUSIONS

The SAE Aero Micro team has the responsibility of developing a remote-controlled aircraft that meets the rules and regulations of the SAE Aero competition. The main goal of the team is to create a plane that can take off and land successfully as well as have stable flight through the air. Critical requirements include a wingspan of 48 inches or less, it must be a safe design, and the entire system must be electric. This report took the black box model, functional model, customer requirements, engineering requirements, and house of quality from early in the semester to give an overview of what the projects requirements and functional breakdown is. It then covered the standards, codes, and regulations that apply to the project. It covered the testing procedures that outlined in detail the tests objectives, required resources, and schedule. Next, risk analysis and mitigation were used to determine each failure point in the plane. An analysis was done to mitigate these failure points and will then improve our design based on these findings. From these findings, the first semester design, outlined in section 5, was chosen. This section contained a comprehensive description of the team's design and an overview of the changes in the existing design compared to the previous design. It described in detail the changes that were made and why they were made and how the team will put the design into practice. The final solution proposed by the team is a flat wing design where the wing is located at the top of the fuselage. The fuselage will contain all electrical components which will be located under or near the wing to help with the center of gravity. Connecting the tail to the fuselage will be a lightweight structure made of rods that will keep the weight of the plane down and center of gravity at an appropriate location. The team decided to use a backwards tricycle landing gear which will help with tipping and landing/takeoff stability.

7 REFERENCES

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8 APPENDICES

8.1 Appendix A: House of Quality

	Light weight	Increase Reliability	Increase Durability	Power limiter	Cargo Bay volume	Low Cost	Increase impact tolerance	Wing span of 48 inches or less	Lift Forces	Drag Forces	Thrust	Ground turning radius	Payload unloading time	Low control surface slop	Must have 4 cells or less battery for the electronics	Adequit servo sizing for aerodynamic forces	Must use 2.4 GHz radio control system	Landing within 200 feet	Takeoff within 8 feet	Cannot exceed 55 pounds	Optimize saftey factor	Meets SAE Rules and Regulations
Light weight																						
Increase Reliability																						
Increase Durability		1		1																		
Low Cost	3			3			1															
Increase impact tolerance	1		9																			
Optimize saftey factor	1	3	3	3			9							1	1							
Meets SAE Rules and Regulations				9	3	1		9				9	9	9	9	9	9	9				

Legend
A SAE Aero Micro 2021
B Hangar 9 Pulse XT
C UMX Turbo Timber

Technical Requirements (1-3-9) / Customer Opinion Survey

Customer Needs	Customer Weights (1: worst-5: Best)	Light weight	Increase Reliability	Increase Durability	Power limiter	Cargo Bay volume	Low Cost	Increase impact tolerance	Wing span of 48 inches or less	Lift Forces	Drag Forces	Thrust	Ground turning radius	Payload unloading time	Low control surface slop	Must have 4 cells or less battery for the electronics	Adequit servo sizing for aerodynamic forces	Must use 2.4 GHz radio control system	Landing within 200 feet	Takeoff within 8 feet	Cannot exceed 55 pounds	Optimize saftey factor	Meets SAE Rules and Regulations	1 Poor	2	3 Acceptable	4	5 Excellent
Meets the requirements of the rules	5	1	1	1	9	9	1	9	9	3	3	3	9	9	9	9	9	9	9	9	9	9	9				BC	A
Safe design	5	1	3	3	9			3							9		9					9	9					ABC
Able to take off and land	5	9	9	9	3					9	9	9			9		9				3	1	3					ABC
Innovative design	2		3	3			1	3		3	3	3			3		1				1	3	3		C	AB		
Manufacturable	3	3	1	1	3	1	9	3		3	3	3			1	3	3	3				9				A	B	C
Low cost	4	3			3		9	9							1	3	3	3							ABC			
Modular compatibility	1		3				1	3					1		3				1	1		1	3		A	BC		
Static load capability	5	9	9	3		9	1							9							9	3	3					ABC
60 Second lift-off time limit	5	3								9	9	9					9			9								ABC
200 foot landing distance	5	3								9	9	9					9		9									ABC
Payload extraction in one minute or less	5					9								9										C				AB
Use of Lithium Polymer Batteries	5		3	3	3		3									9	1	1				1	3				C	AB
Use of Power limiter (450-Watt)	5		3	3	9		1					3					3	3				9	3	ABC				
Must have one cargo bay	5					9								9									3					ABC
Ability to make a turn in air	5									9	9	9			3		9	3					3					ABC
Ability to make a turn on the ground	5												9										9					ABC
Storing mechanism for landing gear	5	3				1	3						9		3		9						9					ABC
Must use an Eletric motor	5				3		3					9				3							9					ABC
Fixed Wing	5		1	1						3	3	3		1	3		1		3	9		9	9					ABC
Functional failsafe for radio control systems	5																		3				9					ABC
Must be equipped with a red arming plug	5																						9	C				AB
Must use model airplane safety net	5																						9					ABC
Appropriate center of gravity	5	3				1			1												1		9					ABC
Must have a radio control system	5															1	1	9										ABC
Technical Requirement Units		pounds	Percentage	Percentage	Watts	Inches cubed	US dollars	Crashes before repair	Inch	Pounds	Pounds	pounds	Inches	Seconds	Degrees	Number of cells	ounces/inch	GHz	Feet	Feet	pounds	Factor of Safety	Percentage					
Technical Requirement Targets		55	100	100		6*6*4	1500		48							4		2.4	200	8	55		100					
Absolute Technical Importance		181	151	124	201	193	163	114	50	225	225	265	136	165	196	131	368	146	121	136	112	233	349					
Relative Technical Importance		11	13	18	7	9	12	20	22	6	5	3	16	10	8	17	2	14	19	15	21	4	1					

8.2 Appendix B: FMEA

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
Product Name: Aero Micro		**Development Team: Melissa Parsons, Jared Laakso, Junjie Shi**				**Page No 1 of 1**			
System Name: Aero Micro						**FMEA Number 1**			
Subsystem Name:						**Date: 07/19/2022**			
Component Name: Full system									
Fuselage	Impact Wear	Poor appearance, potential loss of of structural integrity	5	Hole created in the cargo hold due to constant loading and unloading	1	Loading procedure	1	5	Constant inspection of the cargo hold, replace flooring of cargo hold if any wear is present
	Impact Fatigue	Loss of structural integrity, possible system failure	5	Broken structural rib due to impact or due to cargo loading and unloading, hole created by subsystem connection point	2	Physical inspection, reinforce connection points	2	20	Inspect subsystem connection points to ensure contact points are secure. Reinforce connection points.
	Yielding	Loss of structural integrity, possible sysem failure	9	Overloaded cargo hold, impact or subsystem connection point	1	Physical inspection, loading procedure	1	9	Constant inspection, layer materials to ensure strong connection points, create patches of replacement materials
Wings	Impact Fracture	Loss of structural integrity, poor appearance, complete subsystem failure	10	Crash landing, overweight, over torqued, high speed while being overweight	5	Physical inspection after crash, precision handleing, have a series of replacement parts just in case	1	50	Keep replacement parts on deck, attempt to fix what is needed
	Impact Fatigue	Loss of structural integrity, poor appearance, complete subsystem failure	10	Multiple crash landings	7	Reinforcing ciritical points, physcial inspection	1	70	Constant inspection, layering of materials to create a strong outer shell
	Impact Deformation	Loss of structural integrity, poor appearance, complete subsystem failure	10	Multiple crash landings, high speed while being overweight	6	Series of replacement parts, reinforcement of critical parts	1	60	Create strong connection points and supports, layer extra materials if needed
	Surface Fatigue	Loss of structural integrity, poor appearance, creates drag	8	Take-off, landing, crash landing, general use	6	Physical inspection, wrap the wings in tape to create an easily replaceable and fixable surface	1	64	Layering of materials to create a strong outer shell, layer extra materials if needed
Aileron	Impact Fracture	Complete subsystem failure	10	Crash landing, general use	5	Physical inspection, series of replacement parts	1	50	Have a series of replacement parts, Constant physical inspection
	Surface Fatigue	Poor appearance, creates drag	8	Crash landing, general use	5	Physical inspection, layering of material to ensure a hard surface	7	280	Constant physcial inspection, Layering of materials to ensure a stronger surface
	Impact Deformation	Complete subsystem failure	8	Crash landing, general use	5	Reinforcing ciritical points, physcial inspection	1	35	Physical inspection, Have a series of replacement parts avaiable
	Abrasive Wear	Poor appearance, creates drag, potiental connection point failure, possible warping	4	Crash landing, general use	8	Reinforcing ciritical points, keep moving parts lubricated, physical inspection of connection points	4	128	Layering of materials to create a strong outer shell, layer extra materials if needed
	Low-cycle Fatigue	Potential connection point failure, possible warping	4	General use	10	Lubricate moving parts	6	240	Proper lubrication, layering of materials
Landing gear	Impact Fracture	Complete subsystem failure	10	Crash landing, general use, overweight, high speed landing	1	Physical inspection after crash, have a series of replacement parts in case of failure	1	10	Create strong connection points and supports, have replacement parts if needed
	Impact Fatigue	Deflection, loss of balance	4	Crash landing, general use, multiple high speed landings	10	Physical inspection	3	120	Create strong connection points and supports
	Impact Deformation	Loss of balance	4	Crash landing, general use, multiple high speed landings	2	Physical inspection, measurements	3	24	Use strong materials that can handle deformation,
	Surface Wear	Poor apperance	1	Crash landing, general use	10	Physical inspection, create landing gear out of strong material	2	20	Layering of materials to create a strong outer shell, layer extra materials if needed
	Yielding	Difficulty landing, loss if balance, poor physical appearance	3	Crash landing, general use, overweight, high speed landing	1	Physical inspection, series of replacement parts, balance	1	3	Create strong connection points and supports, evenly spaced to increase balance, have replacement parts if needed
Tail	Impact Fracture	Complete subsystem failure	10	Crash landing, hard landing	1	Physical inspection, replacement parts, wrap the supports with strong material	1	10	Physical inspection, reinforce connection points, reinforce internal structure
	Surface Fatigue	Poor appearance	1	Crash landing, general use	10	Physical inspection, layering of material to ensure a hard surface	3	30	Layering of materials to create a strong outer shell, layer extra materials if needed
	Impact Deformation	Complete subsystem failure	10	Crash landing	5	Physical inspection, reinforce connection points, layering of materials	1	50	Reinforce internal strucuture and connection points. Layering of external material, replacement parts if needed
	Surface Wear	Poor appearance, creates drag	2	Crash landing, general use	10	Layering of material to ensure a hard surface	3	60	Layering of materials to create a strong outer shell, layer extra materials if needed
Elevator	Impact Deformation	Complete subsystem failure	10	Crash landing, general use	6	Physical inspection, replacement parts	2	120	Reinforce internal strucuture and connection points. Layering of external material, replacement parts if needed
	Impact Fracture	Complete subsystem failure	10	Crash landing	1	Replacement of parts	5	10	Reinforce internal strucuture and connection points. Layering of external material, replacement parts if needed
	Surface Wear	Poor appearance, creates drag	3	Crash landing	5	Physical inspection, layering of materials	5	75	Layering of materials to create a strong outer shell, layer extra materials if needed
	Abrasive Wear	Noise, loss of power, poor appearance, potiental complete subsystem failure	7	Crash landing, general use	7	Physical inspection, layering of material to ensure a hard surface, lubrication of moving parts	4	196	Layering of materials to create a strong outer shell, layer extra materials if needed
Motor	Temperature Fatigue	Noise, loss of power, smoke, potiental complete subsystem failure	7	General use, overloading, connection failures	2	Physical inspection, check connecting wires, downtime, ventilation	5	70	Create ventilation points, ensure that all connecting wires are properly installed
	High-cycle Fatigue	Loss of power, warping, smoke, potiental complete subsystem failure	7	General use, overloading, connection failures	4	Physical inspection, downtime, check power levels	5	140	Proper lubrication, ensure proper power distribution, high torque motor
	Impact Fatigue	Noise, loss of power, potiental complete subsystem failure	7	Crash landing, hard landing, overloading	3	Physical inspection, check connecting wires, downtime	5	105	Phsical inspections, check power outputs and connecting wires after an impact
Servos	Temperature Fatigue	Noise, loss of power, smoke, potiental complete subsystem failure	7	General use, overloading, connection failures	2	Physical inspection, check connecting wires, downtime	5	70	Create ventilation points, ensure that all connecting wires are properly installed
	High-cycle Fatigue	Noise, loss of power, potiental complete subsystem failure, smoke	7	General use, overloading, connection failures	4	Physical inspection, downtime, check power levels	5	140	Proper lubrication, ensure proper power distribution, high torque servo, metal gears
	Impact Fatigue	Noise, loss of power, potiental complete subsystem failure	7	Crash landing, hard landing, overloading	3	Physical inspection, check connecting wires, downtime	5	105	Phsical inspections, check power outputs and connecting wires after an impact
Propeller	Impact Fracture	Complete subsystem failure	10	Crash landing, hard landing	7	Physical inspection, have a series of replacement parts	1	70	Physical inspection, reinforce connection points, replacement parts on deck
	Surface Fatigue	Poor appearance, loss of of structural integrity, potiental complete subsystem failure	7	General use, crash landing	8	Physical inspection, have a series of replacement parts	1	56	Layering of materials to create a strong outer shell, layer extra materials if needed
	Abrasive Wear	Warping of the blade, poor appearance, loss of structural integrity	4	Tighting the bolts too tight, crash landing,	3	Proper lubrication, not over tightening	7	84	Adhering to the torque specs, proper lubrication
	Surface Wear	Poor apperance, loss of power	4	General use	10	Layering of material to ensure a hard surface, physical inspection	1	40	Layering of materials to create a strong outer shell, layer extra materials if needed
Structure	Impact Fatigue	Poor appearance, deformation, complete subsystem failure	5	General use	5	Reinforced connection points, layering of stronger materials for the internal and external structure	3	75	Reinforce external structure and connection points, constand physcical inspection
	Yielding	Complete subsystem failure	10	Crash landing, overweight	3	Replacement of parts	1	30	Reinforce external structure and connection points. If completely broken a replacement part will be needed.
	Impact Fracture	Complete subsystem failure	10	Crash landing, overweight	6	Replacement of parts	1	60	Reinforce external structure and connection points. If completely broken a replacement part will be needed.
	Deformation	Balance issue, poor appearance, possible subsytem failure, could lead to yielding	9	Crash landing, general use, overweight, high speed landing	8	Replacement of parts	1	72	Reinforce external structure and connection points. If completely broken a replacement part will be needed.
	Surface Fatigue	Poor appearance, possible yielding if left unckeched	5	General use	5	Reinforced connection points, layering of stronger material for the external structure, physical inspection	2	50	Constant physcial inspection, Layering of materials to ensure a stronger surface

8.3 Appendix C: Budget Analysis

As for the budget, the most important parts will be electronic equipment such as motors, servos, ECs, battery and charger, transmitters and receivers, which will account for nearly half of the budget. The specific price is shown in the figures below.

Motor:

Avian 4250-800Kv Outrunner Brushless Motor

Spektrum - SPMXAM4700

$89.99

Servos:

A4040 MT/HS Micro Metal Gear HV Servo

Spektrum - SPMSA4040

$54.99

Battery and charger:

Smart G2 Powerstage Air Bundle: 3S 2200mAh LiPo Battery / S120 Charger

Spektrum - SPMXPSA200

Transmitter and receivers:

DX6e 6-Channel DSMX Transmitter with AR620

Spektrum - SPM6655

$279.99

ECS:

Avian 60 Amp Brushless Smart ESC, 3S-6S (IC3)

Spektrum - SPMXAE1060

$69.99

The ways of purchasing these equipment are as follows:

Motor:https://www.horizonhobby.com/product/avian-4250-800kv-outrunner-brushless-motor/SPMXAM4700.html

Servos:https://www.horizonhobby.com/product/a4040-mt-hs-micro-metal-gear-hv-servo/SPMSA4040.html

Transmitter and receiver:https://www.horizonhobby.com/product/dx6e-6-channel-dsmx-transmitter-with-ar620/SPM6655.html

ESC:https://www.horizonhobby.com/product/avian-60-amp-brushless-smart-esc-3s-6s-ic3/SPMXAE1060.html

Battery and charger:https://www.horizonhobby.com/product/smart-g2-powerstage-air-bundle-3s-2200mah-lipo-battery-s120-charger/SPMXPSA200.html

The advantage of purchasing from these ways is that we can save taxes and postage (these expenses are not a small amount in most ways), so as to achieve the purpose of saving budget.
In addition, other materials will be purchased locally to save transportation costs. Free materials provided by individuals or factories will not be included in the total budget. The saved budget will be used to deal with emergencies, thereby reducing risks.

8.4 Appendix D: Resources Table

Resources Table			
Classify	Name	Numbers	remarks
Manpower	Working Staffs	3	Team members in SAE Aero team
Materials	Motor	1	Purchase from the Internet.
	Servos	4	
	Transmitter and receiver	1	
	ESC	1	
	Battery and charger	1	
	Bottle of glue	1	
	Pack of wood sticks	1	
	Pack of wood plank	1	
Information	/	/	Any required information can be obtained from textbooks, the Internet, and the NAU library.
Ground	Internet Café	/	A place for meeting and discussion.
	NAU machine shop	/	A site for construction and fabrication.