Final Capstone Report

A2 Aero Micro - 20F12

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DISCLAIMER

EXECUTIVE SUMMARY

This team was tasked with designing and constructing a micro airplane to compete in the 2021 SAE Aero Micro competition. The design must be original work by the team with minimal interaction from people outside of the group.

The competition itself has several requirements that the team must obey, or the team will be docked points or even disqualified. There are many basic requirements the team has to follow, such as using one of the official competition 450W power limiters, using propellers that are not made of metal, have a red power plug, have the team's number be easily visible on the plane, and clearly labeling the planes center of gravity with the classic center of gravity (CG) label. However, there are specific rules that the team must follow for the micro class portion of the competition. The team must not exceed a wingspan of 48". This maximum wingspan replaces the previous year's rule of being able to fit within the competition container, so the plane is still limited in size. The plane must also use electric motor propulsion, utilize no more than a 4-cell Lithium Polymer battery and be able to completely enclose the payload plates. The team will be scored on the amount of cargo they can carry (including any bonus payload), as well as the time it takes for the plane to complete one flight circuit.

The airplane must first be broken down into major components to conduct research on each and develop an innovative design. The wings and airfoil are one of the most important aspects to any plane, and if this is not designed properly, the plane could fail to ever fly. It was determined that the wings are going to be made using a rib and spar design because of the low weight and high strength that can be achieved. The ribs are made from the Clark-Y airfoil laser cut from ⅛" balsa wood sheets. After the ribs are cut and separated approximately 2" apart, wooden spars are placed in the designated cuts in the ribs. A leading edge is also cut from balsa wood to match the same profile as the airfoil itself. Once the aileron is cut and put into place, the team wrapped the wings with MonoKote (a lightweight and clear plastic shrink-wrap). These wings are then connected at the center of the airplane and are secured to the fuselage. The fuselage is made from foam board to maintain focus on being both rigid and lightweight. The tail of the airplane is made of foam board for the same reasons, and it utilizes a conventional tail design. This conventional tail design has both vertical and horizontal stabilizers, and each has a servo-controlled elevator or rudder to maintain control during flight. The airplane has other major components, such as utilizing a carbon fiber rod to connect the fuselage and tail, a tricycle landing gear that allows for movement on the ground not reliant on aerodynamics, and several to-be-determined propulsion components such as the battery, propeller, and controller.

Several technical analyses were performed for the aircraft with these components to determine the engineering integrity of them. The wings were analyzed for any risk of sag or bending moment, and adjustments were made based on this analysis. The wings were determined to still be made of ⅛" balsa wood, but the spacing between them needs to be 2-2.5" to avoid adding unnecessary weight and creating sag. The fuselage also underwent an analysis to determine if the material selection of foam board was feasible, or if the cargo requirement and attachment requirement was too great for the foam board to withstand. The results of this analysis are that the foam board is sufficient, assuming the walls are thick enough to support all the weight while also not causing unnecessary drag. Several other analyses were done to support the tentative final design of the plane, and any necessary adjustments have been made.

The team is in the process of building the plane and hopes to be close to completion by the start of the 2nd semester of capstone. Once the team can conduct test flights, the iterative design process will continue, and the team will make necessary changes to ensure the plane flies properly and can perform well at the competition.

ACKNOWLEDGEMENTS

The Aero Micro capstone team would like to thank Mr. Tim Kelly and the Flagstaff Flyers RC flying group for their significant support during the project. Through intellectual contributions, donations of key items, and their extensive knowledge on RC planes, their help has proven to be invaluable to the team. Tim Kelly has provided countless hours of design aid as well as a place to construct the project and laser cutting support. The Flagstaff Flyers have provided the team with a place to fly their plane, design suggestions, and more. The capstone team would like to graciously thank Tim Kelly and the Flagstaff Flyers for their time and support and hopes that their willingness to support NAU's seniors continues to aid those in the future.

The Aero Micro capstone team would also like to thank Dr. David Trevas for his support during the project. As the team's faculty advisor, David Trevas helped to ensure the project was always moving forward in the right direction and helped to correct any major errors in design before resources were wasted. David Trevas was a key member in helping the team get the project to where it is today, and the team cannot thank him enough for his support.

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1.0 BACKGROUND

1.1 Introduction

The SAE Aero Micro competition is a competition where teams are tasked with constructing a micro airplane with several design constraints. Some of these constraints stated in the 2021 competition rules include a maximum wingspan of 48", implementing a 450-watt power limiter, launching the plane from a 4'x8' platform, and having the payload stored in a cargo bay. The main objective of the competition is to carry the largest amount of payload possible through a flight circuit course, while having the fastest time to the first turn. The 2021 competition will have teams scored on the weight of the payload carried, flight time, technical reports, and many other factors. Unfortunately, due to changes in the competition timeline, the team was forced to drop out of the competition. As a result, the team focused primarily on the purchasing, design, and construction of test stands for the remainder of the project. While the team shifted focus at the end of the project, the majority of time (more than 70%) spent on the project was done with the intent to compete at competition, and thus this report will focus on the airplane more than the test stands.

This project has many real-world applications and is of interest to the sponsor because the ideas developed in this competition can be applied to full scale aircraft and addresses issues seen in real-life airplanes such as efficiency and airspeed. If the team is successful, the sponsor and stakeholders will benefit with NAU gaining respect in the aerospace education industry and future capstone teams possibly being supplied with more money and having a better chance of winning the competition. Additionally, the test stands created by the team will aid future capstone team's in their efforts as they begin their capstone projects and provide them with data to support their designs.

1.2 Project Description

The following is the original project description provided by SAE International:

The SAE Aero Design competition is intended to provide undergraduate and graduate engineering students with a real-life engineering challenge. The competition has been designed to provide exposure to the kinds of situations that engineers face in their real-life work environment. First and foremost a design competition, students will find themselves performing trade studies and making compromises to arrive at a design solution that will optimally meet the mission requirements while still conforming to the configuration limitations. Micro Class teams are required to make trades between two potentially conflicting requirements, carrying the highest payload fraction possible, while simultaneously pursuing the lowest empty weight possible. [1]

This project description describes exactly what the team needs to accomplish in order to be successful in the capstone project. However, the shift at the end of the term to test stand design was another huge project which the team completed. Due to the informality of this project, the team created their own project description:

The goal of the "test stand project" is to purchase or design/construct test stands that successfully measure the thrust created by the motor/propellor and the lift/drag on the airplane wing so that future capstone teams can easily collect this data for implementation into their reports and to validate design choices before performing dangerous test flights.

2.0 REQUIREMENTS

The following section discusses the requirements of the aircraft being designed by the team. This includes, the customer requirements that were derived from the SAE competition rules, the engineering requirements that were established using the customer requirements, a functional decomposition of the aircraft system, a house of quality, and the standards, codes, and regulations applicable to the project. Because the team experienced a shift in the rules and regulations, much of this information has been altered from that of the preliminary report.

2.1 Customer Requirements

For the SAE Aero Micro team, customer requirements were presented in the form of SAE Aero design rules. The SAE competition provides a detailed description of what is expected and what functionalities of the design are required. In short, a competition will be conducted where speed and payload weight/size capacity are contributing scoring factors. Flights and landings must be successful for the score to count. The aircraft must take off from a 4'x8' platform and land within a designated 200-foot landing strip. A complete list of the customer requirements derived from the competition rules is presented below along with a brief description. Additional requirements listed are due to limiting factors such as the budget provided by Northern Arizona University.

1. Wingspan Dimension (The wingspan cannot exceed 48")
2. Electric Motor (Only electric Motors are allowed for the propulsion)
3. Battery Limited to 4 Cell (The maximum battery size is limited to a 4-cell battery)
4. Power Limiter (The aircraft must incorporate a power limiter in the electrical circuit)
5. Carries Metal Payload Plates (Part of the flight score includes the weight of payload plates)
6. Carries Payload Boxes (For each flight attempt at least one delivery box must be carried)
7. Carries Payload Plates in Cargo Bay (Payload plates must be fully enclosed in the fuselage)
8. One Fully Enclosed Cargo Bay (the number of cargo bays for the payload plates is limited to one)
9. Securable Payload Plates (Payload plates must be secured using an approved method)
10. Quick Payload Removal (Both payloads must be uninstalled within one minute)
11. Short Take-Off Distance (The aircraft must takeoff from a 4'x8' platform raised 1 foot)
12. Aircraft Range (The aircraft flight is scored based on the ability to complete the whole course)
13. Controllable in Flight (The pilot must always be able to maintain control of the aircraft)
14. Fast Aircraft (The aircraft flight is scored partially on the time it takes to complete the first leg)
15. Can Carry A Lot of Weight (The aircraft flight is scored partially on the additional weight carried)
16. Short Landing Distance (The aircraft must be able to land within the 200-foot landing strip)
17. Red Arming Plug (the aircraft must be equipped with a red arming plug to ensure safety)
18. Empty CG Markings (The aircraft must display the empty center of gravity location)
19. Gross Weight Limit (The aircraft cannot exceed 55 pounds)
20. 2.4 GHz Radio Control System (The aircraft must use a 2.4 GHz radio controller)
21. Spinners or Safety Nuts (The propellor must be properly secured to ensure safety)
22. No Metal Propellor (Metal propellers are prohibited for the competition)
23. No Lead (The material lead is prohibited from the competition)
24. No Structural Support from Payload (The installed payloads must not help support the structure)
25. Metal Payload Plate securing Hardware (Payload plates must be fastened with metal hardware)
26. Low Cost Build (The team is limited to a $1500 budget which includes registration fees)
27. Durable Design (The design and construction must be durable and reliable)

2.2 Engineering Requirements

Using the customer requirements listed and discussed above, the engineering requirements that will help determine the final design of the aircraft can be derived. Engineering requirements are quantifiable and measurable. Therefore, the derived engineering requirements also include a goal or target value that the design aims to meet, along with a tolerance of that goal's value. The list of engineering requirements that the team derived, and the tolerances is presented next.

1. Wingspan Length (47” +/-1”)
2. Battery (4 Cells -1 Cells)
3. Power Limiter (450 Watts +/-0 Watts)
4. Cargo Bay Volume (185 Inches cubed +/-10 Inches Cubed)
5. Quick Payload Removal (60 Seconds -30 Seconds)
6. Short Take-Off Distance (7 Feet +/-1 Foot)
7. Aircraft Range (500 Feet +/-50 Feet)
8. Can Carry A Lot of Weight (3000 Grams +/-500 Grams)
9. Short Landing Distance (150 Feet +/-50 Feet)
10. Gross Weight Limit (1360 Grams +/-600 Grams)
11. Radio Control System (2.4 GHz +/-0 GHz)
12. Cost (300 US Dollars +/-150 US Dollars)
13. Lift (4000 Grams +/-500 Grams)
14. Thrust (2000 Grams +/-250 Grams)
15. Airfoil Drag (50 Grams +/- 15 Grams)
16. Ground Control Turn Radius (15 Feet +/-5 Feet)
17. Reliability (95 Percent +/- 5 Percent)
18. Crashes Before Major Repair (1.5 Crashes +/- 0.5 Crashes)

2.3 Functional Decomposition

Creating a functional decomposition is a key component in taking the overwhelming task of capstone and breaking it into components that are easier to understand and complete. This section discusses the black box and functional models the team created to dissect the process of building a micro airplane into a workable and viewable processes.

2.3.1 Black Box Model

The team created a black box model of a flying airplane to begin decomposing the larger problem of designing and constructing a full micro airplane. This black box model accepts inputs on the left side and transforms them through the “black box” into appropriate outputs. The functions that occur inside the black box can then be detailed further in a function model to decompose the problem into smaller, simpler problems that the team can address one at a time.

The black box shown in Figure 1 shows the relevant energy, material, and signal inputs and outputs for a flying airplane. The inputs of highest importance are power, the airplane components (wings, landing gear, etc.), and the RC controls. The important outputs are a full RC plane, movement, and appropriate signal indicators.

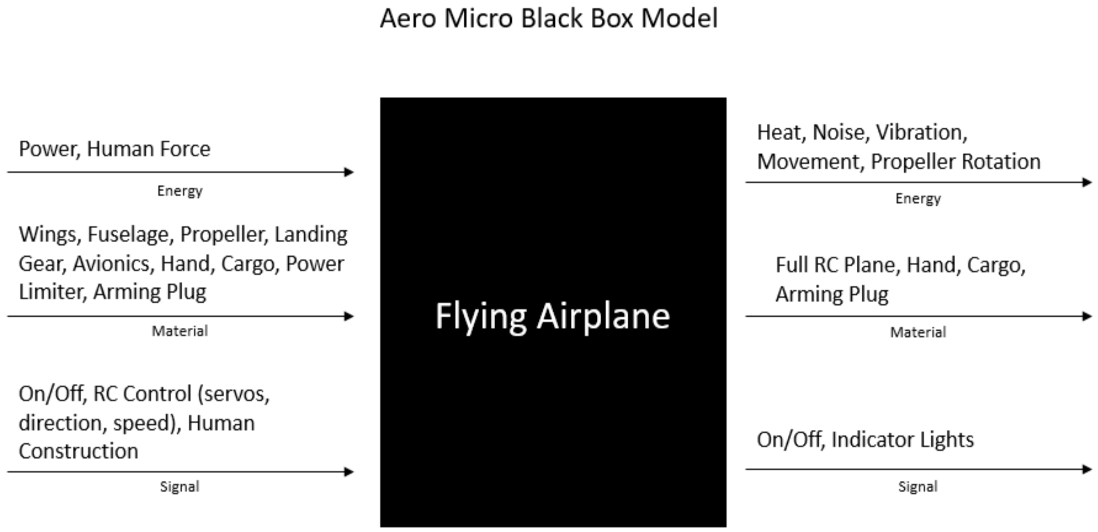

Figure 1 - Black box model for a flying airplane.

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The black box model shown in Figure 1 is very similar to the preliminary report but has been updated to account for the cargo and a power limiter. These material inputs were not considered on the original figure, as the team did not know they needed a power limiter or to carry a new cargo (the 2021 rules had not been distributed yet). The team also added the red arming plug to the model as it seemed like an important material component that had been left out. Otherwise, the black box model has remained unchanged from the original, and Figure 1 is the black box model the team will likely use for the remainder of the project.

2.3.2 Functional Model

After completing the black box model detailed above, the team took the relevant inputs and outputs and began creating a functional model to describe the functions that were occurring within the "black box". This model takes the inputs of energy, material, and signal and describes with arrows how these signals transform to become our outputs. An updated version of this functional model for the team's current progress is shown in Figure 2.

The functional model of a micro airplane (shown in Figure 2) shows the inputs to the system on the left side and the system outputs at various points on the right side. The figure uses orange, green, and blue arrows to show energy, material, and signal inputs respectively and the arrows describe how those inputs move through the system. The team had a comprehensive model created a month ago, however relevant updates to the model include the introduction of the arming plug, power limiter, and cargo described earlier. These material inputs affect the system import power, power delivery, and add a new function of accepting the cargo, which are all shown in Figure 2.

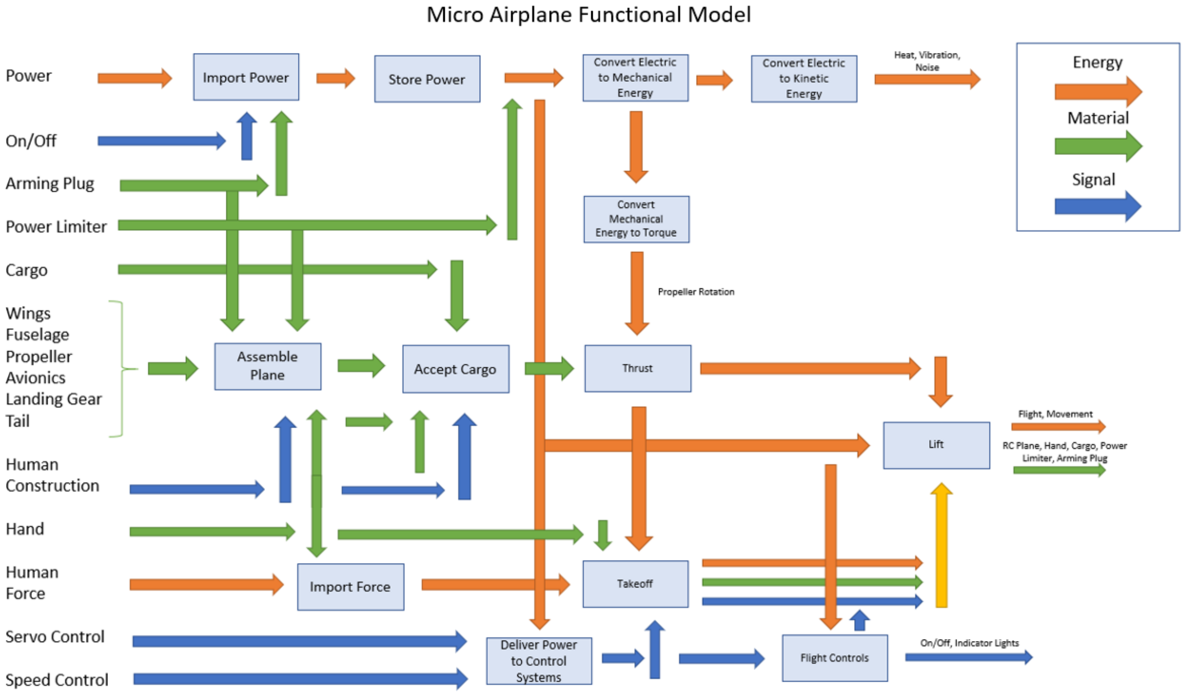


Figure 2 - Functional model for a micro airplane.

The functional model shown in Figure 2 helped the team dissect the problem down into further, more simplistic, components for design and construction. Specifically, it helped to show what systems need to be developed in what order, as certain subsystems and processes will not function without their predecessors. For example, the entire airplane must be assembled before the plane can accept cargo, and the plane must import and store power before beginning to deliver it to necessary subsystems. Additionally, the functional model served as a way of dividing the project into smaller tasks so that each team member could work on a relevant and important subsystem. By creating this model, team members could see what subsystems and tasks were important to work, and how their work contributed to the overall system. In summary, the functional model divided up the intensive task of designing and constructing a micro airplane into specific, measurable, and achievable subtasks.

2.4 Quality Function Deployment (QFD) and House of Quality (HoQ)

Using the customer needs along with the derived engineering requirements, a QFD with a HoQ was completed to better understand the relationship between the customer needs and the engineering requirements (Appendix A).

This house of quality provides the team with an absolute importance rating for each of the engineering requirements listed. This helps the team better understand what components and requirements must be more heavily focused on. This also helps the team understand how the engineering requirements relate to each other. The house of quality has shown the team that the most important engineering requirement is the Cargo Bay Volume. This requirement's score is due to the load capacity aspect of the competition scoring system. Other important engineering requirements include: quick payload removal, the ability to carry a large amount of weight, and the lift force generated by the airfoil. While this helps the team better understand the engineering requirements, many of the customer needs are requirements specified by the competition rules and must be adhered to regardless of the HoQ results. The team must keep in mind all requirements of the competition to ensure that the submitted design is compliant with the rules and regulations. Also included in the HoQ are the specified testing procedures that are discussed in further detail in the Testing Procedures section of this report. The full HoQ can be seen in Appendix B.

2.5 Standards, Codes, and Regulations

To maintain the safety of everyone, present during flight, as well as ensure the engineering integrity of the plane is maintained, there are numerous standards and codes of practice the team must follow. These standards and codes can include rules that the team must abide by, as well as engineering standards that ensure the structural integrity of the plane. Table 1 is a list of some standards and codes the team is applying to this project.

Table 1 - Standards of practice as applied to the project.

Standard Number or Code	**Title of Standard**	**How it applies to Project**
ASTM F2910 [2]	Standard Specification for Design and Construction of a Small Unmanned Aircraft System	Establishes all the basic rules to be followed when designing an unmanned aircraft of 55lbs. or less. It will ensure the team does not pose any risk to themselves and those around during flight.
ASME Y14.5 [3]	Dimensioning and Tolerancing	Ensures all proper dimensioning and tolerancing are performed on drawings and production of airplane parts. Parts will be guaranteed to be within some tolerance zone to ensure construction of the airplane has minimal issues.
LPR 1710.15J [4]	NASA Wind Tunnel Model Systems	Ensures wind tunnel testing for aerodynamics will be conducted in a safe manner. A certified tester will either be present during the test or will teach a team member how to properly do so.
ASME B18.2.1 [5]	Bolts and Screws	All bolts and screws used in the system are guaranteed to be up to standard and do not face the risk of prematurely fracturing. The thread pitch and diameter of each are sure to be within the appropriate tolerance and will always fit with the proper nuts, etc.
2021 Collegiate Design [1]	2021 SAE Aero Design Rules	Ensures all competition rules will be followed to avoid any risk of disqualification. All competition-specific safety requirements are to be added to the plane, and the team will also be aware of how the scoring will take place.
IEEE 128-1976 [6]	Guide for Aircraft Electric Systems	Clearly lays out the standards on properly wiring the electric components of the plane. Will prevent any risk of shorting or causing a fire when current is delivered through the wires. Also ensures the team will have proper radio communication to control the servos and propeller speed.

Table 1 lays out each of the basic standards and codes the team is applying to this project. In general, it will ensure the team is kept safe, as well as ensure the structural integrity of the airplane is maintained. These standards will prevent any risk of fire or shorting any wires when focusing on the electrical systems. It will also ensure that each fastener and part being used is produced within the proper tolerance zone. This will make sure that the team never has an issue with securing the plane together and risking the plane falling apart during flight. Overall, these standards and codes will ensure the safety of everyone present during flight, as well as ensure all parts being produced are not at risk of early failure.

3.0 DESIGN SPACE RESEARCH

To aid in the design, the team conducted research using various sources online. Each team member selected a specific aspect of the aircraft to research using a variety of resources. The culmination of this research is described in this section along with the benchmarking done by the team through this research.

3.1 Literature Review

Tyler's design space research focused on wing planforms and profiles, working to decide which wing planform and what wing profile should be used on the design. Each planform and profile configuration has distinct advantages and disadvantages depending on what type of flight is being performed. Because the team worked to improve load carrying capabilities while also maintaining speed, the design research required selecting a combination that could do both with the best results. Tyler used sources such as websites/blogs about RC planes, the help of the Flagstaff Flyers, and fluid mechanics textbooks to perform this research.

Colton focused on the manufacturing process of the wings, as well as the design of the airplane's tails. For the manufacturing process of the wings, the decision to use a ribbed design was clear right away due to the vast amount of success this method has had in previous competitions. Therefore, the sources are almost entirely dedicated to proper rib construction and the various methods that can be used to construct them. To perform this research, Colton used resources such as the Flagstaff Flyers, videos on construction, and websites/blogs revolving around these concepts.

For Zachary S. Kayser's design space research, the focus was the flight simulator RealFlight 8. RealFlight 8 is a flight simulator that will allow the team to simulate different environmental effects on the aircraft's performance. It will also allow the team to simulate the produced aircraft by altering the specifications of pre-loaded aircraft to be that of the teams RC aircraft. The motor type, servos and much more are included in this altering of specifications. This simulator will also be useful in that it will allow the teams pilot to practice flying the RC aircraft without risking damage to the plane and when the weather conditions won't allow for a safe flight. To perform this research, Zach used sources such as the Flagstaff Flyers, the manual of RealFlight 8, videos on how to use it, and other websites/guides that show how to set up and use RealFlight 8.

Thomas's research was focused on the landing gear. Primarily, the various configurations the team can use was researched. Each configuration has its advantages and disadvantages. The goal of the research was to determine which configurations would satisfy the needs for this project. To perform this research, Thomas used sources such as the Flagstaff Flyers, textbooks on aircraft design, and websites/forums discussing RC plane landing gear configurations.

Daniel's design research was based on the propulsion system that will be utilized on our craft and allow it to fly and carry payload, this being the main goal of the competition. The motor, battery, and propeller chosen can vary greatly depending on the dimensions and weight of the craft, along with its specified flight mission, such as acrobatic, racing, slow flyer, etc. The goal of this project is to build a plane that will carry the most weight, while being as light as possible. Therefore, the research went into finding a propulsion set-up that would allow for a sufficient weight-to-thrust ratio that would allow the team's plane to carry a weighted payload at a slow rate of speed, making it easy to control and land. To perform this research, Daniel used resources such as propulsion calculators, the Flagstaff Flyers, and websites that describe how to select and utilize certain systems.

3.2 State of the Art – Benchmarking

The team has been in constant contact with the Flagstaff Flyers through email, phone calls, and in-person visits to the airfield on the weekends in order to gain their advice and knowledge as they are highly experienced in the field of designing, building, and flying RC aircraft. For the specific type of craft, the team requires a strong, but lightweight aircraft that can fly at a controllable speed with a weighted payload. The most relevant challenges that the team faces with the design of this craft is the selection of material, method of construction, wings, tail, and propulsion system. The correct material and method of construction would ensure that our craft is as light as possible and the body, wings, and tail are strong enough to withstand crash impacts while carrying a weighted payload. Also, the propulsion system must be able to have a substantial weight-to-thrust ratio to be able to carry a weighted payload.

3.2.1 System Level State of the Art – Benchmarking

The team has decided upon three different types of aircraft that could be utilized for the competition, each with their own set of advantages and disadvantages. It is important to research and review these types of aircraft to determine which aircraft would be most appropriate for the requirements set out by the competition.

3.2.1.1 Existing Design #1: Conventional Aircraft

The conventional type of aircraft is the standard, single-motor monoplane that is most used amongst recreational flyers. Since this aircraft is the most popular version of RC aircraft, it is much easier to obtain information and resources for the design and construction. A previous version of this plane is shown in Figure 3.

Figure 3 - Conventional aircraft [7].

3.2.1.2 Existing Design #2: Flying Wing

The next existing design is a flying wing, shown in Figure 4. This type of aircraft is unique in its design and has the benefit of its ease of manufacturing, which is highly important in case it needs alterations or repairs. Additionally, the ease of manufacturing allows this type of aircraft to be assembled quickly and efficiently, which, in turn, would score the team points in the competition. However, this type of craft lacks control and stability in flight and could make it prone to crashing in flight or landing incorrectly, especially when carrying a weighted payload.

Figure 4 - Flying wing design [8].

3.2.1.3 Existing Design #3: Unique Design

The unique design allows the team to be much more creative in the design and tailor the aircraft to further fit the requirements of the team and parameters set out by the competition. The unique design has many benefits to it, such as being scored higher on creativity and allowing possible gains in flight control. On the other hand, developing a unique design has a high risk of not having enough control and lift, therefore leading to a higher chance of the project not being a success. Figure 5 depicts a unique design of a micro airplane.

Figure 5 - Unique airplane design [9].

3.3 Subsystem Level State of the Art Benchmarking

The team can split the airplane into multiple subsystems to conduct research on. These subsystems include the landing gear, wings, and tails. Although these are the main three subsystems research was conducted on, there were also subsystems of propulsion and avionics that were researched separately.

3.3.1 Subsystem #1: Landing Gear

The landing gear is a critical subsystem when it comes to the landing aspect of the project. Typically, it would play a role in taking off, but a requirement for this project is to hand launch the craft. The key criteria for the landing gear are for the craft to be maneuverable on the ground, land, and land within a certain distance.

3.3.1.1 Taildragger

A common configuration for landing gear is the taildragger set up as seen in Figure 6. This set-up, in comparison to others, costs less in terms of material and has less of an impact on the weight of the craft. This is key seeing as how the competition involves carrying a payload and by reducing the weight of the craft this would allow for more weight to be carried. An area of concern with this configuration is the danger of nosing over during the landing process.

3.3.1.2 Tricycle

Another common landing gear setup is the tricycle as seen in Figure 7. This setup in contrast to taildragger will cost more in terms of materials and add more weight to the plan. The advantage to this setup is during the landing process the potential for nosing over is greatly reduced. This setup provides greater protection to the aircraft's propeller and the aircraft as whole unlike the taildragger configuration.

3.3.1.3 Monowheel with Outriggers

Another potential setup is the monowheel with outriggers as seen in Figure 8. Unlike the previous two designs, this setup will cost the least in terms of material and add the least amount of weight to the craft. However, this formation lacks stability during the landing process. If the approach for the landing is not ideal, this could potentially result in a crash especially depending on the conditions of the wind. Additionally, a requirement for competition is that our craft can fly in low winds around 10 mph.

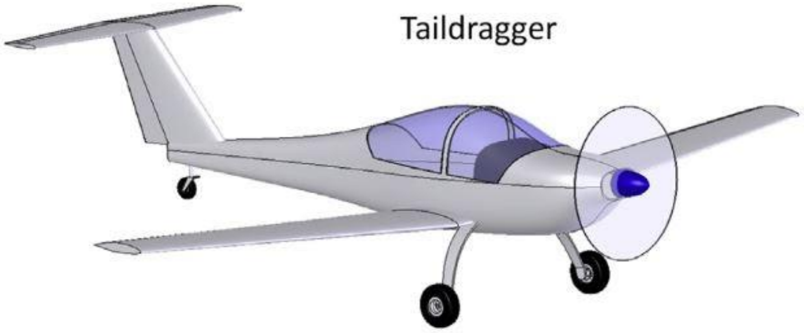


Figure 6 - Taildragger landing gear configuration [10].

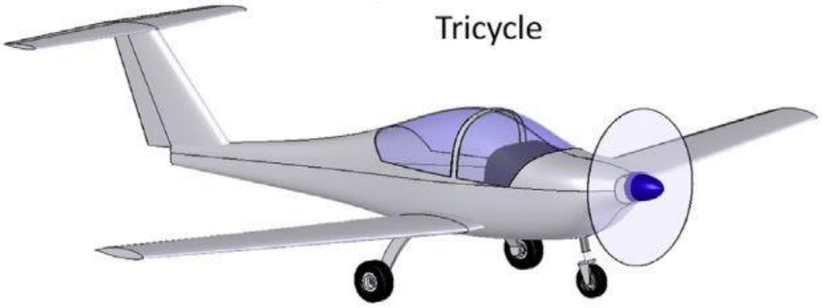


Figure 7 - Tricycle landing gear configuration [10]

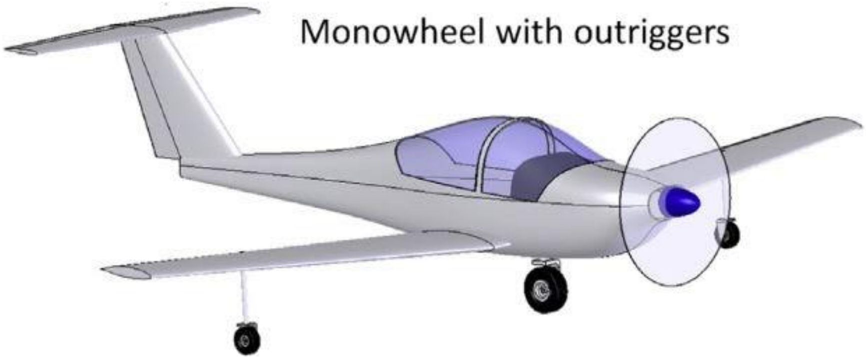


Figure 8 - Monowheel with outrigger landing gear configuration [10].

3.3.2 Subsystem #2: Wings

Another important subsystem to consider are the wings of the airplane. Without wings, the airplane cannot generate any lift and therefore cannot get off the ground and fly. There are several different wing types to consider, from very traditional straight wings, to tapered wings, to the most diverse and creative circular wings.

3.3.2.1 Existing Design #1: Traditional Rectangular Wings

The first and easiest to create set of wings are traditional rectangular wings that you would see on older airplanes like the Piper pa-38 shown in Figure 9. These wings are easy to manufacture and generate large amounts of lift thanks to their larger surface areas compared to a tapered or unique wing of similar size. These wings are usually found on older airplanes, as their manufacturing time and cost is cheaper than tapered or unique wings, and their dynamics are easier to calculate. Some downsides to these types of wings are that they are almost always less efficient than other types of wings, and the bending forces they exert can be strong, especially for long wingspans.

Figure 9 - Piper pa-38 [11].

3.3.2.2 Existing Design #2: Tapered Wings

Another common wing design are tapered wings. While very similar to rectangular wings, these types of wings generally have a slight taper to them (sometimes in the x, y, and z directions). An example of this is shown on the North American Aviation P-51 Mustang shown in Figure 10. This airplane has slight tapers on front and back of the wings, which help to improve with bending moments on the wings, more efficient lift profiles, and reduced drag at the tips. Tapered wings like the one shown in Figure 10 are usually better for more aerobatic type flying or when trying to improve a design for optimal efficiency. The downside to using tapered wings are their harder construction styles, and the reduced lift due to a decrease in wing area.

3.3.2.3 Existing Design #3: Unique Wings

While there are dozens of different wing shapes and types that could be defined, it is easier to compile the other wing designs into a category of unique wings. This category encompasses elliptical, delta, trapezoidal, ogive, swept forward/back and other unique wing designs that are less traditional. The benefits to these wings are varying, but usually provide a unique quality that is ideal for the type of plane such as increased aerobatic capabilities or optimal efficiency for long range flight. The downside to most of these designs are their difficult manufacturing process and unique shape are difficult to quantify the dynamics of. Shown in Figure 11 is a swept back wing on a Boeing 787-9 Dreamliner, which is obviously much more difficult to construct, but would be much more efficient at high-altitude long-distance flight.

Figure 10 - North American aviation P-51 Mustang [11].

Figure 11- Boeing 787-9 Dreamliner [11].

3.3.2.4 Existing Design: Airfoil Selection

While the airfoil is more of a subsystem of the wing's subsystem, it's an important component that is worth briefly mentioning in the wing design section. Through the design space research, the team identified four main airfoil classes: Symmetrical, semi-symmetrical, flat bottomed and under cambered. The symmetrical and semi-symmetrical airfoils will provide higher levels of maneuverability and are usually used for planes that are required to perform acrobatic maneuvers, whereas under cambered and flat-bottomed airfoils provide large amounts of lift and are beneficial for load carrying or long-distance flying. Figure 12 shows a diagram of the four types of airfoils mentioned, which are cut from the Airfield Models [12] website and reformatted by the team.

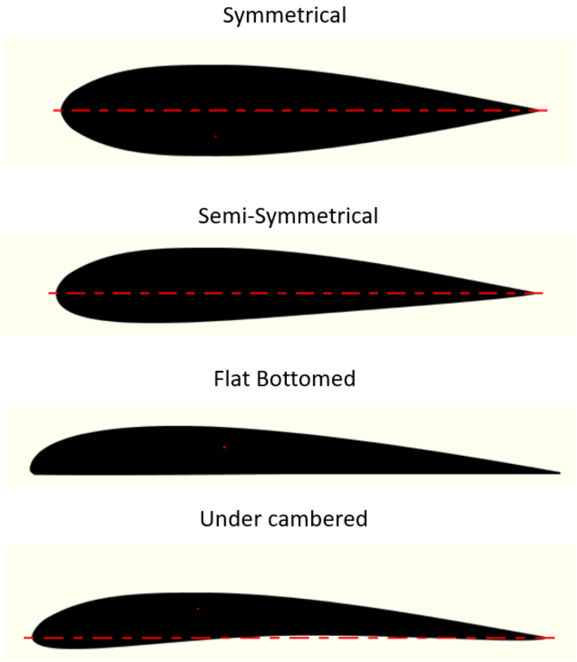


Figure 12 - Four main classes of airfoil [12].

3.3.3 Subsystem #3: Tails

The tails are an important part of the airplane because this is what provides the airplane with stability and control. From the functional decomposition, the servo control and landing of the airplane are critical. This means that the tail plays a major part in each of these subsystems. For the servos to be useful, they must move the tail's rudder/elevator while in the air. This is what will allow the airplane to slow down and be steered different directions. The landing of the airplane is highly dependent on the tails as well because the tails must move to increase the drag to come to a stop. Without tails, the airplane will lack serious control and stability that is critical to the success of the project.

3.3.3.1 Existing Design #1: Conventional Tail

The first tail design is a conventional tail design, as seen in Figure 13. Conventional tails are a great design to consider due to their proven history. Most commercial airplanes use conventional tails because they have very high stability and control for the aircraft. In terms of the competition, the requirements will be met because it allows control in the air while also being able to connect to the landing gear and control the airplane without aerodynamics (a competition requirement).

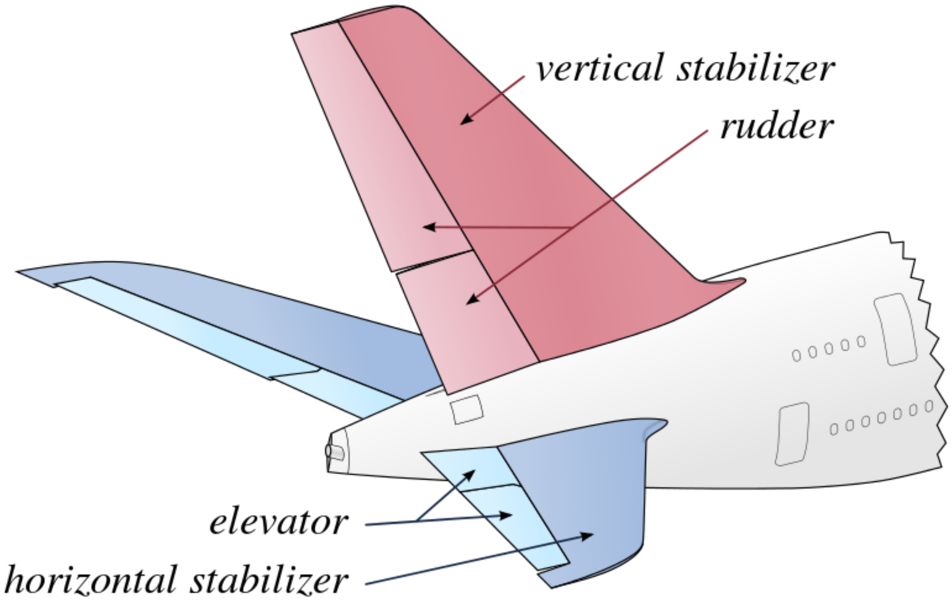


Figure 13 - Conventional tail components [13].

3.3.3.2 Existing Design #2: Boom Tail

The next tail design is known as the boom tail. The boom tail as seen in Figure 14, has a two-rudder set up with two horizontal bars to connect the horizontal stabilizer. This design is an excellent choice in terms of the competition requirements because it allows for simple 'put in place' fastening in order to construct the plane in under three minutes. The two horizontal bars will simply snap into both the horizontal stabilizer and the wings.

Figure 14 - Boom tail design [14].

3.3.3.3 Existing Design #3: Cruciform Tail

The next tail design is the cruciform tail, as seen in Figure 15. The cruciform tail is a modified version of the conventional tail. The main difference between these two designs is the placement of the horizontal stabilizer around midway up the vertical stabilizer. This will allow for a higher control of the airplane but can potentially be harder to manufacture. For the requirements, it will allow extreme control of the airplane while flying, which is essentially the main engineering requirement once the plane is airborne.

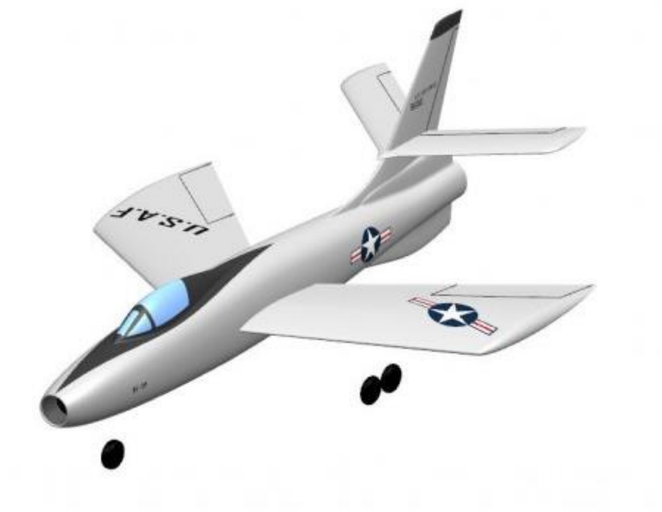


Figure 15 - Cruciform tail design [15].

4.0 CONCEPT GENERATION

To brainstorm possible aircraft solutions, the team collectively generated three original designs. The three designs will be evaluated, and the most suitable design solution will be used moving forward. The three designs that the team created are included in the following sections.

4.1 Full System Concepts

For the full system concepts that were created by the team, three original design concepts were generated. The three concepts show three different ways the customer needs and engineering requirements of the design may be fulfilled.

4.1.1 Full System Design #1: Standard Aircraft

The standard aircraft design is time tested and has proven to be a reliable aircraft design. The standard aircraft design that the team has collectively produced utilizes a Clark-Y airfoil to provide lift and adequate stability of the aircraft (Figure 16). The landing gear configuration for this design is a tricycle type design that will allow the aircraft safer landings than the considered tail-dragger style landing-gear. This design utilizes a conventional tail design and only one propeller and motor. A disadvantage to this design is that it does not appear to be the most original, as it pulls aspects from many existing aircraft styles and combines them in an original way.

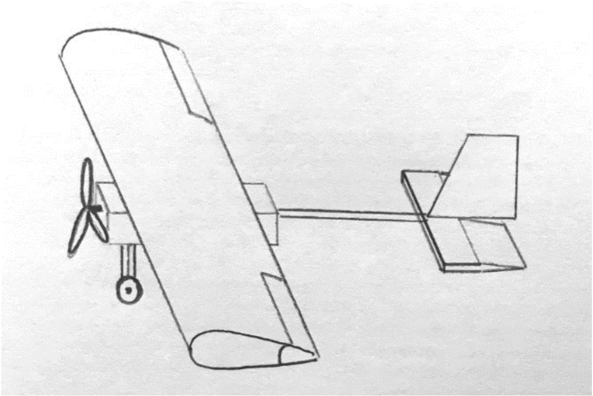


Figure 16 - Standard aircraft design.

4.1.2 Full System Design #2: Flying Wing

The flying wing aircraft is like many of the flying wing aircraft that are used in acrobatics. However, the design that was created by the team places the propeller in the front of the aircraft while typically it would be seen in the rear (Figure 17). This design also utilizes a landing gear while most do not. This design also includes a tail fin with a control surface to increase the design's stability. An advantage to this design is that there is no fuselage component. The fuselage has been incorporated into the airfoil. This may help reduce the aircrafts overall weight. A disadvantage to this design is that it will be highly unstable, making it difficult to keep in the air.

4.1.3 Full System Design #3: Unique Aircraft

The unique design aircraft design was designed with originality in mind. The unique aircraft utilizes a tricycle type landing gear configuration with the front two landing gears located on the wings of the aircraft and three different support beams spanning from the airfoil and fuselage to the tail configuration (Figure 18). This will increase the designs durability however will contribute to the overall weight which the team is attempting to minimize. The tapered wings will also prove to be difficult to manufacture using balsa wood. Another disadvantage of this design is that with an entirely new design there are many aspects that have not yet been tested and may cause aircraft failures.

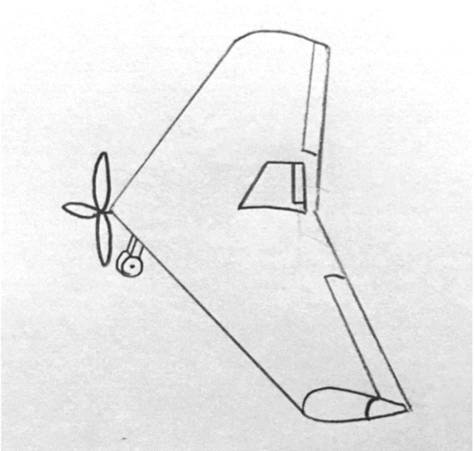


Figure 17 - Flying wing aircraft.

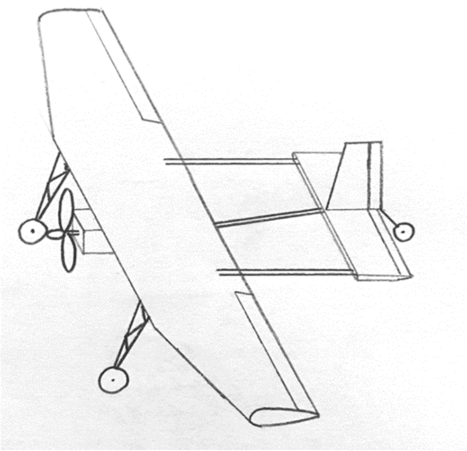


Figure 18 - Unique design aircraft.

4.2 Subsystem Concepts

In this section the team generated concepts for the wings, landing gear, and tail design. The team used decision matrices to evaluate their generated concepts to determine options for a final design.

4.2.1 Subsystem #1: Landing Gear

Using information gathered from research, the team was able to design five potential concepts for the landing gear. Among these five concepts, two concepts stand out as the most viable options as seen in Table 2.

Table 2 - Landing gear decision matrix.

Concepts		Tricycle		Tail Dragger	
Criteria	**Weight**	**Rating**	**Weight Score**	**Rating**	**Weight Score**
Landing Preformance	0.3	5	1.5	2	0.6
Cost	0.15	4	0.6	5	0.75
Weight	0.25	2	0.5	3	0.75
Size	0.3	3	0.9	4	1.2
Total		14	**3.5**	14	**3.3**

4.1.1.1 Design #1: Tricycle with outrigger

The tricycle with outrigger is designed for maximum stability for a landing as seen in Figure 20. However, the tradeoff is increased cost and weight due to all the components. This configuration much like a standard tricycle provides a safeguard from nosing over unlike the taildragger configuration.

4.1.1.2 Design #2: Taildragger

The taildragger configuration, as seen in Figure 19, is a lightweight design that has a minimal cost. This concept is though having the danger of nosing over during the landing process. However, it has the risk of nosing over during a landing. Being lightweight, this design allows for a heavier payload to be carried.

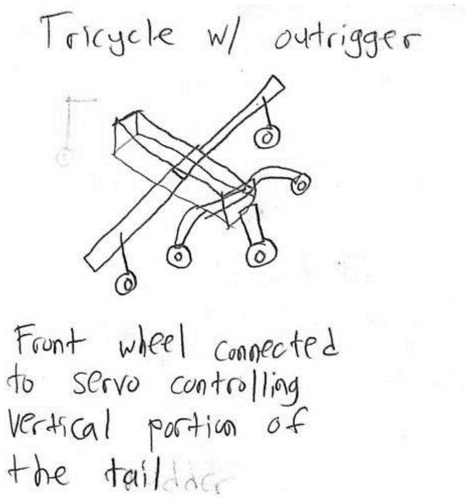


Figure 20 - Tricycle with outrigger landing gear configuration.

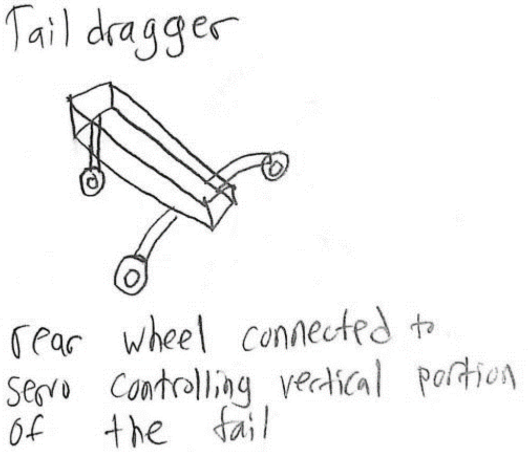


Figure 19 - Taildragger landing gear configuration.

4.1.1.3 Design #3: Monowheel with Outrigger

The monowheel with outrigger is the lightest weight concept among the designs as seen in Figure 21. However, it has a lack of stability if not positioned and handled properly during a landing. Another potential hazard is a key to landing is the approach and if the approach is thrown off by wind this configuration is the most at risk of a serious crash.

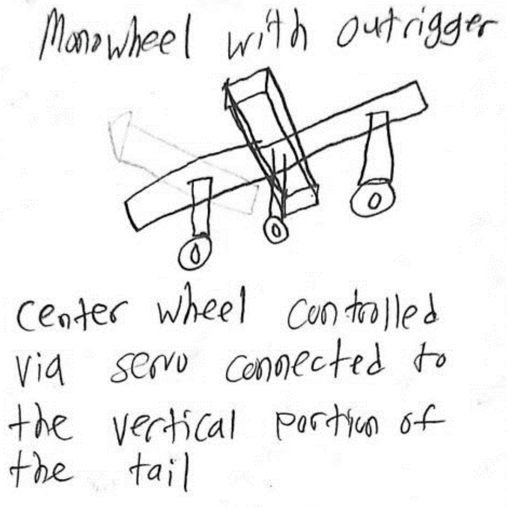


Figure 21 - Monowheel with outrigger landing gear configuration.

4.1.1.4 Design #4: Tandem with Outrigger

The tandem with outrigger is very similar to the monowheel design with the key exception of another wheel in the center of the aircraft, as seen in Figure 22. This design, much like the monowheel, will be lighter and cost less. A key difference though is the prevention of nosing over by having the wheel positioned further up along the fuselage unlike the monowheel design.

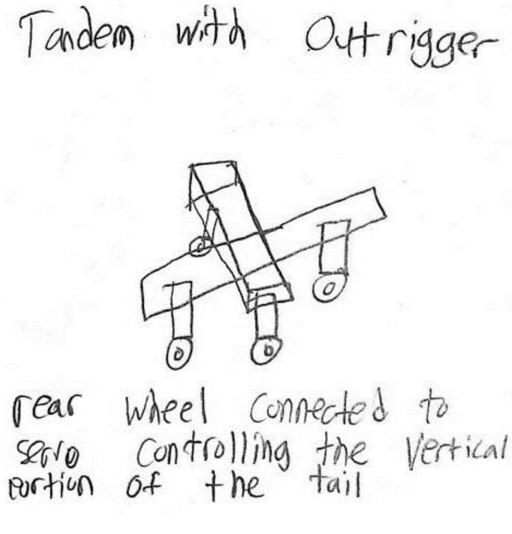


Figure 22 - Tandem with outrigger landing gear configuration.

4.1.1.5 Design #5: Tricycle

The final concept is the tricycle design as seen in Figure 23. The concept costs more and weighs more in contrast to the taildragger design. This concept design mitigates the risk of nosing over during a landing which'll protect the propeller and the aircraft. It is also one of the most used designs across aircraft due to the performance over the year.

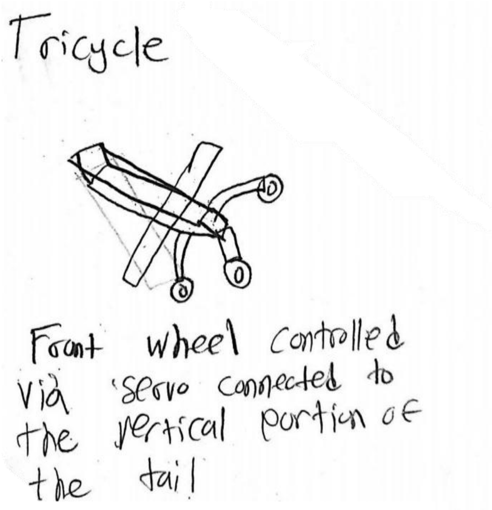


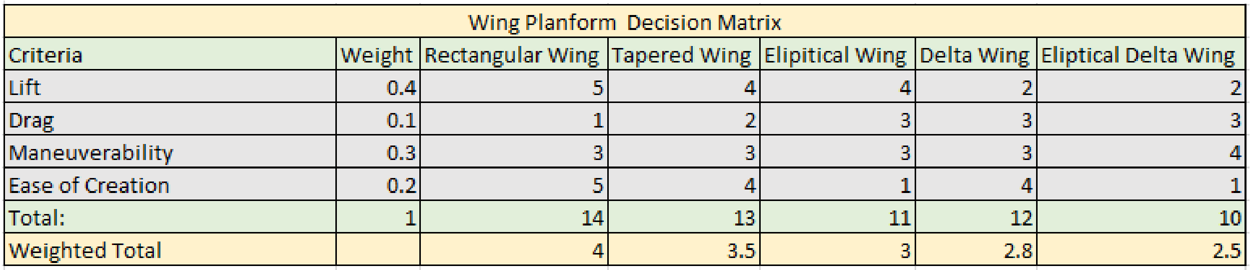
Figure 23 - Tricycle landing gear configuration.

4.1.2 Subsystem #2: Wings

Using ideas from existing wing designs, the team generated five designs for wing shapes to use on the micro airplane. The team then compared these using the decision matrix shown in Table 3. The criteria and their weights were based on the engineering requirements of lift, drag, thrust, durability, and the customer requirements of a reliable design, easy to assemble, and more.

The design with the highest weighted total was the rectangular wing thanks to its extremely high lift and its very simple creation, so it is likely to be the design the team takes into prototyping. All five designs are shown below and are ranked in order of most optimal for the team's purpose to the least optimal.

Table 3 - Wing planform decision matrix.



Wing Planform Decision Matrix						
Criteria	Weight	Rectangular Wing	Tapered Wing	Elipitical Wing	Delta Wing	Eliptical Delta Wing
Lift	0.4	5	4	4	2	2
Drag	0.1	1	2	3	3	3
Maneuverability	0.3	3	3	3	3	4
Ease of Creation	0.2	5	4	1	4	1
Total:	1	14	13	11	12	10
Weighted Total		4	3.5	3	2.8	2.5

4.1.1.6 Design #1: Traditional Rectangular Wings

The traditional rectangular wing design is the most optimal design for the team. This design is easy to manufacture, provides excellent lift, and will break down into easy sections so the team can put it together quickly. The cons to using this wing design are that it is less efficient than others and is less maneuverable in the air. A rough sketch of a traditional rectangular wing is shown below in Figure 24.

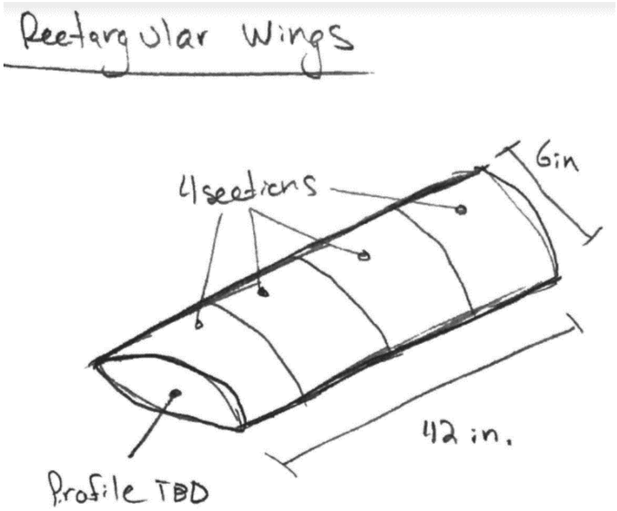


Figure 24 - Traditional rectangular wing.

4.1.1.7 Design #2: Tapered Wings

Tapered wings were also considered very highly in the design of the wing shape. These wings provide excellent lift as well and are still relatively easy to manufacture. Additionally, the forces on these wings at the fuselage are less so than that of rectangular wings. The downsides to using such a wing type is that the plane loses some lift due to the decrease in wing area, and the manufacturing time and cost increases. Also, because tapered wings use different rib shapes, replacement or rebuilding of the wing will take much more work than traditional rectangular wings. A sketch of a possible tapered wing for this system is shown below in Figure 25.

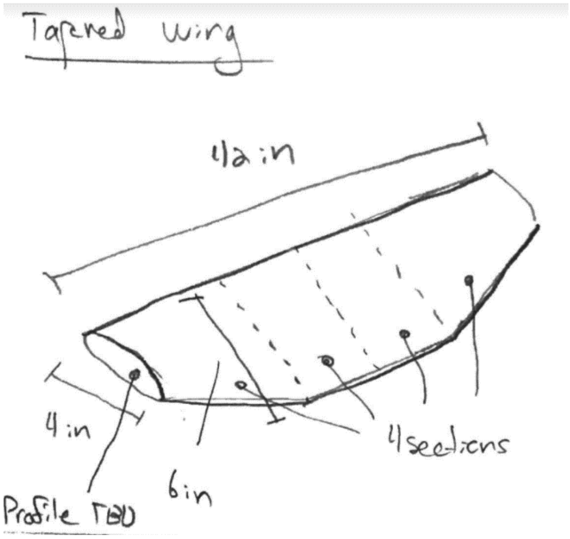


Figure 25- Tapered wing design.

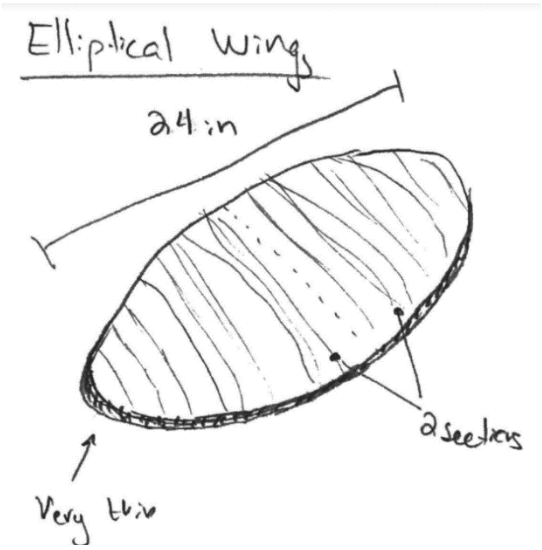


Figure 26 - Elliptical wing design.

4.1.1.8 Design #3: Elliptical Wings

After moving away from rectangular wings, the wing designs become less feasible. A sketch of a possible elliptical wing design is shown in Figure 26. This wing design is the most efficient of all shapes, providing the best lift to drag ratios, however, it comes with many cons. Firstly, this wing shape is very difficult to manufacture for our team (and in the professional industry) which makes it not only cost more, but more difficult to replace. Additionally, we lose some lift due to reduced wing area.

4.1.1.9 Design #4: Delta Wings

A sketch for a possible delta wing design is shown in Figure 27. This design is actually very easy to construct and would likely be easy to break down into the necessary components for assembly. However, this type of wing is better for fast moving aircraft. This wing shape provides increased maneuverability, and is efficient at high speeds, however, its downside is that it has very low lift thanks to the very low aspect ratio and the team cannot benefit from most of its upsides since most micro aircraft are flying at relatively low speeds.

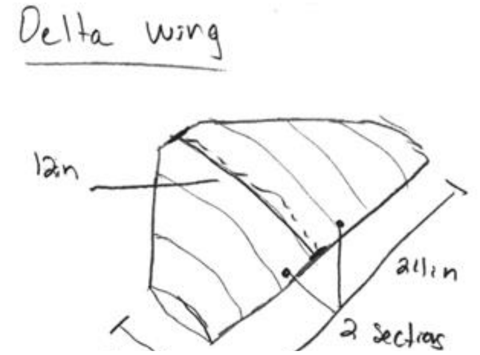


Figure 27 - Delta wing design.

4.1.1.10 Design #5: Delta Elliptical Wings

A final proposed design for a wing shape of the aircraft is delta elliptical wings. While the team has never seen such a design before, it was proposed during brainstorming. This design would likely be very efficient, and have great lift profiles, however it would be virtually impossible to assemble. Construction of such a wing would be extremely difficult and if we were ever to break something, it would be near impossible to repair, especially if a break were to occur at competition. A sketch of this design is shown in Figure 28, however, the team is likely to never pursue such a design as its downsides are many compared to any benefits.

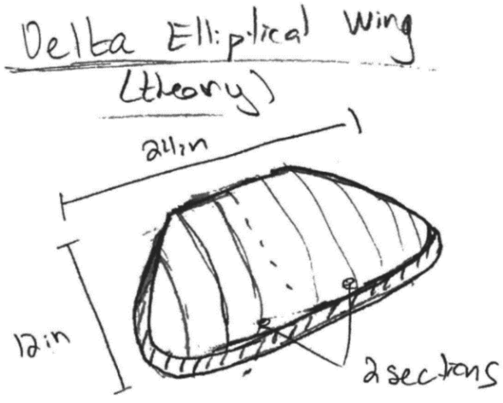
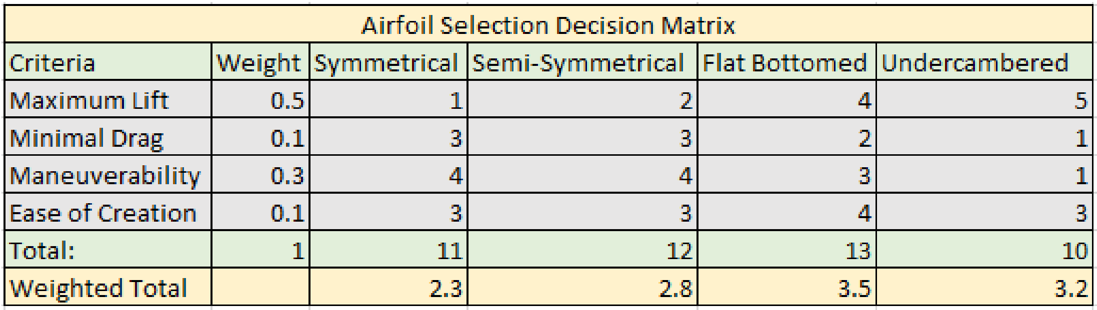


Figure 28 - Delta-elliptical wing design.

4.1.1.11 Airfoil Design/Selection

It is once again worthwhile to note here that airfoils are an important component of wing design but are once again more of a subsystem of the wings themselves, and therefore do not warrant an entire section. The team used the design space research to identify the pros and cons of each airfoil type (which were noted in the previous section) and develop a decision matrix for airfoil selection. This decision matrix used the same decision criteria as the wings with slightly different weights based on virtually the same customer and engineering requirements as the wings. This decision matrix is shown in Table 4 and identifies the flat bottomed and under cambered airfoils as the most viable.

Table 4 - Airfoil decision matrix.



Airfoil Selection Decision Matrix					
Criteria	Weight	Symmetrical	Semi-Symmetrical	Flat Bottomed	Undercambered
Maximum Lift	0.5	1	2	4	5
Minimal Drag	0.1	3	3	2	1
Maneuverability	0.3	4	4	3	1
Ease of Creation	0.1	3	3	4	3
Total:	1	11	12	13	10
Weighted Total		2.3	2.8	3.5	3.2

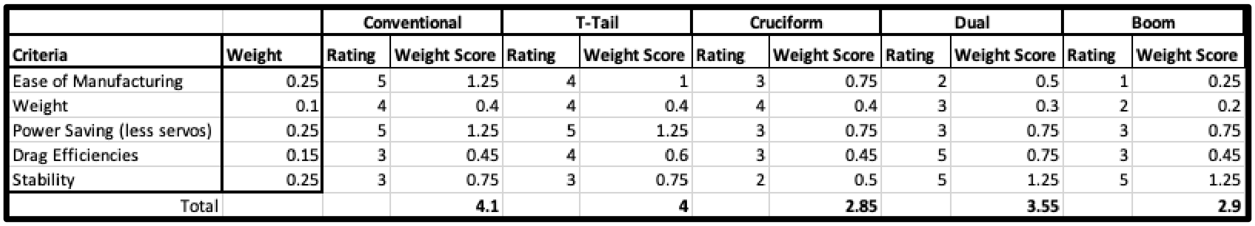
The two airfoils considered were the Selig 1223 [16] and the Clark Y [17] airfoils. The team then used excel to determine the lift and drag on both the Selig 1223 and Clark Y airfoils which is shown in Appendix C and Appendix D respectively.

It is clear from the data that the Selig 1223 airfoil produces a higher lift force at lower speeds than the Clark Y, however it comes with the downsides of higher drag and extremely low maneuverability while flying. Looking at the Clark Y airfoil, we see reasonably high lift (still significantly less than the Selig 1223) and less drag, however by talking to the Flagstaff Flyers and through research online, will provide a much more stable flying experience. Through all of this, the team has determined that the Clark Y airfoil will be the airfoil they will take into prototyping with rectangular wings.

4.1.2 Subsystem #3: Tails

After State-of-the-Art review and research into the various tail configurations, the team was able to develop five potential tails to be used in the tentative final design. Table 5 shows the decision matrix that was used to compare the five different tails designed below.

Table 5 - Tail configuration decision matrix.



		Conventional		T-Tail		Cruciform		Dual		Boom	
Criteria	Weight	Rating	Weight Score	Rating	Weight Score	Rating	Weight Score	Rating	Weight Score	Rating	Weight Score
Ease of Manufacturing	0.25	5	1.25	4	1	3	0.75	2	0.5	1	0.25
Weight	0.1	4	0.4	4	0.4	4	0.4	3	0.3	2	0.2
Power Saving (less servos)	0.25	5	1.25	5	1.25	3	0.75	3	0.75	3	0.75
Drag Efficiencies	0.15	3	0.45	4	0.6	3	0.45	5	0.75	3	0.45
Stability	0.25	3	0.75	3	0.75	2	0.5	5	1.25	5	1.25
Total			**4.1**		**4**		**2.85**		**3.55**		**2.9**

4.1.2.1 Design #1: Conventional

The first design developed is the conventional tail, as seen in Figure 29. The conventional tail is a simple configuration the team was able to consider due to its ease of manufacturing and the ability to control with only two servos. However, the major downside of this design is the lack of creativity. From the decision matrix, it was clear that the conventional tail design is one of the best options that should be considered moving forward. The conventional tail is a proven design, so the team moved forward with it.

4.1.2.2 Design #2: T-Tail

The next design developed is the T-tail configuration. This design, as seen in Figure 30, is essentially a flipped version of the conventional tail. Having the horizontal stabilizer be on the top of the vertical stabilizer rather than the bottom can lead to a higher center of gravity if this issue is to arise. However, manufacturing this design will be slightly harder than the conventional tail because there is a lack of support on the bottom of the tail and ensuring the vertical rudder can still move adds even more of an issue. Nonetheless, this design is the team's second choice and a CAD model will be developed in the future if this becomes the top choice due to center of gravity issues.

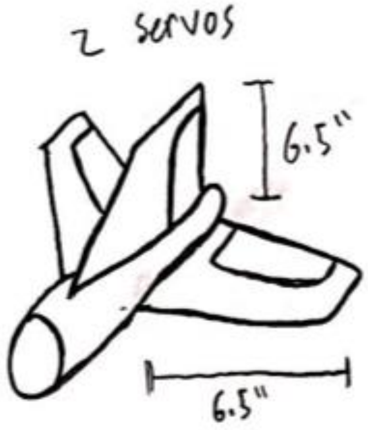


Figure 29 - Conventional tail design.

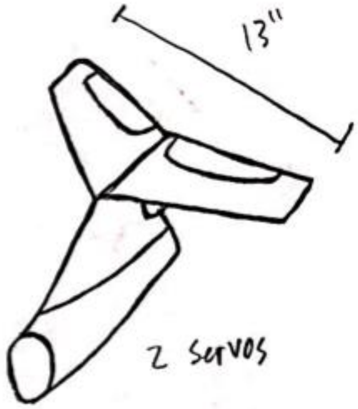


Figure 30 - T-tail design.

4.1.2.3 Design #3: Cruciform

The cruciform tail is the next design that was considered (seen in Figure 31). This design scored lowest on the decision matrix due to several key factors. Manufacturing a tail that is placed around half-way up the vertical stabilizer is far more difficult to manufacture than the others. Finding a proper way to secure the two pieces together, while also not interfering with the ability to control the rudder, adds more work for the team. However, this configuration has very high stability because of the center of gravity being directly in the desired location (middle of the vertical stabilizer). If the team needs to increase the stability and move the center of gravity up but not to the top, this option will become feasible.

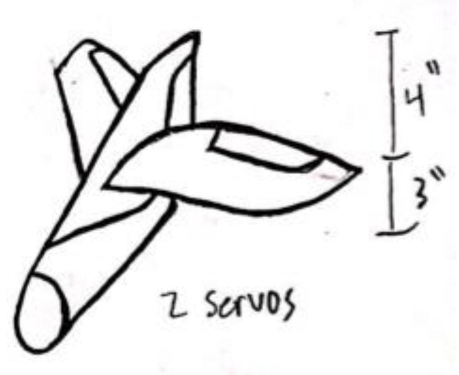


Figure 31 - Cruciform tail design.

4.1.2.4 Design #4: Dual

The dual tail is the next concept the team considered. Figure 32 shows the concept the team generated of the dual tail design. From the decision matrix, it is clear that this is the best option if the team decides to move forward without the conventional or T-tail design. The dual tail has increased control because of the two vertical rudders. By having this control, the team can prevent crashes more than any other version. However, by having two vertical stabilizers, the team must account for three servos, as well as an increased manufacturing difficulty. If control of the plane is lacking while airborne, this design will be the best to move forward with.

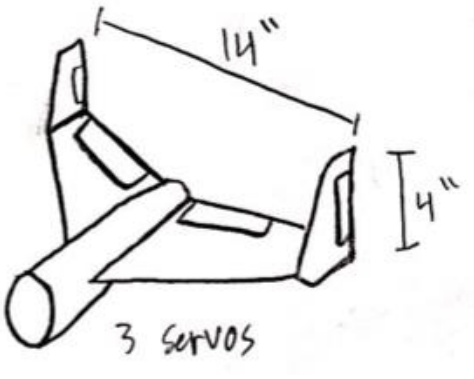


Figure 32 - Dual tail design.

4.1.2.5 Design #5: Boom

The final tail design the team generated is the boom tail, found in Figure 33. The major advantage of using this formation is the extreme stability that is achieved. By expanding the horizontal length of the tail, it will balance out the wings and create one of the most stable versions you can get. On the other hand, this formation requires three servos and is far heavier than any other design. If power/weight is permitted and stability is needed, this is clearly the best option for the team to move forward with.

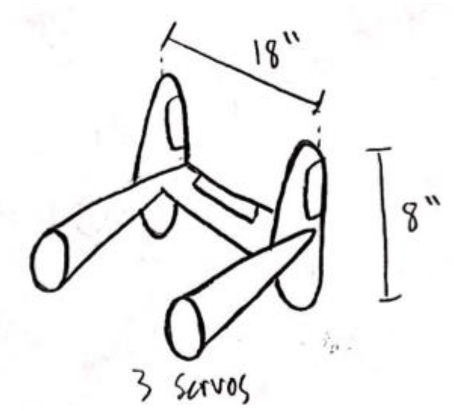


Figure 33 - Boom tail design.

5.0 DESIGNS SELECTED – First Semester

The SAE Aero Micro competition allows teams to design and build many different types of aircraft of various shapes, sizes, and functionalities. Each different design of aircraft has their own unique array of subsystems and components that allow them to perform at varying levels of performance. By putting these various designs into a Pugh Chart and decision matrix, the team is able to determine if a design will perform exceptionally and where it will fall short on expectations. From this, the team will be much greater informed on which aircraft design will be the best match for the team based on scores they achieved.

5.1 Technical Selection Criteria

The criteria used to judge these different types of craft are based on the criteria based on the customer requirements and the engineering requirements. First, the Pugh Chart is based on a non-quantitative analysis of the customer requirements that our craft must be able to achieve. Since the Pugh Chart is not quantifiable, it does not give the team the best idea of which aircraft would be the best one to choose and therefore, a decision matrix will be used to determine the best aircraft design.

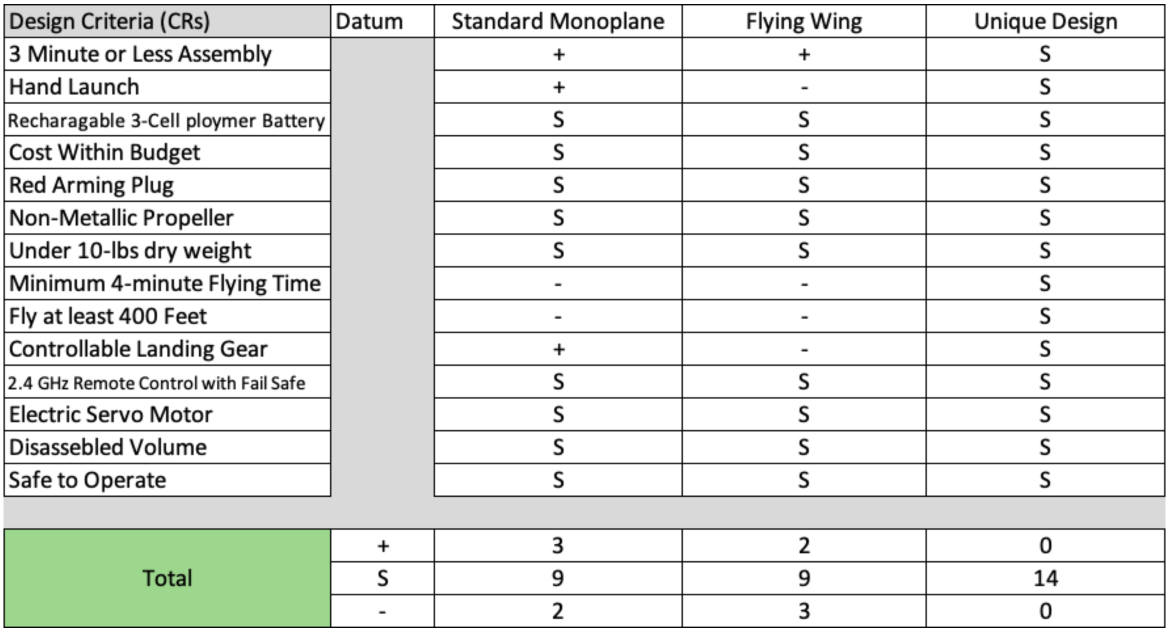
The criteria of the decision matrix are based on the engineering requirements, which mainly reflects the criteria that the team must meet in order to perform well in the competition. Such criteria include how well the craft maneuvers, ease of manufacturing, toughness, etc. These criteria are quantifiable, and they are scored based on how well they can achieve and meet the engineering requirements listed in the chart. From this, the team is best able to identify and select the type of aircraft that will give the greatest chance of success in the competition.

5.2 Rationale for Design Selection

From the specified technical criteria specified above, the three different designs of aircraft in the previous section were set to be evaluated and scored. This gave the team a visible and measurable way to evaluate the various types of aircraft mentioned. Table 6 shows a Pugh chart used to evaluate the airplane design.

The standard monoplane design scored the highest in this chart as the relatively simple and basic design make it easy to assemble quickly and a large wingspan will allow it to achieve lift relatively easy from the hand-launched deployment. In addition, this design will allow the craft to fly at slower velocities and therefore be easier to land. This will allow the controllable landing gear to have a much greater chance of success of steering the aircraft on the runway upon landing. However, due to the increased payload that this craft will be able to carry, it remains questionable whether it will be able to achieve the desired flight time of four minutes and fly 400 feet.

Table 6 - Pugh chart.

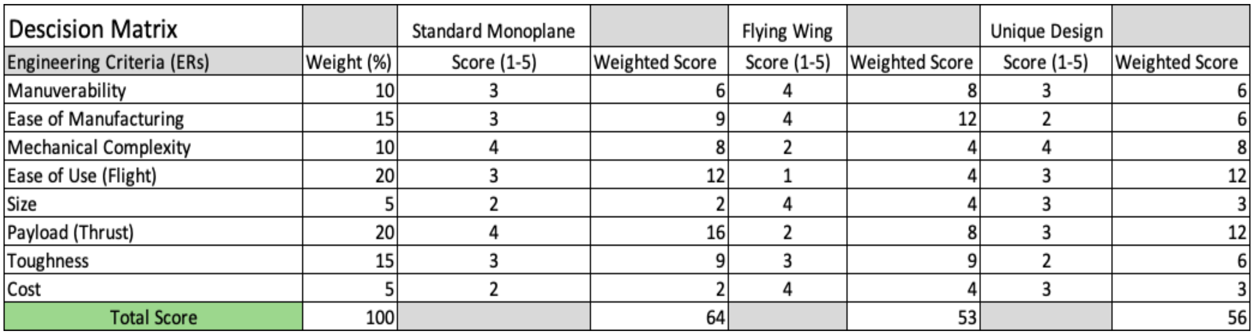


Design Criteria (CRs)	Datum	Standard Monoplane	Flying Wing	Unique Design
3 Minute or Less Assembly		+	+	S
Hand Launch		+	-	S
Recharagable 3-Cell ploymer Battery		S	S	S
Cost Within Budget		S	S	S
Red Arming Plug		S	S	S
Non-Metallic Propeller		S	S	S
Under 10-lbs dry weight		S	S	S
Minimum 4-minute Flying Time		-	-	S
Fly at least 400 Feet		-	-	S
Controllable Landing Gear		+	-	S
2.4 GHz Remote Control with Fail Safe		S	S	S
Electric Servo Motor		S	S	S
Disassebled Volume		S	S	S
Safe to Operate		S	S	S
Total	+	3	2	0
	S	9	9	14
	-	2	3	0

The flying wing is a unique aircraft, based on its geometry alone, which does allow it to have some advantages over other types of aircraft, but it also brings some disadvantages. First, the ease of manufacturing on this craft is one of its highlights, but due its geometry, the area of the plane it uses to achieve lift is relatively small. Therefore, the team may have complications when trying to launch this craft by hand. Due to the lack of stability and control during flight, it is also prone to crashes and hard landings, and this is especially likely to happen when carrying a weighted payload.

An airplane with a unique design has both benefits and disadvantages. Although some creative design concepts were established in the previous section, the overall design and many of the sub-systems remain unknown and are most certainly subject to drastic changes and alterations, thus affecting its ability to meet all the criteria listed. Table 7 shows a decision matrix used to help evaluate the airplane design.

Table 7 - Airplane decision matrix.



Descision Matrix		Standard Monoplane		Flying Wing		Unique Design	
Engineering Criteria (ERs)	Weight (%)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
Manuverability	10	3	6	4	8	3	6
Ease of Manufacturing	15	3	9	4	12	2	6
Mechanical Complexity	10	4	8	2	4	4	8
Ease of Use (Flight)	20	3	12	1	4	3	12
Size	5	2	2	4	4	3	3
Payload (Thrust)	20	4	16	2	8	3	12
Toughness	15	3	9	3	9	2	6
Cost	5	2	2	4	4	3	3
Total Score	100		64		53		56

The decision matrix shown in Table 7 allows the team to give each aircraft a numbered rating on the different engineering requirements that it will need to perform to achieve the highest possible score in the competition. From the results calculated in the table, it is evident that the standard monoplane is the ideal plane to use in this competition. The large wingspan allows the craft to achieve a much greater level of thrust compared to the other craft, which will allow it to carry a greater payload. Furthermore, due to the large surface area of the craft, it will produce a reasonable amount of drag, which makes it fly at a slower velocity and therefore be much easier to maneuver and control. Lastly, this is a very popular type of RC craft, which gives us a substantial amount of information to design and build it, improving the ease of manufacturing and the complexity of the mechanical components.

From this decision matrix, the standard monoplane and a unique design were selected as the monoplane is a simple, yet effective design for an RC aircraft. A uniquely designed airplane was also selected as though some components of the craft remain unknown, it shows more promising early results compared to the flying wing. Furthermore, the unique design can be continuously altered and changed to be more tailored to achieving the engineering requirements.

After analyzing the Pugh chart and decision matrix, the team has decided to move forward with the standard monoplane design. This design consists of a tricycle landing gear configuration, the Clark-Y airfoil, a standard rectangular fuselage, and a conventional tail configuration. Figure 34 shows the tentative final design of the airplane the team has developed in SOLIDWORKS.

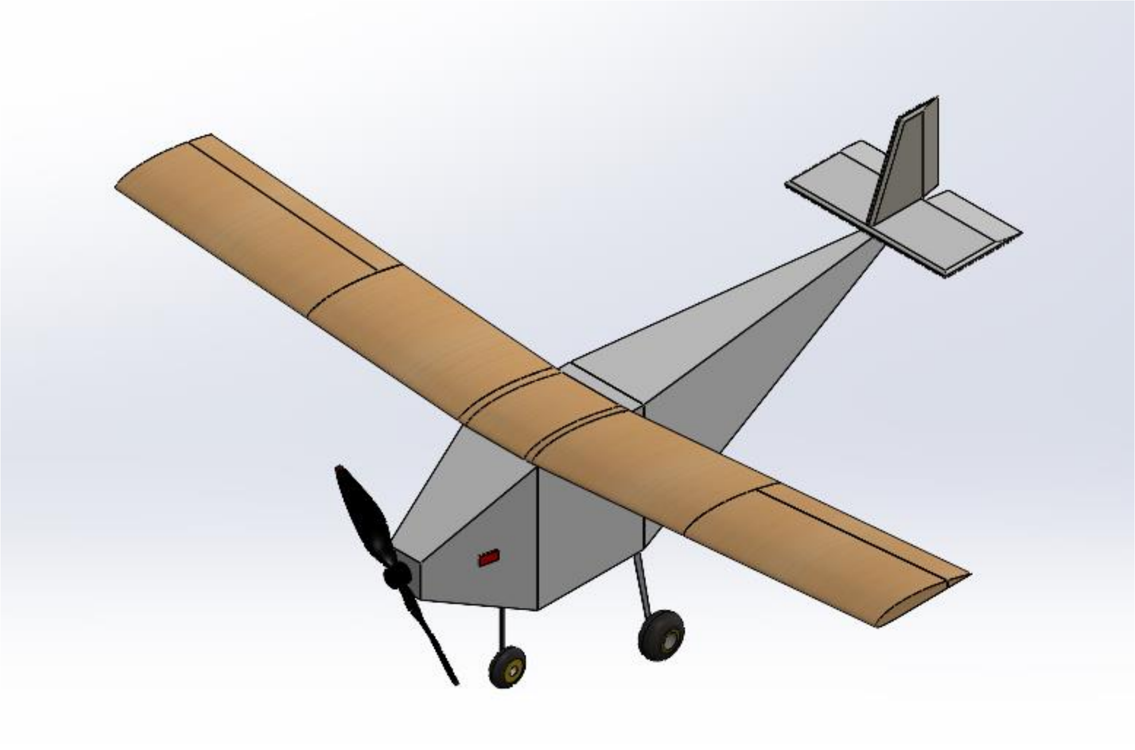


Figure 34 - Tentative design from first semester.

6.0 IMPLEMENTATION – Second Semester

As the team moved into the second semester, the design remained relatively consistent to what was designed in the first semester, however there were several notable changes. These changes will be discussed in the following section as well as how the changes were implemented into the design.

6.1 Design Changes in Second Semester

During the second semester, the team adjusted the design based on aspects of the competition and withdrawal from the competition. These changes overall improved the aircraft and led to less of the budget having to be spent on the design. Therefore, the work that was done in terms of design changes for the second semester improved the airplane while also significantly lowering the price and making the construction much more feasible.

6.1.1 Design Iteration 1: Change in Fuselage Discussion

A key decision change to the fuselage was the addition of access on the top to the cargo bay. The reason for this change was to allow the team quick and easy access during competition to change the load in the aircraft in between flights. Another purpose for this change was to also allow for ease of access to the battery in case the team opted for using multiple batteries to run the motor at max output during each individual flight. Seen in Figure 35 is the cargo bay access added to the design.

Figure 35 - Photograph of the cargo hold access added to the fuselage.

6.1.2 Design Iteration 1: Change in Fuselage Discussion

Another key aspect of the project that was changed during the second semester was the removal of the 450-watt power limiter from the power plant. The power limiter was a requirement set forth by SAE as a part of the competition. Since the team withdrew from the competition there was no point to include the limiter in the design and waste part of the budget purchasing this component. Even if the power limiter was included this would have had no impact on the design since the power plant as whole did not draw more than 450 watts.

6.2 Manufacturing and Assembly Plan

To construct the most efficient airplane possible, the team decided to complete manufacturing and assembly at Tim Kelly's residence. Tim is a member of the Flagstaff Flyers and had several components that he was willing to donate to the team. After designing the entire plane within SolidWorks, the files were sent to LightBurn to be loaded onto Tim's computer and cut using his laser cutter. After all foam board pieces were cut, the pre-marked edges could be folded and glued to construct most of the foam board pieces. After gluing servos and connecting horns onto the various joint surfaces, the connecting rods can be assembled between the two. To make the wings, the balsa wood spars had to be glued into place on the foam board ribs, ensuring the dihedral section was accounted for. After that, the foam board could be rolled on the edge of a table and bent to the shape of the airfoil and the ribs were completed. For the landing gear, there was simply a piece of plywood placed in the bottom of the fuselage with 2 holes cut in it to secure the landing gear with bolts. This same process was used for the front landing gear. After securing all avionics down with glue or spars, the manufacturing and assembly of the plane had been completed. Table 8 below shows the manufacturing process of the airplane from the start to the finish.

Table 8 - Manufacturing plan.

Step #	Item
1	Design in SolidWorks
2	Send files to LightBurn
3	Laser cut foamboard
4	Glue ribs & spars for wings
5	Fold and glue pieces
6	Wire and glue all servos & connecting rods
7	Bind avionics
8	Secure motor/propellor
9	Attach landing gear to fuselage
10	Insert battery, ESC, etc.
11	Secure wings on top of fuselage

A more detailed version of this manufacturing and assembly plan can be seen in the Operation/Assembly Manual in the team's documents. Within that document, you will find the entire process of manufacturing the airplane in much greater

7.0 RISK ANALYSIS AND MITIGATION

Depending on the capstone project, failure in the system can be much more compromising than others. For the aero micro capstone project, failure can be absolutely devastating. The best case in terms of a total failure in the system is that the plane crashes into the ground, harming no one and only slightly destroying itself, but the worst case could result in damage to property or people, and even death. Thus, the team took steps to mitigate potential failures through design decisions to ensure that a total failure should not occur, and if it does the damage to be minimized.

7.1 Potential Failures Identified First Semester

The team created a failure modes and effect analysis (FMEA) last semester during the design portion of the project to help identify potential failure points and mitigate those failures during construction. After reviewing the FMEA this semester, not much has changed since the team had already started construction and understood many of the failure points of the plane itself. The only changes made were the additions of the new potential failures that were added during the second semester (discussed in the following section). The full FMEA (with changes from this semester) is shown in Appendix E and the shortened FMEA is shown below in Table 9.

Table 9 - Shortened FMEA.

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Wings - Part #1 Functions to provide lift to the airplane and keep/control the plane within the air.	Spar Snaps	Total loss of lift: crash,fuselage breaks	Over Torqued, Too much load, velocity too high	40	Ensure durability before competition flight
	Rib Snaps	Loss of lift, further wing breaks, monokote slip	Incorrect bending, too much pressure	10	N/A
	Ribs Shift Apart	Loss of lift, monokote slip	Glue connection breaks, too much force on wings	32	Ensure glue connections are strong
	Spars Slide Out of Place	Fuselage damage, wings fall off, loss of lift	Glue connection breaks, over torqued	24	Ensure glue connections are strong
	MonoKote Rips	Loss of Lift, full monokote loss, crash	Velocity too high, ribs too sharp	12	N/A
	Leading Edge Detaches	Huge drag, complete loss of lift	Glue connection breaks, ribs break	8	N/A
	Dihedral Connection Breaks	Loss of stability, wing breakage, spaw warping	Too much bending stress, glue connection breaks, velocity too high	40	Perform force tests, ensure durability
	Aileron Breaks Off	Loss of controllability, loss of lift, crash	Velocity too high, too much draw, servos too strong	35	Ensure aileron connections are strong,
	Aileron Servo Disconnects	Loss of controllability, crash	Too much power, drag too high	30	Test servos before flight and at high drag
	Rubber bands Break	Loss of lift, wings disconnect, crash	Rubber bands too tight, not enough rubber bands, too much lift	28	Replace rubber bands often
	Rubber bands Cut into Wings	Loss of lift, wings disconnect, crash	Rubber bands too tight, rubber bands connect below wing	28	Ensure connection is behind/in front of wing
	Wings Disconnect from Fuselage	Total loss of lift; crash, fuselage damage	Wing connector breaks, fuselage breaks, too much force	20	Ensure wing connection is very strong
Fuselage - Part #2 Functions to hold all avionics	Breaks Apart	Aircraft crashes	Glue connection breaks, too much force on fuselage	20	High quality assembly
	Delivery Box Falls Out	Flight disqualified	Hardware comes loose from aircraft vibrations	5	N/A
	Payload Plate Falls Out	Flight disqualified	Hardware comes loose from aircraft vibrations	5	N/A

and connects all components and subsystems.	Battery Falls Out	Aircraft losses power and crashes	Hardware comes loose from aircraft vibrations	10	Self-locking hardware
	Center of Gravity Marking Comes off	Weight is placed in wrong spot, competition points deduction	Adhesion to aircraft fuselage insufficient for drag force experienced	12	Replace if necessary
	Contents Shift	Changes center of gravity	Hardware comes loose from aircraft vibrations	30	Self-locking hardware
	Gets Wet	Deformation, glue comes off	Weather conditions	7	N/A
	Aircraft Crashes Deforming Fuselage	Drag coefficient changes potentially causing a crash	Crash from high in air	20	Don't Crash
	Structure Fail Under Landing Load	Landing is considered failure and aircraft receives damage	Too much cargo/load	24	Reinforce bottom of fuselage
	Forces Torque Fuselage	Fuselage breaks, plane deforms and veers off course, crash	Forces on wings too high, damage to fuselage, landing forces	48	Reinforce with bulkheads
	Thrust Deforms Cone	Thrust redirected potentially causing aircraft to crash	Too much thrust	14	Reinforce cone of fuselage
Avionics - Part #5 Controls the airplane and provides power to each system.	Motor Overload	Potential damage and destruction of motor.	Too high of payload carried, torque overload on motor.	240	Measuring load and torque on motor during testing.
	Motor Overheats	Potential of motor catching fire and damaging entire craft.	Consuming excess wattage to meet power needs.	180	Measuring power usage during testing.
	Battery runs out during flight	Loss of flight ability and inevitable crash.	Too much electricity used during flight.	30	Measuring power usage during testing.
	Unresponsive Radio Controls	Inability for plane to take off or control during flight.	Poor or no connection from radio control to craft.	8	N/A
	Disconnection of wires	Some or all electro-mechanical components of plane will not function.	Rough flying, crashes, turbulence, or other forces on craft.	8	N/A
	Propeller breakage	Inability to produce thrust	Landing gear breaking; hits something in air	60	Preflight Check.
	Servo motors unresponsive	Control of aircraft compromised potentially causing aircraft to crash	Loss of range	12	Preflight Check.

	Battery Overloaded	Fire, destruction of plane	Drawing too many Amps	144	Measuring power usage during testing.
	Receiver Fail Safes	Total loss of aircraft control	Incorrect installation or programming.	40	Preflight Check.
	Transmitter Battery Fails	Inability to connect to aircraft radio control system	Controller left on, battery not charged/changed	60	Preflight Check.
Landing Gear - Part #3 Functions to help the airplane takeoff and land.	Front Wheel Servo Failure	Loss of ground steering	Improper Calibration with Controller	24	Test Servo Connection Prior to Flight
	Deformation of Wheels	Cannot move when not airborne	Impact from landing	15	Preflight Check, Durability Test
	Loss of Wheel during flight	Damage fuselage at landing, competition disqualification	Drag force during flight	40	Preflight Check, ensure strong connections
	Connection Rods Break	Plane cannot land, loss of wheels	Impact from Landing or Force experienced during flight	20	Preflight Check
	Wheels disconnect from Fuselage	Plane cannot land, loss of wheels	Impact from Landing or Force experienced during flight	50	Preflight Check
	Wheels Seizing	Plane will come to abrupt stop upon landing, plane breaks	Water gets in axle; dirt gets in axle	63	Preflight Check, Grease Wheels
	Deformation of Landing Gear	Potential for a Crash during landing	Impact from Landing	24	Preflight Check
	Loss of front wheel control	Potential for Propeller and Fuselage damage during landing	Impact from Landing or Force experienced during flight	48	Preflight Check
	Wheels Toe-In	Loss of in-line wheels; plane can't move correctly	Impact from Landing	18	N/A
	Lack of Correct Front Wheel Direction	Crooked wheel upon landing; abrupt crash once on ground	Improper Calibration with Controller	21	N/A

7.2 Potential Failures Identified This Semester

The team only identified three new errors this semester when it comes to the actual airplane design. These error sources were the rubber bands connecting the wings breaking, the rubber bands connecting the wing cutting into the wing, and the fuselage torqueing/flexing. The team identified the flexing error as construction began, noticing that the square fuselage would flex/rotate at the corners. The rubber band potential failures were considered as the team examined the stress on the rubber bands. The team noticed that if the rubber bands were too tight, they may snap and that if they were used for too long, they may wear down. Additionally, the team noticed that if the rubber band connection points were under the wing, the force would act on the edge of the wing rather than straight down, cutting into the foam board. These issues were added to the FMEA and highlighted in yellow.

7.3 Risk Mitigation

After completing the FMEA, the team compiled the ten failure points with the highest RPN scores. The results of the FMEA changed only slightly from the previous semester, with the 10th highest rated score becoming the torqueing/flexing of the fuselage. These failures are listed below along with the mitigation attempts made for each.

1. Failure #1: Motor Overload (RPN: 240)
    a. Description: Too many amps are being pulled and the motor is unable to supply the full amount of power needed.
    b. Cause: Too high of payload carried and torque on motor, causing it to require excess power requirements to meet demand
    c. Effect: Loss of motor overall. The plane will not be able to fly and will crash if already airborne.
    d. Mitigation Attempt: Measuring of load and torque on motor during testing phase.

2. Failure #2: Motor Overheats (RPN: 180)
    a. Description: Motor is attempting to supply too many amps and will reach a temperature past the point of being capable of functioning.
    b. Cause: Motor pulling too many amps or not having ample airflow to cool down.
    c. Effect: Potential of critical internal damage to motor and possible combustion. Severe damage to craft as a result.
    d. Mitigation Attempt: Provide enough cooling to the motor and reduce amperage it’s pulling.

3. Failure #3: Battery Overloaded (RPN: 144)
    a. Description: Electrical demands on the battery are excessive and cause it to prematurely run out of power or become damaged.
    b. Cause: Excessive electrical demands from electro-mechanical components of the craft.
    c. Effect: Battery short-circuits, runs out of power, or overheats with the possibility of combustion.
    d. Mitigation Attempt: Measuring load and power demands on battery during testing phase.

4. Failure #4: Wheels Seizing (RPN: 63)
    a. Description: The wheels no longer rotate which will result in the aircraft sliding on landing or crashing depending on the situation.
    b. Cause: Development of rust in the bearing connection to the wheel.

   c. Effect: Potential for crashing during landing or taking off.
   d. Mitigation Attempt: Checking the wheels during a preflight inspection.

5. Failure #5: Propeller Breaking (RPN: 60)
   a. Description: The propeller bends or loses part of a blade.
   b. Cause: The propeller encounters something.
   c. Effect: The thrust will be reduced, and the aircraft may not get enough lift.
   d. Mitigation Attempt: Practice flying and landing. Make landing gear long to add additional

6. Failure #6: Transmitter Battery Fails (RPN: 60)
   a. Description: The transmitter battery fails to provide power to the transmitter
   b. Cause: Either lack of charge in the battery or factory defect
   c. Effect: The pilot will be unable to send commands to the aircraft during flight
   d. Mitigation Attempt: Testing the transmitter battery prior to flight by ensuring the craft is receiving commands

7. Failure #7: Wheels Disconnect from Fuselage (RPN: 50)
   a. Description: The entire landing gear assembly disconnects from the fuselage
   b. Cause: Disconnection could be caused by impact force from landing or forces exerted on the assembly during flight
   c. Effect: The craft would be unable to land safely, and the team could face disqualification.
   d. Mitigation Attempt: Inspecting the connection assembly prior to flight.

8. Failure #8: Loss of Front Wheel Control (RPN: 48)
   a. Description: The servo controlling the landing gear wheel and the control of the aircraft on the ground is unresponsive.
   b. Cause: Servo not strong enough. Electrical connection lost. Radio signal not received.
   c. Effect: Loss of steering on the ground
   d. Mitigation Attempt: Solder wires well, use proper size servos.

9. Failure #9: Spar Snaps (RPN: 40)
   a. Description: The long rods that connect the ribs and hold the structural shape of the wings snaps and causes separation of ribs.
   b. Cause: Too long of a spar being used or too much weight being applied and causing a large amount of torque.
   c. Effect: Wings will break apart and the plane will not have sufficient lift to fly.
   d. Mitigation Attempt: Minimize moment of inertia of spars and do not add too much weight to the rib sections.

10. Failure #10: Dihedral Connection Breaks (RPN: 40)
    a. Description: The connection of where the wings angle up breaks and the outer sections of the wings are broken and disconnected.
    b. Cause: Poor fastening of the two sections of the wings and too much weight being applied to the end of the wings.
    c. Effect: Wings will break and lose all ability to fly.

d. Mitigation Attempt: Ensure the best fastening method is used to hold them together and reduce weight along the entire wing.

When discussing airplanes, failure in one component generally results in the failure of the entire system. However, certain critical failures lead to more destructive results than others. For this reason, it is sometimes necessary to compromise and choose factors with less destructive results than the ones that are much more highly destructive. In the FMEA, the team analyzed the many different factors of failures that are associated with our craft, their severity, potential effects, likelihood of occurrence, current design controls test, detection, RPN, and recommended action to mitigate the risk of these failures. The FMEA identified all of the potential failures from the different components of the craft and the causes that may cause such failures of these components. This analysis is crucial because we need to identify the failures that pose the most hazardous consequences to the craft. Furthermore, some of the failures identified in the FMEA can potentially cause the complete destruction of the craft and breaking of the rules, which can result in a loss of overall points or a potential disqualification from the competition.

The most important failures that the team had to consider and analyze in the FMEA are the ones that would result in damage, destruction, and possible disqualification from the competition. Such failures include the overloading of the motor, non-functional receiver fail-safes, unsecured payload, overloading of the battery, faulty landing gear, etc. These failures have been put at the highest priority for developing solutions to mitigate the occurrence and likelihood of these failures occurring before or during the competition.

The team has also identified solutions to these failures with minimal compromise to the less severe failures accompanied with the design of the craft. The team has made a design alteration to the design by utilizing the use of a cargo bay that will securely hold and store the payload. The use of a cargo bay is a new requirement of the rules as well as the payload being ejected from the craft would result in a disqualification. Although this redesign has been made to meet the one of the highest severity criteria of failure, the construction of this component will add additional weight to the craft and also reduce the overall aerodynamic efficiency that the craft possessed in the previous design. This in turn, will impose a larger load on the motor and the battery, increasing their risk of suffering overloading and overheating. Though, this redesign and risk-tradeoff were necessary as the craft not having a securable cargo bay for the payload would ultimately result in disqualification for the team from the competition.

8.0 ER PROOFS

Because there are several engineering requirements the team had to meet in order to design a ‘successful’ plane, various methods of testing each requirement were done. These testing methods involved calculations and specific testing, rather than theoretical testing like that of customer requirements. To ensure each was met, a list of each engineering requirement is shown below, and how the team verified the target range of each was met is also shown.

8.1 ER Proof #1 – [Wingspan Length]

For Engineering Requirement one, the Engineering requirement was verified to have been met by measuring the physical aircrafts wingspan once the construction was completed. The wingspan of the airfoil is 46.5” measured from tip to tip. This measurement was taken using a tape measure with an uncertainty of 1/32”. The airfoil design includes a 10-degree dihedral to aid in stability. This feature increases the surface area of the airfoil.

8.2 ER Proof #2 – [Battery]

The competition rules provided by the SAE AERO Micro Competition state that the maximum battery size is a four-cell battery. This is the size the team decided to implement in the design as it will deliver the maximum power while remaining a lightweight battery.

8.3 ER Proof #3 – [Power Limiter]

Engineering Requirement number three was derived from the SAE AERO Micro Competition rules where it is stated that teams must include a 450-Watt power limiter in the aircraft's circuit. The team chose to omit this requirement due to the team being unable to participate in the competition, the expensive nature of the mechanism, and delayed shipment from the SAE vendor. Because the team had at one time planned on incorporating this required power limiter the team selected a motor for the aircraft that would pull a maximum wattage near 450 Watts. The motor that the team selected was tested using the Racerstar thrust test stand that was purchased. The results of this test revealed that at maximum throttle with a fresh fully charged battery would be capable of pulling 530.6 Watts. In this aspect the team failed to meet the requirement but not at all to the team's surprise being that the physical 450-Watt power limiter was omitted from the design.

8.4 ER Proof #4 – [Cargo Bay Volume]

The team was able to verify the engineering requirement of meeting the cargo bay volume by designing the fuselage such that the delivery box fits inside it with ⅛" gaps on each side. Using SolidWorks, the team was able to design the center fuselage with the given dimensions and the team verified these dimensions with a tape measure. After shrinkage from laser cutting and building the mode, the delivery box fits within the fuselage center with 1/16" gaps, fulfilling the cargo bay volume requirement.

8.5 ER Proof #5 – [Quick Payload Removal]

The teams pay load is required to be removable within 60 seconds as required by the competition rules. The team verified that the aircraft payload is removable within that time interval by conducting multiple time trials in which the airfoil is removed, the fuselage top flap is lifted and bot the delivery box and payload plates are removed. The removal of the payloads was completed consistently under 60 seconds as timed by a stopwatch with an uncertainty of 0.005 seconds.

8.6 ER Proof #6 – [Short Take-Off Distance]

To test the engineering requirement of being able to take off from the 8-foot competition runway, the team had to perform tests at the Flagstaff Flyers airfield. By measuring out an 8-foot runway with a tape measure and marking the spot in the ground, the team was able to turn on the motor and have the airplane take flight. After the first 2 tests at 75% throttle, the airplane was not able to take off in the 8-foot runway. However, on the third test with the throttle greater than 100%, the team was able to have the airplane take off right at the 8-foot mark, satisfying the engineering requirement.

8.7 ER Proof #7 – [Aircraft Range]

The SAE AERO Micro Competition rules provide a flight plan in which the aircraft must complete a 300-foot length timed portion. This forced the team to consider the range of the aircraft. To test the range of the aircraft the plane and transmitter were armed. For safety the propeller was removed. with the plane and transmitter armed the plane was walked a distance away from the transmitter until the transmitter signal was lost. This distance was verified using google maps. The distance from the transmitter the plane can fly is 1228 feet before losing signal.

8.8 ER Proof #8 – [Can Carry A Lot of Weight]

During testing using the thrust stand, the team discovered that the drive system of the craft could produce thrust value 4.544 lbs. with the empty dry-weight of the craft at 2.7 lbs. From this, a thrust-to-weight ratio of 1.68:1, allowing the plane to carry a payload of more than half of its dry weight. Additionally, using the lift/drag test stand, the team collected data that revealed that the wings were able to generate a lift value of approximately 2,000 grams (4.4 lbs.) at a wind velocity of 35 MPH and an angle of attack of 10°.

The thrust provided by the motor and the lift generated by the wings demonstrate that the craft can carry a substantial payload, even in Flagstaff with a lower air density. Though the team wishes to perform test flights with the craft using weighted payload to witness how much actual payload can be transported.

8.9 ER Proof #9 – [Short Landing Distance]

Although the team is not sure of the exact distance the competition runway would have been, the team determined that being able to have the plane touch the ground and stop within 10 feet would likely be satisfactory. After landing the plane and having the airplane come to a stop, the team measured the distance from the landing gear's first mark to where it came to a complete stop. After a few tests, the team was able to successfully stop the plane within the desired length.

8.10 ER Proof #10 – [Gross Weight Limit]

Per the competition rules, the gross weight of the aircraft was not allowed to be more than 55 lbs. However, this value is completely unrealistic for a micro airplane, so the team determined that we wanted our plane to weigh around 3 lbs. After constructing the plane, the team used a digital scale and determined a gross weight of 2.7 lbs., well within the range the team hoped for.

8.11 ER Proof #11 – [Radio Control System]

The SAE AERO Micro competition rules state that the radio control system used to control the aircraft must use a 2.4 GHz signal. The transmitter the team has bound to the aircraft was provided by NAU. The transmitter is a 2.4 GHz Spectrum dx 8e transmitter. By utilizing this transmitter, the team ensured that this engineering requirement was fulfilled.

8.12 ER Proof #12 – [Cost]

Final Approach was provided a $1,500 budget for this project. The team was required to enter the SAE competition and validation event costing the team $1,100. The team was refunded $400 of which due to the competition date being changed. The team with the remaining budget was able to build a finished product aircraft and two test stands. The cost of the aircraft has been totaled at $148.85 not including items donated to the team by the Flagstaff Flyers.

8.13 ER Proof #13 – [Lift]

The wings of the craft were specifically designed to generate a large amount of lift so the craft would be able to carry a large amount of payload for the competition. The wings were designed to have a large rectangular profile that would maximize its surface area and therefore generate more lift. The wings of the craft have a surface area of 268 in^2 and were simulated to be able to generate a lift of around 5 lbs., nearly twice the dry weight of the craft. In testing, using the lift/drag test stand, the wings were able to generate a lift of approximately 4.5 lbs. at a wind velocity of 35 MPH and at an angle of attack of 10°. The team found that this wind velocity and angle of attack were the most optimal for generating the most lift. This value can be increased at higher wind velocities and flying at lower altitudes.

8.14 ER Proof #14 – [Thrust]

In order to allow the plane to actually lift off the ground, a certain amount of thrust had to be generated from the motor and propellor combination. After preliminary calculation, the team found that a thrust of around 2000g was needed to propel the plane. After using the purchased thrust test stand, the maximum thrust that was recorded was around 2061g, well over the minimum thrust required. This proves the entire system will have enough thrust to fly, and all other important aspects are with the lift.

8.15 ER Proof #15 – [Airfoil Drag]

The drag generated by the airfoil at various wind velocities and angles of attack were found from the data collected using the lift/drag test stand. The airfoil was found to generate a maximum drag force of 578 grams at 35 MPH and at an angle of attack of 10°. Though this value was nearly 10 times the theoretical value for drag at the same wind velocity and angle of attack. The team was able to establish a proportional correlation between the increase in drag force on the airfoil and the angle of attack.

8.16 ER Proof #16 – [Ground Control Turn Radius]

A successful landing is required during the competition trials for a score to be counted. The team designed the aircraft to ensure that the aircraft turn radius was capable of steering the aircraft and staying on the runway. The aircraft was armed and driven in a circle to verify the turn radius of the aircraft. The turn radius measured with a tape measure measures 6.5 feet.

8.17 ER Proof #17 – [Reliability]

One major aspect of building the micro airplane is being able to consistently fly the airplane without any failure. For example, if the airplane fails to take off sometimes and successfully takes off others, this would be considered an unreliable airplane. To consider the airplane reliable, the team was hoping for a 95% reliability. After successfully being able to control all components of the plane, flying the plane without failure, and landing the plane without any crashes, the airplane worked 100% of the time. Therefore, the goal of building an airplane that works at least 95% of the time was met by the team on the first attempt.

8.18 ER Proof #18 – [Crashes Before Major Repair]

To ensure that the aircraft is structurally sufficient an engineering requirement related to crashes is included. The team is striving for an average of 1.5 crashes before a major repair is needed. The team has experienced two crashes during landing which resulted in very minimal damages requiring zero repairs. Currently the aircraft has exceeded this engineering requirement.

9.0 LOOKING FORWARD

When looking forward, there are several things that can be improved upon by the client or future teams to help increase the success of the airplane. For example, several testing procedures can be completed, and new components such as wings and tails can be constructed to improve the structural integrity of them rather than the current ones that have been crashed. In terms of improving capstone for future SAE Aero Micro teams, it is recommended that the construction of the airplane begins over Winter break to ensure there is plenty of room for error and plenty of time for tests and reconstruction after crashing the airplane.

9.1 Future Testing Procedures

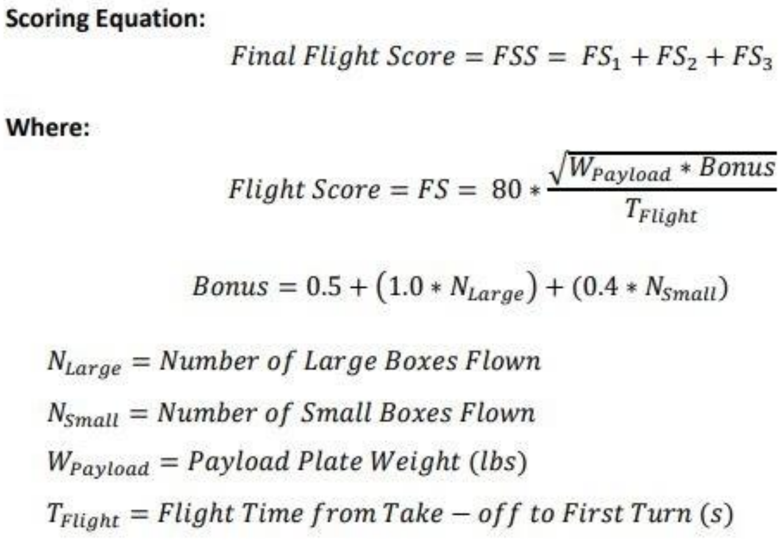
Although all members of the team are graduating and will not be able to complete any future testing procedures, it is hoped that future teams will be able to complete several tests to aid in their designs. This includes testing the airplane as if it were at competition and testing the wing on the test stands designed by the team.

9.1.1 Testing Procedure #1: Competition Flights

This section of the report walks through the process of evaluating the aircraft via competition flights that would have been conducted at the 2021 SAE Aero-micro competition. It also covers how to test and evaluate airfoils and motors using the lift/drag and thrust test stands.

9.1.1.1 Testing Procedure #1: Determine Performance at Competition

For this test the procedures would mirror that of the competition rules since the team was unable to attend the competition. The primary criteria that are being evaluated is the total load the plane can carry and the time to fly that load around a charted course. Seen in Figure 36 is a breakdown of the scoring for the flight that would have been used at competition.



Scoring Equation:

$$Final\ Flight\ Score = FSS = FS_1 + FS_2 + FS_3$$

Where:

$$Flight\ Score = FS = 80 * \frac{\sqrt{W_{Payload} * Bonus}}{T_{Flight}}$$

$$Bonus = 0.5 + (1.0 * N_{Large}) + (0.4 * N_{Small})$$

$N_{Large} = Number\ of\ Large\ Boxes\ Flown$

$N_{Small} = Number\ of\ Small\ Boxes\ Flown$

$W_{Payload} = Payload\ Plate\ Weight\ (lbs)$

$T_{Flight} = Flight\ Time\ from\ Take-off\ to\ First\ Turn\ (s)$

Figure 36 - SAE scoring guidelines [1].

9.1.1.2 Testing Procedure 1: Resources Required

For this test the required resources are a stopwatch, a platform to take off from, the plane, payload plates and boxes, a flight plan and potentially extra batteries for the multiple flights. At competition it was a requirement for the craft to take off from a platform that was 8ft long and a stopwatch to time the duration of the flight. The amount of payload plates, and boxes is entirely up to the user since more weight means more time to complete the flight. Seen below in Figure 37 is the flight plane that would have been followed at the 2021 SAE aero micro competition.

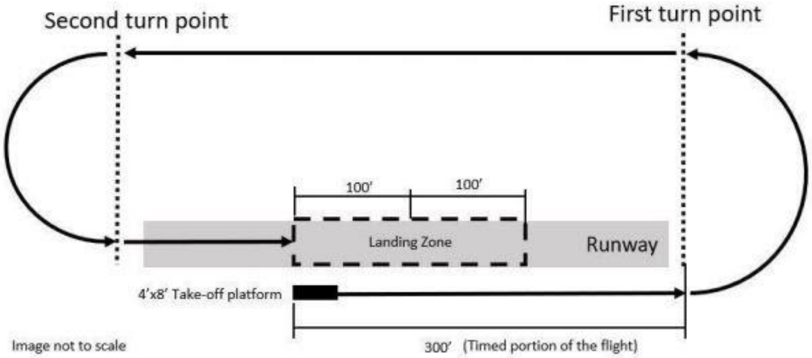


Figure 37 - SAE flight plan [1].

9.1.1.3 Testing Procedure 1: Schedule

The test can be run a few days after handing off to the client. The key preparations for the flight are ensuring all the batteries for the electronics are fully charged. Also ensure to have manufactured as many plates and boxes that one would like to test. Once those preparations have been completed the time to conduct all the test is approximately 2-3 hours. This is contingent on time to conduct a preflight check and weather since the craft can only handle winds of about 5-10 miles per hour.

9.1.2 Testing Procedure 2: Test Stands

For the past several weeks of this current semester, the team has been designing, constructing, and testing test stands that will be used to measure the performance of the drive system and the wings of a selected craft. The thrust stand allows the users to measure the thrust generated by the drive system of the craft. The lift/drag test stand will allow the team to measure the lift and drag forces generated by the wing at various wind velocities and angles of attack.

9.1.2.1 Testing Procedure 2: Objective

The objective of these test stands is to ultimately give them to the future NAU SAE Aero micro teams for use in their projects so that they will be able to accurately and reliably test the performance aspects of the drive system and the wings. Giving future Aero Micro teams the ability to accurately measure the performance aspects of their crafts in the early stages of design and manufacturing will allow them more time to make the necessary modifications to their crafts in order to maximize their performance capabilities.

9.1.2.2 Testing Procedure 2: Resources Required

The test stand to measure the thrust output of the drive system was purchased online and only requires the craft's motor, propeller, and battery to be operated. The stand for the measurement of the lift and drag was designed and built from individual parts and components. This stand required the utilization of a 1 kg load cell for the drag force and a 5 kg load cell for the lift force. The cells are connected to an HX711, which is connected to an Arduino Uno board and connected to a computer for the transfer of collected data. To improve the simplicity and accuracy of receiving data, the team opted for a 16' long cable that would connect the Arduino to a laptop with the Arduino IDE. This was selected overusing Bluetooth modules as it would add complexity to the code and the signal could be blocked or disrupted by the metallic roof of the vehicle. Three 3D printed mounting systems were manufactured to test the forces on the wing at angles of attack of 0°, 5°, 10°. The stand was built on top of a surfboard rack in order to securely strap it in place at the top of a vehicle. A frictionless rail system was added to the stand to allow for a one degree of freedom in order to prevent the drag load cell from experiencing moment and bending forces that could potentially skew the data. Figure 38 shows the load cell test stand fully built on the day of testing.

Figure 38 - Lift/drag test stand with wing attached.

9.1.2.3 Testing Procedure 2: Schedule

For the thrust stand, it is highly recommended that the client has the battery fully charged as the battery is drained quickly when the motor is run at maximum output. It is also recommended that the client record the test with a camera as the thrust value will peak and be displayed very quickly before the battery is overloaded and is unable to supply the sufficient power to keep it at peak output. The test stand for the drag and lift will require the client to securely mount the stand to the top of a vehicle. A passenger in the vehicle will need to monitor the present wind speed using the anemometer and begin the data collection once the appropriate wind speed has been achieved. The data collected on the Arduino serial monitor can then be transferred to an Excel spreadsheet where the data can be further analyzed. Many trials can be performed using the same process at different wind speeds and at different angles of attack using the different 3D printed wing mounts. The data collected from these test stands can be utilized to reach a final determination pertaining to the customer and engineering requirements through analyzation and calculations. Figure 39 shows the test stand mounted to the car on the day of testing.

Figure 39- Lift/drag test stand set up on car.

9.2 Future Work

A problem that the team has encountered many times in the testing of the lift/drag stands is the abundance of highly inaccurate results received from the testing on top of a car due to high winds. Flagstaff is a city that often has windy weather, much more than other cities. Often, the weather can be windy for multiple days in a row and can interfere with the team's ability to collect accurate data in a timely manner. To continue with this project, the team recommends that the future teams design and develop airfoils on a smaller scale that will be able to fit on the test stand to be used in the air tunnel located in the NAU Machine Shop. Currently, the stand and the wing are too large to fit in the wind tunnel and would need to be scaled down to a smaller size to be able to do so. Testing the airfoils inside of the wind tunnel would allow the teams to measure the drag and lift forces on the air tunnel at a constant wind velocity without random gusts of wind from all directions to skew the data. Additionally, the constant wind velocity would allow for many data points to be collected and more accurate results could be achieved in this manner. Based on the constant rule and scoring changes of the competition every year, the procedure for testing outlined in the previous subsection may not be totally applicable to future Aero Micro teams. Though, the procedure for testing and practice of flying the craft with and without payload is crucial for the success of the team in competition as a more skilled pilot will be able to complete the course quickly and prevent the plane from crashing, which is usually a large point reducer in every annual SAE Aero Micro competition. Furthermore, the testing of the craft under simulated competition conditions will allow the teams to gauge the realistic performance of their craft and make the necessary adjustments to the craft in order to improve its performance.

10.0 CONCLUSIONS

Team Final Approach considers the capstone project a major success. The unfortunate reality of the COVID-19 pandemic posed major challenges for the team, including the drop from the anticipated competition and technical issues surrounding the actual construction of the system, but all team members worked hard to get the project to where it is today. The team's successful construction of a micro airplane, and the ability to fly that plane with no issues for multiple test flights while still satisfying the competition guidelines is the greatest accomplishment any team member has had in college. Additionally, the creation and successful use of the test stands provides another great tool and source of inspiration for the following capstone teams. Team Final Approach considers these two major accomplishments as an indication of goal completion, and they reflect the enormous effort that was put in by the team and contributors.

10.1 Reflection

Team Final Approach applied engineering design principles to the SAE Aero Micro competition to design and construct a micro airplane. Doing so provides unique and innovative solutions to airplane design, which contributes to the economic and scientific development of modern airplane design. As airplanes become more intuitive and innovative, the cost to produce them goes down. Additionally, increased efficiency in airplane design reduces costs of airplane flight. As the world has transitioned into a global economy, the need to fly from state to state or country to country becomes ever relevant to stay ahead. Thus, efficient, cost effective, and safe airplane flight is a necessity for any modern person. By applying engineering principles to a micro airplane, the team can develop concepts that improve flight efficiency and safety and apply those concepts and principles to macro airplane design.

The team's design addresses the efficiency issue primarily, as the team worked to maximize the speed to weight ratio of the airplane as much as possible. Doing so improves the overall efficiency of the plane, and by applying these concepts to macro airplane design, can reduce overall costs of travel. The team also ensured the design was safe by considering safety issues in the design (for example, ensuring the wiring was safely done to avoid fires) and by testing the airplane several times.

Finally, in terms of test stands, the team applied engineering principles to design and construct the test stands which allow for easier development of micro airplanes in the future. As the development of airplanes and the improvement of design understanding continues, teams can focus on other major problems rather than working to validate their simplistic designs.

10.2 Postmortem Analysis of Capstone

The following section of the report is a Postmortem of the project. This postmortem will answer the seven fundamental questions of a Postmortem to identify the strengths and weaknesses of the team and project. Doing so will help Team Final Approach to reflect on the project and team and should provide a launching point for future capstone teams to identify their own strengths, weaknesses, points of failure, and more.

10.2.1 Contributors to Project Success

As noted, Team Final Approach considers the capstone project a major success and the team can easily say that they were able to complete the mission and more. With the initial "mission" or goal of the project simply being to construct a micro airplane that meets the requirements of the SAE Aero Micro competition, the team can say that that was completed.

While the team was never able to attend the competition, the micro airplane constructed flew circuits that could easily pass the competition guidelines. While there were areas for improvement in the airplane design and testing (to be discussed in the later section), the team is extremely happy with where the airplane design got to. Additionally, in terms of completing the "mission", the team added to their portfolio the design and construction of a lift/drag test stand and the purchase of the thrust test stand. All of this considered, the team believes that these creations and solutions complete the goals, purposes, and "mission" of the capstone project.

Certain aspects of the project performance were much stronger than others. The team considers the most positive aspect of project performance to be the development time and costs of the project. The team was able to create their designs very quickly compared to teams of the past, and due to donations from the Flagstaff Flyers and other creative uses of material, the team was able to do this work under budget even after losing a lot of money to un-refundable competition fees. The speed of creation allowed the team to test very early on in the project. This early testing lead to a solid final design right away and allowed the team to spend the remainder of the project on test stands. The other positive aspect of the project was the teamwork. The team worked very well together, which allowed the team to finish assignments quickly and efficiently and focus their efforts on design, construction, and testing.

To complete the project, the team used many engineering tools, methodologies, and practices that they did not know before. One of the most important and valuable was laser cutting the foam board of the airplane. Using foam board allowed the team to make the airplane extremely lightweight and very cheaply, which was a major contribution to the success of the airplane. Additionally, implementing fluid mechanics and aerodynamics principles with the fundamental understanding of RC airplane design from the Flagstaff Flyers, the team was able to design the plane in such a way that it flew with no iterations in design.

There were several technical lessons that the team learned during the project. The first is that the theoretical principles and mechanics learned in fluid mechanics and aerodynamics revolving around flight function well enough when applied to a micro airplane scale to allow for flight as long as some leeway is given for safety concerns. The team designed the airplane using these principles, and the final design required no real changes for flight to be achieved. Thus, the principles learned in schooling if applied correctly should result in a flying airplane. Another important technical lesson that was learned was the use of a laser cutter to cut foam board.

Finally, though working with the Flagstaff Flyers, the team learned many technical skills revolving around the construction of RC airplanes. The construction of a RC airplane may seem easy, but the construction is much more technical and complicated than one may think. There are many fine skills required to construct an RC airplane, each with technical lessons and experience. Some of these are:

1. Proper material cutting.
2. Proper glue selection and use.
3. Servo and servo rod placement/insertion.
4. Center of gravity and moment determination and adjustment.
5. Proper motor installation and placement.

While these technical skills can be learned by researching online, it is best to learn from a professional with extensive experience in the field such as Tim Kelly. These technical skills and lessons are extremely valuable, and team Final Approach recommends talking to Tim Kelly and all the Flagstaff Flyers to gain experience and knowledge in these skills before attempting their own construction.

10.2.2 Opportunities/areas for improvement

While the team completed their “mission” and the goals of the project as noted previously, there were still many areas for improvement. Some of these areas of improvement are noted below along with a solution/future work that could be done to improve upon them.

1. Weak testing of the airplane.
    a) While the team took the airplane through several test flights, the team was unable to construct a launch platform to test the lift off capability of the plane. Additionally, while the team is confident the plane could carry weight, no payload plates were added. This lack of testing stems from the shift to test stand design and could easily be done with more time.

2. Airplane’s load carrying capacity and capability could be improved as well as takeoff time.

    a) The shift of the project to the design of test stands meant that the team never went in depth in terms of improving the airplane. While the team had many ideas on how to improve takeoff time and weight carrying, the team focused their final efforts on the test stand since the team believes that the test stands should prove more useful than a slightly better plane.
    b) Some of the improvements the team has considered to increase the load carrying and takeoff time are a better motor for more thrust, a longer chord length for more lift, a higher starting angle of attack for more lift, and more.
    c) The team also considered adding an FPV camera to the plane to aid future team's in their flight.
3. Test stands improvements.
    a) The team tested the test stands just before graduation, which meant that they are likely still lacking in quality.
    b) One major issue with the test stands is that the drag mounting plates still move just slightly. Gluing them in place may aid with this but would make it hard to remove them for calibration.
    c) Another major issue with the test stand is that the anemometer data cannot be directly streamed.
    d) Given more time, the team could improve the test stands greatly.

The most negative aspect of performance for the team was the lack of some mathematical calculation and computational testing. Although several tests were completed (including the thrust and lift/drag test stands), the team lacked in the area of virtual testing before the airplane was constructed. This could have included FEA within SolidWorks, and it could have also included thermal analysis of the motor to ensure the heat dissipated will not affect the plywood or foamboard's integrity.

Another negative aspect of the project was the inability to compete at competition. While the team chose to drop themselves due to the benefits over not competing, the actual lack of competition was overall disappointing. If the team was still attending competition, there would have been forced areas for improvement, and the design would have likely improved. Nonetheless, the team believes the aspects of project performance that were negative were miniscule and did not affect the team's performance.

The biggest problem the team encountered was working around COVID-19 restrictions. Because it was hard to meet due to the global pandemic, the team had to delegate tasks in a way that some members were not so involved in certain aspects of construction or design. This sometimes led to flaws in design, such as the test stand being hard to deconstruct due to the length of the system, or difficulty to adjust the positioning of the avionics. While these flaws did not hinder the overall results, it made the system a bit more difficult to interact with.

There were two main organizational actions that the team could have taken to improve performance. The first would have been to develop a global calendar that all teammates could simultaneously access and edit. This would ensure that every team member knew what had to be done, when it had to be done, and even delegate tasks without needing team meetings to do so. The other organizational action that could have been taken would have been better organization of receipts and budget. The team was not as thorough about collecting and compiling receipts, and the overall budgeting aspect of the project was not as precise as it could have been. While having to move all purchases through NAU's financial department stagnated parts of the project, having a better understanding and organization of the financial side of things may have helped the project get slightly further.

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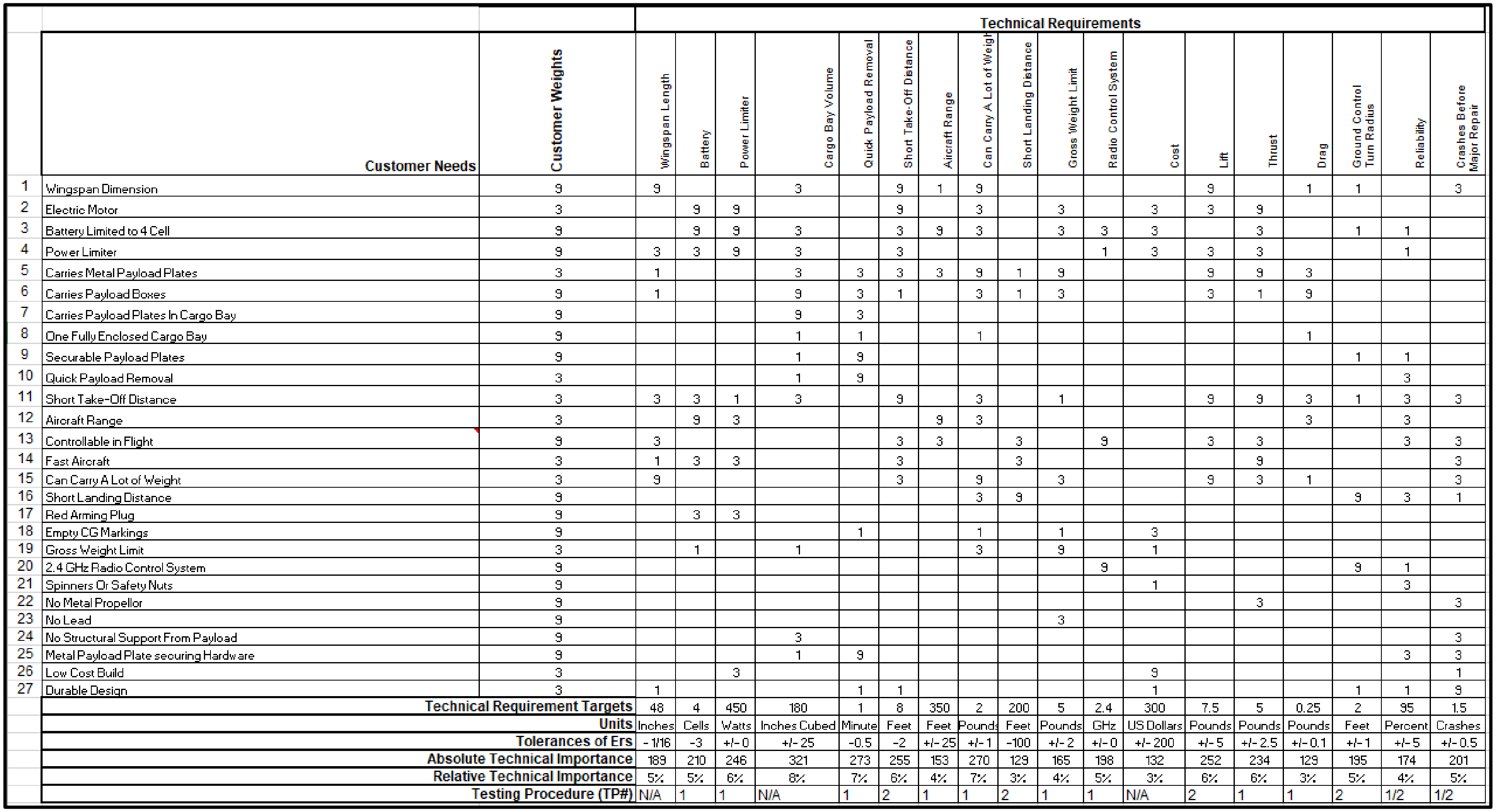
12.0 Appendices

12.1 Appendix A: Quality Function Deployment (QFD)

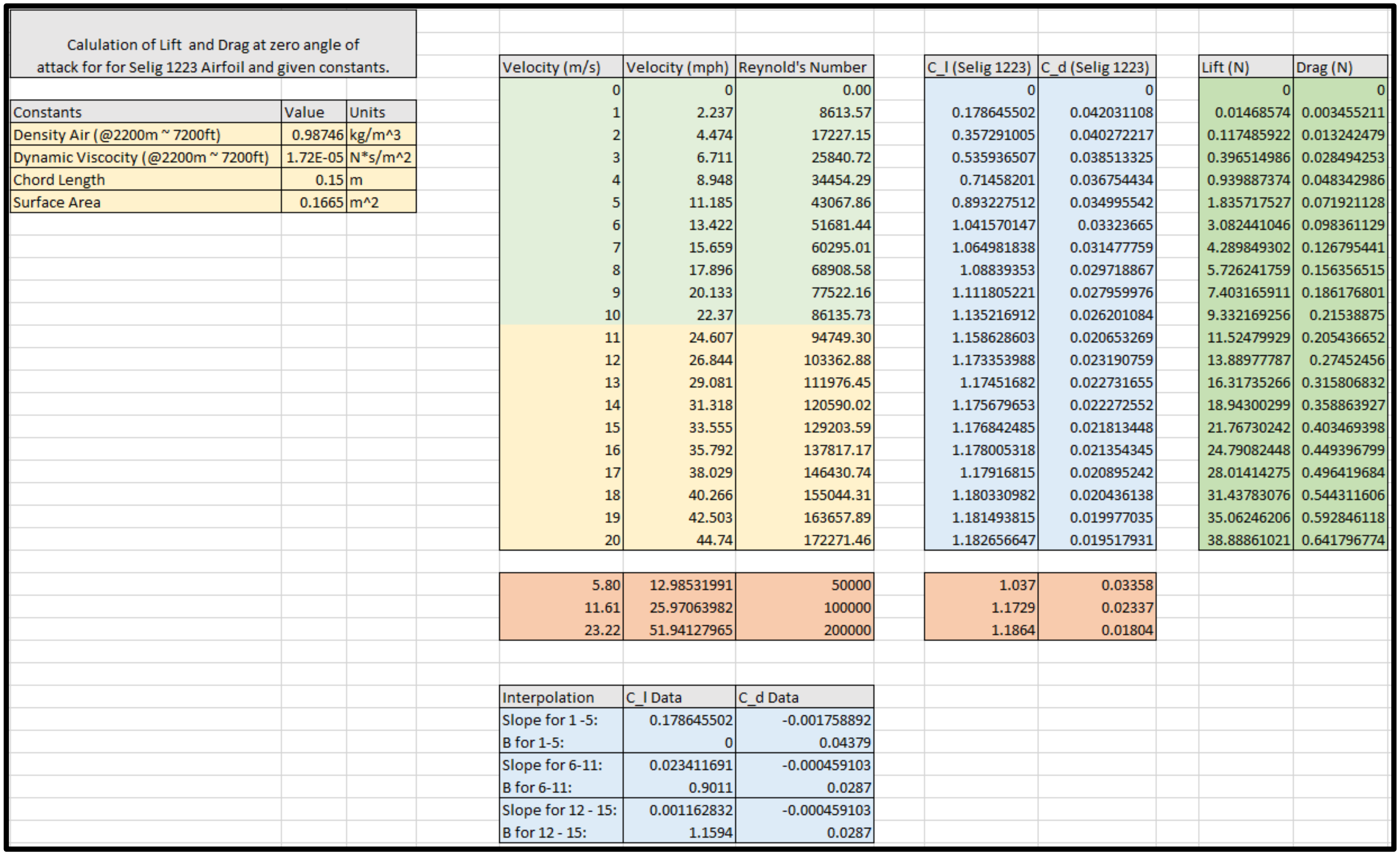


			Technical Requirements																	
	Customer Needs	**Customer Weights**	Wingspan Length	Battery	Power Limiter	Cargo Bay Volume	Quick Payload Removal	Short Take-Off Distance	Aircraft Range	Can Carry A Lot of Weigh	Short Landing Distance	Gross Weight Limit	Radio Control System	Cost	Lift	Thrust	Drag	Ground Control Turn Radius	Reliability	Crashes Before Major Repair
1	Wingspan Dimension	9	9			3		9	1	9					9		1	1		3
2	Electric Motor	3		9	9			9		3		3		3	3	9				
3	Battery Limited to 4 Cell	9		9	9	3		3	9	3		3	3	3		3		1	1	
4	Power Limiter	9	3	3	9	3		3					1	3	3	3			1	
5	Carries Metal Payload Plates	3	1			3	3	3	3	9	1	9			9	9	3			
6	Carries Payload Boxes	9	1			9	3	1		3	1	3			3	1	9			
7	Carries Payload Plates In Cargo Bay	9				9	3													
8	One Fully Enclosed Cargo Bay	9				1	1			1							1			
9	Securable Payload Plates	9				1	9											1	1	
10	Quick Payload Removal	3				1	9												3	
11	Short Take-Off Distance	3	3	3	1	3		9		3		1			9	9	3	1	3	3
12	Aircraft Range	3		9	3				9	3							3		3	
13	Controllable in Flight	9	3					3	3		3		9		3	3			3	3
14	Fast Aircraft	3	1	3	3			3			3					9				3
15	Can Carry A Lot of Weight	3	9					3		9		3			9	3	1			3
16	Short Landing Distance	9								3	9							9	3	1
17	Red Arming Plug	9		3	3															
18	Empty CG Markings	9					1			1		1		3						
19	Gross Weight Limit	3		1		1				3		9		1						
20	2.4 GHz Radio Control System	9											9					9	1	
21	Spinners Or Safety Nuts	9												1					3	
22	No Metal Propellor	9														3				3
23	No Lead	9										3								
24	No Structural Support From Payload	9				3														3
25	Metal Payload Plate securing Hardware	9				1	9												3	3
26	Low Cost Build	3			3									9						1
27	Durable Design	3	1				1	1						1				1	1	9
	Technical Requirement Targets		48	4	450	180	1	8	350	2	200	5	2.4	300	7.5	5	0.25	2	95	1.5
	Units		Inches	Cells	Watts	Inches Cubed	Minute	Feet	Feet	Pounds	Feet	Pounds	GHz	US Dollars	Pounds	Pounds	Pounds	Feet	Percent	Crashes
	Tolerances of Ers		- 1/16	-3	+/- 0	+/- 25	-0.5	-2	+/- 25	+/- 1	-100	+/- 2	+/- 0	+/- 200	+/- 5	+/- 2.5	+/- 0.1	+/- 1	+/- 5	+/- 0.5
	Absolute Technical Importance		189	210	246	321	273	255	153	270	129	165	198	132	252	234	129	195	174	201
	Relative Technical Importance		5%	5%	6%	8%	7%	6%	4%	7%	3%	4%	5%	3%	6%	6%	3%	5%	4%	5%
	Testing Procedure (TP#)		N/A	1	1	N/A	1	2	1	1	2	1	1	N/A	2	1	1	2	1/2	1/2

12.2 Appendix B: House of Quality

Crashes Before Major Repair	C					C				C	C	C				A	A	■
Reliability					A	C	A		A		B	A					■	
Ground Control Turn Radius									A		B					■		
Airfoil Drag	B			A									A	A	■			
Thrust		B	A					B		C			A	■				
Lift	A		B					A		A			■					
Cost		C	A				A				A	■						
Radio Control System		C				A			A		■							
Gross Weight Limit			C	B				A	C	■								
Short Landing Distance						A		B	■									
Can Carry A Lot of Weight				A	C		C	■										
Aircraft Range		A					■											
Short Take-Off Distance	A	B		A		■												
Quick Payload Removal				C	■													
Cargo Bay Volume			C	■														
Power Limiter		A	■															
Battery		■																
Wingspan Length	■																	

12.3 Appendix C: Selig 1223 Lift and Drag Data



Calulation of Lift and Drag at zero angle of attack for for Selig 1223 Airfoil and given constants.

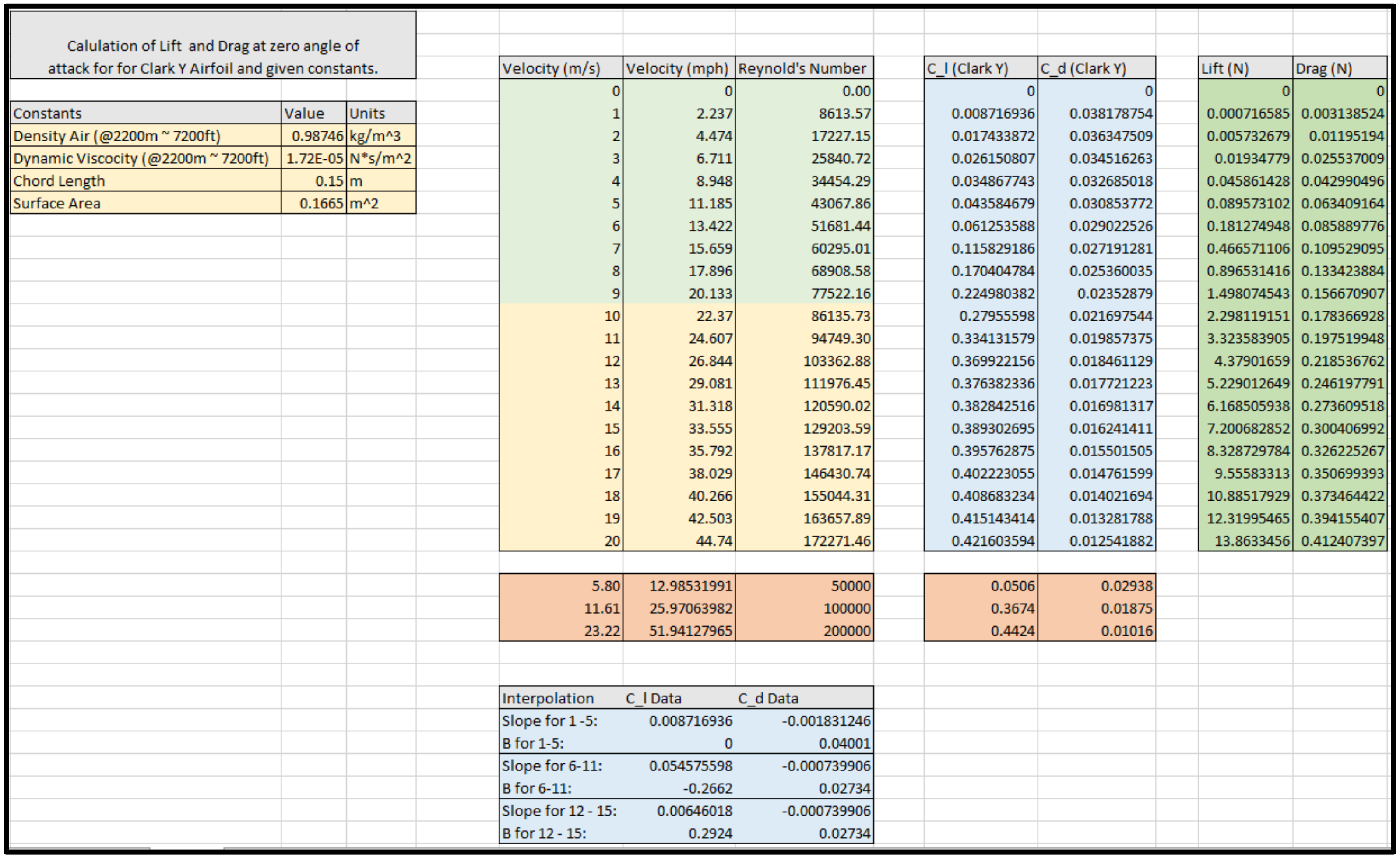
Constants	Value	Units
Density Air (@2200m ~ 7200ft)	0.98746	kg/m^3
Dynamic Viscocity (@2200m ~ 7200ft)	1.72E-05	N*s/m^2
Chord Length	0.15	m
Surface Area	0.1665	m^2

Velocity (m/s)	Velocity (mph)	Reynold's Number	C_l (Selig 1223)	C_d (Selig 1223)	Lift (N)	Drag (N)
0	0	0.00	0	0	0	0
1	2.237	8613.57	0.178645502	0.042031108	0.01468574	0.003455211
2	4.474	17227.15	0.357291005	0.040272217	0.117485922	0.013242479
3	6.711	25840.72	0.535936507	0.038513325	0.396514986	0.028494253
4	8.948	34454.29	0.71458201	0.036754434	0.939887374	0.048342986
5	11.185	43067.86	0.893227512	0.034995542	1.835717527	0.071921128
6	13.422	51681.44	1.041570147	0.03323665	3.082441046	0.098361129
7	15.659	60295.01	1.064981838	0.031477759	4.289849302	0.126795441
8	17.896	68908.58	1.08839353	0.029718867	5.726241759	0.156356515
9	20.133	77522.16	1.111805221	0.027959976	7.403165911	0.186176801
10	22.37	86135.73	1.135216912	0.026201084	9.332169256	0.21538875
11	24.607	94749.30	1.158628603	0.020653269	11.52479929	0.205436652
12	26.844	103362.88	1.173353988	0.023190759	13.88977787	0.27452456
13	29.081	111976.45	1.17451682	0.022731655	16.31735266	0.315806832
14	31.318	120590.02	1.175679653	0.022272552	18.94300299	0.358863927
15	33.555	129203.59	1.176842485	0.021813448	21.76730242	0.403469398
16	35.792	137817.17	1.178005318	0.021354345	24.79082448	0.449396799
17	38.029	146430.74	1.17916815	0.020895242	28.01414275	0.496419684
18	40.266	155044.31	1.180330982	0.020436138	31.43783076	0.544311606
19	42.503	163657.89	1.181493815	0.019977035	35.06246206	0.592846118
20	44.74	172271.46	1.182656647	0.019517931	38.88861021	0.641796774

5.80	12.98531991	50000	1.037	0.03358
11.61	25.97063982	100000	1.1729	0.02337
23.22	51.94127965	200000	1.1864	0.01804

Interpolation	C_l Data	C_d Data
Slope for 1 -5:	0.178645502	-0.001758892
B for 1-5:	0	0.04379
Slope for 6-11:	0.023411691	-0.000459103
B for 6-11:	0.9011	0.0287
Slope for 12 - 15:	0.001162832	-0.000459103
B for 12 - 15:	1.1594	0.0287

12.4 Appendix D: Clark Y Lift and Drag Data



Calulation of Lift and Drag at zero angle of attack for for Clark Y Airfoil and given constants.

Constants	Value	Units
Density Air (@2200m ~ 7200ft)	0.98746	kg/m^3
Dynamic Viscocity (@2200m ~ 7200ft)	1.72E-05	N*s/m^2
Chord Length	0.15	m
Surface Area	0.1665	m^2

Velocity (m/s)	Velocity (mph)	Reynold's Number	C_l (Clark Y)	C_d (Clark Y)	Lift (N)	Drag (N)
0	0	0.00	0	0	0	0
1	2.237	8613.57	0.008716936	0.038178754	0.000716585	0.003138524
2	4.474	17227.15	0.017433872	0.036347509	0.005732679	0.01195194
3	6.711	25840.72	0.026150807	0.034516263	0.01934779	0.025537009
4	8.948	34454.29	0.034867743	0.032685018	0.045861428	0.042990496
5	11.185	43067.86	0.043584679	0.030853772	0.089573102	0.063409164
6	13.422	51681.44	0.061253588	0.029022526	0.181274948	0.085889776
7	15.659	60295.01	0.115829186	0.027191281	0.466571106	0.109529095
8	17.896	68908.58	0.170404784	0.025360035	0.896531416	0.133423884
9	20.133	77522.16	0.224980382	0.02352879	1.498074543	0.156670907
10	22.37	86135.73	0.27955598	0.021697544	2.298119151	0.178366928
11	24.607	94749.30	0.334131579	0.019857375	3.323583905	0.197519948
12	26.844	103362.88	0.369922156	0.018461129	4.37901659	0.218536762
13	29.081	111976.45	0.376382336	0.017721223	5.229012649	0.246197791
14	31.318	120590.02	0.382842516	0.016981317	6.168505938	0.273609518
15	33.555	129203.59	0.389302695	0.016241411	7.200682852	0.300406992
16	35.792	137817.17	0.395762875	0.015501505	8.328729784	0.326225267
17	38.029	146430.74	0.402223055	0.014761599	9.55583313	0.350699393
18	40.266	155044.31	0.408683234	0.014021694	10.88517929	0.373464422
19	42.503	163657.89	0.415143414	0.013281788	12.31995465	0.394155407
20	44.74	172271.46	0.421603594	0.012541882	13.8633456	0.412407397
5.80	12.98531991	50000	0.0506	0.02938		
11.61	25.97063982	100000	0.3674	0.01875		
23.22	51.94127965	200000	0.4424	0.01016		

Interpolation	C_l Data	C_d Data
Slope for 1 -5:	0.008716936	-0.001831246
B for 1-5:	0	0.04001
Slope for 6-11:	0.054575598	-0.000739906
B for 6-11:	-0.2662	0.02734
Slope for 12 - 15:	0.00646018	-0.000739906
B for 12 - 15:	0.2924	0.02734

12.5 Appendix E: Failure Modes and Affect Analysis

Product Name: Micro Airplane		Development Team: Team 20F12: A2 - Aero Micro				Page No 1 of 1			
System Names: Wings, Fuselage, Radio Controls, Landing Gear						FMEA Number: #1			
						Date: 11-15-2020			
Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurrence (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
Wings - Part #1 Functions to provide lift to the airplane and keep/control the plane within the air.	Spar Snaps	Total loss of lift: crash,fuselage breaks	8	Over Torqued, Too much load, velocity too high	5	Check for sag in wings	1	40	Ensure durability before competition flight
	Rib Snaps	Loss of lift, further wing breaks, monokote slip	5	Incorrect bending, too much pressure	1	Visual Inspection	2	10	N/A
	Ribs Shift Apart	Loss of lift, monokote slip	2	Glue connection breaks, too much force on wings	4	Check for sag in MonoKote	4	32	Ensure glue connections are strong
	Spars Slide Out of Place	Fuselage damage, wings fall off, loss of lift	3	Glue connection breaks, over torqued	2	Visual Inspection	4	24	Ensure glue connections are strong
	MonoKote Rips	Loss of Lift, full monokote loss, crash	3	Velocity too high, ribs too sharp	4	Visual Inspection	1	12	N/A
	Leading Edge Detaches	Huge drag, complete loss of lift	4	Glue connection breaks, ribs break	1	Visual Inspection	2	8	N/A
	Dihedral Connection Breaks	Loss of stability, wing breakage, spaw warping	8	Too much bending stress, glue connection breaks, velocity too	5	Visual Inspection	1	40	Perform force tests, ensure durability
	Aileron Breaks Off	Loss of controllability, loss of lift, crash	7	Velocity too high, too much draw, servos too strong	5	Visual Inspection	1	35	Ensure aileron connections are strong,
	Aileron Servo Disconnects	Loss of controllability, crash	3	Too much power, drag too high	5	Visual Inspection	2	30	Test servos before flight and at high drag
	Rubberbands Break	Loss of lift, wings disconnect, crash	7	Rubberbands too tight, not enough rubberbands, too much lift	2	Visual Inspection	2	28	Replace rubberbands often
	Rubberbands Cut into Wings	Loss of lift, wings disconnect, crash	7	Rubberbands too tight, rubberbands connect below wing	2	Visual Inspection	2	28	Ensure connection is behind/in front of wing
	Wings Disconnect from Fuselage	Total loss of lift; crash, fuselage damage	10	Wing connector breaks, fuselage breaks, too much force	2	Visual Inspection	1	20	Ensure wing connection is very strong
Fuselage - Part #2 Functions to hold all avionics and connects all components and subsystems.	Breaks Apart	Aircraft crashes	10	Glue connection breaks, too much force on fuselage	2	Visual Inspection	1	20	High quality assembly
	Delivery Box Falls Out	Flight disqualified	5	Hardware comes loose from aircraft vibrations	1	Visual Inspection	1	5	N/A
	Payload Plate Falls Out	Flight disqualified	5	Hardware comes loose from aircraft vibrations	1	Visual Inspection	1	5	N/A
	Battery Falls Out	Aircraft losses power and crashes	10	Hardware comes loose from aircraft vibrations	1	Visual Inspection	1	10	Self-locking hardware
	Center of Gravity Marking Comes off	Weight is placed in wrong spot, competition points deduction	6	Adhesion to aircraft fuselage insufficient for drag force experien	2	Visual Inspection	1	12	Replace if necessary
	Contents Shift	Changes center of gravity	5	Hardware comes loose from aircraft vibrations	3	Visual Inspection	2	30	Self-locking hardware
	Gets Wet	Deformation, glue comes off	7	Weather conditions	1	Visual Inspection	1	7	N/A
	Aircraft Crashes Deforming Fuselag	Drag coefficient changes potentially causing a crash	4	Crash from high in air	5	Visual Inspection	1	20	Don't Crash
	Structure Fail Under Landing Load	Landing is considered failure and aircraft receives damage	8	Too much cargo/load	3	Visual Inspection	1	24	Reinforce bottom of fuselage
	Forces Torque Fuselage	Fuselage breaks, plane deforms and veers off course, crash	8	Forces on wings too high, damage to fuselage, landing forces	3	Visual Inspection	2	48	Reinforce with bulkheads
	Thrust Deforms Cone	Thrust redirected potentially causing aircraft to crash	7	Too much thrust	2	Visual Inspection	1	14	Reinforce cone of fuselage
Avionics - Part #5 Controls the airplane and provides power to each system.	Motor Overload	Potential damage and destruction of motor.	8	Too high of payload carried, torque overload on motor.	3	Ensure Amperage isn't too Larg	10	240	Measuring load and torque on motor during testir
	Motor Overheats	Potential of motor catching fire and damaging entire craft.	9	Consuming excess wattage to meet power needs.	2	Ensure Proper Cooling	10	180	Measuring power usage during testing.
	Battery runs out during flight	Loss of flight ability and inevitable crash.	3	Too much electricity used during flight.	2	Charge Battery	5	30	Measuring power usage during testing.
	Unresponsive Radio Controls	Inability for plane to take off or control during flight.	2	Poor or no connection from radio control to craft.	4	Test all Components	1	8	N/A
	Disconnection of wires	Some or all electro-mechanical components of plane will not func	2	Rough flying, crashes, turbulence, or other forces on craft.	4	Test all Components	1	8	N/A
	Propeller breakage	Inability to produce thrust	4	Landing gear breaking; hits something in air	3	Visual Inspection	5	60	Preflight Check.
	Servo motors unresponsive	Control of aircraft compromised potentially causing aircraft to cras	3	Loss of range	4	Check Prior to Flight	1	12	Preflight Check.
	Battery Overloaded	Fire, destruction of plane	9	Drawing too many Amps	2	Check Amperage Pulled	8	144	Measuring power usage during testing.
	Receiver Fail Safes	Total loss of aircraft control	10	Incorrect installation or programming.	2	Visual Inspection	2	40	Preflight Check.
	Transmitter Battery Fails	Inability to connect to aircraft radio control system	10	Controller left on, battery not charged/changed	3	Check Battery Power	2	60	Preflight Check.
Landing Gear - Part #3 Functions to help the airplane takeoff and land.	Front Wheel Servo Failure	Loss of ground steering	3	Improper Calibration with Controller	8	Visual Inspection	1	24	Test Servo Connection Prior to Flight
	Deformation of Wheels	Cannot move when not airborne	5	Impact from landing	3	Visual Inspection	1	15	Preflight Check, Durability Test
	Loss of Wheel during flight	Damage fuselage at landing, competition disqualification	10	Drag force during flight	4	Visual Inspection	1	40	Preflight Check, ensure strong connections
	Connection Rods Break	Plane cannot land, loss of wheels	10	Impact from Landing or Force experienced during flight	2	Visual Inspection	1	20	Preflight Check
	Wheels disconnect from Fuselage	Plane cannot land, loss of wheels	10	Impact from Landing or Force experienced during flight	5	Visual Inspection	1	50	Preflight Check
	Wheels Seizing	Plane will come to abrupt stop upon landing, plane breaks	7	Water got in axle, dirt gets in axle	3	Visual Inspection	3	63	Preflight Check, Grease Wheels
	Deformation of Landing Gear	Potential for a Crash during landing	6	Impact from Landing	4	Visual Inspection	1	24	Preflight Check
	Loss of front wheel control	Potential for Propeller and Fuselage damage during landing	8	Impact from Landing or Force experienced during flight	6	Visual Inspection	1	48	Preflight Check
	Wheels Toe-In	Loss of in-line wheels; plane can't move correctly	6	Impact from Landing	3	Visual Inspection	1	18	N/A
	Lack of Correct Front Wheel Directio	Crooked wheel upon landing; abrupt crash once on ground	7	Improper Calibration with Controller	3	Visual Inspection	1	21	N/A