SAE Aero Micro

Final Report

Melissa Parsons
Jared Laakso
Junjie Shi

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

Faculty Advisor: Dr. David Willy

Instructor: Dr. David Willy

DISCLAIMER

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

EXECUTIVE SUMMARY

The SAE Aero Micro team was tasked with developing a radio-controlled electronic aircraft that could compete in the SAE Aero Micro competition. The main objective of the competition is to successfully take off the aircraft within an 8-foot runway to then fly through the course and land within 200ft. Additionally, the plane must be capable of carrying a payload that must be loaded into the plane and takeoff again within 60 seconds. The overall aircraft design is completely dependent on the design team. The team was limited to the rules and regulations of the competition which include a wingspan no larger than 48 inches, cannot exceed 55 pounds, must be a fixed wing, and other required parameters that are included in the customer needs and technical requirements of the report. Although the team was tasked with designing an aircraft per the regulations of competition, the team will not be able to participate in the competition, therefore, some regulations will be disregarded in the design. The primary goal of this capstone was to successfully create an aircraft that can fly. Then if time is allowed, the team will iterate final fixes and additions to the plan to make it competition ready as a secondary requirement. The design process was iterative with changes made to each subsystem throughout the building process. This gave the team the best probability of a successful plane design. This plane's unique design is composed primarily of Depron foam, packing tape, and plywood which is adhered together with hot glue. This design utilizes the lightweight and strength of the Depron foam coupled with packing tape for its structural integrity and weight reduction. The plywood is used for the ribs of the wing and mounting surfaces where more support was required. The landing gear is composed of steel tubing and hobby wheels for model aircraft. The final design of the aircraft is a traditional flat wing plane with a wing located at the top of the fuselage and a front mounted motor. It has a cargo bay located under the wing which is used to carry aluminum blocks which represent the payload. The wheels on the landing gear were made to be very large for rolling over rough surfaces during landing and takeoff. The electronic system is composed completely of Spektrum components for maximum performance and reliability. The resulting plane was able to takeoff, fly, and land successfully on the first flight attempt. The flight characteristics of the plane are very stable through the air and landing was very stable as well. All original components after the flight were not damaged. Important aspects of the plane that made this possible were correct center of gravity, lightweight, thrust to weight ratio, and proper control surface sizing.

ACKNOWLEDGEMENTS

The SAE Aero Micro team would like to formally thank Fred and Tim from the Flagstaff Flyers group. Their knowledge of remote-controlled aircraft and their constant support of the team were a huge part of the team's overall success. The team would also like to acknowledge the Mechanical Engineering faculty at Northern Arizona University, for their constant support and assistance throughout the entire project.

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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 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. The 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. Manufactural (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)

Table 1: Engineering Requirements

Light weight	Pounds	6.5 lbs.
Increase Reliability	Percentage	
Increase Durability	Percentage	
Power limiter	Watts	
Cargo Bay volume	Inches Cubed	$12in^3$
Low Cost	US Dollars	< $1500
Increase impact tolerance	Crashes before repair	
48-inch Wingspan	Inch	48in
Lift Forces	Pounds	> 6.5lbs
Drag Forces	Pounds	< 0.5lb
Thrust	Pounds	4lbs
Ground turning radius	Inches	
Payload unloading time	Seconds	60s
Low control surface slop	Degrees	5 degrees
Must have 4 cells or less battery for the electronics	Number of cells	< 4 cells
Adequate servo sizing for aerodynamic forces	Ounces/inch	90oz/in
Must use 2.4 GHz radio control system	GHz	2.4GHz
Must land within 200ft	Feet	200ft
Takeoff within 8 feet	Feet	8ft
Cannot exceed 55 pounds	Pounds	55lbs
Optimize safety factor	Factor of Safety	1.2
Meets SAE Rules and Regulations	Percentage	90%

Several engineering requirements listed above have been disregarded and are highlighted in red due to the team not competing in the SAE Aero Micro competition. Although these requirements have not been met, the client was pleased with the final design. It is worth noting that only small changes would need to be made to make this a competition-ready plane. This would include having a servo installed to turn the rear landing gear, installing a power limiter and red arming plug, and ability to takeoff within 8 feet.

All other requirements have been satisfied and are within range of the ability to compete in the SAE Aero Micro competition. The team received approval from the client for the requirements that were not met in relation to the competition.

2.3 Functional Decomposition

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 1 showcases the team's updated Functional Decomposition.

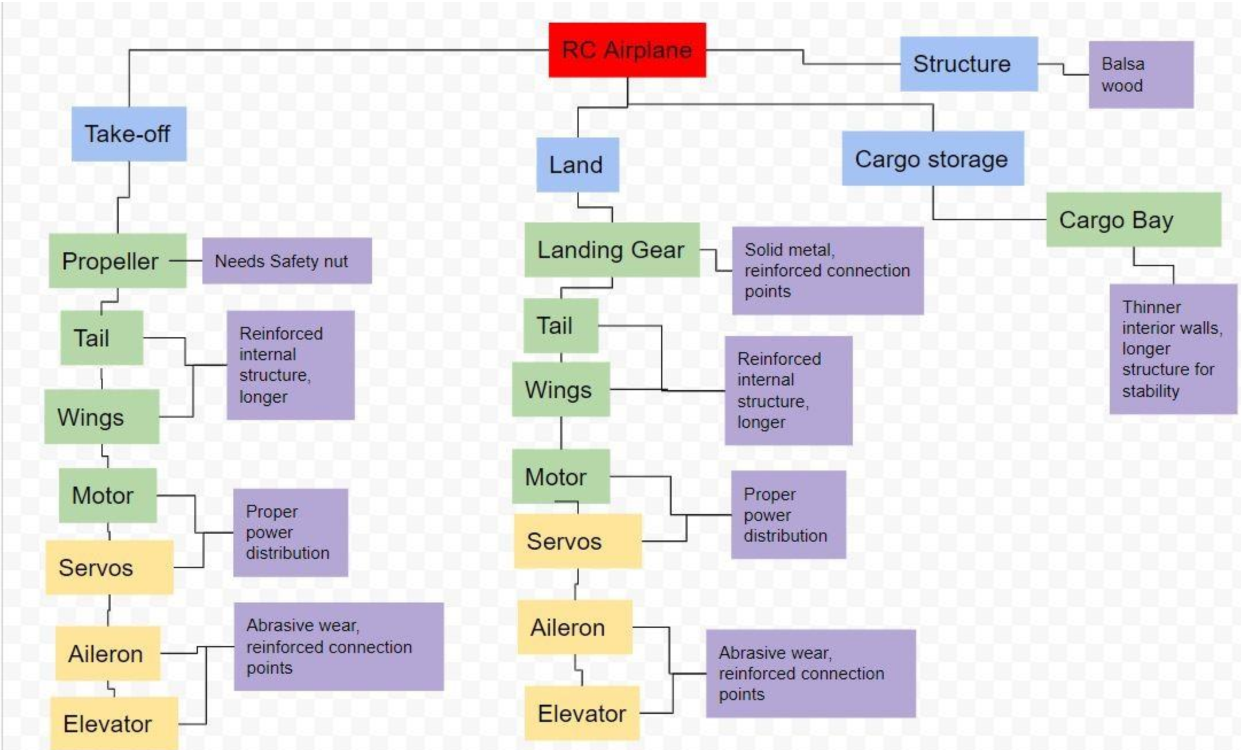

Figure 1: Functional Decomposition

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 cargo storage is one of the main requirements of the competition. These systems were broken down into 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 is 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 drastically shortened, the team intentionally made them smaller in order to ensure that the lift to weight ratio would be higher. Second, the extended fuselage was changed several times mainly due to connection issues. The connection of the extended fuselage to the fuselage was a main failure point, so the team had to devise a way to ensure it would withstand the forces acting on it. This was a common theme regarding connection points; therefore, the structure portion was changed into one of the main subsystems. The third 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 tail and rudder were also chosen to not have an airfoil shape, this was again to reduce weight. The fourth 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. In order to help mitigate this the team added wooden slats in the tail and rudder in between the foam to add more rigidity. The entire plane was also covered with packing tape to not only create a smooth, aerodynamic surface, but also to hold the structure together and add more stability without adding much weight.

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 2 showcases the BBM for the Aero Micro team.

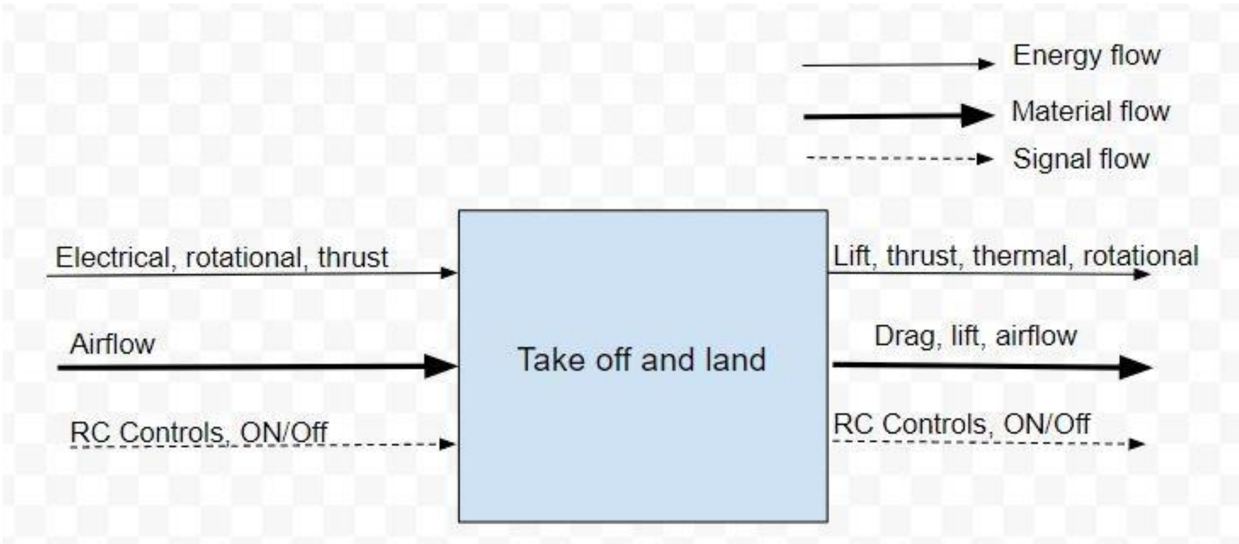

Figure 2: Black Box Model

This visual aid helped 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. Even with the team's choice in an iterative process this black box model helped the team focus on what they needed to plan more for in terms of the outputs and how the inputs would affect the overall design and function of the plane.

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

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 3 shows the updated functional model for the Aero Micro team.

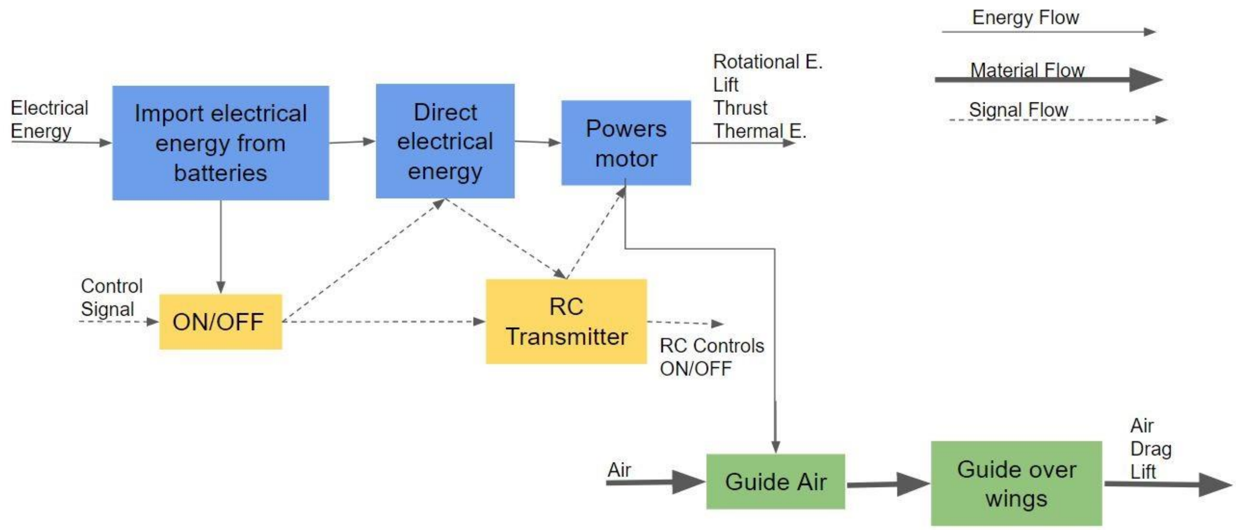

Figure 3: Functional Model

While creating the final design the team relied heavily on the functional model which helped create and analyze the Failure Mode Analysis in Section 9, 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 (Figure 30), 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 (Figure 30) 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, considering 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 8.

2.5 Standards, Codes, and Regulations

This section will provide a table of standards for specifications applicable to this project. These standards come from different parts of society and will be explained in how they apply to the project.

Table 2. Standards, Codes, and Regulations

Standard Number or Code	**Title of Standard**	**How it applies to Project**
ANSI 105-2016	Hand Protection Classification	It helps to reduce the probability of personal injury during the production process and protect the producer. A kill switch was added to the plane to meet this standard.
ASME Y14.5-2018	Dimensioning and Tolerancing	It is used to read and draw, which can increase the accuracy of manufacturing and drawing.
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. This applied particularly with the wooden motor mount, where the team attempted to vent the hot air coming from the motor.
AIIAS-102.1.4-2019	Performance-Based Failure Reporting, Analysis & Corrective Action System	This standard is used to properly create FMEA, ensuring that the failures and potential failures are reported and documented correctly. This holds the team accountable for being honest with their design and the potential failures associated with it.
NAU Machine shop Certification	Advanced Machine shop certification	To use the tools in the machine shop and manufacture the aircraft. The shop holds the highest standards for student safety and understanding. The entire team needed to obtain shop certification before taking part in the machine shop, which again was a critical part in the team's manufacturing process.
NAU IDEA Lab Certification	Advanced Lab certification	The IDEA Lab in NAU’s engineering building requires students to have a solid understanding of SOLIDWORKS and the lab safety manual before conducting any manufacturing processes using the laser cutter. Therefore, the team had to obtain permission and certification to use such devices.

These are only a small portion of the standards that the team upheld during this process. However, the three main standards that the team focused on were the AIIAS-102.1.4-2019 standard, the Machine shop and the IDEA Lab certifications. Safety was the team’s number one priority, so safety training and shop certification were greatly needed to keep the team safe and build a safe device. The AIIAS standard ensured that the team was honest with what they were creating and presenting and how it could fail. Overall, all these standards were used to enlighten the team, keep them safe and create an aircraft that can meet the requirements given.

3 DESIGN SPACE RESEARCH

3.1 Literature Review

The literature review is used to find credible and state of the art sources to justify the team's designs and create accurate and useable concepts for the project. Each student was tasked with finding five credible, relevant sources that apply to the project. These sources covered a range of mediums including textbooks, websites, YouTube, research papers and journals. One team member focused on the general function of remote-control airplanes, while another on the physical properties and performance of remote-controlled aircrafts, and another team member being focused on stable flight and how to reproduce that for a remote-control aircraft. These sources along with benchmarking enabled the team to get a solid understanding of the subsystems they would be working with and how they should proceed with the design process.

3.2 Benchmarking

The benchmarking process involved researching products used in similar applications to the SAE Aero Micro competition and testing the compatibility and validity of the design and products used within them. The team researched the products applications, flight capabilities, and features through watching reviews, videos, and reading the owner's manuals. The team then identified relevant problems and issues with each product that would be detrimental to the competition and found opportunities within each design that could benefit the team in the competition.

3.2.1 System Level Benchmarking

The system level benchmarking for this project was based on existing products in the market used in similar applications to the SAE Aero Micro competition. This includes previous SAE airplanes used to compete in previous competitions, scale model aircraft, and recreational model aircraft used by enthusiasts. Each design was chosen based on similar requirements regarding weight, wingspan, wing type, and other various factors that would apply as restrictions to the competition.

3.2.1.1 Existing Design #1: UMX Turbo Timber

This is a trainer model aircraft that is similar in size that is required for the SAE Aero Micro competition which makes it a great source of information regarding electronic parameters and expected weight of the aircraft. A trainer aircraft is very stable in flight and has a lower flight speed. Because the aircraft is of similar size and weight, the electronics used in the aircraft are designed for similar aerodynamic forces which will serve as a benchmark for the products that will be chosen for the aircraft later in the project. This plane has a flat wing at the top of the fuselage for increased air stability. It has a three-blade propeller which is less efficient than a two-blade propeller but is much quieter in flight. Because the aircraft is so lightweight, having 3 blades is not detrimental to the performance.

Figure 4: Turbo Timber

3.2.1.2 Existing Design #2: Hangar 9 Pulse XT

This is a sport model aircraft of similar size to the SAE Aero Micro competition. This product is referenced for its aerobatic capabilities and electronic selection used. This is designed for more advanced flight in that it can make advanced maneuvers in the air. The flat wing is at the bottom of the fuselage, allowing the plane to be more agile, sacrificing stability.

Figure 5: Hangar 9 Pulse XT

3.2.1.3 Existing Design #3: **Georgia Institute of Technology**

The Georgia institute of technology won the 2021 SAE Aero Micro competition with this plane. This has the most direct relation to the project because it was used in the competition this team is competing in. It is important to study the aircraft because it is a great representation of what is a successful design. It is composed of a delta wing design which excels at stable flight. However, delta wings create high induced drag, and it is harder to take off at slow speeds. To compensate for this, delta wings have a high angle of attack. The aircraft has a truss-based structure which makes the airplane very rigid during its flight. It has a dual rudder design to help with vertical stabilization and turning through the air.

Figure 6: Georgia Institute of Technology

3.2.2 Subsystem Level Benchmarking

This section focuses on existing designs that address subsystem requirements relevant to the project. It assesses the most important subsystems that will have a substantial impact on the overall design. It will go over in detail the subsystems from each product.

3.2.2.1 Subsystem #1: Wings

The wings are part of the plane that generates lift thereby allowing the airplane to fly. Principal factors include wingspan, chord length, cross section, and wing type. These all affect how the aircraft will fly.

3.2.2.1.1 UMX Turbo Timber: High Flat Wing

This design is used on trainer planes which have characteristics of stable flight with little aerobatic capabilities. This is relevant to the design because based off where the wing is located on the fuselage will determine the aircraft's stability and sensitivity to turns in the air. Also, the team's plane needs to be as stable as possible due to no team members having prior experience flying model planes.

3.2.2.1.2 Hangar 9 Pulse XT: Low Flat Wing

This flat wing design found at the bottom of the fuselage is used on most sport model planes which have more aerobatic capabilities for more experienced pilots. This gives the team insight into how wing placement will change handling capabilities and sensitivity to turns in the air.

3.2.2.1.3 Georgia Institute of Technology: Delta Wing

This design is unique which answers critical questions that the team has such as what wings will work and how can they be designed. This delta wing design is a component that can be added to our aircraft which would determine the overall shape and handling characteristics. Delta wings excel at all fields of aerodynamic qualities except it is hard to take off and land at low speeds which the team would have to overcome with a clever design.

3.2.2.2 Subsystem #2: Tail

The tail is composed of the rudder and elevator at the back of the plane. The rudder is a vertical airfoil that controls the horizontal movement of the plane. The rudder is a horizontal airfoil that controls the vertical movement of the plane. It is important to have a successful tail design that effectively turns the plane in the air while being lightweight.

3.2.2.2.1 UMX Turbo Timber: Single Rudder and Elevator

This design is found on most planes where the rudder is found on the top of the fuselage and the elevator is located near the middle of the fuselage. This design will relate to how airflow affects the handling of the aircraft in the air.

3.2.2.2.2 Hangar 9 Pulse XT: Single Rudder and Elevator

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3.2.2.2.3 Georgia Institute of Technology: Dual Rudder and Large Elevator

This design has two rudders located at opposite sides of the wing. The elevator acts as both the elevator and ailerons where they can move independently from one another or as one. This controls the vertical and rotational movement of the aircraft in the air. This design affects the overall design aerodynamic forces of the plane on the rudder and elevator.

3.2.2.3 Subsystem #3: Electrical Components

The electrical components affect the weight and functionality of the plane through handling aerodynamic forces. They handle all moving components on the plane which allow it to fly successfully.

3.2.2.3.1 UMX Turbo Timber: Motor, receiver, esc, and Servos

This design is composed of one motor driving the propeller and four servos used to control the elevator, rudder, and ailerons. This is a similar sized aircraft to what the SAE Aero micro class uses which gives the team a benchmark of components used for similar aerodynamic forces expected on the plane as well as compatible receivers and esc that can be used in competition.

3.2.2.3.2 Hangar 9 Pulse XT: Motor, receiver, esc, and Servos

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3.2.2.3.3 Georgia Institute of Technology: Electrical Components

Unfortunately, this information is unavailable due to confidentiality of the Georgia team. Releasing this information would give other teams an opportunity to undermine their work by copying them, which is why the information is not available.

4 CONCEPT GENERATION

This section consists of the early concepts generated by the team. The team began by deconstructing what a plane was and how it functioned, creating the Black Box Model and the Function Decomposition. After creating the subsystems from these models, the team created a morphological matrix (Appendix E). This matrix consisted of 10 subsystems that would make up the entire system. Each team member would create one design for each subsystem to get a range of unique and viable designs per subsystem. Each team member would then choose one design from each subsystem to create a full system. This led to the team having three full system designs to choose from for the final design (Figure 10). After weighing the pros and cons of each design, the team chose a hybrid design of two final designs (Figure 10).

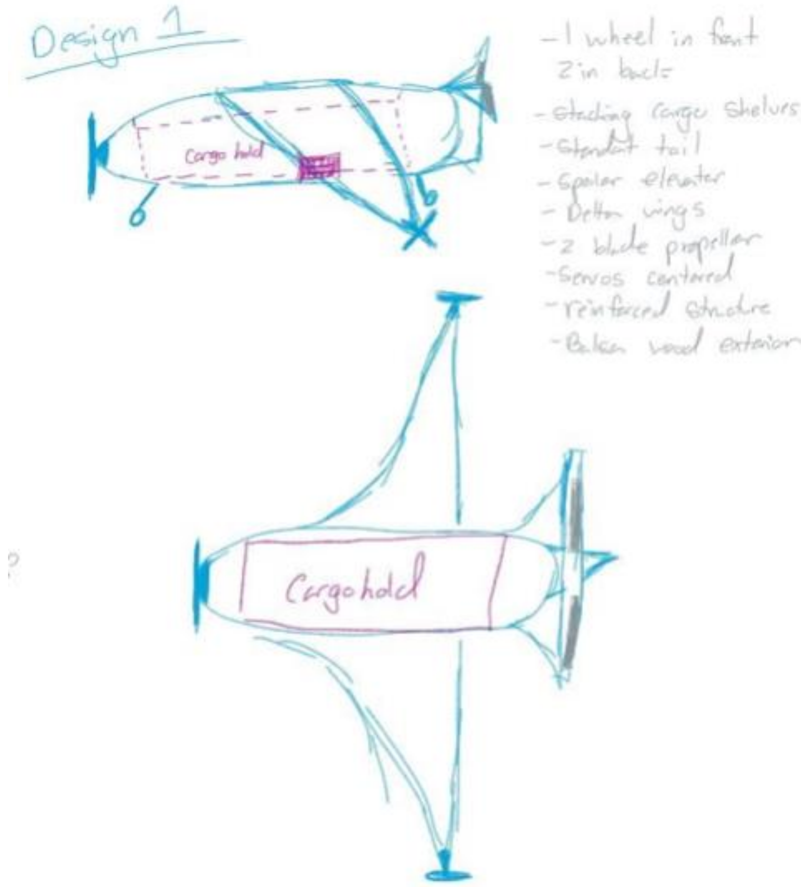

Figure 7: Initial design 1

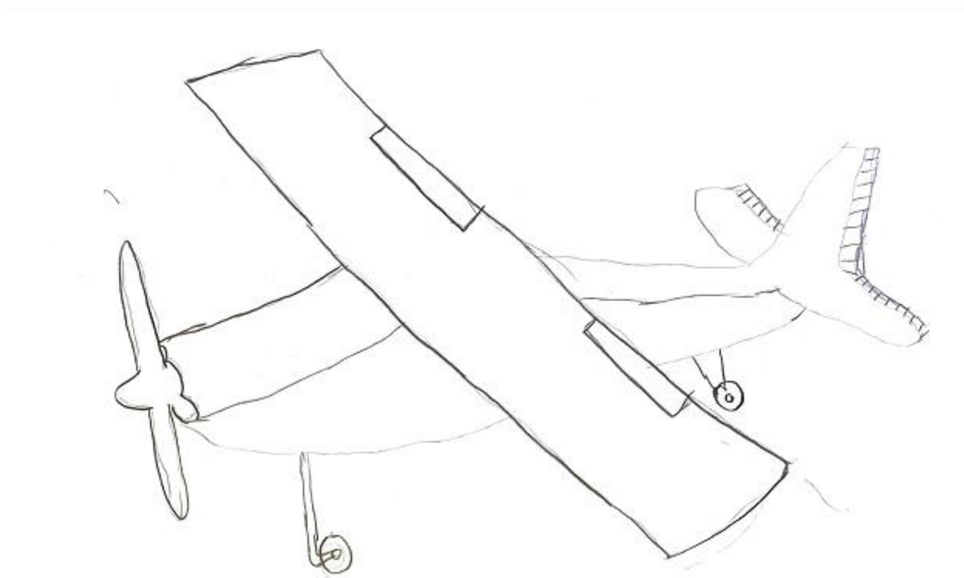

Figure 8: Initial design 2

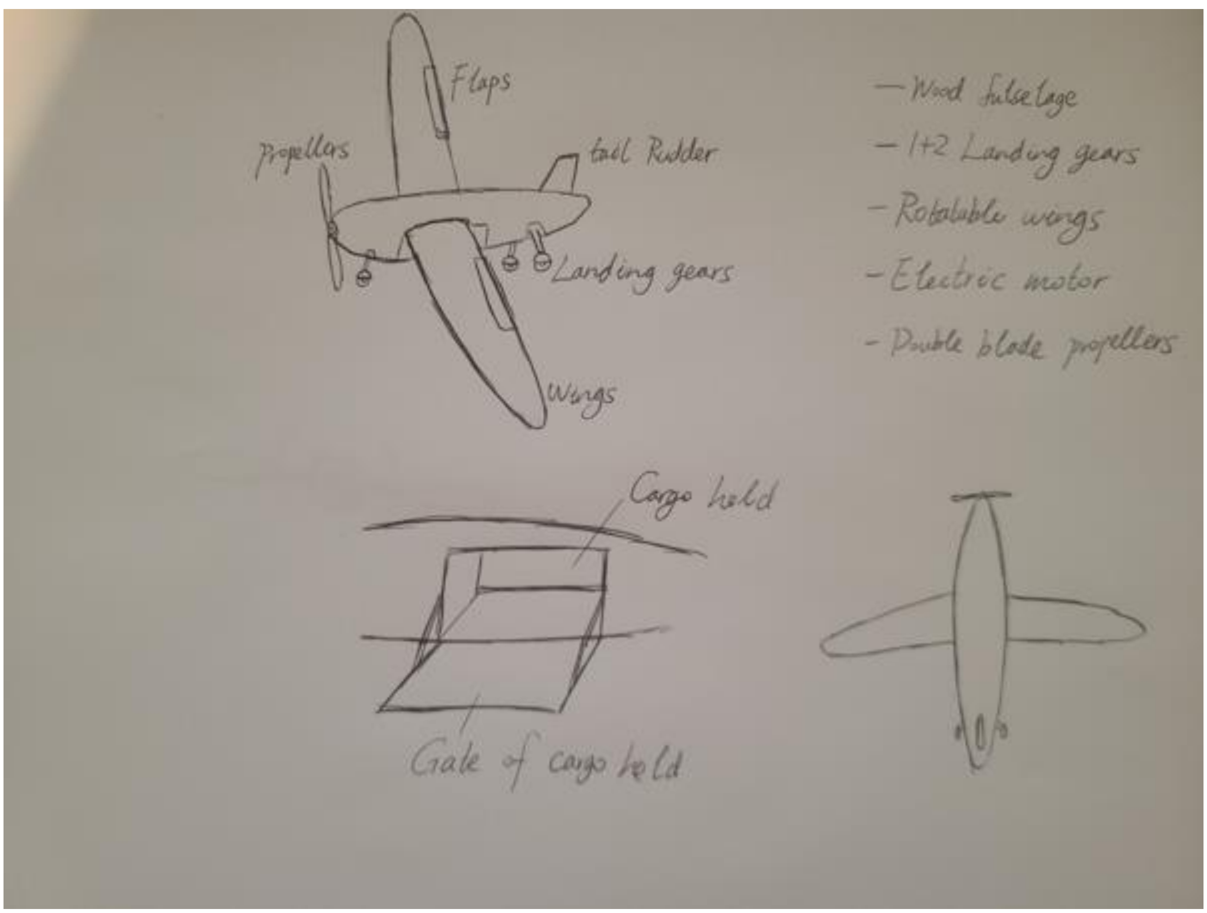

Figure 9: Initial design 3

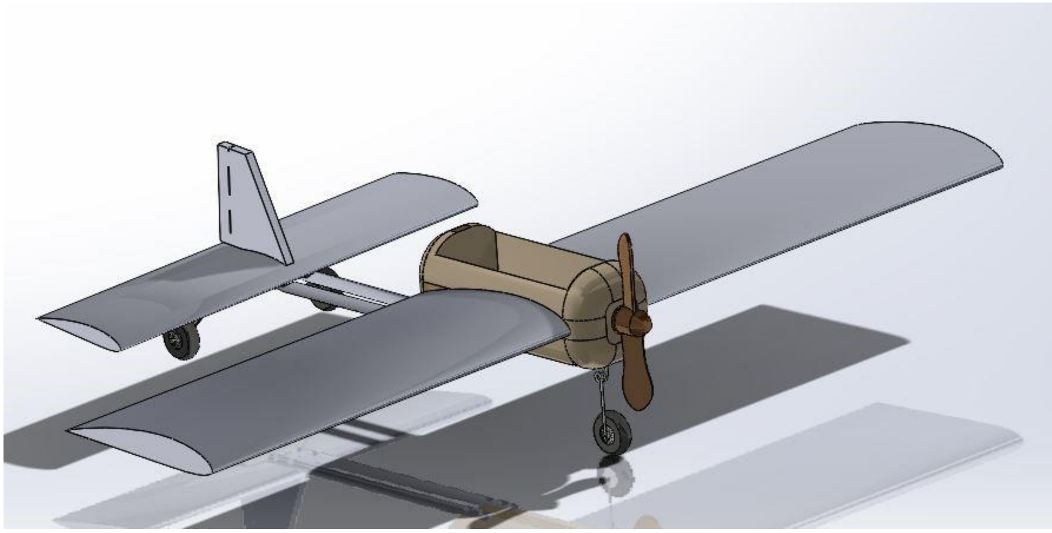
Figure 10: Final design

As stated before, the final design is a combination of designs 2 and 3. For the team this is where the iteration process began, which eventually leads to the current design.

5 DESIGN SELECTED – First Semester

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

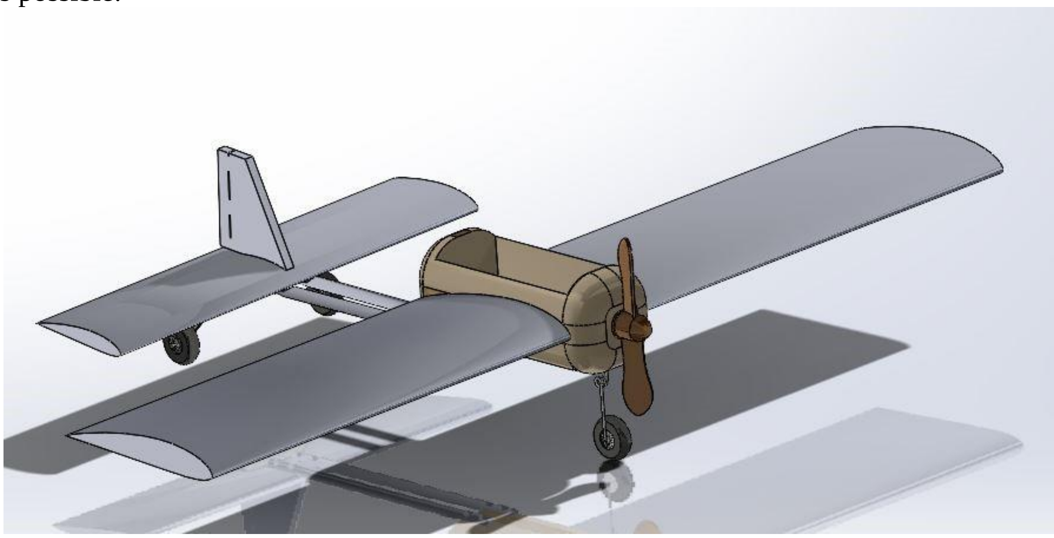

Figure 11: First semester design

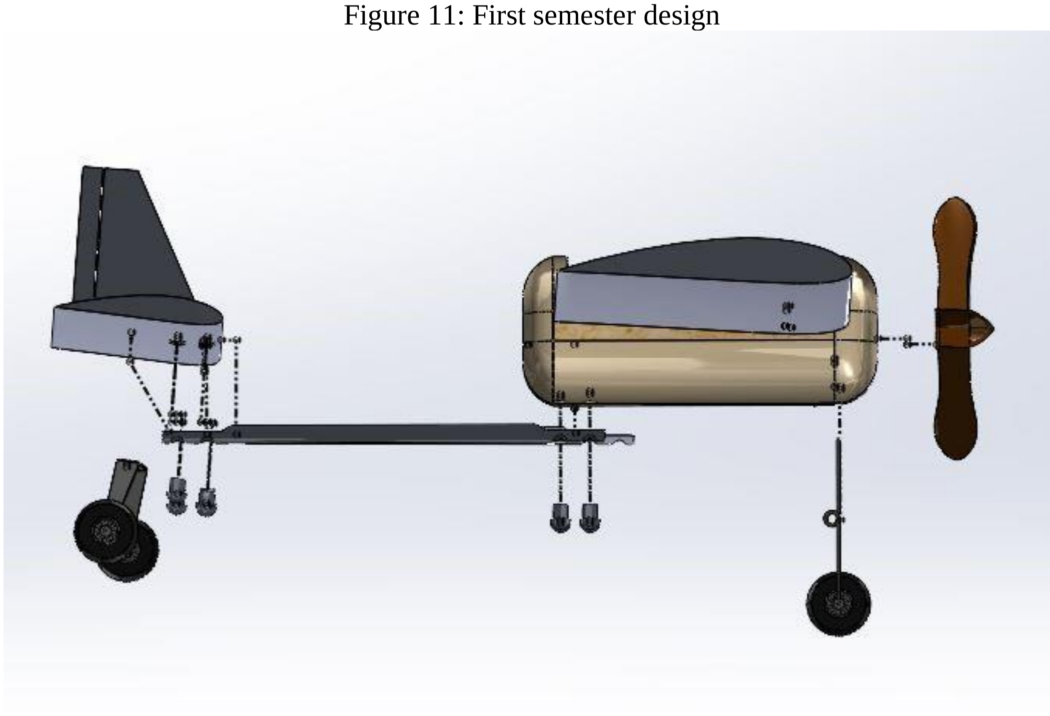

Figure 12: Previous design exploded view

This previous design shown in Figure 12 was found to have many structural flaws, design flaws, and extra components that the team did not need. To point out each flaw, each component will be discussed in a listed format.

Landing Gear:

The previous design had a tricycle style landing gear which is common on aircrafts. However, our plane has most of the weight on the front of the plane which would compromise the structure of this design. Not only would the one wheel and steel rod support the weight of the plane when landing, it would have to steer the plane as well which would make the design more complex, requiring more components, thereby increasing the weight. This is the opposite outcome of what the team was striving for, a lightweight plane. To solve this, the team used a reverse tricycle landing gear design where two wheels are placed at the front of the plane and one wheel is in the rear. We can see the newly implemented landing gears effectiveness from Appendix A and testing results.

The retractable landing gear was unnecessary, and the team chose to build static landing gear. Previously, we thought that the landing gear would produce heavy amounts of drag and prevent the highest performance out of our plane. We were willing to combine extra weight, components, and electronics into the design when it was found to be not necessary.

Wing Location:

The wing as shown in figure 11 is midway on the fuselage. This has structural complexities, and it interferes with the cargo bay. To improve this, the wing is now placed at the top of the fuselage which solves the interference with the cargo bay because structural supports will not be run through it. This will make the structural design simple as well as making the plane more stable in flight because all the weight is located below the wings.

Fuselage:

The fuselage in the previous design is very large and unnecessary. To improve this, we have slimmed it down to save weight and reduce drag. The cargo is made of heavy metal which can fit within the reduced fuselage volume as well as the electronic components.

The section of the fuselage that connects the tail to the main body was previously connected to the bottom of both sections connected with screws. There were also two members made of aluminum. This was structurally not sound and was improved by designing this connection as one larger piece made of foam which makes it lighter and has more surface area to connect the tail and main fuselage body with adhesive.

Prototype:

Figure 13: Prototype first semester

Above is a picture of the team’s prototype built during the fall semester. The goal behind it was to visually assess if the design could glide while falling from the height of a four five story building. The build quality was not up to the current standards of the finished design due to budget constraints. The design was very basic and was to only serve as a baseline as to how it would fall through the air with no additional thrust. The teams’ results concluded that the current design was acceptable because the plane glided successfully from the building to the ground, correcting itself as it flew.

6 Project Management – Second Semester

6.1 Gantt Chart (Appendix F)

For this semester the team was relatively on track. The first few weeks the team was solidifying their design regarding the materials that they would need. They then began the long process of waiting for materials. This was the only time that the team was behind schedule. After the parts arrived, the team began their iterative building process. This took longer than the team was expecting, where it was planned to take two weeks turned into three-four weeks. This was due to the iteration process of the team and attempting to solidify certain parts of the design. However, they were still on track for the 33% build, 66% build and the 100% build.

Planning wise the team feels that they could have done better by having a more comprehensive schedule set for themselves. Having actual dates as deadlines instead of ‘some time this week’, kind of scheduling. This would have greatly reduced the stress of the team. They also would change the bulk workdays. Due to school and work the team would pick a designated day to spend 5-6 hours in the machine shop working. It would have reduced the stress of the team to come in several days a week for a few hours, however, due to the nature of the project and the surrounding environment, it is inevitable.

6.2 Purchasing Plan

Table 3: Testing Purchasing Plan

Part Number	Part Name	Subsystem	Detail	Quantity	Price ($)	Part Status	Vendor
1	Anemometer Wind Speed Sensor	Testing	Wind Speed Sensor	1	44.95	Needs purchasing	Adafruit
2	Arduino uno	Testing	for wind speed sensor	1	19.64	Needs purchasing	Amazon
3	male to male breadboard jumper cables	Testing	for wind speed sensor	1	14.4	Needs purchasing	Amazon
4	9V battery clip to Arduino adapter	Testing	for wind speed sensor	1	6.54	Needs purchasing	Amazon
5	Strain Guage Load Cell 10kg	Testing	For generated lift	1	18.5	Needs purchasing	Adafruit
6	HX711 weighing sensor	Testing	For generated lift	1	7.09	Needs purchasing	Amazon
7	Servo Extension Wires	Electronics	For electronics	1	18.55	Needs purchasing	Amazon
8	Topflight Monokote	Control Surfaces	For control surfaces	1	24.46	Needs purchasing	Amazon

Table 4: Manufacturing Purchasing Plan

Part Number	Part Name	Subsystem	Detail	Quantity	Price ($)	Part Status
1	Avian 4250-800kv Motor	Electronics	Main motor	1	89.99	Purchased ready for assembly
2	Aileron A4040 Servos	Electronics	Main Servos	4	54.99	Purchased ready for assembly
3	Lithium Polymer Battery	Electronics	Main Battery	1	49.99	Purchased ready for assembly
4	RC Transmitter and receiver	Electronics	Controller	1	279.99	Purchased ready for assembly
5	3mm Depron Foam	Structure/Fuselage	Outer Structure (15.4"x24.4")	1	39.95	Purchased ready for assembly
6	ESC	Electronics	Electronic Speed Controller	1	69.99	Purchased ready for assembly
7	Propeller	Propeller	Propeller	2	20.79	Purchased ready for assembly
8	Balsa Wood	Structure	1/16"x11.5"x11.5"	3	23.97	Purchased ready for assembly
9	Gorilla Hot Glue Gun	Adhesive	Adhesive for raw materials	1	16.99	Purchased ready for assembly
10	Gorilla Hot Glue Sticks	Adhesive	Adhesive for hot glue gun	1	8.99	Purchased ready for assembly
11	Packing Tape	Adhesive	Adhesive for raw materials	1	11.28	Purchased ready for assembly
12	Sandpaper 120 Grit 6 pack	N/A	Forming raw material	1	6.97	Purchased ready for assembly
13	Square Carbon Tube	Structure	10mmx10mmx1000mm	1	31.77	Purchased ready for assembly
14	Aluminum	Landing Gear	1"x36"x1/8"	1	N/A	Acquired through SEA Aero
15	Landing Gear	Landing Gear	Landing Gear	1	N/A	Acquired through SEA Aero

16	Plywood	Structure	1/4"x4ftx8ft	1	60.98	Purchased ready for assembly
17	Eva Foam	Landing Gear	10mmx24"x60"	1	36.23	Purchased ready for assembly
18	Loctite	Structure	Thread locker blue	1	7.38	Purchased ready for assembly
19	6mm Depron Foam	Fuselage/Structure	800mmx600mm	1	59.34	Purchased ready for assembly
20	Bullet Adapter	Electronics	4mm female to 3.5mm male	1	11.58	Purchased ready for assembly
21	Safety nut	Propeller	Propeller safety nut	1	6.99	Needs purchasing
					$1,118.30	Total
					$381.65	Remaining

The bill of materials used in the first semester is moderately different than the current bill of materials that was implemented. The largest differences are within the manufacturing BOM where adhesive and bonding components and some building materials were changed. To improve upon this, the team should be more comprehensive in their final design to establish what needs to be used.

6.3 Manufacturing Plan

The manufacturing plan implemented can be found in table 4. As stated above in section 6.2, the first bill of materials that the team made was comprehensive but not accurate. There were certain criteria the team was going to design off that required materials not used this semester. The reason behind materials changing too much is because the team chose an iterative design process. This means that as the aircraft was built, design changes happen every step of the way. When it came to manufacturing the physical plane, many changes occurred to the design because the team found that the implementation of our previous design was subpar and needed to be improved. This led to the bill of materials changing in the way it did. Total costs were not too far off because all materials were cheap and had comparable replacements. To improve upon this the team should have had a more comprehensive and robust design to help us stay more on track with the manufacturing plan.

6.4 Competition requirements

The classic capstone sequence for this project was to compete in the SAE Aero Micro competition held in the spring. Due to the team graduating in the fall, they cannot compete in the competition. Therefore, certain criteria from the engineering requirements can be disregarded because they are directly correlated to prerequisites for the competition. This allowed the team to be more flexible on design and small-detail requirements. This would include but not limited to the integration of a red arming plug located externally on the fuselage, ground turning radius, power limiter, etc. The main goal of the project was to create an aircraft that can successfully fly while following most of the competition rules.

7 Final Hardware

7.1 Final Hardware Images and Descriptions

Figure 14 showcases the final design for this semester.

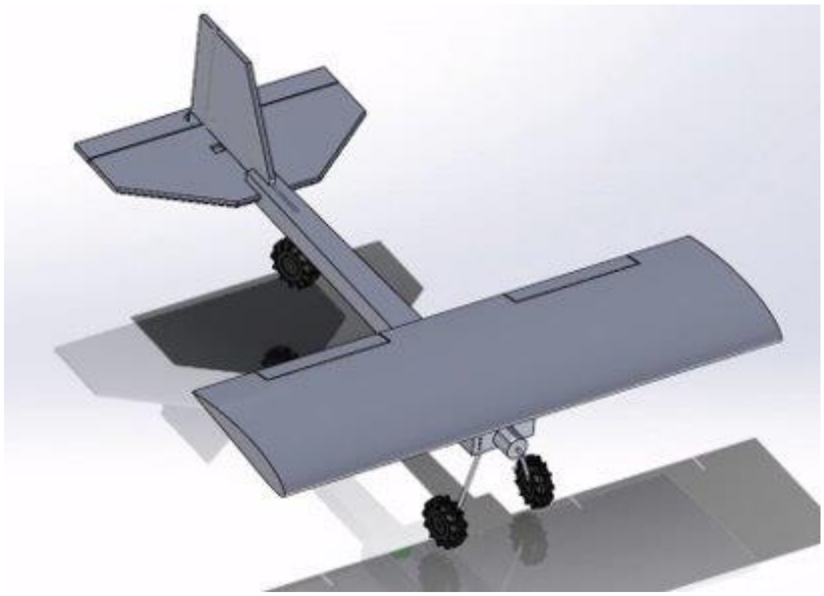

Figure 14: Current design

As stated in Section 6, the entire plane is made of balsa wood, Depron foam, hot glue, and tape. The design itself is lightweight at only 4 lbs. without any added weight. The wingspan is 48 inches with a length of 14 inches. The high set wings and tall front landing gear lead to a high angle of attack, this means that the wings can get more air underneath them ensuring that the plane can take off with very little thrust. The tires that were used here donated by previous NAU SAE competition teams. They are made of a hollow rubber tube and were able to work for both the front and rear landing gear. The Ailerons were taped on and controlled by micro, metal gear servos, and were attached to the ailerons via a thin metal rod and hot glue. The entirety of the plane was covered in packaging tape in order to add structural integrity and create a smooth surface.

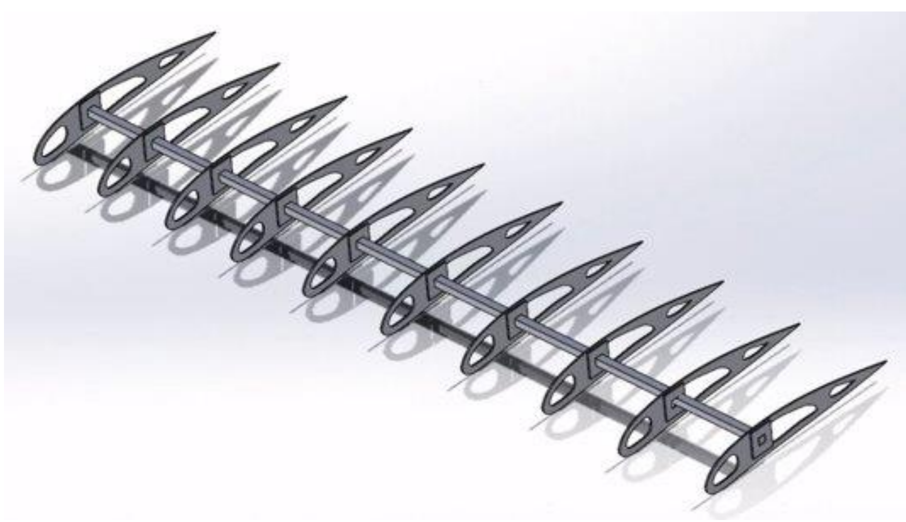

Figure 15: Interior wing view

Figure 15 showcases the interior view of the wings. The wing ribs are made of balsa wood and held together with a carbon fiber rod and hot glue. Previously the wings were overdesigned and heavy due to 20 ribs total instead of 10. The team cut down the number of wings due to their iteration process. These wings were then covered in Depron foam to keep the shape of the airfoil.

Figure 16: Front landing Gear

The front landing gear has a zigzag shape (Figure 16) to diffuse the forces acting on it over the fuselage instead of having them focused on one location. Later the landing gear had extra supports welded onto it to ensure the stability of the system by itself.

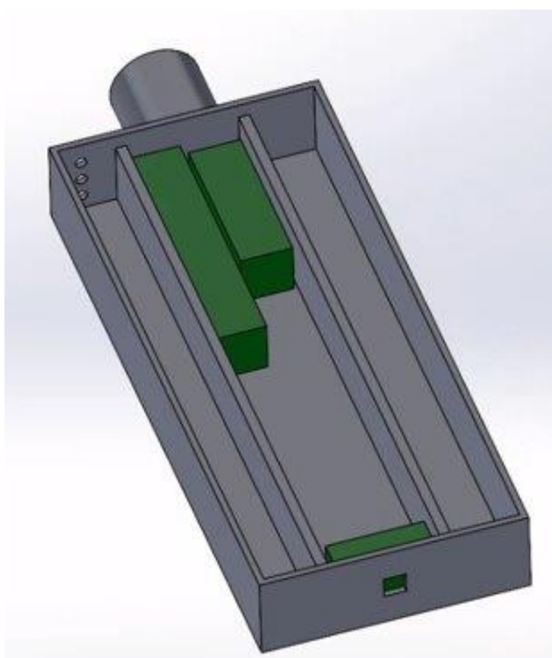

Figure 17: Fuselage with electronic stand-ins

The green boxes in Figure 17 showcase where the electronics are in the fuselage (Figure 17). The center cavity where the electronics sit has a foam cover that separates it from the rest of the cargo hold. This ensures that the team can load and unload the plane quickly without damaging the electronics inside. This also creates an easy access point for maintenance on the plane if needed. The full fuselage is covered in a thin balsa wood cover for extra protection.

7.2 Design Changes in Second Semester

This section outlines the changes that they made to the plane in the second semester, leading up to the current design.

7.2.1 Design Iteration 1: Wing Ribs

With the first design iteration there were 20 interior wing ribs, 10 inside each wing. After beginning construction, the team determined that 20 ribs were over designed and added unneeded weight. Therefor the team cut the number of ribs in half, using 10 ribs for the entire wing, 5 on each side. A secondary change that was made was regarding the thickness of the ribs. Figure 18 showcases the original design of the ribs. All the ribs were cut using the NAU IDEA Lab, however when these were cut, they were too thin, therefore the laser cut through main structural points. The team placed the ribs into SOLIDWORKS and tested different thicknesses to ensure that the ribs would hold up to the forces acting on them.

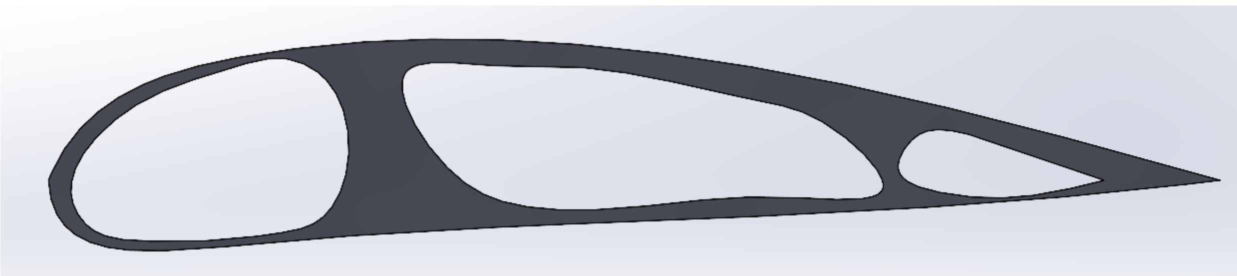

Figure 18: Original wing design

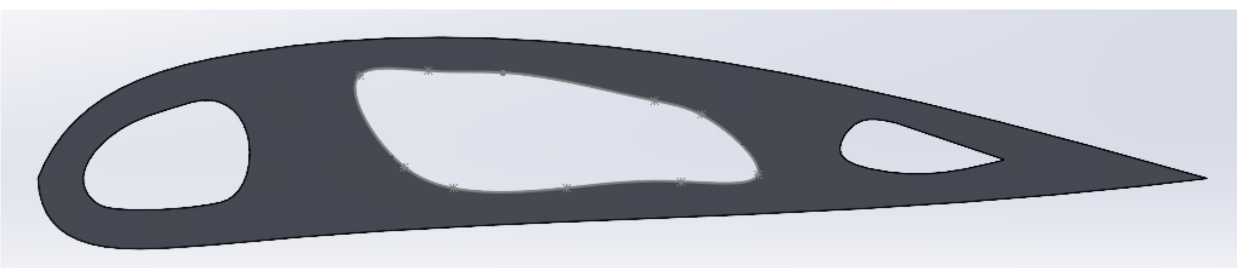

Figure 19: New wing design

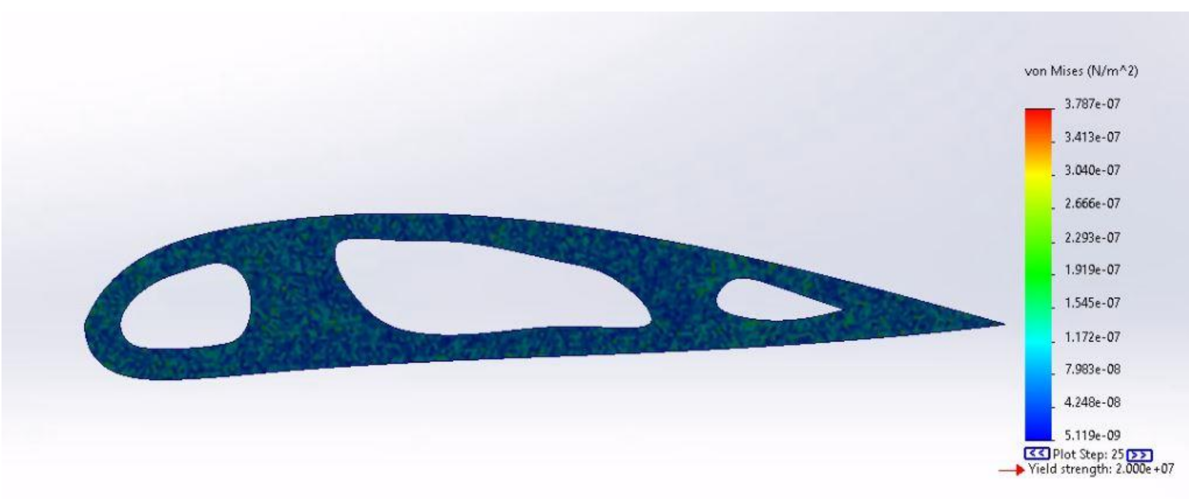

Figure 20: Stresses on new rib

7.2.2 Design Iteration 2: Fuselage

The original fuselage had an open top, with the wings attached to the sides, making it a mid-wing plane. It was also 10 inches wide and 14 inches long. After considering the thrust to weight ratio, the team shrinks the fuselage and focuses on the wings as the main component. The current design now features a smaller fuselage with the wings on the top and the opening to the cargo hold on the bottom. This not only creates a higher pitch for the wings, cuts weight, but also makes the plane more aerodynamic.

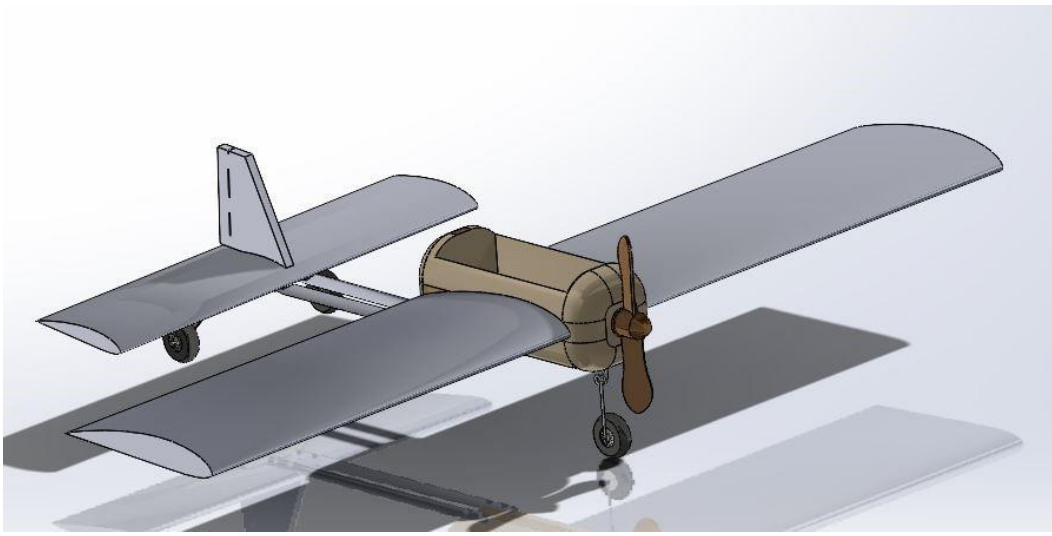

Figure 21: Original fuselage

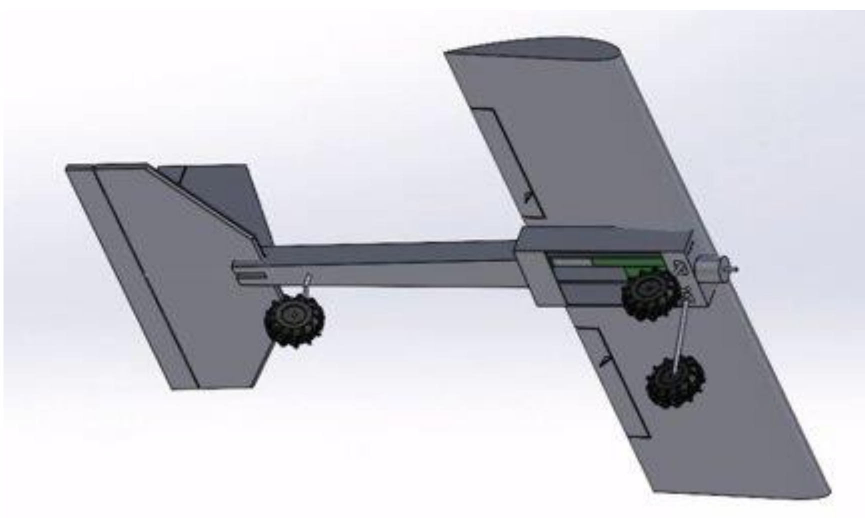

Figure 22: New fuselage design

7.2.3 Design Iteration 3: Extended Fuselage

The extended fuselage attaches to the tail and rudder. In the original design the extended fuselage was two aluminum tubes (figure 18). However, the team was struggling with finding a way to safely attach the tubes to the square fuselage. There was also the question of how stable it will be. Therefore, the team decided to change it to one solid square aluminum tube. However, the problem of attaching the two persisted, and after prototyping the connection, it was determined that the aluminum tube was too heavy and would break the connection created. Therefore, the team settled on a foam extended fuselage with a series of foam and balsa wood ribs to add stability. Again, after prototyping it was determined that the extended fuselage was light, while also being strong enough to create solid connections for the tail and the attachment to the fuselage.

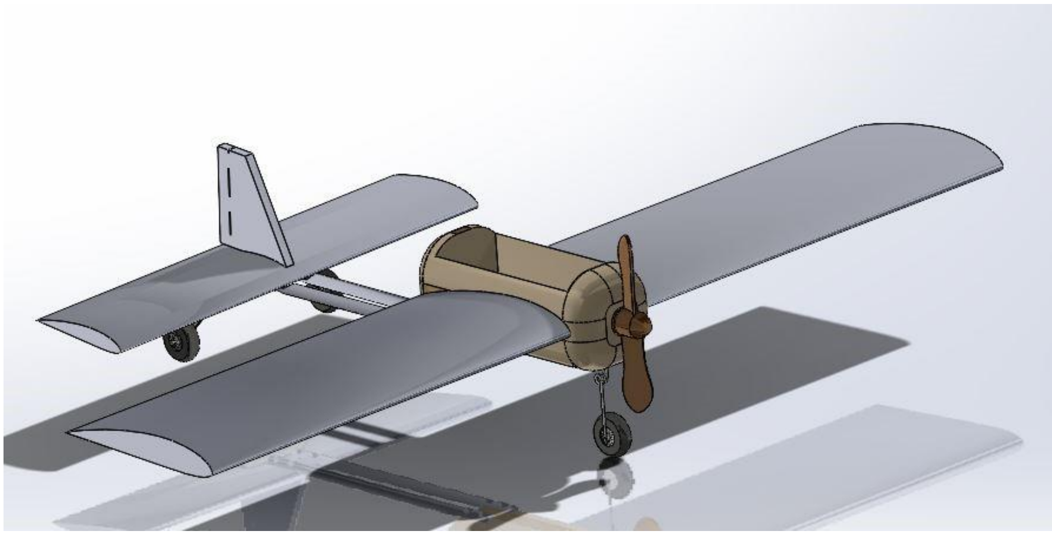

Figure 23: Original extended fuselage

Figure 24: Current extended fuselage

7.2.4 Design Iteration 4: Landing Gear

The landing gear design chosen for every iteration was a tricycle style. The first design had a normal tricycle design, with two wheels in the back and one in the front. However, it became apparent that the one wheel in the front would not be able to hold the forces of the wings and fuselage when it lands. There was also the trouble with balancing the wings. Therefor the team decided to go with an inverse tricycle design. With the two wheels in the front and one in the back. This not only reduced the weight in the tail, but also provided more stability for the wings and could handle the forces of the plane when landing.

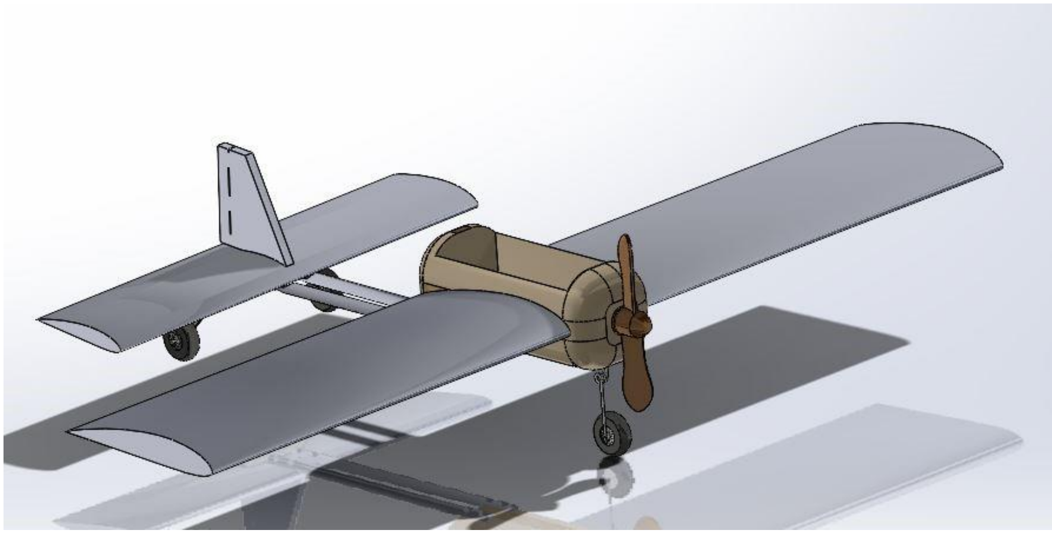

Figure 25: Original Landing gear

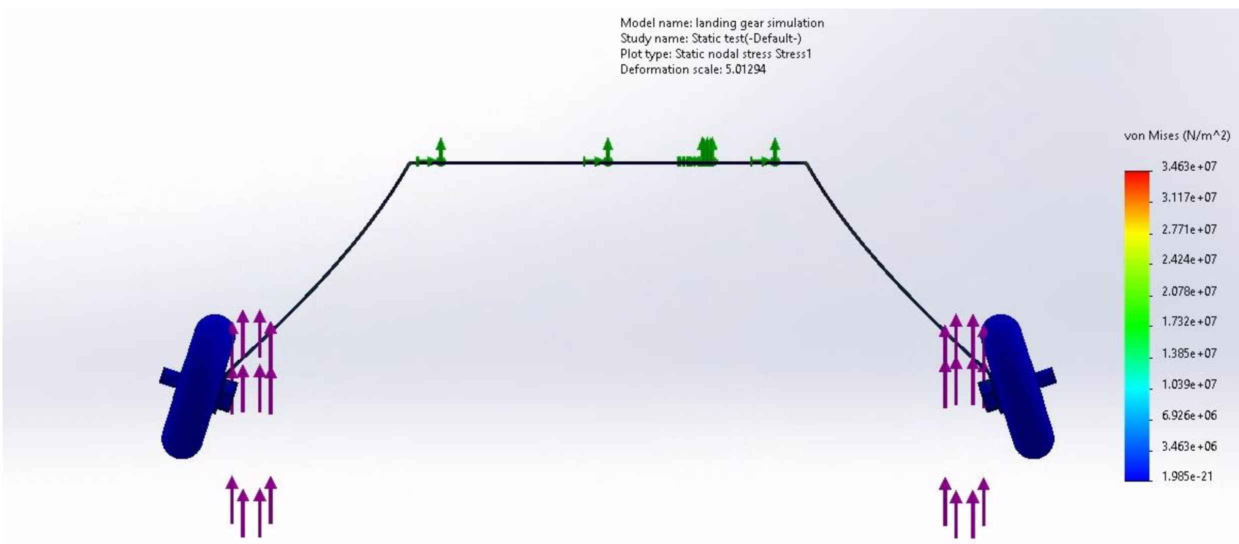

Figure 26: Landing gear forces

7.3 Challenges Bested

There were three main challenges that the team ran into when getting to 100% build. The first being the center of gravity. During the manufacturing process, the team tried to have the center of gravity at 1/3rd the wings' cord length, a normal location for remote control airplanes. While the team was aware of this length, after manufacturing was finished the center of gravity was about $2/3^{rd}$s the length of the wing, which means that the plane is very tail heavy. After consulting with the Flagstaff Flyers, the team added 2.5 lbs. to move the center of gravity further up to the 1/3rd length, enabling more stability for the plane when flying.

The second challenge that the team faced was the thrust to weight ratio. For the competition, the plane could not exceed 55lbs, also the motor that the team bought could hold weights of 6-8 lbs. Therefor the goal was to have a plane under 6 lbs. For this purpose, many small parts were changed to reduce weight. For example, the number of ribs within the wings were reduced, the extended fuselage was made of foam and wood instead of aluminum and the landing gear was made of thin steel rods, instead of aluminum slabs. This led to the final weight of the plane being 6.5 lbs., which is exactly what the team was expecting.

The third challenge was the landing gear. After the landing gear was changed to an inverse tricycle design, with the two wheels in the front and one in the back, there was the problem of how to attach them to the fuselage and the extended fuselage, along with how to ensure that the forces of the plane landing would not destroy the landing gear. For this the team decided on the zigzag pattern of the steel tubes that were touching the fuselage. This ensured that the forces would be distributed throughout the fuselage. This pattern was also adopted for the rear landing gear, ensuring that the forces would be distributed. During the manufacturing process the landing gear was still too unstable so three different supports were added to create a solid stable subsystem. After the forces were distributed, the team attached the landing gear with zip ties and hot glue. This ensured that the landing gear would sit flush with the fuselage and hold itself together during landing.

8 Testing

This section of the report will cover each test conducted by the team. Firstly, it will reiterate the engineering requirements and customer requirements and how they are weighed. Then, it provides what requirements relate to each test. It will discuss each test regarding the questions answered, testing equipment, procedures, and outcomes. Next, it will go over the specification sheets which discuss' our customer requirements and engineering requirements and whether they have been met. It will show a corresponding column as to if the client thinks it is acceptable or not regarding the completion of each requirement.

8.1 Testing Plan

Design Requirements

The customer needs and design requirements are directly connected to the teams QFD (Appendix A). The design requirements were created directly from the customer needs, that come from the competition rules and regulations.

Table 5: Engineering Requirements

Ranking	Engineering Requirements (ER)	Units
ER1	Light weight	Pounds
ER2	Increase Reliability	Percentage
ER3	Increase Durability	Percentage
ER4	Power limiter	Watts
ER5	Cargo Bay volume	Inches Cubed
ER6	Low Cost	US Dollars
ER7	Increase impact tolerance	Crashes before repair
ER8	48-inch Wingspan	Inch
ER9	Lift Forces	Pounds
ER10	Drag Forces	Pounds
ER11	Thrust	Pounds
ER12	Ground turning radius	Inches
ER13	Payload unloading time	Seconds
ER14	Low control surface slop	Degrees
ER15	Must have 4 cells or less battery for the electronics	Number of cells
ER16	Adequate servo sizing for aerodynamic forces	Ounces/inch
ER17	Must use 2.4 GHz radio control system	GHz
ER18	Must land within 200ft	Feet
ER19	Takeoff within 8 feet	Feet
ER20	Cannot exceed 55 pounds	Pounds
ER21	Optimize safety factor	Factor of Safety
ER22	Meets SAE Rules and Regulations	Percentage

Table 6: Customer Requirements

Ranking	Customer Requirements
CR1	Meets the requirement of the rules
CR2	Safe design
CR3	Able to take off and land
CR4	Innovative Design

CR5	Manufacturable
CR6	Low cost
CR7	Modular compatibility
CR8	Static load capability
CR9	60 second lift-off time limit
CR10	200 feet landing distance
CR11	Payload extraction in one minute or less
CR12	Use of Lithium Polymer Batteries
CR13	Use of Power limiter (450-Watts)
CR14	Must have one cargo bay
CR15	Ability to make a turn in air
CR16	Ability to make a turn on the ground
CR17	Steering mechanism for landing gear
CR18	Must use an Electric motor
CR19	Fixed Wing
CR20	Functional failsafe for radio control systems
CR21	Must be equipped with a red arming plug
CR22	Must use model airplane safety nut
CR23	Appropriate center of gravity
CR24	Must have a radio control system

Top Level Testing

Experiment/Tests	Relevant DR's
Generated Thrust Test	ER11, ER19, CR3, CR10
Generated Lift Test	ER9, ER19, CR3, CR10
Takeoff/Flight Test	ER9, ER10, ER14, ER19, CR3, CR8, CR9, CR15, CR23
Payload Test	ER5, ER13, ER21, CR11, CR14, CR23
Landing Test	ER3, ER7, ER12, ER18, CR3, CR8, CR10, CR15, CR16, CR17

Detailed Testing

Generated Thrust Test:

Equipment:

- Thrust force testing bench
- 3 cell battery
- Electric motor
- Propeller
- Radio controller

Design Requirements Tested:

- Thrust
- Takeoff within 8 feet
- Able to take off and land
- Land within 200ft

Recorded Variables:

We will be recording the generated thrust made by the electric motor in grams. The team will need to calculate the thrust to weight ratio after this is found. To do this, we divide the thrust generated by the motor to the final weight of our plane. The theoretical thrust can be calculated using the equation below.

$$Thrust = 4.392399 * 10^{-8} * RPM * \frac{Diameter^{3.5}}{\sqrt{Pitch}} * \left((4.23333 * 10^{-4} * RPM * Pitch) - Velocity\right)$$

The result of this equation is about 3.5lb of static thrust force depending on the variables used.

Process:

The electric motor will be secured to the thrust force testing bench with the propeller installed. The team will secure it in place by screwing the testing bench into a piece of wood on a table. Then we will run the motor at various amounts of throttle and record the generated thrust provided by the digital output in grams.

Answered Questions:

The provided test will answer how much thrust our motor and propeller combination will provide and will tell the team if the plane will be able to take off from finding the thrust to weight ratio.

Generated Lift Test:

Equipment:

- Arduino Uno
- Anemometer
- Load Cell
- Finished Plane
- Load Amplifier
- 2X4 Wood Planks
- Bolts for load cell
- Hardware for Arduino, Load Cell, and Anemometer
- Tiedown Straps
- Vehicle

Design Requirements Tested:

- Lift forces
- Takeoff within 8ft
- Able to take off and land
- Land within 200ft

Recorded Variables:

We will be recording the generated lift of our plane in grams. These results will allow the team to find the lift to weight ratios for different winds speeds. It will tell us at what speed the plane will be able to take off and when it will glide through the air as well as other metrics regarding flying performance. From the team’s previous analysis of lift on the plane, we found that the best ratio from coefficient of drag to lift was at a 2-degree angle of attack. This resulted in a ratio of 16.608. The coefficient of lift itself increases as the attack angle increases, but the drag increases too. The team will choose an angle of attack of 12 degrees for takeoff because the drag at low speeds will not impact takeoff as much as gliding speed.

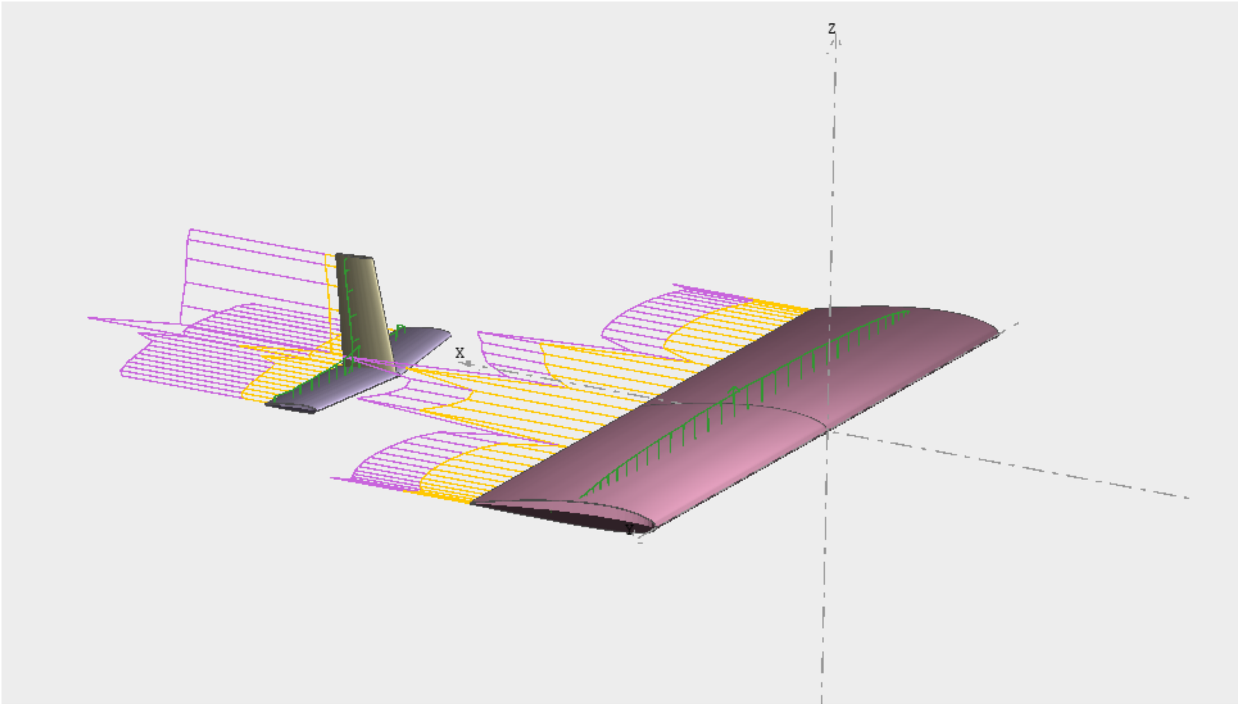

Figure 27: Simulation Results at 3 degrees

V =	27.24 m/s
Alpha =	2.000°
Beta =	0.000°
CL =	0.281
CD =	0.017
Efficiency =	0.931
CL/CD =	16.608
Cm =	3.465
Cl =	-0.001
Cn =	0.012
X_CP =	0.231 m
X_CG =	4.620 m

Figure 28: Simulation Results for 2-degree angle of attack

Process:

The plane will be secured on top of the car with a team member holding it in place. The load cell will be placed under the plane and secured with a wooden plank. The load cell will be attached to the plane via two tie-down straps around the wings and a plank of wood. The driver will proceed to accelerate, and the load cell records the generated lift forces. While this is happening, the anemometer will record the corresponding wind speed for each lift force. The data will be live streamed and recorded to an excel file where the team can analyze it.

Answered Questions:

The provided test will answer what our plane will generate for lift at corresponding wind speeds. It will tell us at what speeds the plane will need to achieve to take off.

Takeoff/Flight Test:

Equipment:

- Finished Plane
- Controller

Design Requirements Tested:

- Lift Forces
- Drag Forces
- Low control surface slop
- Takeoff within 8 feet
- Able to take off and land
- Static load capability
- 60 second lift-off time limit
- Ability to make a turn in air
- Appropriate center of gravity

Recorded Variables:
This is a visual test where the team will try to fly the plane so no hard variables will be recorded. The team will, however, visually assess the plane's takeoff and the flight characteristics it has while in the air. The flight test will also be recorded.

Process:
The team will find a safe flat field to takeoff and try to fly the plane. We will pay special attention to specific variables such as the required throttle to take off, distance until takeoff, use of elevator to takeoff, etc.

Answered Questions:
The test will provide the team with a baseline on what to improve on. If the plane tends to fly in a way that is undesirable, the team needs to reiterate the design. If we need to take off within a shorter distance, we may consider using a larger battery or motor. Questions such as this will be generated throughout this test because we will not know the problem until we are presented with it.

Payload Test:

Equipment:

- Finished Plane
- Payload

Design Requirements Tested:

- Cargo Bay volume
- Payload unloading time
- Optimize safety factor
- Payload extraction in one minute or less
- Must have one cargo bay
- Appropriate center of gravity

Recorded Variables:

This is an interactive test where the team will land the plane from takeoff and time us on how fast we can load and unload the payload in our plane. We need to be under 60 seconds which will be our goal.

Process:
The team will find a safe flat field where we will be able to fly the plane and land it successfully. Once the plane has landed the timer will start and the team will attempt to secure the payload and takeoff again within 60 seconds.

Answered Questions:
This test will allow the team to assess whether we can load and unload the payload within the allotted time. It provides us with experience that will help us reiterate our design to potentially decrease our unload time with our payload and fasten it more securely within the fuselage.

Landing Test:

Equipment:

- Finished Plane
- RC Controller

Design Requirements Tested:

- Increase Durability
- Increase impact tolerance
- Ground turning radius
- Must land within 200ft
- Able to take off and land
- Static load capability
- 200 feet landing distance
- Ability to make a turn in air
- Ability to make a turn on the ground
- Steering mechanism for landing gear

Recorded Variables:
This is a visual test that will allow the team to assess the performance of our plane when attempting to land it. The team will record how safely it lands, can the landing gear withstand the impact, will the landing gear bend, etc. From the team's previous analysis of the landing gear, solid works was utilized to perform a simulation of the impact of a rough landing. The following results were found using an impact force of 3.9 newtons and we can see the deflection is present but not catastrophic.

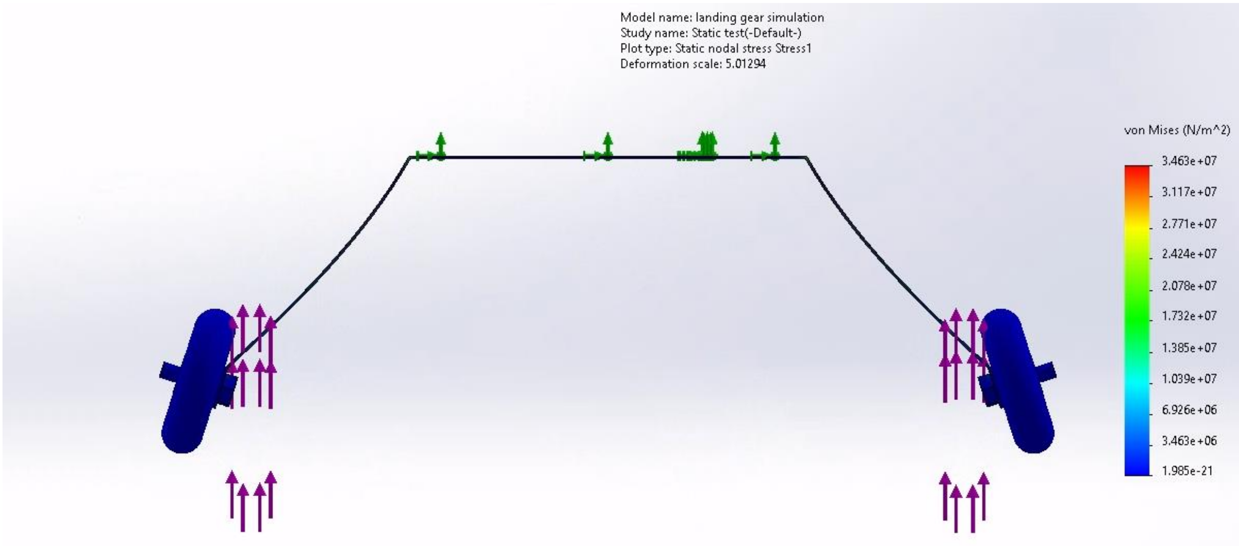

Figure 29: Landing gear simulation

Process:
The team will find a safe flat field where we can fly the plane. Once the plane takes off and completes a successful flight path the team will attempt to land. The process will be repeated several times to acquire accurate data and assumptions. Each flight will be recorded for evidence and studied by the team to determine what can be improved on.

Answered Questions:
From this test the team will answer questions such as can our plane land successfully. It will provide us with results that answer whether the landing gear is adequate for the landing forces. It will answer if our rear landing gear turns on the ground with the static force of the plane while withstanding the force of landing. Other questions may arise during testing and further iterations will be conducted.

QFD

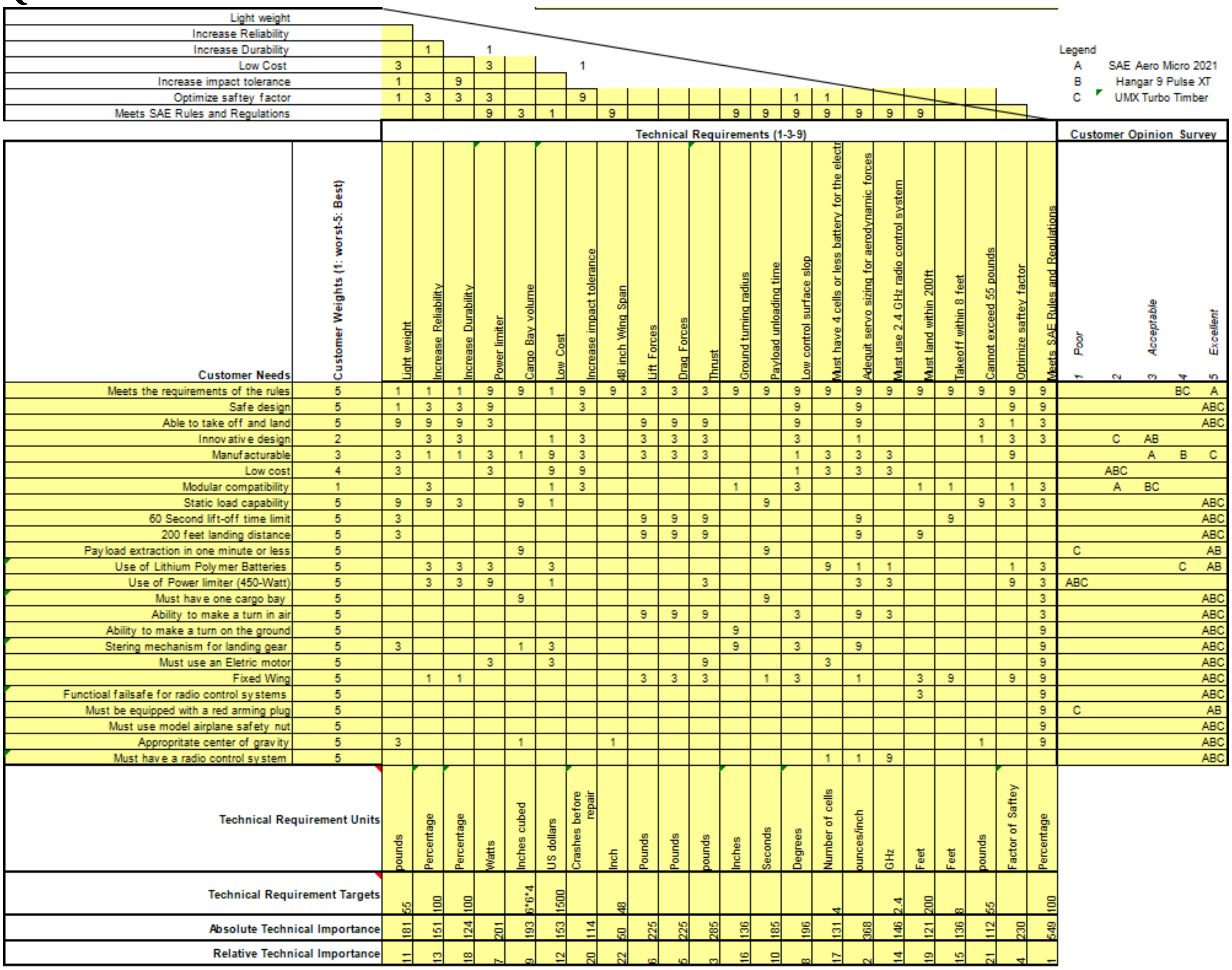

Figure 30: Quality Function Deployment

8.2 Testing Results

Specification sheet Preparation

Regarding the ERs and CRs required, we have made the QFD charts. The main purpose of making this chart is to connect ERs and CRs in a more intuitive way and find out the relationship between them. Based on this QFD, we can make a list of all CRs and ERs to check whether we meet these requirements in the test.

Table 7: The result tables for testing

Customer Requirement	CR met? (√ or ×)	Client Acceptable (√ or ×)
CR1 Meets the requirements of the rules	×	√
CR2 Safe design	√	√

CR3 Able to take off and land	√	√
CR4 Innovative design	√	√
CR5 Manufacturable	√	√
CR6 Low cost	√	√
CR7 Modular compatibility	√	√
CR8 Static load capability	√	√
CR9 60 Second lift-off time limit	√	√
CR10 200 feet landing distance	√	√
CR11 Payload extraction in one minute or less	√	√
CR12 Use of Lithium Polymer Batteries	√	√
CR13 Use of Power limiter (450-Watt)	×	√
CR14 Must have one cargo bay	√	√
CR15 Ability to make a turn in air	√	√
CR16 Ability to make a turn on the ground	×	√
CR17 Sterring mechanism for landing gear	×	√
CR18 Must use an Eletric motor	√	√
CR19 Fixed Wing	√	√
CR20 Functional failsafe for radio control systems	√	√
CR21 Must be equipped with a red arming plug	×	√
CR22 Must use model airplane safety nut	×	√
CR23 Appropriate center of gravity	√	√
CR24 Must have a radio control system	√	√

As shown above, this table lists all Customer Requirements. All our testing plans are carried out around this table. In the table, we divide all CRs into two parts. The blue part does not need to get results through specific tests, but through observation and evaluation. We will conduct a comprehensive evaluation of the project after it is completed to obtain the results of the blue part.

In addition, we also prepared the engineering requirements table. This table lists all our engineering requirements for comparison in the experiment.

Table 8. Engineering Requirements table

Engineering Requirement	Target	Tolerance	Met?	Client Acceptable?
Light weight	55(Pounds)	+∞	Y	Y
Increase Reliability	100 (Percent)	±0	Y	
Increase Durability	100 (Percent)	±0	Y	
Power limiter			N	Y
Cargo Bay volume	6*6*4(Cubed inches)	0	N	Y
Low Cost	1500(Dollars)	-500	Y	Y
Increase impact tolerance			Y	
48-inch Wingspan	48 (inches)	±1inch	Y	Y
Lift Forces			Y	Y

Drag Forces			Y	Y
Thrust			Y	Y
Ground turning radius			N	Y
Payload unloading time			Y	Y
Low control surface slop			Y	Y
Must have 4 cells or less battery for the electronics	4 (Number of cells)	±0	Y	Y
Adequate servo sizing for aerodynamic forces			Y	Y
Must use 2.4 GHz radio control system	2.4 (GHz)	0	Y	Y
Must land within 200ft	200 (ft)		Y	Y
Takeoff within 8 feet	8 (feet)	-1 feet	N	Y
Cannot exceed 55 pounds	55 (pounds)	+∞	Y	Y
Optimize safety factor				
Meets SAE Rules and Regulations	100 (percent)	±0	N	Y

All customer requirements and engineering requirements are acceptable to the client although some of them are not met as seen in the tables. Each requirement not met is catered toward competition standards and therefore does not bear a significant weight on the project. The reason behind this is the team is not competing in the SAE competition and therefore the main goal was to create an airplane that can fly successfully. The team has managed to do this, and the client is satisfied with the outcome.

9 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. Regarding the first semester, 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 section 9.1 are the top ten potential critical failures, with their effects and mitigation strategies. Section 9.2 will discuss in detail the potential failures identified in the second semester.

9.1 Potential Failures Identified First Semester

1. Potential Critical Failure 1: Aileron: Surface Fatigue

Ailerons are on the plane's wings. 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.

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 rising 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.

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. 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.

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

Much like 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.

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, 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.

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.

8. Potential Critical Failure 8: Elevator: Impact Deformation
With the amount of force 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.

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.

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.

9.2 Potential Failures Identified This Semester

Identification of future failures done in the second semester was heavily reliant on the iteration process when designing the plane. As the design was being built, the team looked at the component and assessed what could go wrong and how. This type of designing helped the team identify key issues. It is important to note that the team has found design flaws and were not changed due to complexities that would need to be added and were found to be not necessary for our application.

1. Potential Failure 1: Servo: Ailerons connection
The servos are mounted inside the wings and are secured in place by hot glue. The team found that the servos would detach from the adhesive if too much force was applied. This would completely destroy the functionality of the ailerons. The design was very hard to change, and the ailerons were completely functional in our test flight so the team concluded that the design will not be changed until a problem occurs.

2. Potential Failure 2: Rear Fuselage: Impact and static load
The original design of the rear fuselage connection was to be made from a square, hollow tube of aluminum. While manufacturing it to the plane, the team found it very difficult to find a secure way of mounting it while being able to take the static load of the plane. This was identified as a critical failure point and was reiterated.

3. Potential Failure 3: Front Landing Gear: Impact
The original design was two steel tubes of steel that would connect to the bottom of the fuselage and wheels. It was quickly identified that the design had lateral movement and not enough stability to hold the plane upright. If the team were to test this design while landing, we concluded that it would not be able to

withstand the force and collapse. The team resolved this by welding supports and bending the steel to not allow any lateral movement.

4. Potential Failure 4: Center of Gravity: Location

The center of gravity was located halfway along the chord of the wing which was further back than anticipated. This would cause the plane to have a very jittery flight and would be extremely hard to fly.

5. Potential Failure 5: Safety Factor and drag: Control surfaces and general surfaces

The team assumed that the hot glue holding all the foam together would start to split apart in flight and allow air to flow through undesirable places because there is not a perfect seal. Also, in the event of a crash, everything would explode. Although the depron foam the plane is built out of looks smooth, there are very small pits throughout the foam which would increase aerodynamic drag

6. Potential Failure 6: Servos and Brackets: Control surfaces

All servos and brackets connected to control surfaces are all secured by hot glue. As the plane was flown the team assumed that over time the forces would fatigue the hot glue and it would break free in flight rendering the servos useless. However, the team decided to test until failure with this design because the hot glue could be strong enough to hold the servos and brackets in place for prolonged periods of time. In the hobby industry this is typically how servos are secured.

9.3 Risk Mitigation

Looking at the potential failures list, the team iterated the previous design to mitigate risk as much as possible. Regarding potential failure 1, the team could not find an easy way to change the existing design as seen in figure 31. The solution to this problem was simple where a small hole was cut out in foam underneath the servo where hot glue can be injected below the servo. Using the servo horn, we can firmly hold it in place until the glue dries.

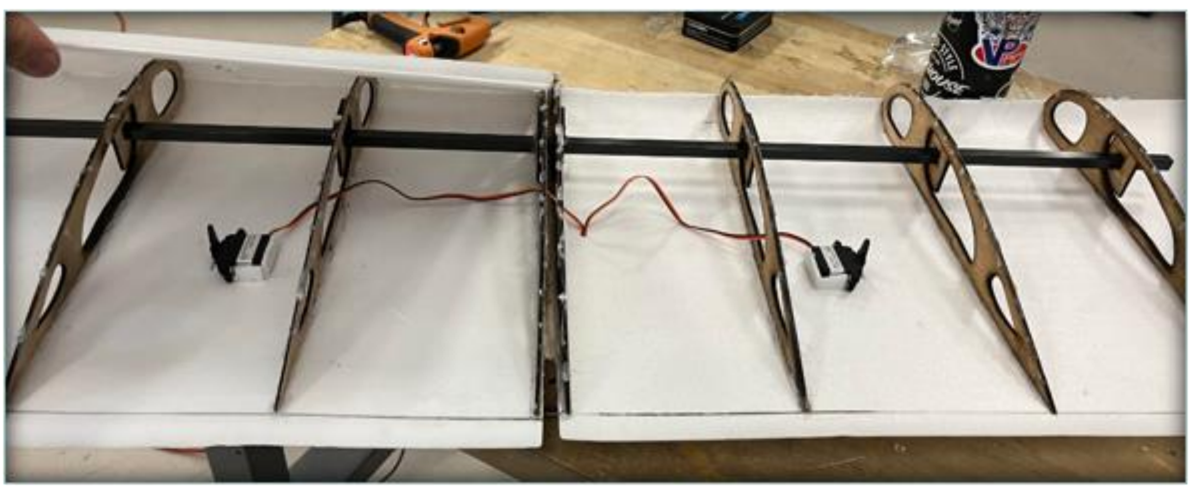

Figure 31: Servos inside wings

The rear fuselage connection was a large concern for the team and possibly the biggest roadblock. We decided to completely disregard the aluminum rod and decided to design it out of foam and plywood. Not only was this much lighter but the foam along with ribs strategically placed made it strong enough for application. The foam was flexible in design so we could make it as big or as small as we needed. This helped with securing it for the rest of the plane because it could be screwed together as well as glued. The aluminum does not adhere to hot glue which was yet another roadblock that the team avoided.

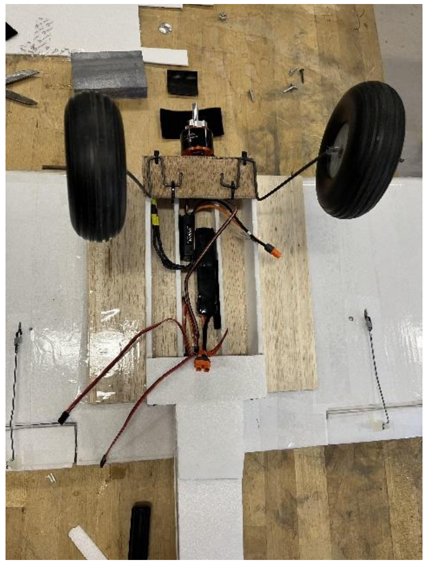

Figure 32: Front landing gear

From Figure 29, we can see that there is no support on the landing gear. When standing the plane up on the table, the team found that the landing gear was flimsy and very bendable. To fix this, we welded steel supports in several locations to strengthen the design.

The center of gravity was located just past the halfway point along the chord of our wing. This was identified by a Flagstaff Flyers member and needed to be addressed, or the plane could not fly. The team shifted weight to correct the center of gravity to one third the chord length from the front to correct this.

The adhesive holding the plane together was good but not perfect. It is heavily impacted by the craftsmanship as well. Small areas had holes and seams where air can get through which is undesirable. Over time the glue would split apart, and the plane would have to be fixed. To fix this the plane was carefully covered with a layer of packing tape to reduce drag and increase the durability of the plane in the event of a crash. Tape has an amazing strength to weight ratio for our application.

10 LOOKING FORWARD

To further meet the Customer needs and engineering needs, it is necessary for our team to make appropriate improvements to the project. This section will discuss how to improve the products of this project based on the team's observation of the whole project. The discussion focuses on two parts: future test procedures and future improvements.

10.1 Future Testing Procedures

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

1. Cargo Bay load test

Test the aircraft's ability to load and unload the cargo. In this test, we will fix a certain weight of cargo in the cargo hold and try to fly to observe the reliability of the aircraft cargo bay. The purpose of this experiment is to ensure that the cargo hold of the aircraft can operate normally, and there will be no failures such as door opening in flight, door jamming and inability to unload.

2. Ground steering test

Test the ground turning ability of the aircraft. The aircraft will be placed on the ground and will only be steered by its landing gear. The purpose of this test is to ensure that the aircraft can turn on the ground, which will help the plane to stop, adjust, enter the runway, and avoid danger.

3. Maximum power flight test

Test the flight performance of the aircraft at maximum power. The aircraft will be adjusted to the maximum operating power after taking off and will fly for a period of time. This test will study the aircraft fuselage's bearing capacity to ensure that the strength of the aircraft and the plane will not crack due to excessive power.

4. Brake test

Test the braking ability of the aircraft after landing. The plane will land normally and start braking after landing. We will record the shortest landing distance of the plane. The purpose of this test is to study the short-range landing capability of the aircraft.

5. Air balance test

Test the aircraft's ability to maintain balance during level flight. The aircraft will take off in adverse weather, such as strong wind, and try to keep balance in flight. This test will study the aircraft's ability to cope with external disturbances such as airflow.

6. High difficulty mobility test

Test the aircraft's ability to perform difficult maneuvers. The aircraft will perform some difficult movements in flight and the team will record the work of the aircraft. The purpose of this test is to study whether the aircraft will crack or disintegrate due to difficult movements.

7. Maximum takeoff weight test

Test the maximum takeoff weight that the aircraft can bear. In this experiment, we will add a lot of weight to the aircraft and try to take off until the aircraft cannot take off due to excessive loading. The purpose of this test is to study the maximum performance of the aircraft in order to find the safety factor of the aircraft.

8. Acceleration test

Test the acceleration performance of the aircraft. We will record the time required for the aircraft to accelerate to different speeds and calculate the acceleration.

10.2 Future Iterations

For the team to take over this project, we would like to put forward the following suggestions:

1. Pay attention to the weak parts of the aircraft.

The aircraft has been damaged in the experiment before, and the tail and landing gear of the aircraft was broken. Although our team has made some repairs, these parts are still more vulnerable to damage than other parts of the aircraft. Therefore, pay special attention to these parts when handling aircraft to prevent accidents.

2. Pay attention to the propeller of the aircraft

Be very careful when starting the propeller of the aircraft! The aircraft's propeller speed is high, and the fins are sharp. Because the aircraft is designed with an external propeller, the safety problem that personnel may touch the propeller in work is not considered. If you accidentally touch the propeller when it is working, the high-speed rotating propeller may cause serious personal injury. Therefore, be careful when starting the propeller and ensure that it is at a safe distance.

3. Pay attention to keeping the battery power sufficient

Ensure that the aircraft battery is always in sufficient power. The aircraft is not equipped with a low battery alarm system, so the operator needs to pay special attention to the battery's condition of the aircraft. Once the aircraft is short of power during flight, it is likely to crash. Therefore, always ensure that the battery power is sufficient.

4. Ensure that the flight is carried out in a wide area

Although the aircraft is lightweight, it does not mean that the aircraft is not heavy enough to cause personal injury during flight. As the aircraft flies fast and its weight is not too light, it may cause serious injury if it accidentally collides with people or objects in flight. Therefore, please ensure the safety of the flight area to avoid casualties.

11 CONCLUSIONS

This project aims to provide a real-life challenge for the team to apply the knowledge learned in the class to daily work. The goal of the team is to build a Fixed wings UAV that can meet Sae Aero Micro Competition Rules, and achieve takeoff, landing, steering and other functions.

After testing, the team achieved initial success. The aircraft has the ability to take off, fly stably, turn in the air, and land.

However, some functions have not been realized, such as ground steering. Therefore, our team will improve the aircraft according to the CRs Table and ERs Table.

11.1 Reflection

1. Our consideration of security

For our team, ensuring the personal safety of users and other personnel is the core design requirement of our project. In order to meet this requirement, our team has carried out a lot of design. To ensure the safety of personnel, we have adopted a lightweight fuselage design to reduce personal injury caused by collisions. In addition, we also adopt safety nuts and other designs to minimize the possibility of accidents. Through these related designs, we can ensure the safety of the project design.

2. Our consideration of environmental friendliness

During the design process, our team fully considered the environmental protection of the project. This project uses rechargeable and reusable batteries as energy supply instead of aviation diesel used in traditional aeroengines. The battery can be charged by solar energy, hydrogen energy, bioenergy, and other energy sources. Therefore, our design has less carbon emissions than traditional UAVs. In today's increasingly serious environmental problems, our design has considerable environmental significance.

3. Our economic considerations

According to engineering principles, our design needs to achieve the goal of making profits for employees. To achieve this goal, our design is based on low cost. Our design widely uses foamed plastics, wood and other materials to ensure flight performance while reducing the cost of manufacturing in order to increase profits.

4. Our consideration of cultural factors

In order to not cause cultural conflicts, our design adopts conservative external devices, concise shapes, and is designed by team members from different cultural backgrounds, so as to minimize the possibility of causing cultural conflicts.

11.2 Resource Wishlist

1. Demand for additional resources

In actual manufacturing, our team encountered some unforeseen problems. Based on the observation of the problem, we have listed the following materials and tools.

Table 9: Additional resources

Name	Numbers
Screwdriver with proper size	1

Aviation tape	1 roll
Welding torch	1
Degradable and stronger foam plastics	3 Square meters
3D printer	1
3D printer supplies	No more than 200 dollars

2. Expectations for additional team members.

As the members of our team are Mechanical Engineering undergraduate students, the foundation of team members in aerodynamics is relatively weak. Members of the team have not taken any courses related to aerodynamics, and their knowledge in aerodynamics comes from self-study. Therefore, the team is eager to get some help from a teammate who is proficient in aerodynamics.

11.3 Project Applicability

For our team, this project is valuable and meaningful. As the project includes design, manufacturing, testing, improvement and other parts, and members need to complete works in a relatively short time, the project fully exercised the ability of team members to solve difficulties and reasonably arranging time. These abilities are difficult to learn in the classroom, but they are crucial to a future career.

The project also covers knowledge from different disciplines, such as fluid mechanics, dynamics, materials science, etc. In order to integrate the knowledge of different disciplines, each member of the team does his best in his work and gives effort to his own strengths, which improves the team members' cooperation ability. In the career, the ability to communicate and cooperate with teammates from different cultural backgrounds and master different technologies is significant, and this project has cultivated this ability of every team member.

In addition, due to the limited budget, the team members considered the issue of reducing manufacturing costs as much as possible, saving funds. In the career, the ability to reasonably arrange budgets is also important. Through the training of this experiment, team members have greatly improved their ability in budget management.

Therefore, we firmly believe that each member of the team is ready for the future career after the work of this project.

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13 APPENDICES

13.1 Appendix A: Landing Gear Calculations and Simulation Results

Simulation conducted was done in Solid works.

Material:

- Bracket: 1060 Aluminum Alloy
- Wheels: ABS Plastic
- Bolts: Annealed Stainless Steel

Applied Forces:

- Force: 3.9 N

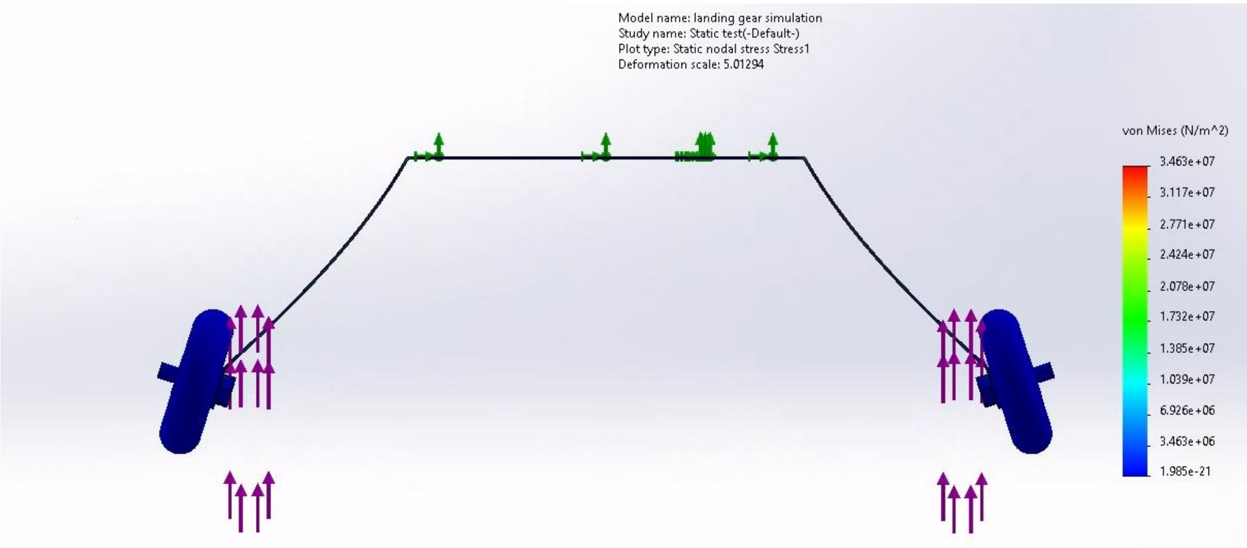


Figure 1: Landing gear displacement front view

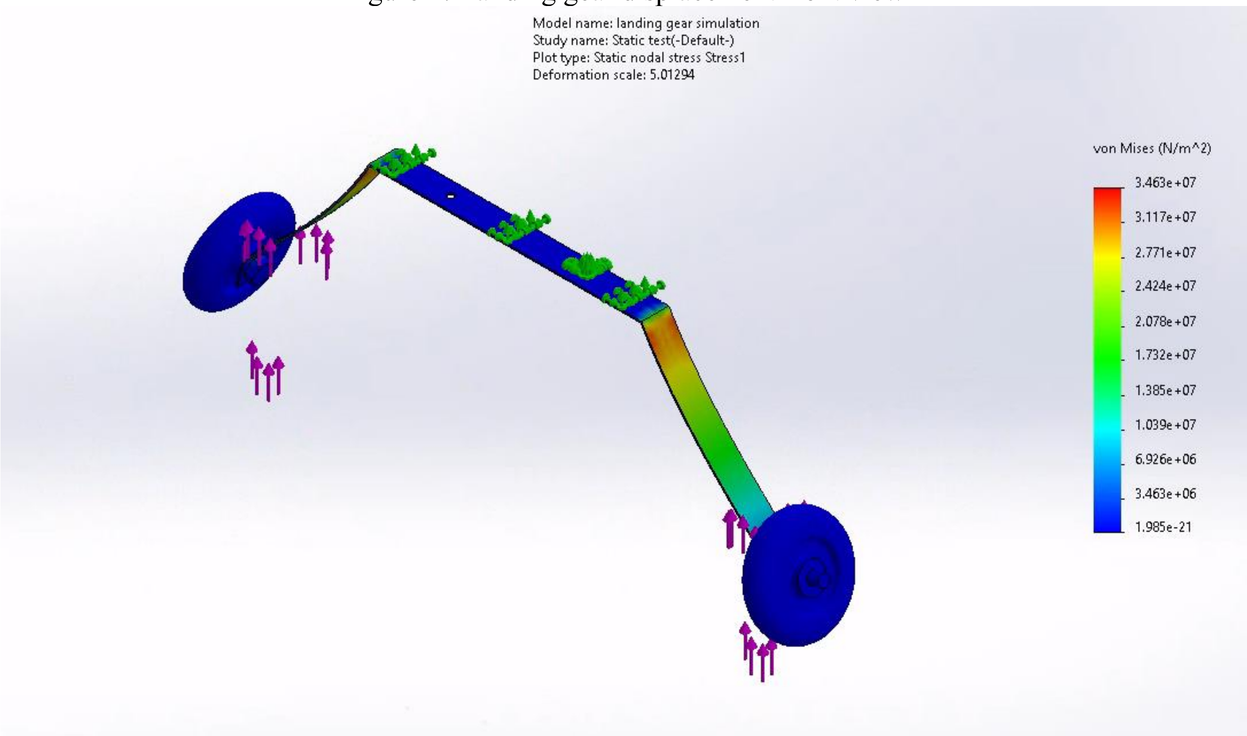


Figure 2: Landing gear displacement isometric view

From these results, this design is adequate for the project because the forces subjected to the bracket bent it within a reasonable amount. If the aluminum passes the point of its modulus of elasticity, it can be manually bent back into place by hand.

Rear Landing Gear Simulations:

Material:

- Bracket: 201 Annealed Stainless Steel
- Wheels: ABS Plastic

Applied Forces:

- Force: 3.9 N
- Torque: 1 N-m

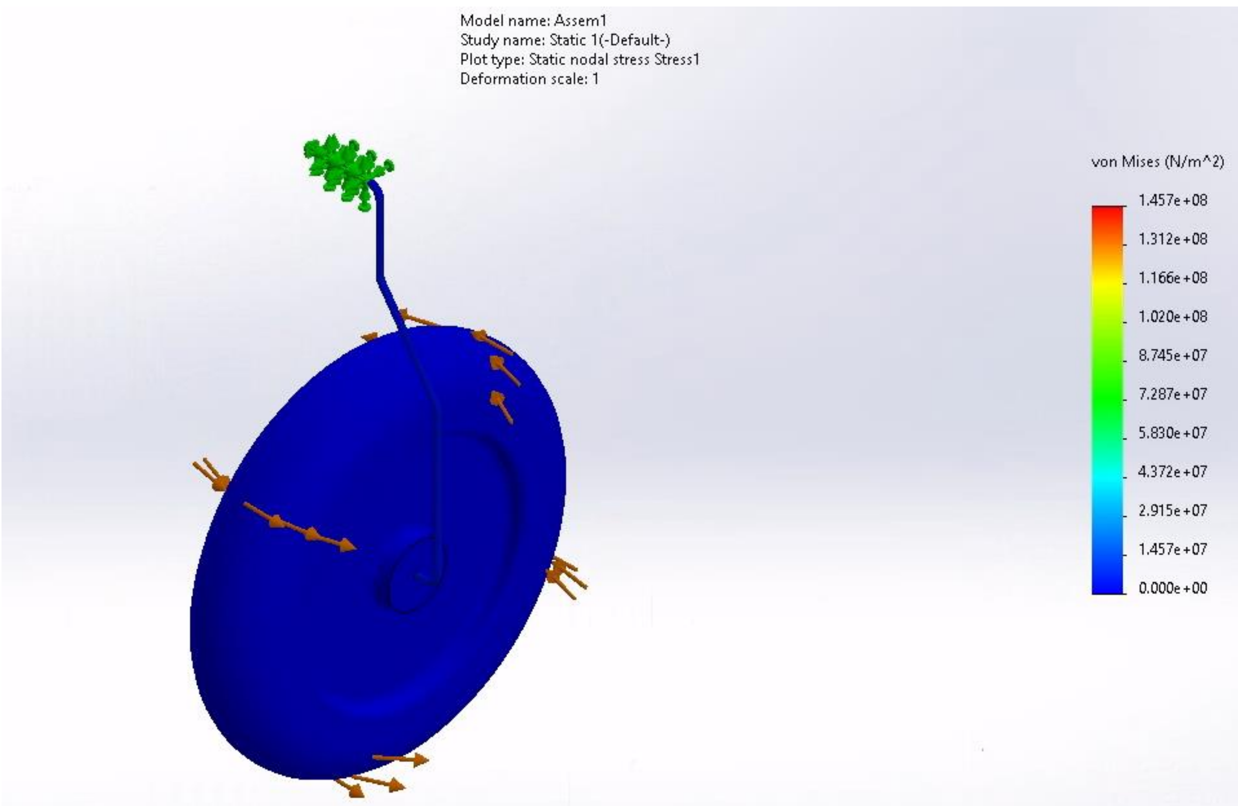


Figure 3: Rear landing gear isometric view

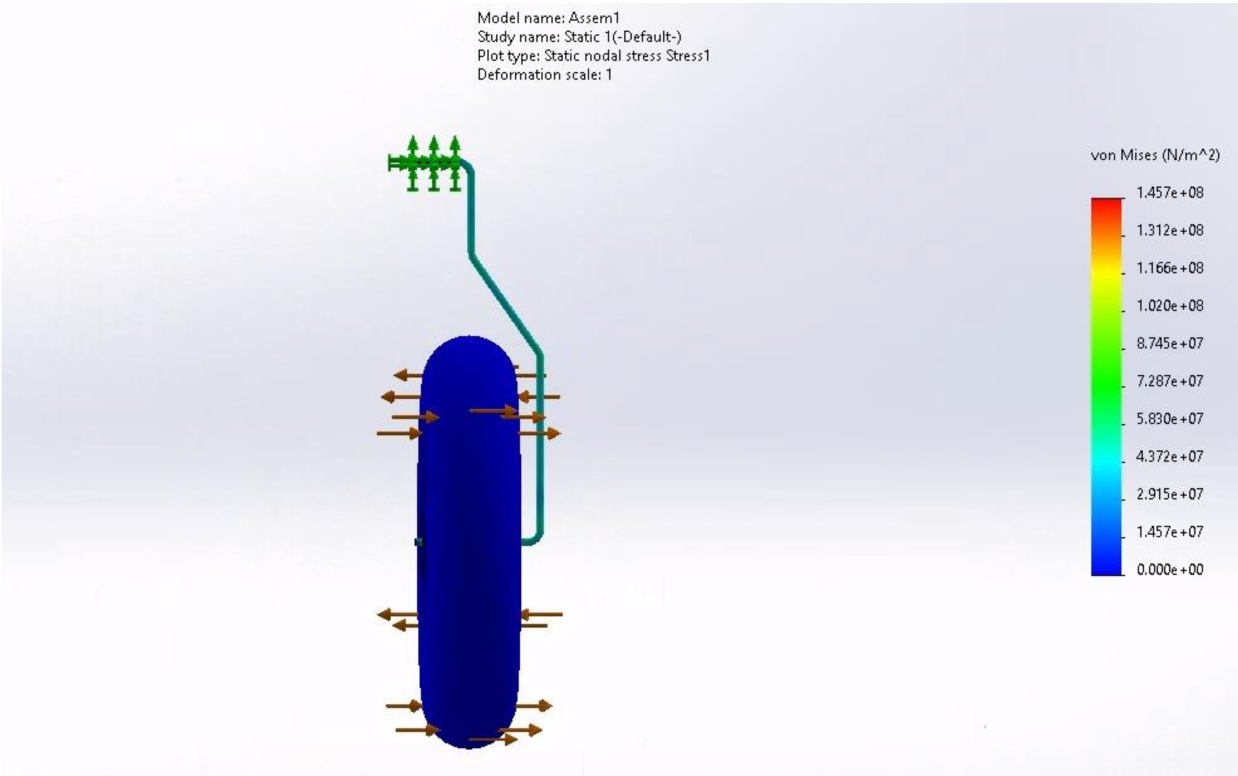


Figure 4: Rear landing gear torque displacement

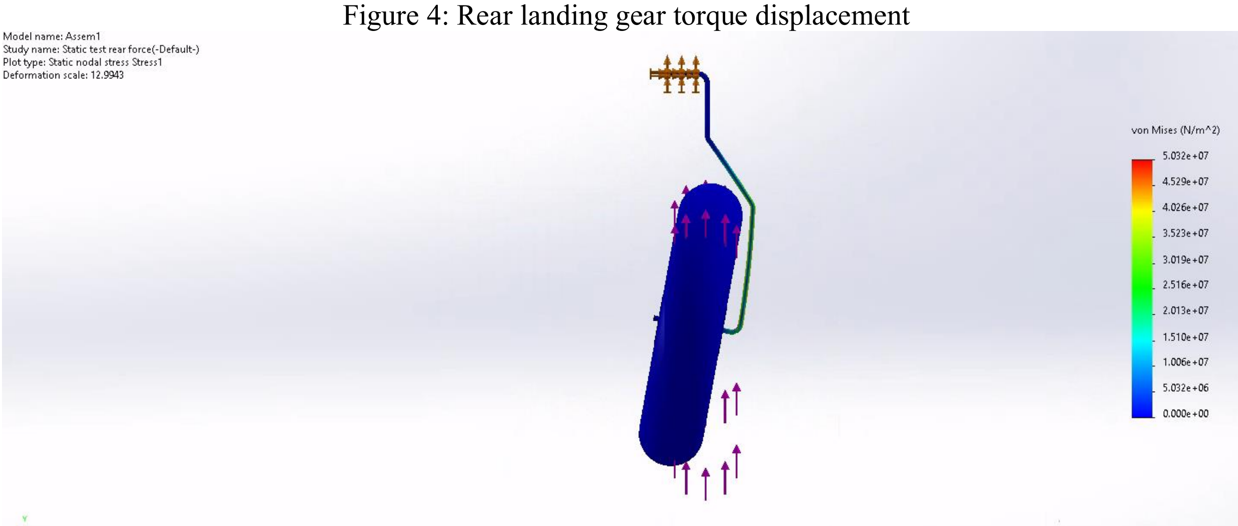
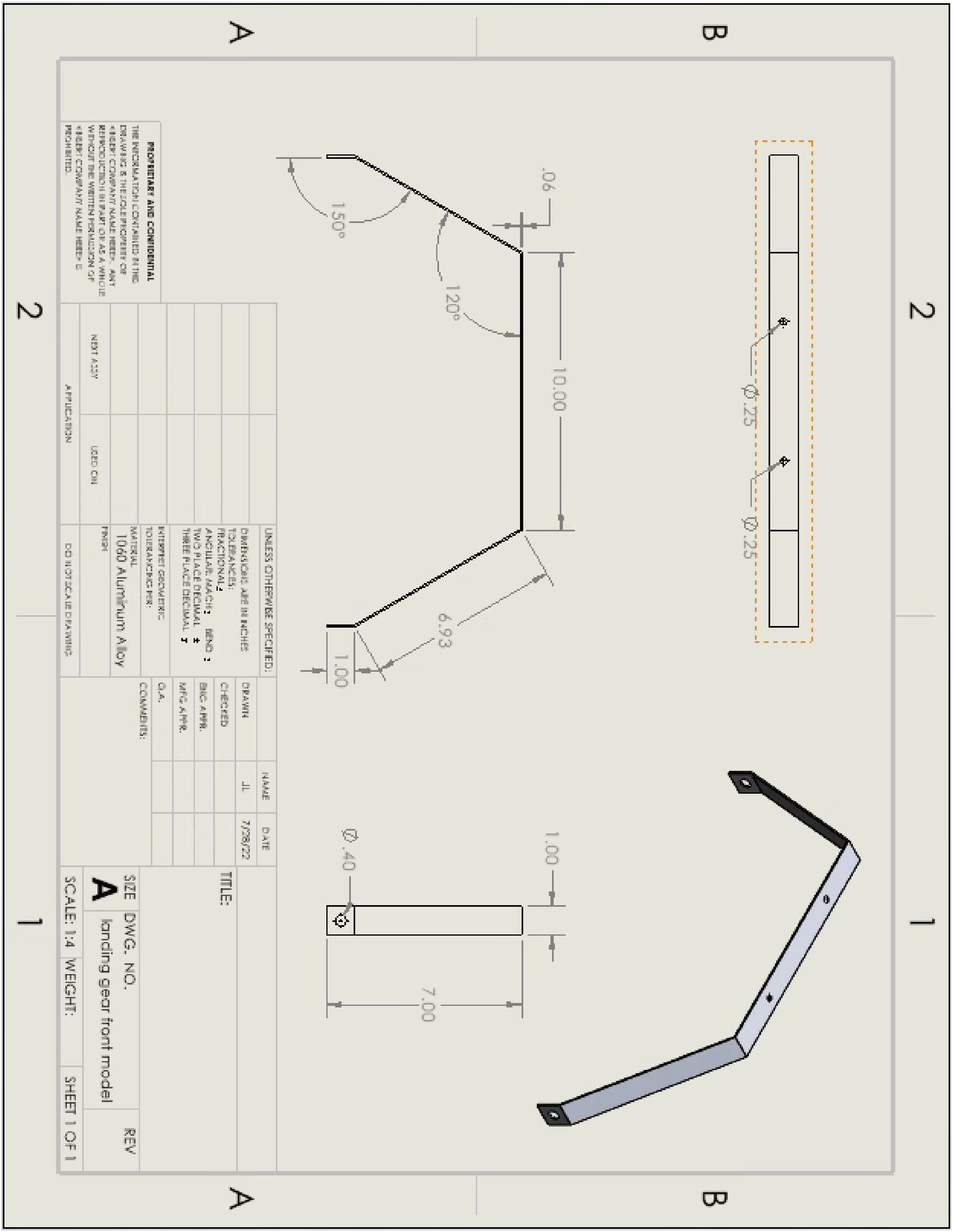


Figure 5: Rear landing gear force displacement

From these results, it can be concluded that this bracket for the rear wheel is adequate for the forces and torque applied. The applied torque is double the maximum torque that can be provided by the servo. There is little displacement in figure 5 thereby displaying the structural integrity of the bracket. From figure 6, the bracket will be bent from the impact of 3.9N of force but will not break. However, the bracket can be bent back to place by hand thereby justifying that this bracket will be adequate for this project.

13.2 Appendix B: Drawing of front landing gear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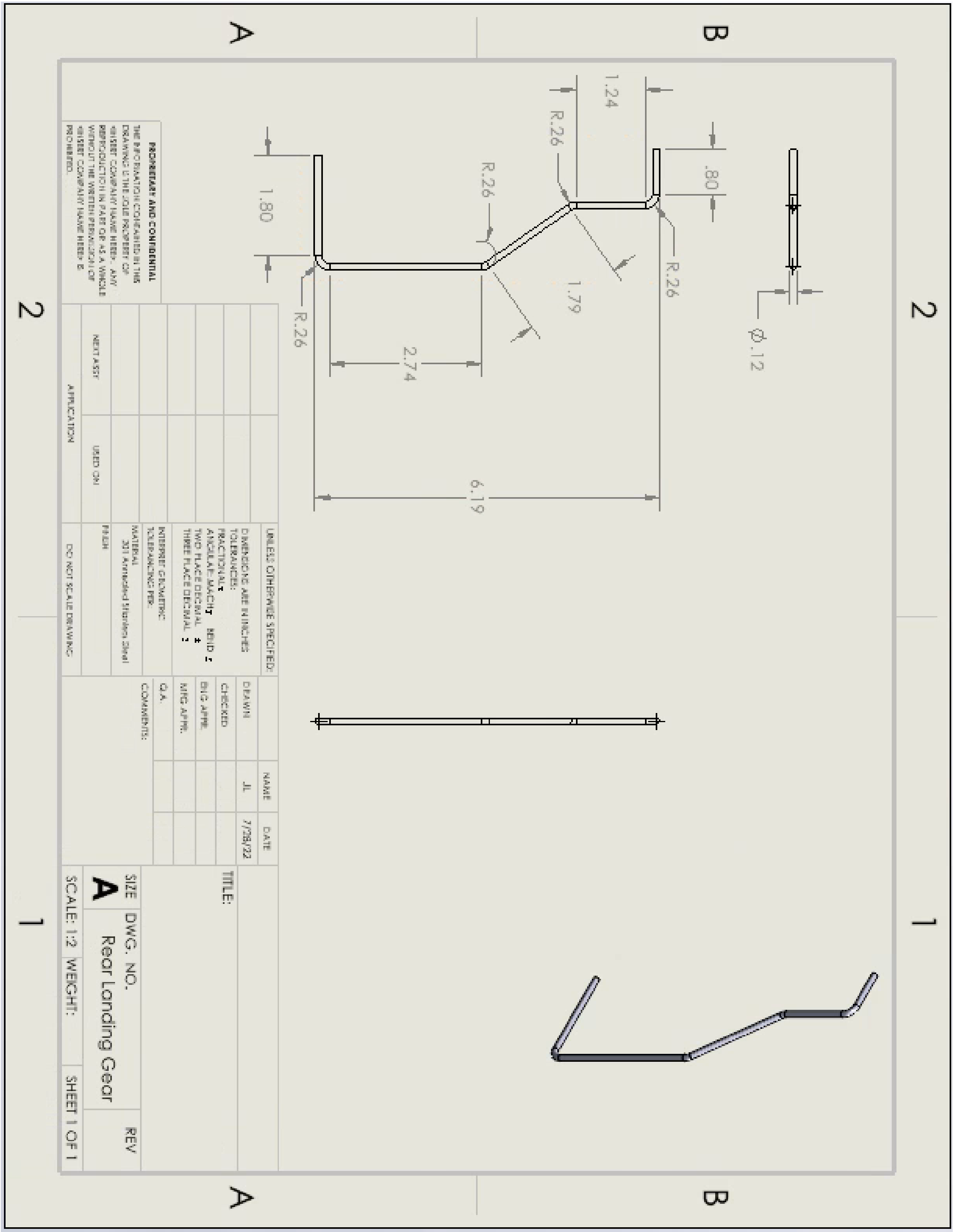
13.3 Appendix C: Drawing of rear landing gear



13.4 Appendix D: FMEA

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurrence (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
Fuselage	Impact Wear	Poor appearance, potential loss 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 system 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 handling, 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 critical points, physical 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 physical inspection, layering of materials to ensure a stronger surface
	Impact Deformation	Complete subsystem failure	8	Crash landing, general use	5	Reinforcing critical points, physical inspection	1	35	Physical inspection, Have a series of replacement parts available
	Abrasive Wear	Poor appearance, creates drag, potential connection point failure, possible warping	4	Crash landing, general use	8	Reinforcing critical 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 appearance	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 structure 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 structure 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 structure 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, potential 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

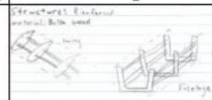
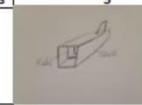
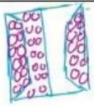
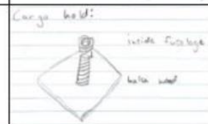
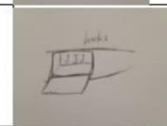
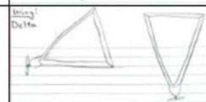
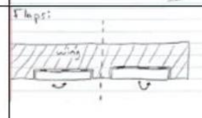
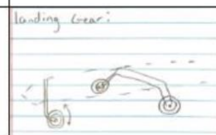
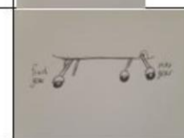
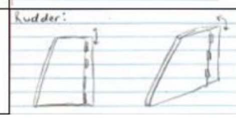
Motor	Temperature Fatigue	Noise, loss of power, smoke, potential complete subsystem failure	7	General use, overloading, connection failures	2	Physical inspection, check connecting wires, downtime, ventilation	5	70	Create ventilation points, ensure that all connecting wires are properly installed
	High-cycle Fatigue	Loss of power, warping, smoke, potential 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, potential complete subsystem failure	7	Crash landing, hard landing, overloading	3	Physical inspection, check connecting wires, downtime	5	105	Physical inspections, check power outputs and connecting wires after an impact
Servos	Temperature Fatigue	Noise, loss of power, smoke, potential 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, potential 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, potential complete subsystem failure	7	Crash landing, hard landing, overloading	3	Physical inspection, check connecting wires, downtime	5	105	Physical 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 structural integrity, potential 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	4	Tightening the bolts too tight, crash landing,	3	Proper lubrication, not over tightening	7	84	Adhering to the torque specs, proper lubrication

		structural integrity							
	Surface Wear	Poor appearance, 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, constant physical inspection
	Yielding	Complete subsystem failure	10	Crash landing, overweight	3	Replacement of parts	1	30	Reinforce external structure and connection points. If it is 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 it is 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 it is completely broken a replacement part will be needed.
	Surface Fatigue	Poor appearance, possible yielding if left unchecked	5	General use	5	Reinforced connection points, layering of stronger material for the external structure, physical inspection	2	50	Constant physical inspection, layering of materials to ensure a stronger surface
Servos	Impact Fatigue	Potential loss of structural integrity	8	Crash landing	3	Reinforced connection points, layering of stronger materials for	5	10	Create a better way to hold servos in place

						the internal and external structure			
	Yielding	Complete subsystem failure	6	use over time	3	Replacement of parts	3	300	Add more adhesive
	Impact Fracture	Complete subsystem failure	10	Crash landing, general use	4	Replacement of parts	6	6	Replace servos if damaged
Rear Fuselage	Impact Fatigue	Complete subsystem failure	6	Static load, landing load	8	Replacement of parts	8	70	Create a larger surface area to connect fuselage
	Yielding	Complete subsystem failure	7	use over time	7	Replacement of parts	9	105	Reinforce external structure and connection points, constant physical inspection
	Impact Fracture	Complete subsystem failure	10	crash landing	9	Replacement of parts	7	50	Reinforce external structure and connection points. If it is completely broken a replacement part will be needed.
	Deformation	Balance issue, poor appearance, possible subsytem failure, could lead to yielding	4	use over time	5	Physical inspection, reinforce connection points, layering of materials	5	5	Bend existing component back to original shape or reinforce
Front Landing Gear	Impact Fatigue	Complete subsystem failure	8	landing	10	Replacement of parts	5	10	Thicker steel tubing
	Yielding	Complete subsystem failure	6	landing	8	Replacement of parts	7	20	Reinforce external structure and connection points, constant physical inspection
	Impact Fracture	Complete subsystem failure	10	landing	9	Replacement of parts	10	50	Weld landing gear back together
	Deformation	Balance issue, poor appearance, possible subsytem failure, could lead to yielding	4	landing	10	Physical inspection, reinforce connection points, layering of materials	10	1	Bend existing component back to original shape or reinforce
Center of Gravity	Flight	Flight complications; unflyable	10	flight	10	Add/decrease weight. shift	10	1	Shift weight

						weight positions			
Safety Factor and Drag	Impact Fatigue	Complete subsystem failure	7	crash landing	4	Physical inspection, layering of materials	3	5	Wrap foam with tape or finishing material
	Impact Fracture	Complete subsystem failure	9	crash landing and flight	6	Physical inspection, check connecting wires, downtime	7	20	Repair damaged area and reinforce with more adhesive or covering surface
	Deformation	Balance issue, poor appearance, possible subsytem failure, could lead to yielding	6	flight	7	Physical inspection, reinforce connection points, layering of materials	4	100	Assess design and make deformed area stronger
	Surface Fatigue	Poor appearance, creates drag	2	flight, crash landing	8	Reinforced connection points, layering of stronger material for the external structure, physical inspection	8	3	refinish surface overtime with use
Servos and Brackets	Impact Fatigue	Complete subsystem failure	8	crash landing	4	Replacement of parts	9	100	Reinforce external structure and connection points, constant physical inspection
	Yielding	Complete subsystem failure	6	use over time	6	Replacement of parts	4	300	Stronger connecting rod
	Impact Fracture	Complete subsystem failure	5	crash landing	4	Replacement of parts	7	65	Add more adhesive
	Deformation	Balance issue, poor appearance, possible subsytem failure, could lead to yielding	1	use over time	6	Physical inspection, reinforce connection points, layering of materials	1	150	Bend existing component back to original shape or reinforce
	Surface Fatigue	Poor appearance, deformation, complete subsystem failure	3	use over time	6	Reinforced connection points, layering of stronger material for the external structure, physical inspection	1	200	add surface finish

13.5 Appendix E: Morph Matrix

Subsystems	1	Descriptions	Design choices	2	Descriptions	Design choices	3	Descriptions
		Pill shaped, Honycomb interwall support, Main strucutre is 3D printed, outer structure is balsa wood	2		rienforced ribbed walls, material is balsa wood	3		Fulselage made of traditional light wood materials, key parts are reinforced by ribs.
		Removable, stacking racks, honeycomb pattern, 3D printed	1		Flat base, weights held down with bolt and nut assembly	2		Integrated cargo hold, with hooks and ropes inside to fix the cargo.
		High set, Small tips, scooped style, thick up front, thin in the back	2		Delta wing high set on fuselage, covers majority of plane	3		The traditional flat wings, fixed on both sides of the fuselage.
		Rubberband pully system	23		Flaps held by flexible plastic to the wings, flaps integrated into wing, each flap contains one servo	2		Each side of the main engine wing contains a flap, which is driven by servos.
		Folds out, second pair of wings, likey aluminum	3		Single wheel up front which steers plane, two wheels located mid body of aircraft, held together by aluminum plate	2		One wheel is set at the front of the fuselage and two wheels are set at the rear, all of which are retractable.
		Fishtail, servo controlled (1)	23		Standard rudder design, controlled by one servo	2		A tail rudder like a Boeing airliner. Driven by servo.

	Spoiler, High enough to control the pitch, servo up and down, 3D printed	1		Flat wing that slightly tilts toward rear of aircraft, entire assembly moves as one, servo controlled	3		Rotatable wing, driven by the same servo on both sides.
	Attached inside the plane at the center of the meeting wings	same		Brushless motor, high KV, located at front tip of aircraft	same		Electric motor, installed at the head of the aircraft, connected with the propeller and the speed can be controlled.
	Attached inside the plane at the center of the meeting wings	same		High torque, lightweight, quick response time, little slop	same		Responsive and precise transmission.
	2 blade, 3 prong extendors to direct the flow around the body	23		Two blade propeller, high pitch on blades	23		Double blade double extenders propeller, made of solid materials.

13.6 Appendix F: Gannt Chart

Peel Eval 3	2022/11/24	1
Peel Eval 2	2022/10/24	1
Website Check 2	2022/11/8	27
Final Report	2022/11/7	29
Product demo& Testing Results	2022/11/7	29
Initial testing Results	2022/11/7	14
Final CAD Packet	2022/10/31	21
Hardware Status Update 100% build	2022/10/17	22
Finalized Testing Plan	2022/10/17	22
Hardware Status Update 67% build	2022/9/26	22
Start Testing plan	2022/10/17	14
Website check 1	2022/9/26	15
Hardware Status Update 33% build	2022/8/29	29
Final Materials Purchasing	2022/9/7	1
Project Management	2022/8/29	5