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Designing a Remote-Controlled Aircraft for the 2024 SAE Aero Design Competition

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ENGR 491 - Senior Design

Spring 2024

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Acknowledgements

We would like to acknowledge Dr. Davis for his guidance and support throughout the project. We would also like to thank Dr. Nelson for his assistance and advice. Also, we would like to thank Justin Amos and Hanno de Coning for their assistance throughout the manufacturing process and at the competition. Finally, we would like to thank the Endeavor Awards Committee, and the Engineering Department for funding our project.

Abstract

The Society of Automotive Engineers (SAE) Aero Design competition allows students to gain real world experience by applying concepts learned within their engineering education to a real-world application. The competition challenges students to design and build a fixed wing, all-electric, remotely controlled aircraft. The team plans on participating in the regular class, where the focus is designing an aircraft to maximize carrying capacity while performing under a 750-watt power constraint.

This is the second year a team from the University of Southern Indiana has participated in the competition. The team's design from the 2023 competition is also evaluated within this report. The competition challenges students across multiple engineering fields, such as mechanical, electrical, and aeronautical engineering. Throughout the project, existing knowledge was revisited, and fresh insight was acquired, fostering continuous learning and growth. The project detailed within this report approached the competition in a way that produced a creative solution to the design of the aircraft. This was done by reviewing and innovating previous projects.

This document presents a review of research about aircraft design, the requirements given from the competition, and similar projects that competed in previous SAE Aero Design competitions. Throughout this report the designs selected for each subsystem are explained and supported through engineering calculations and simulations. The construction, testing, modifications, and testing are then discussed, including the results of the competition.

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1 Introduction

The SAE Aero Design Competition is an event held every year, since 1986, where it was originally called the “Radio Controlled Cargo Aircraft Design Competition.” This name still fits the competition to this day. There being three classes of aircraft design, with the most participation being in the regular class. The other two classes are the micro and advanced class. The regular class still consists of designing a remotely controlled aircraft that maximizes payload capacity, the cargo, while performing under a 750-watt power constraint [10]. The reason for participating in this competition is to overcome real-life engineering challenges, such as designing a system to a series of constraints. This competition provides exposure to scenarios and situations presented in an engineer’s work environment.

The team competed in the regular class of the 2024 SAE Aero Design West Competition. The objective and the deliverables for the regular class are detailed within this section of the report. A review of the entire report is also discussed here. The final completed aircraft at the competition is shown in Figure 1.

Figure 1. Full SolidWorks Design of the Aircraft

1.1 Objective Statement

The objective of this project is to design, construct, and test a remote-controlled, all electric, fixed-wing aircraft to compete in the regular class of the 2024 SAE Aero Design competition.

1.2 Deliverables

The deliverables for this project are:

- An operable remote-control, fixed-wing, aircraft compliant with the 2024 SAE Aero Design Competition rules
- Automated models/simulations used for the design of the aircraft.
- Senior Design/SAE Technical Presentation
- Senior Design/SAE Technical Report
- Senior Design Poster

In Section 2 of the report details the background of the competition and the motivation for the project. Similar projects to this one are also reviewed within Section 2. Section 3 details the lessons learned throughout the design process of this project. Section 4 explains the conceptual designs of the project. Section 5 explains the chosen design for each subsystem of the aircraft. Section 6 contains the steps within the manufacturing process. Section 7 describes the modifications made to each of the subsystems throughout the project. Section 9 discusses the results from the competition and Section 10 gives a conclusion to the report. After Section 10, the references and appendix will be listed.

2 Background

2.1 Motivation

The motivation of this project is to compete in the 2024 SAE Aero Design Competition in Van Nuys, California. Participation in the competition consists of designing a remote-controlled airplane within one of the three design classes. Within this project, the aircraft will be part of the regular class. The first team ever from the University of Southern Indiana competed within the regular class of the competition the previous year, in Spring 2023. With this team being the first from their university, they had little previous experience, resulting in many issues within their design. The project this semester will be redesigning an aircraft to fix these issues and to improve on the previous year. The regular class consists of designing, manufacturing, and competing with an all-electric, fixed wing aircraft under a series of constraints. These constraints are listed within the requirements of the competition, in Appendix C. The regular class pushes participants to understand engineering fundamentals in maximizing payload weight under constrained takeoff and a 750-watt power limit [10]. Maximizing payload weight means carrying the greatest amount of weight possible. Designing with these restraints mimics the real world, in finding efficient ways to design aircraft.

This competition aims to provide students with opportunities to gain real world experience in written, oral, and design performance. The competition develops these experiences by requiring the team to present technical reports and presentations based on their design. This competition provides real life engineering challenges that present situations similar to ones in an engineer's work environment [10]. By gaining this experience the team members will be more fully prepared to enter the workforce as an engineer.

2.2 Similar Projects

The competition started in 1986, leading to many years' worth of designs made for this competition. The first design evaluated within this report is one from the 2023 University of Southern Indiana (USI) team. The 2023 USI team took a unique approach to designing an aircraft for this competition. They used different types of foam boards and light wood dowels for almost the entire aircraft structure. This led to their design being only 13 pounds, with the max weight for the competition being 55 pounds [1]. Their design was lighter than most competitors' planes at the competition, but with their material selection solely focused on weight, they lost the structural integrity of the aircraft. The 2023 USI was still able to compete and make it through technical inspections, placing 24th out of 64 teams [1]. The plane designed by this team is shown in Figure 3, taken on the day of the competition.

Figure 2. Plane used from a previous semester [1].

Another design evaluated was from Northern Arizona University (NAU) in 2019, where a team designed an RC plane in comparison to the Cessna 172. This team used a laser cutter to make most of their structural components out of wood, with a metal beam running through the fuselage. This design was able to carry 12.48 pounds in payload weight, which increased their score during the competition. The scoring for the competition is based on the technical report, presentation, and flight performance. The flight performance is scored on the amount of payload weight carried in a successful flight. By carrying more weight, the 2019 NAU team scored higher in the competition. Their overall design worked well for the competition, placing them 5th out of 37 teams [2]. One recommendation they gave to future teams was to focus on designing the landing gear; this was one of their points of failure. The landing gear failed during their first landing; the landing gear was made from aluminum, which was later reinforced with steel. Figure 4 shows their final design used for the competition.

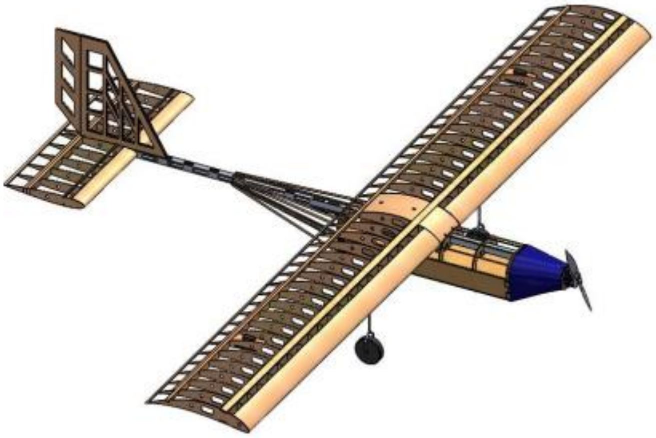


Figure 3. Final Design the Northern Arizona University in 2019 [2].

A third design analyzed was from Worcester Polytechnic Institute (WPI) in the 2018 SAE Aero Design Competition. The 2018 WPI team's design detailed a high structural durability, but also a high weight. This plane was able to take flight but stalled after takeoff, due to being overweight. The plane survived the crash with minimal damage, proving the structural durability [3]. Due to the plane crashing, the team was unable to fully participate in the competition. Although the 2018 WPI team could not fully participate in the competition, they provided good points on structural durability and in creating a manufacturing plan.

The final design evaluated was from a team located at Florida International University (FIU) in 2014. This team looked to participate in SAE Brazil Aero design, where the rules were different from the one for this competition. This competition pushed teams to power their aircraft through internal combustion [6]. Although this competition was slightly different, the 2014 FIU team used several efficient designs for different aircraft components. They also used a laser cutter to make the structural airfoils for the wings. The landing gear designed within this project increased structural durability during landing. The 2014 FIU team used a single metal plate bent at two different angles for the rear landing gear, to take most of the load off the front landing gear. They even used a braking system to allow the plane to land in shorter distances [6]. The designed aircraft was able to carry a payload weight of around 20 pounds. Even though they were able to successfully design an aircraft in correspondence to the SAE Aero rules, the team was not able to attend the competition due to the competition having the maximum number of teams already registered.

3 Lessons Learned

The 2023 USI team yielded several key takeaways from their project. They constructed a plane that was around 13 pounds; 42 pounds under the weight limit. Although the plane was light weight, it lacked structural integrity. On the day the team left to go to the competition, the plane was assembled to run some tests. Once the plane was assembled, it broke into several pieces just from being picked up. The observation made from evaluating this design was to not trade the structural integrity for lightweight materials; there needs to be a balance of the two.

The 2018 WPI team created a design that had high structural strength. They had the opposite problem of the previous team for the University of Southern Indiana. Their plane had a strong structure but was overweight. This problem led to the 2018 WPI team not being able to compete in competition, due to the plane crashing after takeoff. This brings the point back up of balancing the structural integrity and weight of the aircraft.

The 2019 NAU team also had several important design considerations. They used a laser cutter to cut the shape of the airfoil ribs for the wings out of balsa wood. This design allowed for easy manufacturability, as well as a precise airfoil shape. They also used a single metal bar along the fuselage to provide structural integrity to the plane. However, the failing point for this team was the landing gear. They used two vertical aluminum bars as their landing gear structure. Even though they used metal, it still deformed under the stresses of landing. They later switched from aluminum to steel. This increased the weight, but it also increased the durability of the landing gear.

The main lesson learned from the 2014 FIU team is the need to develop a strong landing gear. They used a bent aluminum plate with two wheels for the rear landing gear. Using a bent aluminum plate for the rear landing gear allowed this team to land multiple times without breaking. This could lead to more flights and a higher overall score during the competition. This design of the landing gear proved to be sufficient to hold their plane weight, as well as 20 pounds in payload weight. This design is also simple to manufacture. Figure 5 shows the landing gear designed and built by the 2014 FIU team.

Figure 4. Landing gear used by the Florida International University in 2014 [6].

4 Conceptual Designs

Design 1

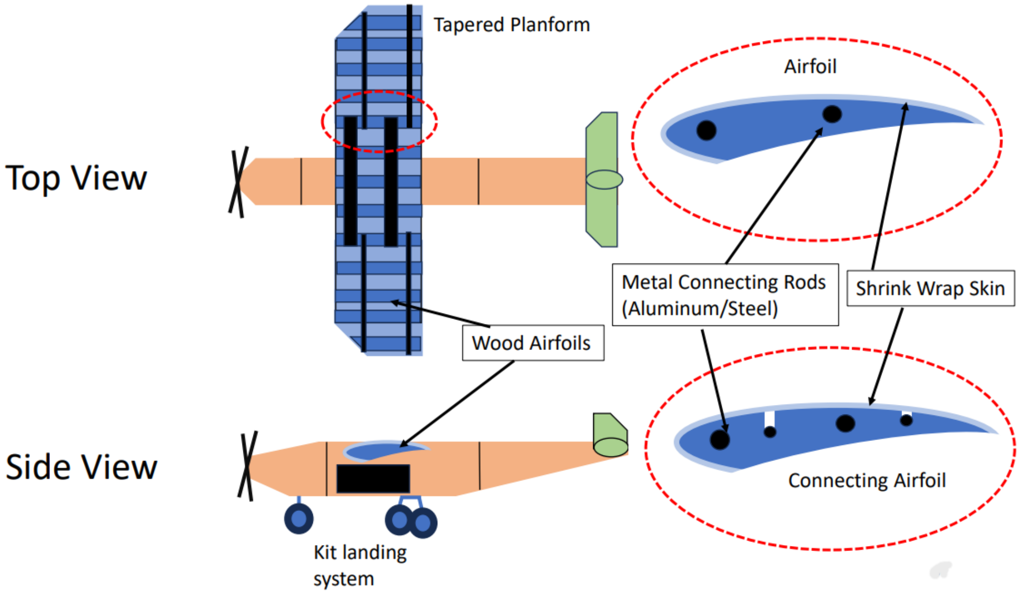


Figure 5. Concept Design 1

The first conceptual design for the 2024 USI is shown in Figure 5. It has a tapered wing and tail planform, and the wings connect on the top of the fuselage. The tapered wing reduces the drag slightly. The landing gear would just be a kit landing gear that would be bought online. Two Aluminum rods would go through the airfoils to connect the separate airfoil sections. To make the design modular, the connecting airfoil has slots for the outside rods to slide into and connect. The whole design would be covered in shrink-wrap.

Pros:

- The wings have multiple support rods to secure the wing connections.
- The tapered wings produce low drag.

Cons:

- The modular connections are less secure than other possible connections.
- There is little control over the reliability of the landing gear because manufacturing is outsourced.

Design 2

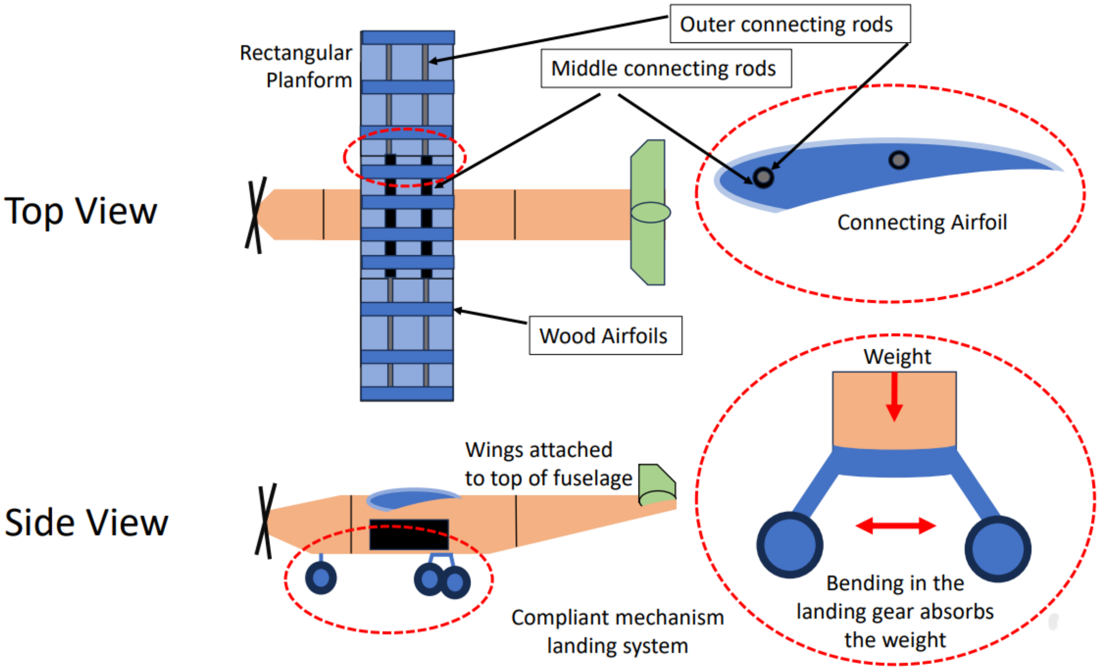


Figure 6. Concept Design 2

The second design analyzed is shown in Figure 6. has a rectangular planform wing with the wings attached to the top of the fuselage. This allows for an easy manufacturable design, but it adds more drag than the other planform designs. The wing module that is attached to the fuselage would have two hollow rods connecting the airfoils, and outside wing modules would have slightly smaller rods that slide into the inside rods to connect. The landing gear is a flexible mechanism that is designed to deflect slightly to cushion impact, but it is still strong enough to support the weight of the plane during landing and takeoff. This is done by choosing a material that would provide the appropriate stiffness to support the maximum weight of the plane.

Pros:

- The wings have a simple manufacturing process.
- Landing gear absorbs large forces due to landing.
- Modular connections are simple with lower tolerances than other designs.

Cons:

- Wing planform produces more drag than other wing planforms.
- There is more material than other designs and therefore more weight than other designs.

Design 3

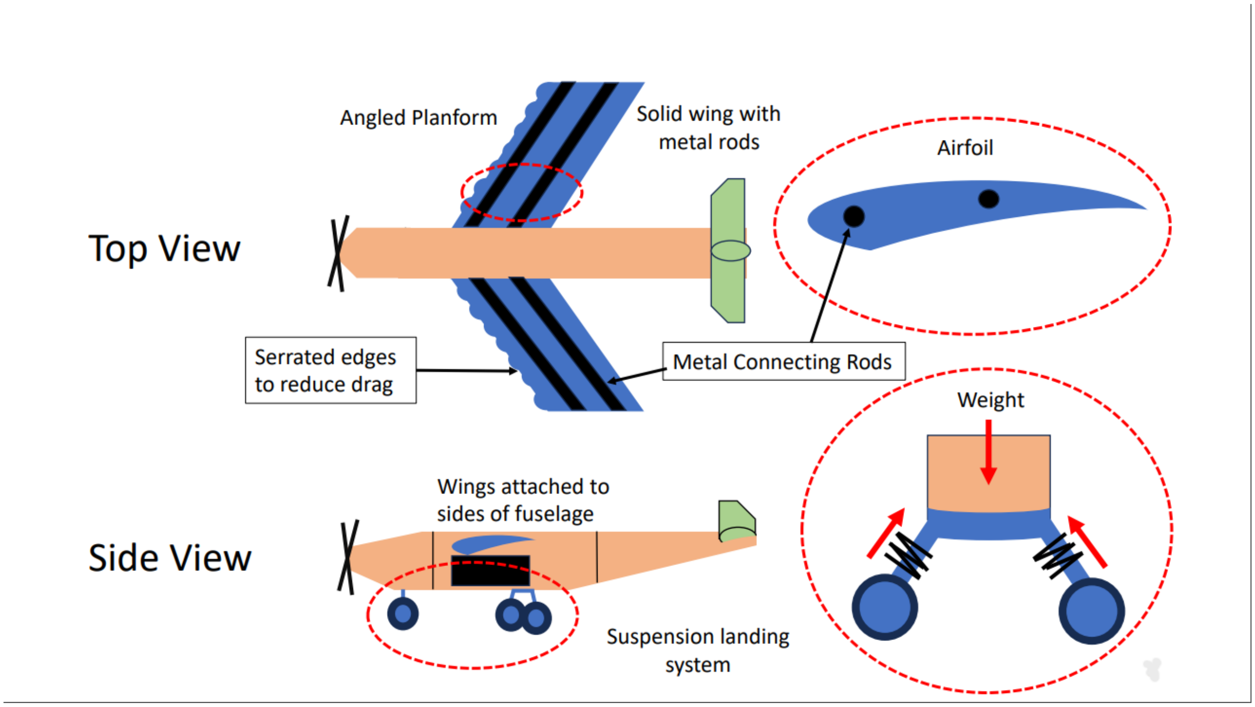


Figure 7. Concept Design 3

The third design is shown in Figure 7. It has an angled wing planform that attaches to the sides of the fuselage. This wing design has the lowest drag, but it is much more complicated to manufacture than other designs. The wings have a patterned leading edge that would further reduce the drag of the wings, but the increased complexity of the design also increases the difficulty of the manufacturing. The wing modules have two rods running through the airfoils that align with each other, and the wings are connected on the surface of the wing. The landing gear system has a suspension to soften impact put on the design.

Pros:

- The wings produce the least amount of drag.
- The suspension system can be designed to absorb high shock loads.

Cons:

- The design is hard to manufacture because of the increased complexity.
- The landing gear is a complicated design with more connecting parts.

5 Final Aircraft Design

The design of the aircraft was broken down into several different subsystems: the wings, fuselage, tail, and landing gear. These subsystems are key to aircraft design. The wings produce the lift force needed to fly. The fuselage connects all the subsystem and holds the electrical components, such as the propeller motor. The tail adds stability during flight, and it holds two out of the three control surfaces needed for directional flight. The landing gear supports the aircraft during takeoff and landing. This section of the report details the design for each of these subsystems. Figure 9 shows the full SolidWorks model of the aircraft.

Figure 8. Full SolidWorks Design of the Aircraft

5.1 Wing Design

The wing of an aircraft is the structure that produces lift and drag. The wing is the subsystem that produces the force needed for flight. The design requirements given from the competition are listed below. The wings of the aircraft shall…

- Break down into modular sections 48 inches or less.
- Measure a wingspan between 120 and 180 inches.
- Create an amount of lift greater than the total weight.

Figure 10 shows the full design of the wings created in SolidWorks. A rectangular planform was chosen for easy manufacturability. The total wingspan measures 168 inches or 14 feet; this meets the requirement of the wingspan being between 120 and 180 inches. This wingspan was chosen to maximize the amount of lift the wings can produce. The larger the wingspan the more lift the wings can produce. The maximum wingspan was not chosen to leave room to work with in the manufacturing process. The materials for the wings include balsa wood, bass wood, and an aluminum tube. The aluminum tube runs through the full wingspan at approximately a quarter of the chord length, this around 6 inches from the leading edge. Balsa wood airfoil ribs are spaced throughout the length of the wings to hold the airfoil shape; these are cut with a CNC machine. Bass wood dowels of varying diameters will run through different sections to increase the structural integrity. The entire structure is then covered in a shrink wrap to hold the shape of the wing.

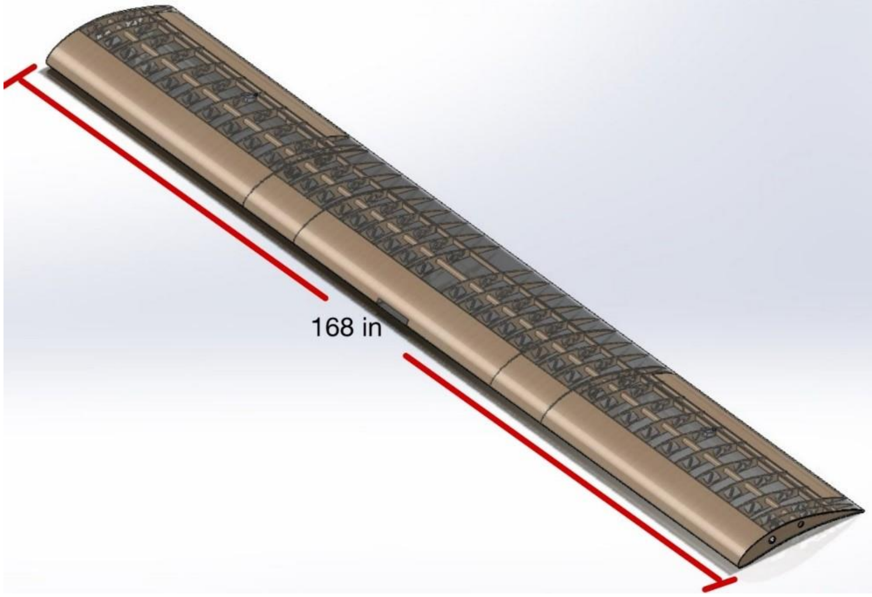
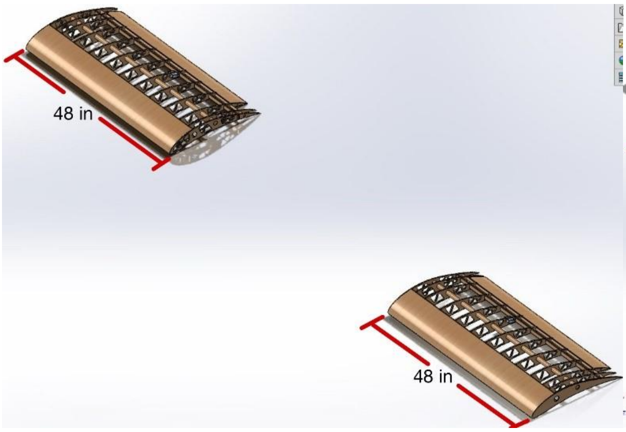


Figure 9. Wing Design created in SolidWorks.

Each modular section, the outermost section of the wings, the middle sections, and the section that connects to the fuselage, are shown in Figures 11, 12, and 13 respectively.



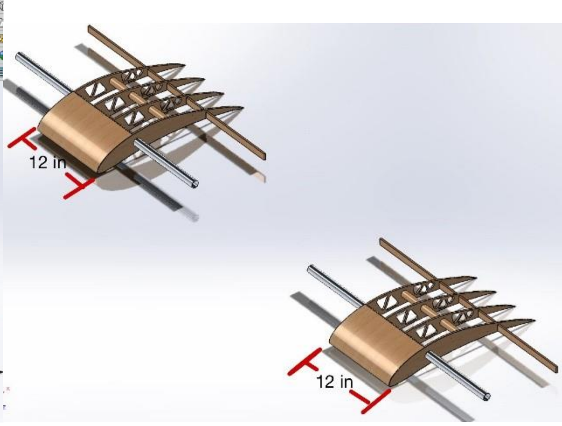


Figure 10. (left). The outermost section of the wings containing the ailerons.

Figure 11. (right). Middle sections of the wings containing modular connections.

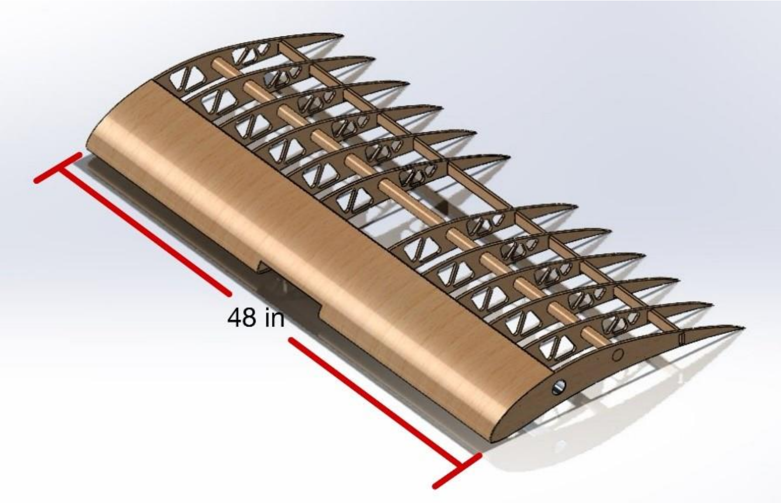


Figure 12. Wing section that connects to fuselage.

The outermost sections of the wing are 48 inches, this meets both requirements that they must be at least 42 inches, and 48 inches or less. The middle sections are both 12 inches, with a hollow aluminum rod that runs through it at a full length of 36 inches. The section that connects to the fuselage is 48 inches. This shows that the wings are fully modular with sections of 48 inches or less.

5.2 Calculating Lift

Lift was calculated to determine if the wings met the requirement of creating enough lift to for the aircraft to fly. For the aircraft to be able to fly, the wings need to create a lift force greater than the total weight. The aircraft weight was estimated from the completed model in SolidWorks. The total aircraft weight was estimated to be close to 15 pounds, with the weight of the wings being 8.65 pounds. For the plane to be able to achieve lift-off, the lift needs to be greater than 15 pounds.

The equations needed for calculating lift are shown in Appendix H. Calculating lift is based on several factors. These factors include: the coefficient of lift, angle of attack, chord length, wingspan, and velocity. The coefficient of lift is related to the airfoil chosen. The airfoil is the cross-sectional shape of the wings. This shape is shown in Figure 14, along with the airfoil nomenclature. The chord line, used to measure the chord length is also shown in Figure 14. The airfoil used within this design is the Eppler 423. This airfoil is shown in Figure 15.

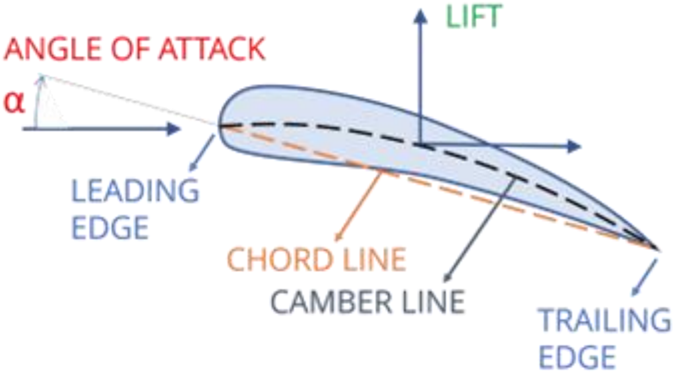


Figure 13. Airfoil shape and nomenclature [12].

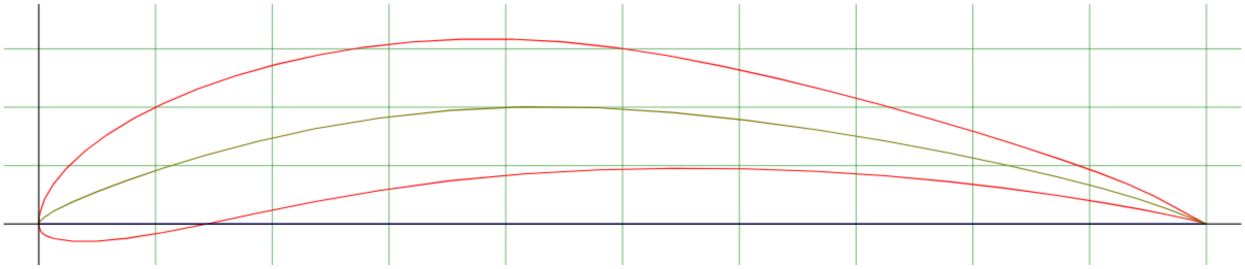


Figure 14. Eppler 423 airfoil shape [13].

Two airfoils were analyzed: the NACA 2412 and the Eppler 423. The NACA 2412 is shown in Appendix H. This airfoil was not used in the final design due to the Eppler 423 yielding higher coefficients of lift, leading to higher amounts of lift. To find the coefficient of lift, the graphs for coefficient of lift versus angle of attack were evaluated. This graph is shown in Appendix H. The angle of attack chosen for the calculations was around 8 degrees. This angle was chosen to produce the maximum coefficient of lift, which would produce results closer to the maximum lift. Using this angle of attack and the graph the coefficient of lift is found to be 1.75, which is unitless. This is shown in Appendix J by the lines on the graph. The wingspan for the calculation is just the total length of the wings, this length is 168 inches for the aircraft. The chord length is 24 inches. This chord length was chosen to get a aspect ratio, a ratio of the wingspan to chord length, of around 7. This value is typical for RC aircraft, an aspect ratio between 5 to 7 helps with the stability. The lift calculation was then done using these values for different values for the velocity. Table 1 shows the calculated forces for lift and drag at different speeds. Both the lift and drag are shown in pounds of force. The velocity is given in meters per second.

Table 1. Lift and Drag calculations in newtons and pounds for the wings.

Velocity (ft/s/s)	Lift (lbs.)	Drag (lbs.)
13.1	10.03	0.04
16.4	15.67	0.06
19.7	22.57	0.09
23.0	30.71	0.12
26.2	40.11	0.16
29.5	50.77	0.20

The table shows that the wings create around the same force as the weight at a velocity close to 16.4 feet per second. These calculations were done using a MATLAB code (Appendix I) developed by the team, these calculations were also checked by hand. These calculations illustrate that the wings can produce the amount of lift needed for flight. These calculations also show that the drag of the wings is small, with the drag sitting at 0.06 pounds at a velocity of 16.4 feet per second.

5.3 Wing Simulation

SolidWorks simulations show the amount of lift and drag at different velocities. Table 2 includes the values from these simulations. To find the maximum velocity of the aircraft produced by the motor, the thrust was subtracted from the drag. This shows at what speed the aircraft can no longer accelerate, giving the maximum velocity. This value would typically be used to calculate the maximum weight of the aircraft. Table 2 shows that the maximum weight allowed during the competition, 55 pounds, was reached before the maximum velocity. Using this data, the aircraft can potentially carry a payload weight of close to 40 pounds. This prediction is decreased to 30 pounds to keep environmental/outside factors in consideration.

Table 2. Model for maximum velocity.

Velocity (ft/s)	Lift (lbs)	Drag (lbs)	Thrust (lbs)	Thrust-Drag (lbs)
0	0	0	18.76	18.76
7.33	1.17	0.01	16.90	16.89
14.67	4.82	0.05	15.04	14.99
22.01	10.8	0.10	13.18	13.08
29.34	22.6	0.17	11.32	11.15
36.68	36.2	0.26	9.47	9.21
44.01	56.4	0.38	7.61	7.23

Stress simulation with SolidWorks was conducted to determine the shape of the aluminum tube that runs through the length of the wing. Simulation was also conducted to test if the wing structure could withstand the forces during flight. Simulation was first conducted on a hollow aluminum square tube that ran the length of the wingspan. This square tube was chosen due to the variety of sizes available locally. This simulation yielded a deflection of 2.81 inches at the end of the wings, compared to the total wingspan of 168 inches. The load for this simulation was set to the maximum weight of the competition – 55 pounds. A second simulation was done using an aluminum tube with a diameter of 1.25 inches and a thickness of 0.049 inches. The same load was applied in this simulation, producing a deflection of around 4.4 inches. This aluminum tube decreased the weight of the wings by close to 5 pounds. If the aluminum beam was used the lift would need to be even higher to produce flight and decrease the amount of payload weight that the plane could carry. These simulations showed that the aluminum tube was the best option for the design, decreasing the wing weight by 5 pounds and only increasing the deflection by around 2 inches. The simulation is shown in Figure 16.

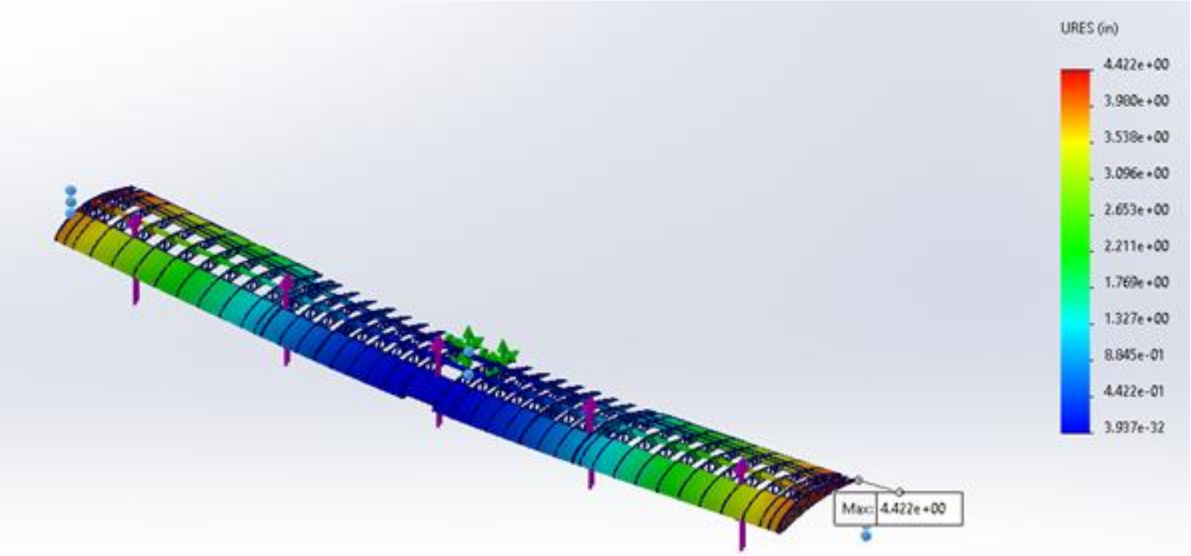


Figure 15. Stress simulation with the circular aluminum rod at 55 pounds of force.

5.2 Fuselage Design

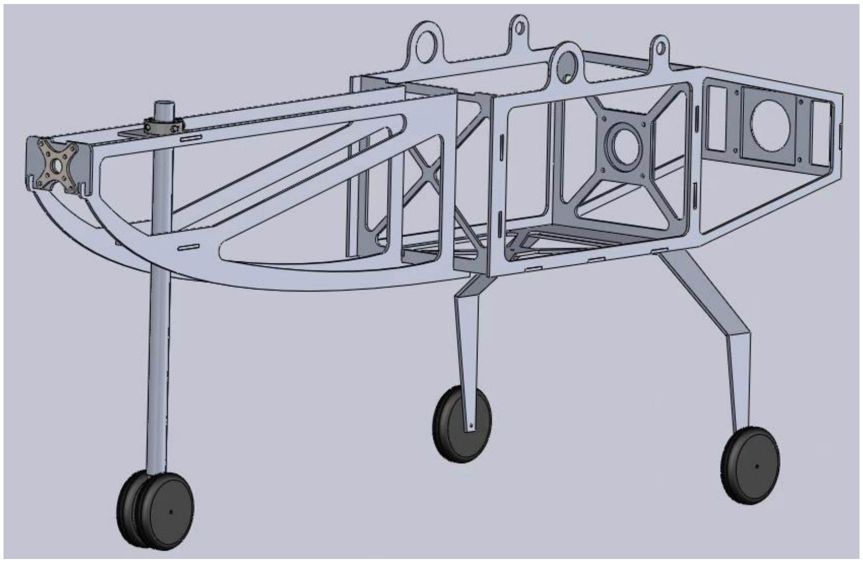


Figure 16. Final Fuselage Design

Figure 16 shows the fuselage, which is the main body of the aircraft, and it is where the wing, tail, landing gear, cargo bay, and motor connect. Additionally, this is the place where the electrical components are placed as well as the cargo plates that are required for the competition. This fuselage is 42.7 inches long, 7 inches wide, and 15.5 inches height. This fuselage is made of different 1/8 aluminum parts that, when connected, give the fuselage its shape. Each individual piece has tabs and slots that help with alignment and welding of the fuselage.

- <u>Wing Connection:</u>

The wing is attached to the fuselage using the two tabs located on the top of the frame where the aluminum tube and the wooden rod pass through the frame from side to side. The aluminum tub passes through the bigger tab, and the wooden rod passes through the smaller tab. The aluminum tube is secured in place by welding it to the frame, while glue is used to secure the wooden rod.

- <u>Tail Connection:</u>

The tail arm has two aluminum plates that are welded to it, which facilitates the attachment to the aluminum frame, and each plate is attached to the frame using four bolts. The inner most plate is connected to the end of the tail arm, and the function of the middle hole is to allow the cables for the servo motors pass inside the arm. The outside plate is located 8.5 inches from the inner plate, and it brings additional support to the tail arm. Since the tail arm is passing through this plate, the diameter of the middle hole is the outside diameter of the tail arm. This plate helps distribute the moment the moment from the tail arm between the two points, and it prevents the tail arm from causing excessive stress on one section of the fuselage frame.

- <u>Landing Gear Connection:</u>

The landing gear of the aircraft consists of 2 different sections: the front landing gear and the rear landing gear. The front landing gear is a 0.75 diameter aluminum tube located on the nose of the aircraft, and it is attached to the frame using two shaft collars. One of the collars is located at the top of plate a, and the other is located at the top of plate b as shown in Figure 17. This placement of the shaft collars prevents the tube from sliding up and down while allowing it to rotate, so the aircraft can be steerable as required by the competition. Moreover, the rear landing gear consists of a single aluminum piece that is bent to the shape shown on Figure 17, and it is attached to the bottom of the aircraft using three bolts. The design of this landing gear is wide at the top where it attaches to the frame and narrow at the bottom where it attaches to the landing gear wheels. This design allows it to be flexible and lowers the weight of the part while still being able to support the weight of the aircraft according to simulations.

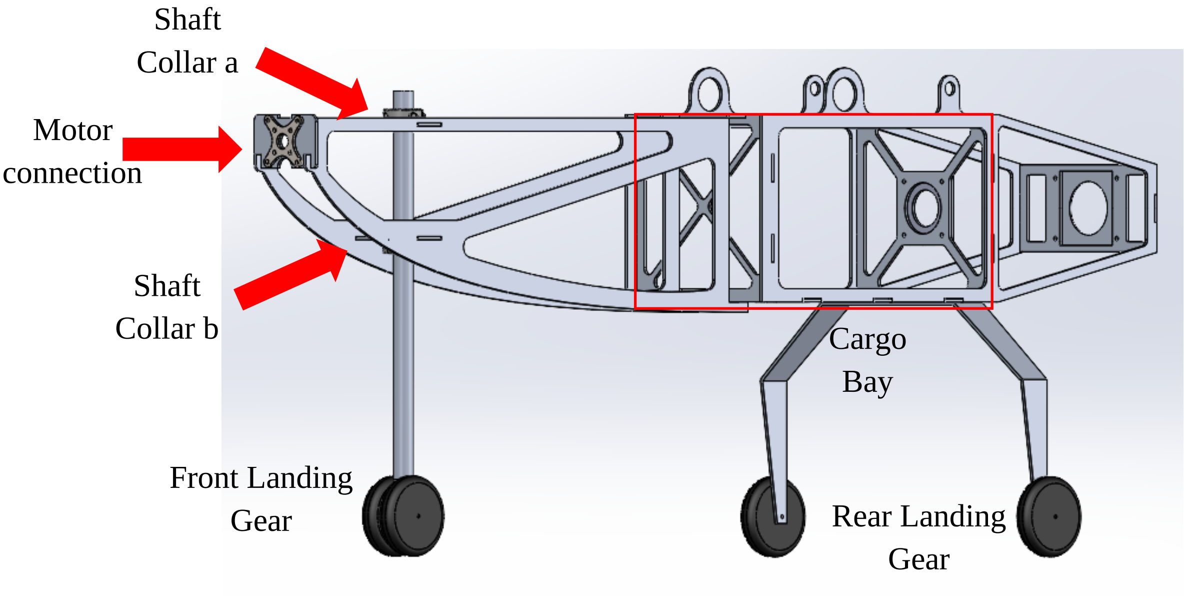


Figure 17. Landing gear and Cargo Bay

- Cargo Bay:

The cargo bay of the aircraft is a requirement of the competition since the plane needs to carry weight in order to score points in the competition. The cargo bay is located in the center of the fuselage frame where the center of gravity is located since weight addition in this place will not affect the wight balance of the aircraft. The payload or cargo plates are shown in Figure18, and they are attached to the frame using a bolt and nut that secures them in place during flight. This attachment choice was made because the competition requires the team members to unload the payload plates after a successful flight in one minute or less.

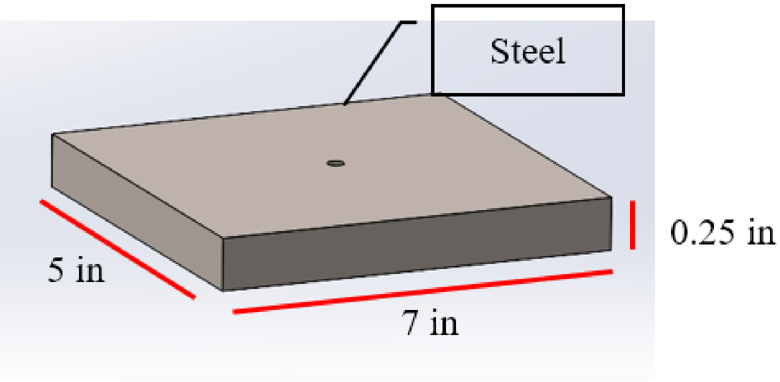


Figure 18. Cargo Plate design

- Motor Connection:

The main motor of the aircraft is attached to a plate on the front of the nose of the aircraft shown in Figure 17. This plate has 4 holes that align with four holes on the bracket provided by the manufacturer, which is where the motor is attached to. At the bottom of the plate is a dent which allows the three cables from the motors connect to the Electronic Speed Controller (ESC) located in the interior of the nose. The hole in the middle of the plate and motor bracket is where the motor shaft is located.

5.2.1. Simulation

After the design was completed, a Finite Element Analysis (FEA) was performed in SolidWorks to ensure that the final fuselage design is going to maintain its integrity when exposed to different forces. Figure 19 shows a force of 50 lbs. evenly distributed across the front and rear landing gear simulating the weight of the aircraft. This force was selected since it is the maximum weight of the aircraft allowed in the competition.

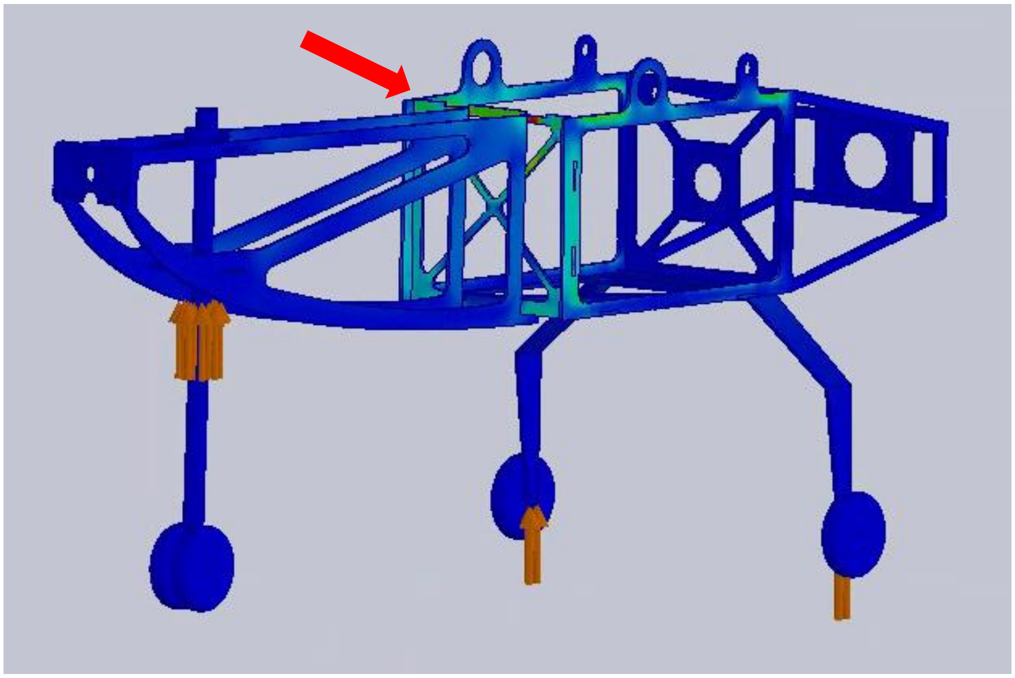


Figure 19. FEA simulation of fuselage in SolidWorks

The simulation shows how the force is distributed along the frame. The peak stress point in this simulation, denoted by the orange/red color, is at the top of the fuselage frame, and it is the weakest point of the fuselage. This happens due to the moment produced by the nose on this part, and it can be addressed in the manufacturing section by reinforcing this area using aluminum.

5.3 Tail

The main function of the tail is to provide stability and control to the aircraft. Based on the main function, the requirements for the tail design are that the designd shall:

- Be 45-65% of the fuselage length.
- Have elevators with a range of motion of 60 degrees.
- The tail shall weigh less than 3 lb.
- The Elevators and Rudder shall be controlled with servos.

The final design was chosen to be a 14-foot rectangular wing planform with a 7-foot body. The wings are made of 12 individual airfoils that are connected by basswood beams that run throughout the length of the wing planform. The body is composed of the fuselage and the tail. The tail is the subsystem of this project that will be discussed in detail in this report.

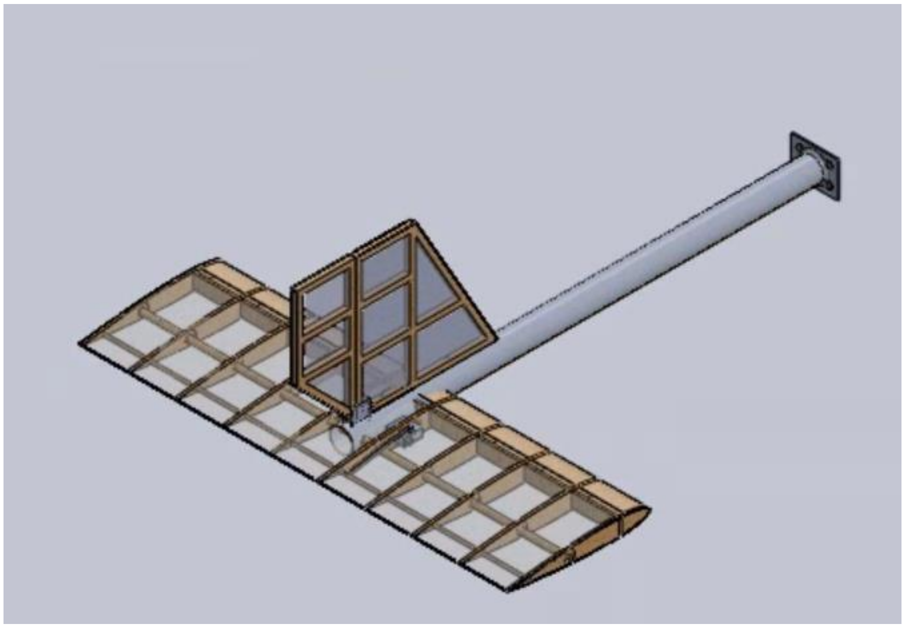


Figure 20. Final Preliminary Tail Design

The final tail design is shown in Figure 20. The empennage can be broken down into 3 subsystems: the horizontal stabilizer, the vertical stabilizer, and the tail arm. The general dimensions for the empennage design were originally based on the guidelines for tail sizing that is discussed by Ning [7]. The tail arm is typically 45% to 65% of the fuselage length, the aspect ratio is 3 to 5 for the horizontal tail and 1.3 to 2 for the vertical tail, and the horizontal tail area is 20 to 25% of the wing area. The tail volume coefficient is used for determining the stability of the horizontal and vertical stabilizer. These coefficients are used for analyzing the effectiveness of the stabilizer dimensions. The horizontal tail volume should be greater than 0.2. The vertical tail volume should be greater than 0.02. These values provide the minimum stability required to fly. These equations are shown below in Equation (1) and Equation (2).

$$V_v = \frac{S_v L_v}{S_w b} = 0.0248 \tag{1}$$

$$V_h = \frac{S_h L_h}{S_w c} = 0.214 \tag{2}$$

Where S_v is the vertical tail area, L_v is the distance from the vertical tail's aerodynamic center to the aircraft center of gravity, S_w is the wing area, b is the wingspan, S_h is horizontal tail area, L_h is the distance from the horizontal tail's aerodynamic center to the aircraft center of gravity, and c is the chord length.

Horizontal stabilizers

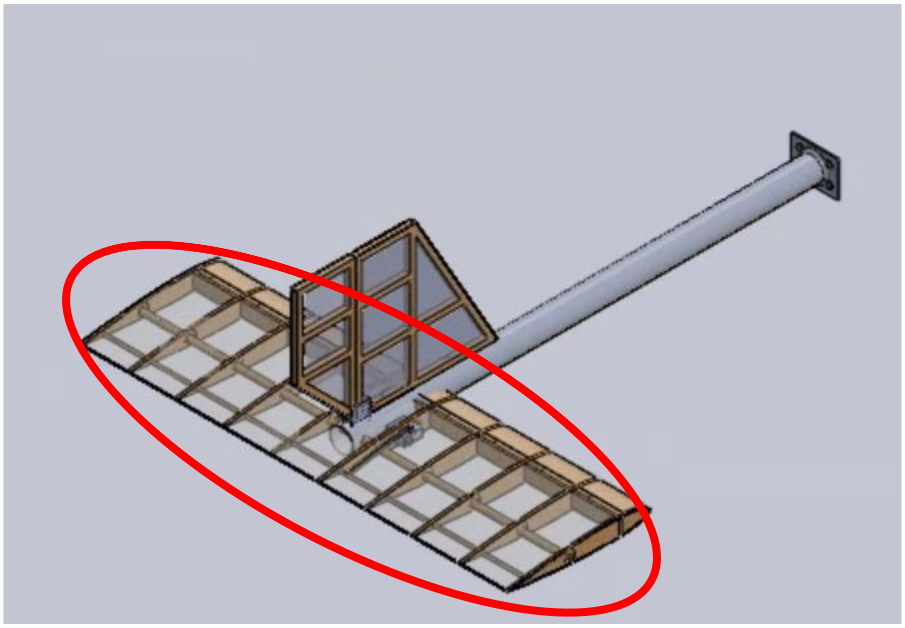


Figure 21. Horizontal stabilizer

The horizontal stabilizer is shown in Figure 21. The horizontal stabilizer airfoil must be symmetrical because, in the neutral position, it should only provide stability and not motion. The NACA 0012 airfoil shape was chosen for the airfoil, because of the lower drag coefficients and higher lift to drag ratio compared to other airfoil shapes. This airfoil is shown in Figure 22. The airfoil was chosen to be 12 inches long including the 5-inch elevators. The elevator is a part of the stabilizer and is the control surface that rotates the plane up or down. The horizontal stabilizer was chosen to be 3 ft long. This gives a horizontal tail volume coefficient of 0.214. This number is above the 0.2 requirement.

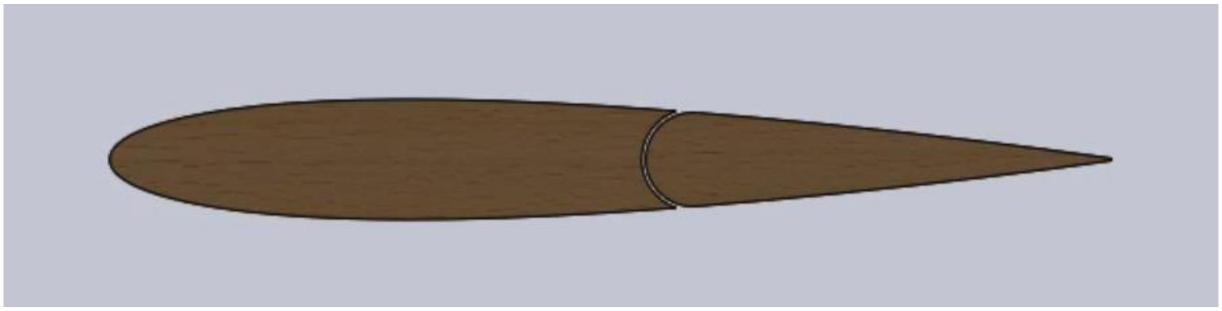


Figure 22. Horizontal Stabilizer Airfoil

To reduce the weight of the plane and to allow for easier manufacturing, the horizontal stabilizer is designed using individual airfoils connected with support rods instead of a solid stabilizer. The airfoils are then covered in shrink-wrap to reduce drag. The airfoils are made from balsa wood and cut using the laser cutter. The supporting rods are going to be yard sticks and basswood rods. One of the airfoils will have a cutout to allow the elevator servos to connect. This allows the design to meet the requirement that the elevator will be controlled by servos.

Vertical stabilizer

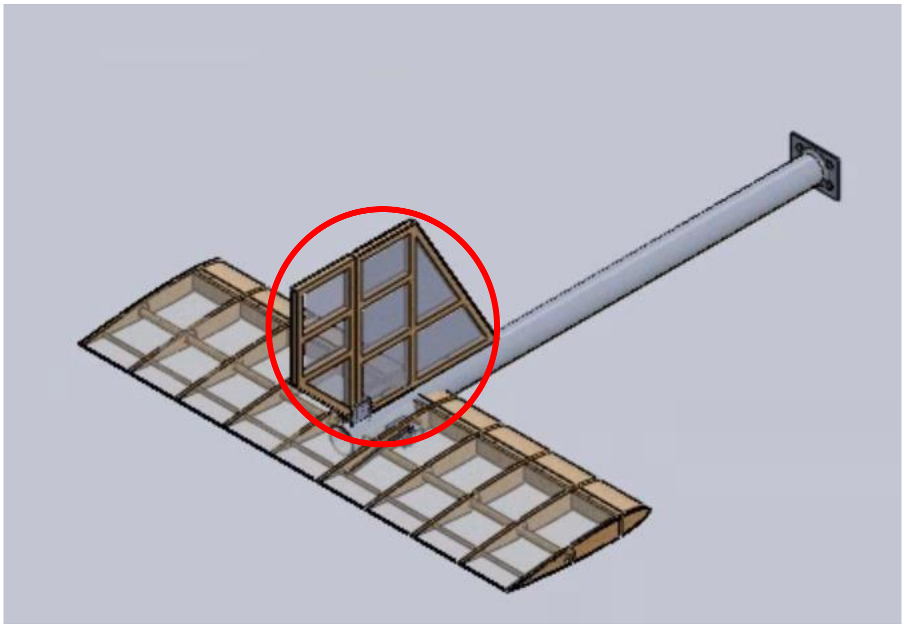


Figure 23. Vertical Stabilizer

The vertical stabilizer is shown in Figure 23. The vertical stabilizer was chosen to be 18 inches tall and 18 inches wide. A 5-inch-long rudder is used. A part of the rudder is cut at an angle to allow the elevators a full 45 degrees of motion to satisfy the requirements. These dimensions are shown in Figure 24. This gives a vertical tail volume coefficient of 0.0248. This number meets the required 0.02. This value will be adequate for this design because the aircraft maneuverability does not have to be high for the simple 180 degree turns during the competition course. The vertical tail stabilizer is made of basswood that is cut by a CNC machine. The vertical stabilizer will then be connected to the tail arm with bolts.

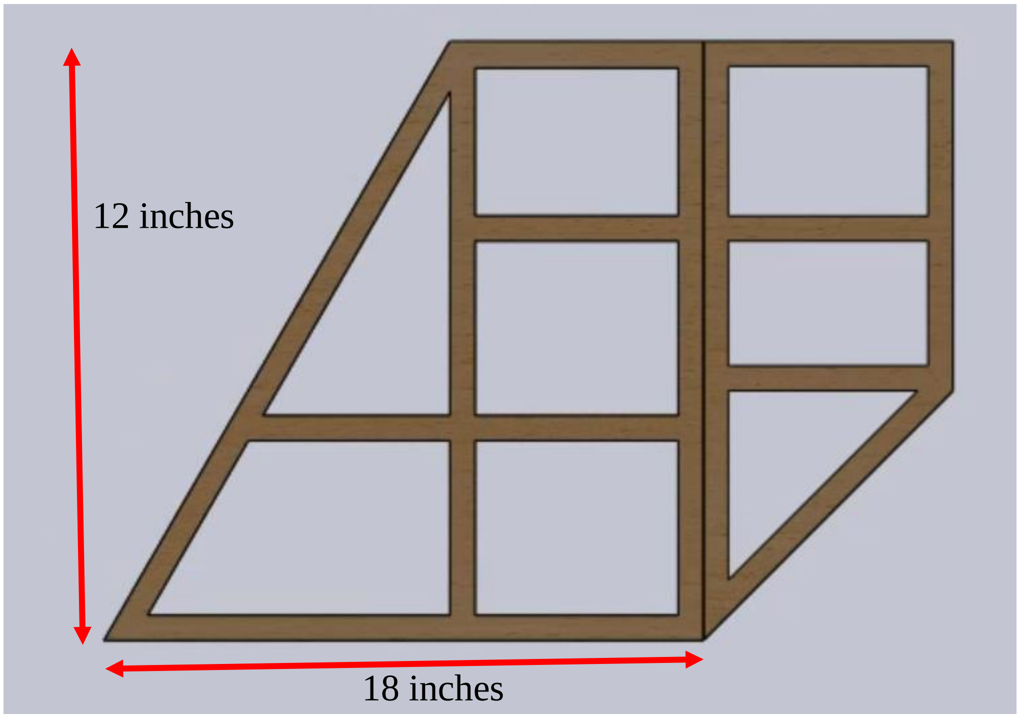


Figure 24. Vertical Stabilizer Side View

Tail arm

The tail arm is shown in Figure 25. The Tail arm is made of a 2-inch diameter aluminum tube. Holes are created to connect the horizontal and vertical stabilizer. This meets the requirement that the tail will be able to attach and detach from the fuselage. On the end of the tail arm that connects to the fuselage, a 1/16-inch-thick plate is welded to the tube. The plate can then be bolted to the fuselage.

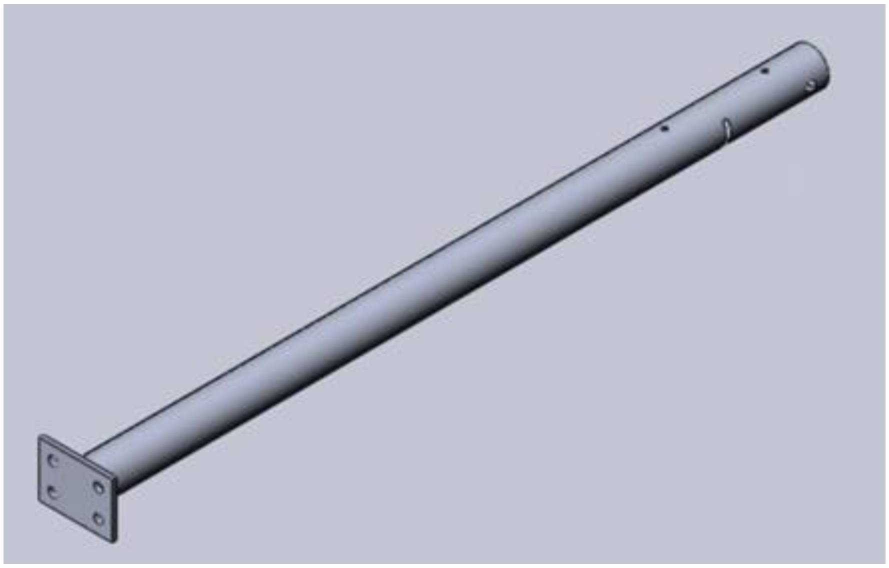


Figure 25. Tail Arm

Preliminary Testing

Once the final tail design was assembled in SolidWorks, an FEA stress simulation was done to ensure the final design could withstand the stresses from flight. A force of 55 lbs. was distributed across the horizontal stabilizer to simulate the forces due to pressure and wind that occur during flight. The result from this simulation is shown in Figure 26.

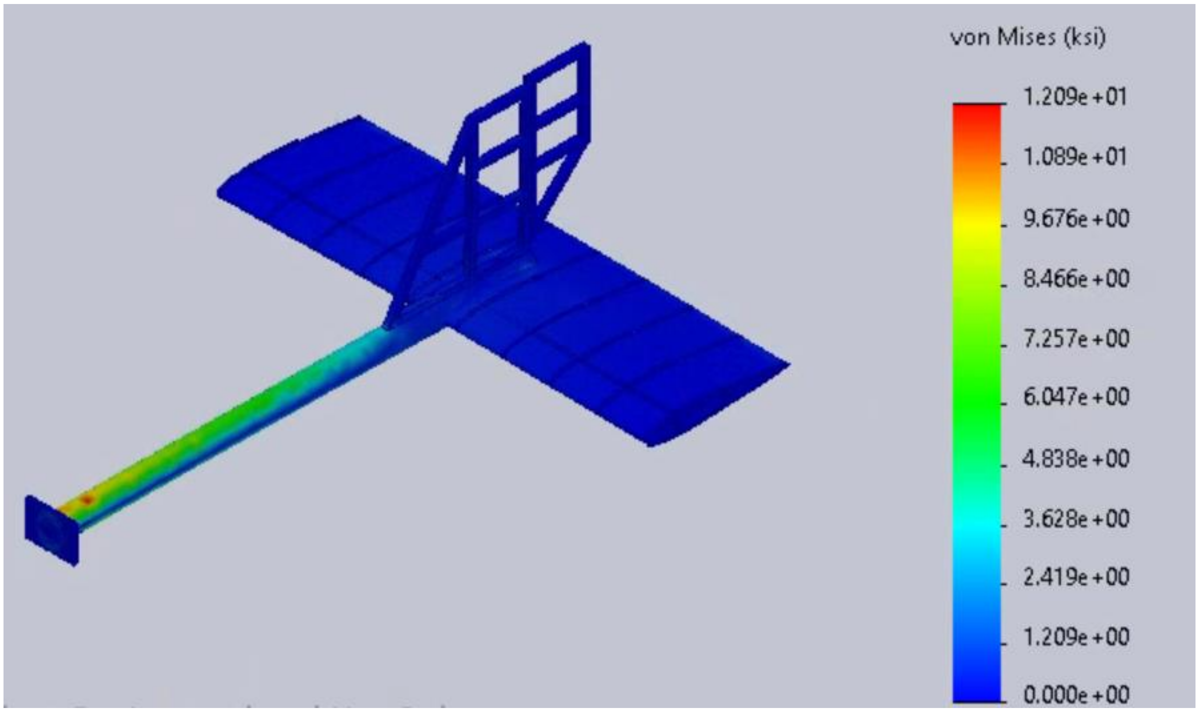


Figure 26. Empennage FEA Simulation in SolidWorks

Balsa wood has a yield strength of 0.145 ksi and aluminum has a yield strength of 35 ksi. The maximum stress on this design is 12.09 ksi. This stress is well within the allowable stress for the aluminum arm. The balsa wood would fail under these stresses, but the wooden parts are not exposed to these higher stresses. The aluminum tail arm is the part that is exposed to the higher stresses as shown in Figure 26. Therefore, the balsa wood can adequately support the stress in the airfoils, and the aluminum can adequately support the stress in the tail arm. The overall weight of the empennage is approximately 3 - 4 lbs.

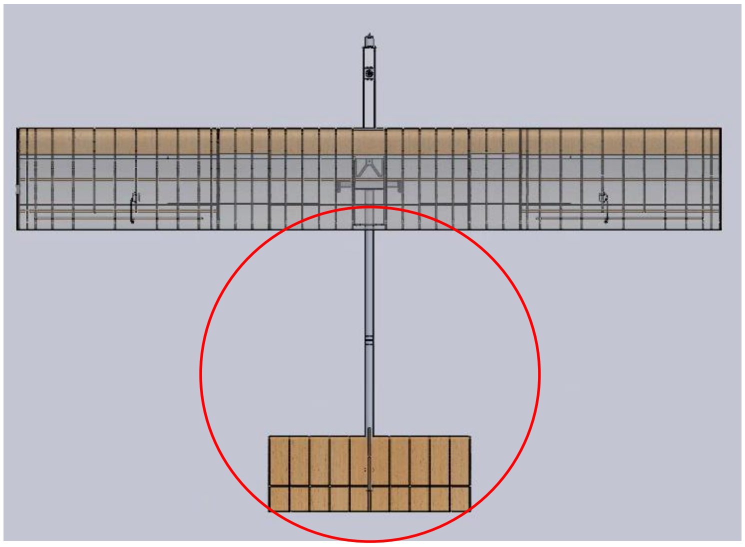


Figure 27. Preliminary Final Design Top View

5.4 Electrical Components

The aircraft needs different electrical components to operate propulsion system, control surfaces, landing gear, and communication. The electronic speed controller, power limiter, receiver and transmitter, and several servo motors were purchased by the 2023 SAE design team and were implemented in the 2024 design.

a) Electrical Motor:

Figure 28. Main motor: Cobra 4130/20

The motor selected for the aircraft is the Cobra 4130/20 brushless motor. This motor has a capacity of 300kV, which means that it provides 300 RPM per volt supplied. The reason for the 300kV is because at low kV, the torque is higher allowing the motor to comfortably move big propellers with aggressive pitch; thus, producing more trust at low speeds. Since this aircraft has large dimensions and weight, a large amount of thrust is necessary, otherwise, the plane is not going to be able to take off.

b) Battery:

Figure 29. Main battery: 22.2V 6S Lipo Battery 4000mAh

The battery used in the aircraft is the 22.2V Liperior 6S Lipo battery with 4000mAh capacity. Since the competition requires the battery to be 6S and 22.2V, the only thing that can be chosen is the capacity, and the team decided to use a 4000mAh battery because of it will allow the team to fly without needing to charge the battery between flights at the competition.

c) Electronic Speed Controller:

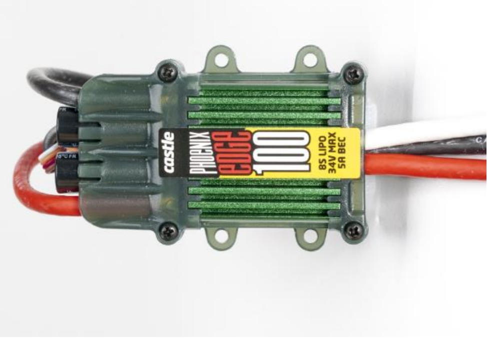


Figure 30. Phoenix Edge 100A Electronic Speed Controller

An electronic speed controller controls the brushless motor movement or speed by activating the appropriate MOSFETs to create the rotating magnetic field so that the motor rotates. ESCs have different amperage ratings, and the rating used in an aircraft is based on the motor maximum current. The Cobra 4130/20 has a maximum current rating of 52 Amps, so the 100A ESC used by the 2023 has almost doubled the rating of the motor, which means that it will work with no issues.

d) Power Limiter:

Figure 31. SAE required power limiter.

The power limiter required by the competition is a 750-Watt device that is purchased from the competition website. The power limiter facilitates equitable competition between teams, and no modifications can be made to this device.

e) <u>Servo Motors:</u>

Figure 32. Servo Motors

Servo motors play a crucial role in controlling various aircraft components, including the landing gear, ailerons, rudder, and elevator. These servo motors were successfully implemented by the 2023 team, so the 2024 team decided to use them in the new design.

f) <u>Receiver and Transmitter:</u>

Figure 33. FLYSKY transmitter and receiver

The receiver and transmitter were purchased together by the previous team. The receiver is located in the aircraft, and it is connected to the motor and the servos. This receiver is connected to a separate battery pack that allows it to operate without the necessity of being connected to the main battery. This secondary battery pack consists of 4 AA batteries connected in series providing 6V to power the receiver and the servo motors. Moreover, the secondary battery pack uses a switch to turn on and off the receiver. Finally, the transmitter, on the other hand, is the controller used to operate the aircraft from the ground.

5.4.1 Electrical Components wiring diagram.

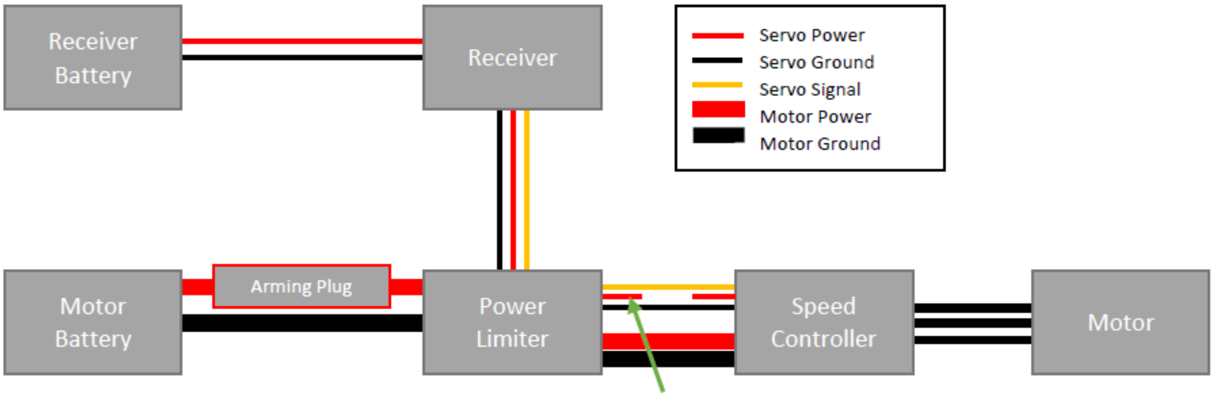


Figure 34. Wiring diagram provided in the competition rules.

The wiring diagram shown in Figure 34 is provided on the rules document provided for the competition. This diagram provides the proper way to wire the electrical component. This diagram also provides where the arming plug is connected. The arming plug is a device that cuts the power from the motor battery to the power limiter if it is not connected. This arming plug is a safety feature required by the competition and it can be seen in Figure 35a, as well as the proper placement in the aircraft, Figure 35b. When the arming plug is disconnected, the battery does not provide power to the motor.

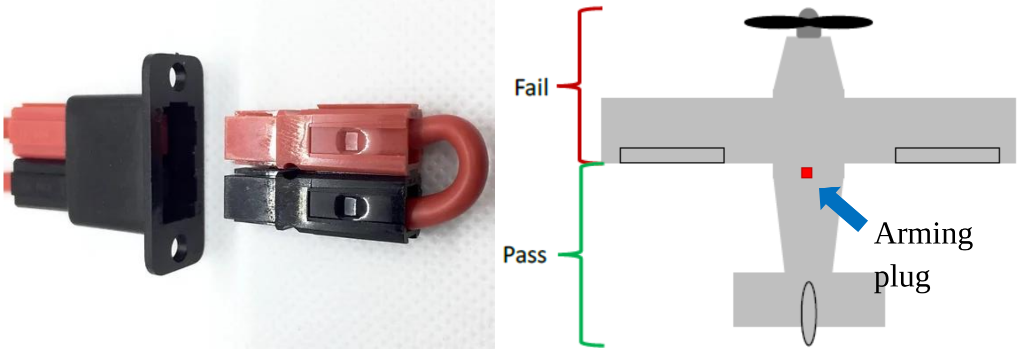


Figure 35. a) [left]arming plug. b) [right]arming plug location

6 Manufacturing

Within this section of the report, the manufacturing processes for each of the subsystems will be explained. The wings were constructed first, then the fuselage, and lastly the tail. The connections between these subsystems will also be explained.

6.1 Wings

The first subsystem that was constructed was the wings. The 46 individual airfoil ribs were cut on a CNC machine out of ¼ inch balsa wood. After being cut out, the airfoil ribs were sorted into the sections of the wings that they belong to and numbered. As seen in Figure 28, not all the airfoils were the same shape, this is due to the different sections of the wing. The outer most section of the wings contain the aileron control surfaces; this caused these airfoil ribs to have the tailing edge cut separately. The airfoils are shown in Figure 36. The airfoil ribs had triangular shapes cut out to reduce the overall weight of the wings, while keeping the structural integrity.

Figure 36. Balsa Wood Airfoils for Wing

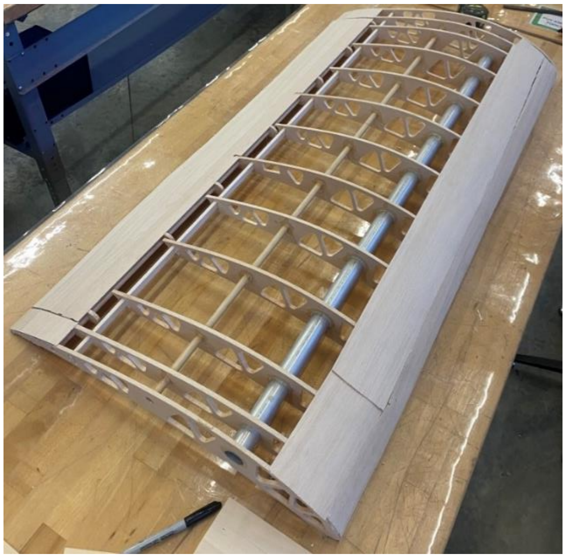


Figure 37.Section of wing made from balsa wood, bass wood, and an aluminum tube

An aluminum tube, bass wood beams, and bass wood rods were inserted into the airfoils to secure them in the correct position and then glued down. A thin sheet of Balsa wood was glued to the leading edge of the airfoil and the ailerons. The results after this step are shown in Figure 37.

The servos and control rods were attached to move the ailerons, and the individual sections were then shrink wrapped. Figure 31 shows an end section of the wing, with the aileron deflected at two different angles. This figure shows the servos mounted to control the aileron.

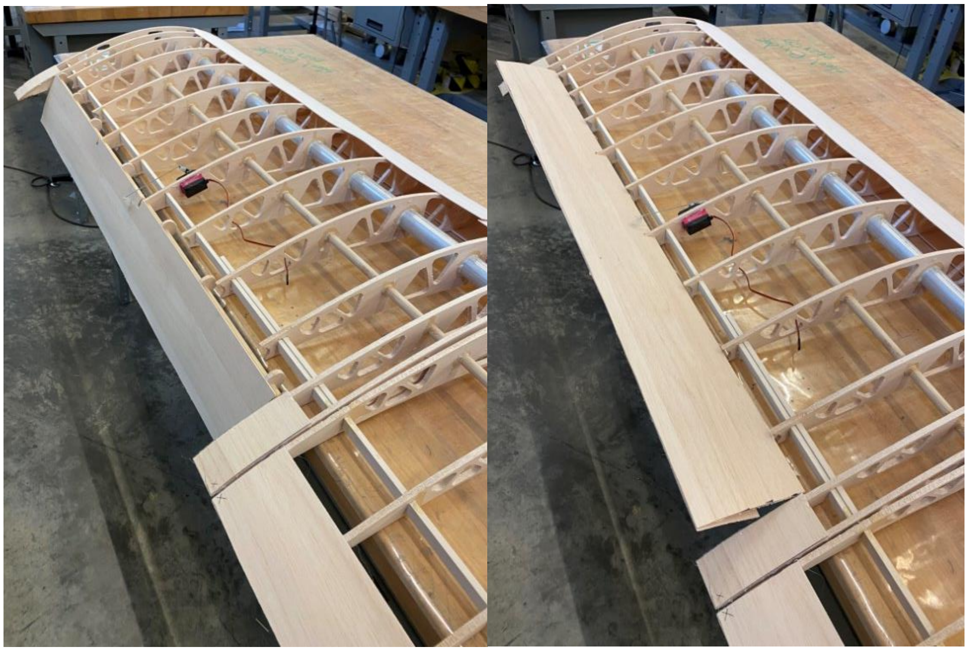


Figure 38. End Section of the Wing showing the aileron deflected at two different angles with the servo motors.

After mounting the servo motors for the ailerons, the wings were then wrapped in a MonoKote shrink wrap. The wings were wrapped in a shrink wrap to provide a smooth surface. With a smooth surface, the wings will produce less drag. First the shrink wrap was cut to length and then the plastic sheet was removed from the opposite side of the shrink wrap. The shrink wrap was then heated up and that side of the shrink wrap would act as an adhesive, sticking to any flat surfaces it was pressed against. A heating iron was used to press the shrink wrap against the balsa wood. Once the shrink wrap was pressed against the surfaces of the wing, a heating gun was used to further shrink the MonoKote wrap and remove any wrinkles. The right side of Figure 39 shows the beginning of this process on one of the middle sections of the wing. Figure 40 shows the finished result on one whole end of the wing. The heating iron is shown.

Figure 39. Process of shrink wrapping the wing

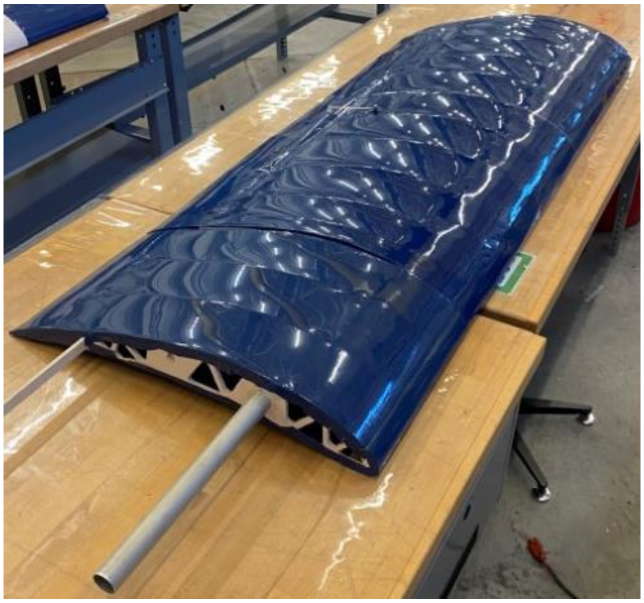


Figure 40. Wing shrink wrapped.

Figure 39 The process of shrink wrapping the wing and the heating iron used.

This process was repeated for each modular section of the wing. Figure 40 shows the entire wing shrink wrapped.

Figure 41. The entire wing covered in shrink wrap and connected to the fuselage.

6.2 Tail

The tail airfoils were cut out on a CNC machine out of ¼ inch balsa wood. The vertical stabilizer skeleton was also cut on the CNC machine. Holes were milled in the 2-inch diameter aluminum tube, and the tube was cut into 3-foot sections. Wood dowels and wood beams with a diameter of 0.5 inches were run through the airfoils and the aluminum tube. The airfoils were glued into place. This is shown in Figure 42. Thin strips of balsa wood were glued to the airfoil ribs to add support for shrink wrapping. The rudder was attached with a hinge to the vertical stabilizer. Metal angles were attached to the aluminum tube, so that the vertical stabilizer can detach for easier shipping. The servos were then attached, and the ribs and vertical stabilizer were shrink wrapped. Wires were run through the aluminum tube to the fuselage.

Figure 42. Tail Construction

6.3 Fuselage/ Landing Gear

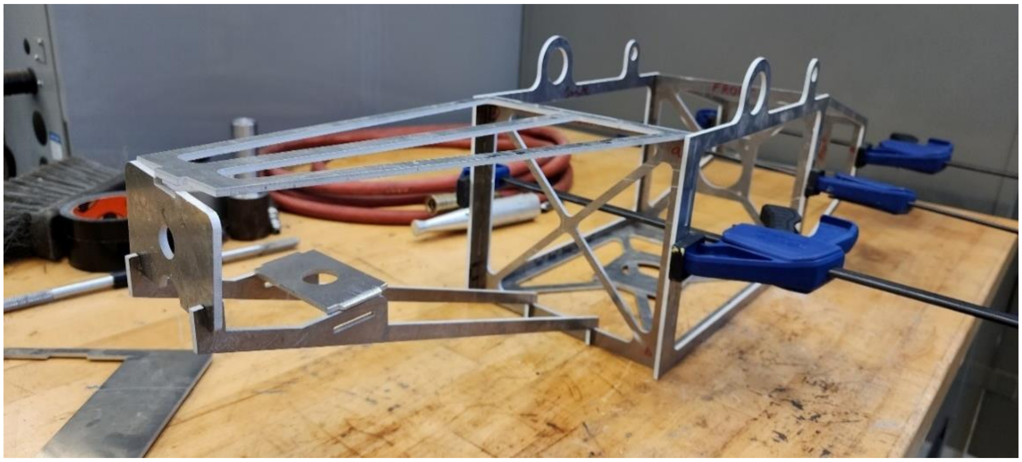


Figure 43.Fuselage after being cut in the waterjet.

The individual aluminum pieces of the fuselage were cut using a waterjet. Waterjets display precision, although certain cuts may not achieve perfection; thus, the pieces that did not fit were modified using a file sander. Figure 43shows the pieces assembled together prior to welding. Each piece was sanded down using an air compressor Dremel to help the welding process. It is important to note that the nose design was modified during the manufacturing process, and it is explored in more detail in section 7.

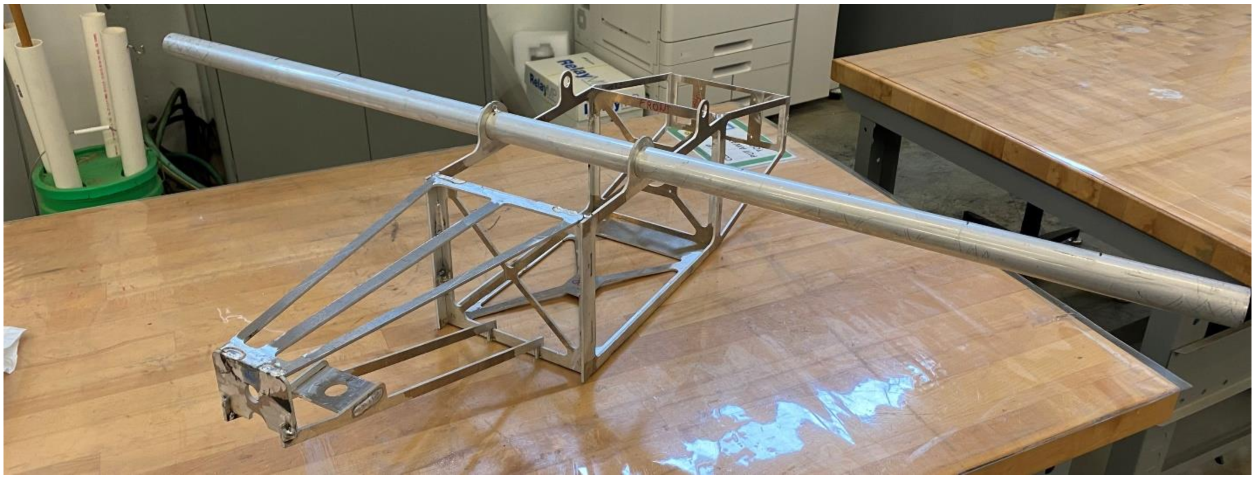


Figure 44. Fuselage after welding

Figure 44 shows all the pieces of the fuselage welded together including the aluminum tube from the middle section of the wing. When welding 1/8-inch aluminum, the process can be complicated, leading to imperfections in the fuselage, but the material maintained its integrity and the imperfections did not affect the overall product.

Figure 45. Ribs for the middle wing section added to the welded fuselage.

Figure 45 shows the ribs placed on the aluminum tube from the middle section of the wing. This part of the wing follows the same procedure explained previously in section 6.1 for the manufacturing of the wing.

Figure 46. Cargo Bay access door and balsa wood for shrink wrap on the aluminum frame.

Figure 46 shows the cargo bay door. This door was placed to access the payload and some electrical components. The red circle shows the balsa wood added to the side of the fuselage frame to facilitate the adherence of the shrink wrap.

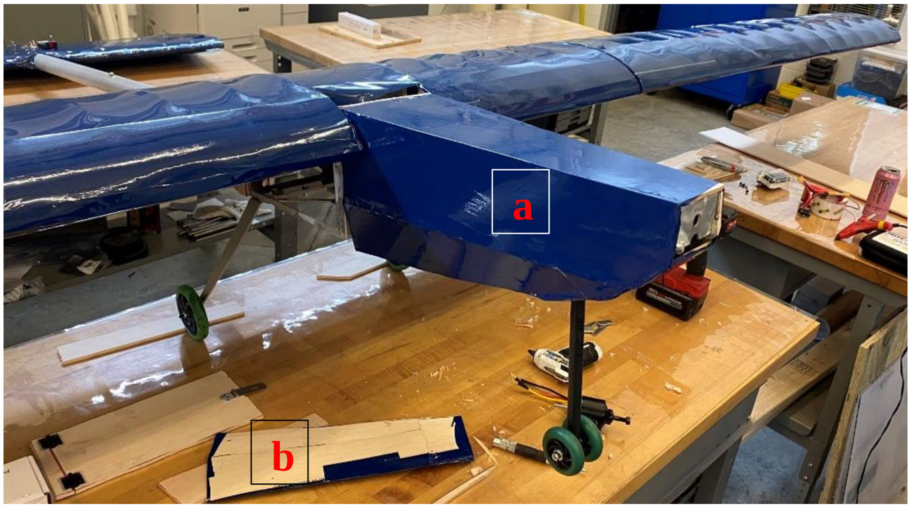


Figure 47. Nose cover.

Figure 47 shows the nose cover, which is made out of balsa wood. It is made up of 2 pieces: a) a piece that covers most of the nose, and b) the bottom cover. The large part is inserted in the direction of the arrow in the figure and secured in place using self-tap screws. Finally, the bottom cover is placed and secured using similar screws.

Figure 48. Fuselage to tail attachment.

Figure 48 shows the tail to fuselage attachment. The tail arm was initially attached to the plates using JB weld, but it did not dry properly, so the tail arm was tig welded to the plate in the circle.

The other plate was not welded since it was not necessary, so it was left with the JB weld that was initially applied.

Figure 49. Landing gear manufactured.

Figure 49 shows the landing gear. The front landing gear was cut and attached to the fuselage using aluminum shaft collars. The rear landing gear was cut in the waterjet as a flat piece and then bent to shape using a metal bender. Finally, holes were drilled in both pieces to attach the wheels. These wheels used bolts to keep them in place while allowing them to rotate.

6.4 Electrical.

The electrical components were connected following the diagram from the design, and the devices were secured in placed using zip ties as shown in Figure 50. The receiver was placed in the cargo bay since it was the place where all servo motor cables were located, so the receiver was mounted on the wall without intervening with the payload plates.

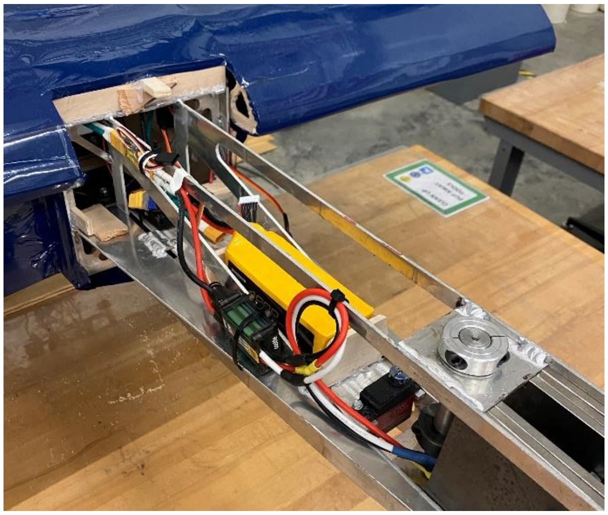


Figure 50. Electrical Components mounted on the fuselage.

7 Modifications

7.1 Wings

There were several changes that were made to the design of the wing to improve the structural integrity and decrease the weight. One of these changes was the amount of airfoil ribs that were added to support the aileron control surface of the wing. Figure 51 shows these extra supports, the blue circles show the original supports holding the aileron rod that acts as a hinge. The red circles within the figure show the extra supports added to the aileron.

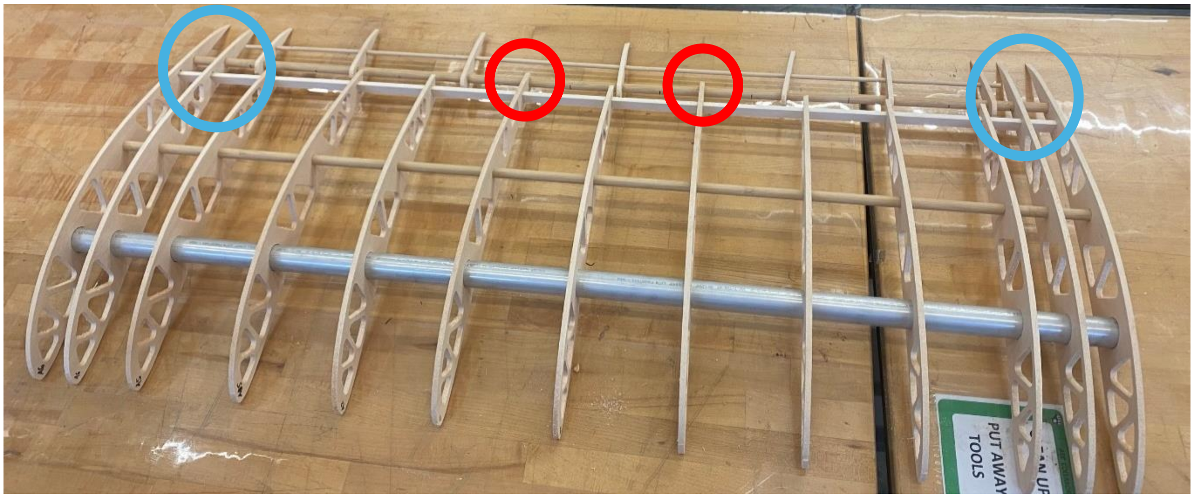


Figure 51. Modifications were made to the ailerons to increase the support of the rod acting as a hinge.

Another modification made to the wings was the change to the aluminum tube. This aluminum spar was originally a square aluminum tube. Both were analyzed with FEA with the force applied at the maximum weight of the competition – 55 pounds. The circular tube had a deflection of around 4.4 inches compared to the 2.8 inch of the square tube, this increase of deflection was countered by the decreased weight of the wings of 5 pounds. With the decrease of weight and a slight increase in deflection, the circular aluminum tube was chosen for the wings. Another change that occurred was that the 1-inch wood dowels that were originally used to add support throughout the wings were switched to a ½ inch diameter wood dowel. This also led to a decrease in weight of the wings.

During the manufacturing process the end sections of the wings ended up being around ½ inch over 48 inches. This would cause the aircraft to not meet the requirements of the competition, prohibiting the aircraft from flying. This led to the final modification that was made to the wings. The end sections were decreased in length by about 1.5 inches. Figure 52 shows one of the sections being cut down. Once these sections were cut down, they were repaired using the shrink wrap.

Figure 52. The end section of the wing being cut down to length.

7.2 Fuselage/Landing Gear

Figure 53. Aircraft assembled, and counterweight added on the nose.

The fuselage and landing gear suffered major modifications during the manufacturing process due to an increase in the weight of the aircraft caused by the center of gravity being misplaced. Once every component was assembled, the center of gravity was located behind the rear landing gear and not in the center of the fuselage, and around 10 pounds of weight was needed on the nose of the aircraft to move it to the desired place. Figure 53 shows the assembled aircraft with steel blocks on the nose to keep it from resting on the tail.

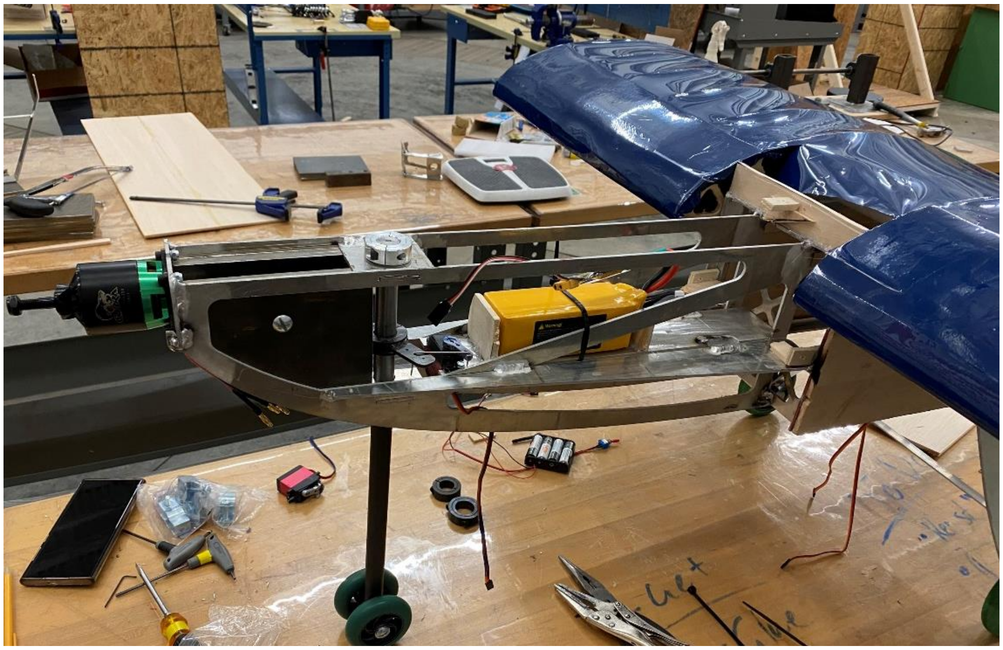


Figure 54. Modified nose design with ballast added at the end.

To address this issue, the nose was extended around 12 inches from the original design to create a larger moment arm, and ballast was added to the end as shown in Figure 54. Since the nose was longer, the added ballast was around 6 lbs. total. Moreover, this nose could have been extended more than 12 inches, but the team decided to keep the fuselage as one piece under 48 inches, which prevents from sectioning the fuselage into two parts. Finally, this modification made the fuselage 47.5 inches in length, from nose to end of fuselage excluding the motor.

Figure 55. Failure of aluminum landing gear and the switch to a steel landing gear.

Furthermore, the landing gear was changed from aluminum to steel because the weight added to the aircraft affected the rear landing gear as shown in Figure 55. There is a possibility that the heat from welding the bar across the landing gear weakness the material, but the team did not have time to examine the reasons of it failing. Instead, the team decided to use 1/8th steel cut in the water jet and bent to shape using the metal bender.

Figure 56. Steering mechanism for the front landing gear

The front landing gear was changed from aluminum tube to a solid steel rod since ballast was added to the nose as shown in Figure 56. This landing gear also uses aluminum shaft collars to be attached to the fuselage. Since the nose was modified, the last thing to be implemented was the steering mechanism. This mechanism is a 4-bar linkage that was placed in an angle when build due to limitations in the space.

Figure 57. Cargo plates with hole and size modification and the cargo bay mounting for the plates

Finally, since the center of gravity was adjusted, the hole to secure the payload plates to the fuselage ended up being off by 1.5 inches, and to solve this problem, longer plates were designed with an off-centered hole to attached them to the fuselage. This modification ensured that the center of gravity was not shifted when payload plates were added.

7.3 Tail

The tail arm was originally designed to be 4 feet long with a 3 by 1-foot-wide horizontal stabilizer. This did not provide enough stability for the aircraft. The tail dimensions were changed to have a 4-foot-long horizontal stabilizer with a 6-foot tail arm. This increased the weight of the tail, but the increased volume coefficient allowed the plane to be controlled with more accuracy during flight. The team decided to be an acceptable tradeoff.

Some complications arose when the final plane was constructed because of the increased weight of the tail. This change in weight distribution moved the center of gravity location to further back on the tail instead of under the wings. Therefore, the fuselage had to be redesigned and counterweights were added to correct the center of gravity. The correct location of the center of gravity is vital to the controllability of the plane and the success of a flight. This did, however, further increase the overall weight of the aircraft.

8 Testing

Once the aircraft was constructed multiple checks were done to ensure the aircraft would be able to fly at the competition. Each detachable section was measured to make sure all parts were under 48 inches. All controls were checked for full range of motion and neutral starting positions. The motor was turned to full speed to ensure that the electrical components were connected correctly. The center of gravity was checked by finding the position on the fuselage where the plane was balanced. Finally, the total weight of the plane was weighed. No test flight was done before the competition, due to time constraints.

9 Competition

9.1 Shipping and Technical Inspection

The aircraft was shipped to the competition in a wood crate. The aircraft was unpacked at the competition and assembled. The next step was technical inspections. At technical inspections, the modular sections were measured to meet the 48-inch constraint. After this the officials at the competition went through the technical and safety requirements. This was to confirm that the aircraft was compliant with the competition rules. Slight adjustments were required to be made at this time, while the officials completed the rest of the inspection. These adjustments include adding glue to support the connections between the control surfaces and the control arms, coming from the servos.

The officials also measured the lengths of the different subsystem to compare to the 2D drawing submitted with the technical report. While measuring the different subsystems, a 5-point deduction was given for a change to the fuselage design. This change was detailed within section 7.2 of this report. The extension of the nose was added to shift the center of gravity to the correct position. This extension changed the design given within the technical report submitted, resulting in a deduction.

After the deduction and the adjustments were made, the aircraft passed technical inspection. At this point, the aircraft was allowed to fly at the competition. Passing technical inspection illustrated that the aircraft met all the technical and safety requirements of the competition. Flights commenced the next day after the competition.

9.2 Flights at Competition

Figure 58 shows the concept of operations for the flights at the competition. The red represents the starting line, where the plane was set for takeoff. From there the aircraft was controlled by the pilot on the side of the runway to takeoff within 100 feet. Then it flew the length of the runway and returned to the starting line, completing a circuit. The aircraft then landed within 400 feet of the starting line.

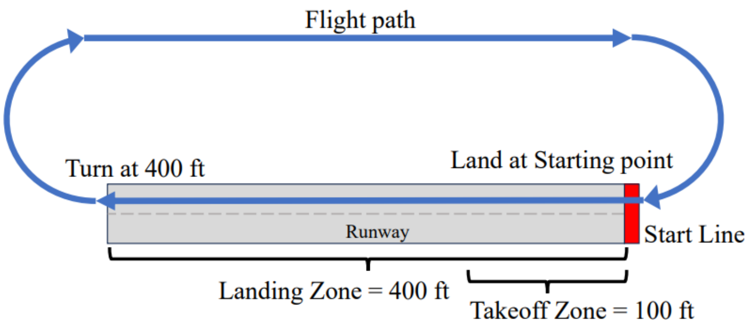


Figure 58. Concept of Operations of Flights.

The aircraft was able to fly three times. On the first flight the aircraft flew the full loop and had a successful landing. During the flight the aircraft temporarily went into a no-fly zone, this disqualified the flight, and it was unable to score. The aircraft then completed a second successful flight that scored, carrying no payload weight. On the third flight, 12 pounds was added to the payload weight. At this weight the aircraft was unable to take off; it was too heavy. The fourth flight carried a payload weight of 7.2 pounds successfully. The final flight was attempted with 9.6 pounds of payload weight. This flight was too heavy for liftoff, leading to our maximum payload weight sitting at 7.2 pounds.

9.3 Competition Scoring

The scoring from the competition was based on the technical report and presentation submitted. It was also based on flight performance at the competition; the amount of payload weight the aircraft could carry. The design report placed 19th, the presentation placed 23rd, and the flights placed 7th out of 33 teams. Overall, the team placed 15th out of 33 teams for the competition.

10 Conclusion and Future Recommendations

10.1 Future Recommendations

For future recommendations, many teams at the competition had anywhere between 10 and 30 people. Having a larger team would allow for a greater distribution of the workload, this could lead to a better design and a higher quality of work. This would make the team more successful at the competition.

Another recommendation would be to pay more attention to the center of gravity. This is one of the key factors that go into whether an aircraft can fly. If the aircraft is nose heavy then it will not be able to takeoff and if it is tail heavy, the plane will stall. It is important to pay attention to the center of gravity throughout the whole design process. Anytime there are adjustments made to the design, such as extending the tail or the nose, this can change the center of gravity. One error made within this project is observing the center of gravity early on and not updating it after redesigning different components. This led to an increase in aircraft weight by almost double, shifting the predicted aircraft weight from 15 to 30 pounds. This increase in weight stopped the aircraft from carrying the predicted payload weight. The result of this was a decrease in score at the competition and a 5-point deduction within technical inspection.

10.2 Conclusion

The aircraft designed and constructed within this project successfully met all the technical requirements of the competition. This was supported by passing technical inspection on the first attempt. During the competition it took many other teams several attempts to pass technical inspection. The USI team from the 2023 competition attempted technical inspection 5-6 times before they were able to pass. This illustrated that the aircraft was compliant with all the competition technical and safety requirements.

The aircraft was able to complete several successful flights, showing improvement from the 2023 USI team. The aircraft was able to carry a payload weight of 7.2 pounds, placing the total aircraft weight, that successfully flew, at around 38 pounds. The aircraft did not reach its predicted payload weight of 30 pounds. This could be contributed to the increase in aircraft weight from shifting the center of gravity. The nose was extended, and ballast was added to shift the center of gravity to the correct position. This decreased the payload weight by close to 23 pounds.

Overall, the team placed 15th out of 33 teams for the 2024 SAE Aero Design West Competition. The flight performance was placed 7th out of 33 international teams. The team competed successfully against schools from all over the world. The aircraft was completed in time for the competition, passed through technical inspection on the first try, and successfully flew multiple times.

10 References

[1] Dawson Barnard, Clayton Davis, Hilda Magallón Gálvez, *Designing a Remote-Controlled Airplane for the SAE Aero Design Competition*, Evansville, IN: Department of Engineering, University of Southern Indiana, Spring 2023. Print. Senior Design Report.

[2] Caleb Hatcher, Damian Lumm, Angel Montiel, et. al., *SAE Aero Design Report*, Northern Arizona University, 2018-2019. Print. Senior Design Report.

[3] Ryan Capozzi, Emily Chretien, Shintaro Clanton, et. al., *Remote Control Aircraft for the SAE Aero Design West Competition*, Worcester, MA: Worcester Polytechnic Institute, April 26, 2018. Print. Project Report.

[4] Leland M. Nicolai, *Estimating R/C Model Aerodynamics and Performance,* Lockheed Martin Aeronautical Company, June 2009. Print. Technical Paper.

[5] Nestor Aguirre, Leah Evans, Martina Kvitkovicova, et. al., *SAE Aero Design Report,* FAMU-FSU College of Engineering, January 2020. Print. Design Report.

[6] Andrés Cardenas, Arjav Patel, Nestor Paz, *SAE Brazil Aerodesign,* Florida International University, November 19, 2014. Print. Senior Design Report.

[7] Anderson, John David, and Mary L. Bowden. *Introduction to Flight*. McGraw-Hill, 2022.

[8] Yechout, Thomas R., et al. *Introduction to Aircraft Flight Mechanics: Performance, Static Stability, Dynamic Stability, Classical Feedback Control, and State-Space Foundations*. American Institute of Aeronautics and Astronautics, Inc., 2014.

[9] Andrew Ning. *Flight Vehicle Design.* Scholarsarchive.byu.edu, 2018. Textbook

[10] SAE Aero Design Rules Committee. *2024 Collegiate Design Series SAE Aero Design Rules.* PDF, 2024.

[11] Remmerie, Wouter. “Fundamentals of Airfoil Design and Selection.” *AirShaper*, AirShaper, 12 Sept. 2018, airshaper.com/videos/airfoil-design-for-a-drone/kAXN3MlQxxc.

[12] *E423 (E423-IL)*, airfoiltools.com/airfoil/details?airfoil=e423-il. Accessed 7 Dec. 2023.

Appendix

APPENDIX A – Project Schedule

Table 3. Fall schedule outlined for the senior design project.

Goal	Date
Fall 2023:	
SAE Aero Design West Registration Opens	9/18/23
Estimated Budget for Project	9/27/23
First Draft Senior Design Proposal	9/29/23
Final Senior Design Proposal	10/6/23
Initial Design Concepts	10/11/23
Senior Design Proposal Oral Presentation	10/16/23
Preliminary Design Oral Presentation	11/13/23
SAE Aero West Registration Closes	11/20/23
Pre-Senior Design Report Due	12/7/23

Table 4.Spring schedule outlined for the senior design project.

Spring 2024:	
Arrange Weekly Meetings with Faculty Advisor	1/8/24
Critical Design Review	2/8/24
Order Parts for Project and Begin Construction on Final Design	2/9/24
Due to SAE Aero Design West • Design Report, 2D drawings, and Data Sheets	3/4/24
Test Flights and Adjustments	3/18/24 - 3/21/24
Senior Design Project Complete	3/22/24
Ship Aircraft Parts, Tools, and other Supplies	3/25/24 – 3/27/24
Design Presentation Review	3/29/24
Flight Demonstration Readiness Review Presentations to SAE Aero _Design West	3/29/24
Draft Report due to Advisor	4/5/24
SAE Aero Design West Competition in Van Nuys, California	4/12/24 - 4/14/24
Senior Design Presentation	4/19/24
Senior Design Poster Session	4/25/24
Final Report and Shared Drive	4/26/24
Final Report submitted to SOAR	5/3/24

APPENDIX B - Budget

Table 5. Budget outlined for the senior design project.

Product	Quantity	Cost ($)
Registration Fee	1	1500.00
Travel Fees	3	Unknown
Minor Tools	2	93.00
Gorilla Glue	2	26.00
Wood Dowel Rods 10 Pack	1	25.00
Batteries	1	54.00
Propeller Motor	1	88.00
Propeller	3	52.00
Power Limiter	1	85.00
Wiring Harness	1	72.00
Arming Plug and Connector	1	20.00
RC Transmitter Controller and Receiver	1	60.00
Wheels	2	21.00
Control Rod connector kit	1	9.00
MonoKote Shrink wrap	9	153.00
Balsa wood	60	657.00
Bass wood	5	77.00
Aluminum Materials	2	147.00
Additional Material		400.00
	Estimated Total:	$3500.00

APPENDIX C – Requirements

High-Level technical requirements:

The aircraft shall…

- Be able to break up into modular sections less than 48-inches.
- Weigh under 55 lb.
- Take off within 120 seconds and within 100 feet.
- Land within 400 feet.
- Be able to fly with and without cargo.
- Not contain lead, fiber reinforced plastics, rubber bands, or gyroscopic stabilizers.

Subsystem Requirements:

The wings of the aircraft shall…

- Be between 120 inches and 180 inches.
- Have modular sections at the end of each wing shall be greater than 42 inches.

The tail of the aircraft shall…

- Be 45-65% of the fuselage length.
- Have elevators with a range of motion of 60 degrees.
- The tail shall weigh less than 3 lb.
- The Elevators and Rudder shall be controlled with servos.

The electrical system of the aircraft shall…

- Have a 750-Watt power limiter.
- Include an arming plug to manually power down the propeller motor.
- Be controlled by 2.4 GHz radio control system with a functional fail-safe system that will reduce the throttle to zero immediately if the radio signal is lost.
- Include a receiver system with a battery independent of the propeller motor battery.

The fuselage of the aircraft shall…

- Have a center of gravity directly under the wings with a tolerance of ±3 inches.
- Have a length of 50-60% of the wingspan.
- Have a cargo bay that can be unloaded within 1 minute.

APPENDIX D – Applicable Standards and Concept of Operation

Table 6. Applicable Standards for project.

Design Factor	Reason
Public heath safety and welfare	Per the requirements from the competition there are no fly zones, where if a plane is flown in these areas, the flight is disqualified. These areas are restricted for the safety of the people and teams attending.
Global	Not applicable due to no global effects
Cultural	Not applicable due to no cultural effects
Social	No applicable due to no social effects
Environmental	Not applicable due to no environmental affects
Economic	The senior design project was given a budget from which the project must be completed. With a restraint on the budget, the material cost must be a design consideration.
Ethical and Professional	Not applicable due to ethical or professional effects

APPENDIX E – Weight Table

Table 7. Weight table for project

Item	Mass (kg)	25% Increase (kg)	Total (kg)	Total (N)	Total (lbs)
Motor	0.21	0.05	0.26	2.55	0.57
Batteries	0.30	0.08	0.38	3.68	0.83
ESC	0.10	0.03	0.13	1.23	0.28
Fuselage	1.20	0.30	1.50	14.72	3.31
Wings	4.00	1.00	5.00	49.05	11.04
Tail	0.80	0.20	1.00	9.81	2.21
Landing Gear	0.30	0.08	0.38	3.68	0.83
Servo Motors (5)	0.07	0.02	0.08	0.80	0.18
Control Rods	0.05	0.01	0.06	0.55	0.12
Propeller	0.05	0.01	0.06	0.61	0.14
Wiring	0.08	0.02	0.10	0.98	0.22
Component Mounts	0.40	0.10	0.50	4.91	1.10
Total:			9.44	92.56	20.83

APPENDIX F – Failure Modes and Effects Analyses

Table 8. FMEA before competition

Item	Failure Modes	Cause of Failure	Possible Effects	Probability	Level	Possible action to reduce effects
Materials	Late Arrival Incorrect parts	Shipping delays Service Errors	Incomplete Aircraft Failure to compete	Low	Critical	Order necessary parts long in advance. Order through reliable services.
Motor/ Electronic components	Parts shortage Defective	High Demand Manufacturing error	Incomplete Aircraft Failure to compete	Low	Critical	Research backup providers for parts with high demand. Order backup components
Wings Fuselage Tail	Incomplete	Lack of Materials Poor time management Low manufacturing experience	Incomplete Aircraft Failure to compete	Medium	Critical	Develop a detailed manufacturing plan. Order extra materials. Gain experience through training in the AEC.
Wings/ fuselage	Breaking	Defective materials Poor workmanship Damage during handling/transport	Destruction of subsystem	Medium	Critical	Quality Control on materials used. Careful handling when needed. Developed manufacturing plan.
Modular connections	Incorrect sizing	Poor collaboration on subsystem connections	Subsystems do not fit together	Medium	Critical	Detailed manufacturing plan. Quality collaboration while developing design.

FMEA 2: At Competition

Table 9. FMEA at competition

Item	Failure Modes	Cause of Failure	Possible Effects	Probability	Level	Possible action to reduce effects
Landing Gear	Breaking	Material Selection Defective materials Poor Workmanship Overweight Aircraft	Destruction of Aircraft Disqualified Flight	Medium	Critical	Quality Control on materials used. Simulation to test handling weight. Control over manufacturing to produce structural integrity.
Wings	Breaking	Material Selection Damage during transportation Damage during handling Overweight Aircraft	Destruction of Aircraft Disqualified Flight	High	Critical	Quality Control on materials used. Simulation to test handling weight. Provide suitable packaging to prevent wear during transportation/handling.
Fuselage	Rupture	Material Selection Damage during transportation Damage during handling	Destruction of Aircraft Disqualified Flight	Medium	Critical	Quality Control on materials used. Provide suitable packaging to prevent wear during transportation/handling.
Propeller	Warping	Material Selection Damage during handling Poor weather conditions	Destruction of Aircraft	Low	Critical	Quality Control on materials used. Careful handling when needed. Quality material selection, with properties that can withstand weather conditions.
Wires	Severing	Damage during handling/transportation Poor workmanship	Loss of power to Aircraft	Low	Medium	Quality material selection. Close design of wiring harness mounts. Proper packaging for transport. Quality control of the manufacturing process.
Control rods	Buckling	Material Selection Defective Materials	Low Control of Aircraft	Low	Medium	Quality Control on materials used.

APPENDIX G – Mechanical and Functional Block Diagrams

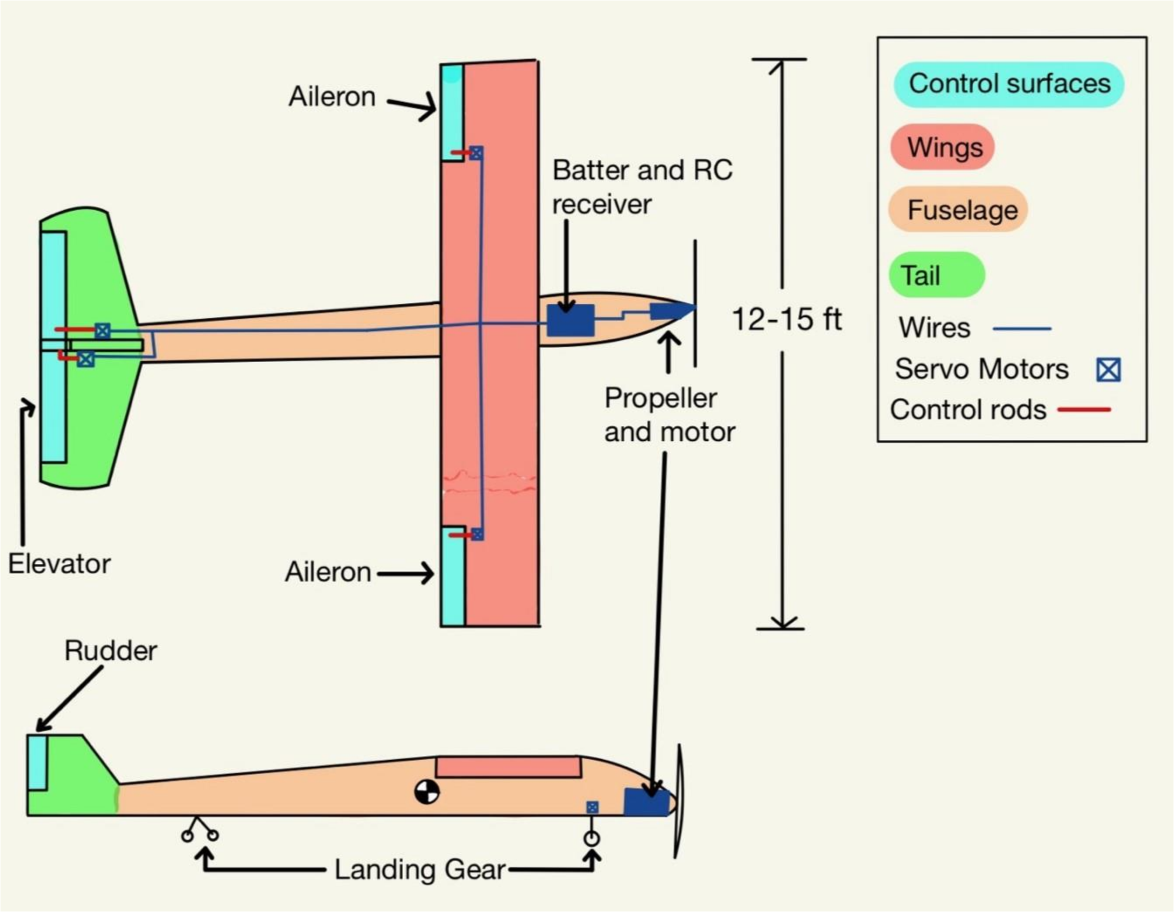


Figure 59. Mechanical Block Diagram

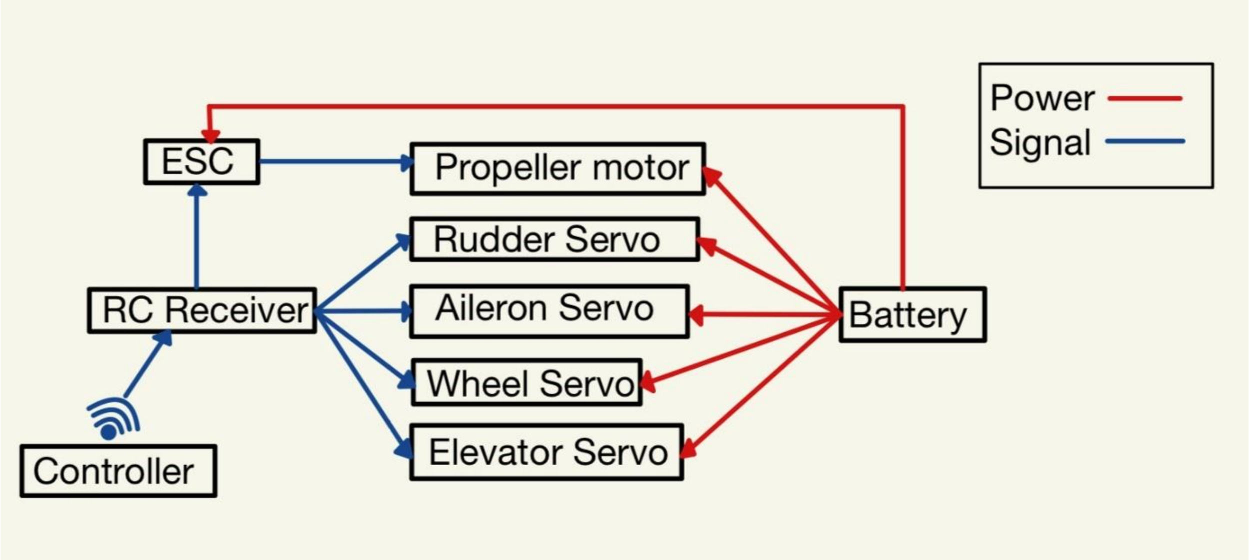


Figure 60. Functional Block Diagram.

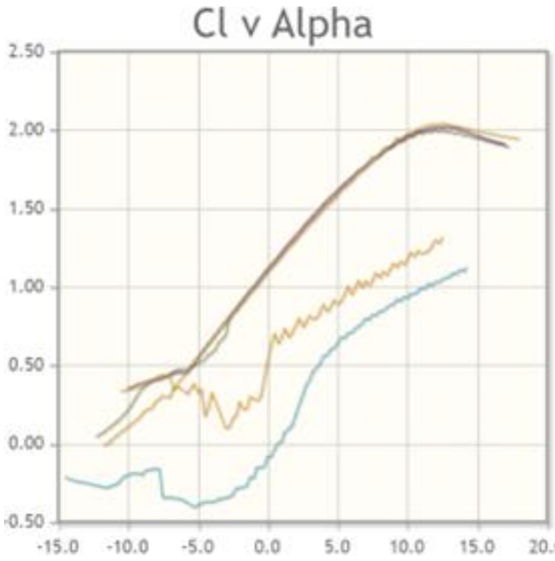
APPENDIX H - Equations and Aerodynamic Graphs

$$L = q * S * C_l \tag{1}$$

$$D = q * S * C_d \tag{2}$$

$$q = 12 * \rho * V^2 \tag{3}$$

$$Re = \frac{\rho * V * c}{\mu} \tag{4}$$



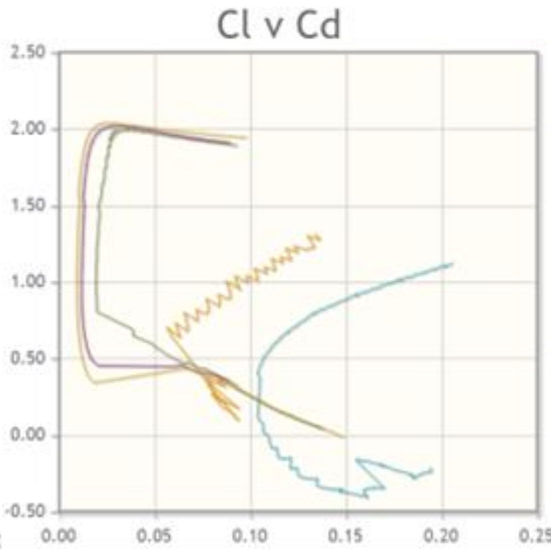


Figure 61. Angle of Attack versus coefficient of lift graph for E423 airfoil.

Figure 62. Coefficient of lift versus coefficient of drag graph for E423 airfoil.

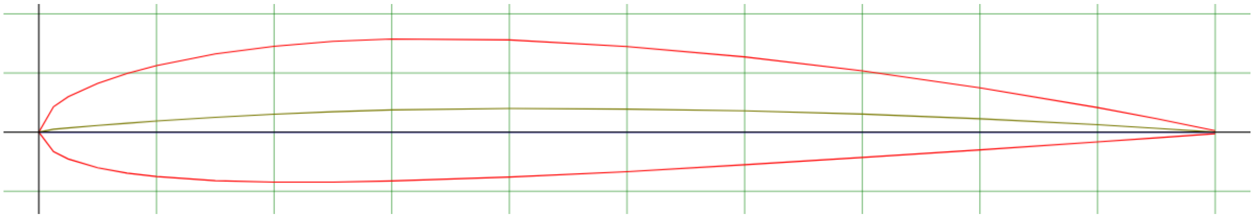
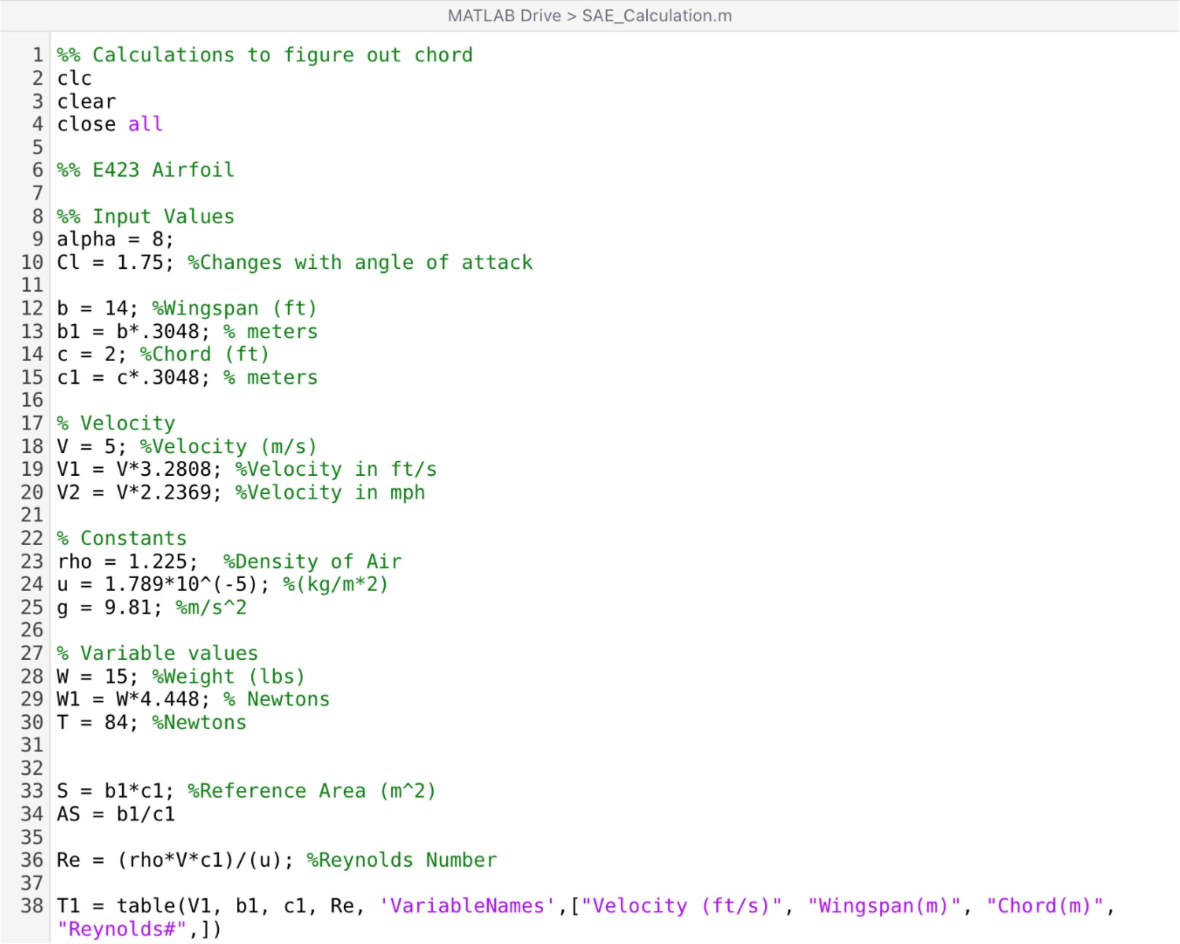
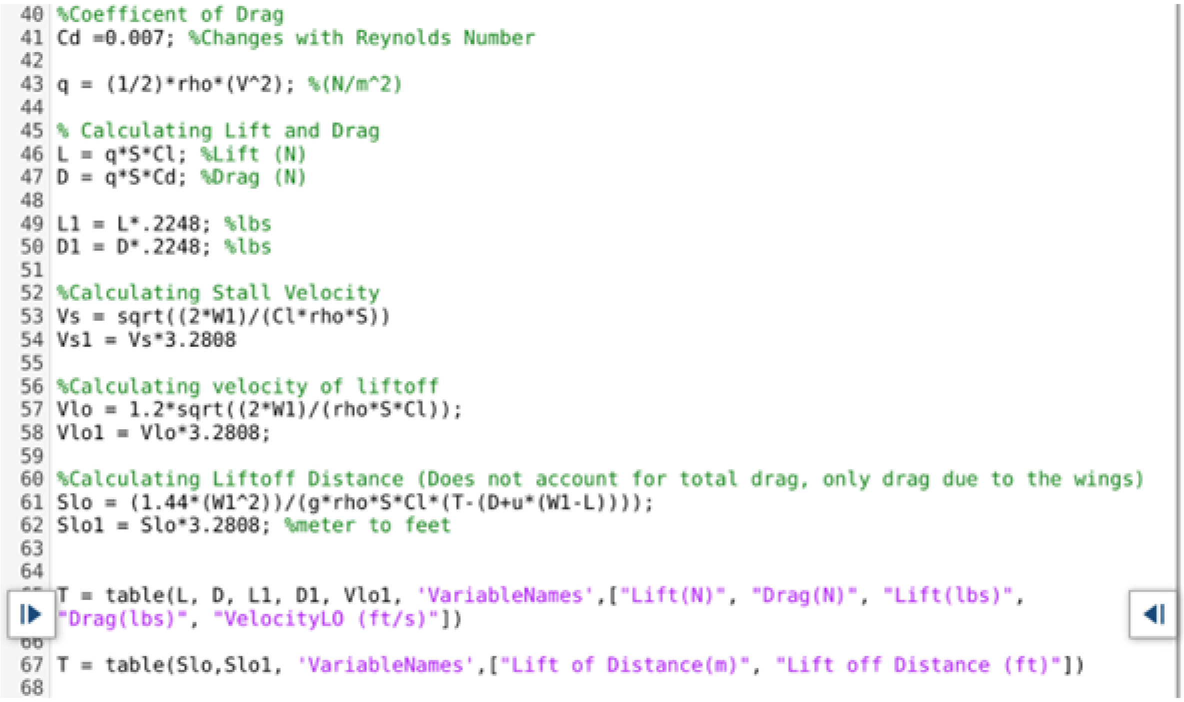


Figure 63. NACA 2412 airfoil shape [13].

APPENDIX I – MATLAB Code for Lift and Drag Calculations



```matlab
%% Calculations to figure out chord
clc
clear
close all

%% E423 Airfoil

%% Input Values
alpha = 8;
Cl = 1.75; %Changes with angle of attack

b = 14; %Wingspan (ft)
b1 = b*.3048; % meters
c = 2; %Chord (ft)
c1 = c*.3048; % meters

% Velocity
V = 5; %Velocity (m/s)
V1 = V*3.2808; %Velocity in ft/s
V2 = V*2.2369; %Velocity in mph

% Constants
rho = 1.225;  %Density of Air
u = 1.789*10^(-5); %(kg/m*2)
g = 9.81; %m/s^2

% Variable values
W = 15; %Weight (lbs)
W1 = W*4.448; % Newtons
T = 84; %Newtons


S = b1*c1; %Reference Area (m^2)
AS = b1/c1

Re = (rho*V*c1)/(u); %Reynolds Number

T1 = table(V1, b1, c1, Re, 'VariableNames',["Velocity (ft/s)", "Wingspan(m)", "Chord(m)",
"Reynolds#",])
```



```
%Coefficent of Drag
Cd =0.007; %Changes with Reynolds Number

q = (1/2)*rho*(V^2); %(N/m^2)

% Calculating Lift and Drag
L = q*S*Cl; %Lift (N)
D = q*S*Cd; %Drag (N)

L1 = L*.2248; %lbs
D1 = D*.2248; %lbs

%Calculating Stall Velocity
Vs = sqrt((2*W1)/(Cl*rho*S))
Vs1 = Vs*3.2808

%Calculating velocity of liftoff
Vlo = 1.2*sqrt((2*W1)/(rho*S*Cl));
Vlo1 = Vlo*3.2808;

%Calculating Liftoff Distance (Does not account for total drag, only drag due to the wings)
Slo = (1.44*(W1^2))/(g*rho*S*Cl*(T-(D+u*(W1-L))));
Slo1 = Slo*3.2808; %meter to feet


T = table(L, D, L1, D1, Vlo1, 'VariableNames',["Lift(N)", "Drag(N)", "Lift(lbs)",
"Drag(lbs)", "VelocityLO (ft/s)"])

T = table(Slo,Slo1, 'VariableNames',["Lift of Distance(m)", "Lift off Distance (ft)"])

```