# SAE AERO REGULAR

## Final Proposal


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**2020-2021**


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# DISCLAIMER

# EXECUTIVE SUMMARY

The following report will summarize the work of NAU's 2021 SAE Aero, Regular Class, Capstone Team. In this document the team will be providing documentation, data, and other metrics to be able to validate the design and work that taken place over the Spring 2021 Spring semester. Our team, NAU Flight Division has been working on creating and designing an aircraft form the wheels up to meet the qualifications presented by the Society of Automotive Engineers, Aero Design Competition rule book. For 2021 there were a few new rules that changed the way our team needed to look at the competition. While these changes happened in 2020 the competition was canceled due to Covid 19, and due to our team's timeline, we will not be able to compete at this competition this year either. However, the work that we are providing in this document is meant to outline some of the reasons for why as well as how we determined some of the design decision. As well as our thoughts on how to carry the new oversized payload requirements as well as the short takeoff and landing requirements.

# TABLE OF CONTENTS

## Contents

# List of Figures



# List of Tables

# 1 BACKGROUND

## *1.1 Introduction*

In the following document the Society of Automotive Engineers Aero Capstone (SAE Aero) team will be outlining our project thus far and give information to better explain how the team has arrived certain ideas and criteria. The team was tasked to create and produce a prototype aircraft to improve on the previous models. In previous years Northern Arizona University Aero Club (Skyjacks) has participated in this competition. Our Capstone team has been tasked with looking at these previous models and ideas that have been done and to improve them. We need to identify some of the flaws and as well as identify some of the strengths of some of these designs. In doing so we are going to create an aircraft we deem to out compete the previous iterations, by producing a prototype and testing it.

## *1.2 Project Description*

Our sponsor, Dr. Oman gave the following description to the team in preparation for the project, here is the description.

"The SAE Aero Regular Design competition is a real-world design challenge designed to compress a typical aircraft development program into one calendar year, taking participants through the system engineering process of breaking down requirements. The goal of the challenge is to create an RC airplane no greater than 12 feet in wingspan that can compete in an international competition. The challenge this year will be to analyze last year 2019 design to determine how to optimize their system for flight and competition. Prior to the 2019-20 team, the Aero Regular challenge was to create a system that could carry a payload of tennis balls. Last year's 2019-20 rules were changed so that the payload is now a soccer ball."

# 2 REQUIREMENTS

For the SAE Aero Capstone project, the team has been tasked with analyzing and improving the previous design from the 2020 SAE Aero Capstone team. This will require a detailed analysis of the existing design from the previous semester as well as determining the customer needs and requirements for the project. The team will be relating the customer requirements to the engineering requirements and presenting a house of quality in this section of the report.

## 2.1 Customer Requirements (CRs)

The customer requirements are as follows: reliable design, durable and robust, cost, safety of operation, manufacturability, cargo capacity, flight maneuverability, ground maneuverability, lightweight, and stability. These customer requirements were determined by meeting with the client as well as reviewing the SAE Aero Competition rules for the 2020 competition. All customer requirements will be rated on a 1-10 scale with 10 being the most important.

The reliability and robustness and durability of the design are weighted at 7, 8 and 8 respectively. The aircraft will be scored on the best of several iterations of the flight competition, as well as intermediate testing and refinement. This means that the aircraft must be able to sustain multiple flights and landing cycles without critical component failures. The team has also determined that the aircraft should be able to determine non-ideal landing and takeoff cycles without critical failures that prevent the aircraft from performing.

Cost is rated at a 7. Funding is limited for the project budget, and additional funding can only be procured if the project physically cannot be completed within the budget, with a strong submission in writing to the client. This results in a high score, but not a 10 as the client is willing to provide more funds if the project cannot be completed within the budget constraints.

Safety is rated at a 9. Safety is a high priority for the team and the client and therefore is one of the highest rated customer requirements. If an aircraft that cannot safely perform the tasks required in the competition is created, it will not be used by the team in competition. This is a point of high concern for the team as well as the client and will be a consideration for the entire design of the aircraft. The team must be able to maintain positive control over the aircraft at all times.

Manufacturability is a 5 rating. The team will not be producing the aircraft on a large scale. The team must only be able to manufacture and fly one aircraft, so ease of production and mass manufacturing is not a high priority. The team must be able to manufacture the aircraft themselves and that is the only requirement from the client in this area.

Ground maneuverability, flight maneuverability, and stability are rated at 10, 7, and 10, respectively. This is because of the competition rules. The team must have control over the aircraft on the ground with steering wheels if equipped with landing gear and an effective rudder if otherwise equipped. This is due to the safety requirements of the customer needs and the competition rules, as well as the team's requirement for safety. The aircraft also has a high-rating for-flight maneuverability and stability because the team must be able to control the aircraft in flight. Flight maneuverability has a lower score than ground maneuverability because once in the air, the aircraft must be controllable, but the aircraft does not have to be highly maneuverable to complete the assigned tasks. Stability is incredibly important because the team must create an aircraft that will maintain and complete multiple flights without crashing or other failures.

Cargo capacity and weight are the final two customer requirements rated at 2 and 7 respectively.

This is because the other flight characteristics are more important to the team and the competition than the overall cargo capacity. The aircraft must only be able to carry a minimum payload, and anything extra would lead to a higher score in the overall competition. Weight is rated higher due to the constraints on the power allowed on the aircraft. To have enough power to maintain desired flight characteristics for the aircraft, the overall weight must be minimized so that the power available can be allocated effectively for the entire aircraft.

*Table 1: Table of CR and the ranking of impotence*

| Customer Requirements | Number of Importance |
| --- | --- |
| Reliable design | 7 |
| Durable | 8 |
| Robustness | 8 |
| Cost | 7 |
| Safety of operation | 9 |
| Manufacturability | 5 |
| Cargo Capacity | 10 |
| Flight Maneuverability | 7 |
| Ground Maneuverability | 10 |
| Stability | 10 |
| Cargo Capacity | 2 |
| Weight | 7 |

## 2.2 Engineering Requirements (ERs)

The team defined engineering requirements to quantify goals for the customer requirements that the aircraft will be capable of achieving. The first of these engineering requirements is weight(lbs.). The team must have a final design that weighs 55 lbs. or less [1]. The design goal is to have an aircraft that weighs a maximum of 15lbs including the weight of the cargo. This goal weight is decided to maintain a minimum of 45 watts/lb. for the power to weight ratio of the aircraft. This requirement will not be allowed to exceed a tolerance of +2.5lbs. Anything over that will result in unacceptably poor flight characteristics based on the power to weight ratios. Less than 15lbs is acceptable.

Power in watts is the next requirement. The team has a limit of 1000W for the entire aircraft [1]. The team will aim to be as close to 1000 max watts as possible to maximize the flight characteristics of the aircraft and its ability to take off and maintain control of the aircraft at all speeds. The team will aim to minimize the wattage for auxiliary servos and controls responsible for controlling the aircraft so that the team can use the most powerful electric motor system to maintain airspeeds and maneuverability.

Amperage(mAh) and voltage(V) are the next engineering requirement. The minimum allowable amperage is 3,000mAh and the allowable voltage is 22.5V [1]. These are specified by the competition rules and must be met. The only allowable voltage is 22.5V, so there is no tolerance for this parameter. The team will aim to minimize the overall amperage for the aircraft so that the team can use a smaller battery pack with minimal weight. 3,000mAh is the target parameter with an upper tolerance of 4,000mAh.

Takeoff distance(ft) and landing distance(ft) are the next engineering requirements. Per the competition rules, the aircraft must be able to take off in a maximum of 100ft and land in 400ft [1]. The aircraft must meet these requirements. The team aims to have a takeoff distance of 50ft and landing distance of 200ft, with 75ft and 300ft as the upper tolerance limits for each parameter.

Wingspan will be measured in inches. This will not be allowed to exceed 120 inches [1]. The team aims to maximize the wingspan of the aircraft with the current selected design. The team will have a wingspan of 114 inches, with a tolerance of +/- 6 inches. This will allow for changes in the overall design and for ease of manufacture of the overall aircraft.

Cargo capacity will be measured in in^3. The minimum allowable size for the cargo bay is 729in^3 if square and 382in^3 if spherical. This is the minimum allowable size that will accommodate one fully inflated size 5 soccer ball. The team aims to have a cargo bay within 50in^3 for the rectangular cargo bay and 30in^3 for a spherical cargo bay. This will allow for the free movement of the cargo inside the cargo bay without preventing it from exiting the aircraft. Staying within the specified tolerance will also prevent excessive movement of the cargo, potentially impacting the flight of the aircraft.

The speed of the aircraft will be measured in MPH. The target maximum speed of the aircraft will be 20 MPH, +/- 2.5 MPH. This is to maintain a sufficiently high speed so the aircraft will generate enough lift to fly effectively. This value is subject to change as the design develops.

Lift, drag, and thrust will be measured in lbf. Currently, the team does not have specified targets for each. The requirements are that the lift generated must be enough to fly the aircraft effectively at a maximum speed of 20 MPH. Drag force must not exceed the thrust generated by the motor and props. The target lift to drag ratio is 15. The tolerance is +/-5. This is to maintain enough lift to effectively fly the aircraft and maintain effective control.

Durability, reliability, and factor of safety will be measured with numeric values. The targets for each are 4, 4, and 1.2. The aircraft must be able to accomplish at least 4 flight cycles without a failure for both reliability and durability. This is to ensure that the aircraft will perform as expected and it will be capable of repeated testing and competition cycles. Factor of safety for all components will be 1.2 to ensure that each component will withstand initial and repeated cycles as well as being safe throughout each flight cycle.

Table of engineering requirements is available on the next page.

*Table 2: Table of the Engineering requirements.*

| ER's | Units | Quantity |
|---|---|---|
| Weight | pounds | 55 |
| Power per pound | watts/pound | 45 |
| Power | watts | 1000 |
| Batter Amperage | milliamp hour | 3000 |
| Battery voltage | volt | 22.2 |
| Takeoff | feet | 100 |
| Landing | feet | 400 |
| Wingspan | inch | 120 |
| Cargo Capacity | sq inches | 800 |
| Speed | miles per hours | 20 |
| Lift > weight | N/a | N/a |
| Thrust > Drag | N/a | N/a |

## *2.3 Functional Decomposition*

In this section the team is going to break down the main task of our project to understand what needs to be done in order for success. The black box will give a good overview of main objective of our project while the functional model will give a good in depth look at what components need to do what to make something happen.

### 2.3.1 Black Box Model

In this section we will be reviewing the black box model for our teams RC plane design. This is to help the team visualize the main process of our project. This helps identify what is the inputs and what are the outputs.

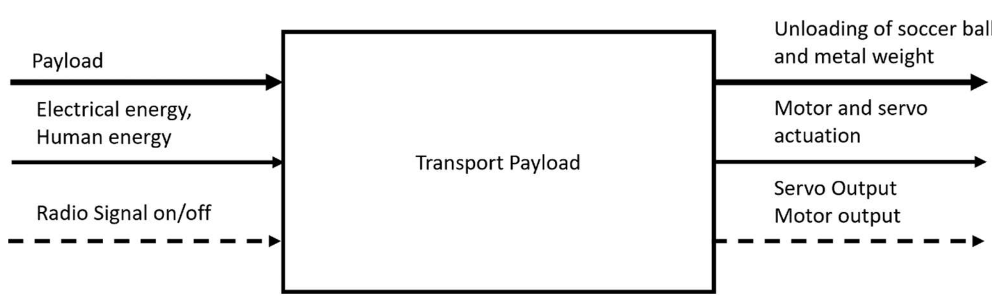



*Figure 1: Black box model*

We pick transport payload as the main idea as this is really the main goal of the competition. We want to pick up a payload and move it and by doing this successfully you complete the requirement for competition. With this as the overarching idea we need to know what it will take to make that happen. For materials in and out of the system they are relatively easy, we are going to add payload (soccer ball, steel weight) and then after a flight will be taking these materials out of the aircraft. For energy, there is a little more. The whole system run on electricity, so we need to include that. There is also Human energy of the person on the ground having to control the aircraft. Finally, there is signal and the signal from the transmitter on the ground will control the aircraft moving the servos and motor. All in all, this black box allowed the team to better understand what we need to do to make the aircraft work from a very overarching point of view.

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

The functional model is a way for the team to see what is going on with our aircraft. It gives a good visual to if this happened than this will happen and allows for the team to easier see what computes to make our project to work. Our function model also demonstrated what needs to go into our system in order to get the responses we want.

There have been no changes to the black box model form the previous report. There were no comments on changing anything nor does the team believe we need to change anything.

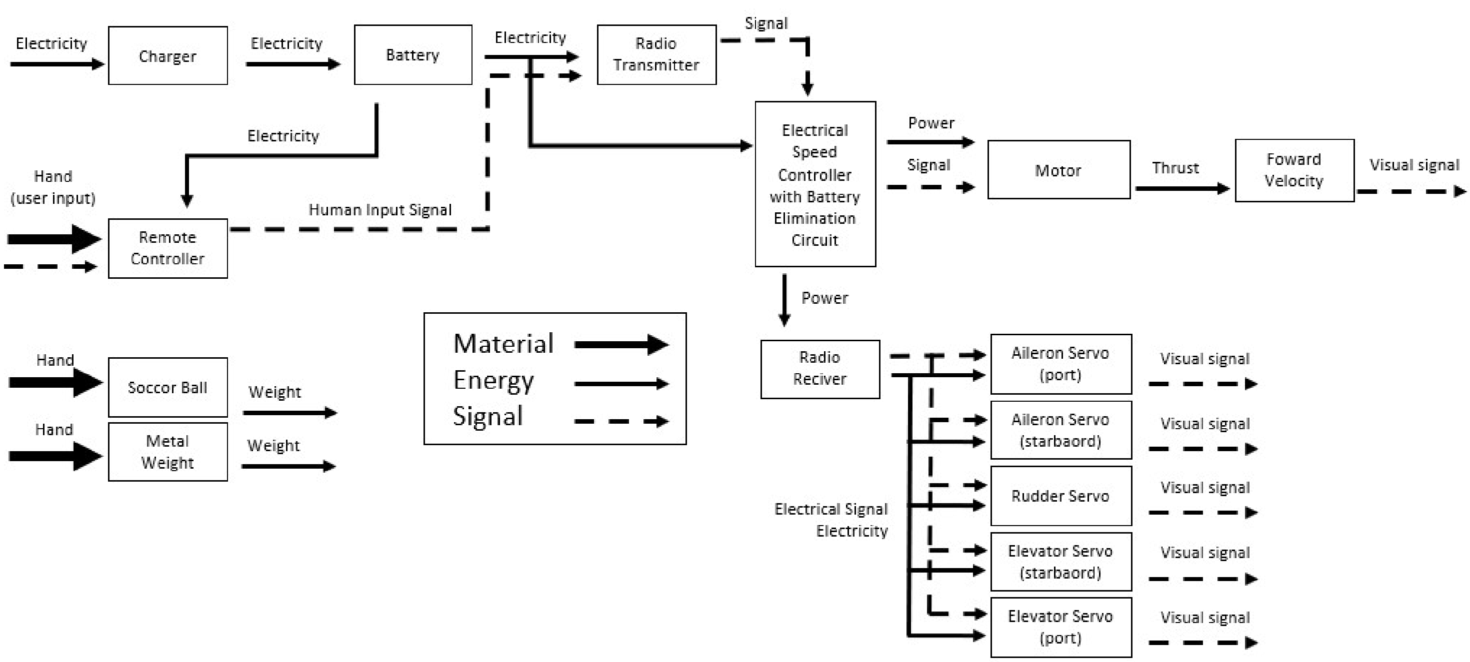



*Figure 2: Functional Model*

## 2.4 House of Quality (HoQ)

The house of quality for space purposes has been placed in the appendices as appendix A.

The house of quality help rates the customer requirements to the engineering requirements. It also helps relate engineering requirements to other engineering requirements. This is created in a matrix that allows for the comparison of two different things. This is helpful as the team needs to evaluate how to relate the CR to the ER and by visually looking at them, it makes sure the team can validate and focus on the ones that are more important than others. While all are important there are always tradeoffs, and you cannot get one thing without sacrificing something else. The HoQ allows for a much easier and quicker visual as the team works on other parts of the project. We can but this up and look to see if we change the wingspan how that could affect everything else in our system. While the HoQ takes time to set up due to the complex thinking of interconnected subcomponents it is useful and has and will be beneficial to the team as we continue to design and prototype our project.

For the testing procedures of the house of quality please refer to the testing procedures section of this report.

## *2.5 Standards, Codes, and Regulations*

The design team is expected to follow the rules of the SAE Aero Regular competition only [1]. This set of competition rules dictates the design constraints and describes what the team's aircraft must be able to do and is the basis for several of the customer needs and constraints for the engineering requirements. The team must also follow the NSPE Engineering Code of Ethics, which is standard for all engineering, even for a small-scale project such as this. This is important because the safety of others is of the utmost importance in all circumstances. The team must also keep in mind the American Society of Mechanical Engineers (ASME) standard on drawings and tolerancing when producing our CAD files as we get ready to produce our design and supply drawing to other to show and depict our design.

# 3 Testing Procedures (TPs)

While the work that the team has put in thus far shows that the aircraft we have designed will fly and preform the way our team has intended we need to make sure that this is the case. Our team has produced everything in the perfect world where we have neglected real world conditions like wind for example. While assumptions like these are necessary to keep the project going, we need to make sure that we did not overestimate our design in any way. To do this the team has set forth the following testing procedures to test all aspects of the aircraft to make sure that it is ready for its maiden test flight.

## *3.1 Testing Procedure 1: Propulsion system*

This crucial part of our design is one of the most important pieces to test. Without proper thrust our aircraft will not be getting off the ground. Failure to get off the ground means that in a competition setting our team would receive a zero form the judges on the scoring rubric.

### 3.1.1 Testing Procedure 1: Objective

Our team needs to see what propeller the best for our application is to provide the best speed for our design. This test will fulfill the speed engineering requirement. Note, this test will only get the static thrust from the propeller. The team plans on developing a way to test the dynamic forces but currently have not found a test method for this.

### 3.1.2 Testing Procedure 1: Resources Required

For this part of testing the team is investigating getting a test stand that is commercially available. This test stand comes with not only the stand but the software to interpolate the data. Below is a table of the data the team can expect to get from the test stand as well as what the test stand looks like.

*Figure 3: Test stand design [10]*

Table 3: Data possible to collect [2]

| **Measured data** | **Data computed by the software** |
|---|---|
| Thrust | Mechanical power |
| Torque | Electrical power |
| RPM | Motor efficiency |
| Current | Propeller efficiency |
| Voltage | Overall system efficiency |
| Temperature | |
| Wind velocity | |

### 3.1.3 Testing Procedure 1: Schedule

Testing motors and propellers should not take too long to run. Our team expects to start running these tests when the fall semester starts to be able to get the data, we need prior to the first aircraft is completely built. This test is a standalone test a simply requires the material to be able to complete the tests.

## *3.2 Testing Procedure 2: Landing Gear Force testing*

One of the biggest issues that previous teams have had at competition is there landing gear not being able to take the impact of landing. While most teams in their reports do not explain what has happened here our team believe that the landing gear is not rated for the force of landing due to most teams are trying to save weight in this area. Our team will also try to save weight as well but are also going to make sure that the landing gear can take a max impact force is the aircraft were to fall out of the sky.

### 3.2.1 Testing Procedure 2: Objective

Our team plans on testing the landing gear as part of the durability and reliability of the aircraft to investigate this engineering requirement as we believe it is an area that can be easily overlooked. Due to competition rules if anything were to fall off the aircraft the team automatically loses their flight score for that round. To make sure that does not happen we will be testing our gear.

### 3.2.2 Testing Procedure 2: Resources Required

To test our gear, we will first need to make the gear, but our team is planning on making a simple test stand that will allow us to drop the landing gear from specific heights and add weight to do load testing. The stand will be relatively simple and most likely scrap two by fours that will have a hinge at one end. This will give use a moment arm to adjust the weight and force that the gear will experience to make sure our design is strong enough for worst case scenario.

### 3.2.3 Testing Procedure 2: Schedule

This test is once again a stand-alone test and can be done at any point before the end of the semester. The design for the gear is to make it replaceable in case we do find out that the design is insufficient we can make a new set of gear and bolt it on. Due to this testing can be performed when after our gear is manufactured.

## *3.3 Testing Procedure 3: Lift, Thrust, Drag, and Weight*

Another important part of the aircraft is overcoming weight and drag to produce enough lift and thrust so that the aircraft will fly. For testing procedure three we will be looking at how to test the lift and drag, one of the engineering requirements.

### 3.3.1 Testing Procedure 3: Objective

The objective is to make sure that the aircraft flies and overcome the weight and drag forces.

### 3.3.2 Testing Procedure 3: Resources Required

For our team to be able to test these four forces on the aircraft we will continue to use simulators to validate the design but eventually we will need to test the aircraft in real life therefore we will need to have an aircraft built and complete and ready for flight to test it. We will also need a location to do this. Most likely a local air strip outside of town that is suited for RC plane flight.

### 3.3.3 Testing Procedure 3: Schedule

This test is dependent on the aircraft being fully functioning and ready to fly due to this we will need to have the aircraft built which mean that this is time dependent on how long it takes for our first iteration to be complete.

## 3.4 Testing Procedure 4: Power Amperage Voltage

To be able to run the electronic components of the aircraft we are going to need to test the system to see what kind of power the team can get out of the components.

### 3.4.1 Testing Procedure 4: Objective

The objective is to see what kind of volage the battery supplies. Even when they are rated at a certain voltage, they never give the number on the battery. To see what these values are the team will hook up the electrical harness and be able to test each junction of the harness. This will fulfill the engineering requirement for power, amperage and voltage.

### 3.4.2 Testing Procedure 4: Resources Required

The team will connect all components to the wiring harness of the aircraft, and this will allow for the use of a voltage meter to see what each component is getting and what is the max power draw on the battery.

### 3.4.3 Testing Procedure 4: Schedule

This test is dependent on getting all the components of the aircrafts electrical system as well as what motor the team will go with prior to this test. The team will need to complete Test 1 in this document prior to test 4.

## 3.5 Other testing procedures

The only engineering requirements that were not discussed in this section were the wingspan, cargo capacity and takeoff and landing distance. For the cargo space this is available via the computer aided design and therefore does not require a testing procedure. Wingspan will be double check with a take measure but the same as the cargo capacity the team will get this number from the CAD. Lastly the takeoff and landing distance. This will be tested but this will get tested during the same time as the tests for lift and drag and due to this there was no need for an additional section. If the aircraft does not get off the ground than this criterion is not meet if it is then the criteria will be check for the distance on both takeoff and landing. This should sum up the rest of the engineering requirements and give the team empirical ways to prove these parts of the aircraft and their functions.

# 4 Risk Analysis and Mitigation

In this section the team will be looking at possible modes of failure and how detrimental each component is to the aircraft. We will have more in the FMEA in the appendix but due to the rules of competition there are only two ways this can go. We either lose our aircraft, due to a system failure or we lose that round at competition due to the rules. Either way these are both bad options, and with this in mind the team is going to try and mitigate these issues through rigorous testing.

## *4.1 Critical Failures*

### 4.1.1 Potential Critical Failure 1: Fuselage Breach

According to the rules and regulations of the SAE Aero 2021 Competition [1], the payload may not at any point be exposed to air flow during flight, meaning that the payload must be fully enclosed inside the fuselage during flight. If the payload is ever exposed during flight, that run will be automatically discounted and the team will not earn points for that run. For this reason, any failure that results in exposure of the payload has been considered a critical failure.

One such failure is a breach of the fuselage. A breach in the fuselage would result in airflow across the payload and other, less predictable and potentially negative results. The fuselage acts as a control surface, so if a significant amount of that surface is lost in a breach, the aircraft may experience increased drag, decreased lift, or potentially crash.

A fuselage breach would most likely be caused by wear of the outer material of the fuselage or a rip or tear of the outer fuselage material. The best way to mitigate this type of failure is to create a detailed flight checklist to perform checks on the aircraft before every flight and to ensure the material can handle expected forces due to takeoff, turbulence, and wind gusts.

### 4.1.2 Potential Critical Failure 2: Fuselage Hatch Failure

Another failure that would expose the payload to airflow is a failure of the fuselage hatch, in which the latch for the hatch either comes unlatched or the hatch comes off completely. This would also result in unpredicted flow across the fuselage, likely leading to increased drag and decreased lift.

This type of failure would likely be due to either improperly latching the latch mechanism on the hatch or wear on the latch mechanism and hinges that allow the hatch to close. To mitigate this type of failure, the team should include checking the latch and hinges in their detailed flight checklist and ensure the latch is properly enclosed and secure before flight. The team may also consider using multiple latches or perhaps even quick release pins, supposing they do not affect flight coefficients too much, to ensure the hatch remains closed during flight.

### 4.1.3 Potential Critical Failure 3: Structural Rib Failure

As defined by the team, a structural rib failure would be any permanent bend or break in one or multiple structural ribs in the aircraft. This type of break would severely change the flow across the aircraft and likely result in a crash if the failure were not caused by a crash in the first place. It should be noted that an aircraft crash would result in a terminated run and the team would not receive any points for that run. The fuselage ribs would also be very difficult to replace, especially during the competition, making this a critical failure.

A structural rib failure would likely be due to either a crash or wear on the ribs due to bending moments induced by the wings. The best way to mitigate this is to add checking the fuselage ribs to the detailed flight checklist, ensure all the team members are well versed in flying the aircraft, and to ensure the rib structure can handle the bending moments that are expected to be induced on the ribs by the wings.

### 4.1.4 Potential Critical Failure 4: Control Surface Failure

Malfunctioning of control surfaces such as Ailerons, Elevators, Rudder and associated servos will cause critical aerodynamic instability, and a shift of the center of mass of the aircraft along its principal axes. The yaw, pitch and roll will be unpredictable, and this would lead to an unrecoverable stall. Flight control surfaces also maintain the maximum angle of attack and lift throughout the flight-course and failure of the control surfaces will result in an altitude drop, potentially leading to a crash.

Such malfunctions are rare. However, if flight control surface failures do happen, it would likely occur due to the failure of cables, pulleys, pushrods and servos connected to the cockpit and/or radio controls due to fatigue, stress and foreign object obstructions. The best way to avoid this scenario is by conducting a rigorous preflight check. The pins, counterweights and other exposed components will be checked during preflight but uncommon failures could still happen during flight. In those cases, the best approach is to program the flight control system in such a way that would automatically override the failing control surfaces through the others to maintain altitude. Increasing the power will also temporarily help maintain altitude. Then, the best route to take is to proceed with an emergency landing of the aircraft. Ground effect will be an important factor in the follow up process of safely gliding the aircraft into a (controlled) crash landing.

### 4.1.5 Potential Critical Failure 5: Flight-Control-System (FCS) Failure

This critical failure has a high chance of occurrence if the on-board flight control system and the ground radio control interface loses communication. Those systems could also fail by themselves due to software and firmware malfunctions. Radio control gear typically consists of a transmitter, receiver and servos. Any external electrical or magnetic current will cause interference and would cause radio reception problems. Fluctuating weather patterns also pose a risk towards radio reception problems. There problems can be easily mitigated. Using a GHz radio will increase the stability of the radio signals and using a wider external antenna would increase the operating range of the aircraft. In an instance of the on-board FCS failing, there's nothing to be done to mitigate a crash scenario. A secondary fail-safe system could be utilized to handle such a problem and safely land the aircraft.

### 4.1.6 Potential Critical Failure 6: Structural Failure of Wings

Catastrophic structural failure of the wings will occur due to fatigue and external stresses. Aircraft wings could also experience oscillating stresses causing the wings to repeatedly bend up and down with the energy accumulating increasing at a steady state. Even though this won't cause commercial aircraft wings made of Aluminum to snap off because it's mathematically impossible, it has a high chance of snapping off the team's balsa-wood wings. These problems can be avoided by running a highly accurate FEA and CFD study on the aircraft. This should be conducted by a skilled engineer who's competent at engineering analysis. A limit load can be calculated, and this will establish the maximum g-force limit the wings can withstand before plastic deformation occurs. Failure due to other external stresses and friction can be avoided by selecting the right materials, and by fabricating a sturdy rib structure. Good lubrication of the connecting surfaces is also necessary to negate friction.

### 4.1.7 Potential Critical Failure 7: Landing Gear Yielding

This failure mode would likely occur due to an extreme impact in combination with another critical failure mode. It is unlikely that this failure mode would occur on its own. The failure could occur if the aircraft were to impact the ground directly on a single side of the landing gear from a relatively large height

(50+ ft) while at cruising speed, or while making descent towards the landing area. These problems will be avoided by ensuring that the landing gear are designed such that each of the two sides of the landing gear can withstand the extreme impact from height while cruising instead of a normal controlled landing. This will ensure that the aircraft landing gear will be able to survive the impact with the ground without damaging the fuselage or wings directly, minimizing potential damage. This will be avoided by initially calculating the worst possible impact and designing the aircraft accordingly, then performing an FEA of the aircraft landing gear that meet the force requirements. Fatigue is not a large concern because of the difference between the normal operating forces, the crash forces, and the amount the aircraft will be flown. Normal operation will have few forces, and the aircraft will not be used extensively, so number of landing cycles will be in the dozens at most, so fatigue is not a critical failure mode.

### 4.1.8 Potential Critical Failure 8: Damaged Fuselage

This failure would occur if the fuselage were damaged or punctured in some way. It would cause an excessive source of drag on the aircraft that would impede the flight controls and reduce the effectiveness of the overall design at flying through the air. This would potentially lead to damage of control surfaces or loss of control of the aircraft. The worst case of this failure would be that the skinned fuselage panels could induce enough drag so that the panels would become further damaged and cause the aircraft to fail. The team will avoid this failure by visually inspecting the aircraft before each flight to ensure that all panels and the entire fuselage are undamaged and in good condition for the flight. This would prevent a catastrophic failure and damage or destruction of the aircraft.

### 4.1.9 Potential Critical Failure 9: Poor Control Surface Assembly

This failure consists of failure to assemble the control surfaces onto the aircraft properly. This would result in potentially lose control surfaces, or the shearing of connections that cause a control surface to no longer function or remove itself from the aircraft entirely. This would result in a loss of control and a crash of the aircraft. This would cause catastrophic damage to the aircraft, especially if the failure occurs during a maneuver. This failure can be avoided by properly tightening all the fasteners for the construction of the aircraft to ensure that at initial takeoff all components are properly connected and secured. In subsequent flights, the team would check and re-tighten all fasteners as needed to ensure that no components have come lose during use and that this critical failure will not occur during the flight of the aircraft.

### 4.1.10 Potential Critical Failure 10: Thrust

If the team was to lose the propulsion system for this aircraft the team would be dead in the air with no way to get to the ground nicely. While commercial aircraft can guild to the ground for safety reasons our design does not have this safety feature as we are asking for as much lift as possible and this increases drag and if the motor is lost the team will not have enough airflow over out control surfaces to land the aircraft. We have made this decision because of the fact that the team wants to push the envelope of the aircraft but in doing so we are afraid we have lost this safety feature.

## *4.2 Risks and Trade-offs Analysis*

During every design there are always tradeoff. For your project a lot of our design trade off were driven due to the competition rules. For example, carrying two soccer balls can help your flight score but by carrying two your payload compartment will be bigger, and this detracts from you flight score. Due to this the team is only going to do one soccer ball. Other things like wingspan and max weight are also part of our flight score and we are trading off less cargo for smaller wingspan which will help our flight score. With regards to risk once again this is trade off, our team does not want to add any extra weigh to the aircraft then necessary. By doing this we are spec'ing some of the lightest components which does not always mean better. This is a risk but due to the safety that is in place at competition and the fact that no life is in immediate danger, we are mitigating the risk of injury in that regard while raising the risk of aircraft failure. This is a trade off we think will be okay as we are rigorously testing our design before it takes its maiden flight.

# 5 DESIGN SELECTED – First Semester

This chapter explores the current final design, and the methodology behind the creation of the design. The design description will fully describe the current model with a thorough explanations of how the design has changed since presented in the preliminary report, and why those changes were made. The implementation plan will provide a complete description of the team's plan to implement the design by fabrication, programming simulations, writing software and future physical and operational changes.

## 5.1 Design Description

### 5.1.1 Improvements from the previous CAD model

*Figure 4: Previous CAD model*

Illustrated above is the previous CAD model that gives a basic representation of the geometry of the team's design. Illustrated below, is the improved CAD model with a complete wing and rib structure that includes the final airfoil. Changes to the airfoil will be discussed later in this chapter. The propeller is only modelled for display purposes as the team will be buying a propeller from the market. The landing gear is accurate, and the fuselage is currently an open body. In other words, the fuselage will be fully closed on a future update on the CAD model. For now, it only visualizes the fuselage geometry, positioning of the payload, and the center of mass of the model.

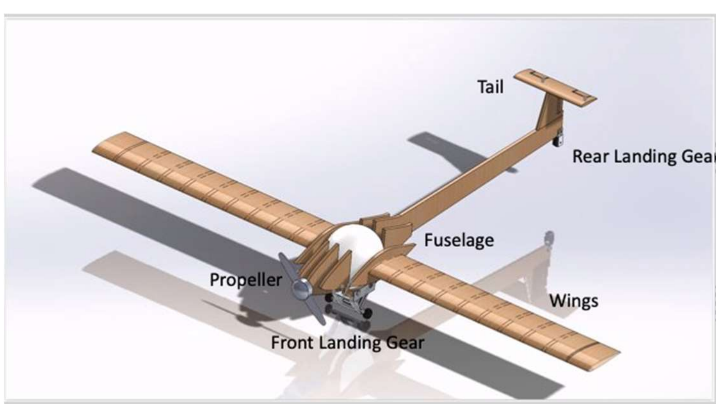



*Figure 5: Current CAD model*

### *5.1.2 Current CAD Assembly – Detailed Description*

Illustrated below, is the wire-frame engineering drawing of the final CAD model. Notice the rib structure that contains the NACA 2412 airfoil. Detailed engineering drawings with dimensions of the sub-assemblies can be accessed by referring to Appendix B.

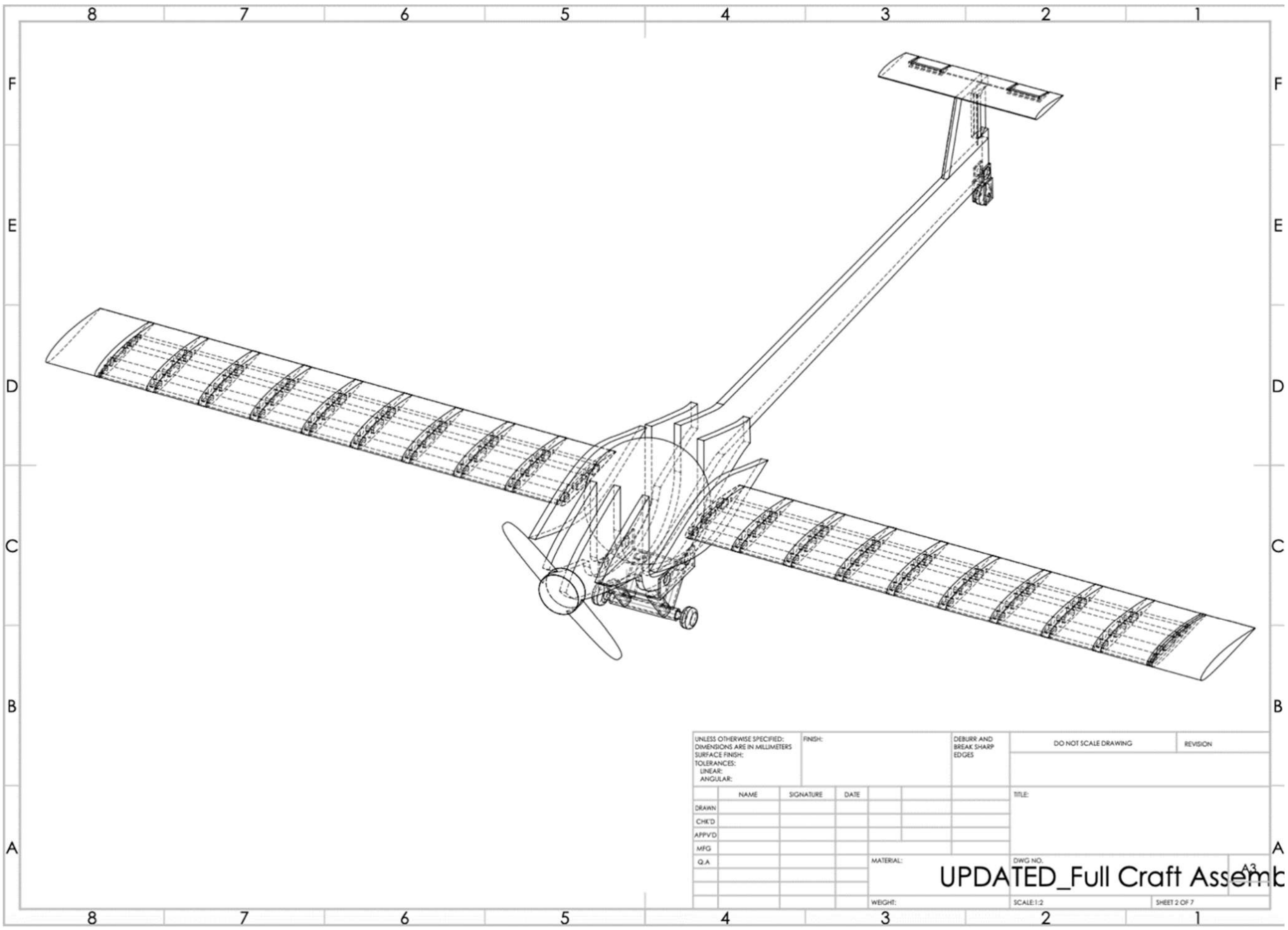



*Figure 6: Final CAD Assembly: Engineering Drawing*

The aircraft's fuselage and wings are sourced from Balsa Wood, as the material properties of Balsa Wood perform well under the aircraft operating parameters. The wings are based on a NACA 2412 airfoil, and it includes 10 individual airfoils expanded and connected via a rib structure to get a maximum total wingspan of 6.56168 ft. The ailerons and elevators are not modelled on the CAD assembly yet and will be included in the future. The T-tail has two "tailerons" and connects to the top of the rudder. The payload will be between the wings to achieve the best center of gravity for the team's aircraft. Stress concentrations will be high around this area and further improvements are being made to negate the stress concentrations at this location. The main landing gear consists of two wheels attached directly to the fuselage without any reinforcing bars. The secondary landing gear is a singular wheel connected to the tail of the aircraft to maintain structural integrity during taxiing, takeoff and landing. The propeller will be twin blade and it will be purchased from a commercial manufacturer.

### *5.1.3 Airfoil Selection Process and Engineering Analysis*

After a thorough airfoil batch analysis, the team selected a NACA 2412 airfoil. The analysis was initially done on OpenVSP and QBlade. Through the course of the project, the team's airfoil engineer and wing design team lead moved on to using the software XFLR5 for the airfoil analysis. For the first part of this study, an individual analysis was conducted on NACA 2414, 2314, 2312, 1414 airfoils with the following conditions at standard atmospheric pressure.

The purpose of this analysis was to graphically estimate the maximum and minimum angles of attack, alpha. Therefore, the angle of attack was varied from -5 degrees to +14 degrees with increments of 10 degrees.

Airfoil Wingspan: 1 meter(s)

Chord Length: 0.2 meter(s)

Reynolds Number: 107 000

Mach Number: 0.044

Ambient Temperature: 20 deg. C

The analysis was run on XFLR5 by using the vortex panel method with every airfoil being globally refined by 100 panels. The Reynolds number was calculated for a low, cruising altitude with constant velocity. The findings are as below. The boundary layer is displayed in *red* for some figures.

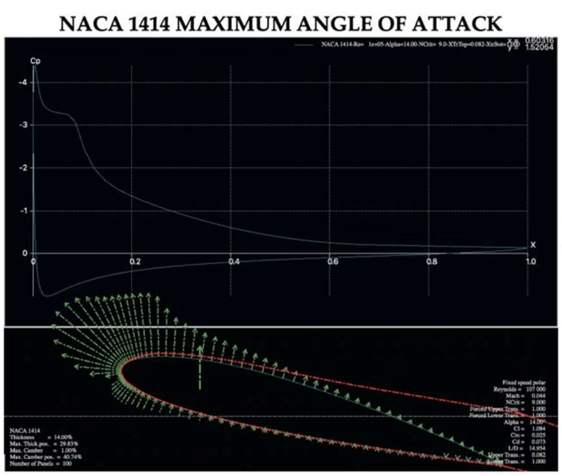



*Figure 7: NACA 1414 Pressure forces*

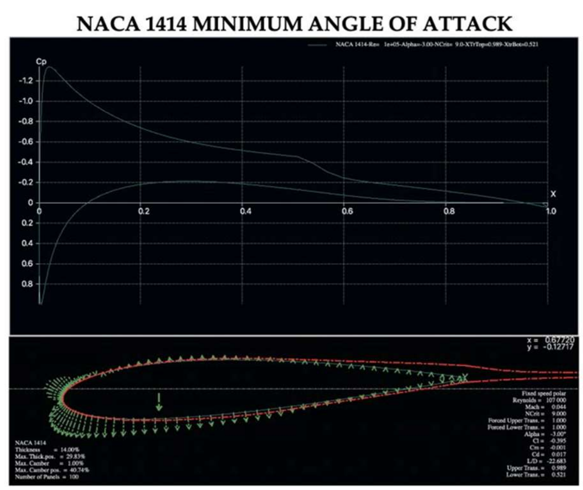
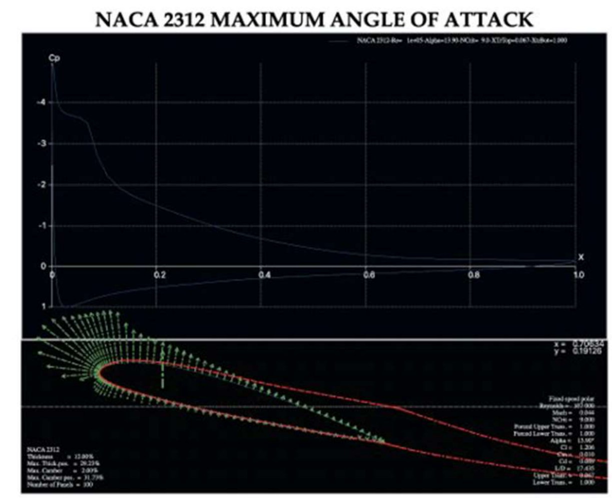



*Figure 8: NACA 1414 Pressure forces*



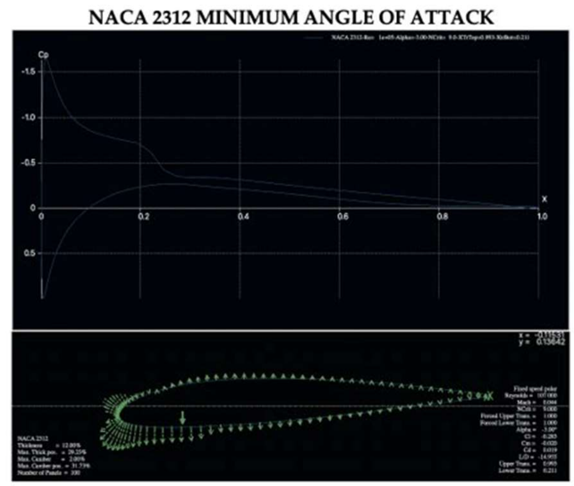
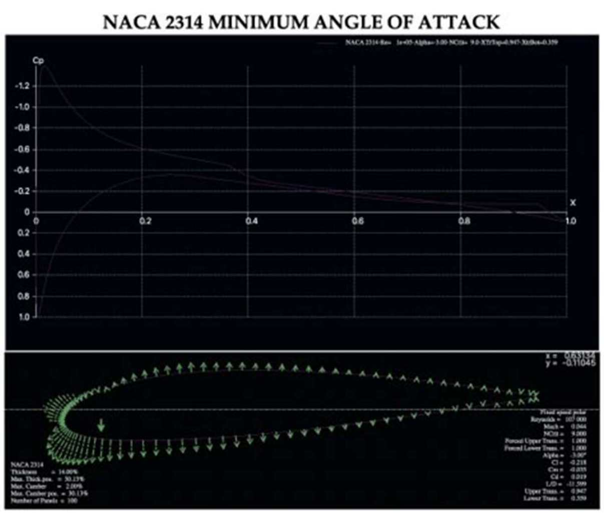




*Figure 11:NACA 2312 Pressure forces*



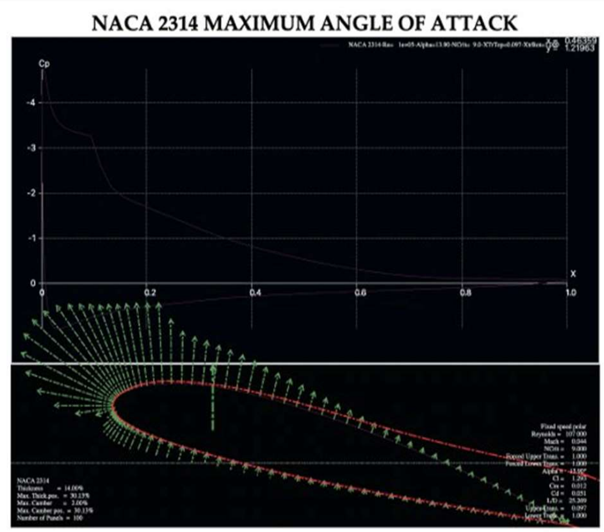




*Figure 10: NACA 2314 Pressure forces*

*Figure 9: NACA 2314 Pressure forces*

For the batch study, multiple Reynolds numbers, Mach numbers and a range of attack angles were used to compare the performance of all the airfoils. The wingspan, chord length and ambient temperature is the same as before.

*Table 4: Data imputed into XFLR5*

| | |
|---|---|
| Airfoil Wingspan: | 1 meter(s) |
| Chord Length: | 0.2 meter(s) |
| Reynolds Numbers: | 50 000, 107 000, 150 000 |
| Mach Numbers: | 0.0, 0.044 |
| Ambient Temperature: | 20 deg. C |
| Alpha: | -0.3 degrees to +13.9 degrees |

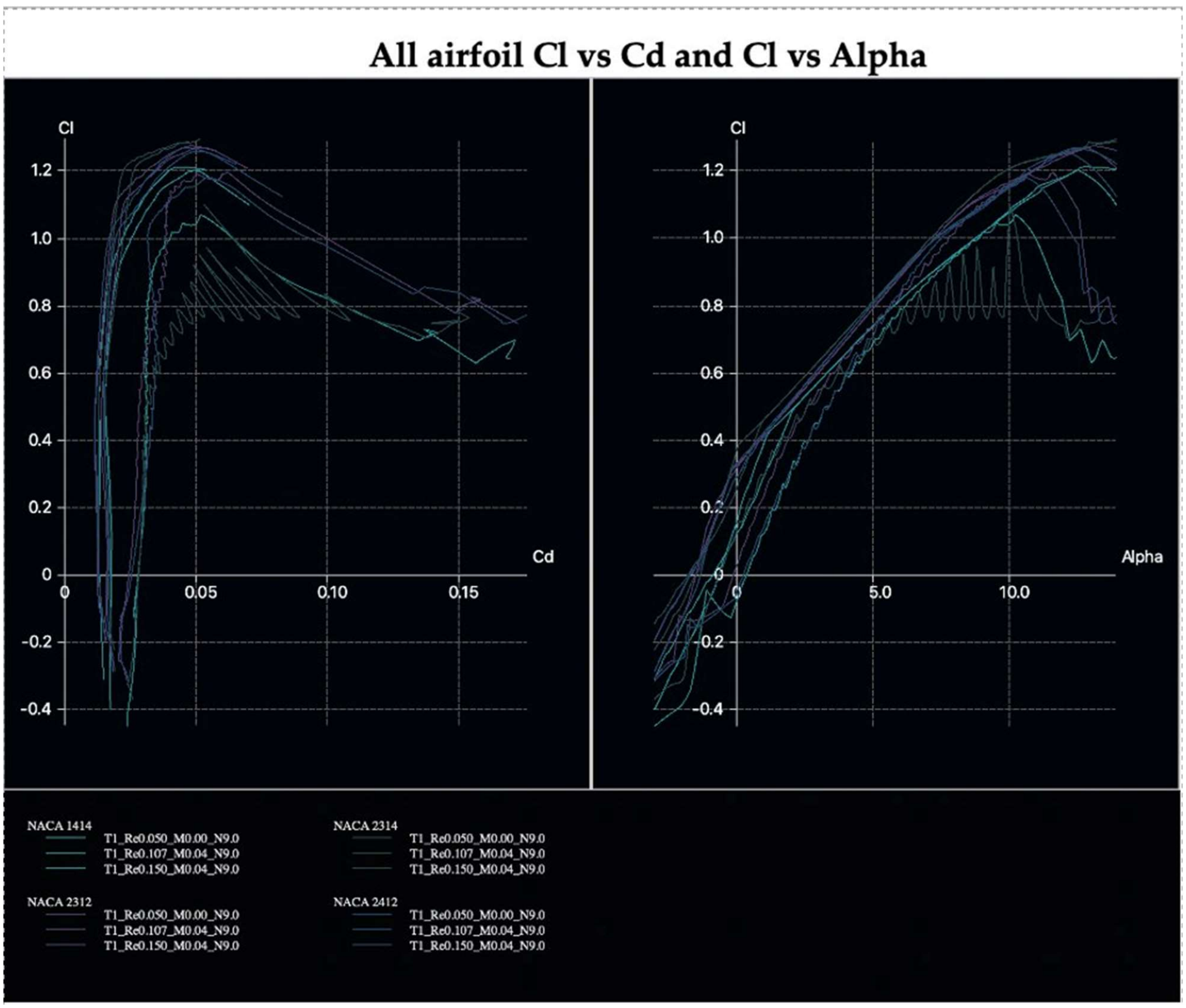



*Figure 12: Cl vs Cd and Cl vs Alpha*

Notice how the Coefficients of Lift and Drag performs well under all the Reynolds numbers and Mach numbers for the NACA 2412 airfoil. If you observe how the Coefficient of Lift performs under an increasing angle of attack for the NACA 2412 airfoil, you can see that it's the only airfoil that can withstand an angle of attack above 10 degrees. Additional graphs are displayed below for further

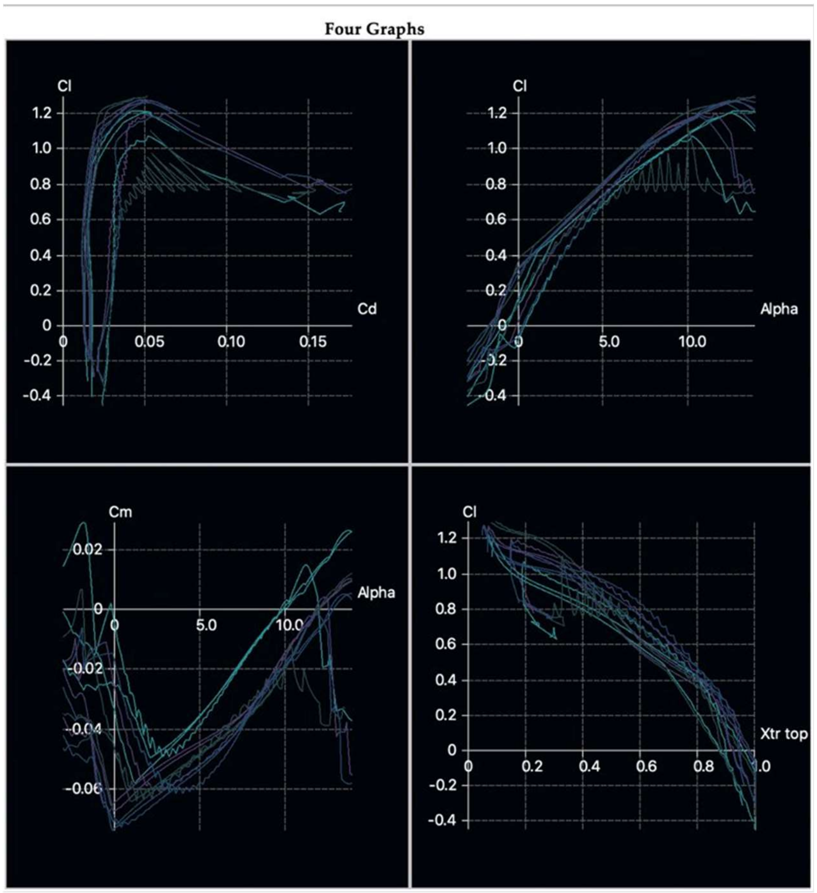



*Figure 13: Graphs of Cl, Cd, Cm, Alpha*

**All Graphs**

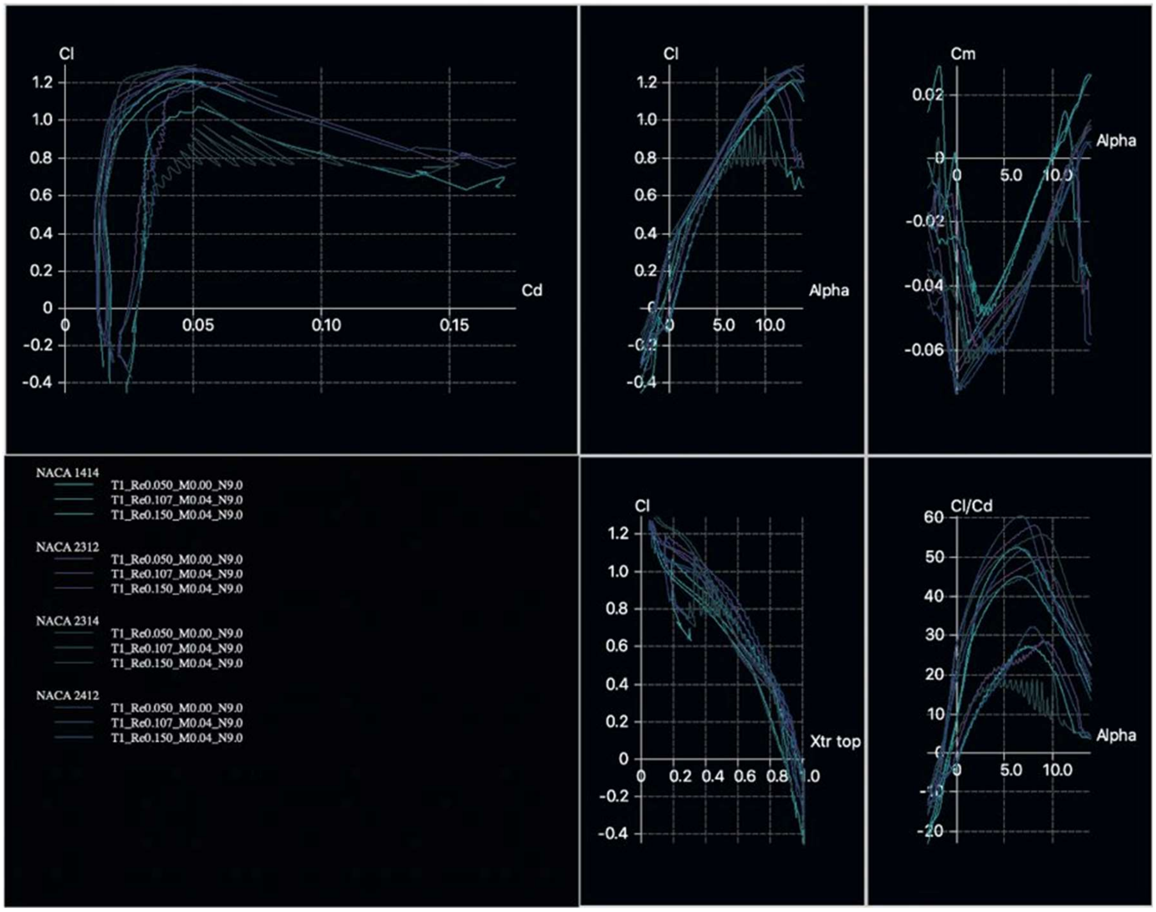



*Figure 14: Graphs of Cl, Cd, Cm, Alpha*

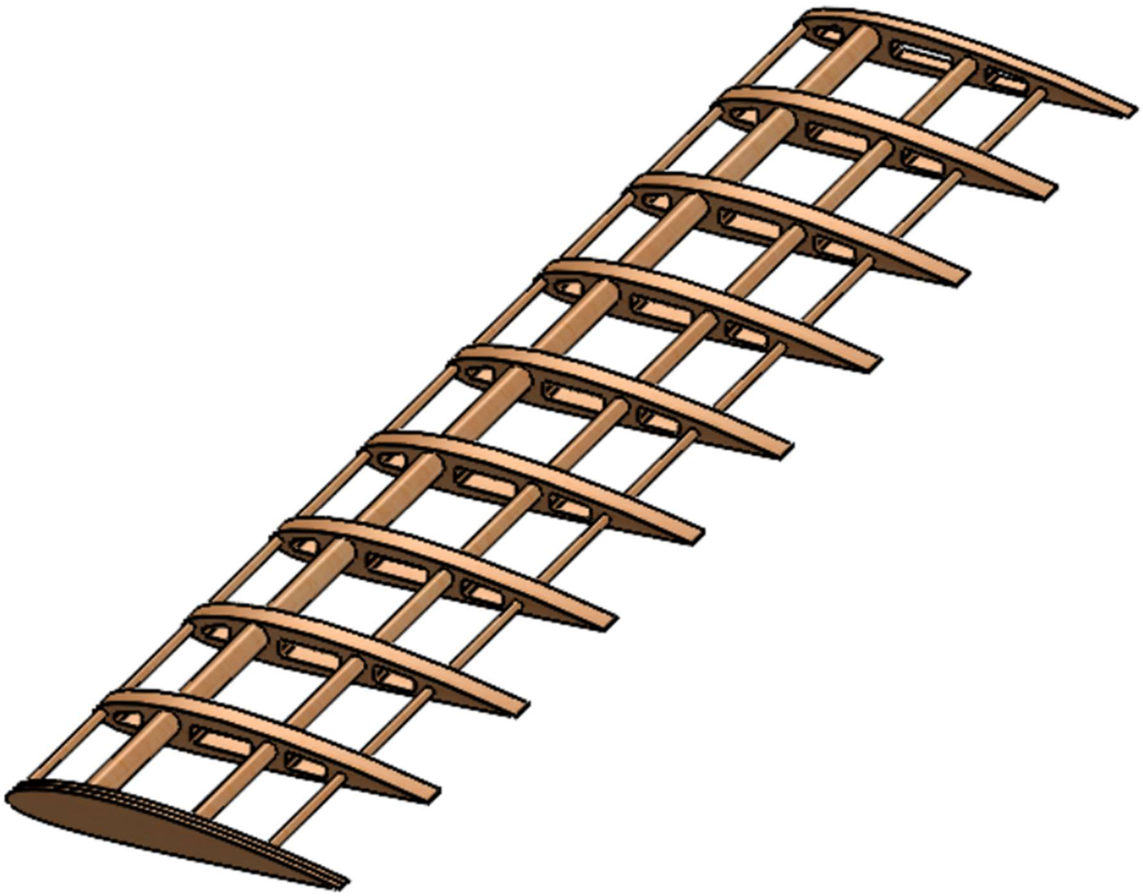


*Figure 15: Airfoil design*

### 5.1.4 Landing Gear Forces and Factor of Safety

The stress analysis for the landing gear was conducted on MATLAB. The figure below shows the program fully.

```
Command Window
Enter impact duration in seconds: 0.05
Enter impact type:
(1) Free Fall at Cruise
(2) Free Fall
(3) Normal Landing: 1
Enter Initial x-dir velocity in mph: 22.5
Enter Height of Aircaft in Free Fall conditions in ft: 75

F_mag =

  658.9188

Enter Outer Diameter of Langing gear in inches: 0.25
Enter Wall thickness in inches: 1/16
Enter Material Tensile Strength in psi: 70000
Enter Material Yield Strength in psi: 50000

Fs_Yield =

    1.6296

length of landing gear in inches: 4
Enter Diameter of Wheel: 4
Enter Modulus of Elasticity in psi: 10600000

deflection =

    0.0096

fx >>
```

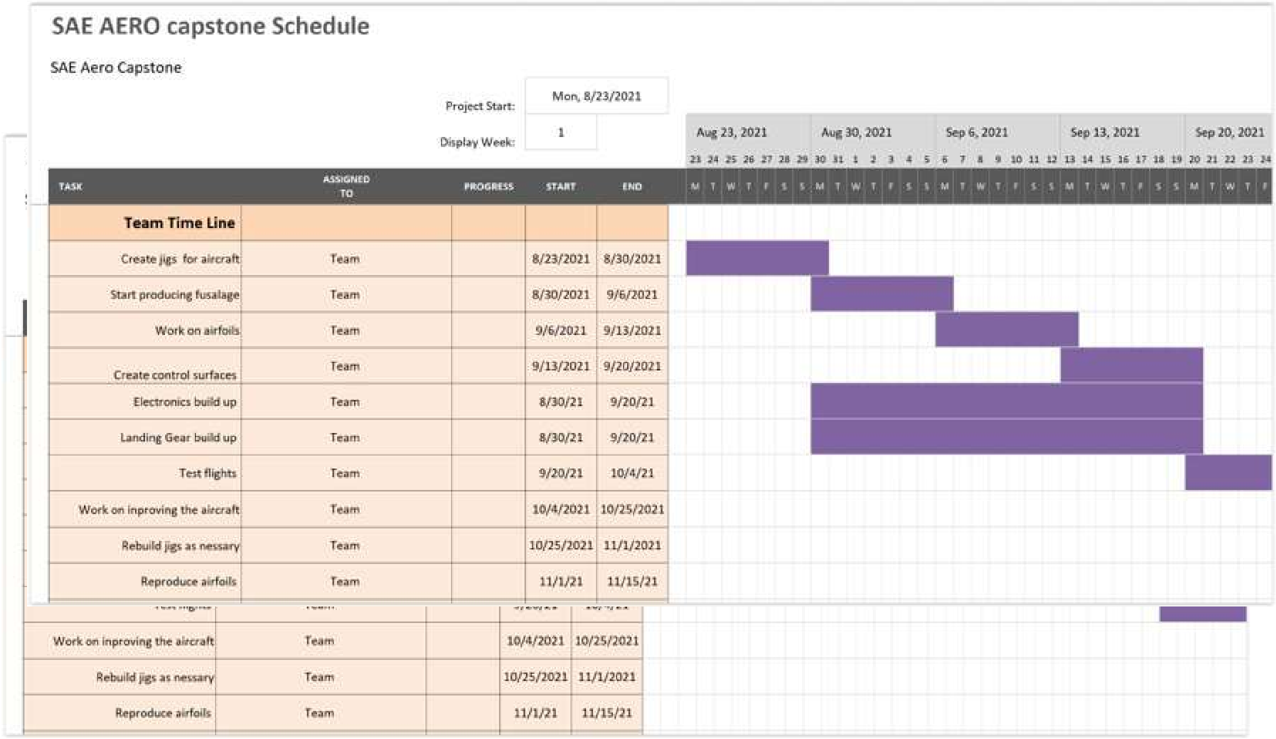
*Figure 16: Screenshot of Matlab Landing gear analysis*

The findings showed that the worst-case scenario would result in a 658 lbf landing impact, and a conservative factor of safety of 1.62 was made with the analyzed material being 2024-T3 Aluminum. It's very important to note that the total expected weight has been reduced since the publication of the preliminary report. The material changes will also reduce the expected costs.

## 5.2 Implementation Plan

Before entirely moving into prototyping, the team plans to continue analyzing how the aircraft will perform under expected and unexpected circumstances using NASA's OpenVSP and XFLR5, which is an extension of xfoil. Doing so will ensure that the team absolutely should or should not continue moving forward with the proposed design. These analyses will be performed in the weeks leading up to the upcoming Individual Analytical Analysis, in which each team member will perform further analysis on each component they are working on. Once the team members are confident in their design and backed by their analyses. They will move forward with prototyping. Because the design is relatively complex in shape, the team will be requesting permission from Perry Wood, who overlooks all fabrication chop activity on campus, to gain access to Northern Arizona University's laser cutter. The team currently plans to make a few proof-of-concept models of the airfoils with ailerons, the fuselage, and the tail to see physical models of how these parts may move and fit together. The airfoils and fuselage will be made using some balsa wood and will likely be scaled down for now. The team wants to request access to the wind tunnel in the fabrication shop to get a real test of how the airfoil and fuselage will react in working condition. If the team cannot make the complex shapes required by the design, then they may switch to 3D printed parts from the NAU Makerlab. If they cannot gain access to the wind tunnel, then they will move forward with full prototyping to figure out how they will apply the control surfaces to the frames. Below in are short Bills of Materials showing the potential costs of the proof-of-concepts and the first real prototype. This prototype will be constructed using the tools available in the fabrication shop with the training and permission from Perry Wood.

The Gantt Chart below in Figure 17 displays the current projected schedule for next semester. This schedule shows that the team will start the next semester by making the jigs and cutouts for the aircraft and start producing the fuselage. After, the team will spread out to creating the airfoils for the wings and tail, start implementing the electronics that control the propeller and the ailerons and "tailerons". The team will then work on adding the control surfaces, making the landing gear, and implementing the steering electronics and controls and in the back wheel. Finally, the team will begin flight testing around the end of September and fix/improve on any aspects and issues as necessary before finalizing the final design.



SAE AERO capstone Schedule

SAE Aero Capstone

Project Start: Mon, 8/23/2021

Display Week: 1

| TASK | ASSIGNED TO | PROGRESS | START | END |
|---|---|---|---|---|
| **Team Time Line** | | | | |
| Create jigs for aircraft | Team | | 8/23/2021 | 8/30/2021 |
| Start producing fusalage | Team | | 8/30/2021 | 9/6/2021 |
| Work on airfoils | Team | | 9/6/2021 | 9/13/2021 |
| Create control surfaces | Team | | 9/13/2021 | 9/20/2021 |
| Electronics build up | Team | | 8/30/21 | 9/20/21 |
| Landing Gear build up | Team | | 8/30/21 | 9/20/21 |
| Test flights | Team | | 9/20/21 | 10/4/21 |
| Work on inproving the aircraft | Team | | 10/4/2021 | 10/25/2021 |
| Rebuild jigs as nessary | Team | | 10/25/2021 | 11/1/2021 |
| Reproduce airfoils | Team | | 11/1/21 | 11/15/21 |


| TASK | ASSIGNED TO | PROGRESS | START | END |
|---|---|---|---|---|
| Work on inproving the aircraft | Team | | 10/4/2021 | 10/25/2021 |
| Rebuild jigs as nessary | Team | | 10/25/2021 | 11/1/2021 |
| Reproduce airfoils | Team | | 11/1/21 | 11/15/21 |




*Figure 17: Screenshot of next semester Gantt chart*

The picture above in Figure 5 shows what the current proposed design should look like, while the next picture below in Figure 18 shows an exploded view of the model. This view shows how all the parts should fit together as the team assembles the parts.

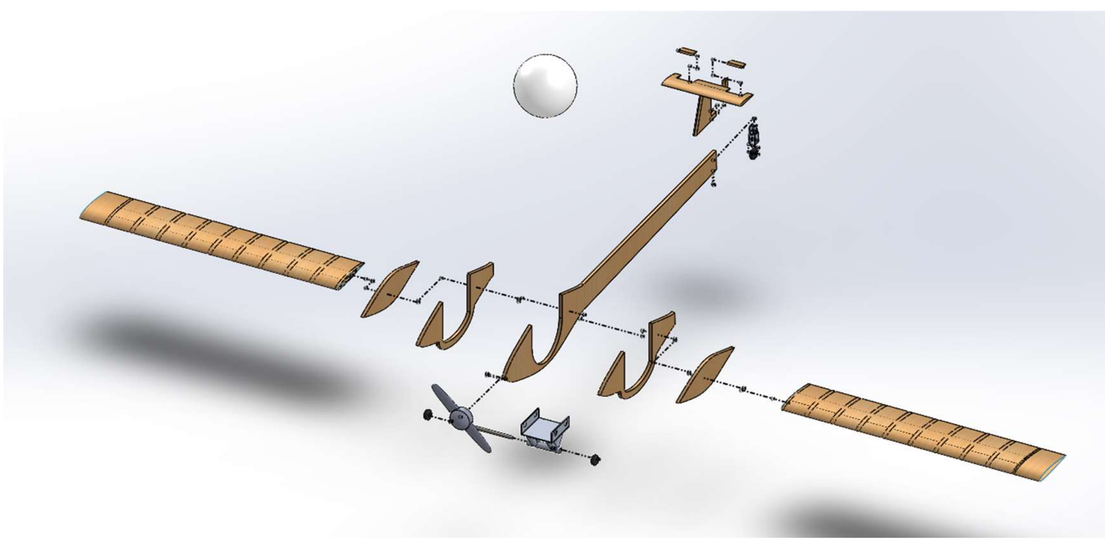


*Figure 18: Disassembled design*

# 6 CONCLUSIONS

In conclusion our team has outlined what our design looks like as of today as well as what our criteria were to make our design by fulfill these requirements. Our team has also looked at the ways we will test our subs systems to make sure that our aircraft will fly the day we take it for its initial test flight. In this document we have also looked at worst case scenario to be prepared for what is at stake when we take our design to the skies.

Our team has created a design to fulfill the customer requirements the engineering requirements and make sure we are compliant with the 2021 SAE Aero Regular rules. We have created a design for an aircraft to full fill all of these requirements. The team has also created a CAD model of the aircraft to be able to visualize the final design and to start analyzing the design through simulation products.

# 7 References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# 8 APPENDICES

## 8.1 Appendix A: House of Quality

System QFD

Project: SAE Aero Capstone

Date: 3/5/2021

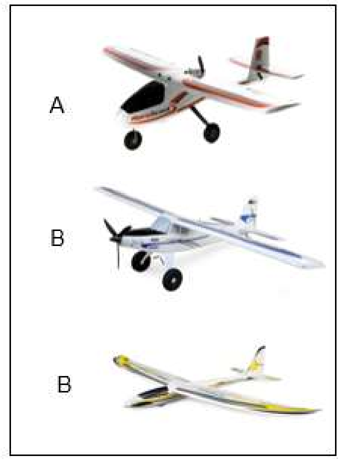
Input areas are in yellow

| | |
|---|---|
| 3 | Strong paritive |
| 1 | Moderate paritive |
| 0 | No Effect |
| -1 | Strong negative |
| -3 | moderate negative |

| # | Technical Requirement | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Weight (less than 55 lbs) | | | | | | | | | | | | |
| 2 | Power per pound (roughly 45 watts/lb) | | | | | | | | | | | | |
| 3 | Power Watt less than 1000W | | | | | | | | | | | | |
| 4 | Batter Amperage >3000mAh | | | | | | | | | | | | |
| 5 | Battery voltage >22.2V | | | | | | | | | | | | |
| 6 | Takeoff <100 ft | -3 | | | | | | | | | | | |
| 7 | Landing <400ft | -3 | | | | | | | | | | | |
| 8 | Wingspan <120 inches | -1 | | | | | 3 | 3 | | | | | |
| 9 | Cargo Capacity <800 sq inches | | | | | | | | 1 | | | | |
| 10 | Speed >20 MPH | -3 | | | | | 3 | 3 | | | | | |
| 11 | Lift > weight | -3 | -1 | | | | 1 | | 3 | | | | |
| 12 | Thurst > Drag | | | | | | 3 | | | | 1 | | |

Technical Requirements

| # | Customer Needs | Customer Weights | Weight (less than 55 lbs) | Power per pound (roughly 45 watts/lb | Power Watt less than 1000W | Batter Amperage >3000mAh | Battery voltage >22.2V | Takeoff <100 ft | Landing <400ft | Wingspan <120 inches | Cargo Capacity <800 sq inches | Speed >20 MPH | Lift > weight | Thurst > Drag | 1 Poor | 2 | 3 Acceptable | 4 | 5 Excellent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Reliable design | 7 | | | | | | | | | | | | | | | AB | | C |
| 2 | Durable | 8 | | | | | | | | | | | | | | ABC | | | |
| 3 | Robustness | 8 | | | | | | | | | | | | | | ABC | | | |
| 4 | Cost | 7 | | 5 | | | | | | | | | | | A | | B | | C |
| 5 | Safety of operation | 9 | 3 | | | 1 | 1 | | | | | | | | | | | | ABC |
| 6 | Manufacturability | 5 | | | | | | | | 2 | | | | | | | AB | | C |
| 7 | Cargo Capacity | 10 | 9 | 5 | | | | | | 7 | | | | | C | | AB | | |
| 8 | Flight Manerverability | 7 | 9 | 5 | | | | | | 3 | 1 | | | 3 | | C | | AB | |
| 9 | Ground Maneuverability | 10 | 2 | 1 | | | | | | 1 | | | | | C | | B | A | |
| 10 | Stability | 10 | 1 | | | | | | | 5 | 1 | | | | | | AB | | C |
| 11 | Cargo Capacity | 2 | 9 | | | | | | | | | | | | ABC | | | | |
| 12 | Weight | 7 | | 9 | | | | 9 | 9 | 2 | 3 | 1 | 9 | | | | AB | | C |
| | Technical Requirement Units | | pounds | Watts/pound | Watts | milliamp hour | volt | feet | feet | inch | sq inches | Pile per hours | N/a | N/a | | | | | |
| | Technical Requirement Targets | | 55 | 45 | 1000 | 3000 | 22.2 | 100 | 400 | 120 | ## | N/a | N/a | N/a | | | | | |
| | Absolute Technical Importance (Low=1) | | 228 | 193 | 0 | 9 | 9 | 63 | 63 | 175 | 38 | 7 | 63 | 21 | | | | | |
| | Relative Technical Importance (Low=1) | | 12 | 6 | 5 | 3 | 2 | 9 | 8 | 1 | 7 | 4 | 11 | 10 | | | | | |




| Legend | |
|---|---|
| A | AeroScout S 1.1m |
| B | TurboTimber 1.5m |
| C | Carrconda Evolution 1.5m |

*Figure A1: House of Quality*

## 8.2 Appendix B: CAD Assembly: Dimensioning

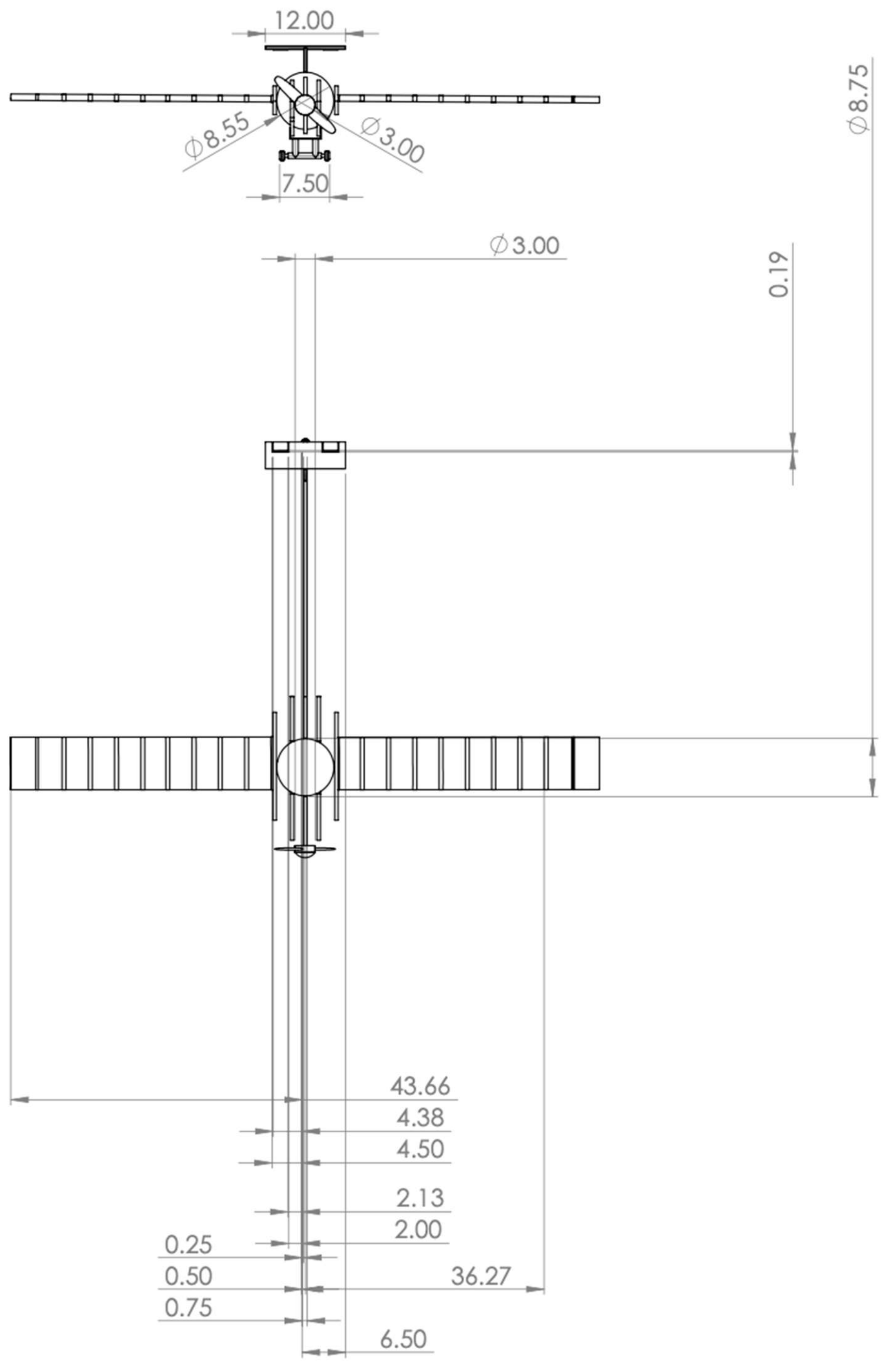



*Figure B1: Full Aircraft Dimensions*

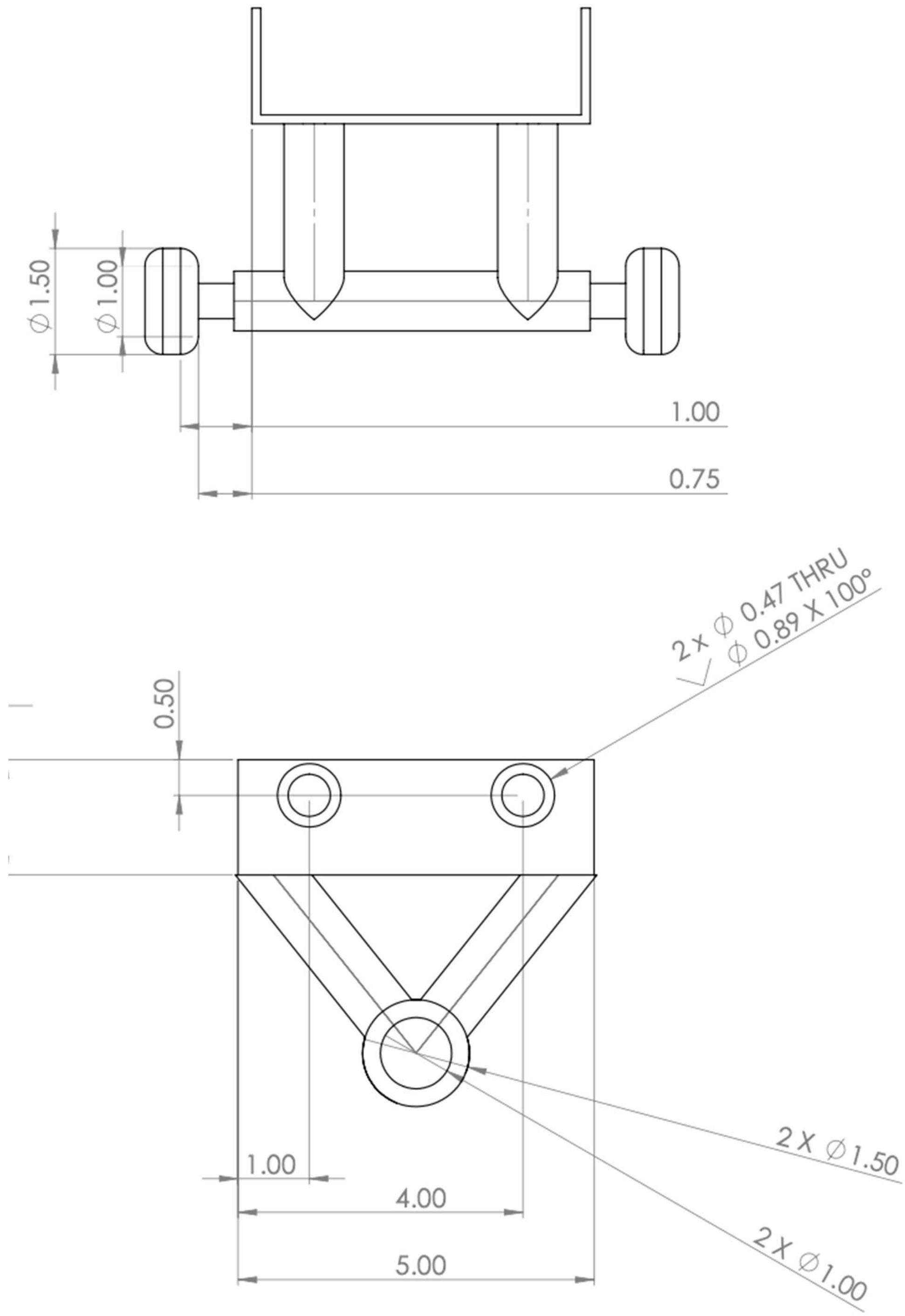



*Figure B2: Landing Gear Dimensions*

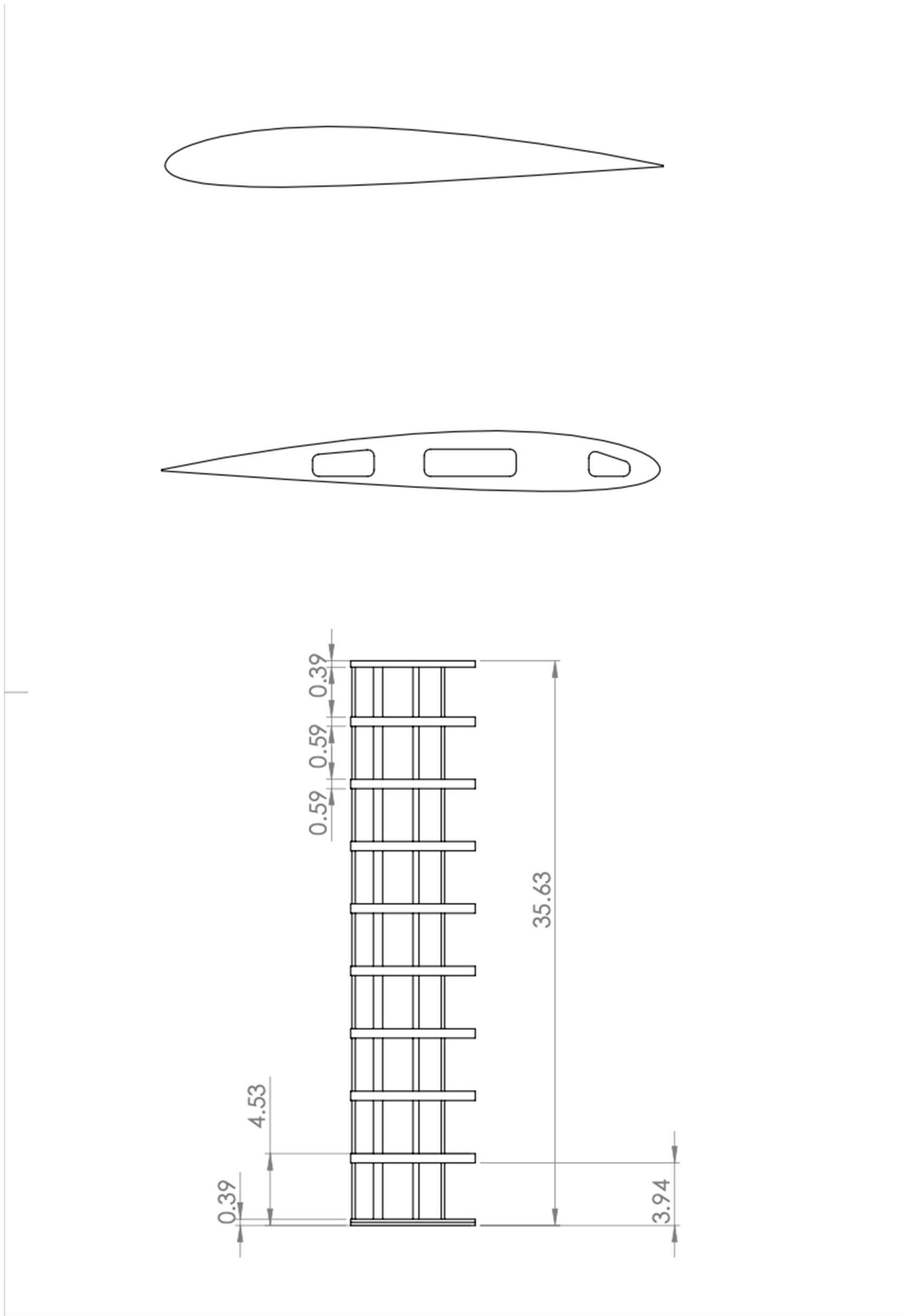



*Figure B3: Wing Dimensions*

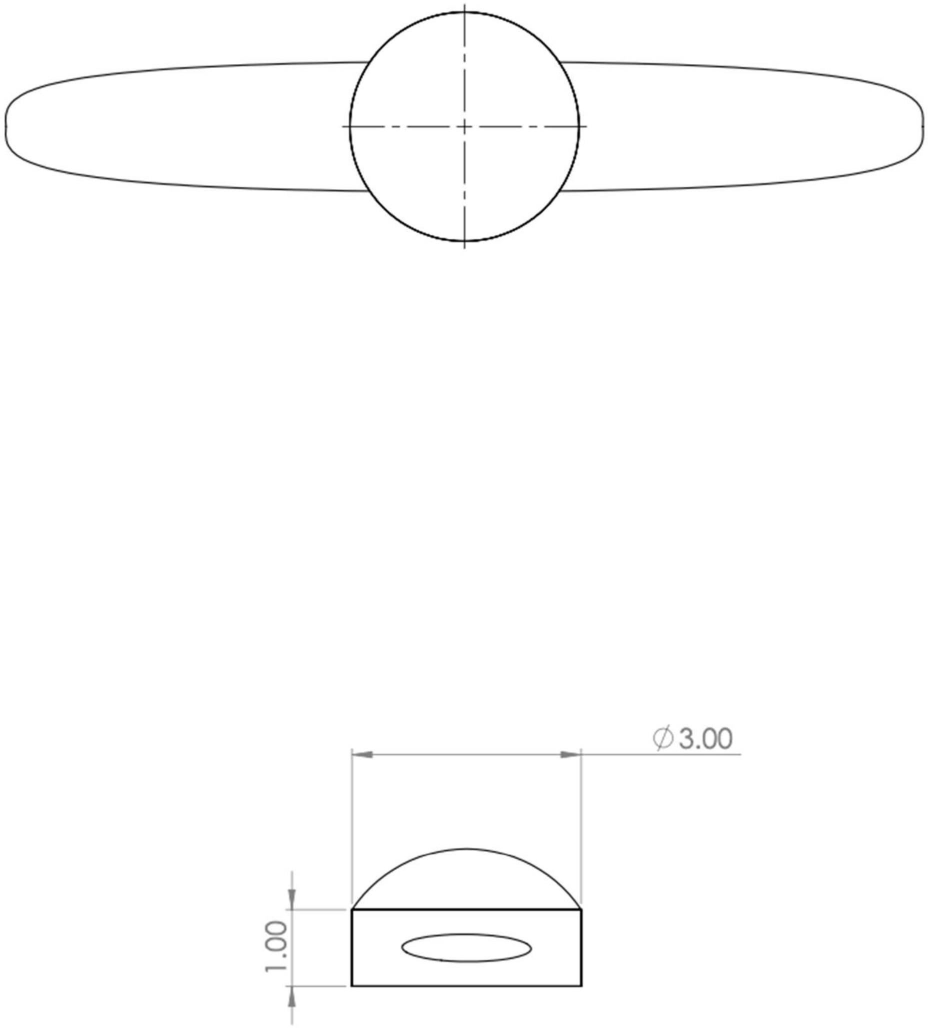



*Figure B4: Propeller Dimensions*

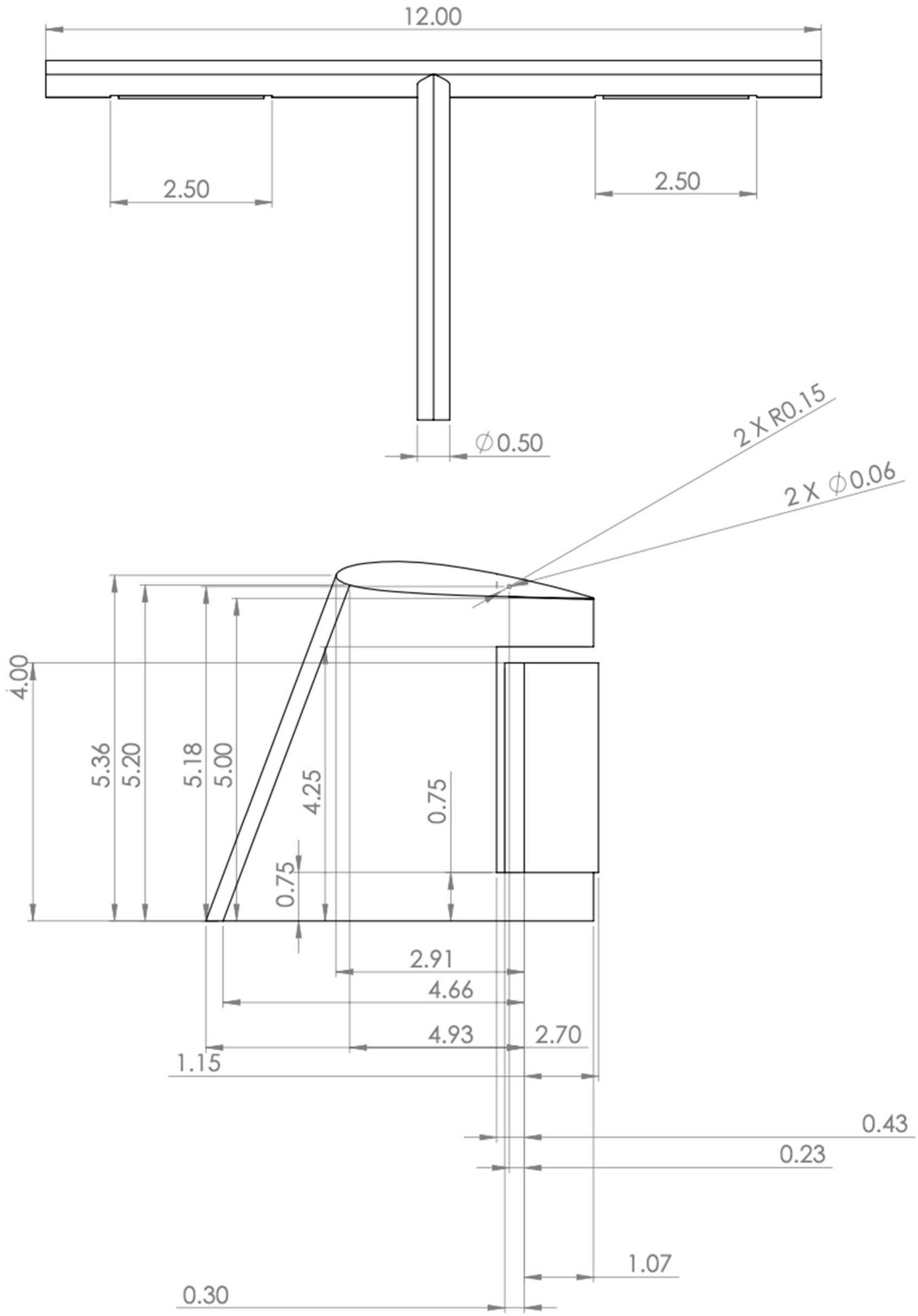



*Figure B5: Rudder Dimensions*

## 8.3 Appendix C: FMEA

*Table C1: FMEA*

| Part | Potential Failure Mode | Potential Effect(s) of Failure | Potential Causes and Mechanisms of Failure | RPN | Recommended Action |
|---|---|---|---|---|---|
| Electronics | 0 | 0 | 0 | 0 | 0 |
| motor | loss of power, stops rotating | loss of propulsion, crash | bad electronics | 60 | Buying spare parts to prevent this issue |
| battery | loss of power, short circuit | loss of control surfaces and propulsion, crash | bad electronics | 60 | Buying spare parts to prevent this issue |
| elevator servo | stops rotating, components stop working | loss of control surfaces, crash | bad electronics | 96 | Buying spare parts to prevent this issue |
| aileron servos | stops rotating, components stop working | loss of control surfaces, crash | bad electronics | 96 | Buying spare parts to prevent this issue |
| propeller | breaks, cracks | loss of propulsion, crash | ground stick | 54 | 0 |
| rudder servo | stops rotating, components stop working | loss of control surfaces, crash | bad electronics | 96 | Buying spare parts to prevent this issue |
| wheels | flat tire, fall off support | emergency landing, loss of round | bad electronics | 60 | Buying spare parts to prevent this issue |
| transmitter | runs out of power | loss of control surfaces and propulsion, crash | bad electronics | 10 | 0 |
| receiver | runs out of power | loss of control surfaces and propulsion, crash | bad electronics | 10 | 0 |
| electrical speed controller | does not receive signal from receiver | loss of control surfaces and propulsion, crash | bad electronics | 10 | 0 |
| charger | short circuits | fries the electronics on the craft | bad electronics | 20 | 0 |
| wires | short circuits | loss of power, crash | bad electronics | 40 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| Airplane Components | 0 | 0 | 0 | 0 | 0 |
| land gear | falls of aircraft | emergency landing, loss of round | hard impact | 256 | Extra time during assembly is required |
| payload compartment | opens during flight | fail trail at competition | poor fastening | 280 | Extra time during assembly is required |
| spars | break due to load | unstable flight, crash | over stressed | 126 | 0 |
| ribs | break due to load | unstable flight, crash | over stressed | 126 | 0 |
| skin | gets puncture | induced drag, crash | over stressed | 105 | 0 |
| stringers | break due to load | unstable flight, crash | over stressed | 84 | 0 |
| flaps | fall off aircraft, stuck down | induced drag, crash | poor assembly | 105 | 0 |
| ailerons | fall off aircraft, stuck up/down | uncontrollable bank, crash | poor assembly | 126 | 0 |
| elevators | fall off aircraft, stuck up/down | uncontrollable bank, crash | poor assembly | 126 | 0 |
| rudder | fall off aircraft, stuck left/right | uncontrollable turn , crash | poor assembly | 126 | 0 |
| horizontal stabilizer | falls of aircraft | uncontrollable pitching moment, crash | poor assembly | 168 | Extra time during assembly is required |
| vertical stabilizer | falls of aircraft | uncontrollable yaw, crash | poor assembly | 168 | Extra time during assembly is required |
| leading edge | gets puncture | induced drag, crash | poor assembly | 144 | Extra time during assembly is required |
| fusalage | gets puncture | induced drag, crash | over stressed | 126 | 0 |

## 8.4 Appendix D: Bills of Materials

*Table D1: Proof of Concept Bill of Material Costs*

| Proof of Concept Costs | | | | |
|---|---|---|---|---|
| Balsa Wood Sheets [2] | 17.99 | 1 | 17.99 | https://www.walmart.com/ip/Baltic-Birch-Hobby-Wood-Sheets-12mm-x-12-x-12/956400582?wmlspartner=wlpa&selectedSellerId=0 |
| Wood Glue [3] | 3.97 | 1 | 3.97 | https://www.homedepot.com/p/Gorilla-8-oz-Wood-Glue-62000/100672167?source=shoppingads&locale=en-US |
| Fishing Line [4] | 1.97 | 1 | 1.97 | https://www.walmart.com/ip/Zebco-Omniflex-Monofilament-Fishing-Line-30-Pound-Tested/16777057?wmlspartner=wlpa&selectedSellerId=0 |
| | | Sub Total | 23.93 | |

*Table D2: Prototype 1 Bill of Material Costs*

| Prototype Costs | | | | |
|---|---|---|---|---|
| Balsa Wood Sheets [2] | 17.99 | 1 | 17.99 | https://www.walmart.com/ip/Baltic-Birch-Hobby-Wood-Sheets-12mm-x-12-x-12/956400582?wmlspartner=wlpa&selectedSellerId=0 |
| Balsa Wood Sheets [5] | 7.51 | 1 | 7.51 | http://www.balsawoodinc.com/product/48-16 |
| Wood Screws [6] | 1.68 | 2 | 3.36 | https://www.homedepot.com/p/Phillips-10-4-in-Phillips-Square-Flat-Head-Wood-Screws-25-Pack-25400/100348669?source=shoppingads&locale=en-US |
| Machine Screws [7] | 13.05 | 1 | 13.05 | https://www.mcmaster.com/screws/flat-head-screws/hex-drive-flat-head-screws/alloy-steel-hex-drive-flat-head-screws-9/ |
| Aluminum Square Tubing [8] | 5.46 | 1 | 5.46 | https://store.buymetal.com/aluminum/square-tube/6063-t52-t6/aluminum-square-tube-6063-t52-t6-1-0.125.html |
| Caster Wheels [9] | 3.27 | 1 | 3.27 | https://www.walmart.com/ip/Super-Sliders-2-Heavy-Duty-Rubber-Plate-Caster-Wheel-90-lb-Load-Capacity-1-Pack/16782104?wl13=4252&selectedSellerId=0 |
| | | Sub Total | 50.64 | |

## 8.5 Appendix D: Bills of Materials continued estimate

*Table D3: Bill of material*

| Bill of Materials | | | |
|---|---|---|---|
| Parts | Cost per unit | Quantity | Total cost |
| **Electronics** | | | |
| Transmitter | $ 229.99 | 1 | $ 229.99 |
| Reciver | included | 0 | |
| ESC with built in BEC | $ 109.99 | 1 | $ 109.99 |
| Motor | $ 118.99 | 1 | $ 118.99 |
| Power Limiter | $ 75.00 | 1 | $ 75.00 |
| Arming Plug | $ 12.95 | 1 | $ 12.95 |
| Battery | $ 129.99 | 1 | $ 129.99 |
| Servos | $ 16.99 | 5 | $ 84.95 |
| Wireing | $ 5.99 | 3 | $ 17.97 |
| Propeller | $ 20.00 | 3 | $ 60.00 |
| | | Sub Total | 839.83 |
| **Fuselage** | | | |
| Bass wood (assorted) | $ 4.49 | 5 | $ 22.45 |
| Balsa wood (assortec | $ 25.00 | 1 | $ 25.00 |
| Wood glue | $ 6.99 | 1 | $ 6.99 |
| Miscellaneous hardw | $ 2.00 | 25 | $ 50.00 |
| Soccer ball | $ 8.00 | 1 | $ 8.00 |
| Payload plates | $ 5.00 | 10 | $ 50.00 |
| | | Sub Total | $ 162.44 |
| **Landing Gear** | | | |
| Wheels | $ 11.23 | 2 | $ 22.46 |
| Aluminum bits | $ 1.03 | 5 | $ 5.13 |
| | | Sub Total | $ 27.59 |
| **Wings, Stabalizers** | | | |
| Bass wood (assorted) | $ 4.49 | 5 | $ 22.45 |
| Balsa wood (assortec | $ 25.00 | 1 | $ 25.00 |
| | | Sub Total | $ 47.45 |
| **Prototyping costs** | | | |
| Foam core board | 1.77 | 3 | $ 5.31 |
| Dowel (3/16 x 12) | 1.27 | 1 | $ 1.27 |
| Glue | 2.97 | 1 | $ 2.97 |
| Clear Tape | 2.99 | 1 | $ 2.99 |
| Zip | 9.97 | 1 | $ 9.97 |
| | | Sub Total | $ 22.51 |
| | | | $1,099.82 |

## 8.6 Appendix E: NACA 2412 Airfoil Operating Points

| | | |
|---|---|---|
| 1 | 0.0013 | 0 |
| 0.95 | 0.0114 | 0 |
| 0.9 | 0.0208 | 0 |
| 0.8 | 0.0375 | 0 |
| 0.7 | 0.0518 | 0 |
| 0.6 | 0.0636 | 0 |
| 0.5 | 0.0724 | 0 |
| 0.4 | 0.078 | 0 |
| 0.3 | 0.0788 | 0 |
| 0.25 | 0.0767 | 0 |
| 0.2 | 0.0726 | 0 |
| 0.15 | 0.0661 | 0 |
| 0.1 | 0.0563 | 0 |
| 0.075 | 0.0496 | 0 |
| 0.05 | 0.0413 | 0 |
| 0.025 | 0.0299 | 0 |
| 0.0125 | 0.0215 | 0 |
| 0 | 0 | 0 |
| 0.0125 | -0.0165 | 0 |
| 0.025 | -0.0227 | 0 |
| 0.05 | -0.0301 | 0 |
| 0.075 | -0.0346 | 0 |
| 0.1 | -0.0375 | 0 |
| 0.15 | -0.041 | 0 |
| 0.2 | -0.0423 | 0 |
| 0.25 | -0.0422 | 0 |
| 0.3 | -0.0412 | 0 |
| 0.4 | -0.038 | 0 |
| 0.5 | -0.0334 | 0 |
| 0.6 | -0.0276 | 0 |
| 0.7 | -0.0214 | 0 |
| 0.8 | -0.015 | 0 |
| 0.9 | -0.0082 | 0 |
| 0.95 | -0.0048 | 0 |
| 1 | -0.0013 | 0 |

*Figure E1: airfoil x y coordinates*