A2 Aero Micro - 20F12

Preliminary Proposal

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DISCLAIMER

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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 constraints. Some of these constraints include the dry weight of the plane being less than ten pounds, fitting within the specified-volume competition container (12.125” X 3.625” X 13.875”), and fully assembling the plane in under 3 minutes. The main objective of the competition is to carry the largest amount of payload while having the lowest weight aircraft. Teams are scored on the assembly time, weight of plane, payload carried, technical reports, and many other factors. This project is of interest to the sponsor because the ideas developed in this competition can be applied to full scale aircraft. This project addresses the issues seen in real-life airplanes where the payload is limited for smaller planes. If the team is successful, the sponsor and stakeholders will benefit in the idea of NAU gaining respect in the aerospace education industry, as well as being supplied more money in the future for the teams to have a better chance of winning the competition.

1.2 Project Description

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].

2.0 Requirements

The following section contains the project requirements. These requirements are necessary for both designing and building a micro RC plane that will fly and will ensure all other components and functionalities are met. This includes both the customer needs as well as the engineering requirements. Also included is a house of quality, functional decomposition, black box model, and functional model/work-process diagram/hierarchical task analysis.

2.1 Customer Requirements (CRs)

For the SAE Aero Micro team, customer requirements were presented in the form of competition rules. The competition provides a detailed description of what is expected and what functionalities of the design are required. A complete list of the customer requirements is presented below.

1. Cost under $800
2. Durable and Robust design
3. Reliable design
4. Safe to operate
5. Assembly time under 3 minutes
6. Disassembled size fits inside of provided box

7. Hand-launchable
8. Battery equal to or smaller than 3s 2200 MAh
9. No metal propellers
10. Under ten pounds
11. Must include red arming plug
12. Carries 2” diameter PVC payload.
13. Identifying Marks

2.2 Engineering Requirements (ERs)

Using the customer requirements listed above, the engineering requirements can be derived. Engineering requirements are quantifiable and measurable. The derived engineering requirements also include a goal or target that must be met. The list of engineering requirements is presented next.

1. Volume
2. Assembly time
3. Packaged Weight
4. Battery
5. Cost
6. Red Arming Plug
7. Identifying Marks
8. Range
9. Radio Control
10. Ground Control
11. Material Selection
12. Durability
13. Lift
14. Thrust
15. Drag
16. Fail Safe
17. Restoration

The volume requirement has been set by the customer-need, stating that the plane must be disassembled and fit into a 13.875 x 12.125 x 3.625-inch box. The plane must also be able to be assembled in under three minutes which is the maximum target for the assembly time. The total packaged weight of the RC plane is stated by the competition rules to be equal to or less than ten pounds. The rules of the competition also state that the maximum battery size is limited to a 3s 2200MAh LiPo battery. The SAE Aero Micro team has been given a budget of $1500, however, the competition requires a $700 entry fee leaving $800 to design, prototype, and produce a final product. Therefore, the cost requirement has been set to $800.

Stated by the competition rules, the design must also include an arming plug that is in a conspicuous place and must be the color red. The competition rules also state that the aircraft must be fitted with the proper identifying marks with the team number being a minimum of one inch in height. The description of the competition states that the plane must be able to fly 400 feet before making a U-turn. The target range of the aircraft was consequently set to 425 feet. The radio controller that controls the aircraft must be 2.4 GHz as stated by the competition rules. The rules of the competition also state that the aircraft must be maneuverable on the ground by means other than the aerodynamics of the plane. The goal of the ground control is to be able to make turns of radius equal around five feet.

The material selection requirement needs the material to be lightweight yet strong enough to withstand the stresses of flight. The durability of the aircraft is tied to the material selection. The team has set a goal that the aircraft should be able to withstand an impact at 5 MPH while resulting in minimal damage to the aircraft. The lift of the aircraft, the thrust and the drag are all tied to the physical model of the aircraft and must allow the aircraft to achieve lift while being stable yet maneuverable. A fail safe is an engineering requirement that the team would like to include as well in case the receiver loses signal with the transmitter. The final engineering requirement included is restoration. The team anticipates that while testing the aircraft major crashes or failures may occur. The restoration goal is in place to keep the production time of each component to a minimum in order to fix any problems that may arise.

2.3 Quality Functional Deployment (QFD) and House of Quality (HoQ)

Using the customer needs along with the derived engineering requirements, a house of quality or QFD was completed in order 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 will also help 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 volume of the aircraft. Other important engineering requirements include lift force, packaged weight, and thrust force.

2.4 Functional Decomposition

The following section discusses the black box model and functional decompositions that were created by the team in order to break the project down into digestible pieces to work on. The black box model provides a very simple diagram of inputs that are taken into the “black box” and processed to create the outputs. The functional decomposition provides a more in depth look at how all these functions interact.

2.4.1 Black Box Model

The team created a black box model (a diagram that relates important outputs to important inputs through

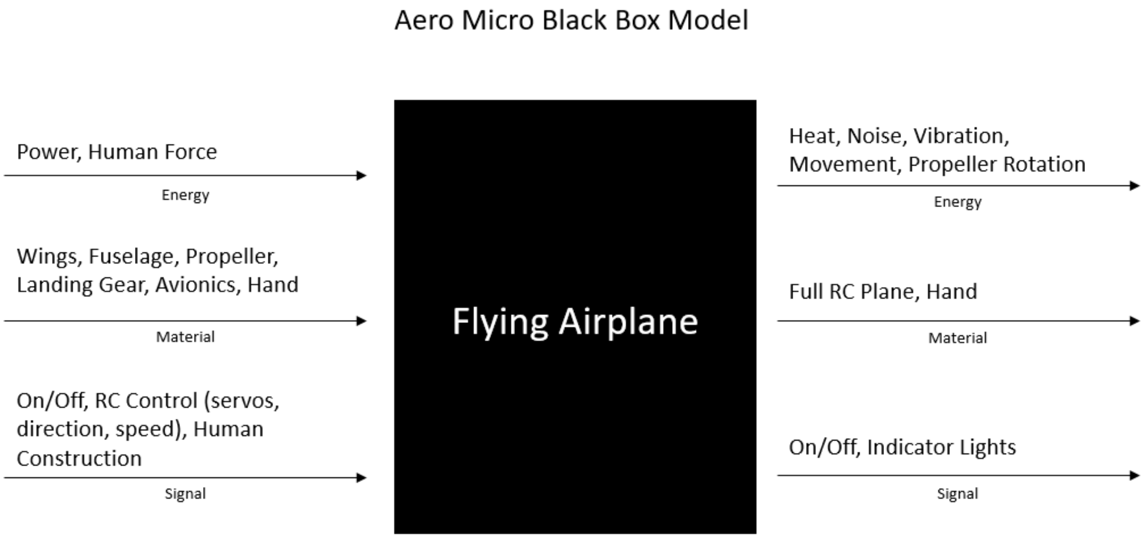


Figure 1: Black Box Model for a Flying Plane

an undefined “black box”) for a flying airplane to assist in the decomposition of the project. The black box model shown in figure 1 shows the major inputs and outputs of our system. The most important inputs are the material components that make up the major subsystems of our design, including the main focuses right now: tail, landing gear, and wings. The black box model also shows the various outputs of the system, including the movement of the plane (flight) and the constructed plane. The complexities that go on inside the black box are defined by the functional model shown in figure 1, however, the black box model helps to define some important subsystems, energy types, and control signals that will be necessary to construct the plane.

2.4.2 Functional Model

This section of the report describes the functional model of a micro airplane. This model takes in the inputs from the black box model and describes how those inputs are converted to the outputs on the same model, essentially describing what is going on inside the “black box”. Figure 2 shows the functional model of our system, with the different colored arrows representing the different types of movement throughout the system (energy, material, or signal).

Creating this functional model was important for the team, as it showed how each of the major components interacted with each other. For the micro aero team specifically, it helped to show what systems need to be developed in what order, as certain systems and processes will not function without their predecessors. For example, the wings, fuselage, landing gear, avionics, and tail all need to be developed before the team can even consider assembling the plane, and the plane needs power and signal inputs combined with the assembly before the plane can start creating the torque needed to create thrust. Thus, the team has used this functional model as a way of planning out what systems to work on, the big ones being the tail, landing gear, wings, avionics, and fuselage. While the team continues to work and theorize all five of these subsystems, the three that have been designed in detail so far (and which are discussed in the subsystems sections) are the wings, tail, and landing gear.

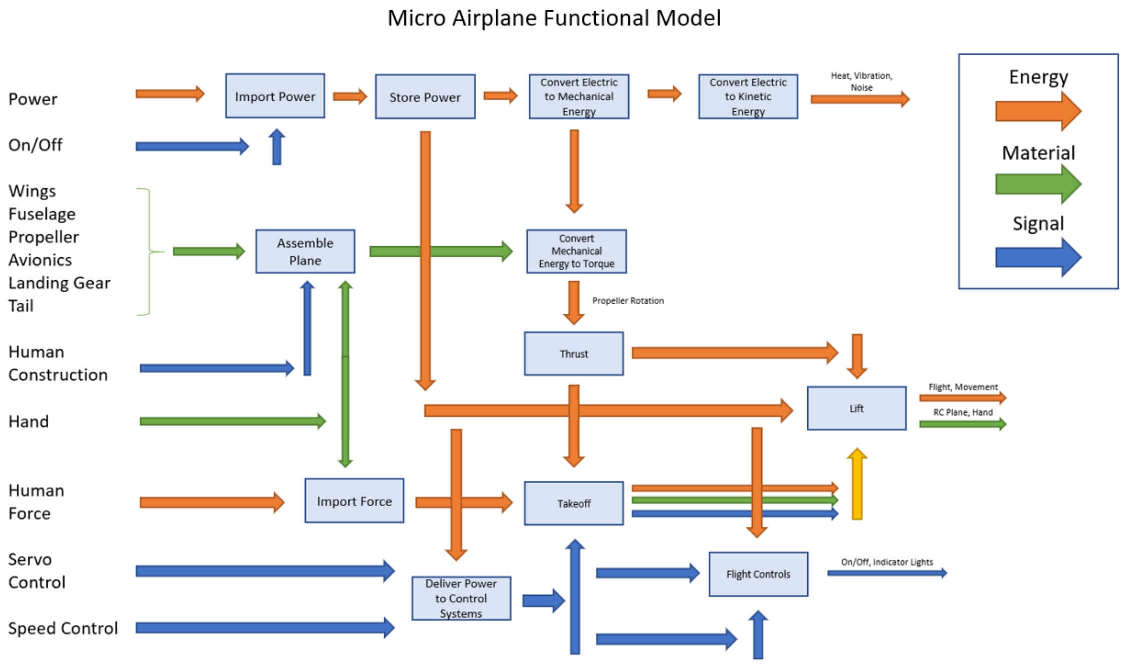


Figure 2: Functional Decomposition

3.0 DESIGN SPACE RESEARCH

For this project, the team conducted research using various sources to pull information from. This assisted in the design of the aircraft. Each team member selected a specific aspect of the aircraft to research using a variety of resources.

3.1 Literature Review

The team used various resources to conduct research on their aspect of the project. This included firsthand conversations with experienced RC aircraft builders, online forums, and academic resources. During this research, team members focused on trying to generate potential design concepts from the information gathered to aid in generating design concepts for the aircraft.

3.1.1 Tyler Darnell

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. Five of the most important sources are listed below, along with a brief summary of that source and the type of information pulled from that source.

1. Flagstaff Flyer's RC Flying Club [2]

The Flagstaff Flyers have been an amazing source of information and inspiration for all members of the team. The members of the Flagstaff Flyers have over 100 years of RC Airplane flying experience combined and can answer almost any question you ask them. They were able to provide important information on what type of airfoil works best, and the pros and cons to each, and what wing shape would be best for our application. Additionally, the many RC planes they have at their airfield offer design inspiration for everyone, and each member has unique insights on flying RC planes.

2. Airfield Models - RC Plane Design Website [3]

Airfield models is an in-depth website covering everything one needs to know about building and designing RC planes. The sections on the website cover everything from wing shape, to airfoil profiles, to construction techniques. Tyler obtained important information about all the different airfoil classes from this website, and some more information on elliptical and rectangular wings.

3. 9 Types of Aircraft Wing in Depth [4]

While not the most technical article, this article by Aircraft Compare provided a look at nine different wing shapes for flying aircraft. This article helped to point out the most popular wing shapes for planes, and the advantages and disadvantages to using both. This article was the main source of inspiration for the five designs of wing shape in the subsystem section below.

4. Introduction to Fluids Mechanics [5]

Introduction to Fluid Mechanics is an in-depth textbook covering all things fluid mechanics, but the sections of lift and drag are essential when it comes to designing airplanes. The information contained in the textbook allows the team to compute lift and drag on wings using different airfoil types, an essential part of wing design.

5. ProAdvice 2: The Wing Planform [6]

This article from ProAdvice is an in-depth look at different wing planforms. It provides a list of some of the common planforms, as well as data on the lift distribution of each type of planform. This article provides information that is useful for technical wing design, as well as several new and interesting planforms that the team had not seen nor considered.

3.1.2 Colton Farrar

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.

1. Flagstaff Flyer's RC Flying Club: Tim Kelly [7]

The first source is from Tim of the Flagstaff Flyers. Tim was able to give advice on the thickness of the ribs, as well as advice on where to access a laser cutter. However, the information he gave only went so far and he is not able to tell us specific values as this might ruin the integrity of the competition and the engineering needed to be put into it.

2. Injection Molding Video [8]

The next source was a YouTube video with a person constructing airplane tails using a modified version of injection molding. This person simply used to expand bottled foam and sprayed that into an enclosed airfoil shape to get the desired profile in an extremely simple manner.

3. Rib Thickness Forum Discussion [9]

The third source is from an online forum known as rcuniverse.com. On this forum, the discussion was about the considerations that must be made when choosing the thickness of the airplane ribs. Some of these considerations include not causing any unwanted 'dip' in the wings by spacing the ribs too far apart and not causing any moment in the wings from the ribs being too thin.

4. Laser Cutting Website [10]

The fourth source is machinemfg.com where the basics of laser cutting was explored. This source helped Colton understand the precision and reliability that laser cutting can provide. From this source, Colton was able to confirm laser cutting will be the correct process for both the wings and the fuselage.

5. RC Tail Forum Discussion [11]

The final source comes from quora.com where a discussion was held between various users about the proper tail design that RC airplanes should use. The specific pros/cons found from this source are discussed later in this report, but it was concluded that conventional tails are likely the best tail orientation.

3.1.3 Zachary S. Kayser

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.

1. RealFlight 8 Manual [12]

The first source investigated was the RealFlight 8 simulator manual. The manual is one of the best resources for understanding this product and explains in depth nearly everything that the team may need to know about the simulator.

2. How to setup RealFlight 8 with the Spektrum WS 1000 Wireless Dongle [13]

RealFlight 8 is often sold along with a wired transmitter that can be plugged directly into the computer that is running the simulator however, the transmitter that the team is in possession of is not this remote. In order to be able to use the simulator with the transmitter possessed a WS1000 dongle is required. The second source reviewed explains in detail how the dongle can be used along with the Spektrum brand transmitter.

3. Flagstaff Flyer's RC Flying Club: Jeff Wheless [14]

The team has been consulting a group local to Flagstaff called the Flagstaff Flyers. Some members of the group also use the RealFlight 8 simulator and have been very helpful in the understanding and setup of RealFlight 8 for the team. The Flagstaff Flyers have recommended that the simulator be used to simulate various weather conditions that the team may face during the competition.

4. Nodd RC - 040 - RealFlight Custom Planes [15]

The fourth reviewed source for information on RealFlight 8 was a video detailing the process for uploading a fully customized aircraft. This is a very comprehensive way of simulating the aircraft that the team designs. This way of simulating the aircraft creates a completely custom version of the designed aircraft.

5. Basics to Editing a Plane on RealFlight | FloRc [16]

The fifth and final source that was reviewed regarding the flight simulator is a video describing how pre-loaded aircraft within the simulator can be customized to be more similar to the aircraft designed by the team. This way of simulating the aircraft is much easier but is not as comprehensive as the previously stated method.

3.1.4 Thomas O'Brien

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.

1. Flagstaff Flyers: Tim Kelly and Rich Busch [17]

Tim Kelly and Rich Busch, of the Flagstaff Flyers, provided insight to the various landing gear configurations one could use for an aircraft. They provided information on the advantages and disadvantages to the various configurations depending on the purpose of the aircraft. The insight they provided was based on their experience in building and testing various aircraft with different landing gear configurations

2. General Aviation Aircraft Design [18]

This textbook provided insight not only into the different landing gear configuration, but other variables that need to be considered when positioning the landing gear on the aircraft. The position seems to revolve around the location of the center of gravity of the aircraft.

3. Aircraft Landing Gear Development and Design [19]

This source provided an in-depth guide into the multiple variables that play a role in designing landing gear. This source provided information regarding a large-scale aircraft, but in principle, the teams craft would face the same challenges just on a smaller scale.

4. Flite Test Forums - Landing Gear [20]

The Flite Test forums provided insight into what other builders and designers were doing when constructing their landing gear. This provided the team insight into potential challenges they could face when building their craft based off of certain design choices. This prompted the team to consider these factors during the design phase before they present a problem when building and testing the design.

5. Lightweight RC Plane Landing Gear Tutorial [21]

This source elaborated on potential construction for a landing gear configuration. It also touched on other factors a landing gear design will have on an aircraft's performance for the team to consider when generating concepts.

3.1.5 Daniel Varner

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.

1. eCalc-Setup Finder [22]

This website is an online calculator that allows a user to find a wide variety of propulsion systems for their specific craft, based on the parameter that an individual input. These inputs include: the dimensions of the craft, weight, flight mission, altitude, etc. This tool greatly improves the ease and efficiency for any team or individual to find the appropriate propulsion setup for their craft, as this process would otherwise be extremely difficult and time-consuming with inexperienced individuals in the field of RC aircraft.

2. eCalc-PropCalc [23]

Once a propulsion setup has been selected from the eCalc-Setup Finder, this calculator will then give many crucial performance outputs to the user, such as the thrust-to-weight ratio, load on the battery, estimated flight time, etc. This will allow the user to verify whether the setup will work for their specific craft or if alterations and adjustments must be made in order to achieve the desired performance.

3. Flagstaff Flyers RC Flying Club [24]

The team consulted with Tim Kelly of the Flagstaff Flyers to get his advice on how they can determine the propulsion set-up for their various types of planes. The team was advised to increase the diameter of the propeller to increase the thrust of the plane and allow it to fly at a slower velocity. However, he did give the team a few different recommendations on the motors and propellers that could be used for this type of payload carrying, slow flying plane that we are designing. Lastly, he advised the team that our motor and propeller should not be selected until the body of the aircraft is fully built, so that the dimensions and weight of our craft will be certain.

4. Analysis of a Contra-Rotating Propeller Driven Transport Aircraft [25]

A report detailing the performance results of aircraft with contra-rotating propeller systems and comparing them with other aircraft, such as a jet-powered Boeing 737-800. Contra-rotating propellers are two propellers on the same engine that spin in opposite directions and can generate a much greater amount of thrust compared to other standard propeller-driven and even jet engine aircraft. There is an interest to use contra-rotating propellers in our craft as it will allow our craft to generate a much greater amount of thrust, without substantially increasing the dry weight of the craft.

5. Contra-Rotating Propellers How To [26]

This is a tutorial for how to create a contra-rotating propeller system for an RC plane aircraft. This design does call for the use of two motors and, obviously, two propellers. The construction of this design would possibly require some machining to be accomplished and would also increase the mechanical complexity of our craft, and possibly increase the load on the motor and battery and decrease the overall flight time of our craft.

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 in order 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 in order to determine which particular type of 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 [27]

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 [28]

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 Design [29]

3.3 Subsystem Level State of the Art Benchmarking

The team is able to 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.

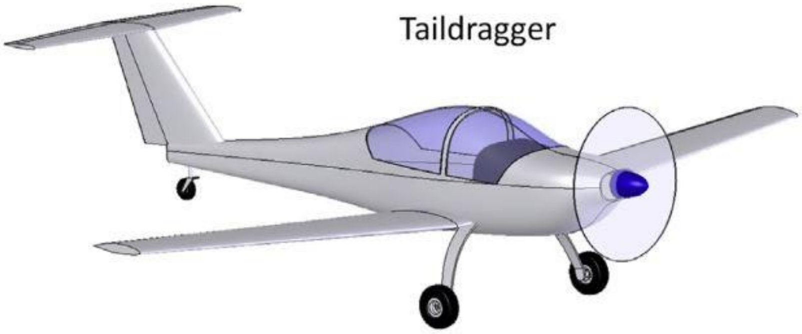


Figure 6: Taildragger Landing Gear Configuration [30]

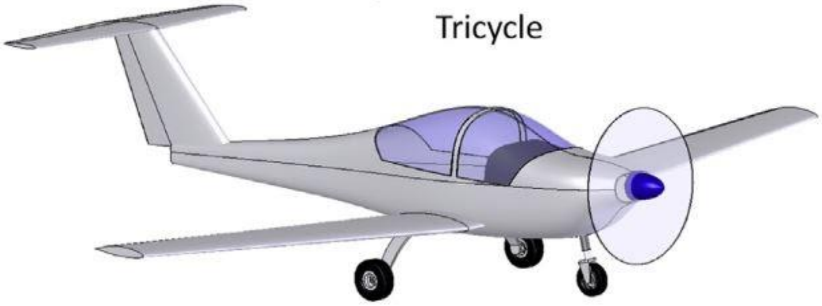


Figure 7: Tricycle Landing Gear Configuration [30]

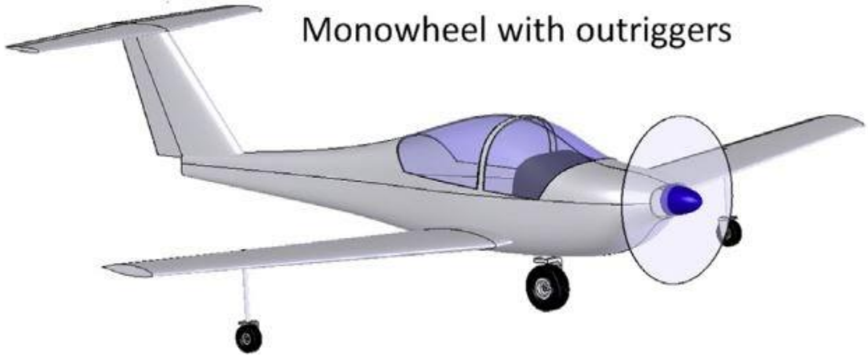


Figure 8: Monowheel with Outrigger Landing Gear Configuration [30]

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 [4].

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 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 [4].

Figure 10: Boeing 787-9 Dreamliner [4].

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 11 shows a diagram of the four types of airfoils mentioned, which are cut from the Airfield Models [3] website and reformatted by the team.

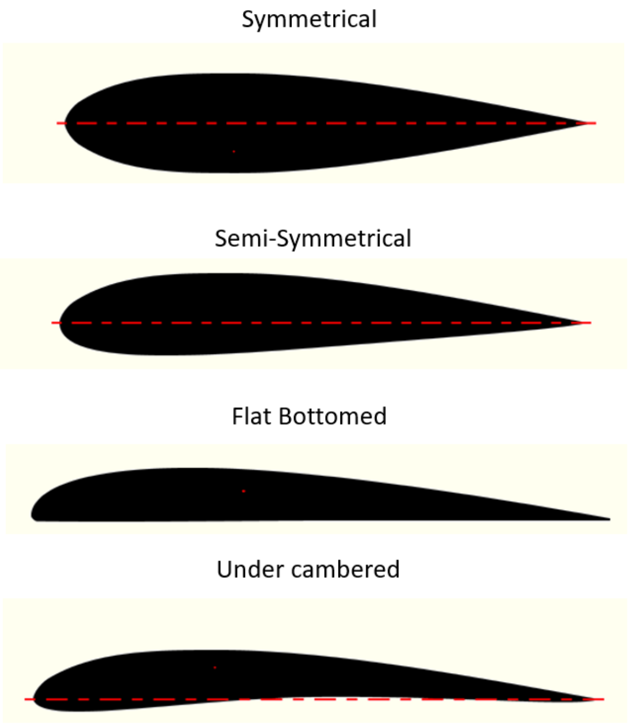


Figure 11: Four Main Classes of Airfoil [3].

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 12. 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).

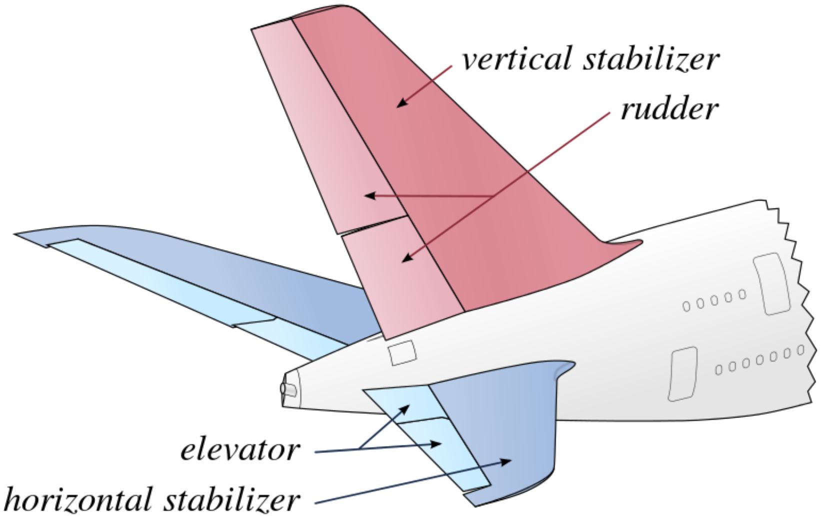


Figure 12: Conventional Tail Components [31]

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 13, 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 13: Boom Tail Design [32]

3.3.3.3 Existing Design #3: Cruciform Tail

The next tail design is the cruciform tail, as seen in figure 14. 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 14: Cruciform Tail Design [33]

4.0 CONCEPT GENERATION

In order 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 15). 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.

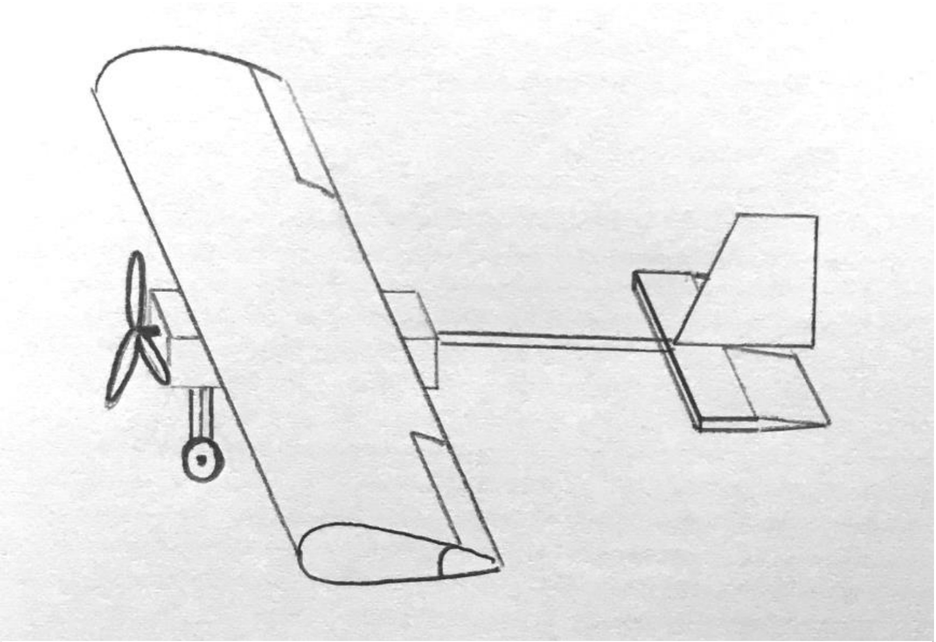


Figure 15: Standard Aircraft Design

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 16). 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 17). 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.

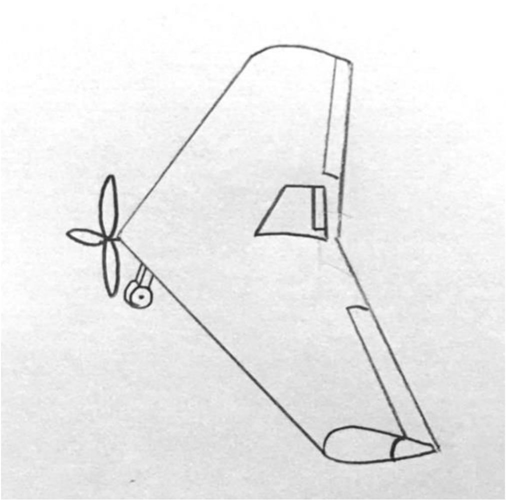


Figure 16: Flying Wing Aircraft

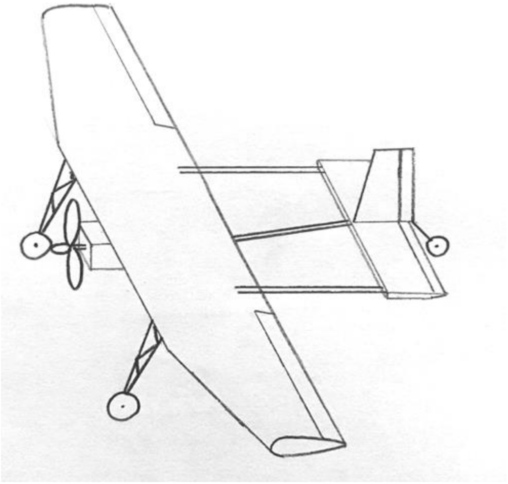


Figure 17: Unique Design Aircraft

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 1.

Table 1: 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 18. 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.

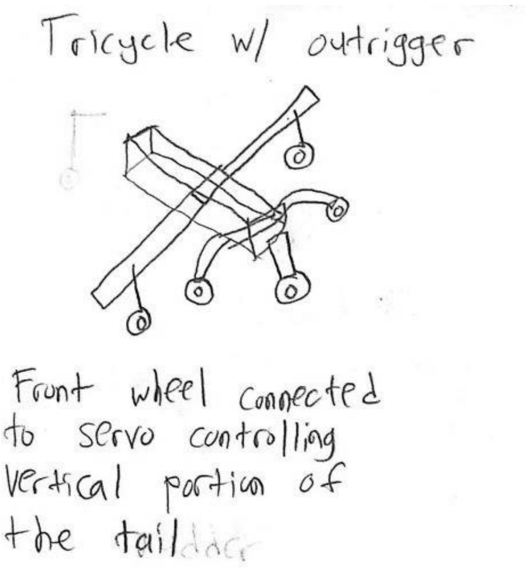


Figure 18: Tricycle with Outrigger Landing Gear Configuration

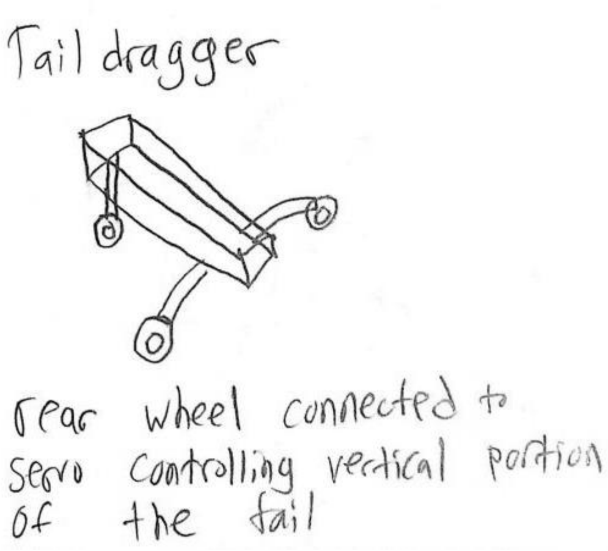


Figure 19: Taildragger Landing Gear Configuration

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 20. 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.

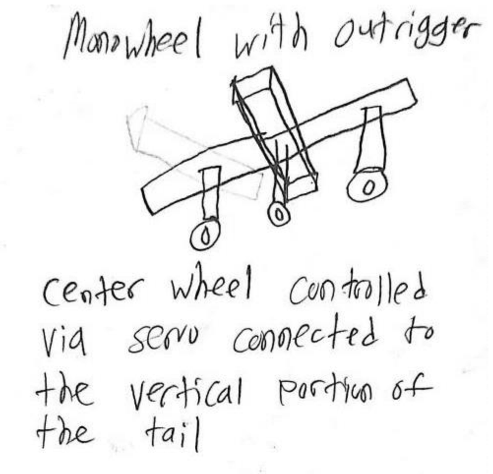


Figure 20: Monowheel with Outrigger Landing Gear Configuration

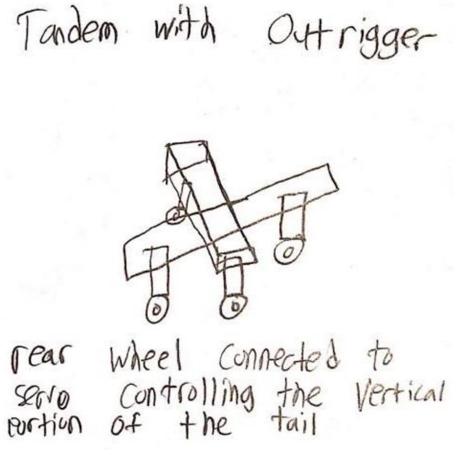


Figure 21: Tandem with Outrigger Landing Gear Configuration

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 21. 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.

4.1.1.5 Design #5: Tricycle

The final concept is the tricycle design as seen in Figure 22. 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.

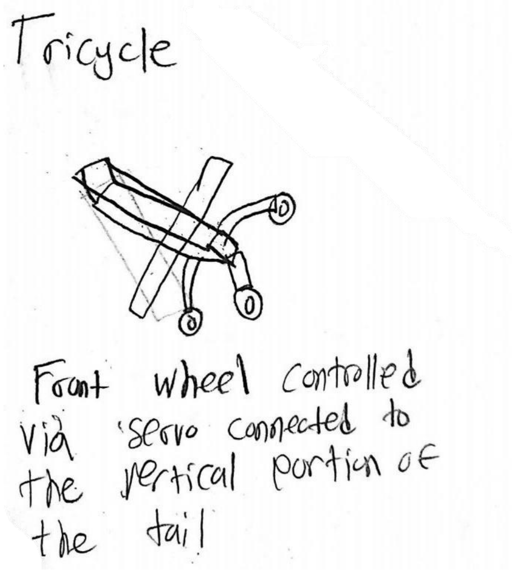


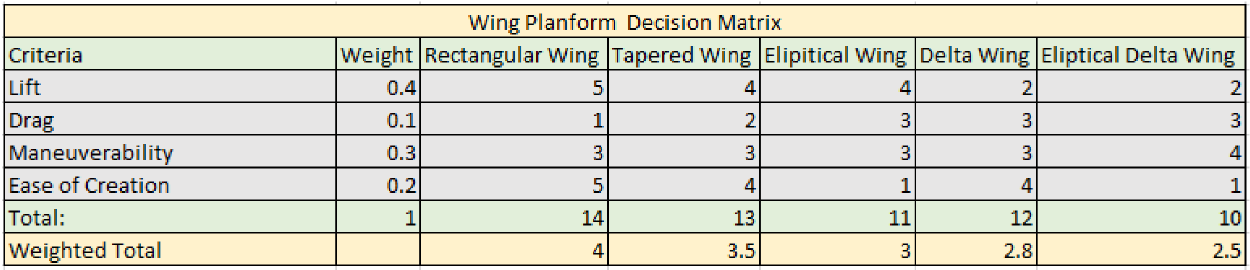
Figure 22: Tricycle Landing Gear Configuration

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 2. 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 2: 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

4.1.2.1 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 23.

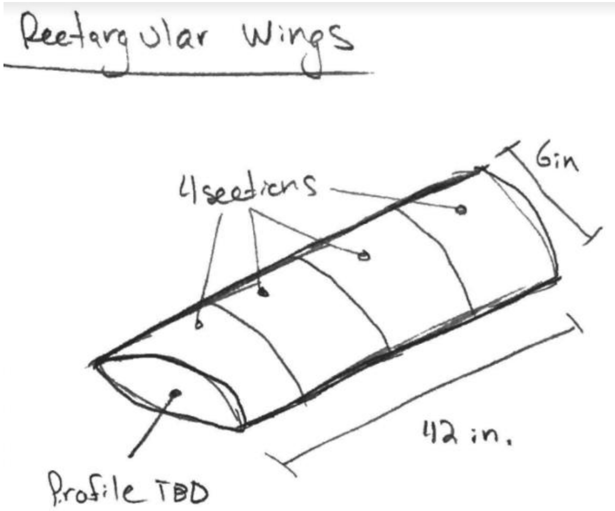


Figure 23: Traditional Rectangular Wing

4.1.2.2 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 24.

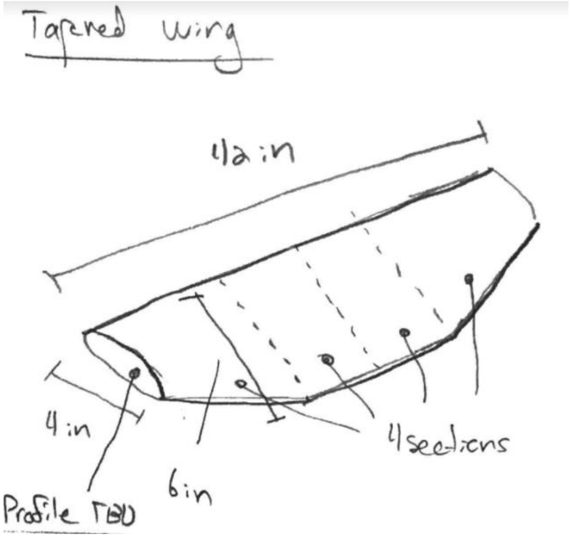


Figure 24: Traditional Rectangular Wing

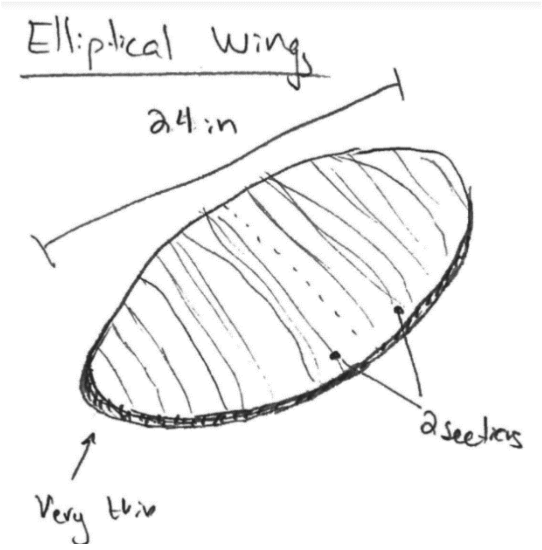


Figure 25: Elliptical Wing

4.1.2.3 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 below in figure 25. 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.

4.1.2.4 Design #4: Delta Wings

A sketch for a possible delta wing design is shown in Figure 26. 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.

4.1.2.5 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 27, however, the team is likely to never pursue such a design as its downsides are many compared to any benefits.

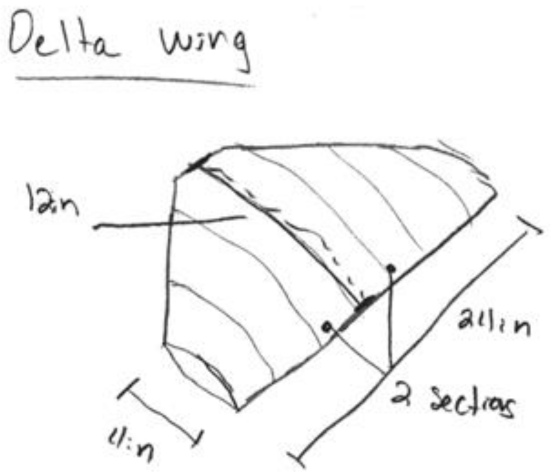


Figure 26: Delta Wing

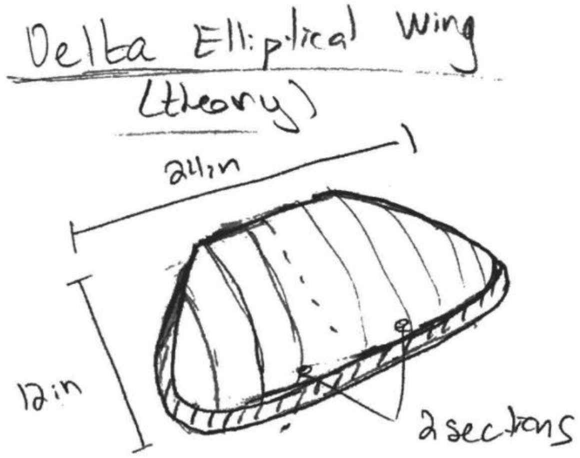


Figure 27: Delta Elliptical Wing

4.1.2.6 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 3 and identifies the flat bottomed and under cambered airfoils as the most viable.

Table 3: Airfoil Selection 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 [34] and the Clark Y [35] 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 B and Appendix C 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.

4.1.3 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 4 shows the decision matrix that was used to compare the five different tails designed below.

Table 4: 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**

4.1.3.1 Design #1: Conventional

The first design developed is the conventional tail, as seen in Figure 28. 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 and developed a CAD model, as seen in Figure 28.

4.1.3.2 Design #2: T-Tail

The next design developed is the T-tail configuration. This design, as seen in Figure 29, 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.

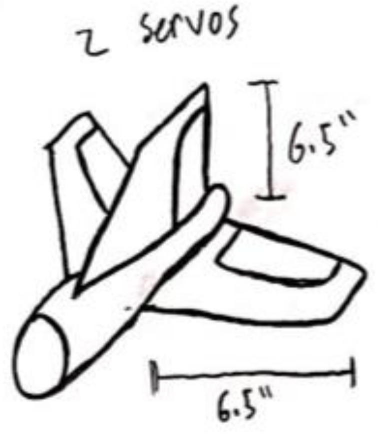


Figure 28: Conventional Tail Concept

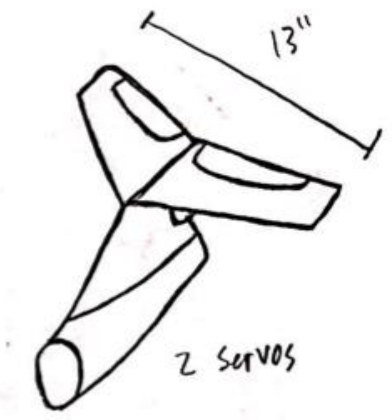


Figure 29: T-Tail Concept

4.1.3.3 Design #3: Cruciform

The cruciform tail is the next design that was considered (seen in Figure 30). 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.

4.1.3.4 Design #4: Dual

The dual tail is the next concept the team considered. Figure 31 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.

4.1.3.5 Design #5: Boom

The final tail design the team generated is the boom tail, found in Figure 32. 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.

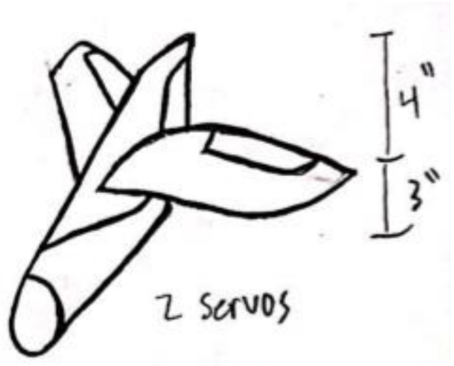


Figure 30: Cruciform Tail Concept

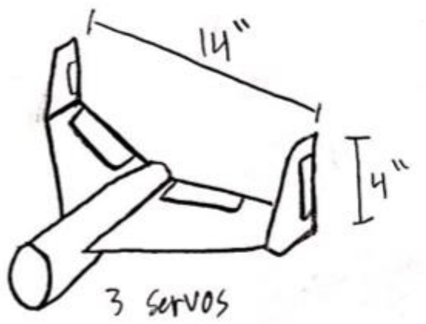


Figure 31: Dual Tail Concept

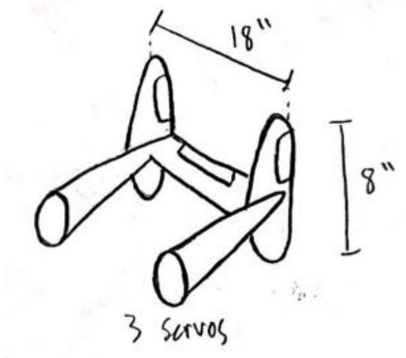


Figure 32: Boom Tail Concept

5.0 DESIGNS SELECTED – First Semester

5.1 Technical Selection Criteria

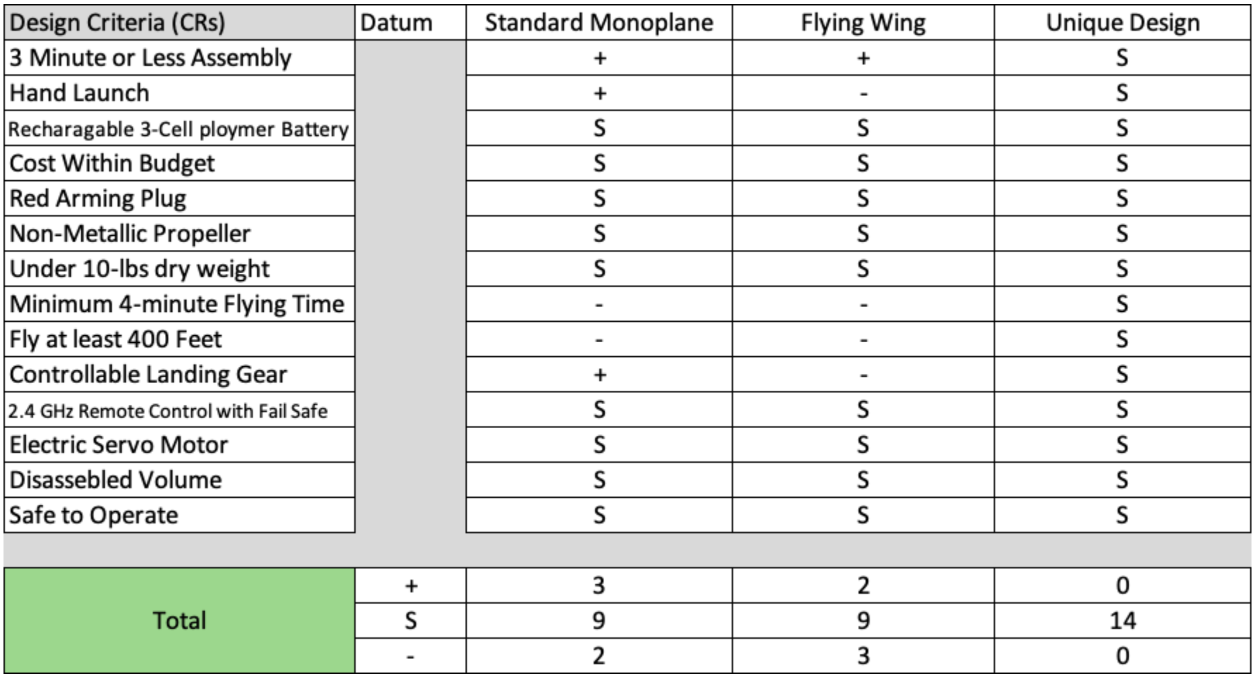
The criteria used to judge these different types of craft are based on the criteria based on the customer requirements and the engineering requirements. First, the Pugh Chart is based on a non-quantitative analysis of the customer requirements that our craft must be able to achieve. Since the Pugh Chart 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 5: Pugh Chart



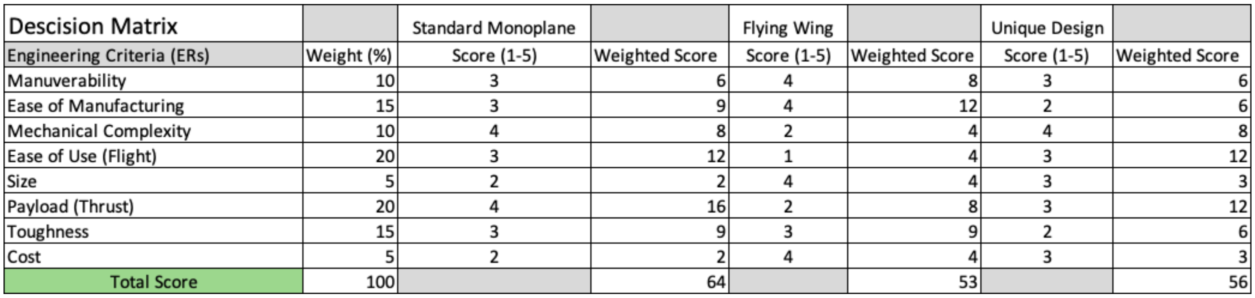
Design Criteria (CRs)	Datum	Standard Monoplane	Flying Wing	Unique Design
3 Minute or Less Assembly		+	+	S
Hand Launch		+	-	S
Recharagable 3-Cell ploymer Battery		S	S	S
Cost Within Budget		S	S	S
Red Arming Plug		S	S	S
Non-Metallic Propeller		S	S	S
Under 10-lbs dry weight		S	S	S
Minimum 4-minute Flying 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 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.

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 6: 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 6 allows the team to give each aircraft a numbered rating on the different engineering requirements that it will need to perform in order to achieve the highest possible score in the competition. From the results calculated in the table above, 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 in order 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 33 shows the tentative final design of the airplane the team has developed in SOLIDWORKS.

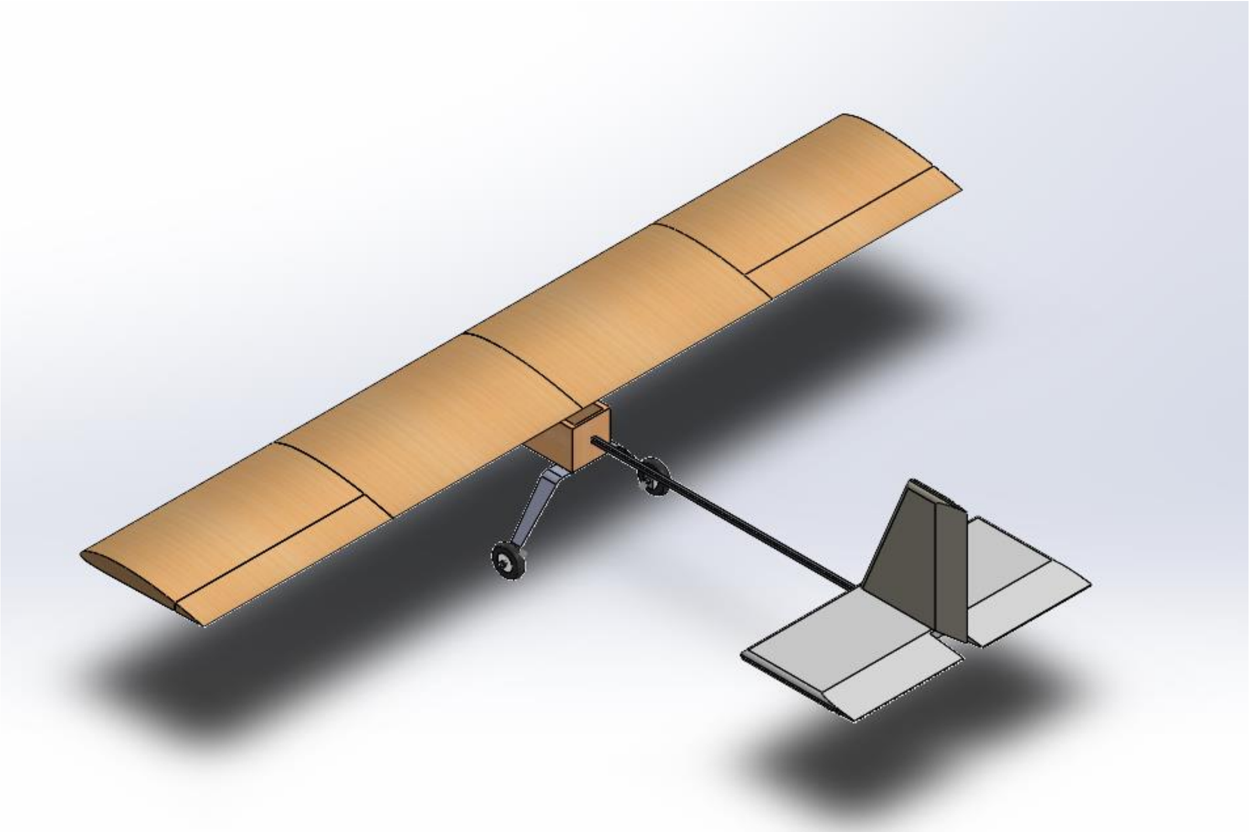


Figure 33: Tentative Final Design

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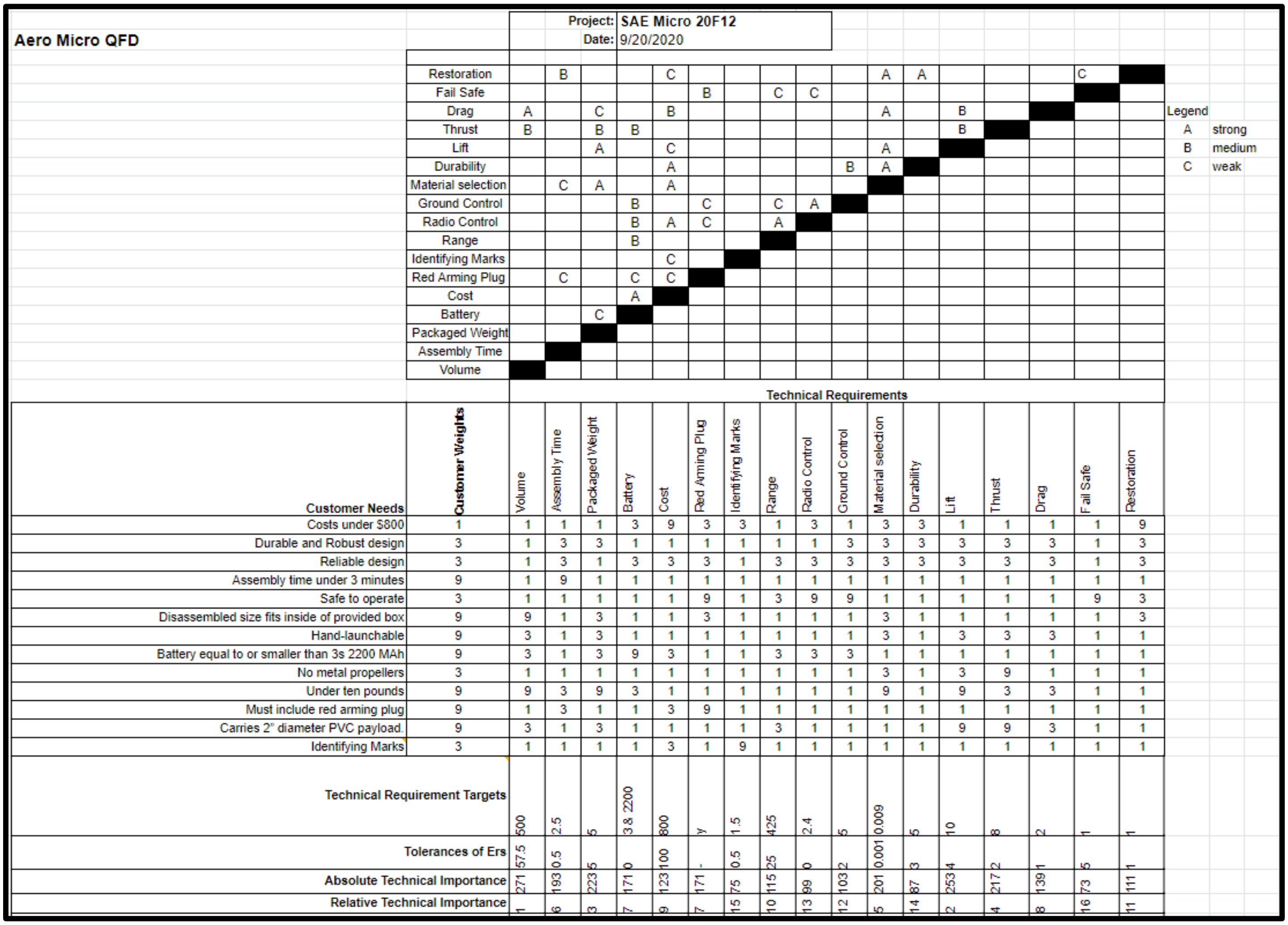
7.0 APPENDICES

7.1 Appendix A: Quality Functional Deployment (QFD) House of Quality (HoQ)



Aero Micro QFD

Project: **SAE Micro 20F12**
Date: 9/20/2020

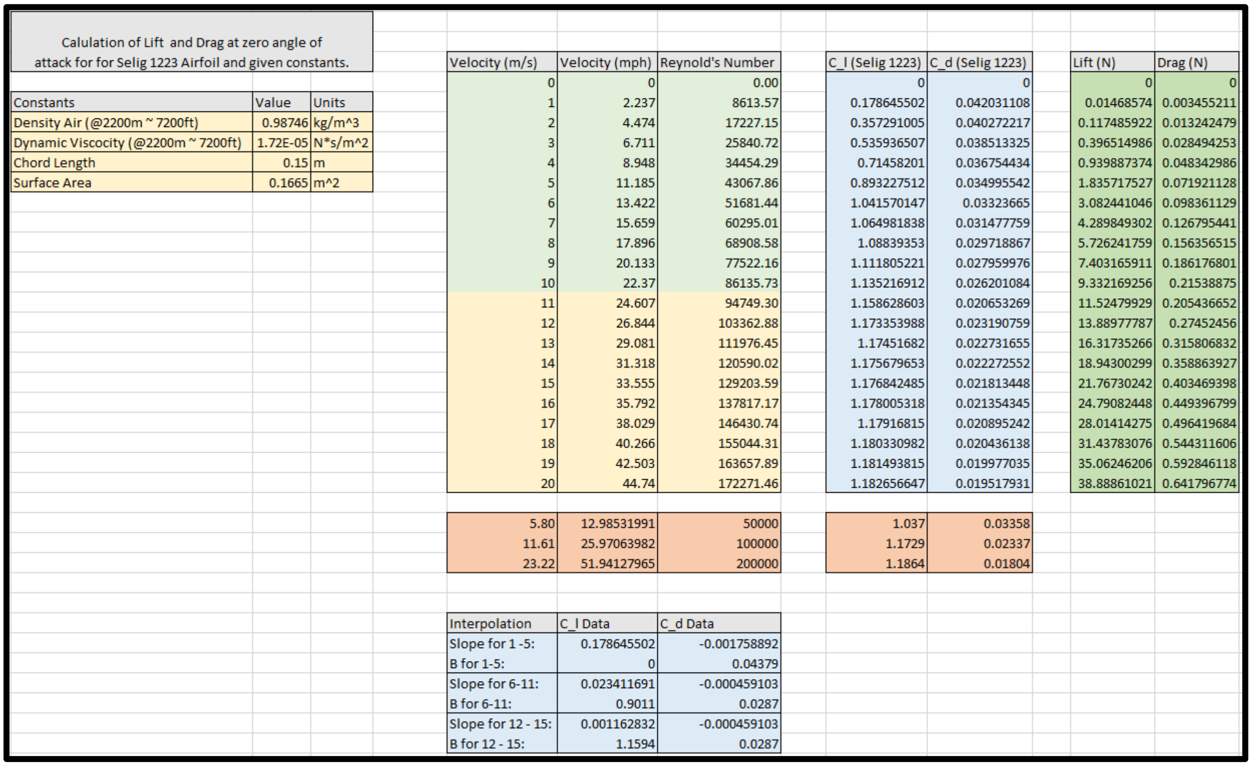
	Volume	Assembly Time	Packaged Weight	Battery	Cost	Red Arming Plug	Identifying Marks	Range	Radio Control	Ground Control	Material selection	Durability	Lift	Thrust	Drag	Fail Safe	Restoration
Restoration		B			C						A	A				C	■
Fail Safe						B		C	C							■	
Drag	A		C		B						A		B		■		
Thrust	B		B	B									B	■			
Lift			A		C						A		■				
Durability					A					B	A	■					
Material selection		C	A		A						■						
Ground Control				B		C		C	A	■							
Radio Control				B	A	C		A	■								
Range				B				■									
Identifying Marks					C		■										
Red Arming Plug		C		C	C	■											
Cost				A	■												
Battery			C	■													
Packaged Weight			■														
Assembly Time		■															
Volume	■																

Legend
A strong
B medium
C weak

Technical Requirements

Customer Needs	**Customer Weights**	Volume	Assembly Time	Packaged Weight	Battery	Cost	Red Arming Plug	Identifying Marks	Range	Radio Control	Ground Control	Material selection	Durability	Lift	Thrust	Drag	Fail Safe	Restoration
Costs under $800	1	1	1	1	3	9	3	3	1	3	1	3	3	1	1	1	1	9
Durable and Robust design	3	1	3	3	1	1	1	1	1	1	3	3	3	3	3	3	1	3
Reliable design	3	1	3	1	3	3	3	1	3	3	3	3	3	3	3	3	1	3
Assembly time under 3 minutes	9	1	9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Safe to operate	3	1	1	1	1	1	9	1	3	9	9	1	1	1	1	1	9	3
Disassembled size fits inside of provided box	9	9	1	3	1	1	3	1	1	1	1	3	1	1	1	1	1	3
Hand-launchable	9	3	1	3	1	1	1	1	1	1	1	3	1	3	3	3	1	1
Battery equal to or smaller than 3s 2200 MAh	9	3	1	3	9	3	1	1	3	3	3	1	1	1	1	1	1	1
No metal propellers	3	1	1	1	1	1	1	1	1	1	1	3	1	3	9	1	1	1
Under ten pounds	9	9	3	9	3	1	1	1	1	1	1	9	1	9	3	3	1	1
Must include red arming plug	9	1	3	1	1	3	9	1	1	1	1	1	1	1	1	1	1	1
Carries 2" diameter PVC payload.	9	3	1	3	1	1	1	1	3	1	1	1	1	9	9	3	1	1
Identifying Marks	3	1	1	1	1	3	1	9	1	1	1	1	1	1	1	1	1	1
Technical Requirement Targets		500	2.5	5	3 & 2200	800	y	1.5	425	2.4	5	0.009	5	10	8	2	1	1
Tolerances of Ers		57.5	0.5	5	0	100	-	0.5	25	0	2	0.001	3	4	2	1	5	1
Absolute Technical Importance		271	193	223	171	123	171	75	115	99	103	201	87	253	217	139	73	111
Relative Technical Importance		1	6	3	7	9	7	15	10	13	12	5	14	2	4	8	16	11

7.2 Appendix B: Selig 1223 Airfoil Data



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

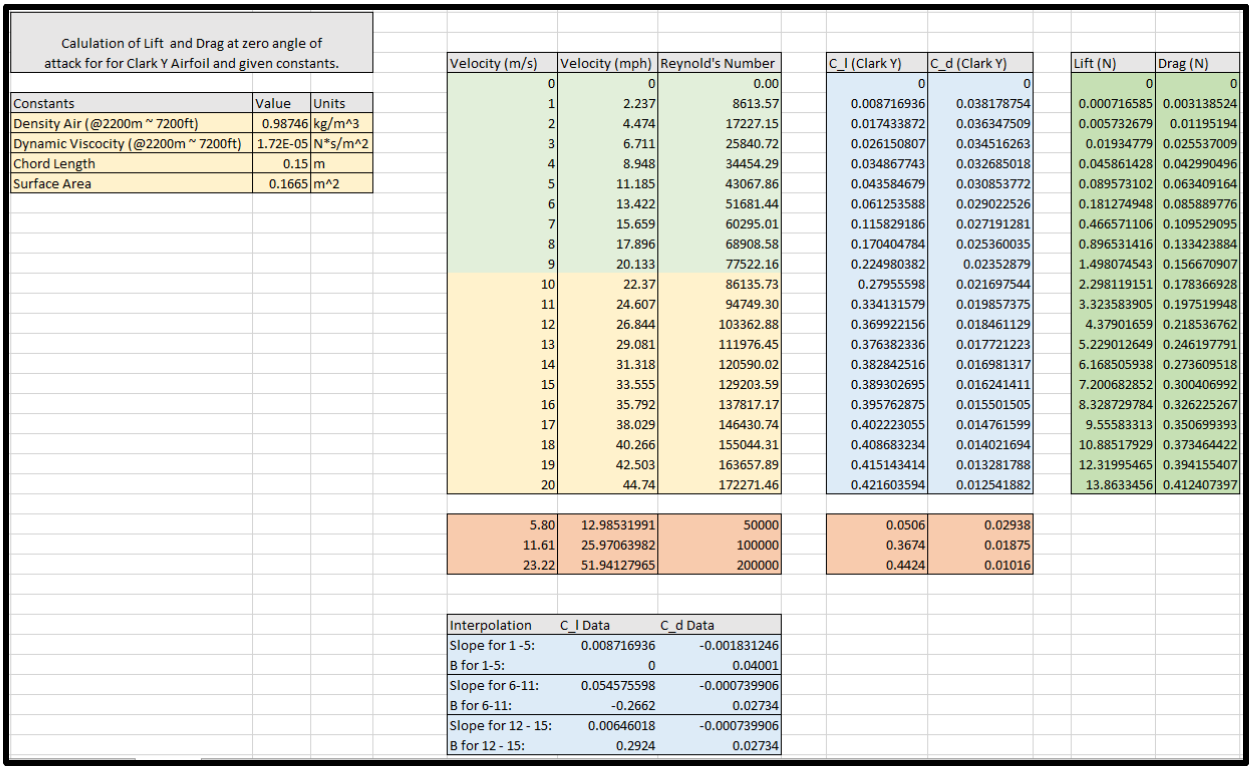
Constants	Value	Units
Density Air (@2200m ~ 7200ft)	0.98746	kg/m^3
Dynamic Viscocity (@2200m ~ 7200ft)	1.72E-05	N*s/m^2
Chord Length	0.15	m
Surface Area	0.1665	m^2

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

7.3 Appendix C: Clark Y Airfoil 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