SAE Aero Micro Design

Final Report

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2019-2020

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DISCLAIMER

EXECUTIVE SUMMARY

Our aircraft design team, the Prop Dogs, was formed in August 2019 with two main goals: to successfully design and manufacture a senior capstone design project at NAU, and compete in the 2020 SAE Aero West competition. The purpose of the senior capstone design is to demonstrate engineering fundamentals and key knowledge gained at NAU. The purpose of the SAE competition is to proudly represent our school and our sponsor, W.L. Gore & Associates.

This document contains the complete design proposal for a fixed-wing, remote controlled aircraft intended for competition at the SAE Aero Micro class event in April 2020. The SAE Aero Micro Class competition is an international event where hundreds of universities compete and showcase their talents to prospective job recruiters. The goal of the SAE Aero Micro competition is to design an aircraft that carries the highest payload at the lowest empty weight. The design must strictly adhere to a vast set of rules and constraints. Noteworthy constraints include a gross weight limit of 10 pounds, disassembled storage contained in a box 12 ⅛" x 3 ⅝" x 13 ⅞", electric-only motor, hand-launch takeoff, and battery storage greater than or equal to a 3-cell 2200 mAh capacity. Upon design completion, the competition scores each team based on their in-flight performance and assembly time.

Given the design description and constraints, the overall design was divided into five subsystems. The five subsystems are the wing, fuselage, landing gear, propulsion/drive, and in-flight control mechanisms. When generating concept designs, each subsystem allowed for three subsystem concept variants, respectively. The final product of concept generation combined these variants to yield three unique full-design variants. The first design considered featured a single wing, dual aileron with an elevator and rudder, rear steer, single motor, and elliptical taper fuselage. The second design considered was a single wing, dual aileron with rudder, front steer, single motor, and elliptical taper fuselage. The final design variant featured a dual wing, dual elevator with rudder, rear steer, single motor, and elliptical taper fuselage. Each design was compared using a pugh chart and decision matrix, where the selection criteria were based on customer and engineering requirements. Furthermore, manufacturability and design constraints were taken into account.

The final design solution features a single wing, dual aileron with rudder, rear steer, single motor, and tadpole fuselage design with external payload mounting. This design, shown in Figure 1, was superior in meeting requirements and manufacturability constraints. The wing design is a Clark Y airfoil with a 52 inch wingspan and a uniform 6 inch chord length. The drive components include a 8"x4.7" propeller, 800W max brushless electric motor, 45A max electric speed controller, and a 3-cell 1800 mAh LiPo battery. The fuselage frame, weighing 0.22 lbs, internally houses the entire drive system and is 3D printed using ABS. The frame externally supports a ¼ " diameter, 10" long carbon fiber rod, which is connected to the T-shaped tail. The tail dimensions are a 26 inch span and a 5 inch chord length. The landing gear wheels are 1.5 inches in diameter and supported by thin aluminum rods. With a 2-lb payload, the overall weight is assumed to be 4 lbs. The thrust generated is approximately 60 oz under ideal loading. Thus, the thrust-to-weight ratio of 0.94 suggests successful flight. However, the entire design depends upon testing validation, including weight, thrust, lift, and strength tests. Validation will begin January 2020.

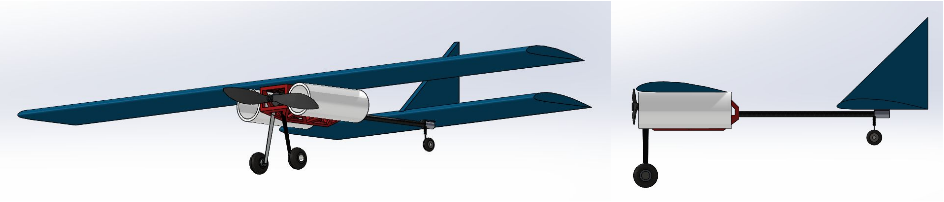

Figure 1: Final Design

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1 BACKGROUND

1.1 Introduction

The SAE Aero Design competition is composed of three classes: regular, advanced, and micro. The SAE Aero Micro Class is a design competition that tasks the team with designing and constructing a small unmanned aerial vehicle (SUAV). The SUAV is a fixed-wing plane that is controlled from the ground by one of the team members via wireless remote controller. The objective of this class is to carry the highest payload with the lowest empty weight. There are various constraints to the design, including a gross weight limit of ten pounds, disassembled storage within a box 12.125 inches X 3.625 inches X 13.875 inches, and a hand-launch takeoff [1]. This competition also addresses issues in engineering design, professionalism in presentations, prototyping, and manufacturing products. The SAE Aero competition is highly renowned and first began in 1986. This year there will be 85 teams attending in Fort Worth Texas from April 3-5 of 2020 for the Western division [1]. While competing, our team will represent both the team sponsor W.L. Gore and Northern Arizona University. Thus, the success of our SUAV is crucial in representing our sponsors well. Finally, the benefits of successfully completing the design are representing NAU and W.L. Gore proudly and showcasing our engineering abilities.

1.2 Project Description

The following is SAE's original project description:

> "The SAE Aero Design competition is intended to provide undergraduate and graduate engineering students with a real-world design challenge. These rules were developed and designed by industry professionals with the focus on educational value and hands-on experience through exposure to today's technical and technology advancement. These rules were designed to compress a typical aircraft development program into one calendar year, taking participants through the system engineering process of breaking down requirements. It will expose participants to the nuances of conceptual design, manufacturing, system integration/test, and sell-off through demonstration" [1].

2 REQUIREMENTS

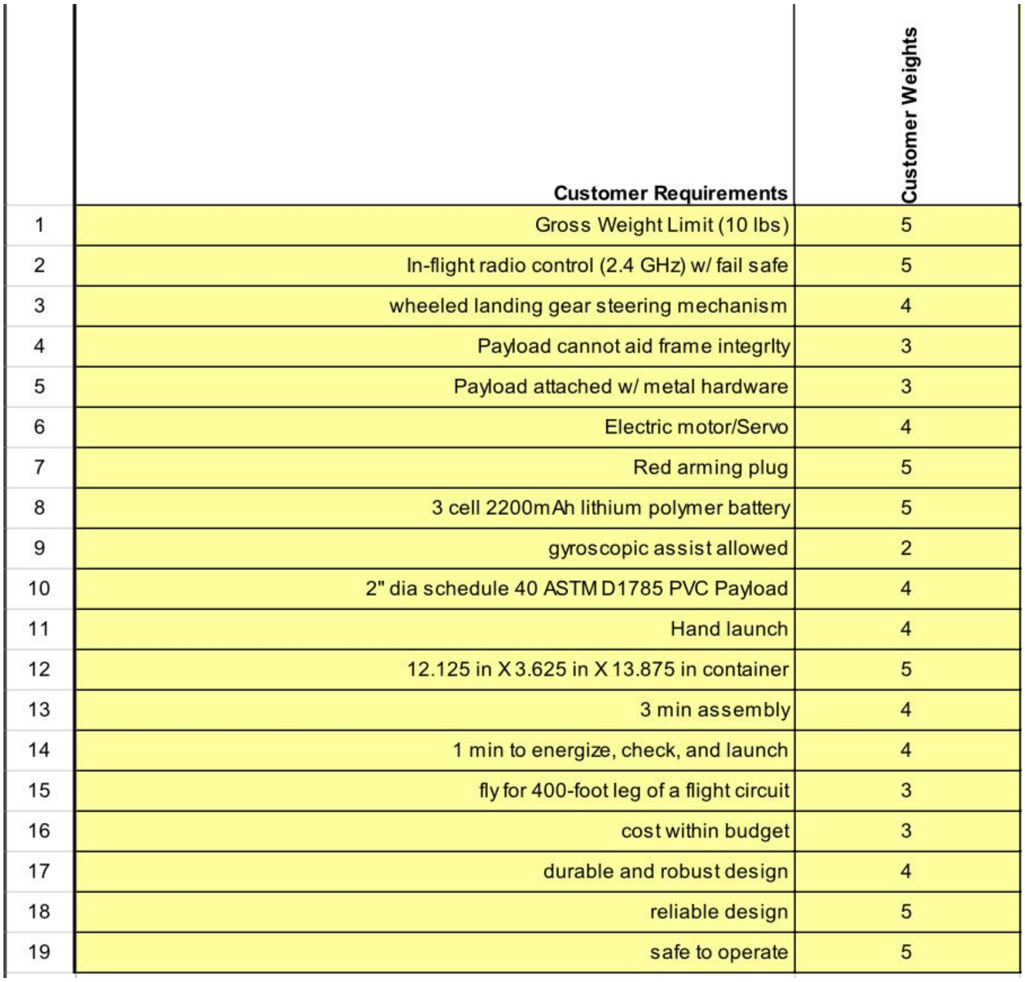
Following the original system breakdown for the SAE Aero Micro fixed-wing plane, the next step in the design process is developing design requirements. The purpose of design requirements is to provide necessary data for concept generation and selection. This section presents the customer requirements, engineering requirements, and house of quality developed for the aero micro design.

2.1 Customer Requirements (CRs)

Customer requirements (CRs) are necessary to fully define a complete list of design requirements. CRs are provided by customers/stakeholders to describe what the design needs to accomplish, while also not arriving at a solution for said requirements. These CRs were generated through NAU faculty advisor interviews, the SAE Aero Micro Design competition rulebook, and instructor requirements. First, when interviewing the faculty advisor , Dr. John Tester, the team was provided with the following insight: follow all the rules exactly as stated, or the design will automatically fail. Consequently, the meeting with

Dr. Tester yielded no direct CRs, but rather encouraged the team to reference the rulebook. So, in reading the 2019-2020 SAE Aero Design competition rulebook, the team developed the first 15 CRs, shown below in Table 1. Each CR in Table 1 directly corresponds to at least one competition rule. Each CR is weighted based on its importance to success in the competition from 1 to 5. With each CR being a rule directly from the rule book each had a very high weighting. Descriptions of each rule and subsequent CR are provided within Table 1 for reference [1].

Table 1: Customer Requirements



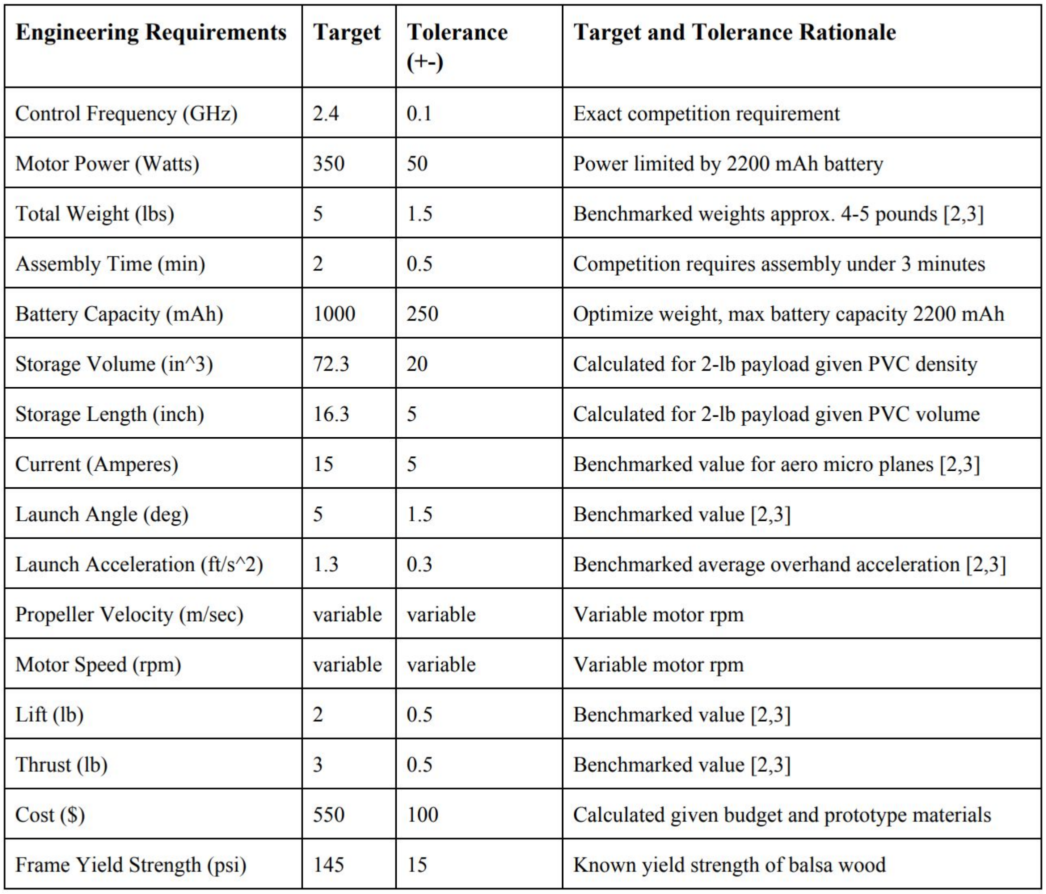
	Customer Requirements	Customer Weights
1	Gross Weight Limit (10 lbs)	5
2	In-flight radio control (2.4 GHz) w/ fail safe	5
3	wheeled landing gear steering mechanism	4
4	Payload cannot aid frame integrlty	3
5	Payload attached w/ metal hardware	3
6	Electric motor/Servo	4
7	Red arming plug	5
8	3 cell 2200mAh lithium polymer battery	5
9	gyroscopic assist allowed	2
10	2" dia schedule 40 ASTM D1785 PVC Payload	4
11	Hand launch	4
12	12.125 in X 3.625 in X 13.875 in container	5
13	3 min assembly	4
14	1 min to energize, check, and launch	4
15	fly for 400-foot leg of a flight circuit	3
16	cost within budget	3
17	durable and robust design	4
18	reliable design	5
19	safe to operate	5

The final method of gathering CRs was through implementing mandatory instructor requirements. These requirements (CR's 16-19) are seen above in Table 2. The design must be manufactured within budget to ensure no monetary loss, while subsequently using project funds to develop a durable and robust design which are both weighted at 4 and 5. Finally, the design must operate reliably by functioning predictably and not dangering people upon malfunction.

2.2 Engineering Requirements (ERs)

Given the CRs generated above, the next step in the design process was to translate CRs into engineering requirements (ERs). While customer requirements define what the plane must do, the purpose of ERs are to define how the plane will fulfill those requirements. So, each ER was generated by relating a measurement characteristic to at least one of the CRs. In general, the title of each ER describes which component of design or CR is being measured. The complete list of ERs is shown below in Table 2.

Table 2: Engineering Requirements



Engineering Requirements	Target	Tolerance (+-)	Target and Tolerance Rationale
Control Frequency (GHz)	2.4	0.1	Exact competition requirement
Motor Power (Watts)	350	50	Power limited by 2200 mAh battery
Total Weight (lbs)	5	1.5	Benchmarked weights approx. 4-5 pounds [2,3]
Assembly Time (min)	2	0.5	Competition requires assembly under 3 minutes
Battery Capacity (mAh)	1000	250	Optimize weight, max battery capacity 2200 mAh
Storage Volume (in^3)	72.3	20	Calculated for 2-lb payload given PVC density
Storage Length (inch)	16.3	5	Calculated for 2-lb payload given PVC volume
Current (Amperes)	15	5	Benchmarked value for aero micro planes [2,3]
Launch Angle (deg)	5	1.5	Benchmarked value [2,3]
Launch Acceleration (ft/s^2)	1.3	0.3	Benchmarked average overhand acceleration [2,3]
Propeller Velocity (m/sec)	variable	variable	Variable motor rpm
Motor Speed (rpm)	variable	variable	Variable motor rpm
Lift (lb)	2	0.5	Benchmarked value [2,3]
Thrust (lb)	3	0.5	Benchmarked value [2,3]
Cost ($)	550	100	Calculated given budget and prototype materials
Frame Yield Strength (psi)	145	15	Known yield strength of balsa wood

It is important to note the target and tolerance rationale provided in Table 2. The rationale describes how each value was determined. Prior to conducting testing on components such as propellers and airfoils, many of the target and tolerance values originate from benchmarked values. Other target values are derived by calculations, known values, and competition requirements.

2.3 Functional Decomposition

The Functional Decomposition for the SAE Aero Micro is quite simple. The overall function of our design must fly under the certain criteria. There are other guidelines in the SAE Aero Micro rules, but in order to receive any decent result, the aircraft must fly. Some of the important components of the design are the fuselage/payload design, wing design, and propulsion mechanics. In order to carry the desired payload, the design of the fuselage and payload mechanism must be placed in such a way that is aerodynamic and able to be thrown by a human hand. The wing design is strictly based on the airfoil decided, which determines the amount of lift and drag on the aircraft. Finally, the propulsion is based upon the motor and propeller efficiency, which in turn creates thrust. Thrust determines how much weight the aircraft can carry because it is dependent on velocity of the aircraft. The only changes that have been made to the project at this point in time is changing our fuselage design to an uglystick design and knowing what motor, ESC, and battery the team will be using in the final design.

2.3.1 Black Box Model

The Black Box Model simplifies the Functional Decomposition. The 'material inputs' are components of the actual design: motor, battery, wing, radio controller, and propeller. The airflow is a material component because it is something that is tangible. These 'material inputs' are the 'material outputs' because they do not change. The 'energy inputs' are electrical energy and kinetic energy. The aircraft is wired and is controlled by an RC device, so electrical energy will be the 'energy output' as well. On the other hand the kinetic energy from throwing the aircraft initially is converted into mechanical energy. The 'input signals' are wind direction, radio frequency, aim, and on/off. All of the previous signals will become 'output signals' besides wind direction because while the device is in the air it will be adjusted to the airflow, so it turn be flight direction.

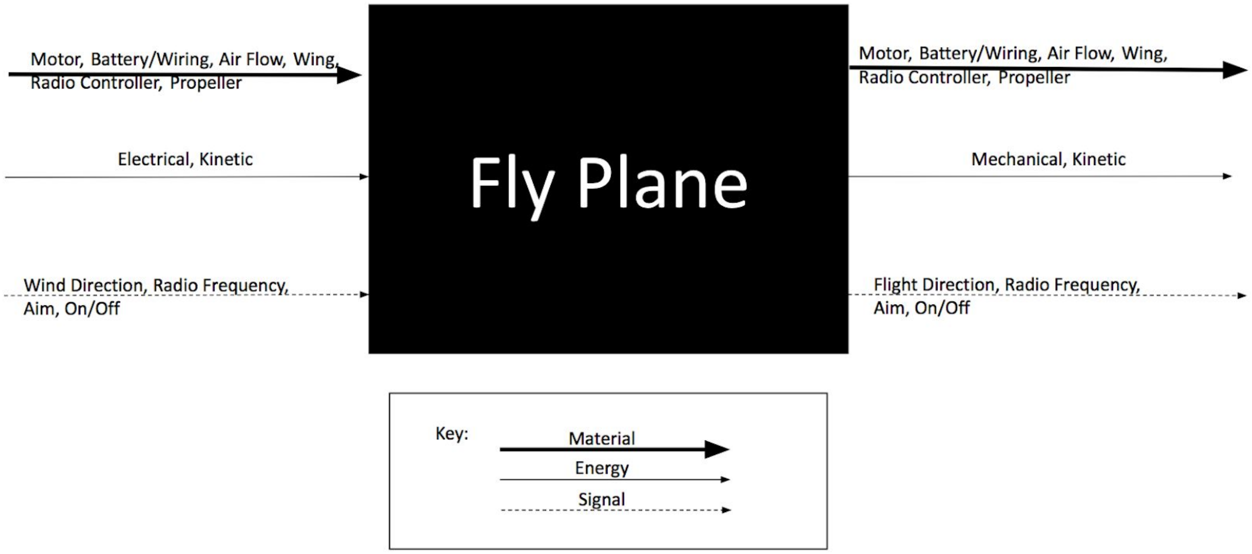


Figure 2: Black Box Model

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

The Functional Model is shown below (Figure 3). The flow chart directs all the inputs of the Black Box Model (Figure 3) and describes what they do physically. All the 'material inputs' when they are imported they will then direct the airflow; this will create flight (signal) and lift, thrust, and drag (material). All the remaining inputs are then needed to drive the electricity component of the aircraft. The RC Controller provides an input and integrated with electricity and controller frequency actuates the motor, which converts electrical energy to rotational energy. This then determines the thrust and flight path. All of the following inputs are needed to create a successful flight. This is an important aspect to our design in that the team is able to break down the inputs and their path through the functional model to be successful in the competition. By having this we can pinpoint problems in the design and backtrack through the functional model to understand what went wrong.

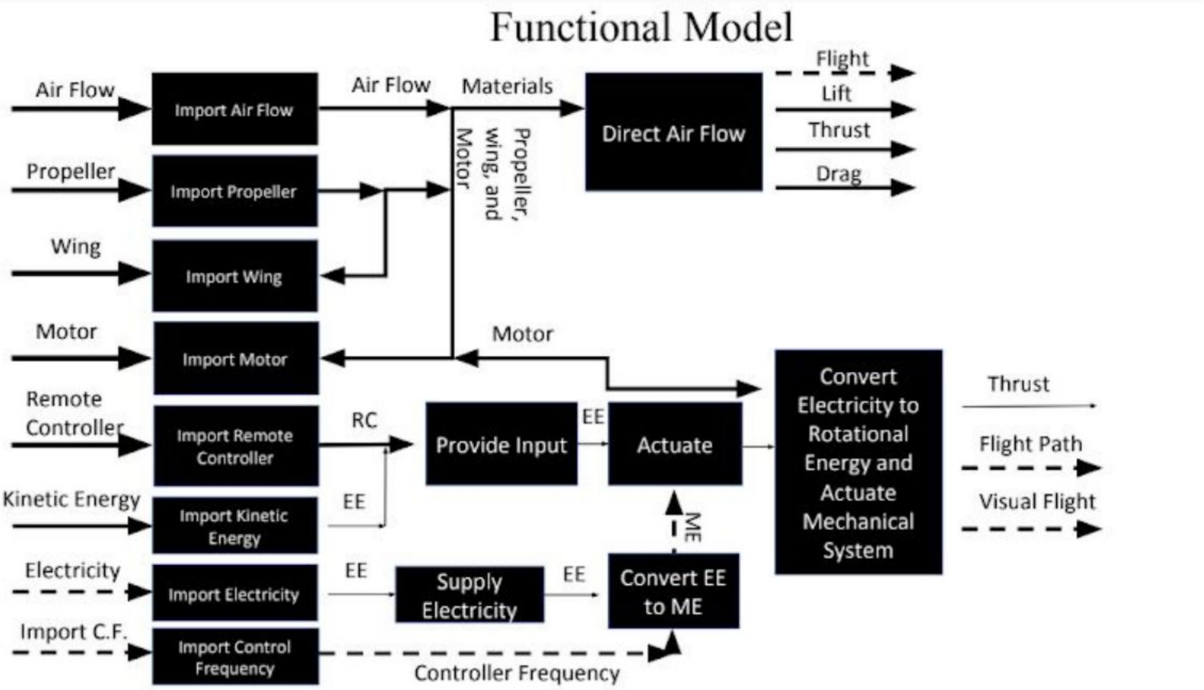


Figure 3: Functional Model

2.4 House of Quality (HoQ)

After defining both the CRs and ERs for the project, the next step was to compare CRs and ERs to each other using a quality function deployment (QFD) system. The purpose of the QFD was to determine the relative importance of each ER and compare how each ER affects other ERs. The relative importance of each ER was determined by how well the ERs satisfied each CR. In this system, CRs are given a customer weight (1-5), and each ER is scored (1,3, or 9) on the relationship with all CRs. Then, the sum of the scoring for each ER is added and compared to yield to relative technical importance. Next, ERs are compared to ERs to determine the design relationships when changing variables. The results for the relative technical importance of ERs and relationships between ERs are shown in the QFD in Appendix Table A1.

Upon completing the QFD, the ranked importance of each ER and the relationships between ERs were defined. As shown in Appendix Table A.1, the top 5 most important ERs were weight, power, thrust, payload storage length, and lift, respectively. The reason the top 5 ERs scored so high is they are crucial measurements to determine flight characteristics. Nearly the entire success of flight is dependent upon the weight, power, thrust, storage length, and lift of the aircraft. Understanding the importance of these engineering requirements provided the team with the necessary knowledge to research and generate concept designs that fulfill such requirements. Furthermore, the QFD shows that weight, power, thrust, and lift are all interconnected. So, if the team considered a smaller motor or battery to conserve weight, this will drastically affect the thrust and lift characteristics of the plane. Realizing this, future iterative designs must account for interrelated variables such as weight, power, thrust, and lift.

Testing procedures will be taken to ensure each of the ERs will be satisfied. These testing procedures are fully explained in section 3.

2.5 Standards, Codes, and Regulations

For this project there are some codes and standards that are necessary to be practiced to ensure safety. The first code listed below in Table 3 is provided by the Academy of Model Aeronautics (AMA). The code is titled Devices Academy of Model Aeronautics National Model Aircraft Safety Code and lays out basic safety regulations including; not flying in a careless or reckless manner, flying over unprotected people, vehicles, and occupied structures, etc. The second code on Table 3 provided by the Society of automotive engineers (SAE) is the 2020 SAE Aero design rules. This rule book is the backbone of our design and by following all of the rules which are our customer requirements the team will be successful when it comes to the time of competition. The last code on the list comes from the International Electrotechnical Commission (IEC). This code gives basic safety guidelines when using lithium batteries such as making sure to test batteries for over discharge to avoid explosion. By following each of these standards and codes the team will not only be successful in competition but ensure safety throughout the duration of the project.

Table 3: Standards of Practice as Applied to this Project

Standard Number or Code	**Title of Standard**	**How it applies to Project**
AMA	Devices Academy of Model Aeronautics National Model Aircraft Safety Code [2]	Helps in ensuring safety while flying and prepping plane before flight.
SAE	2020 Collegiate Design Series SAE Aero Design Rules [1]	All rules and regulations for competition.
IEC 60086-4 Ed. 5.0 b:2019	Primary Batteries - Part 4: Safety Of Lithium Batteries [3]	Gives precautions to ensure safety while using lithium batteries.

3 Testing Procedures (TPs)

Before we fly our design in the SAE Micro competition in Dallas-Fortworth in early April experimental tests must be conducted in order to justify the materials we used and the final design manufactured. The customer requirements and engineering requirements are based upon the criteria of the SAE competition rules and regulations. Based upon the FMEA (4.1) there are 4 subsystems that have multiple components each that can fail, which will then lead to critical failure, i.e. aircraft crashing. In order to test those critical components our team will be conducting five testing procedures: A Flight test, Weight test, Assembly test, Propeller test, and finally the tensile strength test.

3.1 Testing Procedure 1: Thrust Test

The thrust test will be conducted to satisfy the thrust engineering requirement. Thrust is the force that moves the plane forward and in turn creates lift under the wing. This test will be conducted in 98 c well before any of the other tests are taken. This test will be the determining factor of whether or not the team needs a new motor or propeller.

3.1.1 Testing Procedure 1: Objective

The objective of the thrust test is to satisfy the engineering requirements for thrust which the team targeted at around 3 pounds of force. This test will be conducted using a scale and a mount which will be connected to both the scale and the motor with the propeller attached. After everything is mounted, the motor will be connected to the ESC and battery. Then the scale will be zeroed out. The motor will be actuated using the remote controller to full power thus rendering a negative value on the scale which is our max thrust. This value will then be inputted into our software ecalc as a known value for thrust which will then be used to calculate our potential lift.

3.1.2 Testing Procedure 1: Resources Required

The resources required for this test include; a scale, a mount for the scale and motor, the ESC, the battery, and the remote controller. Only two team members are necessary to be present for this test and it will be conducted in the machine shop on campus 98c.

3.1.3 Testing Procedure 1: Schedule

This test is scheduled to be within the first week of the second semester, so all of the resources as stated above will need to be either ordered or manufactured during winter break. After all the components are in the team's possession the test will be conducted January 15th.

3.2 Testing Procedure 2: Tensile Strength Test

The tensile strength test is important because it will demonstrate whether or not the material chosen can withstand the stress and strains of the flight itself or the landing of the flight, i.e. the external forces of crashing or simply landing. In order to manufacture the wing, fuselage, and the landing gear, the materials of these components must meet the flight test requirement. There will be members bending and twisting that will need to stay in place, but also be able to be disassembled. The engineering requirement that this satisfies is the Frame Yield Strength.

3.2.1 Testing Procedure 2: Objective

The goal of the tensile strength test is to determine the maximum amount of force that is needed to crack, fracture, snap or bend the material that is tested. The materials for the aircraft that the test will be conducted on are the wing material (balsa wood) and the aluminum connectors/wiring that form the landing gear.

3.2.2 Testing Procedure 2: Resources Required

The soils lab has all the required devices in order to test the strength of these desired materials. The Tensile Testing Machine will determine the amount of force is needed to cause any type of deflection and this will be shown through graphical methods through the software. After several experiments the results will determine when the material's integrity is compromised.

3.2.3 Testing Procedure 2: Schedule

This test is a preliminary test that dictates large components of the aircraft: wings, fuselage, and landing gear. These materials must be tested before the final construction takes place. January 15th is the date at which these tests will be performed; this will give the team ample time to create the frame/wing to our desired specifications.

3.3 Testing Procedure 3: Flight Test

The Flight test will be one of the final testing procedures conducted before the final demonstration because the aircraft's ability to be able to fly appropriately and accurately and land with limited damage inflicted is based upon the previous testing procedures. This testing procedure will test all of the engineering requirements and customer requirements, but more specifically it will test that the aircraft is capable of flying a 400 foot leg in the air and that the wheeled landing mechanism can be steered. This test will be conducted several times after each iteration or updated design, but the first scheduled test is February 21st.

3.3.1 Testing Procedure 3: Objective

The objective of the flight test is to reassure the team that the aircraft can fly properly. The aircraft will need to be completely constructed, and this includes the ailerons, drive system, and rudder actuates correctly in response to the remote controller. The fuselage, landing gear, wings, and electrical components will need to be completely finished and ready for the flight test.

3.3.2 Testing Procedure 3: Resources Required

The resources required to perform the flight test are few because the only requirement is the actual design to be fully constructed. The weather will be the most troublesome component to this test because it is the middle of winter in Flagstaff in February, so depending on the temperature, wind velocity, humidity, and snow, this will dictate our flight performance. If needed the flight can be performed indoors, i.e. the Health and Learning Center on NAU's campus. There will be little to no obstacles in comparison to the outdoor elements.

3.3.3 Testing Procedure 3: Schedule

February 21st will be the time when the first flight test will take place. This will give the team enough time to construct version 1 of the completed design in the spring semester.

3.4 Testing Procedure 4: Weight Test

Testing the weight of the completed design will be necessary because the design cannot exceed the max weight of 10lbs. The storage volume is another engineering requirement because the collapsed design of the aircraft must be able to fit in a 12.125 inches X 3.625 inches X 13.875 inch cubed cardboard box.

3.4.1 Testing Procedure 4: Objective

The objective of the weight test is to see whether or not our design exceeds the SAE competition rules of 10 lbs. This test will combine the storage volume and weight limit capacities in one test by disassembling the finalized design and placing it in the storage container to see if it can fit and then following this the components will be weighed. This will determine if the proposed dimensions of the components will satisfy the engineering requirements of the weight and the limited storage volume.

3.4.2 Testing Procedure 4: Resources Required

The resources required will be a box of the desired dimensions: 12.125 inches X 3.625 inches X 13.875. This will be made of cardboard as per the competition rules. In addition to the storage volume, the team will need access to a scale that can measure pounds, so we can be as accurate as possible. The location of where the weigh in is measured will be building 98C because it needs to be a hardwood or tile floor in order to register the correct reading.

3.4.3 Testing Procedure 4: Schedule

The schedule for this is dependent upon having the design completed. The flight test is scheduled for the third Friday of February, so the weight test will be conducted the week prior. The hard deadline that the weight test must be conducted by is February 21st, the same date as the flight test.

3.5 Testing Procedure 5: Assembly Test

Testing the time it takes to assemble the aircraft within our engineering requirement of three minutes is pertinent to the success of the team receiving high scores in competition. By doing this test the team will understand the components of the aircraft that need to be modified to both ensure structural integrity and speed of assembly which is a somewhat difficult trade to make. This test will be taken once the final design is complete.

3.5.1 Testing Procedure 5: Objective

The objective of the assembly test is to ensure that our SUAV will be able to be assembled out of our 12.125 inch X 3.625 inch X 13.875 inch box within 3 minutes. The first step of this test is to collapse the plane and fit it within our box. The next step is to start a stopwatch and begin assembling the plane as quickly and methodically as possible. The main components that will need to be assembled are the wings and tail. This test will be run through 10 times for practice and speed while working together with the team. The target for this assembly time is 1.5 minutes which is exactly half of the given time during competition.

3.5.2 Testing Procedure 5: Resources Required

The resources required for this test include the 12.125 inch X 3.625 inch X 13.875 inch cardboard box, a stopwatch, and the final design of the aircraft. The location of this test will most likely be done in the machine shop on campus 98c. All team members will be present while this test is taken.

3.5.3 Testing Procedure 5: Schedule

The schedule for this test is also dependent upon the completion of the final design. This test should be done after the flight test, to ensure that the team is not wasting time practicing assembly for an aircraft that does not even fly. This test will be done the same day as the flight test on the 21st of February just as long as it is done after.

4 Risk Analysis and Mitigation

The risk analysis and mitigation is pertinent in any engineering project. It allows the group to perform more efficiently in the final result and when performed properly can withstand conditions that are unexpected. If the material or component of the design fails during the testing procedures the team must create a solution to reduce the risk of that part failing before the competition. If risk analysis and mitigation does not occur during the design process than when that component fails there will be no solution to that problem. The overall benefit of performing a risk analysis and mitigation is to maximize the progress rather than the digress in the manufacturing stage; this will also minimize the amount of materials that are purchased/used.

The potential failures in our project range from buckling to fracturing and then to multiple wiring connection failures. The designed aircraft is not a large object; it is a fairly small device that must be able to withstand its own weight, but maintain flight. The small components of the aircraft: wings, propeller, landing gear are very prone to failure because of the material properties and the result of the external force that is applied. We will mitigate the testing procedures by selecting the appropriate materials that will withstand the desired force, stress, and strain, but is also cost efficient.

4.1 Critical Failures

4.1.1 Potential Critical Failure 1: Frame of Landing Gear

The top potential failure occurs in the frame of the landing gear; this occurs when the strength of the aluminum alloy fails and buckles when the aircraft lands. This failure can simply be caused by the stress and strain of the material itself. If this aluminum connectors cannot withstand the force of the aircraft landing then buckling will occur. This failure can be mitigated by testing the material of the landing gear before constructing the finalized design. The RPN is 120 and this is higher than all other potential failures because of the occurrence factor; based on previous designs, due to benchmarking, the frame of the landing gear fails more often than any other component.

4.1.2 Potential Critical Failure 2: Motor in the Drive system

The next potential failure is the motor in the drive system and this is due to improper discharge of voltage from the battery. The cause of this is due to the motor being too powerful. The detection factor is high because it is hard to detect the discharge of the battery to the motor. There are no physical observations that can be used to determine whether or not there is a failure. The RPN is 105, which is the second highest.

4.1.3 Potential Critical Failure 3: Propeller - Landing Gear

The propeller is terms of landing gear can fail if the propeller comes into direct contact with the ground before the landing gear. This coincides with the first failure; if the frame buckles than the propeller will break upon impact. The severity of this failure is high because there will be two main components of the aircraft will fail. The RPN is 100, with the severity, occurrence, and detection to be 5, 5, and 4 respectively.

4.1.4 Potential Critical Failure 4: Ailerons - Wings

The ailerons are an important subsystem to the aircraft design because it steers and turns the aircraft. The wiring from the servo motor to the ailerons systems must work appropriately in order for the aircraft to turn. The cause of this failure would be assembly/user error. The team would test the ailerons before the initial flight to be sure that the wings function properly.

4.1.5 Potential Critical Failure 5: Rudder - Wings

The rudder is another component that steers the aircraft, but it performs this is the tail of the aircraft. This failure is identical to the failure of the ailerons because it is due to the manufacturing of the wiring system from the servo motor. Both the rudder and ailerons have a 96 RPN.

4.1.6 Potential Critical Failure 6: Battery - Drive

The battery is an essential component to the aircrafts design because it powers the propeller and the servo motor. If the battery does not comply with the motor or servo motor than there is a potential of an improper discharge. The detection factor is the highest for this failure because the battery will be over exerted or work improperly in a flight test. The only resolution is to test the battery with the proper electrical components and make sure the battery does not overcharge.

4.1.7 Potential Critical Failure 7: Main Cabin Landing Gear - Fuselage

The landing gear connection to the main cabin (fuselage) would be due to a fastener failure. As long as the fasteners work initially the only concern would be tolerance buildup. If testing the aircraft so many times can affect the fastener strength over a period of time. The RPN is not too high at a value of 48, which the ideal failure RPN is 30. In order to mitigate this failure is to double check the fasteners that contribute to the landing gear.

4.1.8 Potential Critical Failure 8: Propeller - Drive

The propeller is one of the most critical components of the aircraft, but it is the most exchangeable part because the propellers are so readily available. There is still a potential failure that the propeller might crack or fracture, and the cause of this is due to tolerance buildup. If the propeller begins to show any sign of ware then it will be evaluated and tested to see if the propeller needs to be replaced.

4.1.9 Potential Critical Failure 9: Rear Tail - Wings

The rear tail or the empennage is critical for flight. 70-80% of the weight of the aircraft is in the front or the nose of the plane. This means that the rest of the weight is in the rear of the plane. The potential failure for the empennage would be that cracks will occur. This is due to tolerance buildup, but in order to mitigate this failure the team would need to document how the rear tail performs and how the structure is impacted after each flight test. The last two potential failures have a relatively low RPN of 48.

4.1.10 Potential Critical Failure 10: Tail Dragger and Front Landing Gear

The tenth and final critical failure mode is the landing gear in its entirety to fail during landing. The cause of this is due to the fracture of the landing components and/or the flexion of the components laterally. This is dependent on how ‘soft’ landing is because the more force that is exerted vertically downward the more weight the landing gear must be able to hold. This critical failure’s RPN is 45, which is a nice value based on or target value of 30. We must test the landing gear appropriately to feel confident that the landing gear will remain intact.

4.2 Risks and Trade-offs Analysis

The critical failures that were observed and calculated were based upon the four systems: drive, fuselage, wings, and landing gear. The majority of the failures do correlate to one another because there are so few components in this aircraft. All of the ailerons, rudder, and propeller mechanisms are based upon the battery and drive system. If there is an issue with the wiring of the aircraft then both the ailerons and rudder will not work properly. Besides the potential failure of the propeller cracking, the failure of the propeller is based upon the motor, drive, or the landing gear buckling or flexing. The overall mitigation would be do perform flight checks before each trial and during the testing procedures to ensure that every potential failure will be accounted for and observed by all the members of the team. The failures for the landing gear and wings are dictated by the materials that the team will use. If the testing procedures are performed properly than the analysis of the overall subsystem will be able to be analyzed through small checks and observations before trial period. In regards to the risk and tradeoff analysis, the components that are readily available and replaceable are the propeller, battery, and parts of the landing gear assembly, because these components are cheap and available there is very little severity to the system, but the occurrence is a higher value, so in the end the risks and trade-offs are taken into account.

5 DESIGN SELECTED – First Semester

This section details the design selection process throughout the first semester. The selection process begins with concept generation and selection conducted in the preliminary report. Then, the preliminary design is re-evaluated to provide the exact materials and dimensions for the final design. Finally, the preliminary design lacks the exact resources needed for final design. So, section 5 provides an in-depth implementation plan for the final design.

5.1 Design Description

5.1.1 Preliminary Design

The preliminary report details the concept generation process, where each subsystem yielded unique concept variants to fulfill the subsystem requirements. The final product of concept generation combined one subsystem variant from each subsystem to produce three full-design variants. Each full-design variant is shown below in Table 4.

Table 4: Full-Design Variants

Subsystem	Full-Design Variant	Full-Design Variant 2	Full-Design Variant 3
Drive	Single motor	Single motor	Single motor
Fuselage	Unibody elliptical taper with external payload storage	Unibody with internal payload storage	Unibody elliptical taper with wing payload storage
Wings	Single wing	Single wing	Dual wing
Landing Gear	Tail-dragger	Tricycle	Tal-dragger
In-Flight Control	Dual aileron with elevator and rudder	Dual aileron with rudder	Dual aileron with elevator and rudder

Following concept generation, the next step was to compare each full-design variant and select the design that performs best given a unique subsystem combination. Designs were compared using a pugh chart and decision matrix, where the selection criteria are CRs and ERs. The Pugh Chart and Decision Matrix are provided in appendix tables Tables B1 and B2, respectively.

As shown in appendix Table B1, all three designs scored the same as the datum when compared to most competition requirements. However, design 1 had the highest positive score compared to the datum. The rear steering mechanism allows for greater control upon landing, so the radio control and reliability CRs scored higher with design 1. Next, the elliptical tapered fuselage with external fasteners allows for payload storage on the fuselage rather than wings, providing more area to store weight and greater durability. Thus, design 1 scored higher in durability, flight characteristics, assembly time, and weight CRs. Design 2 scored the second highest in the Pugh chart evaluation. The tricycle front steer prevents rollover landings, making design 2 more durable and robust. The deletion of elevators simplifies the control system while also limiting the weight of actuators, so design 2 also scored higher in weight and control CRs.

As shown in appendix Table B2, the decision matrix also scores design 1 as the highest. The main differences between designs 1 and 2 were the fuselage and landing gear designs. Design 1 features external payload storage with a rear wheel steering mechanism. This allows for decreased assembly time, increased landing capability, increased payload capacity, and less drag. The most important considerations are the decreased assembly time and decreased drag. Equations for payload assembly time and drag are shown in equations 1 and 2, respectively.

$$t_{assembly} = C_{fastener}N$$

$$Drag = C_D(0.5\rho v^2 A)$$

In equation 1, the assembly time is dependent on the fastener coefficient and the number of fasteners. Design 1 features external payload snap-on fasteners while design 2 features internal payload storage. Therefore, design 1 has a lower assembly coefficient and the same number of fasteners as design 2. Thus, the assembly time for design 1 is lower than design 2. Finally, the drag equation is dependent on the coefficient of drag and the cross-sectional area. Design 1 features a smaller fuselage with external storage, resulting in a smaller area and drag coefficient than design 2. Therefore, design 1 has a lower drag force than design 1. Thus, from the Pugh Chart and decision matrix comparison, design 1 was selected as the preliminary design. The rough CAD with various views for design 1 is shown below in Figure #.

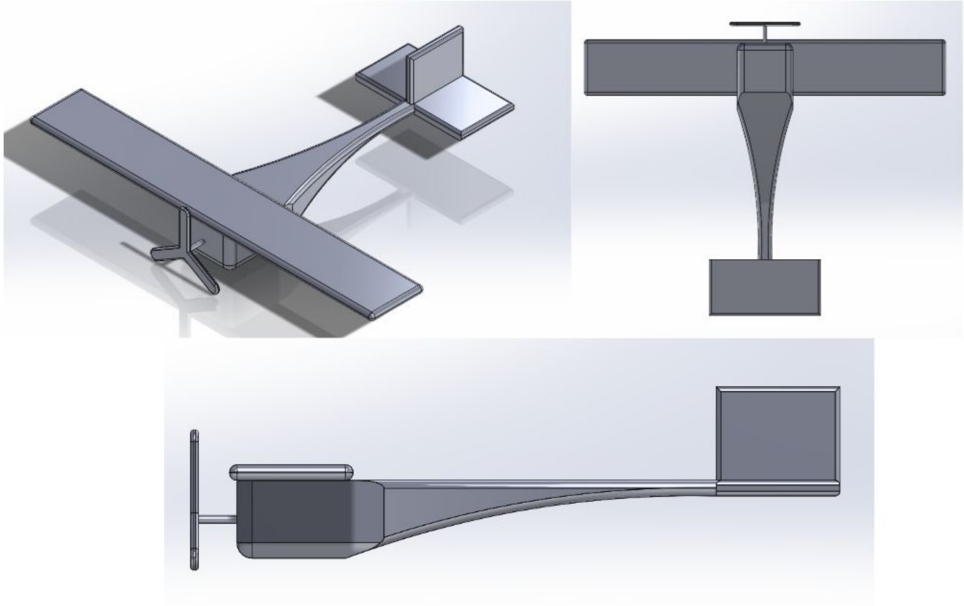


Figure 4: Preliminary Design CAD Model

5.1.2 Final Design Changes

Following the preliminary design, the next step in generating a final design was determining any necessary changes to the preliminary design. Two major changes were made for the final design: deleting the elevator and replacing the unibody fuselage with a tadpole design. First, the elevator design was deleted to simplify manufacturing and decrease the weight, assembly time, and cost [4,5]. Our design features ailerons that operate independently to turn the plane and operate in unison to land the plane. Furthermore, the rudder steers the back end of the plane upon landing, so that the plane will land straight despite any form of cross wind. Thus, the elevator was deemed unnecessary and the final design will proceed with no elevator.

Second, the unibody fuselage design shown above in Figure 4 internally houses the drive components (motor, speed controller, battery, and receiver) and tapers down, eventually connecting to the tail wing. This design cannot work for two reasons: manufacture and size constraints. After determining the drive specifications, the square portion of the fuselage frame must be approximately 6 inches in length. In order to balance the plane, the tapered portion of the fuselage must be approximately 10 inches in length. Given the size constraints, a 16 inch unibody fuselage will not fit within the box. So, the solution to this is a tadpole design, where the 6 inch fuselage frame that houses the drive components is connected to a 10 inch carbon fiber rod. The tadpole design is shown below in Figure 5, and is discussed in further detail in the design specifications section.

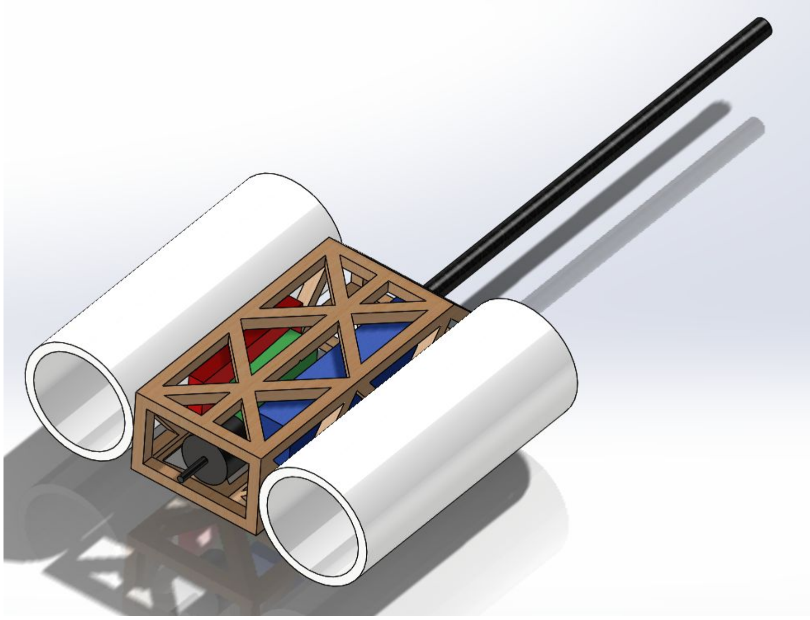


Figure 5: Fuselage Tadpole Design

5.1.3 Design Specifications

Once the final design changes were determined, the next step was to develop the exact specifications for each subsystem of the design. The specifications include dimensions, make/model, and material used to fulfill each subsystem. Subsystem specifications are described below.

5.1.3.1 Drive Specifications

The drive subsystem is broken down into four main components: propeller, electric motor, electric speed controller (ESC), and the battery. The first step was to select a propeller fit for our plane size. If the total weight of the plane is assumed to be 4 lb, and approximately 100W/lb is needed to fly, then approximately 400W of power is needed to fly [6]. 400 W of power is equal to 0.2 glow equivalent, a measurement of gas engine displacement in cubic inches [6]. So, given the propeller chart in Figure 6, the team selected an APC Electric 8"x4.7" SF propeller. This propeller has an 8 inch diameter with a 4.7 inch pitch, and is designed for slow-fly planes.

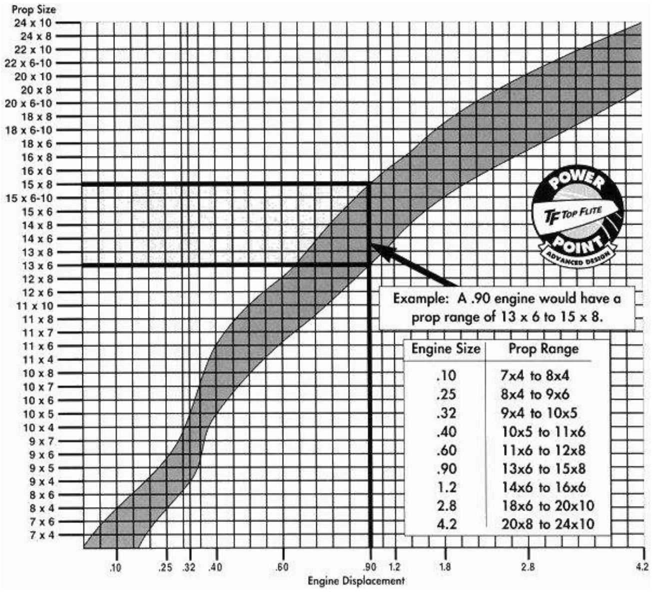


Figure 6: Propeller Selection

Next, there were thousands of motors that could work for our airplane. So, we narrowed our search by choosing from one manufacturer: Scorpion Propulsion. Of Scorpion's hundreds of motors, the Scorpion HK-2520-1880 motor was selected due to its high energy-to-weight ratio, brushless technology, and 800W max power. Furthermore, this scorpion motor is compatible with a Scorpion ESC.
When combined with the APC Electric 8"x4.7" SF propeller, the motor generates a thrust-to-weight ratio of 0.94 under ideal output and 1.20 under max output. These thrust-to-weight ratios suggest desirable flight performance [3].

The final step in drive selection was to select an ESC and battery. The main consideration when selecting an ESC was that the motor will not draw more current than the max rating of the ESC. At max output, the motor draws 41A of current. From this, we selected a Scorpion brushless ESC with a 45A rating. Finally, the battery selection was contingent upon the max electric load and flight time. The max battery discharge the drive will draw is 23C, and desirable flight time is approximately 3-5 minutes. From this, the team selected an 1800mAh 3-cell 35c lithium polymer battery. This battery not only meets the rules, but also can supply up to 50C discharge and a flight time of 4 minutes. All of the drive specifications are listed below in Table 5. Pictures of each component are shown in Figures 7-10.

Table 5: Drive Specifications

Drive Part	Brand/Model	Size	Weight (oz)	Cost ($)
Prop	APC Electric SF 8x4.7	8" dia x 4.7" pitch	0.25	2.45
Motor	Scorpion HK-2520-1880KV	1" dia, 0.8" length (0.63 in^3)	3.64	80.00
ESC	Scorpion Commander 15V 45A ESC SBEC (V3)	2.83"x1.18"x0.32" (1.06 in^3)	1.55	60.00
Battery	Lumenier 1800mAh 3s 35c Lipo Battery	4.1"x1.34"x0.79" (4.34 in^3)	4.94	20.00

Total		6.03 in^3	10.38	162.45

Figure 7: APC Electric 8x4.7 SF

Figure 8: Scorpion HK-2520-1880KV

Figure 9: Scorpion Commander 45A ESC

Figure 10: Lumenier Battery

5.1.3.2 Fuselage Specifications

As shown in the drive specifications Table 5, the fuselage frame must internally house all of the drive components. From this, the required length, width, and depth of the fuselage frame is 6.5”x2.75”x2.5”, respectfully. The 6.5 inch length of the fuselage frame means that the 6 inch chord length of the wings will mostly cover the frame. Also, the 6.5 inch length provides enough support to fasten the external PVC payload. The fuselage frame will be comprised of ¼” thick ABS members and 3D printed to ensure rapid prototyping. The final design of the fuselage frame is shown below in Figure 11.

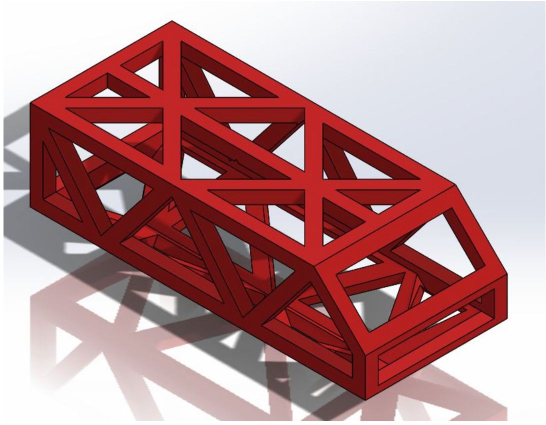


Figure 11: Fuselage Frame

5.1.3.3 Wing Specifications

In order to generate the thrust and lift necessary to fly the plane, the airfoil, wingspan, and chord length must be selected. First, the Clark Y airfoil will be used to generate the lift. The Clark Y is widely used for RC planes and provides a smooth stall entry and sufficient lift. The airfoil is largely flat on the bottom, making it easier to manufacture. The wing shape will be a rectangular platform with a uniform chord length of 6 inches and a wingspan of 52 inches. The long, rectangular wingspan maximizes the lift area and stability of the aircraft. However, in order to fit within the box, the wings must be segmented into four sections of 13 inches. The wings will be constructed out of a balsa wood frame and exterior. The airfoil and wing design is shown below in Figure 12.

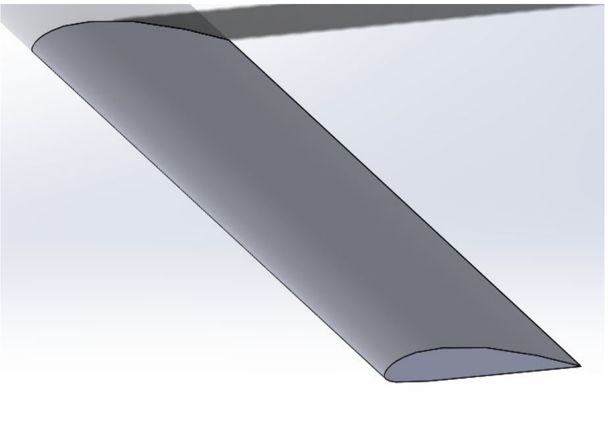


Figure 12: Wing Design

5.1.3.4 Landing Gear Specifications

The landing gear will feature two independent front wheels and a rear wheel that steers the plane upon landing. In order to support landing, the selected wheels are 1.5 inches in diameter and supported by thin aluminum rods 5 inches in length. The 5 inch length of the rods ensures the propeller will not strike the ground upon landing. The rear wheel is 1 inch in diameter and supported by a rod-and-spring suspension approximately 2 inches in length. The front and rear wheels are shown below in Figure 13 and 14.

Figure 13: Front Landing Gear

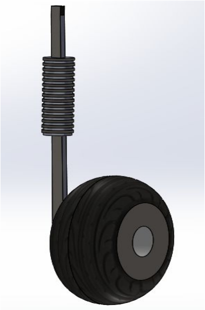


Figure 14: Rear Landing Gear

5.1.3.5 Control Specifications

The fixed-wing plane is operated by a controller and receiver. The controller sends a signal to the receiver, which then sends input to various channels. Our design has a motor, two ailerons, rudder, and rear wheel that will be actuated by the receiver. Each of these components operates on a unique channel within the receiver. This means the design must incorporate a 5-channel controller and receiver pair into the design. Furthermore, the two ailerons, rudder, and rear wheel need an electric motor and linkages to convert rotational energy to linear motion. For this, the team will use four servo motors externally mounted using control horns on the wings, rudder, and tail wing. For example, the rotary motion of the servo motor will push/pull a rod which is fastened to control horn on an aileron. This, in turn, pushes or pulls the aileron, essentially steering the plane while in flight. The servo motors, push/pull rods, and control horns are shown below in Figures 15-17.

Figure 15: Servo Motor

Figure 16: Push/Pull Rods

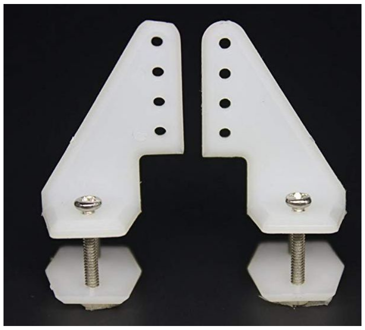


Figure 17: Control Horns

5.1.4 Prototype

The current-state low fidelity prototype features the 3D printed fuselage frame, which successfully houses the receiver, ESC, and battery. The prototype is shown below in Figures 18 and 19. Some key learnings from creating the prototype include mounting procedures for the carbon fiber rod, motor, and landing gear. The next iteration of the fuselage frame will have built-in mounting points for all of the components previously mentioned.

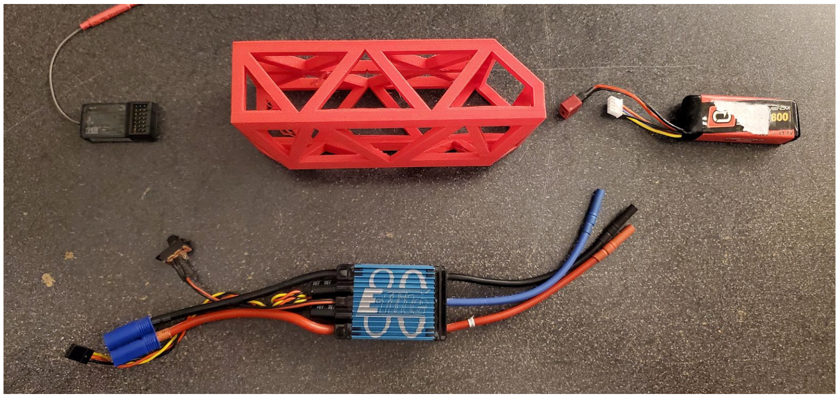


Figure 18: Prototype Exploded View

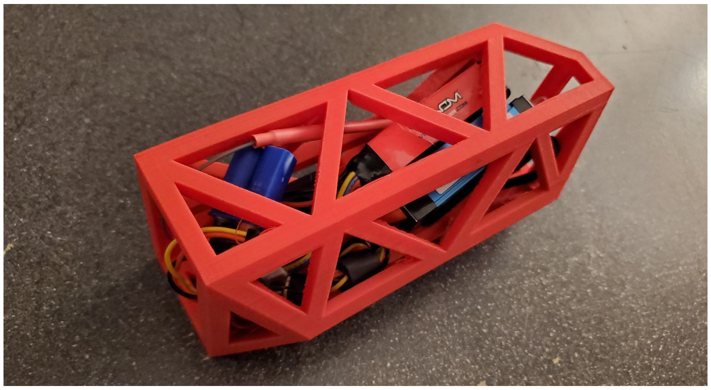


Figure 19: Prototype Housing

5.2 Implementation Plan

This section provides a complete description of how we plan to implement our design. The team has already purchased software necessary to calculate flight data, meaning there is no need to write code or program simulations to predict the thrust and lift required or generated for our design. Furthermore, in-flight operator procedures will be purchased along with the controller and receiver. So, the remaining implementation steps include constructing a prototype, conducting test procedures, and iterating the prototype once completed. A complete list of the implementation plan is provided in Table 6 below. The implementation plan includes the dates, description, and resources needed to carry out the design. A visual schedule of the implementation plan is provided via Gantt Chart in Appendix Figure C1.

Table 6: Implementation Plan

Start	Finish	Description	Resources needed
11/18/19	12/13/19	Purchase all materials	$475 total cost. Use purchasing links to buy items and request refunds through Karine Story
12/16/19	1/10/20	Fabricate base plane prototype (fuselage, wings, landing gear)	Manufacture in-house using purchased materials. Utilize laser cutter and machine shop in bldg. 98C
1/13/20	1/17/20	Weight/center of mass test and assembly test	Weigh in machine shop. Balancing COM test kit and assembly box are available in bldg. 98C.
1/13/20	1/17/20	Conduct drop test	Grass field and yardstick needed for drop test
1/20/20	1/24/20	Re-calculate thrust and lift given exact weight and COM	Use E-Calc software to program exact dimensions and weight to find true thrust and lift desired
1/20/20	1/24/20	Conduct propeller thrust test	Static thrust test in Dr. Schafer's lab
1/27/20	2/7/20	Fabricate and install plane drive mechanisms	Drive materials, base plane, mounting materials, and bldg. 98C needed to install drive
1/27/20	2/7/20	Fabricate and install plane control mechanisms	Control materials, base plane, mounting materials, and bldg. 98C needed to install servos and linkages
2/10/20	2/14/20	Conduct ground check and flight test	Complete plane assembly, safety equipment, and open field (South Fields)
2/17/20	2/28/20	Evaluate design based on flight test and make changes	E-Calc software, research articles, extra materials, Dr. Tester, and bldg. 98C are required for design iteration
3/2/20	3/13/20	Finalize design and prepare for competition	E-Calc software, extra materials ($200), bldg. 98C, and the south fields are needed for design finalization

As shown in the implementation plan, the only costs associated with implementing the design are in purchasing the complete bill of materials and purchasing any extra materials needed for design iteration. All fabrication, installation, and testing will be conducted in-house at NAU for zero cost. Thus, the total implementation cost is $675, assuming $200 for extra materials and $475 for BOM materials. The complete bill of materials is provided in Appendix Table C1. When factoring in registration expenses of $1100, the total project cost becomes $1775. When compared to the $2000 budget, this leaves an extra

$225 for unforeseen expenses.

With the implementation plan in place, the CAD model provides a basic understanding of what the plane will look like. The current-state CAD includes the drive, fuselage, wings, and landing gear subassemblies. However, CAD is missing control components: namely the ailerons, control horns, push/pull rods, and servo motors. Furthermore, the mounting hardware for the payload and the fuselage cover material are not included. The final assembly for the fall semester is shown below in Figure 20. The exploded view of the assembly is provided in Figure 21.

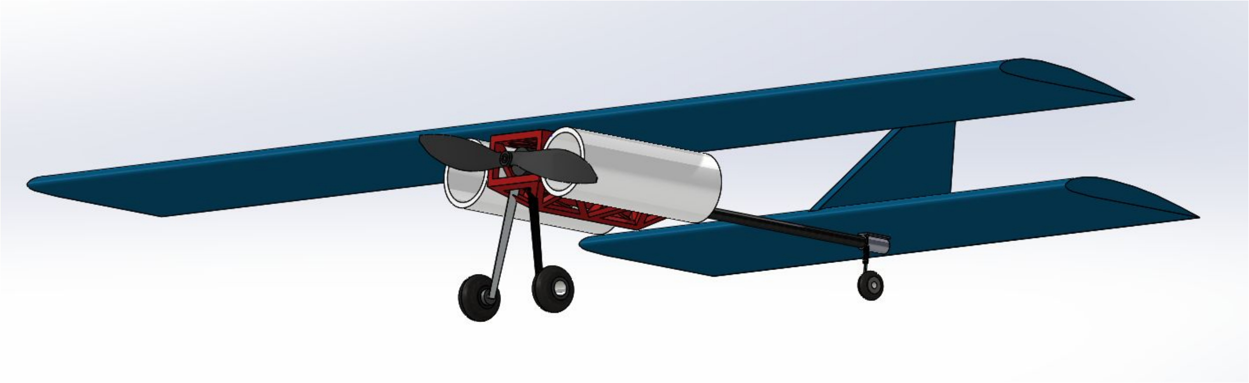


Figure20: Final CAD Assembly Fall Semester

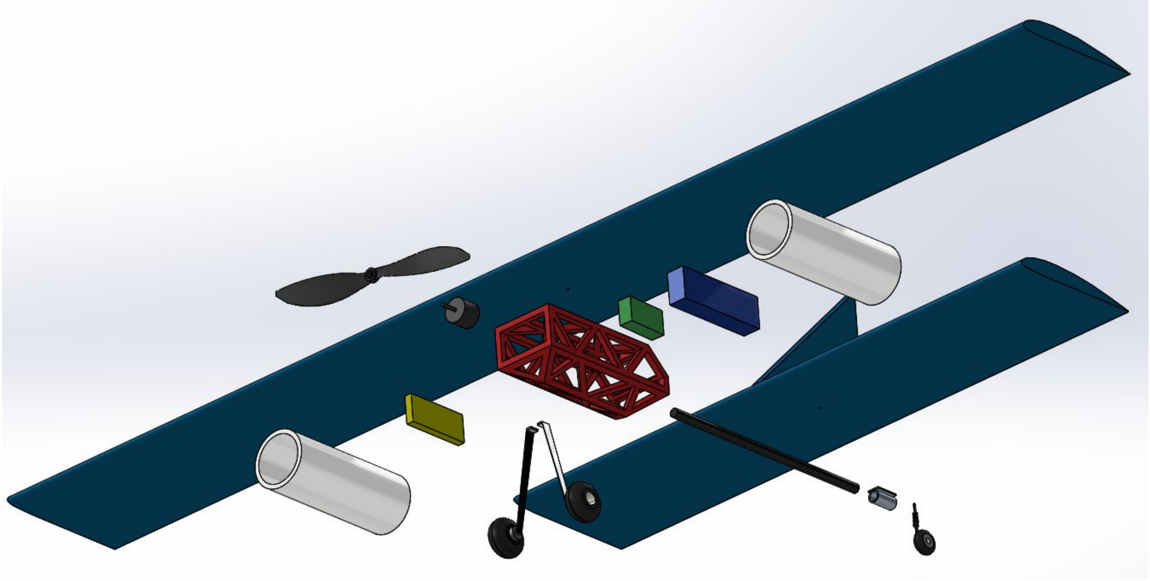


Figure 21: Final CAD Exploded View Fall Semester

6 CONCLUSIONS

The main goals of our project are to successfully design and manufacture a senior capstone design project at NAU and compete in the 2020 SAE Aero West competition in the Micro Class. Thus, our team was tasked to design an aircraft that carries the highest payload at the lowest empty weight. The design must also strictly adhere to a vast set of rules and constraints. Noteworthy constraints include a gross weight limit of 10 pounds, disassembled storage contained in a box 12 ⅛” x 3 ⅝” x 13 ⅞”, electric-only motor, hand-launch takeoff, and battery storage greater than or equal to a 3-cell 2200 mAh capacity. Furthermore, the design must be assembled in less than three minutes. Competition scoring is based on assembly, flight, and the final presentation and report.

Throughout the Fall semester, our team developed a final design proposal for the SAE Aero Micro competition and for our senior capstone at NAU. The first steps included research, benchmarking, and defining customer needs and engineering requirements. Next, the team conducted concept generation by separating the overall design into subsystems and generating design variants for each subsystem. Once combined, these design variants were evaluated and the top-performing design was selected for prototyping.

The final design solution has a single wing design, featuring the Clark Y airfoil with a 52 inch wingspan and 6 inch chord length. The plane is controlled using a dual aileron with rudder setup and servo motors for each mechanism. The landing gear is a rear steer tail-dragger design, supported by thin aluminum rods and 1.5 inch wheels. The plane's power is provided by a 1800mAh battery, 45A brushless ESC, 800W brushless motor, and an 8x4.7 propeller. The fuselage features an ABS frame and carbon fiber rod to house the drive components and connect with the wings and external payload. With a 2-lb payload, the overall weight is assumed to be 4 lbs. The thrust produced by the motor and prop is approximately 60 oz under ideal conditions. Thus, the thrust-to-weight ratio of 0.94 suggests successful flight.

The future steps are to manufacture and test the design. For this, the team generated testing procedures and a design implementation plan. In order to have a functional design by the time of competition, the team must strictly adhere to the implementation plan. The tests conducted on the plane will allow for design validation before competition. Lastly, the proposed design is expected to be iterated, ensuring easier manufacture and greater performance.

7 REFERENCES

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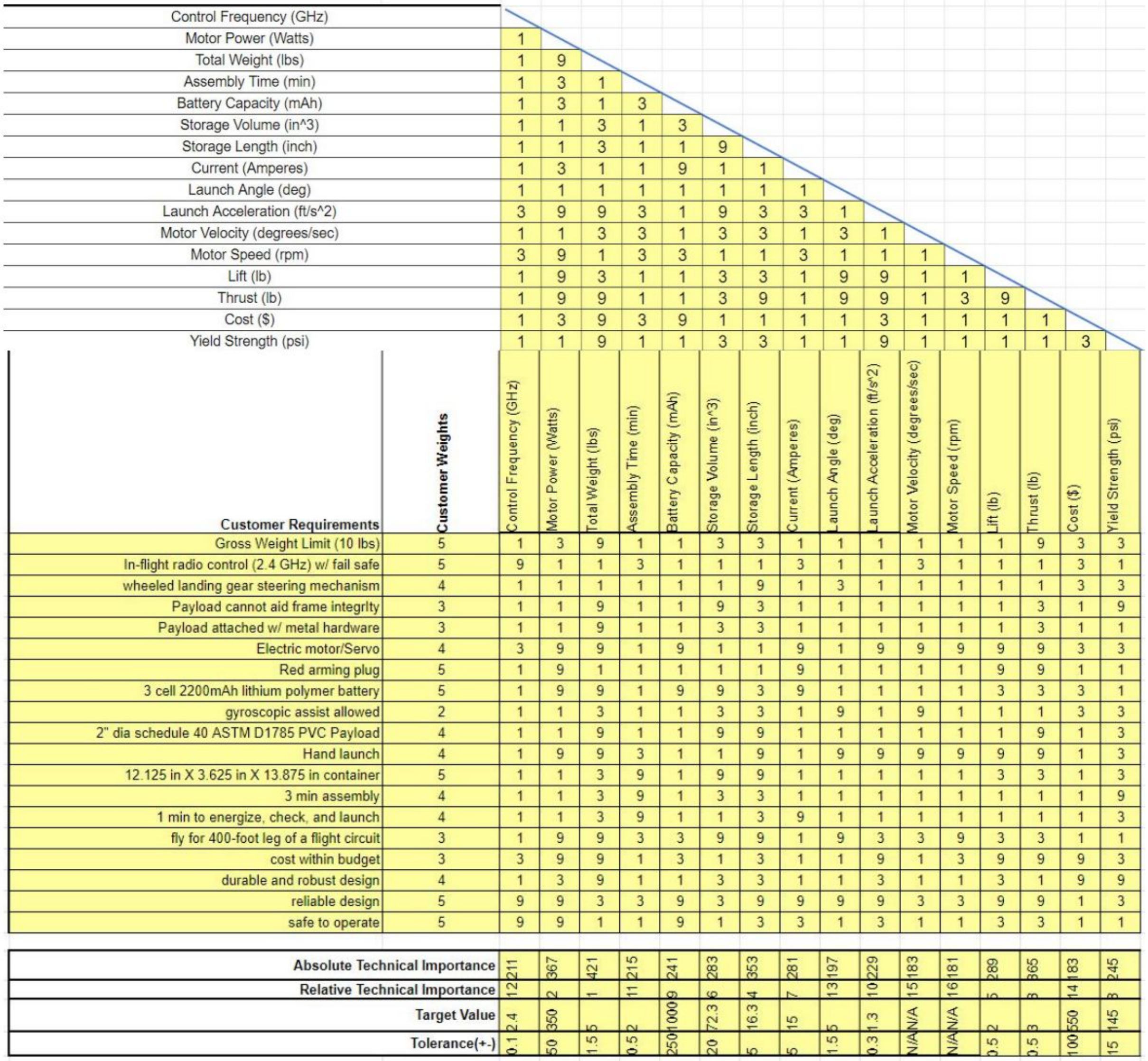
8 APPENDICES

8.1 Appendix A: House of Quality

Table A1: QFD

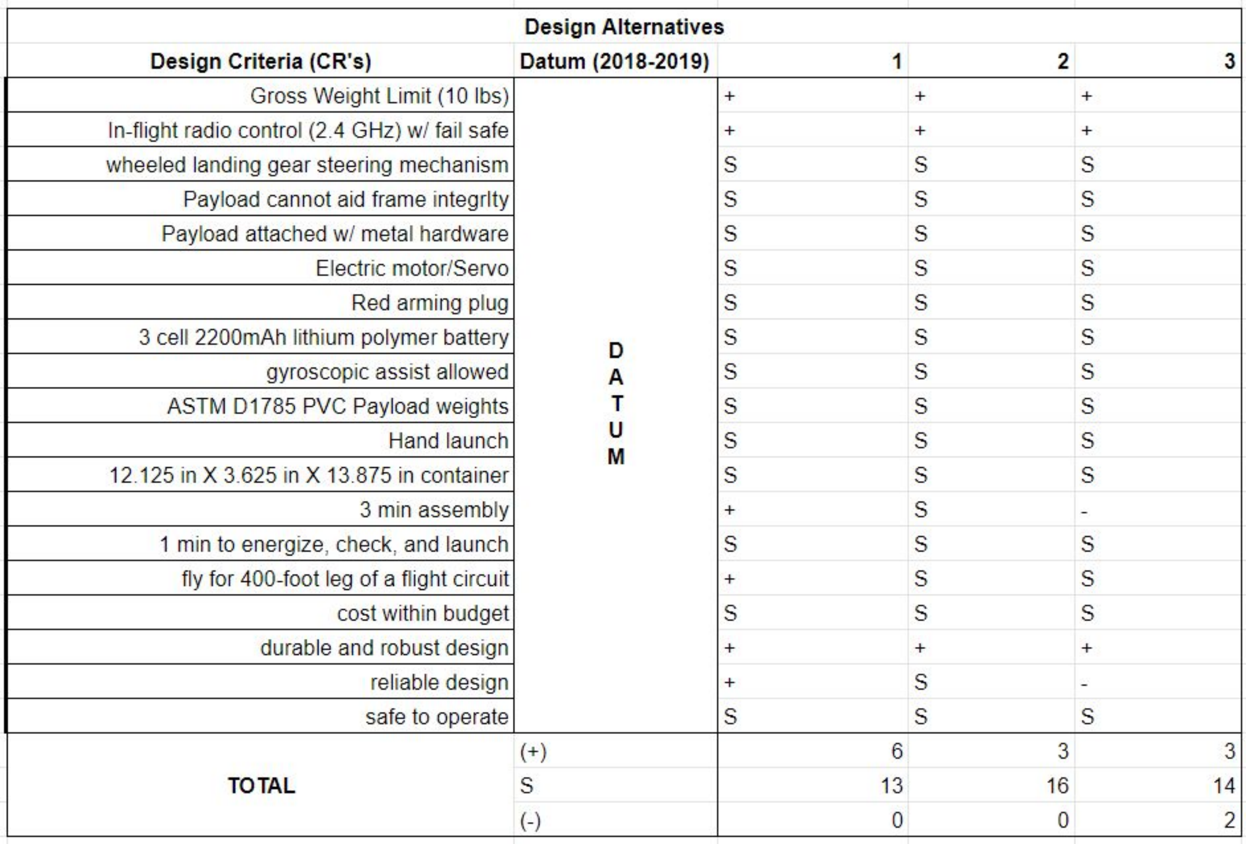


	Control Frequency (GHz)	Motor Power (Watts)	Total Weight (lbs)	Assembly Time (min)	Battery Capacity (mAh)	Storage Volume (in^3)	Storage Length (inch)	Current (Amperes)	Launch Angle (deg)	Launch Acceleration (ft/s^2)	Motor Velocity (degrees/sec)	Motor Speed (rpm)	Lift (lb)	Thrust (lb)	Cost ($)
Control Frequency (GHz)															
Motor Power (Watts)	1														
Total Weight (lbs)	1	9													
Assembly Time (min)	1	3	1												
Battery Capacity (mAh)	1	3	1	3											
Storage Volume (in^3)	1	1	3	1	3										
Storage Length (inch)	1	1	3	1	1	9									
Current (Amperes)	1	3	1	1	9	1	1								
Launch Angle (deg)	1	1	1	1	1	1	1	1							
Launch Acceleration (ft/s^2)	3	9	9	3	1	9	3	3	1						
Motor Velocity (degrees/sec)	1	1	3	3	1	3	3	1	3	1					
Motor Speed (rpm)	3	9	1	3	3	1	1	3	1	1	1				
Lift (lb)	1	9	3	1	1	3	3	1	9	9	1	1			
Thrust (lb)	1	9	9	1	1	3	9	1	9	9	1	3	9		
Cost ($)	1	3	9	3	9	1	1	1	1	3	1	1	1	1	
Yield Strength (psi)	1	1	9	1	1	3	3	1	1	9	1	1	1	1	3

Customer Requirements	Customer Weights	Control Frequency (GHz)	Motor Power (Watts)	Total Weight (lbs)	Assembly Time (min)	Battery Capacity (mAh)	Storage Volume (in^3)	Storage Length (inch)	Current (Amperes)	Launch Angle (deg)	Launch Acceleration (ft/s^2)	Motor Velocity (degrees/sec)	Motor Speed (rpm)	Lift (lb)	Thrust (lb)	Cost ($)	Yield Strength (psi)
Gross Weight Limit (10 lbs)	5	1	3	9	1	1	3	3	1	1	1	1	1	1	9	3	3
In-flight radio control (2.4 GHz) w/ fail safe	5	9	1	1	3	1	1	1	3	1	1	3	1	1	1	3	1
wheeled landing gear steering mechanism	4	1	1	1	1	1	1	9	1	3	1	1	1	1	1	3	3
Payload cannot aid frame integrIty	3	1	1	9	1	1	9	3	1	1	1	1	1	1	3	1	9
Payload attached w/ metal hardware	3	1	1	9	1	1	3	3	1	1	1	1	1	1	3	1	1
Electric motor/Servo	4	3	9	9	1	9	1	1	9	1	9	9	9	9	9	3	3
Red arming plug	5	1	9	1	1	1	1	1	9	1	1	1	1	9	9	1	1
3 cell 2200mAh lithium polymer battery	5	1	9	9	1	9	9	3	9	1	1	1	1	3	3	3	1
gyroscopic assist allowed	2	1	1	3	1	1	3	3	1	9	1	9	1	1	1	3	3
2" dia schedule 40 ASTM D1785 PVC Payload	4	1	1	9	1	1	9	9	1	1	1	1	1	1	9	1	3
Hand launch	4	1	9	9	3	1	1	9	1	9	9	9	9	9	9	1	3
12.125 in X 3.625 in X 13.875 in container	5	1	1	3	9	1	9	9	1	1	1	1	1	3	3	1	3
3 min assembly	4	1	1	3	9	1	3	3	1	1	1	1	1	1	1	1	9
1 min to energize, check, and launch	4	1	1	3	9	1	1	3	9	1	1	1	1	1	1	1	3
fly for 400-foot leg of a flight circuit	3	1	9	9	3	3	9	9	1	9	3	3	9	3	3	1	1
cost within budget	3	3	9	9	1	3	1	3	1	1	9	1	3	9	9	9	3
durable and robust design	4	1	3	9	1	1	3	3	1	1	3	1	1	3	1	9	9
reliable design	5	9	9	3	3	9	3	9	9	9	9	3	3	9	9	1	3
safe to operate	5	9	9	1	1	9	1	3	3	1	3	1	1	3	3	1	1
Absolute Technical Importance		211	367	421	215	241	283	353	281	197	229	183	181	289	365	183	245
Relative Technical Importance		12	2	1	11	9	6	4	7	13	10	15	16	5	3	14	8
Target Value		2.4	350	5	2	1000	72.3	16.3	15	5	1.3	N/A	N/A	2	3	550	145
Tolerance(+-)		0.1	50	1.5	0.5	250	20	5	5	1.5	0.3	N/A	N/A	0.5	0.5	100	15

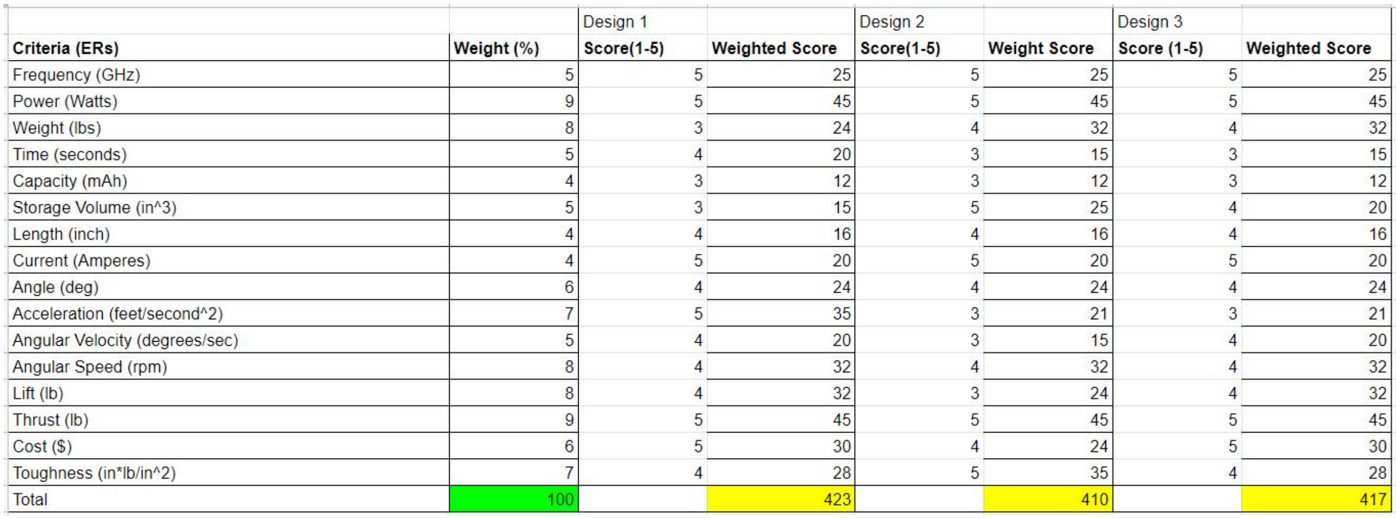
8.2 Appendix B: Concept Evaluation

Table B1: Pugh Chart



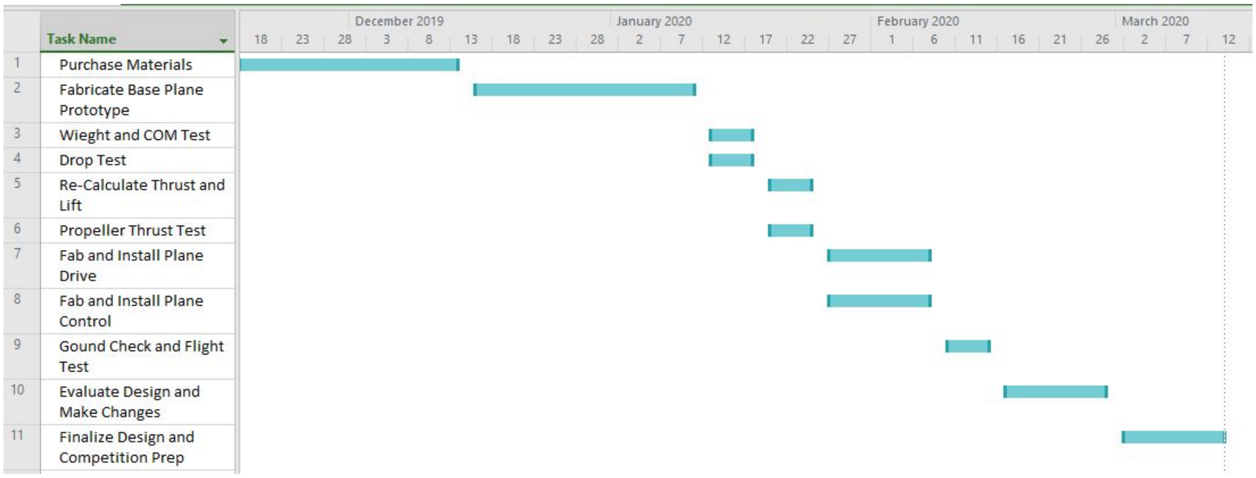
	Design Alternatives			
Design Criteria (CR's)	**Datum (2018-2019)**	**1**	**2**	**3**
Gross Weight Limit (10 lbs)	**DATUM**	+	+	+
In-flight radio control (2.4 GHz) w/ fail safe		+	+	+
wheeled landing gear steering mechanism		S	S	S
Payload cannot aid frame integrIty		S	S	S
Payload attached w/ metal hardware		S	S	S
Electric motor/Servo		S	S	S
Red arming plug		S	S	S
3 cell 2200mAh lithium polymer battery		S	S	S
gyroscopic assist allowed		S	S	S
ASTM D1785 PVC Payload weights		S	S	S
Hand launch		S	S	S
12.125 in X 3.625 in X 13.875 in container		S	S	S
3 min assembly		+	S	-
1 min to energize, check, and launch		S	S	S
fly for 400-foot leg of a flight circuit		+	S	S
cost within budget		S	S	S
durable and robust design		+	+	+
reliable design		+	S	-
safe to operate		S	S	S
TOTAL	(+)	6	3	3
	S	13	16	14
	(-)	0	0	2

Table B2: Decision Matrix



		Design 1		Design 2		Design 3	
Criteria (ERs)	**Weight (%)**	**Score(1-5)**	**Weighted Score**	**Score(1-5)**	**Weight Score**	**Score (1-5)**	**Weighted Score**
Frequency (GHz)	5	5	25	5	25	5	25
Power (Watts)	9	5	45	5	45	5	45
Weight (lbs)	8	3	24	4	32	4	32
Time (seconds)	5	4	20	3	15	3	15
Capacity (mAh)	4	3	12	3	12	3	12
Storage Volume (in^3)	5	3	15	5	25	4	20
Length (inch)	4	4	16	4	16	4	16
Current (Amperes)	4	5	20	5	20	5	20
Angle (deg)	6	4	24	4	24	4	24
Acceleration (feet/second^2)	7	5	35	3	21	3	21
Angular Velocity (degrees/sec)	5	4	20	3	15	4	20
Angular Speed (rpm)	8	4	32	4	32	4	32
Lift (lb)	8	4	32	3	24	4	32
Thrust (lb)	9	5	45	5	45	5	45
Cost ($)	6	5	30	4	24	5	30
Toughness (in*lb/in^2)	7	4	28	5	35	4	28
Total	100		423		410		417

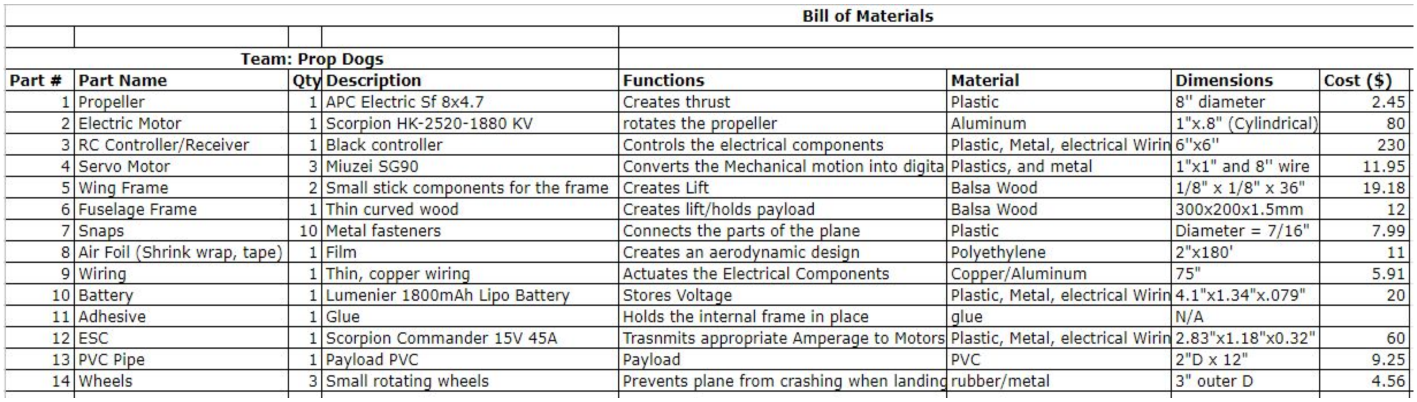
8.3 Appendix C: Implementation Plan (BOM and Gantt Chart)



	Task Name
1	Purchase Materials
2	Fabricate Base Plane Prototype
3	Wieght and COM Test
4	Drop Test
5	Re-Calculate Thrust and Lift
6	Propeller Thrust Test
7	Fab and Install Plane Drive
8	Fab and Install Plane Control
9	Gound Check and Flight Test
10	Evaluate Design and Make Changes
11	Finalize Design and Competition Prep

Figure C1: Implementation Gantt Chart

Table C1: Bill of Materials



				Bill of Materials			
	Team: Prop Dogs						
Part #	**Part Name**	**Qty**	**Description**	**Functions**	**Material**	**Dimensions**	**Cost ($)**
1	Propeller	1	APC Electric Sf 8x4.7	Creates thrust	Plastic	8" diameter	2.45
2	Electric Motor	1	Scorpion HK-2520-1880 KV	rotates the propeller	Aluminum	1"x.8" (Cylindrical)	80
3	RC Controller/Receiver	1	Black controller	Controls the electrical components	Plastic, Metal, electrical Wirin	6"x6"	230
4	Servo Motor	3	Miuzei SG90	Converts the Mechanical motion into digita	Plastics, and metal	1"x1" and 8" wire	11.95
5	Wing Frame	2	Small stick components for the frame	Creates Lift	Balsa Wood	1/8" x 1/8" x 36"	19.18
6	Fuselage Frame	1	Thin curved wood	Creates lift/holds payload	Balsa Wood	300x200x1.5mm	12
7	Snaps	10	Metal fasteners	Connects the parts of the plane	Plastic	Diameter = 7/16"	7.99
8	Air Foil (Shrink wrap, tape)	1	Film	Creates an aerodynamic design	Polyethylene	2"x180'	11
9	Wiring	1	Thin, copper wiring	Actuates the Electrical Components	Copper/Aluminum	75"	5.91
10	Battery	1	Lumenier 1800mAh Lipo Battery	Stores Voltage	Plastic, Metal, electrical Wirin	4.1"x1.34"x.079"	20
11	Adhesive	1	Glue	Holds the internal frame in place	glue	N/A	
12	ESC	1	Scorpion Commander 15V 45A	Trasnmits appropriate Amperage to Motors	Plastic, Metal, electrical Wirin	2.83"x1.18"x0.32"	60
13	PVC Pipe	1	Payload PVC	Payload	PVC	2"D x 12"	9.25
14	Wheels	3	Small rotating wheels	Prevents plane from crashing when landing	rubber/metal	3" outer D	4.56

8.4 Appendix D: Critical Failures

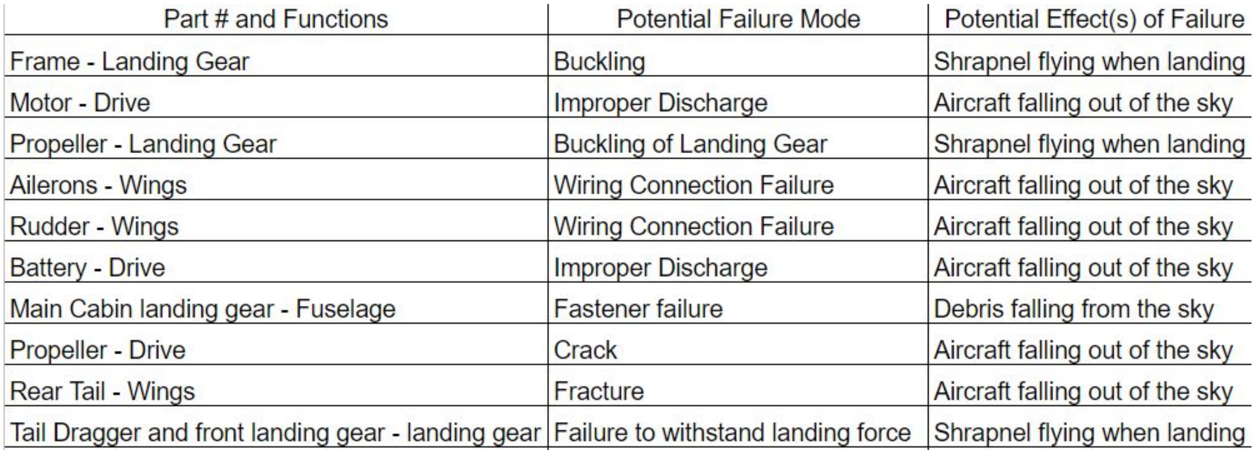
Table D1a: Full FMEA

SAE Aero Micro		Prop Dogs					
System Name							
Subsystem Name							
Component Name							
Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Detection (D)	RPN
Subsystem 1: Drive							
ESC	Improper Transfer of Voltage/Current	Aircraft falling out of the sky	2	Wiring issue	2	8	32
Propeller	Crack	Aircraft falling out of the sky	3	Tolerance Buildup	4	4	48
Propeller	Shaft Displacement	Aircraft falling out of the sky	2	Propeller rotates too fast	2	3	12
Propeller	Fracture	Aircraft falling out of the sky	2	Tolerance Buildup	4	3	24
Battery	Improper Discharge	Aircraft falling out of the sky	3	Overcharged battery	3	7	63
Motor	Deforms Propeller	Aircraft falling out of the sky	4	ESC transfer error to the motor	2	2	16
Motor	Improper Discharge	Aircraft falling out of the sky	5	Motor is too powerful than the battery	3	7	105
Wiring	Connection failure	Aircraft falling out of the sky	4	User error	2	2	16
Drive	Overheating	Aircraft falling out of the sky	6	Rapid testing with no substitution	2	3	36
ESC	Magnetized Interference	Aircraft falling out of the sky	2	ESC is too close to the battery	1	10	20
Subsystem 2: Fuselage							
Main Cabin	Overheating	Debris falling from the sky	6	Drive system heats up corresponding area	2	3	36
Main Cabin	Improper Weight Distibution	Debris falling from the sky	3	Center of Gravity it too far forward	4	2	24
Main Cabin	Fracture	Debris falling from the sky	4	Tolerance Buildup	3	3	36
Main Cabin to Wings	Adhesive failure	Debris falling from the sky	2	Lack of adhesive	3	5	30
Main Cabin to base rod	Adhesive failure	Debris falling from the sky	2	Lack of adhesive	3	5	30
Main Cabin to Payload	Fastener deflection	Debris falling from the sky	3	Payload is too heavy	2	4	24
Main Cabin landing gear	Fastener failure	Debris falling from the sky	3	Tolerance Buildup	4	4	48
Main Cabin to landing gear	Fracture	Debris falling from the sky	3	Tolerance Buildup	5	3	45
Main Cabin to shaft	Fastener failure	Debris falling from the sky	3	Tolerance Buildup	3	4	36
Main Cabin to propeller	Interference	Debris falling from the sky	2	Propeller cannot withstand certain conditions	2	8	32

Table D1b: Full FMEA

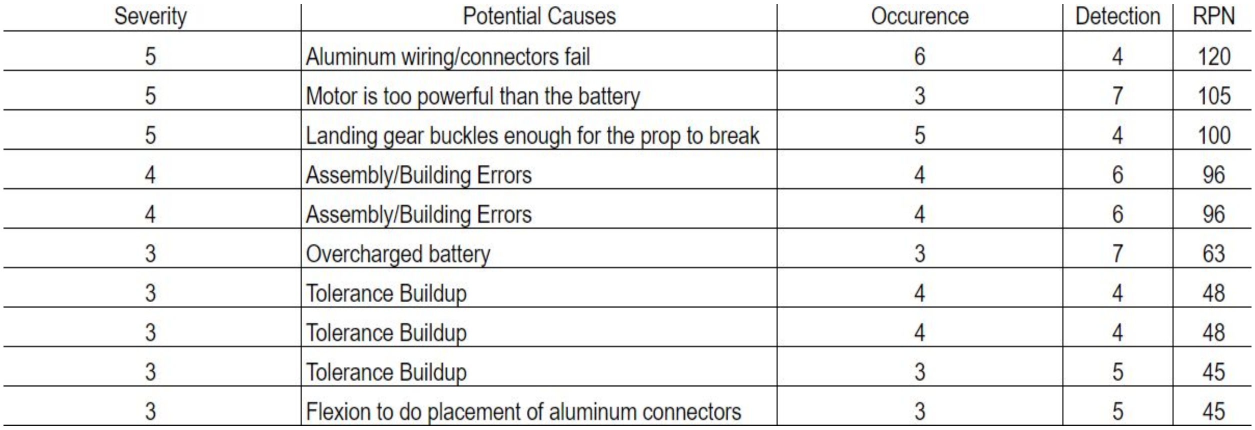
Subsystem 3: Wings								
Wings	Crack	Aircraft falling out of the sky	3	Tolerance Buildup	3	3	27	
Wings	Frame Buckling	Aircraft falling out of the sky	4	Landing	2	2	16	
Wings	Adhesive failure	Aircraft falling out of the sky	2	Lack of adhesive	2	4	16	
Wings	Hinge Disconnection	Aircraft falling out of the sky	3	Assembly/Building Errors	3	2	18	
Rear Tail	Fracture	Aircraft falling out of the sky	3	Tolerance Buildup	3	5	45	9
Rear Tail	Spins uncontrollably	Aircraft falling out of the sky	3	Tail Heavy	3	4	36	
Ailerons	Wiring Connection Failure	Aircraft falling out of the sky	4	Assembly/Building Errors	4	6	96	4
Rudder	Wiring Connection Failure	Aircraft falling out of the sky	4	Assembly/Building Errors	4	6	96	5
Rear Tail	External Forces (Wind)	Aircraft falling out of the sky	2	Area of the tail in addition to the cross wind	2	4	16	
Wings	Fastener Disconnection	Aircraft falling out of the sky	2	Assembly Error	3	5	30	
Subsystem 4: Landing Gear								
Wheels	Condenses	Shrapnel flying when landing	3	Wheels cannot withstand weight	1	3	9	
Frame	Buckling	Shrapnel flying when landing	5	Aluminum wiring/connectors fail	6	4	120	1
Frame	Detaches from Fuselage	Shrapnel flying when landing	3	Worn Adhesive or fastener failure	4	3	36	
Wheels	Crack	Shrapnel flying when landing	2	Landing on uneven terrain	1	4	8	
Frame	Compresses	Shrapnel flying when landing	2	Landing force	2	4	16	
Wheels	Unable to Rotate	Shrapnel flying when landing	2	TIght non-lubed Wheels	2	1	4	
Tail Dragger	Collapses before front wheels land	Shrapnel flying when landing	3	Aluminum alloy connector can't withstand force	3	4	36	
Propeller	Buckling of Landing Gear	Shrapnel flying when landing	5	Landing gear buckles enough for the prop to break	5	4	100	3
Controllability	Landing Gear is offset - Crash	Shrapnel flying when landing	4	Landing Gear/Wheels are not level	2	2	16	
Tail Dragger and front landing gear	Failure to withstand landing force	Shrapnel flying when landing	3	Flexion to do placement of aluminum connectors	3	5	45	10

Table D2a: Top 10 Critical Failures



Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure
Frame - Landing Gear	Buckling	Shrapnel flying when landing
Motor - Drive	Improper Discharge	Aircraft falling out of the sky
Propeller - Landing Gear	Buckling of Landing Gear	Shrapnel flying when landing
Ailerons - Wings	Wiring Connection Failure	Aircraft falling out of the sky
Rudder - Wings	Wiring Connection Failure	Aircraft falling out of the sky
Battery - Drive	Improper Discharge	Aircraft falling out of the sky
Main Cabin landing gear - Fuselage	Fastener failure	Debris falling from the sky
Propeller - Drive	Crack	Aircraft falling out of the sky
Rear Tail - Wings	Fracture	Aircraft falling out of the sky
Tail Dragger and front landing gear - landing gear	Failure to withstand landing force	Shrapnel flying when landing

Table D2b: Top 10 Critical Failures



Severity	Potential Causes	Occurence	Detection	RPN
5	Aluminum wiring/connectors fail	6	4	120
5	Motor is too powerful than the battery	3	7	105
5	Landing gear buckles enough for the prop to break	5	4	100
4	Assembly/Building Errors	4	6	96
4	Assembly/Building Errors	4	6	96
3	Overcharged battery	3	7	63
3	Tolerance Buildup	4	4	48
3	Tolerance Buildup	4	4	48
3	Tolerance Buildup	3	5	45
3	Flexion to do placement of aluminum connectors	3	5	45