EML 4905 Senior Design Project

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REQUIREMENT FOR THE DEGREE OF
BACHELOR OF SCIENCE
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MECHANICAL ENGINEERING

2014 SAE AERO DESIGN® EAST COMPETITION
100% Report

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This B.S. thesis is written in partial fulfillment of the requirements in EML 4905. The contents represent the opinion of the authors and not the Department of Mechanical and Materials Engineering.

Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Fred Al-Abdala, Claudia Eyzaguirre, and Luis Vallejos and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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Abstract

The SAE Aero Design series provides engineering students with the opportunity to face a real-life engineering challenge by designing an aircraft based on a set of requirements. This competition not only focuses on technical knowledge in the aeronautics field, but also emphasizes in interpersonal communication, oral communication, and written skills by making a percentage of the score based in the design report and the oral presentation. Seventy- five university teams from different parts of the world will compete against each other putting their engineering, communication, and writing skills to the test. The competition will be held in Marietta, Georgia on April 11-13, 2014. The SAE Aero Design features three classes of competition; Regular, Advanced, and Micro. Our team will participate in the regular class. The objective of the regular class competition will be to design a remote controlled cargo aircraft and predict the aircraft's payload capacity while complying with the requirements of the competition.

For the design of the aircraft, the team will conduct studies on different design alternatives to select the best option based on cost, manufacturing time, loads, etc. To engage in current research in aerodynamics and to create a design that will have global acceptance, we will use current technology available to design the aircraft. The team will use a computational fluid dynamic (CFD) software to improve the airplane's design to obtain maximum lift while reducing drag. Experimental validation of obtained CFD analysis will be done by using wind tunnel testing. The team will also perform structural optimization using finite element analysis through software such as SolidWorks and ANSYS. Other testing concepts include a test stand to analyze thrust of different motor and propeller combinations. Through the research performed in this project, we wish to obtain results that can be used in future design of aircrafts to increase efficiency.

1. Introduction

1.1 Problem Statement

Annually, the Society of Automotive Engineers (SAE) hosts the Aero Design Series where engineering students are faced with the opportunity to take part in a real-life challenge by designing an aircraft based on set requirements. At this event our team will compete against university teams from different parts of the world such as Canada, Egypt, India, Brazil, Bangladesh, Poland and Mexico. The competition will be held in Marietta, Georgia on April 11-13, 2014. The SAE Aero Design features three classes of competition; Regular, Advanced, and Micro (Alvarado). We will participate in the regular class. Based on the rules of the competition, each team is required to design a fully electric cargo airplane that will be able to complete a predetermined circuit carrying the predicted maximum payload while taking off and successfully landing within the specified parameters. The competition is divided into 3 phases as follows (Alvarado):

Phase 1: Technical report: Proposal describing the team's requirement compliance.

Phase 2: Technical Presentation and Inspection.

Phase 2A – Payload Loading Demonstration (timed event during Oral Presentation).

Phase 2B – Payload Unloading Demonstration (timed event during Oral Presentation).

Phase C – Oral Presentation.

Phase 3: Flight Competition.

1.2. Motivation

The motivation behind this project is the aspiration to implement the theoretical knowledge acquired in different courses and put them to work in a real life scenario. The extensive research needed to design a successful aircraft will reinforce the concepts of aerodynamic, fluids mechanics, propulsion systems and mechanics of materials learned throughout our college experience. The development of a cost efficient, functional and unique design for our RC aircraft will be the final representation of the understanding of previously mentioned subjects. In addition, the passion the team members have towards the aviation industry and the chance to represent Florida International University at a worldwide event motivates the team to be determined to excel in the competition.

1.3 Literature Survey

Humanity's fascination with the idea of flying dates to over two thousand years ago with early records of aviation (Crouch, 2004). Early attempts in aviation included kites hot air balloons and gliders. The 1800s involved several attempts at lighter than air aircrafts, including the first fully controllable free-flight. At the same time, innovators experimented with heavier that air aircrafts. Several inventions and experiments where performed that contributed to the goal of creating a functioning aircraft. In 1900s, the Wright brothers built and tested a series of kite and glider designs in the attempt to build a powered design. On December 17, 1903 after several failed attempts the Wright Brothers sustained the first flight by a powered and controlled aircraft. The first flight lasted about 12 seconds and spanned about 120 feet (Institution, n.d.). Figure 4 illustrates the Wright Flyer in flight in Kitty Hawk, North Carolina.

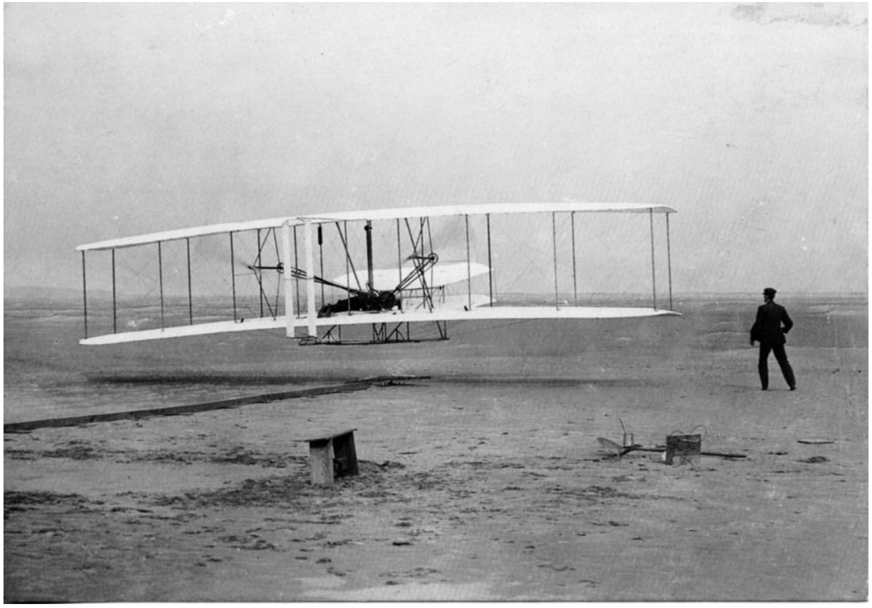


Figure 1 First Flight by a Powered and Controlled Aircraft (Daniels, 1903)

Further inventions in aviation followed that event. The greatest advancement in aircraft technology was done during WWI and WWII. The need to be ahead in technology at war favored the development in the field. Several aircraft where created during this era to be used by fighter pilots (Overy, 1980).

Figure 2 Me 262, world first operational jet fighter (Force, 1945)

After the war was over, a great increase in commercial aviation was seen. Now days, the aviation industry has grown incredibly. Technology and innovation has allowed for people to travel from continent to continent and even to outer space.

2. Project Formulation

2.1. Overview

The SAE Aero Design competition is split up into 3 classes: Regular, Micro, and Open. It was decided to compete in the Regular class since it challenged us as engineers to test our knowledge. Each category sets parameters in regards to the size and dimensions of the aircraft, the weight, and power plant.

2.2. Project Objectives

The team's objective is to work as a together to successfully design, test, and build a scale cargo-airplane within the competitions limits and technical requirements. This is all to improve our understanding and skills regarding engineering as a whole: we not only have to be concerned with the design of the plane but also with its economic and time counterparts.

2.3. Design Specifications, Constraints and Other Considerations

To qualify to compete in the SAE Aero Design Series, your aircraft needs to comply with the requirements specified by the competition. Each class has their own requirements. The key requirements on which we will be designing our aircraft for the regular class are the following:

- The aircraft cannot exceed 65lbs (including cargo).
- Have a maximum combined length, width and height of 175 inches.
- Become airborne with a takeoff distance up to 200 feet
- The aircraft must land within 400 feet of the landing zone.
- Aircrafts with fixed wings only.
- Fiber reinforced plastic is prohibited. No lead weights. No metal propellers or prop savers. No gyroscopic assist.

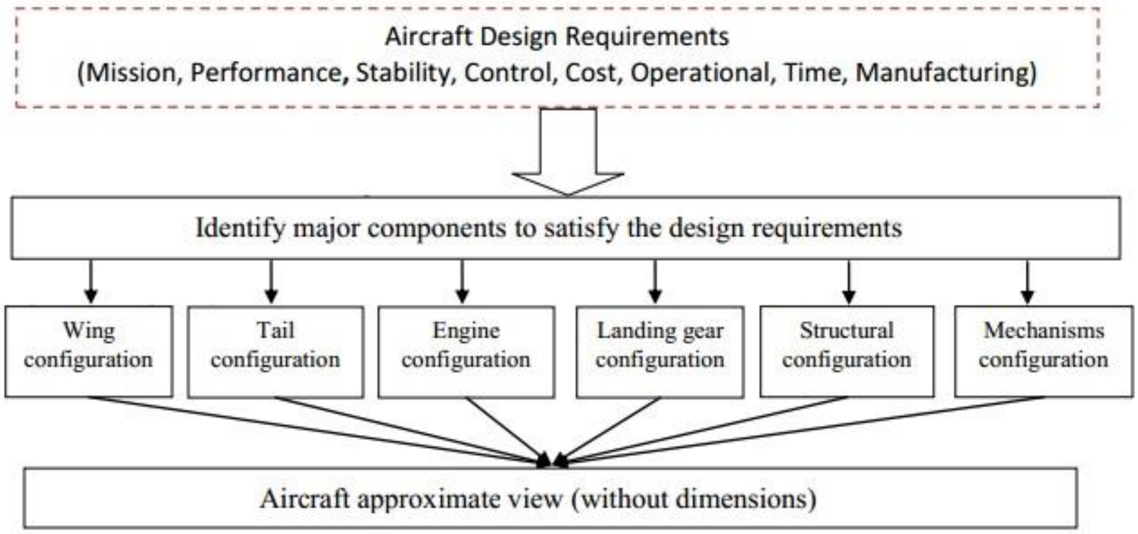
- Commercially engine mount and propeller are available.
- Aircraft must use a Single electric motor only.
- Lithium polymer batteries only. 4000mah, 25C. 4 cell 14.8 volt. Use a 1000 power limiter
- Payload and support, the weights must act as a homogeneous mass.
- Must use a spinner or a rounded safety nut. Analysis and testing of servo sizing is a must.
- Aircraft controls must not feature excessive slop. This leads to reduced controllability or control flutter in some cases.

A complete description of the competition guidelines and requirements can be found on Appendix A.

3. Design Alternatives

3.1. Overview of Conceptual Designs Developed

When designing an airplane, there are numerous alternatives relating to the design of the wings, empennage, and fuselage. The team will research the benefits and disadvantages of different airfoil shapes, tail designs, fuselage designs, and wing shape, size, and position. Ailerons and flaps will be researched as well since they are very important components of the wing. Figure 3 illustrates the major components that make up an aircraft and the procedure the team will follow to obtain a conceptual design.



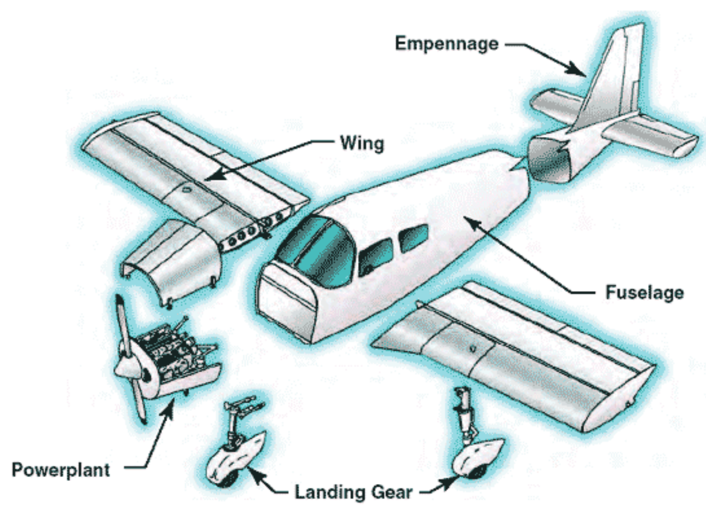


Figure 3 Aircraft major components (Airplane components, 2008)

3.1.1. Wing Design Alternatives

One of the biggest challenges of this competition is to create the most lift possible at the wings. Since the set requirements restrict the aircraft's wingspan and motor power, the team needs carefully choose a wing design that will optimize the maximum load that the plane will carry. The team's objective is to attain the maximum length of the airplane's wingspan possible without compromising the control and stability of the airplane. To achieve this, we need to take into consideration the fact that the fuselage and the height of the airplane will be affected by this criterion as well as the maneuverability of the airplane.

3.1.1.1 Wing Position

As previously mentioned, there are numerous alternatives in the selection of the design of the airplane's wings. One of the factors to take into consideration while designing is the position of the wings. Figure 4 reflects the possibilities of wing position.

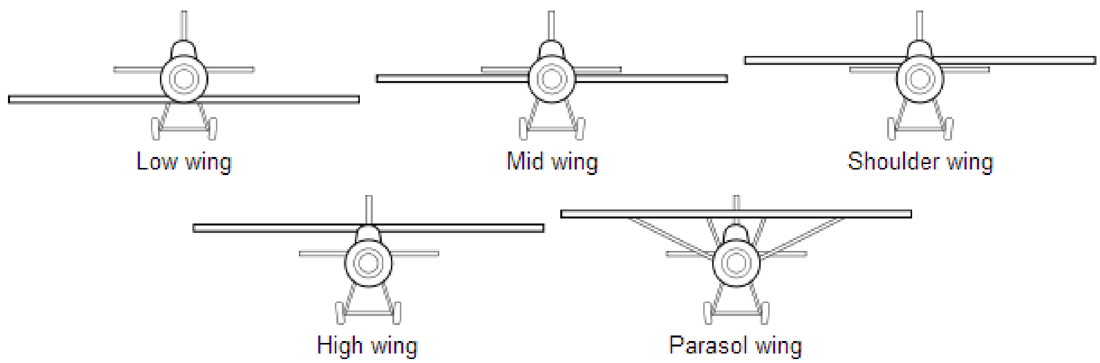


Figure 4 Wing Position Alternatives (Inchbald, 2009)

The team will emphasize on three wing position alternatives which will function best based on our requirements; low wing, mid wing and high wing.

- <u>Low Wing:</u> Since the competition requires the airplane to have the payload inserted from the top and readily available to be inspected by judges, our first approach was to select the bottom wing in order to simplify the design. The main advantage for this wing position selection is the construction of the wing and the mounting of the landing gear. Since the structure of the wing could be manufactured as one piece, its strength would be perfect to withstand the weight of the fuselage and payload located above it.

A disadvantage of this choice is the fact that the center of gravity of the plane would be above the wings making it the least stable design choice. Moreover, based on research of previous competitions, many airplanes undergo great wind gusts that shake the plane making it very hard to land and in many cases the low clearance between the wing and the floor were a decisive factor between a good landing and a crash. The low clearance wings have a greater risk of scraping the floor when landing. A solution to this problem would be to raise the airplane by making a landing gear higher, but this has an impact on the total height of the plane.

- Mid Wing: A mid wing design allows us to have the same loading capabilities as the bottom wing while giving us more clearance between the tip of the wings and the floor. When it comes to stability, the mid wing provides good stability and maneuverability in cargo planes. In this configuration, we can work with the position of the payload to find a center of gravity as close as possible between the wings. This type of wing and center of gravity configuration is the most desired in the case of aerobatic airplanes which generally implement a symmetric type airfoil. For our purposes, we are not required to do any acrobatics while flying and even though it is a nice capability to have, we do not necessarily need it. The major disadvantage of this type of wing is the fact that it needs to be constructed in in two parts and attached to the side of the fuselage. In order to withstand the bending moment and shear stresses at the root of the wing associated with this design, we have to make the wing and fuselage stronger at these points and as a result we will be using more material and more weight would be added to the plane.
- High wing: The last wing position possibility is above the fuselage. We tried to avoid this particular configuration since at the time of loading and unloading the payload we need direct access to the cargo compartment straight from the top of the plane. The high wing position

provides a number of advantages to the design that cannot be underestimated. This type of wing will offer the most stability during flight since the center of gravity will be directly underneath the wings. Even though this configuration does not provide as much maneuverability, we are not required a difficult course of flight. The competition rules require taking off and landing in the same direction and the same runway, making the course a simple circular path. The high wing will give us the most clearance with the floor reducing the risk of touching the ground with the wing when landing. As far as the fabrication of this wing, it would be ideal to make it in one piece. To make this option feasible, a quick way to load the payload will have to be deliberated.

3.1.1.2 Wing Shape:

When it comes to wing shapes, there are numerous types of shapes and each one of them has its advantages and disadvantages. Figure 5 illustrates some wing shape possibilities. We will only concentrate in the shapes that are more suitable for our requirements while remaining simple at the time of construction. The tree types of shapes chosen are elliptical, tapered and rectangular wings.

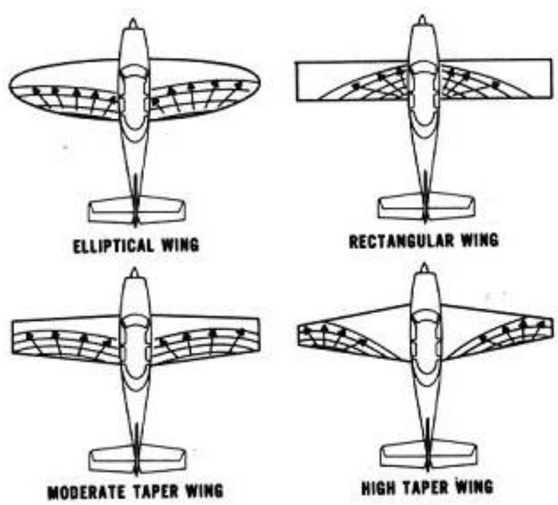


Figure 5 Wing Shape Alternatives (Wing Planform)

- Elliptical: This is the ideal subsonic departure point since it offers a minimum of induced drag for a given aspect ratio. An aspect ratio refers to the ratio of wing span to wing chord. The major disadvantage with this type of wing is the difficulty of its construction. Similarly, the stall characteristics of this wing are inferior to those of the tapered and rectangular wings.
- Tapered: Even though a tapered shape is not as aerodynamically efficient as the elliptical, it is one of the most desired shapes when it comes to weight and stiffness. In order to achieve the aerodynamic capabilities of an elliptical shape, tapered wings are customized through a variation of airfoils and wing twist until they produce a wing lift distribution as close as possible to the elliptical.
- Rectangular: This shape is the easiest to design and build, but also the least efficient of the three. A simple rectangular shape as it comes would create more drag than the two previous options. Even though in theory this is the easiest option to construct; for an optimum lift distribution adjustments to the airfoil profile and wing twist are required, making it a challenge design.

3.1.1.3 Ailerons and flaps

Ailerons are located on the outer most part of the wing and they are used to roll the aircraft. Figure 6 illustrates the components in a wing. Flaps are mounted on the trailing edge of the wing; they are bigger than ailerons and are located closer to the fuselage. Flaps help on increasing the angle of curvature of the airfoil and as a consequence increasing lift coefficient and drag, reducing the distance necessary to take off and land. This part of the design in directly related to the wing shape and needs to be determined once the selection is done. In the same manner as the wing construction, the ailerons and flaps are easier to design in the case of the rectangular and tapered wings than it is in the elliptical case.

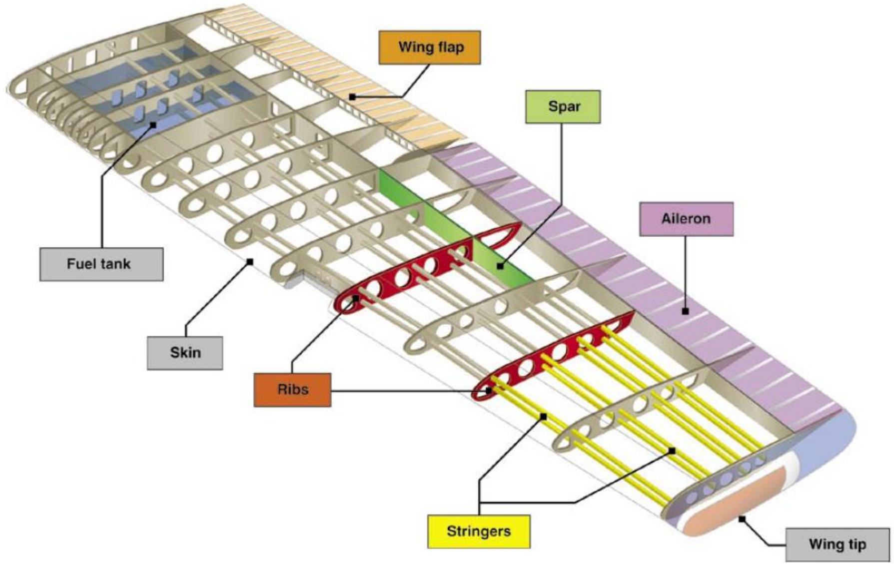


Figure 6 Wing Components (Wing Components, 2008)

3.1.2. Airfoil

The shape of the airfoil selected determines the drag and lift the aircraft will experience. It is crucial to select a shape that will optimize our design. Figure 7 illustrates common shapes of airfoils.

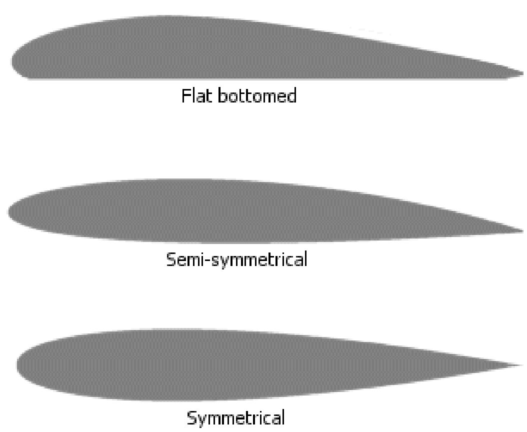


Figure 7 Airfoil Shapes (Carpenter)

- Flat bottom: After reviewing different sources, we realized that for our particular case this shape will be of poor performance since it does not provide as much lift as the other two candidates. After consulting with experienced pilots, this type of airfoil is commonly used in aircraft modeling giving a more predictable behavior when flying.

- Symmetrical: This type of airfoil will provide lift and very good handling of the plane. This type of airfoil will generate lift based on the angle of attack of the wing. A symmetrical airfoil is the most desired case on aerobatic airplanes since it would behave in the same manner with the airplane ion the inverted position.
- Cambered: In contrast to a symmetrical airfoil, a cambered shape can produce lift at zero angle of attack. It provides the maximum lift coefficient and it reduces the stalling speed, meaning we can still flight at low speeds compared to symmetrical and flat bottom airfoils. This is the best choice for our purposes since we do not have a time limit to flight or perform aerobatics. Figure 8 illustrates the characteristics of the airfoil.

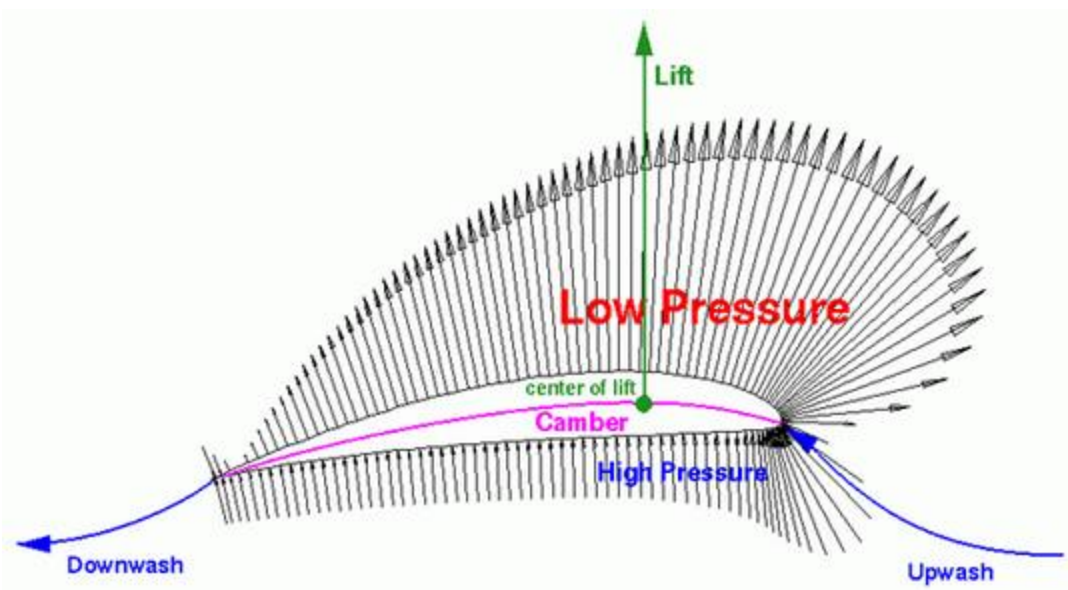


Figure 8 Pressure Vectors and Flow Over a Camber Section (Carpenter, Pressure vectors, 2011)

3.1.3. Fuselage

The fuselage is the main body of the aircraft, since it supports the empennage as well as the attachment of the power plant, landing gear and wings. There are three distinct parts of the fuselage nose, center, and rear. These will carry different loads depending on the purpose of the aircraft. However, the center section is generally always the largest and strongest of all three. This is due to the lift generated by the wings of the aircraft while in flight, which is transmitted using the center section to carry the complete airframe. The design of the aircraft is considered to be that of a cargo aircraft, with a truss fuselage and tapered nose and tail sections.

3.1.3.1 Battery (Payload bay)/Compartment

In normal aircrafts, the fuselage houses the passengers and the cargo. For this competition the fuselage will house only the payload area, this consists of the payload and payload support. A closed payload bay is required, with a volume dimension of 4x4x10 inches +1/8,-0. The payload bay has to have four sides, including bottom and top, and the aircraft must be able to take flight with or without the payload included. The payload support must also be made removable and the weights must remain fixed and as a homogeneous mass during and after flight.

3.1.3.2 Fuselage stresses

Different stresses exist when the aircraft is on flight, and these stresses can act isolated or combined in a single part of the aircraft design. Figure 9 illustrates the forces acting on the fuselage that cause stresses.

- Tension and compression: These stresses are forces that push and pull the struts of the aircraft.

- Bending: are stresses that influence the interior structural members such as the wings spars while the aircraft is in flight; they apply tension in the lower side of the spar and compression in the top of it.
- Shear: stresses also exist in the aircraft; they are caused when forces push one another in a parallel displacement, and for instance when pieces of metal are being slide over the other. In aircrafts rivets and bolts carry shear.
- Torsion: stresses are also present in the aircraft, for instance when the engine exerts a force on the turbine axis or the crankshaft

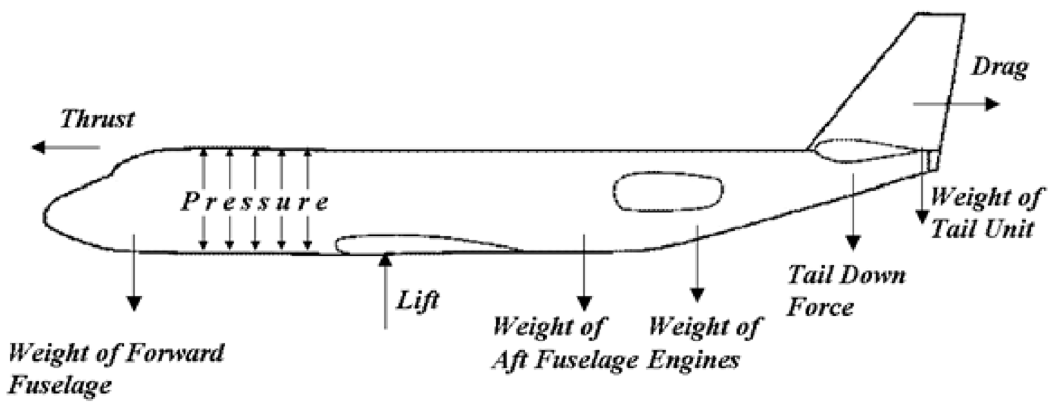


Figure 9 Forces Acting on Aircraft

3.1.4. Empennage

The empennage is the entire tail group which consisting of the vertical stabilizer, the horizontal stabilizer, rudder, and the elevator. Figure 10 illustrates the components mentioned. The tail of the airplane provides lift, stability and control. The tail is not design to create lift as the wing does; it is only intended to generate moment about the center of gravity of the plane in order to provide stability. The horizontal tail generates moment and the vertical tail yawing moment. The horizontal tail includes the elevators and the vertical tail the rudder. Just as wing shapes, there are several options available for the design. The shapes that we will take into consideration for our design are the conventional, T-tail, and H-tail configurations. Each one of them will offer advantages and disadvantages.

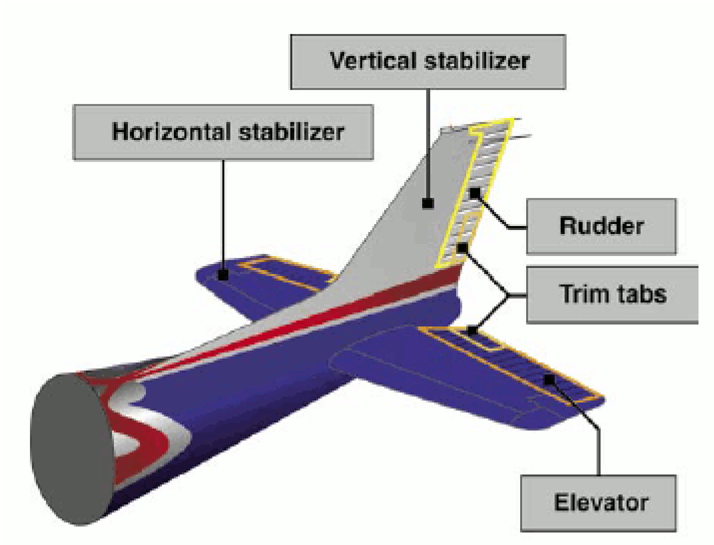


Figure 10 Empennage Components (Empennage components., 2008)

- Conventional: Is the most widely used in commercial aircrafts and it provides sufficient lift and stability with the benefit of light weight. Since the horizontal and vertical parts of the tail are attached to the fuselage it makes them structurally simple and light.

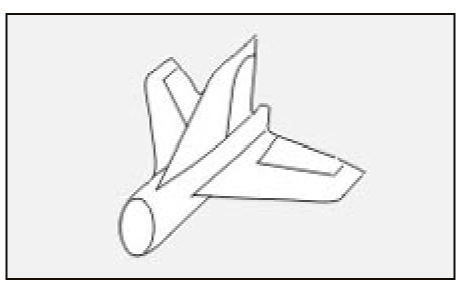


Figure 11 Conventional Tail Design (III, 2002)

- <u>T-tail:</u> This tail is heavier than the conventional tail due to the stronger vertical tail necessary to support the horizontal tail weight and lifting forces. Since the horizontal tail is above the wing it is more aerodynamically efficient and a therefore its size can be reduced.

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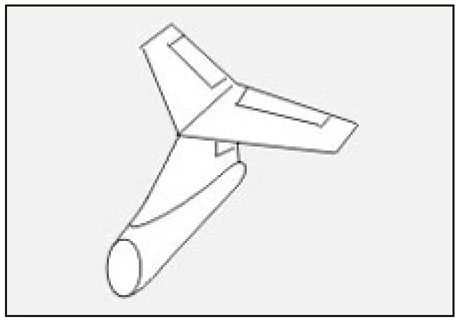


Figure 12 T-Tail Design (III, 2002)

- <u>H-tail:</u> Is primary used to place the vertical tail in undisturbed air, allowing the rudders to be more effective and as a consequence they can be reduced in size. This type of tale is heavier than the conventional but it will allow a smaller vertical tail which could give us more room to expand our wingspan. This design is more effective than a same height conventional tail.

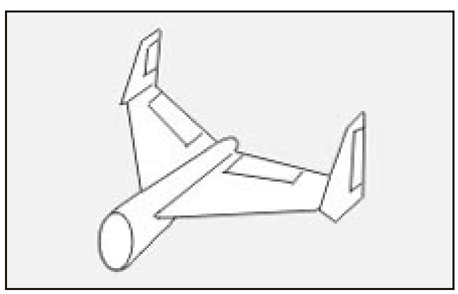


Figure 13 H-Tail Design (III, 2002)

3.2. Design Alternatives

3.2.1 Design Alternative A

Table 1 Design Alternative A Specifications

Wing Position	Wing Shape	Empennage
Low Wing	Elliptical Wing	Conventional Tail

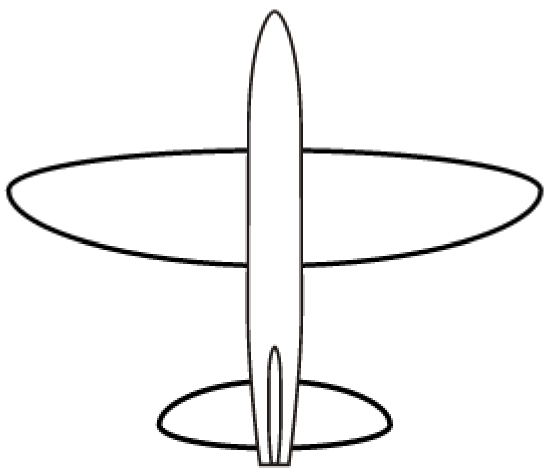


Figure 14 Design Alternative A

The benefits to this design alternative are a low induced drag due to the elliptical shaped wing configuration, accessibility in the payload compartment due to the low wing configuration, and sufficient lift and stability due to the conventional tail design. Disadvantages to this alternative include difficulty in the construction of the elliptical wing design, less stable design due to low wing configuration, and low clearance between wing and floor.

3.2.2 Design Alternative B

Table 2 Design Alternative B Specifications

Wing Position	Wing Shape	Empennage
High Wing	Tapered Wing	Conventional Tail

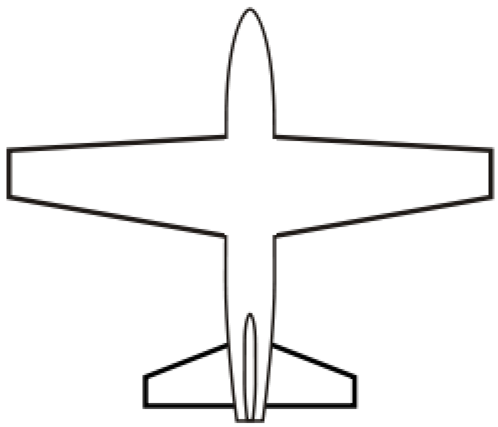


Figure 15 Design Alternative B

This design alternative will not be as efficient as the elliptical shaped wing but by customizing the airfoil we can achieve a distribution similar to the elliptical configuration. The high wing design will give the aircraft the desired stability and clearance. A disadvantage to this alternative is the limited access to the payload compartment.

3.2.3 Design Alternative C

Table 3 Design Alternative C Specifications

Wing Position	Wing Shape	Empennage
High Wing	Tapered Wing	H-Tail

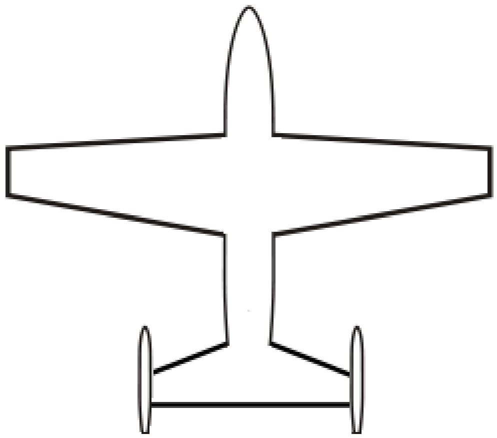


Figure 16 Design Alternative C

As the previous alternative, this design will give the aircraft the desired stability and clearance. Additionally, the T-Tail will be more efficient than the conventional tail. Disadvantages to this alternative are the limited access to the payload compartment and added weight due to the T-tail configuration.

3.3. Feasibility Assessment

In order to select an optimal design alternative for our airplane, the previous options where analyzed based on desired characteristics such as stability, construction, lift, and efficiency.

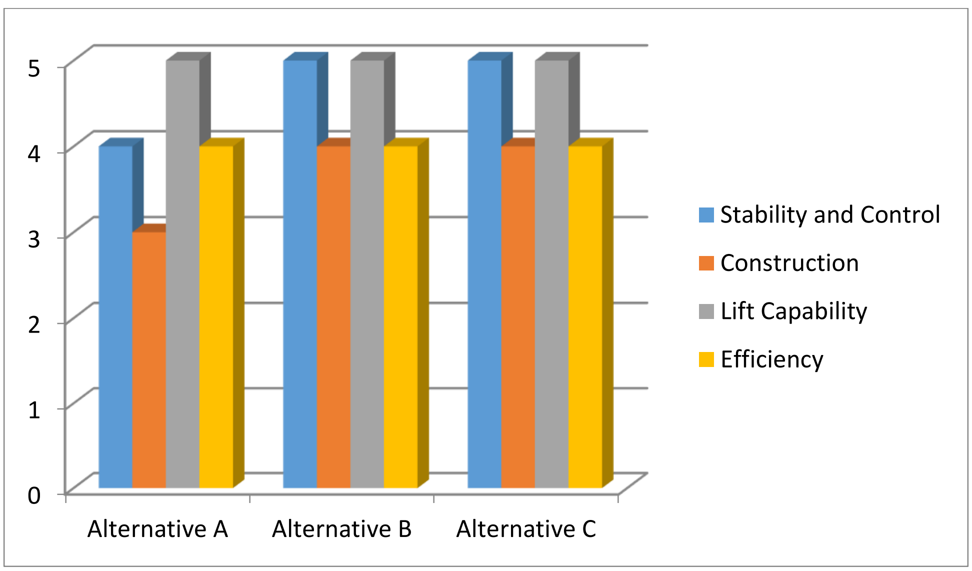


Figure 17 Feasibility Assessment

Based on the results alternative B and C will have similar desired characteristics. Further selection will be decided based on material cost.

3.4. Proposed Design

One challenging part of our design is the stress analysis in the structure. Since most of the lift force is applied at the wings, considering the tail also provides lift, it makes them a very crucial part of the structure. For the construction of the wing we are considering a mixture of wood, metal and plastic. Based on the weight and cost of these materials we have to make the best selection possible for our airplane.

For the construction of the wing ribs we are considering balsa wood since it is light, cheap and easy to work on. Likewise, in order to add more strength and rigidity to the structure we are planning to add an internal transversal support made out of metal. The selection of this transversal support will be made between aluminum, steel and titanium rods or I beam shapes depending on the availability, dimensions and cost of the material. Moreover, the final layer of the wing will be covered with a plastic film that would perfectly shape the airfoil perimeter providing a smooth finish.

Based on the research and description of the different combinations described above we have a basic idea of how the wings should look like. As a first approach, a cambered airfoil with high lift coefficient will be considered. The wing position proposed is the high wing since it will provide us with the most stability and safe landing as a consequence of lower center of gravity and wing clearance with the floor respectively. For the top loading constrain we are considering making the wing as a one piece structure that could be tilt with a hinge and latch mechanism in order to provide access to the cargo bay.

As far as wing shape the most appealing design is the tapered. It will offer a good wing lift distribution while maintaining the construction of the wing, flaps and ailerons simple. As previously mentioned, the structure would be a one piece wing over the top of the fuselage and it would be made out of balsa wood, internal metal supports and a plastic film cover. Once the wings and fuselage design have been decided we will concentrate in the tail section of the plane, for which we propose either a conventional or H-tail. As mentioned, the conventional tail serves its purpose and it is light weight, while the H-type tail is heavier but its shorter vertical stabilizer will allow us to expand even more our wingspan.

4. Preliminary Design

In order to develop the preliminary design there are three parameters that are determined during the design phase which will govern the aircraft size, power plant requirements and the manufacturing cost. These fundamental parameters are the c (W_{TO}), the wing reference area (S), and the engine thrust (T) or engine power (P). The first parameter that should be determined is to estimate the maximum take-off weight. The calculation of the W_{TO} depends on past history, research is made to obtain weight of previously built RC aircrafts with similar requirements to make the results as accurate as possible. The maximum take-off weight is broken into four elements; payload weight (W_{PL}), crew weight (W_C), fuel weight (W_f), and empty weight (W_E).

$$W_{TO} = W_{PL} + W_C + W_F + W_E$$

For our calculations the crew weight and fuel weight will be zero since there’s no crew on the airplane and our motor will be an electric motor.

Component	Weight (Lb)
Frame	8
Motor	0.66
Battery	2
Servos	1.3
Estimated total	11.96

The empty weight based on previous designs and weight of components is estimated to be 11.96 lb. On previous competitions teams have been able to lift a total of 30 lb. of payload. Since the power source has changed from a gas engine to an electric motor we will be more conservative and make our payload weight 25 lb. Therefore, the estimated maximum take-off weight for our aircraft is 36.96 Lb.

Once the W_{TO} is calculated the next step is to determine the wing reference area (S) and the engine thrust (P). To determine these parameters an analytical approach is taken from performance requirements and theories from which reliable results can be obtained. The plane's performance requirements used to size the aircraft are the following:

- Stall speed (V_s)
- Maximum speed (V_{max})
- Maximum rate of climb (ROC_{max})
- Take-off run (S_{TO})
- Ceiling (h_c)
- Turn requirements

For our application we will disregard the rate of climb and ceiling requirements since they are not requirements given by the competition. This parameters will be used to relate each requirement to the wing loading (The ratio between aircraft weight and the wing area represented by W/S) and the power loading (The ratio between aircraft weight and the engine power represented by W/P).

4.1 Stall Speed

The stall speed is the minimum speed at which an aircraft is capable of flying; meaning obtaining a lift to be able to match your weight and not lose altitude. This means that slower the airplane flights the higher the angle of attack needed to match the weight if the airplane. If the aircraft continues to increase the angle of attack while reducing speed it will reach a point where the aircraft will stall. If the aircraft is flying at stall speed then it cannot climb; if it flies below its stall speed the aircraft cannot stop descending. Increasing angle of attack without increasing airspeed will result in a stall. Therefore, for the aircraft to fly the aircraft's weight must be balanced with the lift

$$L = W = \frac{1}{2}\rho V_s^{\,2} S C_{L_{\max}}$$

Where ρ is the air density at the specified altitude, and C_{Lmax} is the aircraft maximum lift coefficient. By dividing both sides by S we obtain the following equation to determine the weight to area ratio.

$$\left(\frac{W}{S}\right)_{V_s} = \frac{1}{2}\rho V_s^{\,2} C_{L_{\max}}$$

Solving this equation will give the limit for the stall requirements for the aircraft. The following figure represents the area that are accepted by the requirement.

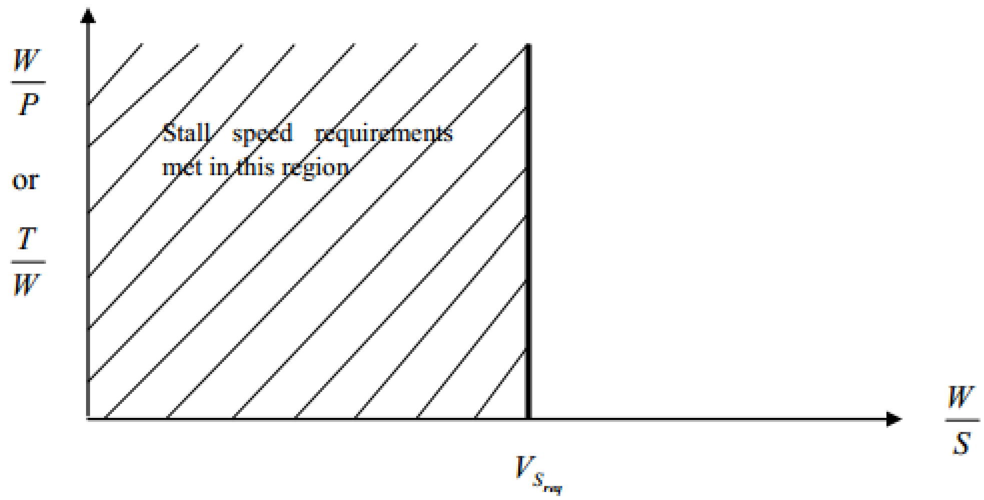


Figure 18 Stall speed contribution

4.2 Maximum Speed

For a prop-driven aircraft flying at a maximum constant speed the maximum available power must be equal to the maximum required power. The following equation expresses this relationship.

$$P_{avl} = P_{req} \Rightarrow \eta_P P_{\max} = TV_{\max}$$

In this equation the engine thrust, T, must be equal to the aircraft's drag; meaning that the power is decreasing with increasing altitude. This relationship between altitude and power is represented by the following equation

$$P_{alt} = P_{SL}\left(\frac{\rho}{\rho_o}\right) = P_{SL}\sigma$$

By substituting the drag equation we obtain the following expression

$$\eta_P P_{SL}\sigma = \frac{1}{2}\eta_P \rho V_{\max}^2 SC_D \cdot V_{\max} = \frac{1}{2}\rho V_{\max}^3 SC_D$$

Where

$$C_D = C_{D_o} + C_{D_i} = C_{D_o} + K \cdot C_L^2 \quad \text{and} \quad K = \frac{1}{\pi \cdot e \cdot AR}$$

The value of C_{Do} was estimated using typical values for aircrafts from the following table

Table 4 Typical values of the zero-lift drag coefficient

No	Aircraft type	C_{Do}
1	Jet transport	0.015 – 0.02
2	Turboprop transport	0.018 – 0.024
3	Twin-engine piton prop	0.022 – 0.028
4	Small GA with retractable landing gear	0.02 – 0.03
5	Small GA with fixed landing gear	0.025 – 0.04
6	Agricultural	0.04 – 0.07
7	Sailplane/Glider	0.012 – 0.015
8	Supersonic fighter	0.018 – 0.035
9	Homebuilt	0.025 – 0.04
10	Microlight	0.02 – 0.035

Substituting C_L and C_D into the previous equation and then dividing by the weight will give the relationship of the power loading to the wing loading which is a non-linear function

$$\left(\frac{W}{P}\right) = \frac{\eta_P}{\frac{aV_{\max}^3}{\left(\frac{W}{S}\right)} + \frac{b}{V_{\max}}\left(\frac{W}{S}\right)}$$

The area under the curve of the above function will satisfy the requirements for the maximum velocity. The following figure illustrates the matching plot of this function.

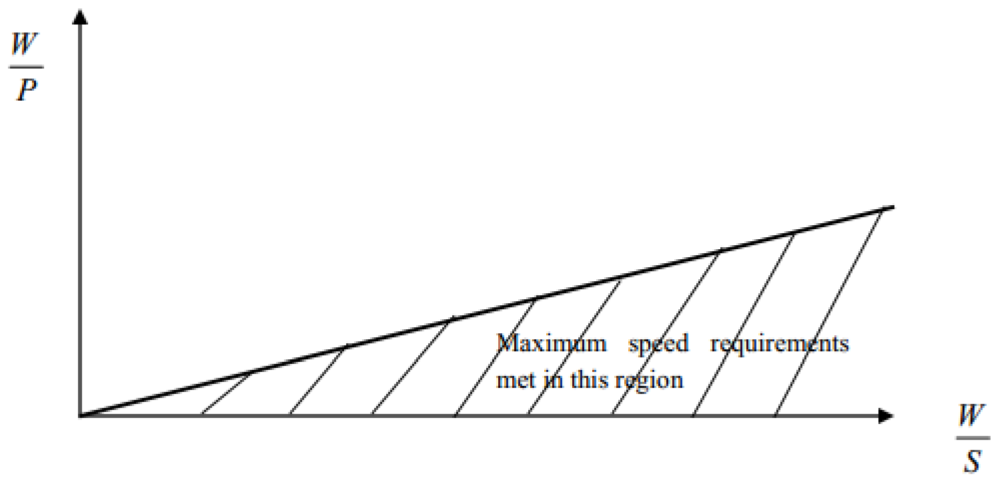


Figure 19 Maximum speed contribution

4.3 Take-Off Run

Take-off run is defined as the distance between the starting point to the location of standard obstacle that the aircraft must clear. In our case, the competition requires for the aircraft to be airborne before the end of the 200 feet runway. In a prop-driven aircraft, the engine thrust is a function of propeller efficiency and the aircraft speed. Conversely, the aircraft speed in this case is not constant. The take-off speed is estimated to be

$$V_{TO} = 1.1V_s \quad to \quad 1.3V_s$$

At take-off, the propeller efficiency is much lower than the maximum attainable efficiency, for our application we will use a prop efficiency for a fixed-pitch propeller of 0.5. The relationship between the power loading and wing loading is given in the following equation

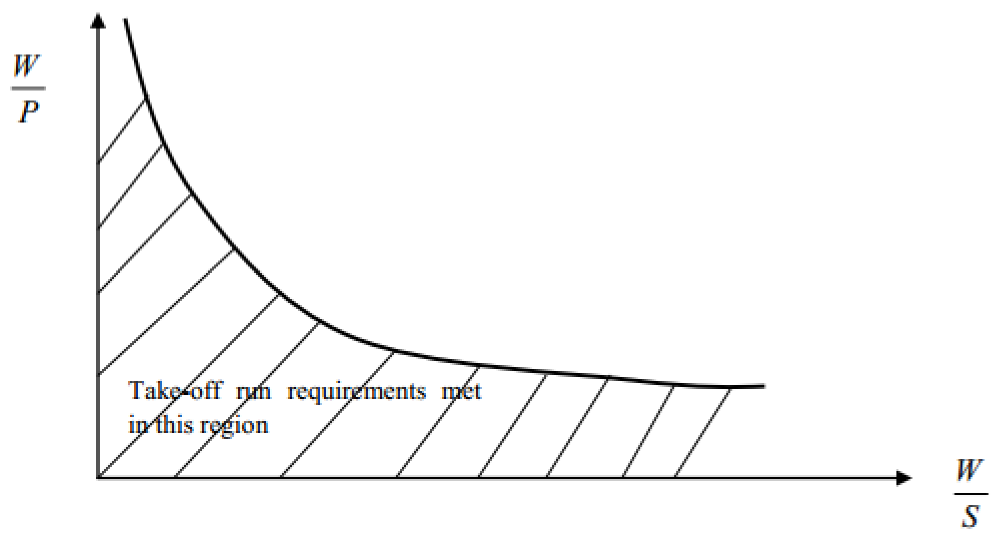
$$\left(\frac{W}{P}\right)_{S_{TO}} = \frac{1-\exp\left(0.6\rho g C_{D_G} S_{TO}\frac{1}{W/S}\right)}{\mu-\left(\mu+\frac{C_{D_G}}{C_{L_R}}\right)\left[\exp\left(0.6\rho g C_{D_G} S_{TO}\frac{1}{W/S}\right)\right]}\frac{\eta_P}{V_{TO}}$$

Where S_{TO} = 200 feet, $C_{L_R} = \frac{2mg}{\rho S V_R^2}$ and the coefficient of friction is estimated from the following table

Table 5 Friction coefficients for various runway surfaces

No	Surface	Friction coefficient (μ)
1	Dry concrete/asphalt	0.03-0.05
2	Wet concrete/asphalt	0.05
3	Icy concrete/asphalt	0.02
4	Turf	0.04-0.07
5	Grass	0.05-0.1
6	Soft ground	0.1-0.3

The region below the function will satisfy the requirement for the take-off run, the following figure illustrates this region.



Figure

20 Take-off run matching plot

4.4 Construction of matching plot

To obtain the value of the design point all functions described above need to be plotted together. The point to the left of the stall speed which satisfies all under the curve requirements will be the design point for the design. Once this value is obtained the following equations will be used to calculate the optimal wing area and engine power.

$$S = W_{TO} \Big/ \left(\frac{W}{S}\right)_d \qquad P = W_{TO} \Big/ \left(\frac{W}{P}\right)_d$$

Using the following parameters for our aircraft the matching plot is obtained and the design point is selected.

Table 6 Design parameter

Vstall	10.14978	Density GA kg/m^3	1.121	Cl max	2.2
Westi	15.8757	Density SL	1.225	Cdo	0.03
Vmax m/s	11	a	0.018375	b	0.137909
Sto	60.9	Clr	1.8	µ	0.04
Prop. Eff	0.75	AR	6	K	0.070736
e	0.75	Sesti m^2	1.226	σ	0.915102
Cdg	0.12	Vto	12.17	Eff. To	0.5

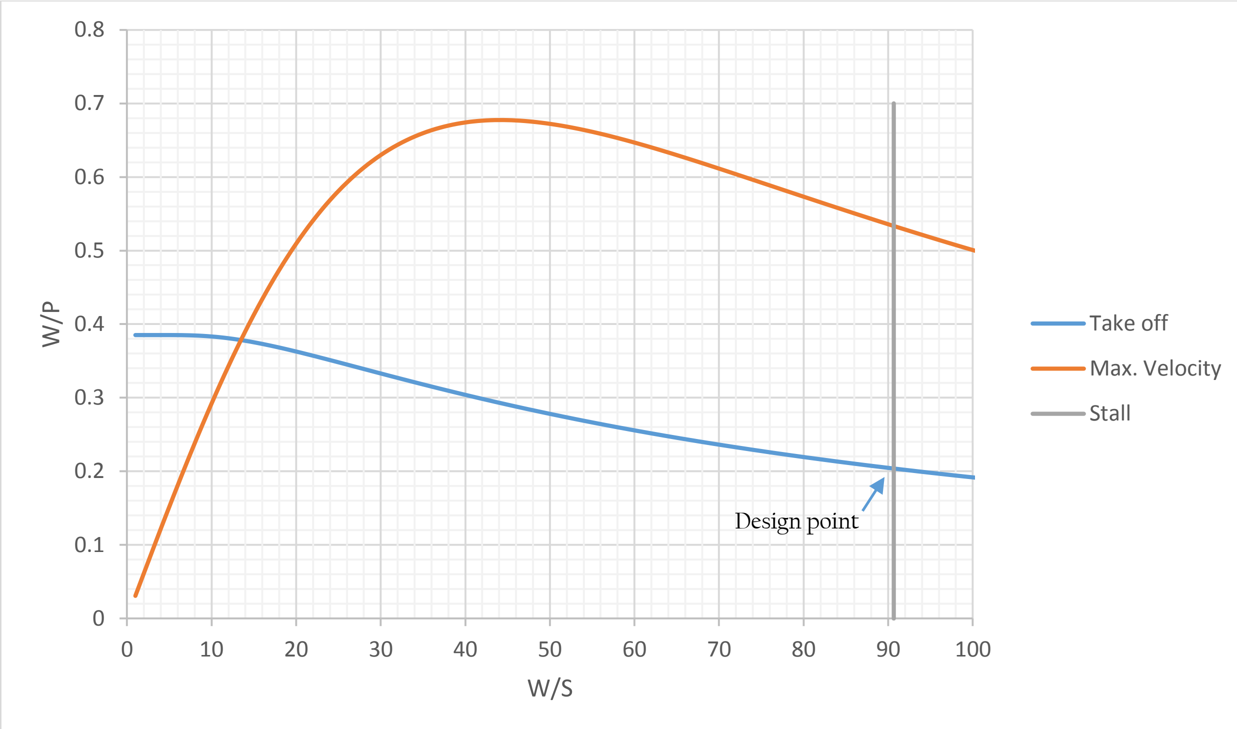


Figure 21 Matching plot

Through the plot we obtain a wing loading ratio of 121 and a power loading ration of 0.169. Solving for the area and required power from the above equations gives a value of 1.286 m^2 and 921 watts.

5. Wing Loading

Wing loading is the ratio of the aircraft total weight divided by the area that generates lift which is generally the main wing even though in the canard type planes the tail will also be part of the lifting area. This parameter affects many aspects on the performance of the plane. Among the most important aerodynamic parameters based on our competition are the total take-off weight, landing distance needed to stop the plane, climb rate and turning ability. Choosing the right wing loading for the plane is crucial for our design since the wrong value will affect the ability of the plane to lift the payload or in the contrary add unnecessary weight to the structure of the plane.

In the case of our high lift, short runway for take-off and landing application we need to find the airfoil and angle of attack that will create the lowest drag while in the runway and the maximum lift during flight. Based on these parameters we plotted a wide variety *Cl* ratio that changed as a function of the angle of attack (AOA) of the airfoil. For the calculations we used the data provided by the airfoil S1223 from -5 to 16 degrees which is the point where the airfoil starts to stall. The following formula shows the criteria used to generate the plots

$$\frac{W}{S} = \frac{1}{2} * \rho_{air} * v^2 * Cl$$

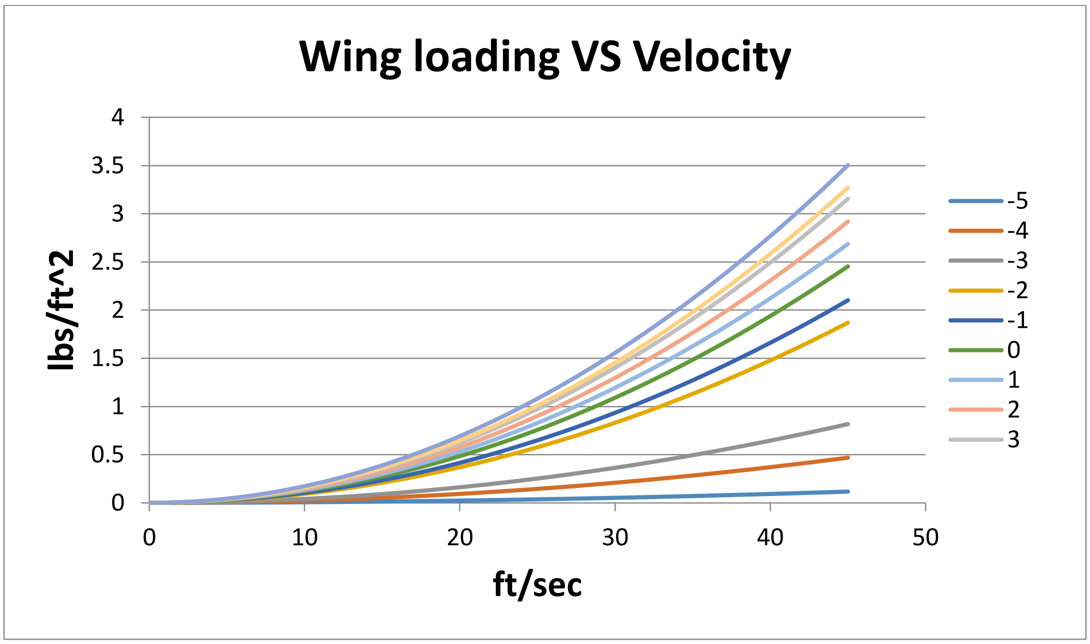


Figure 22 Angle of attack (-5 to 5)

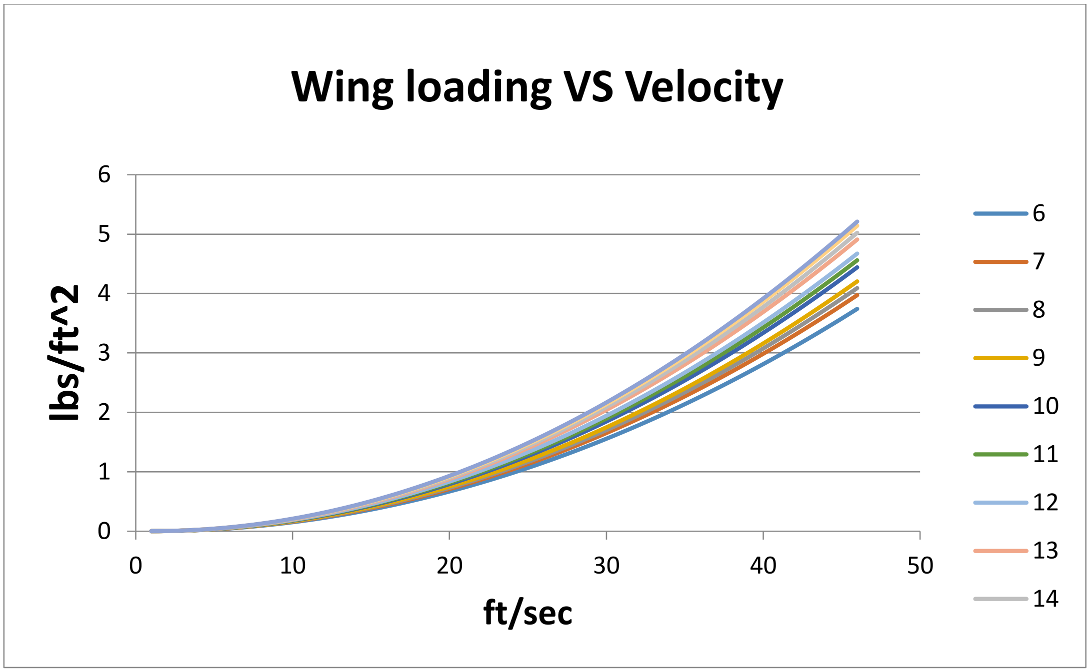


Figure 23 Angle of attack (6 to 16)

As observed in the formula above, the wing loading increases as a function of velocity and coefficient of lift. Since this particular airfoil starts stalling at around 17 degrees of AOA we should design our wing at a conservative 70% of this constraint. The maximum velocity achieved by the aircraft in flight can be estimated from the following formula created specifically for RC aircrafts and validated experimentally thought out the years

$$Flight\ speed = \ 0.70 * Pitch\ speed$$

$$Pitch\ speed = \frac{RPM * Pitch}{1056}$$

$$RPM = \ .080 * Kv_{motor} * V_{battery}$$

Where the flight speed is given in mile per hour and the 1056 is a conversion factor, the Kv value depends on the motor chose for the application, V is the voltage of the battery and the pitch depends on the propeller used with the motor. In order to choose the right propeller we will conduct bench testing to ensure the selection of the most powerful combination. Some of the values that we are currently working with are the 700 Kv from the 0.60 Rimfire motor, 14.8 volts from our batteries and a pitch value of 8 inches per revolution. With these values as an initial parameter we have calculated a flight speed of roughly 43 mph without taking drag forces into account. Taking into consideration the drag forces and friction factor of the runway we estimated a take-off velocity of approximately 30 mph, that is 44 ft./sec which at 12 degrees AOA provides a wing loading of 3.4lbs/ft^2. With an estimated total weight of 35 lbs. including the payload, we would need 10.3 ft^2of area for the wings. Taking into consideration that only 90 inches of our wing generate lift, we would have design a wing that has at least 1500 in^2. If we consider a constant cord wing this would generate a cord length of 17 inches.

6. Airfoil Analysis

To analyze different properties of potential airfoils we decided to compare them using the XFLR5 and Profili software. The XFLR5 program is an analytical tool used to simulate the flight of model aircrafts at low Reynolds numbers, however as it is described in the software's disclaimer it can only be used for model aircrafts, for low Reynolds number. Profili was used to determine the final solutions since profili is a much more professional and reliable software. The xflr5 program provides the user with a direct and inverse analysis capabilities, it also lets the user change the size of the airfoil to input by manipulating the airfoil data from the specific airfoil to be used. We are using the xflr5 version 6.09.06 to analyze the following airfoils:

- Clark_Y
- FX-74-CL5-140
- FX63-137
- S1223

All airfoils where analyzed using a range from 25,000 to 300,000 reynolds number, in 25,000 increments. The reason behind this is because we want to know how the coefficients of lift and drag will change when the model aircraft is increasing its velocity until the point where it mantains a relative constant velocity on flight.

This analysis is also done from a negative angle of attack of 8 degrees to a 20 degrees angle of attack to determine stall charactersitics.

6.1 Clark Y airfoil

Mostly used in the construction of model aircraft, the Clark_Y airfoil designed by Virginius E.Clark, has great performance at medium Reynolds numbers airflows. This airfoil has a good lift vs. drag ratio on lightweight base models due to its high camber. It’s also commonly used due to the relative easiness to construct and repair aircraft models with this type of airfoil.

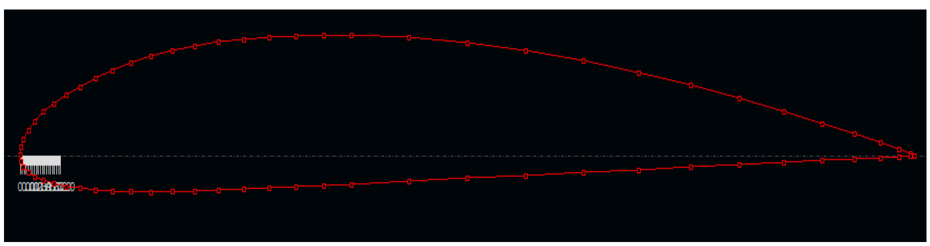


Figure 24 Clark Y airfoil

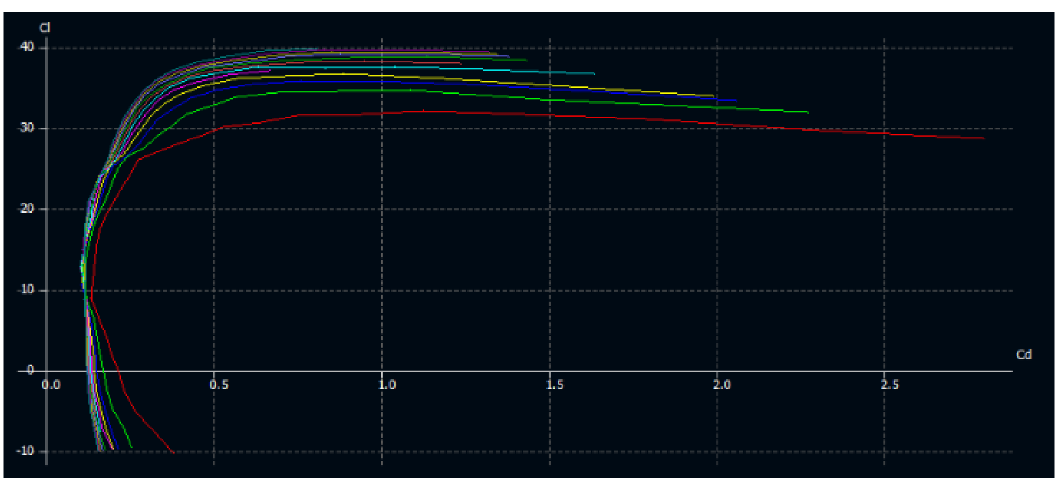


Figure 25 Clark Y airfoil coefficient of lift vs. coefficient of drag

Figure 26 illustrates the coefficient of lift as it increases relative to the angles of attack; we can also see that for negative angles of attack and increasing Reynolds number the coefficient of lift remains with little deviation.

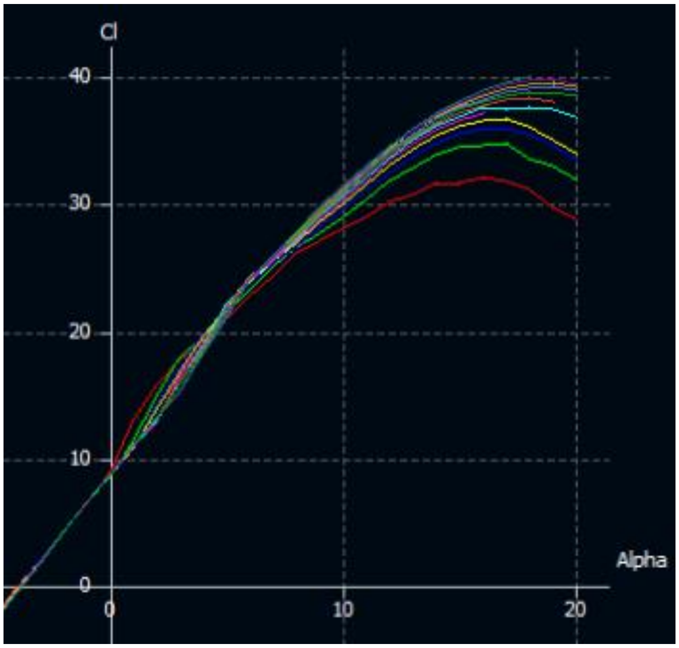


Figure 26 Clark Y airfoil coefficient of lift vs. angle of attack

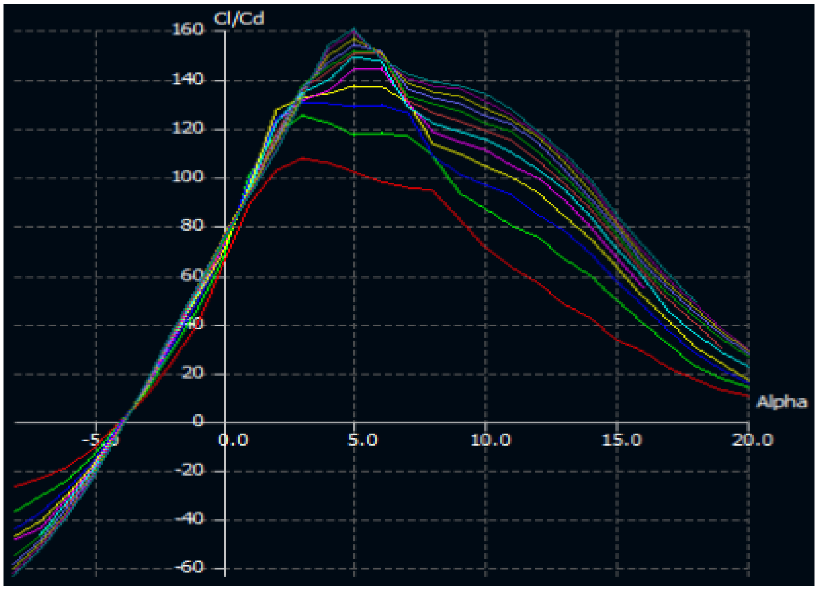


Figure 27 Clark Y airfoil ratio of lift to drag coefficients vs. angle of attack

Figure 27 illustrates how the maximum value for the C_l/C_d ratio vs. the angle of attack occurs around a 5° angle of attack. And its increasing as the angle of attack increases until it hits the 5° degree and then the higher the angle, the lower the ratio of lift to drag coefficient.

6.2 FX-74-CL5-140

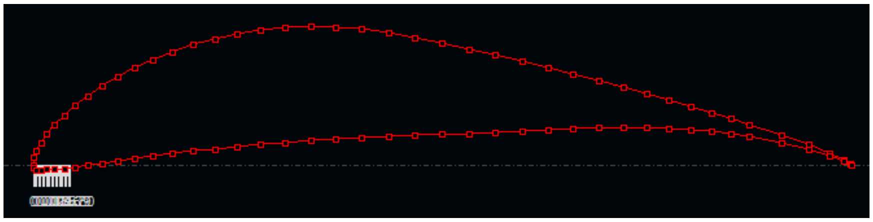


Figure 28 FX-74-CL5-140

It can be seen in Figure 29 that the xflr5 software could not converge for values under 2° for the given Reynolds number, this means that only values recorded start from relative 2° and ahead. We can see that the maximum value for the coefficient of lift occurs at approximately 13°. We can see also from this graph that as the angle of attack increases so does the lift coefficient.

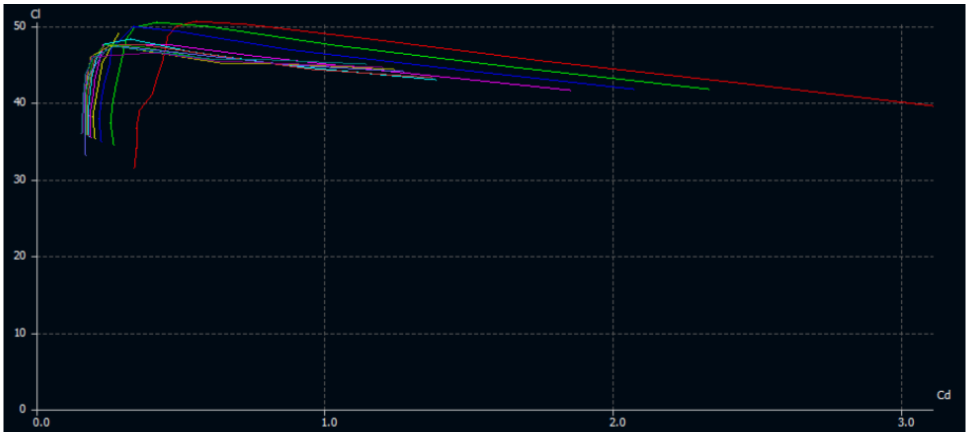


Figure 29 FX-74-CL5-140 lift vs. drag coefficients

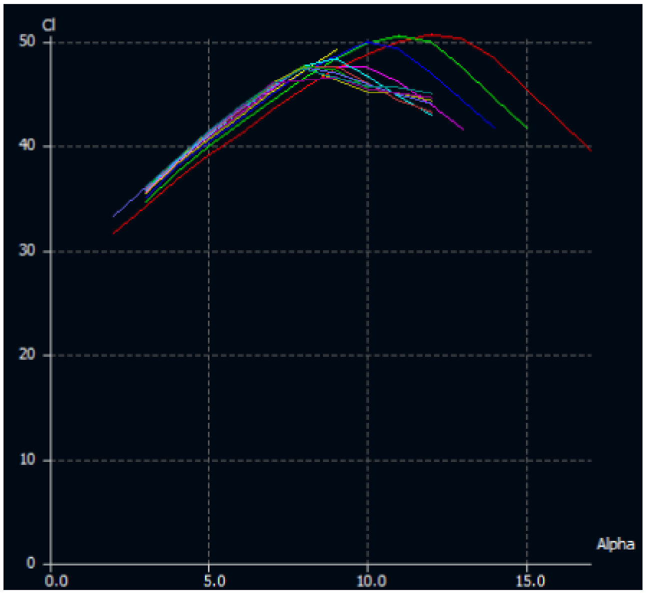


Figure 30 FX-74-CL5-140 lift vs. alpha

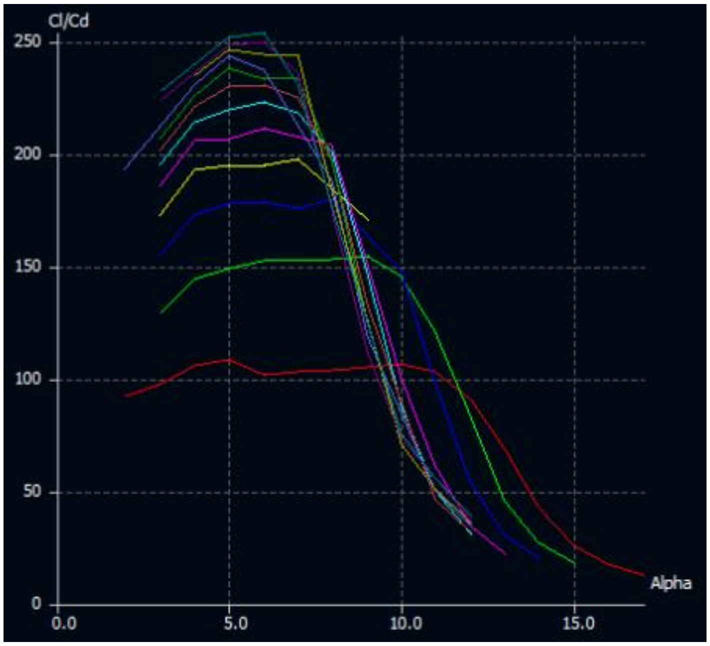


Figure 31 FX-74-CL5-140 Y airfoil ratio of lift to drag coefficients vs. angle of attack

For the FX-74-CL5-140 airfoil, the maximum value of the ratio of lift to drag coefficients occurs at an angle of 6°**.** We can also see that as the angle of attack and Reynolds number increase, this coefficient rapidly decreases starting at an 8° angle.

6.3 FX63-137

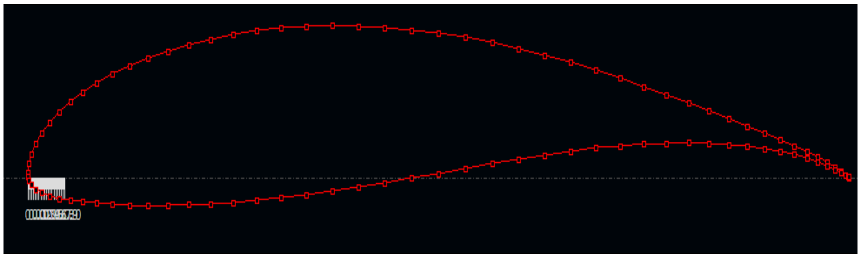


Figure 32 FX63-137 airfoil

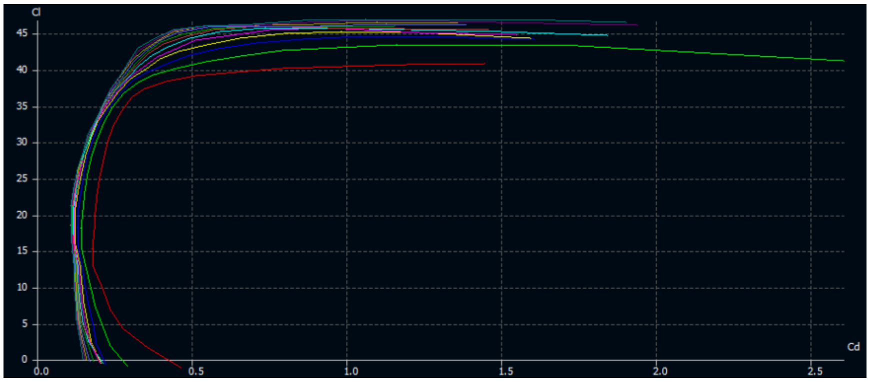


Figure 33 FX63-137 airfoil Lift vs. drag coefficients

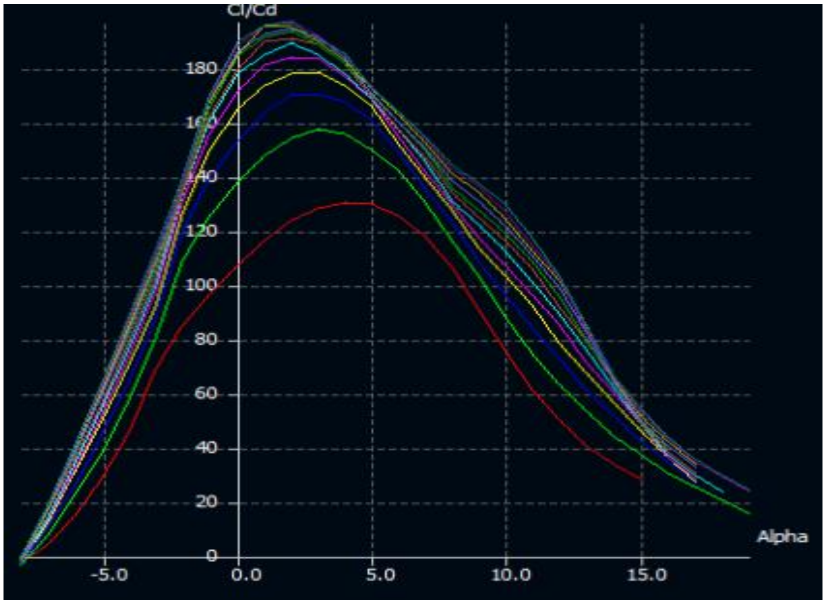


Figure 34 FX63-137 airfoil. Ratio of lift to drag coefficients vs. angle of attack

The FX63-137 airfoil according to the XFLR5 program provides a maximum value of lift to drag when the angle of attack is at 2°, it also shows that the program could converge for values of angle of attack starting from -8°. There is no rapid decrease of the ratio, this ratio of lift to drag is decreasing steadily as the speed of the aircraft and the angle of attack increases. The higher the Reynolds number, the smaller the divergence of this lift to drag ratio.

To compare the analyzed airfoils with each other Profili software was used. This analysis is done from a negative angle of attack of 8 degrees to a 20 degrees angle of attack to determine stall characteristics. Figure 35 illustrates the comparison of the airfoils performed. Through the results the team decided to pick the S1223 airfoil due to its lifting properties. Although the other airfoils provided easier construction and lower drag the S1223 would allow the team to obtain the desired lift.

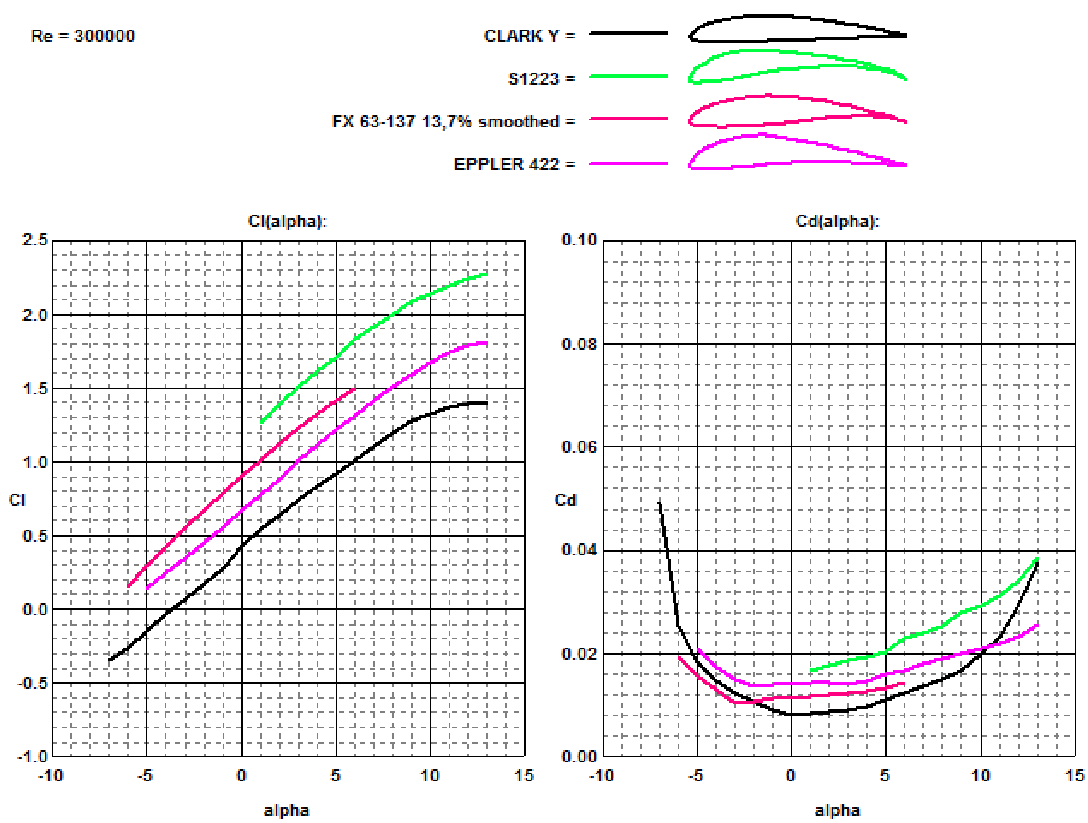


Figure 35 Airfoil Comparison

7. Computational Fluid Dynamic Analysis

Computational Fluid Dynamic (CFD) uses numerical methods and algorithms to solve and analyze problems on the flow of substances. Through the use of computers, calculations are performed to simulate the interaction of the liquid and the gases projected on surfaces. The method involves discretizing creating a region of space which is known by a space frame, and dividing this control volume into smaller volumes, called meshing. The software uses Navier–Stokes equations to solve an algebraic matrix in each cell through iterations until the residual is small enough. Even with simplified equations and high-performance supercomputers only approximate results can be achieved in many cases. Continuing research is working on making the results obtained through simulations more accurate. Verification of the data obtained by CFD is usually conducted in wind tunnels or other physical scale models. CFD will be performed on the potential airfoils to analyze their aerodynamic properties.

To begin the analysis a mesh needs to be done to obtain accurate results. The analysis will be done using 1e-6 meshing size. Due to difference in airfoils a configuration meshing was extremely difficult for the S1223 Airfoil. Our team tried meshing using different relevance centers, smoothing, max size and growth rate. The following figure illustrates the successful mesh of the model.

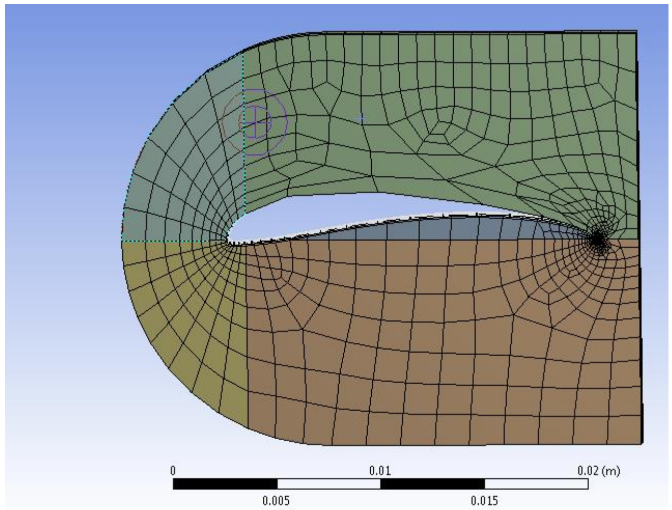


Figure 36 Airfoil meshing

To analyze the airfoil some geometry configurations need to be set up. Figure 37 illustrates the box around the airfoil which is treated as a fluid for analysis purposes. The back of this box is defined as the outlet, whereas the entire edge of the box excluding the outlet is the inlet, and the five surfaces surrounding the airfoil are the front and back surfaces.

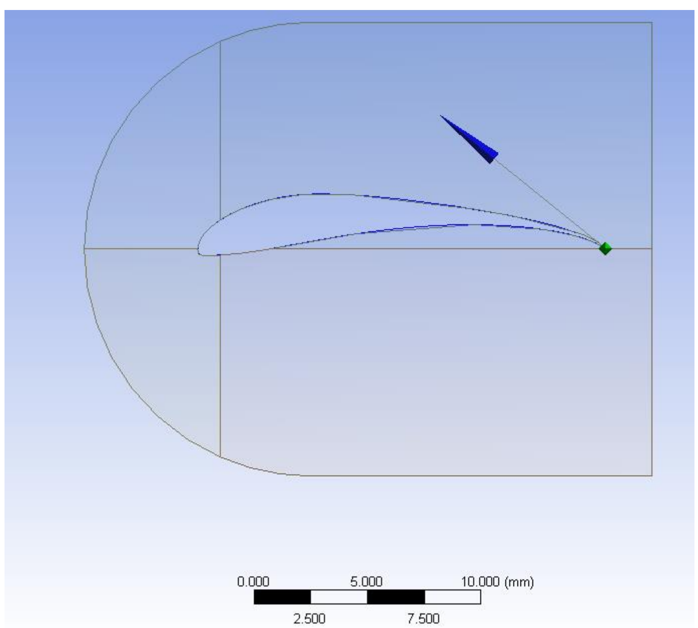


Figure 37 Geometry configuration

As it is shown from the graph on Figure 38, convergence criterion for all values was changed from 0.001 to 1e-5. This graph is the plot of the residuals vs. the number of iterations which are up to 200 in this case. Moreover, as it is shown residuals rise at first and then slowly start to fall. However, there is also some fluctuation or up and down motion of the residuals. These are called reverse flow and disappear as the number of iterations increases.

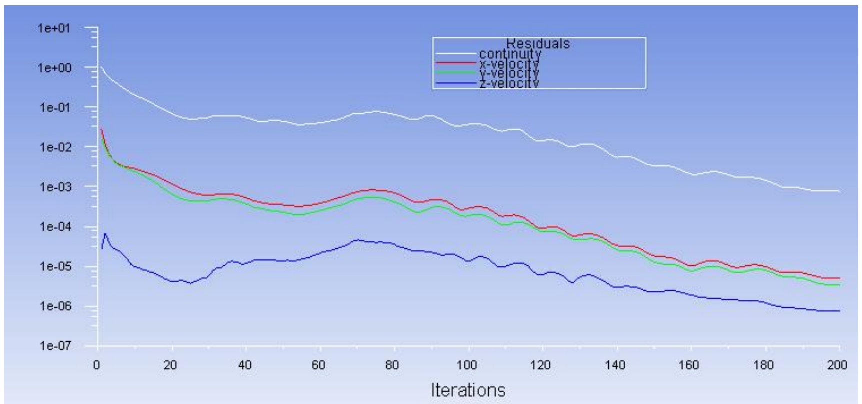


Figure 38 Residual Plots

This Figure 39 comes from the graphics and animations vectors set up. By displaying the interior part fluid surfaces under a multiplied scale of ten. Here, colors display the magnitude of velocity.

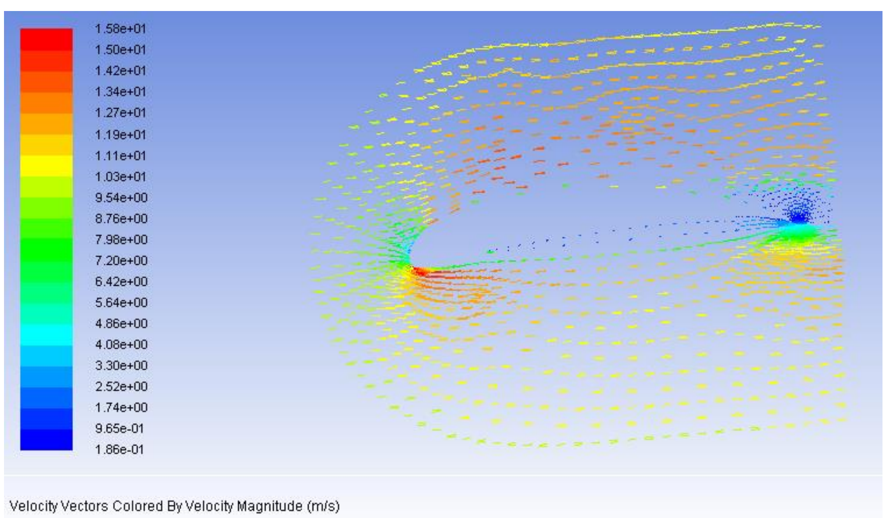


Figure 39 Velocity profile

Figure 40 is a plot of velocity, where it is shown that three profiles (0.0,0.05,0.2) reach the free stream velocity of 10 m/s regardless of position along the airfoil. On this plot, the Y axis acts as a direction vector while the X axis represents the velocity plot.

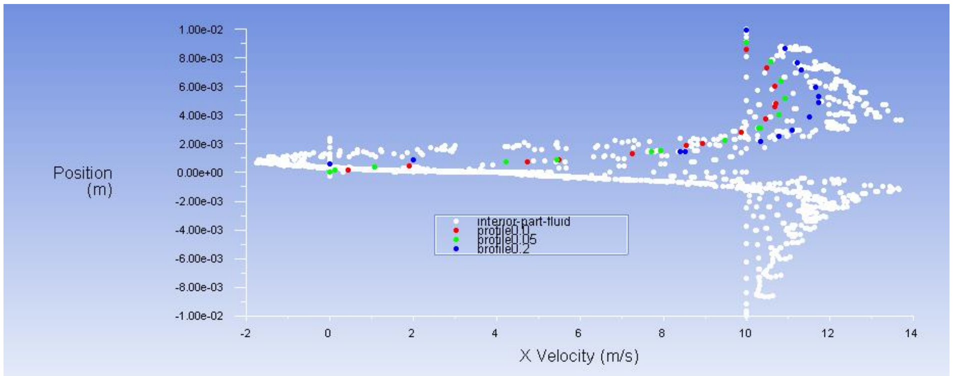


Figure 40 Velocity vs position

To analyze the lift the airfoil will produce we ran the same simulations with change of angle of attack. The velocity will remain constant but the angle of attack will be varied from zero degrees to 14 degrees in a period of two seconds. The following are the results obtained.

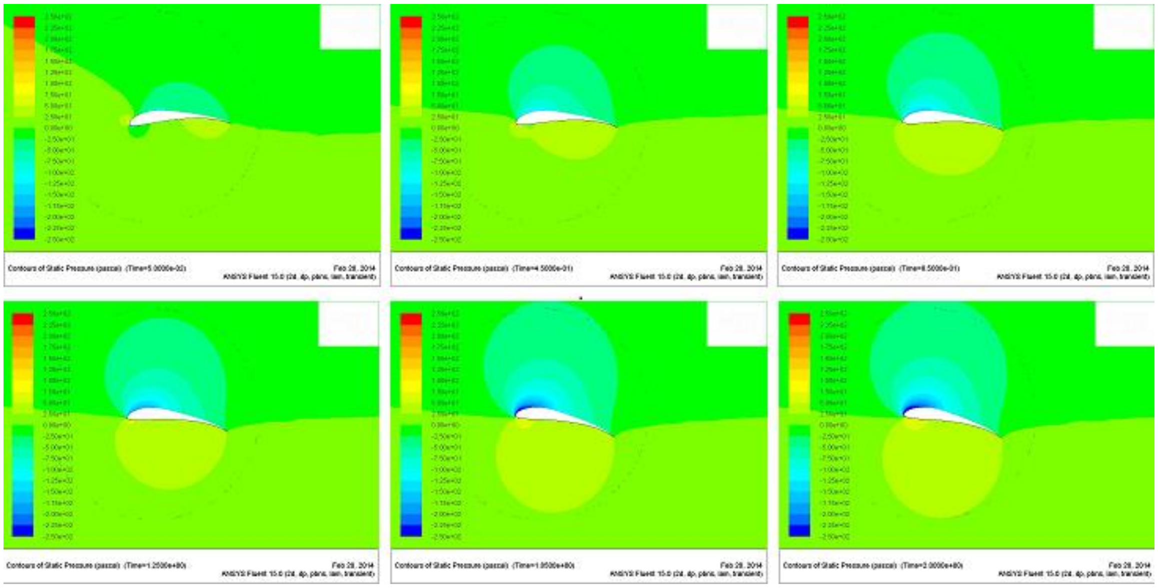


Figure 41 CFD variable angle of attack

Through the results it is noticeable that at a zero angle of attack the airfoil will not produce the required pressure to obtain enough lift. Therefore, it is calculated that through the iterations performed the incident angle on the wing should be around 3 degrees to obtain enough lift to have the aircraft airborne.

8. Project Management

8.1. Overview

Behind a successful project is good project management. In order for the team to achieve a successful design, the team will be challenged to comply with the competition requirements, time, quality and budget. Through project management we will be able to organize tasks to the team efficiently to meet project deadlines, maintain a desired budget, and monitor and control the development of the aircraft.

8.2. Breakdown of Work into Specific Tasks

This development of the aircraft consisted of three phases; design, manufacture, and validation & testing. For the design phase, the design of the airplane broke down into three main components; structure, propulsion, and electrical. The design of the airplane was distributed between the members based on the components required. Some components such as wing design require more than one team member to assist in the design process.

Once the design phase was completed we began the construction of the airplane. This will be distributed between the team members based on the skill they feel more comfortable with.

Throughout the development of the aircraft, testing was performed to the parts designed to evaluate whether their characteristics meet the desired results. For this we used finite element analysis, computational fluid dynamic analysis, wind tunnel testing, and bench testing.

8.3. Breakdown of Responsibilities among Team Members

The responsibilities on each member where distributed taking into consideration their expertise in the area. Table 7 represents the division of responsibilities among the team members. The task assigned to each member will make that student the leader in the specified task. Nevertheless, team members will assist each other in all aspects of the project.

Table 7 Division on Workload

Task	Designated Member
Research	All members
Fuselage Design	Fred Al-Abdala
Wing Selection	Luis Vallejos
Empennage Design	Claudia Eyzaguirre
Design Analysis	Claudia Eyzaguirre
Bench Testing	Fred Al-Abdala
Wind Tunnel Test	Luis Vallejos
Construction	All members

8.4. Organization of Work and Timeline

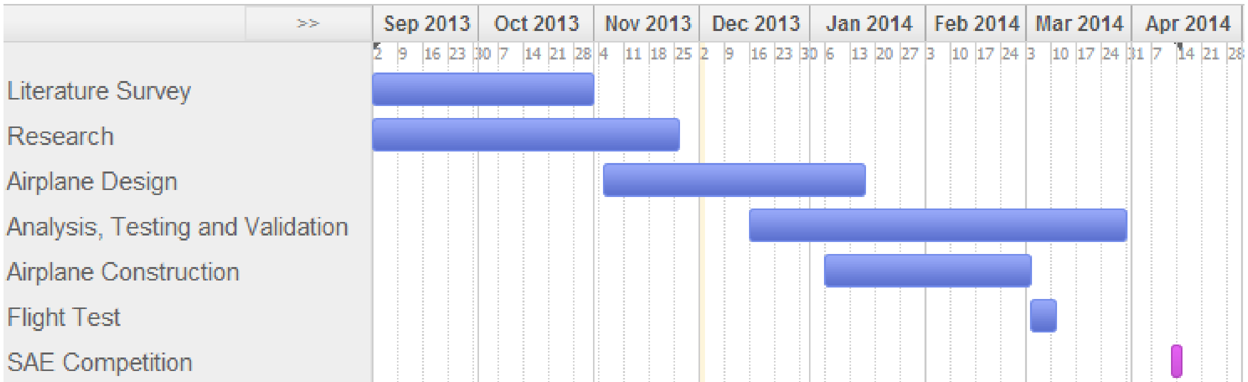


Figure 42 Project Timeline

9. Analytical Analysis

9.1 Kinematics Analysis

Using the laws of kinematics we will guarantee the performance of our aircraft. Our main concern is having enough lift to be able to induce flight. Knowing the take-off distance limit for our competition and the kinematic equations for linear motion all we need is the information of the coefficients of the wings aerodynamics. To induce flight the aircraft needs to be able to produce enough thrust force to achieve the necessary lift.

From kinematics:

$$\sum F = m * a$$

$$a = \frac{\sum F}{m}$$

Where:

$\sum F = sum\ of\ forces$

$a = acceleration$

$m = mass\ of\ the\ aircraft$

$$\sum F = F_{motor(thrust)} - F_{friction} - F_{drag}$$

Knowing acceleration, we can use kinematics to find velocity as follows:

$$V^2 = {V_O}^2 + 2 * a * \Delta x$$

Where:

$V^2 = Take\ off\ velocity$

$V_O = initial\ velocity, starts\ from\ rest = 0$

$\Delta x = takeoff\ distance$

Solving for the acceleration:

$$a = \frac{V^2}{2 * \Delta x}$$

Substituting back into the acceleration equation:

$$\frac{V^2}{2 * \Delta x} = \frac{\sum F}{m}$$

This means that the minimum truss force needed for lift is equal to:

$$\frac{V^2}{2 * \Delta x} * m + F_{friction} + F_{drag} = \sum F_{motor(thrust)}$$

All of these unknowns need to be specified in order to solve for the minimum motor thrust. We know that the force of friction is produced between the tires of the aircraft and the takeoff pavement. This means that we approximate the friction coefficient; we also know that the drag force can be calculated from wind tunnel testing and it is dependent on the takeoff velocity and the aircraft configuration.

After the building phase and wind tunnel testing, we will know the mass of the wings, payload, and aircraft's fuselage (including components).

9.2 Wings

The wings of the aircraft are an essential component to the performance of the plane. Hence, an analysis of the forces that exists along the wing and in the body of the aircraft is of great relevance. In order to determine the forces that exist on the wings when attached to the fuselage, we threat this case as a simple cantilever beam that experiences a distributed load along its length. This load is the lifting force.

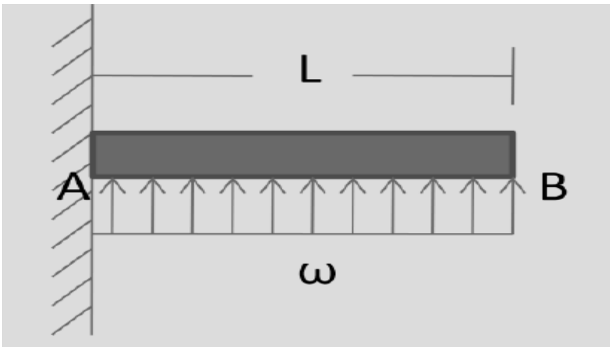


Figure 43 Loading on beam

From the diagram above, we can calculate the shear and bending moment diagrams that the wings experience along its entire length. To obtain the necessary forces at any point in the beam, we pick a section and cut the beam at an arbitrary point we will call C. this point C must be between point A and B. we must then replace the distributed load and include the resultant force. This resultant force is equal to the load times half of the beam's length. In this new section, the beam will experience a moment and a shear force, which are represented in the free body diagram.

The new free body diagram is as follows:

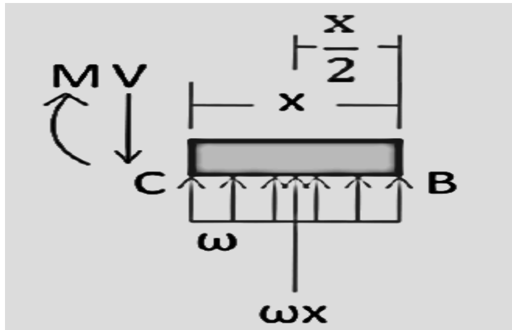


Figure 44 Moment calculation

To calculate the free body diagram, both the shear force and moment must be defined. Using the laws of Kinematics:

$$\sum F_Y = 0;$$

$$\omega * x - V = 0$$

$$V = \omega * x$$

Where:

$$V = Shear\ force$$

$$\omega = Lift\ force$$

$$x = Distance\ from\ the\ beam'starting\ edge.$$

$$M = Moment$$

Known for the Moment at arbitrary point C:

$$\sum M_c = 0;$$

$$\omega * x * \frac{x}{2} - M = 0$$

$$M = 0.5 * \omega * X^2$$

As expected, maximum shear and moment values occur at the point where the wing is attached to the fuselage and at the center point of both wings. This is due to the payload weight adding to the lift force of the aircraft. We took this condition in consideration when designing our fuselage; this is why the fuselage we design has additional truss supports in the payload cargo to sustain these peak forces in the aircraft.

The main goal is to avoid breaking the wings attachment to the fuselage during flight or take off.

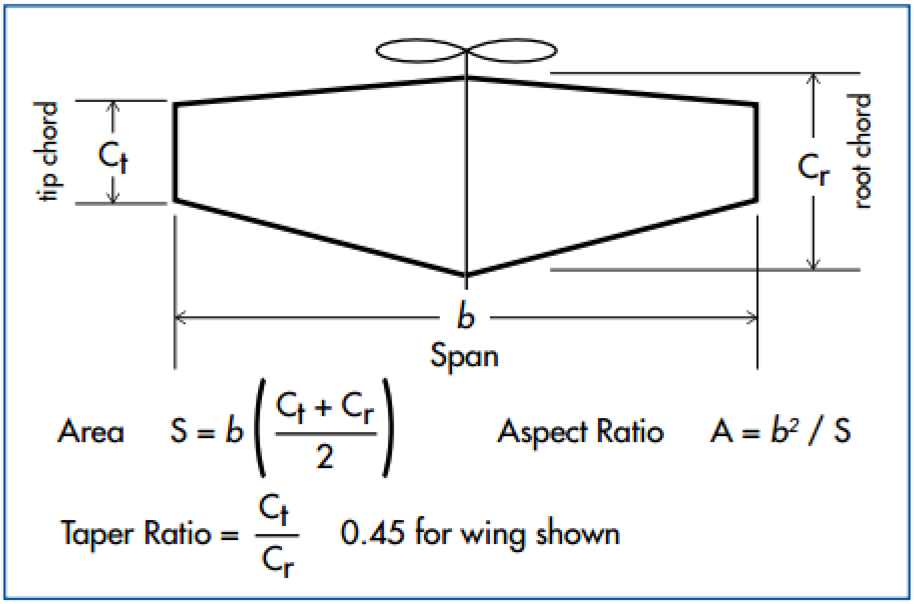


Figure 45 Tapered wing ratio

For the design of the wing a tapered design was considered to obtain higher stability as well as lift. Figure 45 shows the calculations needed to find the tapered wing ration. We will use 45% for the ratio since it will be as efficient as using an elliptical shape wing. The airfoil selected for the design will be the S1223 based on research made on airfoils for heavy lift cargo planes (Selig, 1995).

For the wing design Sadrey's method was used. The drag polar of the airfoil selected was evaluated to determine the incident angle of the wing. To facilitate construction, the same airfoil was selected at the root and tip of the wing. An aspect ratio of 5 was determined based on the surfaced obtained and desired wing span. The lifting line theory was used to analyze if the wing parameter chosen will result in an elliptical distribution. By solving several aerodynamic equations simultaneously, the amount of lift that a wing is producing can be determined. Using MathLab to solve the equations we evaluated using our design parameters. Figure 46 illustrates the results obtained, since the lift distribution was an elliptical shape no modifications are needed on the wing's selected parameters.

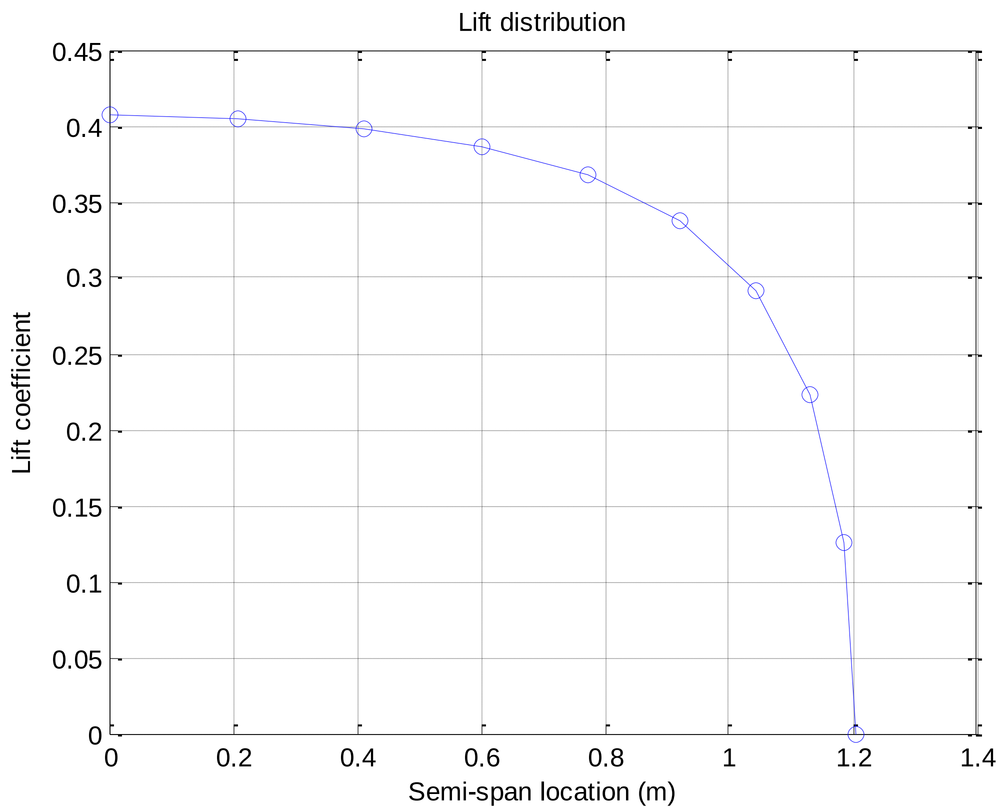


Figure 46 Lift Distribution

9.3 Fuselage

It is important to try to make the surface of the airplane as rounded as possible or on the contrary it will experience separation drag. Aircraft structural members are designed to carry loads, and every square inch of every component must be considered in relation to the physical properties of the material of which it's made. Five mayor stresses contribute to the aircraft analysis; these are tension, compression, torsion, shear and bending. For our design we are placing the heaviest structural members at intervals were concentrated loads exists, and at points where other elements such as stabilizers and the wings attach.

For our design we are building a warren truss fuselage. They are the second best fuselages possible when flying scale aircrafts. Truss fuselages can manage tension and compression loads, they are light and are usually riveted or bolted into one piece. Usually trusses are made of balsa wood or aluminum. Another reason of why we chose truss fuselage is due to their high strength to weight ratio and extreme rigidity.

In this design, compound trusses are used. Compound trusses are constructed by connecting two or more simple trusses to form a single rigid body. A simple truss is composed of three members that form a triangle.

When analyzing trusses, it is assumed that the centroid axis of each member coincides with the line that connects the center of the adjacent members. It is also assumed that members carry only axial force and that they are connected by frictionless hinges. In the same manner, all loads and support reactions are applied at joints only.

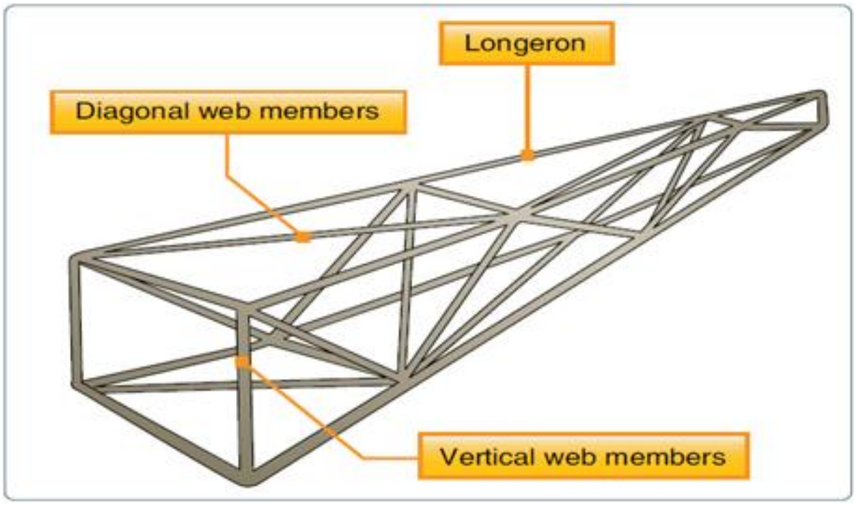


Figure 47 Warren Truss

Deviations occur in our design since not only axial forces exist, but also shear and bending forces thus the truss is analyzed as a frame. When dealing with truss, zero force members need to be defined in order to cut down the number of unknowns when solving the equations. A zero force member is found when two members that are connected to a joint have no external loads or reactions applied to it. Or when three members are connected to a joint, from which two are collinear, and the joint has no support or external loads. To test for failure in each member in the fuselage, two methods can be used to determine the forces of the members. These methods are the method of joints, and the method of sections which will be used to determine the tension and compression loads at each element in the truss frame.

Trusses can also fail by buckling, which is given by the formula:

$$P_{cr} = \frac{\pi^2 * EI}{(k * L)^2}$$

Where

P_{cr} Buckling force.

K=effective length factor (it is equal to one for ideal truss).

$E = Young\ modulus$

$I = moment\ of\ inertia$

9.4 Aerodynamic Performance

To analyze the performance of the motor and propeller selected the software MotoCalc was used. By entering the plane parameters and the parameters of the motor, battery, and speed controller selected we can obtain a plot of the thrust and lift produced by this selection. Through this software we are able to change components and see how the power plant will behave. This helps to narrow down the options on motor, propeller, and battery combination to reduce cost in testing by only purchasing the best options. Through the program we selected two motors that will be tested as well as a range of propellers. The battery discharge rate that gave the best performance for our needs was 30C.

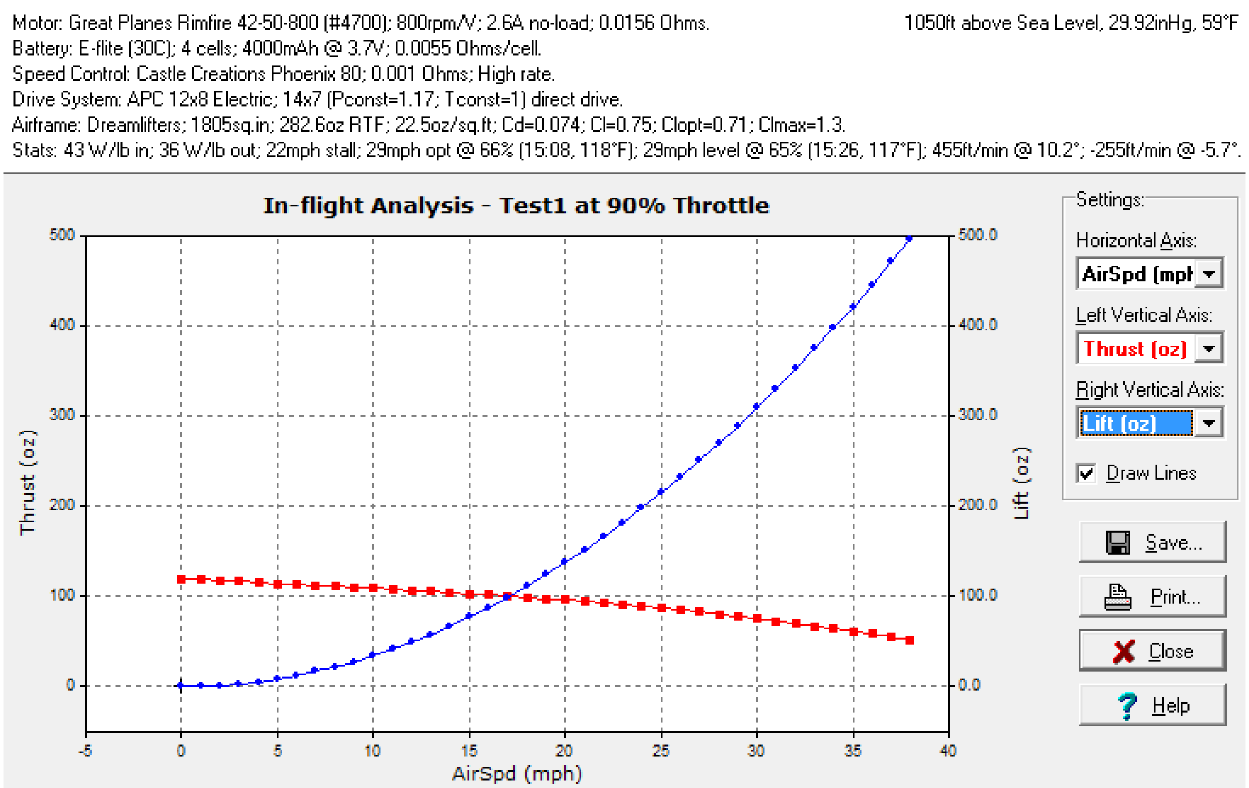


Figure 48 Thrust Analysis

Through this program we are able to see that the maximum watt input will be 763.5 watts which will be below the 1000 watt limit.

9.5 Aircraft Sizing

9.5.1 Tail Design

A very important component in design is aircraft stability. Aircraft stability is defined as the tendency of an aircraft to return to the original trim conditions if diverted by a disturbance as is gust. The major function of the tail is to provide control. The elevator, located in the horizontal stabilizer, provides longitudinal control, while the rudder, located on the vertical stabilizer, provides the directional control. The purpose of the vertical tail is to generate a yawing moment to balance the aircraft. The vertical stabilizer needs to counteract the rolling moment generated by propeller rotation. This is to maintain aircraft lateral trim and prevent an unwanted roll. To obtain stability the aircraft must at trim, meaning the aircraft will not rotate about its center of gravity. To accomplish this the summations of all forces and moments must be zero about each. Tail size was designed using historical guidelines. To calculate the area of the horizontal and vertical stabilizer the following formulas where used.

$$S_{VT} = \frac{c_{VT} b_w S_W}{L_{VT}}$$

$$S_{HT} = \frac{c_{HT} C_W S_W}{L_{HT}}$$

Where c_{VT} and c_{HT} are the tail volume coefficients, b_w is the wing span, S_W is the wing surface area, L are the vertical and horizontal tail moment arms, and C_W is the wing chord. Since we are using a twin tail, the value obtained for S_{VT} is the sum of both vertical tails. The moment arm is measure from 25% of the chord's length. Illustrates each of the previously described parameters on the aircraft.

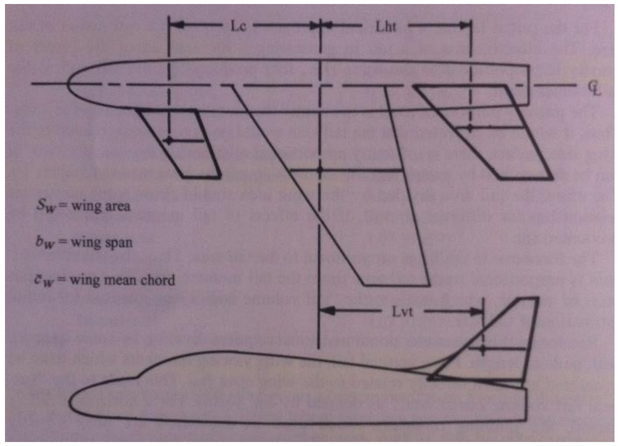


Figure 49 Initial Tail Sizing (Raymer, 2006)

The values for the volume coefficient was obtained from historical data. Table 8 represents typical values of horizontal and vertical tail volume coefficients based on aircraft application. We will be using the values reflected for homebuilt aircraft. This values are also the same if an agricultural aircraft was chosen which also complies with the desired aircraft features.

Table 8 Typical Volume Coefficient Values

No	Aircraft	Horizontal tail volume coefficient ($\bar{V}_H$)	Vertical tail volume coefficient ($\bar{V}_V$)
1	Glider and motor glider	0.6	0.03
2	Home-built	0.5	0.04
3	GA-single prop-driven engine	0.7	0.04
4	GA-twin prop-driven engine	0.8	0.07
5	GA with canard	0.6	0.05
6	Agricultural	0.5	0.04
7	Twin turboprop	0.9	0.08
8	Jet trainer	0.7	0.06
9	Fighter aircraft	0.4	0.07
10	Fighter (with canard)	0.1	0.06
11	Bomber/military transport	1	0.08
12	Jet Transport	1.1	0.09

When determining the aspect ratio of the tail a lower aspect ratio is desired; this is because the deflection of the elevator creates a large bending moment at the tail root. Therefore, a lower aspect ratio results in a smaller bending moment. The aspect ratio of the tail was obtained based on data from the following table;

Table 9 Tail Aspect Ratio (Raymer, 2006)

	Horizontal tail		Vertical tail	
	A	λ	A	λ
Fighter	3–4	0.2–0.4	0.6–1.4	0.2–0.4
Sail plane	6–10	0.3–0.5	1.5–2.0	0.4–0.6
Others	3–5	0.3–0.6	1.3–2.0	0.3–0.6
T-Tail	—	—	0.7–1.2	0.6–1.0

A factor that must be taken into consideration when designing the tail is its location. The location of the horizontal tail is critical to the stall characteristics of the aircraft. The aircraft will become unstable and picthup may happen if the tail enters the wing wake during stall. To avoid this we used Figure 50 as a guide to select the wing location. Since we are flying at subsonic speed the location where our parameters land on the plot are acceptable.

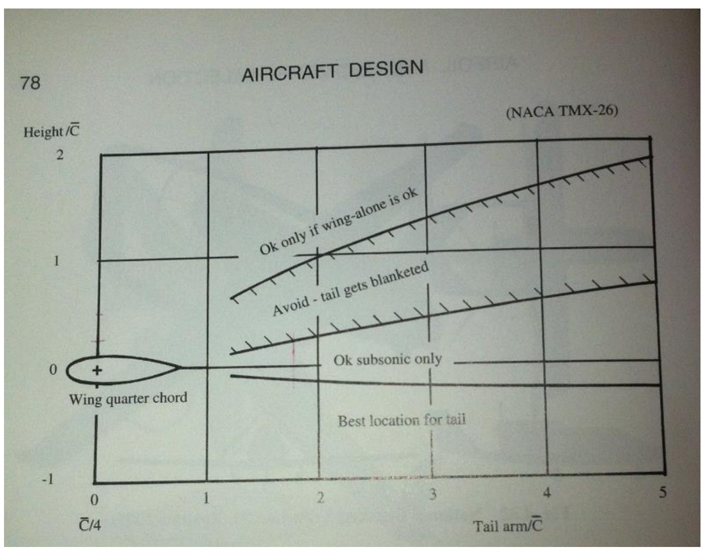


Figure 50 Aft Tail Positioning

9.5.2 Control Surfaces

The elevator in the horizontal tail is designed to provide longitudinal control, while the rudder as part of the vertical tail is responsible for providing the directional control. As a rule of thumbs for control surfaces, ailerons should be around 25% of the chord and 25% of the span, Rudders

25% of stabilizer area, and Elevator 12% of stabilizer area.

10. Servo Sizing

The formula used to calculate the torque is as follows:

$$T = 8.5 \times 10^{-6} \cdot \frac{C^2 V^2 L \sin S1 \tan S1}{\tan S2}$$

Where:

C = Control surface chord in cm

L = Control surface length in cm

V = Speed in MPH

S1 = Max control surface deflection in degrees

S2 = Max servo deflection in degrees

- Control linkages have zero offset at hinge line and are perpendicular to horns at neutral.
- Control mechanisms are frictionless and surfaces are mass-balanced.
- The pushrods are longer than the servo and control horns.

	Aileron(s)	Elevator(s)	Rudder
Average control surface chord (cm)	10.16	7.62	15
Average control surface length (cm)	38.1	81.28	25.4
Maximum deflection of servo arm from center (degrees)	40	40	50
Maximum deflection of control surface from center (degrees)	25	25	35
Maximum required torque at maximum airspeed (oz-in)	12.6	15.1	26.2

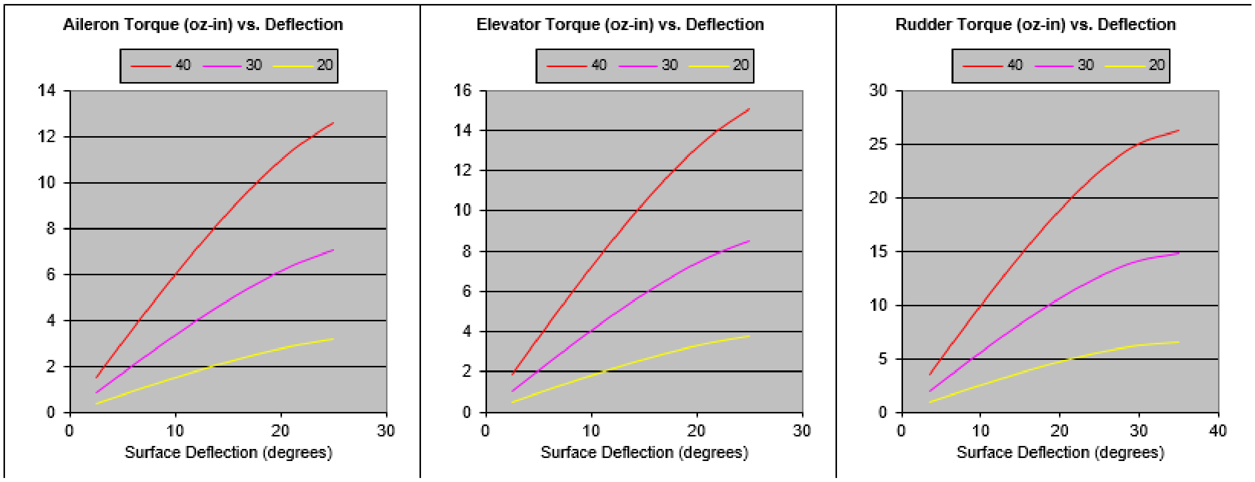


Figure 51 Servo Torque vs Deflection

11. Major Components

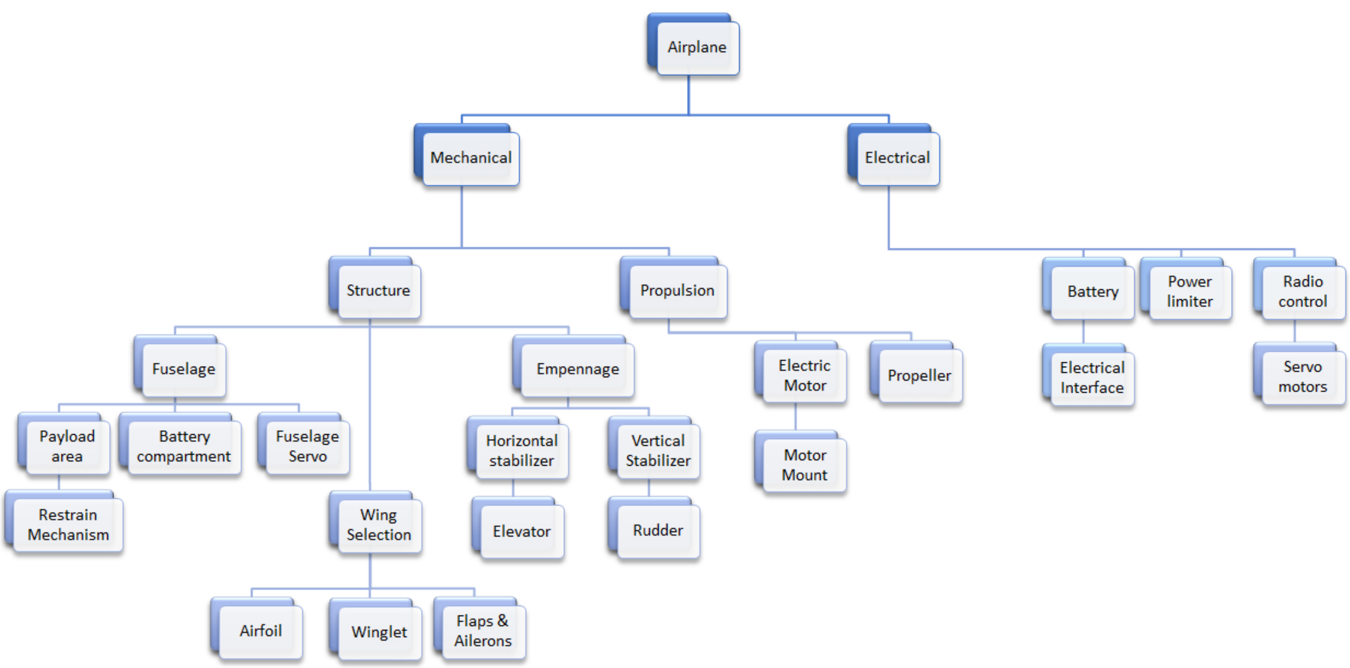


Figure 52 Product Hierarchy

The airplane is broken down into two main systems, mechanical and electrical. Figure 52 illustrates the major component of each system. Components that were designed include the fuselage, wings, and empennage. The electrical components along with the propulsion system for the aircraft will be purchased from available suppliers. The team placed emphasis on the design and optimization of the wings, fuselage, and empennage to attain high lift capacity.

12. Proposed Structural Design

11.1 Wings

The structure on the wing will be constructed using Balsa wood to make the structure light allowing for more payload to be lifted. Leaving the wing as one piece will give more support and less reinforcement will be needed to support the structure. A drawback to this option will be limited access to the payload area. Since the competition requirements specify that the payload needs to be loaded through the top of the aircraft, having a one piece wing might become inconvenient.

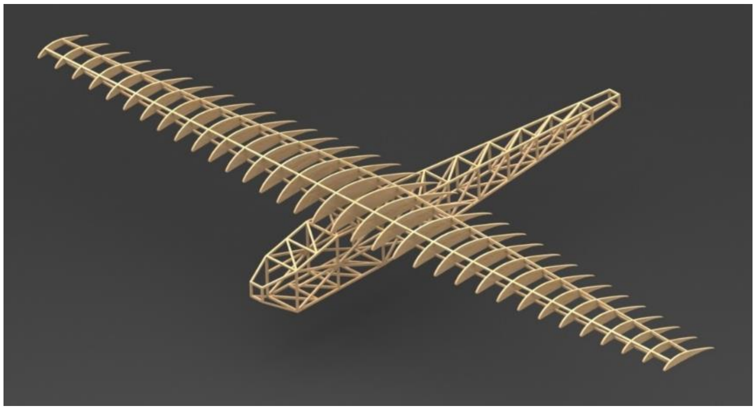


Figure 53 Structure of Wings and Fuselage

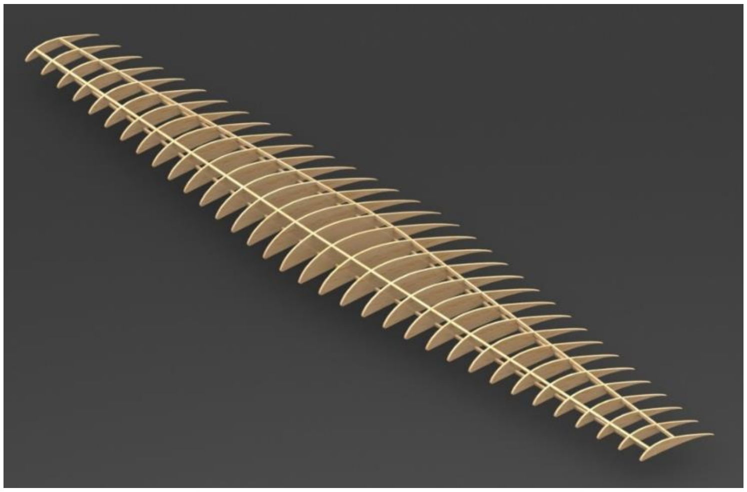


Figure 54 Wing Structure

The structure of the wing will be improved using SolidWorks's finite element analysis to decrease the number of ribs needed in the structure and so reducing weight and material costs. Figure 56 illustrates the mid-section of the wing and the selected airfoil.

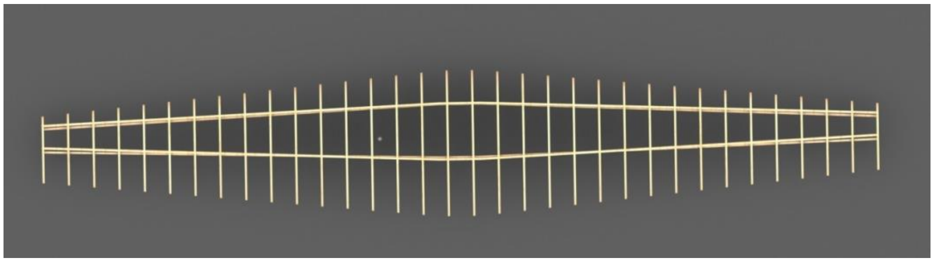


Figure 55 Top view of wing

Figure 56 Section cut of wing

11.2 Fuselage

Similar to the wings, the fuselage structure will be analyzed using SolidWorks to determine reliability in the structure, as well as, improving the fuselage to reduce cost.

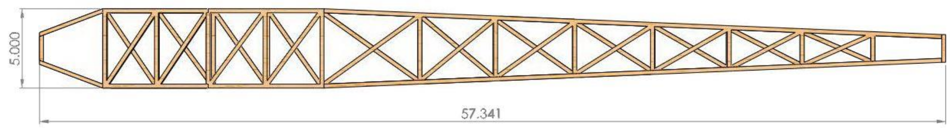


Figure 57 Fuselage top view

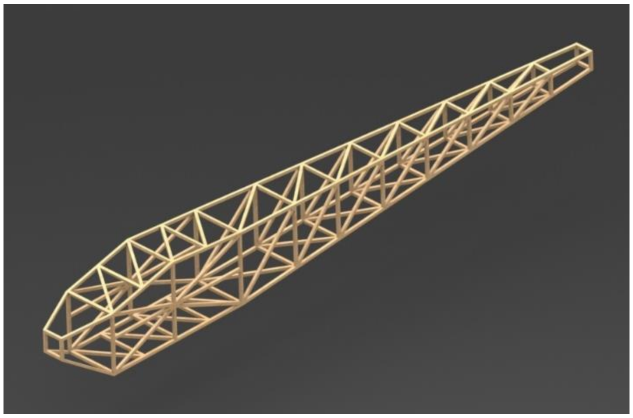


Figure 58 Fuselage Structure

Figure 59 Front view of fuselage

11.3 Empennage

For the empennage the team selected an H-tail design. This shape will give the aircraft the stability it requires and at the same time it will help to obtain a higher wing span since the vertical stabilizer does not need to be as tall to be efficient.

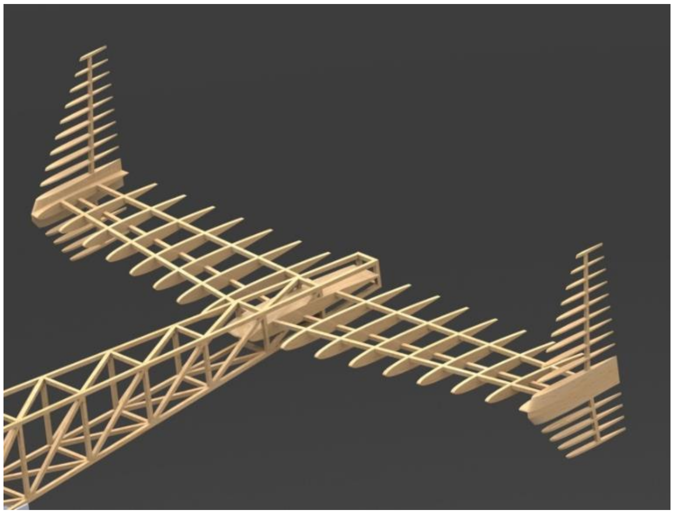


Figure 60 Empennage design

13. Structural Analysis

In order to design a competitive airplane for the competition we have to pay particular attention to the weight and efficiency of the plane. Much of its efficiency is directly related to the aerodynamic aspect of the design which tries to increase lift as much as possible while maintaining a low coefficient of drag. During the aerodynamic design process little or no attention is directed towards the structures that will sustain the loads applied to them. During this structural analysis we will evaluate different designs and materials as well as the manufacturing challenges. The materials selected for this analysis are balsa wood and 6061-T6(SS) for which their properties are listed in the following tables.

Table 10 Balsa properties

Balsa Wood		
Property	Value	Units
Elastic Modulus	3E+09	N/m^2
Poisson's Ratio	0.29	N/A
Shear Modulus	3E+08	N/m^2
Density	159.99	kg/m^3
Tensile Strength in X		N/m^2
Compressive Strength in X		N/m^2
Yield Strength	19999972	N/m^2
Thermal Expansion Coefficient in X		/K
Thermal Conductivity	0.05	W/(m·K)
Specific Heat		J/(kg·K)
Material Damping Ratio		N/A

Table 11 Aluminum Properties

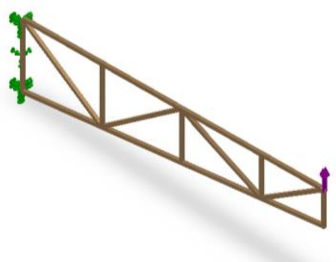
Aluminum 6061-T6 (SS)		
Property	Value	Units
Elastic modulus	6.90E+10	N/m^2
Poisson's ratio	0.33	N/A
Shear modulus	2.60E+10	N/m^2
Mass density	2700	kg/m^3
Tensile strength	310000002.1	N/m^2
Compressive Strength in X		N/m^2
Yield strength	275000000.9	N/m^2
Thermal expansion coefficient	2.40E-05	/K
Thermal conductivity	166.9	W/(m·K)
Specific heat	896	J/(kg·K)
Material Damping Ratio		N/A

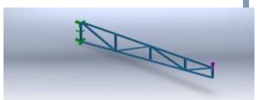
12.1 Empennage Lateral Side Sticks

Our first approach for the design of the empennage was made based on the assumption that it would be constructed fully in ¼" by ¼" balsa wood sticks. Some of the benefits of this construction are the low cost, light weight, relatively easy to manufacture and it will be easy to repair if necessary during the competition. In the other hand we had the biggest disadvantage is that the construction requires tedious work and is very time consuming.

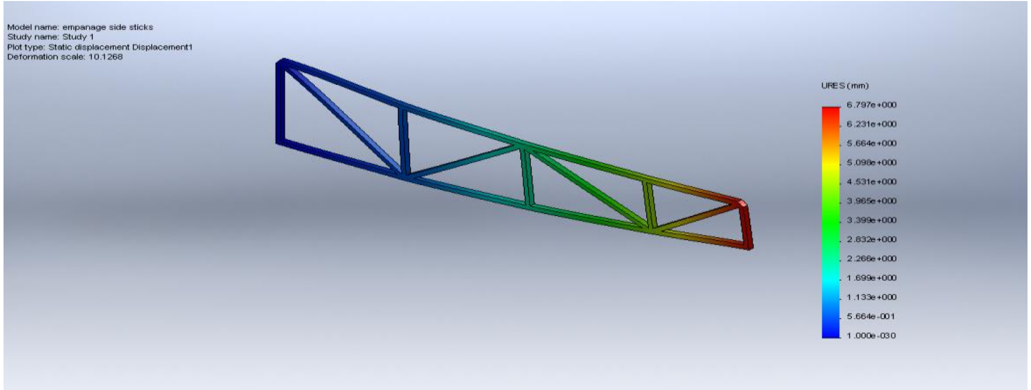
Based on a factor of safety of 1 we found the maximum load that this structure can withstand before breaking. The part was fixed at the left side of the picture as denoted with the green arrows and a load of 40N was applied upwards at the other end where the purple arrow is located. The respective plots for maximum displacement, factor of safety and total weight are shown below.

Table 12 Empennage Sticks

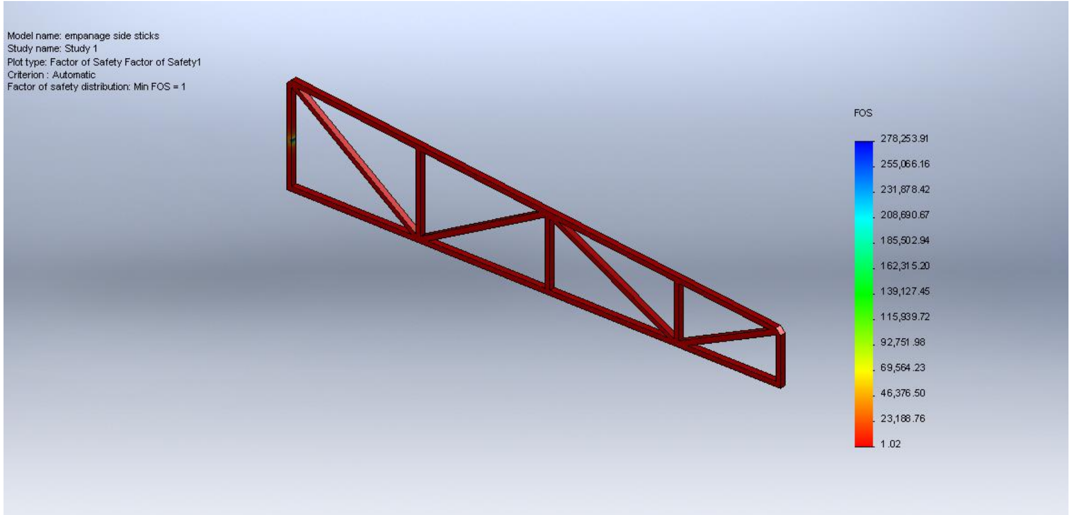


Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
	Solid Body	Mass:0.0162088 kg Volume:0.000101312 m^3 Density:159.99 kg/m^3 Weight:0.158846 N	Lateral side of empennage (1/4”sticks)

Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm Node: 509	6.79718 mm Node: 4251



Name	Type	Min	Max
Factor of Safety1	Automatic	1.01918 Node: 5004	278254 Node: 8167



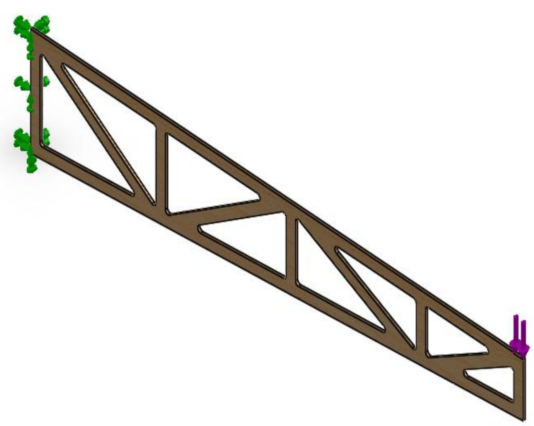
As we can see in the plots above the part was able to handle 40N of load with a factor of safety of 1 while undergoing a deformation of 6.8 mm. The total mass for this part is 101 grams.

13.2Empennage Lateral Side One Piece Laser Cut

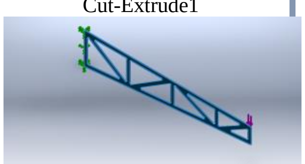
The second approach for the design of the empennage was to get its four side's laser cut in balsa wood. Among the advantages of having this parts cut for us is the assembly time that will be reduced drastically since we do not have to cut one by one the sticks and we would not have to wait as much time for the drying process. Since we are going to design each side separately we can choose the thickness and width of each section in order to make it lighter while maintaining a factor of safety of at least 1.2.

The part was fixed at the left side of the picture as denoted with the green arrows and a load of 40N was applied upwards at the other end where the purple arrow is located. The respective plots for maximum displacement, factor of safety and total weight are shown below.

Table 13 One piece empennage

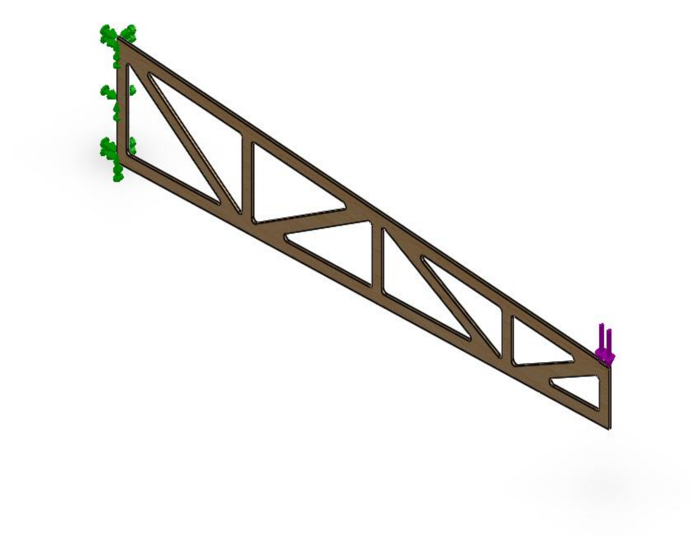


Empennage Laser

Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude1 	Solid Body	Mass:0.0146945 kg Volume:9.18462e-005 m^3 Density:159.99 kg/m^3 Weight:0.144006 N	Lateral side of empennage (Laser cut)

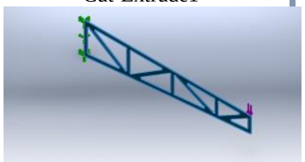
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 163	7.7184 mm Node: 1396

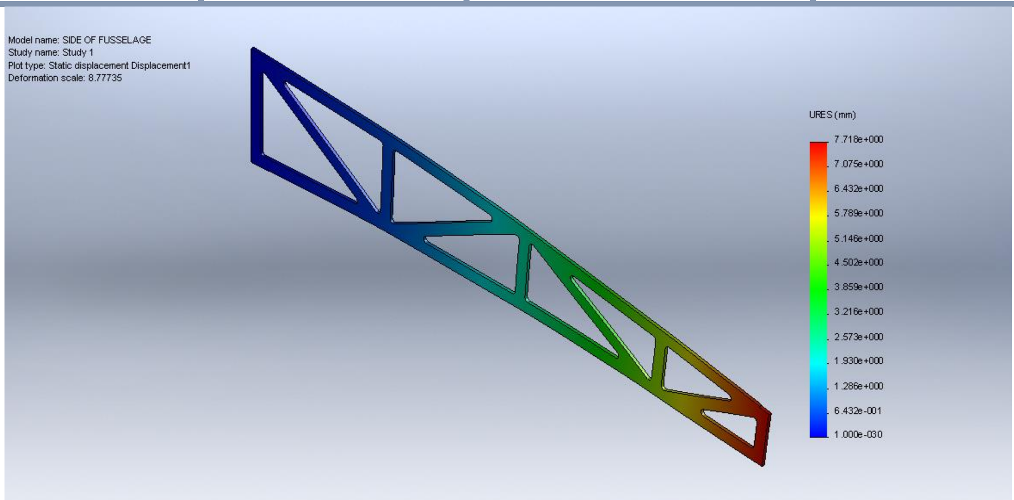
Table 13 One piece empennage



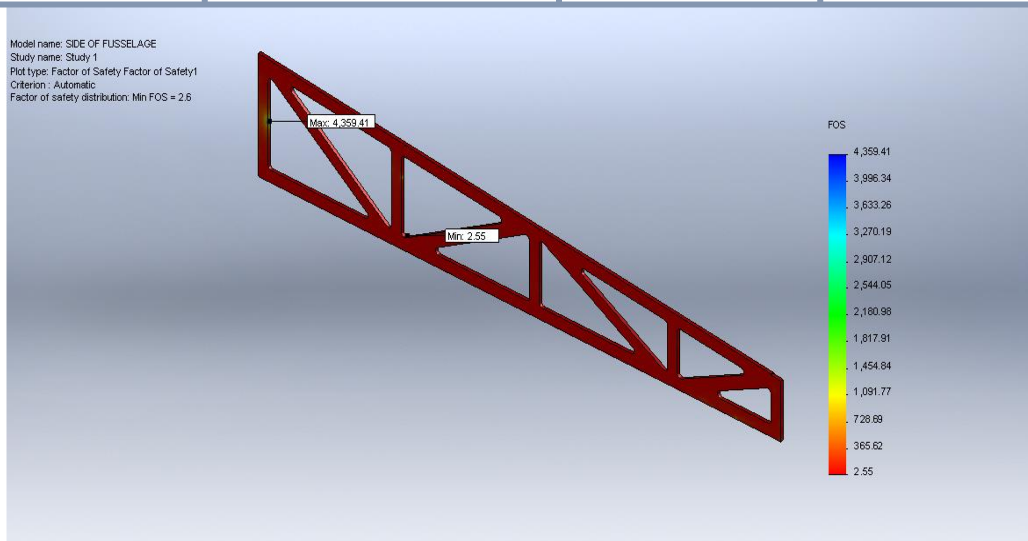
Empennage Laser

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude1 	Solid Body	Mass:0.0146945 kg Volume:9.18462e-005 m^3 Density:159.99 kg/m^3 Weight:0.144006 N	Lateral side of empennage (Laser cut)



Name	Type	Min	Max
Factor of Safety1	Automatic	2.55245 Node: 3488	4359.41 Node: 8066



Empennage Laser FoS

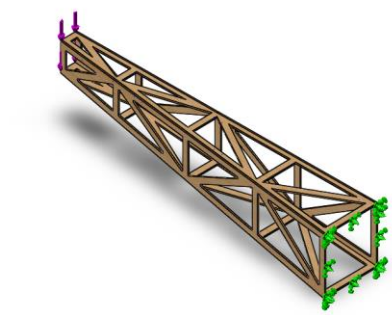
As we can see in the plots above the part was able to handle 40N of load with a factor of safety of 2.55 while undergoing a deformation of 7.7 mm. The total mass for this part is 85 grams. As a result of these parameters we have chosen to construct our empennage with the laser cut process since we are applying the same load we obtained a factor of safety 2.5 times greater than the sticks while making it 16 grams lighter. The maximum deflection was affected by less than 1mm with respect to the other design which is acceptable considering that the total length of the empennage is 673 mm (26.5”). The only disadvantage of using this design is the higher cost of manufacturing which is compensated with the faster construction of the part.

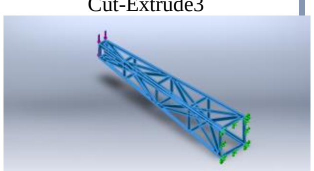
12.3 Empennage Structure

After making a selection on the manufacturing process of the empennage we designed the entire section and performed simulation analysis in Solidworks in order to establish the maximum loads and torques that the structure would sustain without failure.

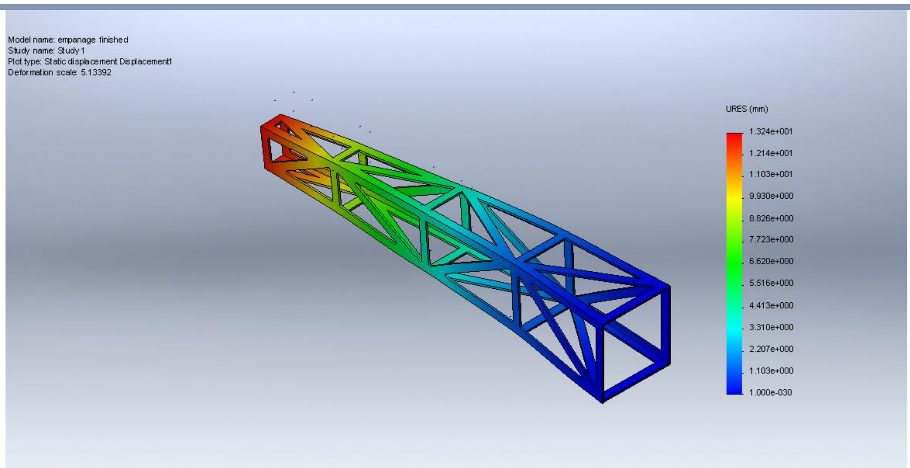
The structure was fixed at the right side of the part where it will connect to the payload area as denoted with the green arrows and a load of 220N was applied downwards at the other end to simulate the force applied by the tail in the fuselage, the purple arrows show the location of such force. The respective plots for maximum displacement, factor of safety and total weight are shown below.

Table 14 Empennage Structure

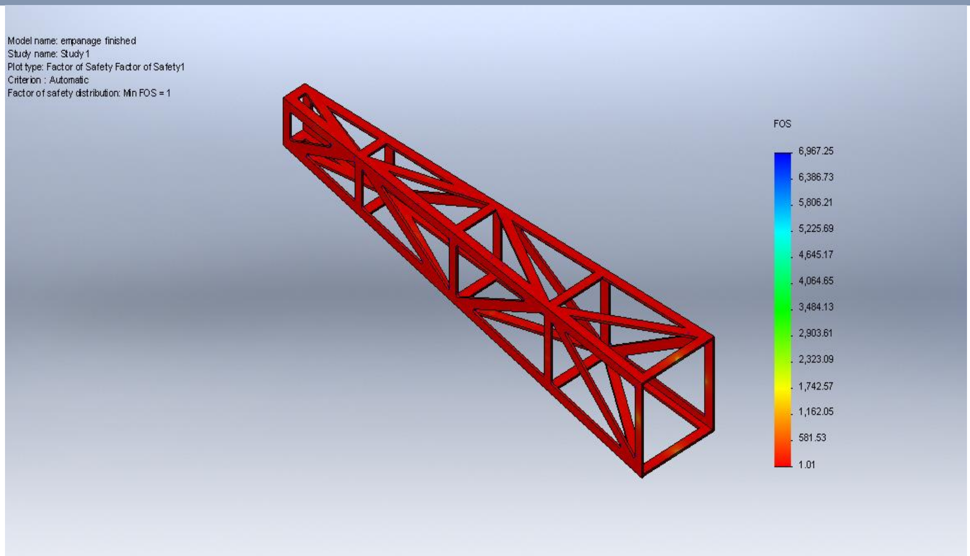


Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude3 	Solid Body	Mass:0.0503966 kg Volume:0.000314999 m^3 Density:159.99 kg/m^3 Weight:0.493886 N	Complete empennage assembly (laser cut)

Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm Node: 433	13.2396 mm Node: 6704



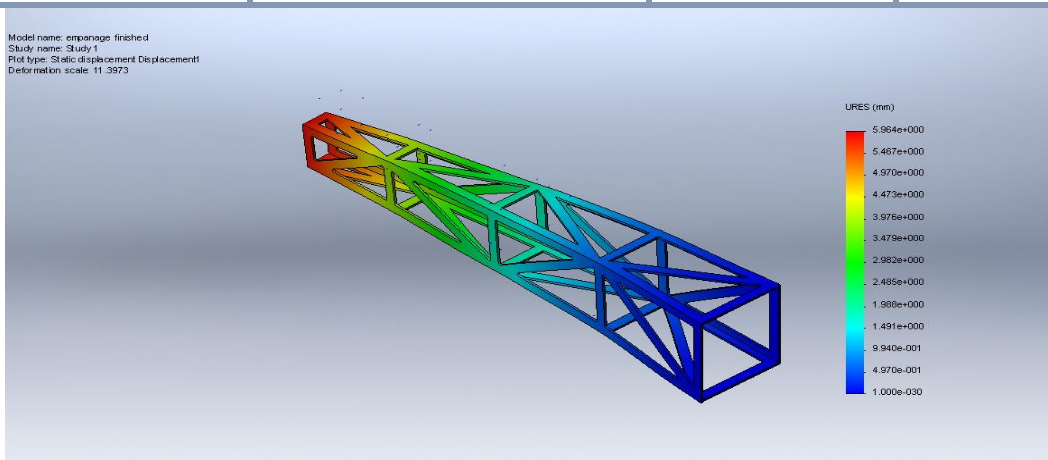
Name	Type	Min	Max
Factor of Safety1	Automatic	1.0066 Node: 1717	6967.25 Node: 17634



Empennage Structure FoS

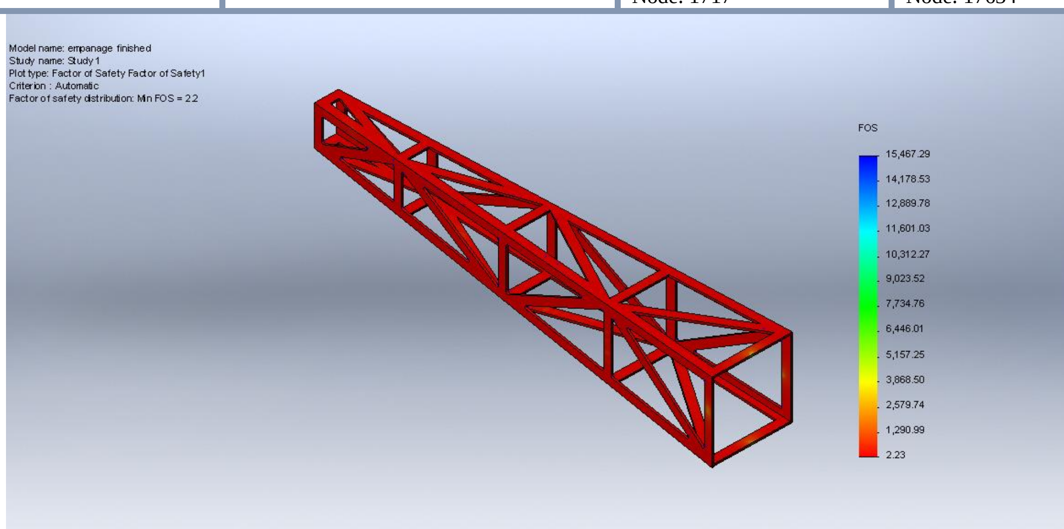
As we can see in the plots above the part was able to handle 220N of load with a factor of safety of 1.01 while undergoing a deformation of 13.2 mm. The total mass for this part is 315 grams. These values represent the maximum load and deformation that the structure can handle but they are not the values we will experience in the actual part since that maximum load generated by the tail in order to keep the plane balanced does not exceed 100N. For a more realistic value of deflection and factor of safety we re-run the simulation with a load of 100N keeping the same fixtures. The respective plots are shown below.

Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm Node: 433	5.96378 mm Node: 6704



Empennage Structure Displacement 1

Name	Type	Min	Max
Factor of Safety1	Automatic	2.23466 Node: 1717	15467.3 Node: 17634

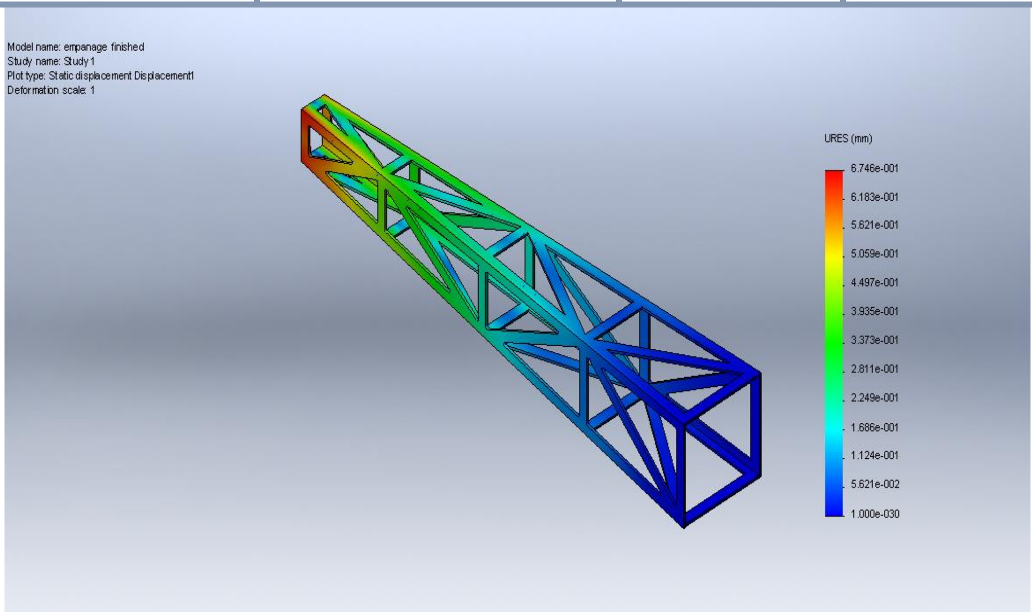


With the more realistic loads in place we obtained a maximum deflection of 5.9mm and a factor of safety of 2.2. Even though these results represent valuable data for our design, at this point we have not considered any torque that could be generated by the horizontal stabilizers of the tail along the empennage, in the following simulation results we show the effects of torque along the longitudinal axis of the fuselage.

12.4 Torque Applied

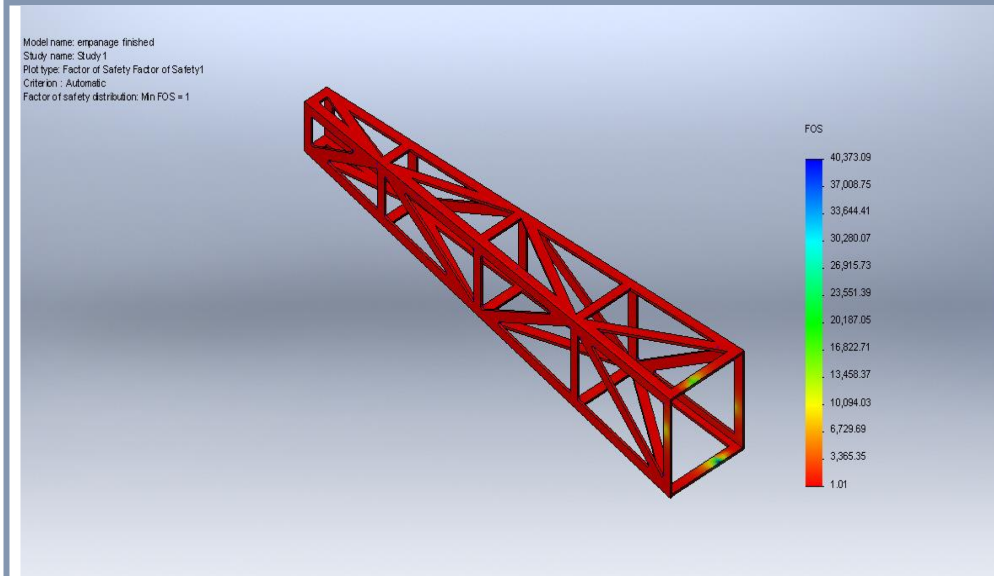
In this simulation we calculated the maximum torque that the structure will resist before failure. We started by applying the same type of fixture as in the previous two examples and adding two opposite forces, one in each side of the part, representing the possible moments applied by the tail.

Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm Node: 273	0.67456 mm Node: 2477



Empennage Structure Displacement

Name	Type	Min	Max
Factor of Safety	Automatic	1.00897 Node: 14092	40373.1 Node: 3526

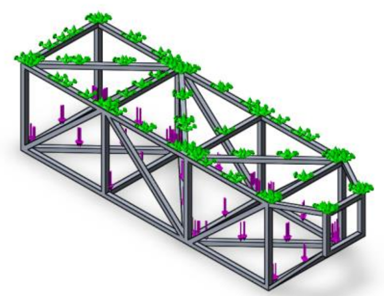
Name	Type	Min	Max
			

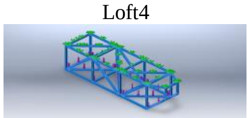
As we can observe in the previous plots, the structure was able to withstand 90N/cm with a factor of safety of 1.01. We can see how the maximum deflection due to torque is negligible reaching only 0.67mm. With these values in place we can be certain that the empennage will not fail due to the torques applied to it or the up and down forces generated by the tail in order to keep the airplane stable.

12.5 Payload Aluminum

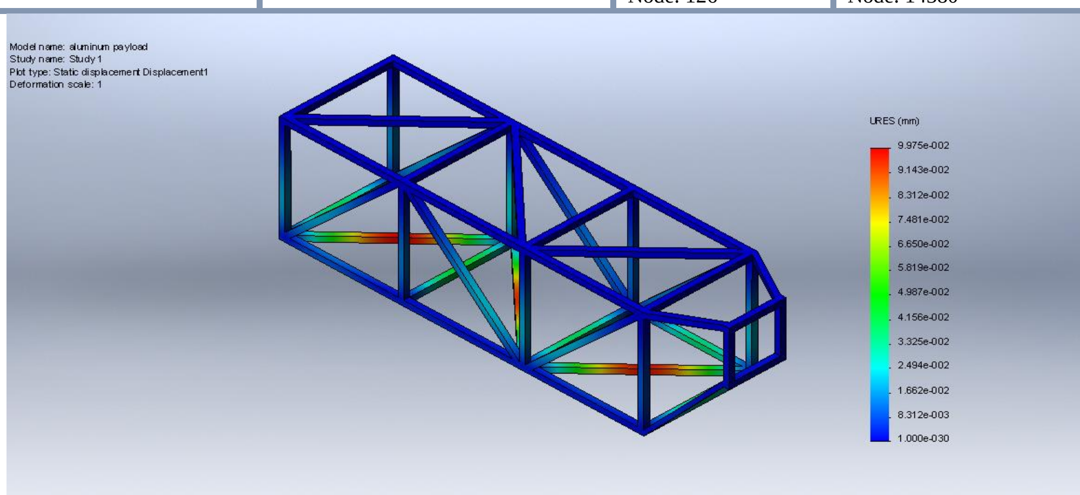
For the payload area we decided to go with an entire aluminum structure since this is the part of the airplane that will suffer the most stress. Taking into consideration that the payload will be placed inside this area along with the electronics, battery and servos, also the wing will be connected to the sides of it, we agreed to use a material that will bring extra strength to the plane as well as keeping the weight relatively low. The aluminum cage adds more weight to the structure but will give us the peace of mind that this key part of the plane where everything connects will not fail.

The structure was fixed in the top surface as shown by the green arrows and was applied a load of 300N to the bottom face where the payload will be attached. This 300N are far above the initially estimated 140N of load. We run this simulation with an excess load to prevent any errors generated by the program.



Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Loft4 	Solid Body	Mass:0.642908 kg Volume:0.000238114 m^3 Density:2700 kg/m^3 Weight:6.30049 N	Aluminum Payload

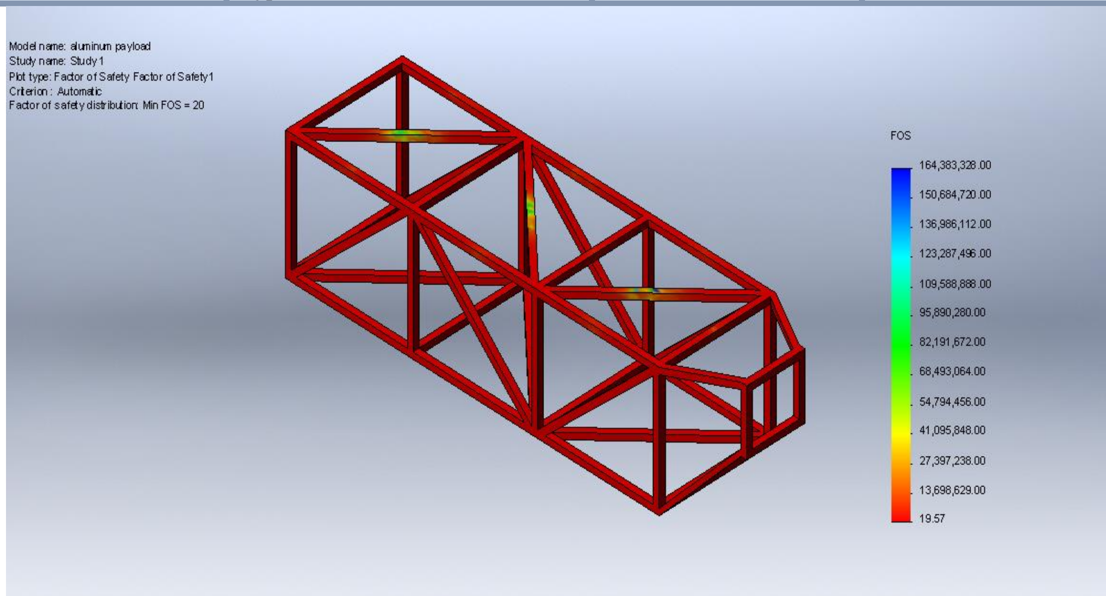
Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm Node: 126	0.0997465 mm Node: 14380



Payload Area Displacement

Name	Type	Min	Max
Factor of Safety	Automatic	19.5747 Node: 15844	1.64383e+008 Node: 7156

Name	Type	Min	Max



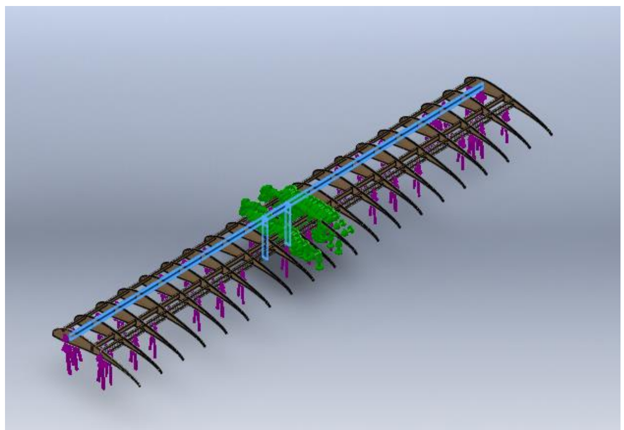
Payload Area FoS

As a result of our selection we can see how this aluminum structure exceeds by far the basic requirements of our plane providing a factor of safety of 20 and a negligible deformation of 0.1mm. In this case of excessive factor of safety we could take the same approach as we did in the construction of the empennage and try to achieve the same strength while reducing weight but the cost of manufacturing a laser or CNC cut in aluminum is much greater than doing it in aluminum sticks of ¼” by ¼”.

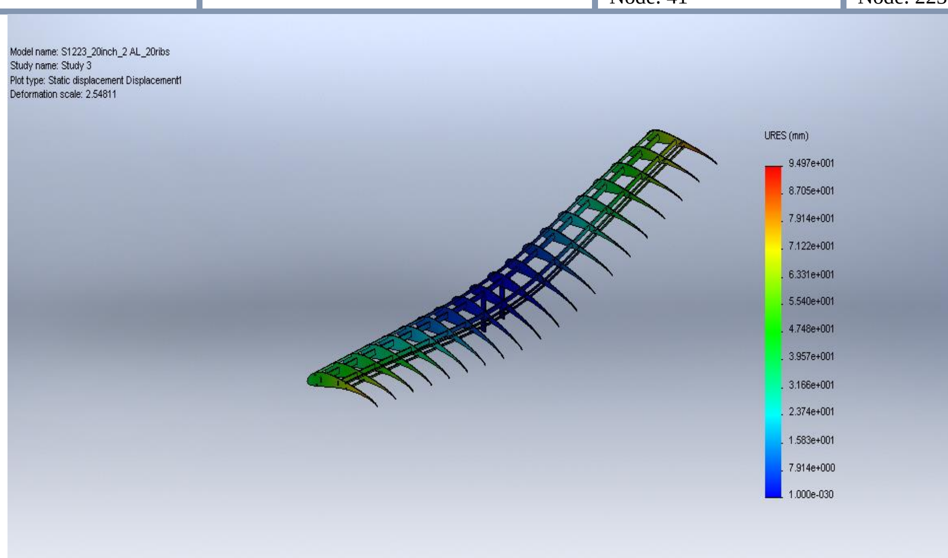
12.6 Wing all balsa wood 20 ribs

Probably the most important component of the airplane is the wing, it will generate the lift necessary to maintain the plane in the air. Since this is also the biggest structure on the plane it could be very heavy, in order to reduce the weight as much as possible while maintaining a factor of safety of at least1.2 and maintaining the deflection parameters low, we will run different simulations with different configurations.

The first structure is composed of 20 ribs with e thickness of 4mm each, four stringers of ¼” by ¼” that go across the entire structure and two spars of 1” by ¼” and ¾” by ¼” respectively. All these components have being assigned balsa wood as material in order to run the simulation. The wing structure was fixed at the center ribs which represent the joint of the wing with the fuselage and a load of 180N was applied to the bottom of the structure to represent the pressure created by the airfoil during flight.

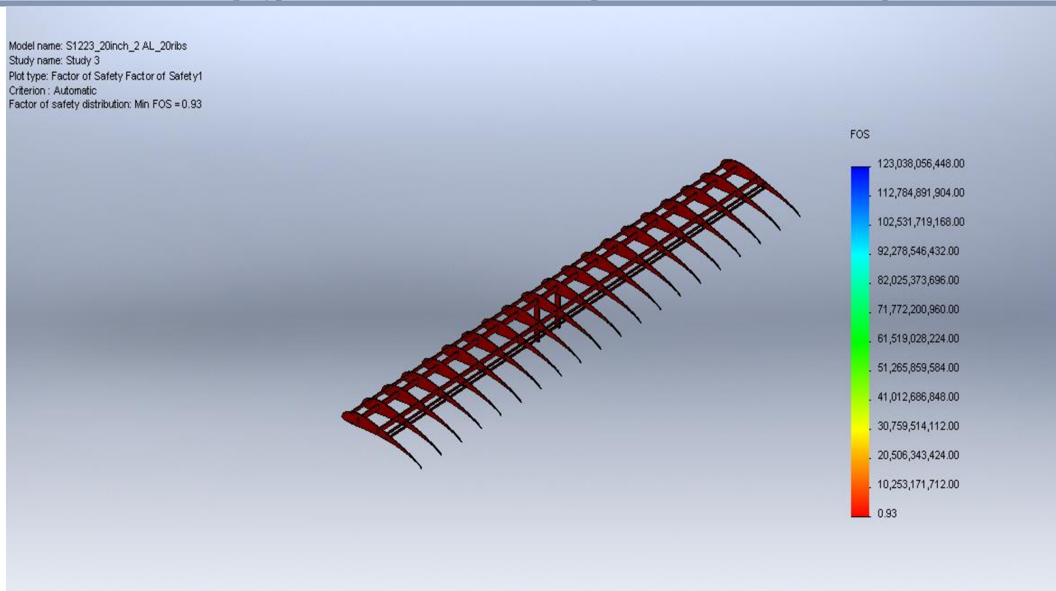


Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 41	94.9659 mm Node: 22387



Name	Type	Min	Max
Factor of Safety1	Automatic	0.934404 Node: 3502	1.23038e+011 Node: 24297

Name	Type	Min	Max



Wing Structure FoS

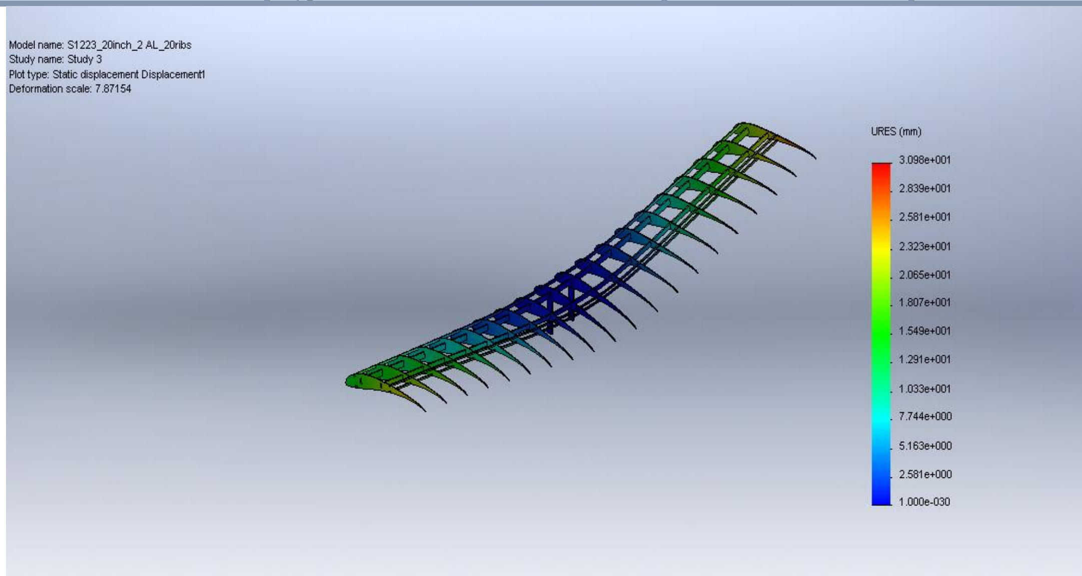
After running the first simulation we can see that the wing fails under such load giving as a result a factor of safety of 0.93 and a very large deflection of 95mm at the outer tip of the wing. Even though this approach is very appealing in the sense that it only introduces 390 grams to the whole plane, it is not strong enough to withstand the load.

12.7 Wing 20 Ribs 1 Aluminum Spar

The second combination selected to run the simulation was to change the material assigned to the larger spar of 1” by ¼ by aluminum instead of wood. In this simulation we kept the same fixture as the previous example and the same amount of load distributed along the structure.

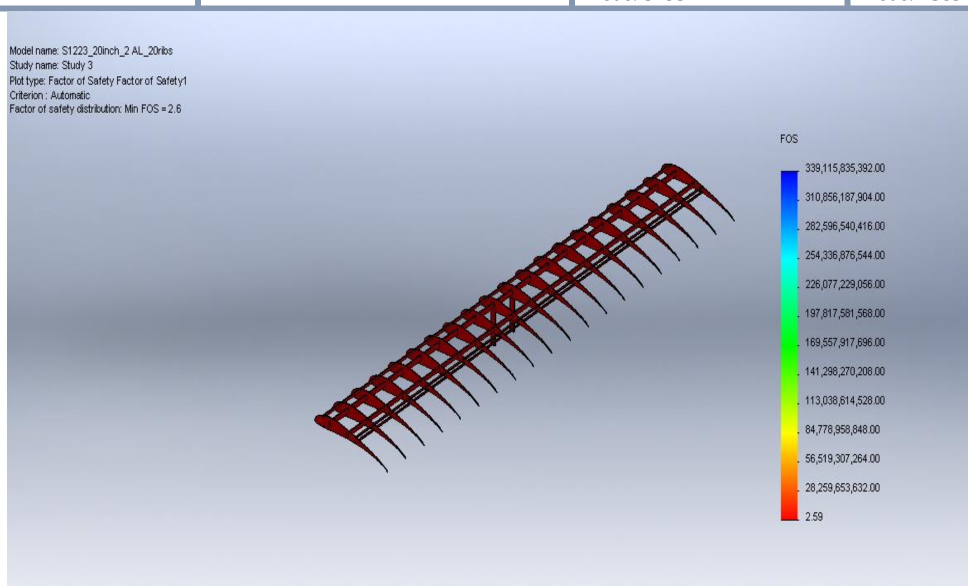
Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm Node: 41	30.9751 mm Node: 22387

Name	Type	Min	Max



Wing Structure Displacement 1

Name	Type	Min	Max
Factor of Safe2ty1	Automatic	2.59008 Node: 3493	3.39116e+011 Node: 23894



Wing Structure FoS 1

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12.8 Wing 20 Ribs 1 Aluminum Spar

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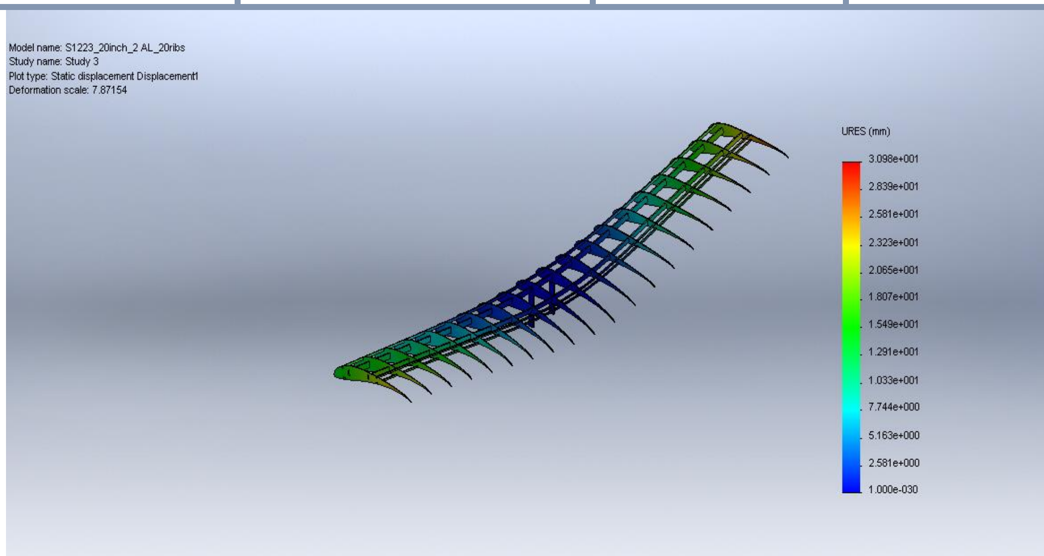
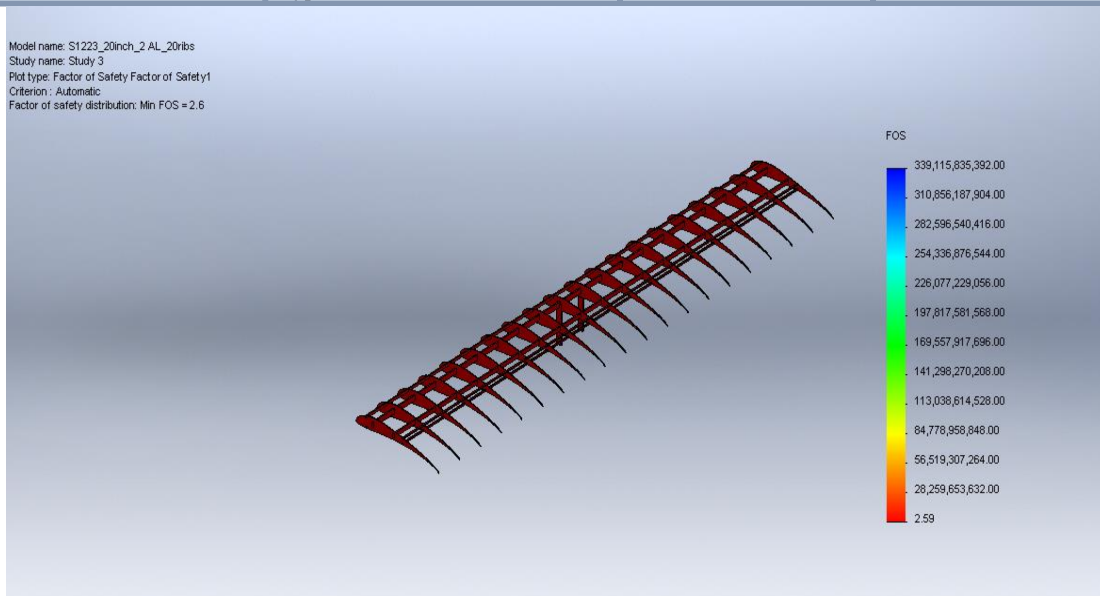
Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm Node: 41	30.9751 mm Node: 22387



Wing Structure Displacement 1

Name	Type	Min	Max
Factor of Safety1	Automatic	2.59008 Node: 3493	3.39116e+011 Node: 23894

Name	Type	Min	Max



Wing Structure FoS 1

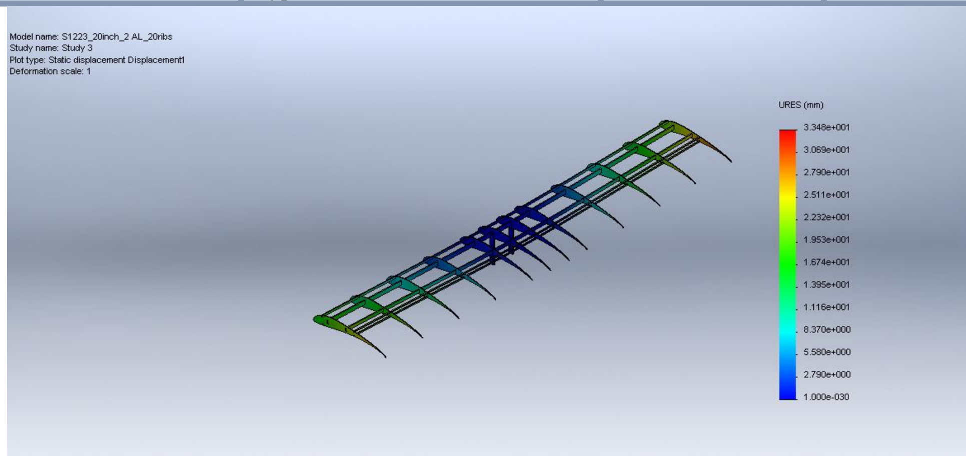
In this second simulation we can see how the factor of safety increased from 0.93 to 2.59 and the maximum displacement decrease drastically from 95mm to 31mm. These values are acceptable in order to fight the plane but they are still well above the target previously set, which means that we can still perform changes that will improve our design.

12.9 Wing 12 Ribs 2 Aluminum Spar

In this third simulation we will replace the material chosen for the second spar of ¾”by ¼” by aluminum in order to reduce the maximum displacement at the tips of the wing. We will also try to remove some ribs from the assembly to compensate the extra weight added by the aluminum.

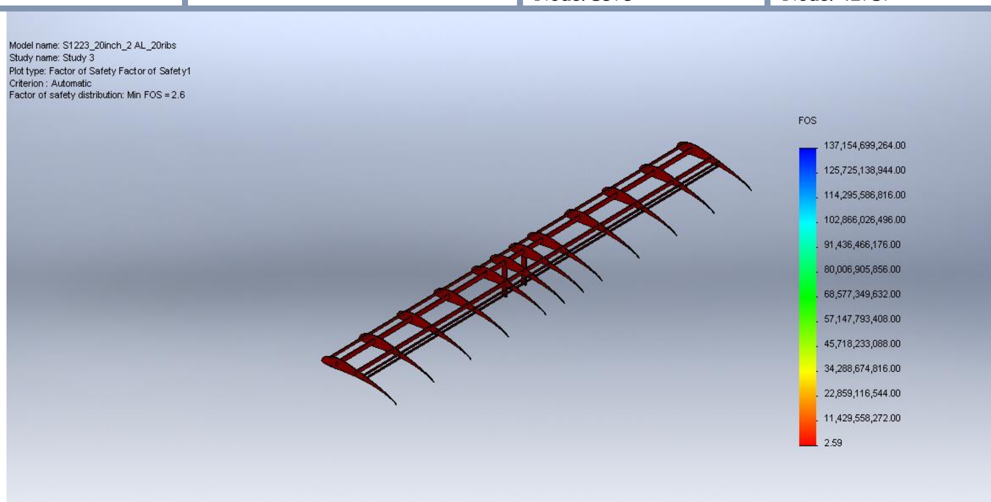
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 9	18.4797 mm Node: 30292

Name	Type	Min	Max



Wing Structure Displacement 2

Name	Type	Min	Max
Factor of Safety1	Automatic	2.59012 Node: 3979	1.37155e+011 Node: 42737

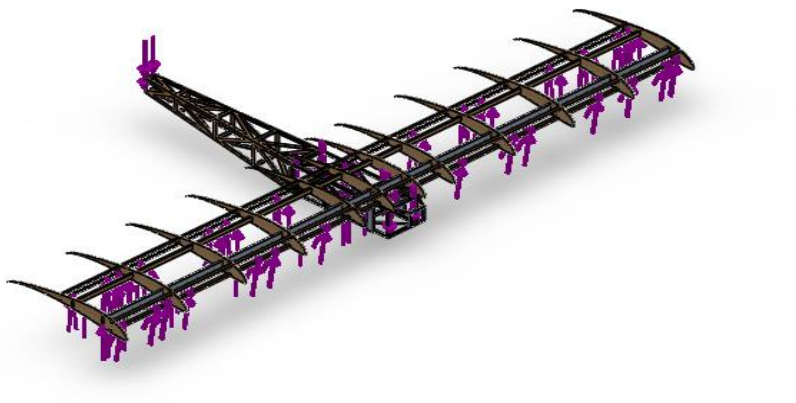


Wing Structure FoS 2

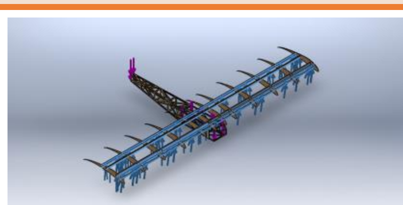
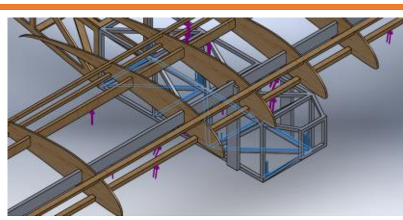
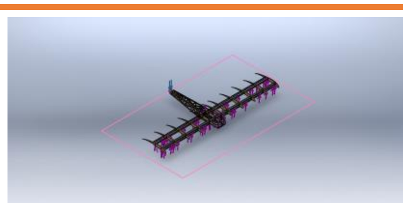
In this third simulation it can be seen how we were able to maintain a factor of safety of 2.59 and decrease the maximum displacement from 31mm to 18mm. The added reinforcement of the second aluminum spar added extra rigidity that allowed us to remove 8 ribs from the structure. The total weight of the structure is 1400 grams.

12.10 Final Assembly Selection

Finally we will run mate all the parts previously analyzed and we will run a simulation of the whole structure. This simulation should ressemble the results previouly obtained in the individual parts. Once again we applied the same loads to the wing, empennage and payload area and fixed the geometry by the supports at the wing that connect with the payload area.

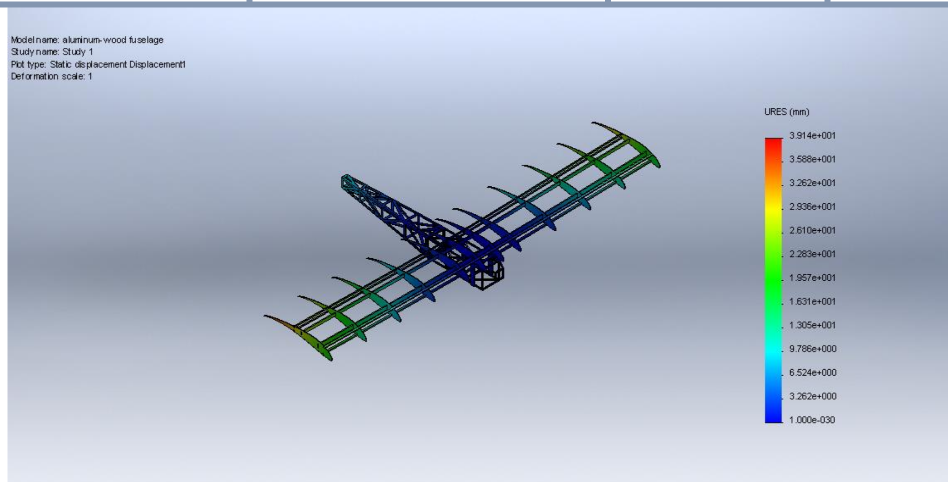


Assembly Loads

Load name	Load Image	Load Details
Wing		**Entities:** **6 face(s)** **Type:** **Apply normal force** **Value:** **180 N**
Payload		**Entities:** **1 face(s)** **Type:** **Apply normal force** **Value:** **150 N**
Empennage		**Entities:** **2 face(s), 1 plane(s)** **Reference:** **Top Plane** **Type:** **Apply force** **Values:** **-80 N**

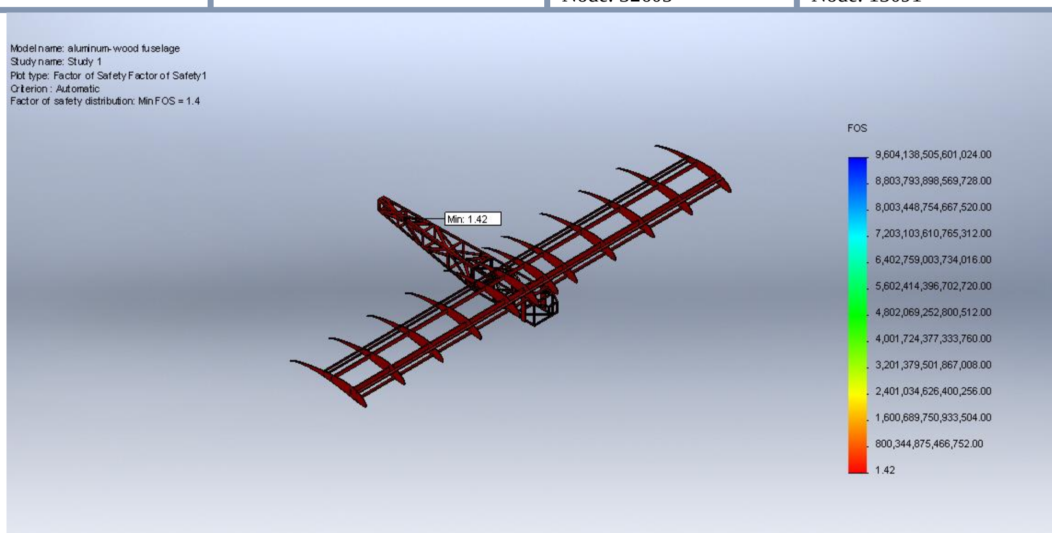
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm	18.144 mm

Name	Type	Min	Max
		Node: 13069	Node: 25285



Assembly Deflection

Name	Type	Min	Max
Factor of Safety	Automatic	1.42059 Node: 32605	9.60414e+015 Node: 13091



Assembly FoS

After running the simulation of the empennage, payload area, and wing structure we can see how the minimum factor of safety and maximum deflection points match the results of the parts when analyzed individually. We have a minimum factor of safety of 1.4 located at the empennage which is also shown in the individual analysis of the part and a maximum deflection of 18mm locate at the tip of the wing which is also shown in the independent analysis. The total estimated mass of the structure 2397 grams which is a good portion of the total weight of the plane.

14. Cost Analysis

An important aspect of every project is to maintain low costs. This can be accomplished by researching suppliers for competitive prices and being efficient as an engineer by using time accordingly. Table 15 represent the estimated total cost for this project. The team will apply with FIU to obtain funding for trip expenses, as well as, contacting airlines to obtain better fares. Human hours are calculated with an average engineer salary of $25/hour.

Table 15 Cost Analysis

	Cost
Competition Registration	$700
Prototype	$1945.60
Human hours 104 hours	$2600
Plane tickets & lodging	$984

15. Prototype System Description

There are two design options the team is considering. One of them includes the use of a ducted fan propeller. This design is to be analyzed using CFD to obtain aerodynamic properties. The following figures illustrate the design the team is considering.

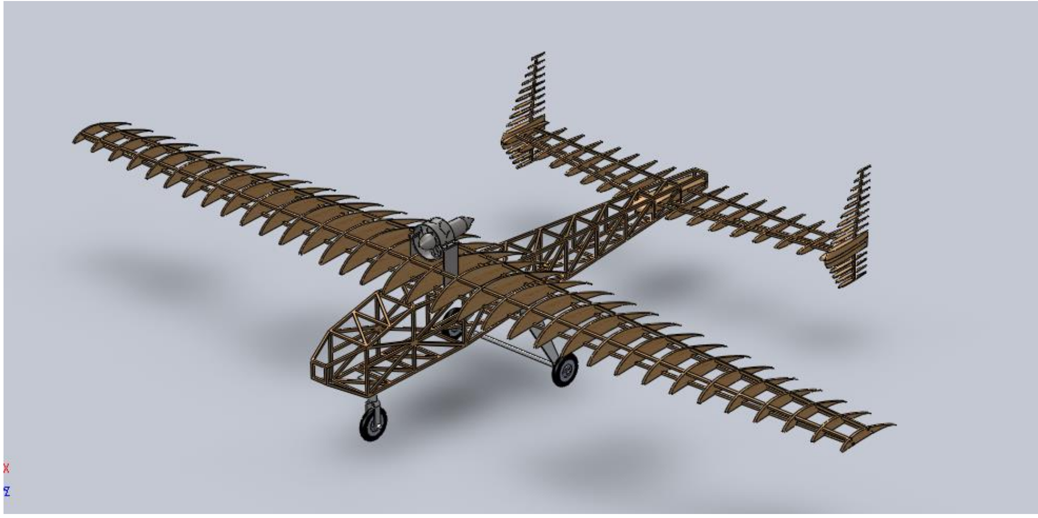


Figure 61 Design alternative 1

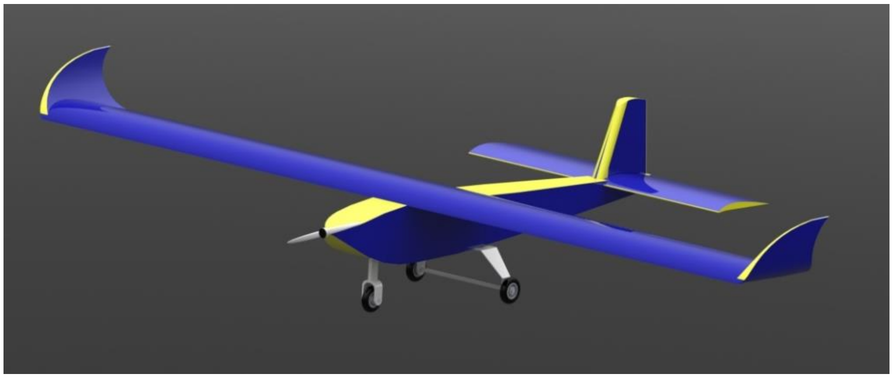


Figure 62 Design alternative 2

16. Prototype Cost Analysis

A main factor in our design is to keep the prototype cost low. This is accomplished by reducing the material needed in the design. The prototype cost analysis estimated in this section is for the current design which does not include optimization. The team's goal is to reduce costs through design and structural optimization.

Table 16 Prototype Cost Analysis

Component	Cost
Radio Control	Donated
Electric Motor	$315.00
Batteries	$435.00
Servo Motors	$365.00
Landing Gear	$180.00
Raw Materials	$650.00
Total:	$1945.60

17. Tests on Prototype

17.2 Wind tunnel testing

Computational fluid dynamic (CFD) analysis was performed on the entire aircraft with the purpose of reducing drag and increasing lift capacity. To validate our results wind tunnel testing was performed to obtain experimental data to compare to the CFD analysis results. The airfoil was drafted and 3D printed to perform the test. To make our results more realistic, the 3D printed part was wrapped with the same material of which the aircraft will be wrapped.

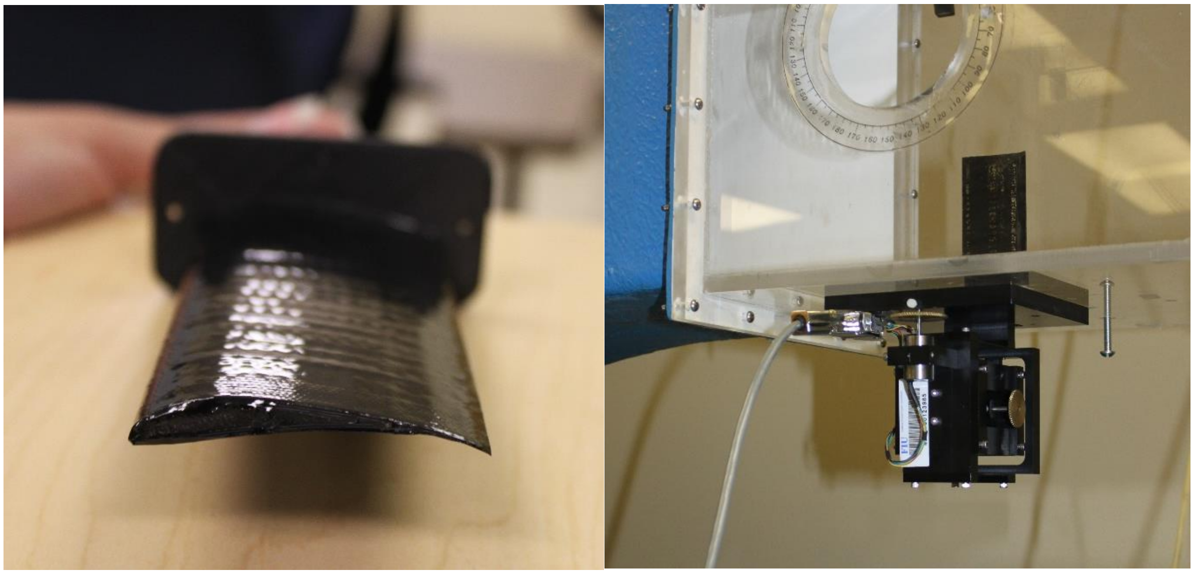


Figure 63 Wind tunnel testing

17.3 Thrust Test

A bench test was performed to confirm the results analyzed on MotoCalc. Through this test a scale was connected to the motor to be able to calculate the amount of thrust the motor will generate. Two different engines were tested along with different propeller sizes to obtain the best combination. The engines tested where a .32 rimmfire and a 52 E-flite.

Figure 64 Propellers tested

Figure 65 Thrust bench test

A power meter was connected to the powerplant to record the amount of watts the engine was using. The results obtained suggested we should use an 18x8 propeller which pulled a maximum of 11lbs using 965 watts.

Propeller	Rimfire .32		E-Flite 52	
	Pulled (lb)	Power (watts)	Pulled (lb)	Power (watts)
13x6.5	6.8	537	-	-
14x7	7.8	636	-	-
15x6	8.2	661	7.1	504
16x8	8.10	723	8.14	740
18x8	-	-	10.8	960
18x10	10.2	1400	11.8	1100

18. Manufacturing

For the construction of the aircraft the material used was balsa wood, plywood, and spruce. To bind the materials together adhesives such as epoxy and cyanoacrylate (CA). After considering the amount of material and team the team will be using when constructing the tapered wing, we decided the best decision was to make the wing rectangular. The ribs and side of fuselage was laser cut to obtain an accurate design.

Figure 66 Laser cut Parts

To build the wing a 1:1 drawing was printed on a plotter to serve as a guide of the location of the ribs, stringers, and wing supports. The ribs that are connected to the fuselage and the ailerons where cut out of light plywood to give rigidity to the structure. The rest of the ribs where cut out of balsa to keep the wing light weight. The ribs where aligned and glued with CA to the stringers.

Figure 67 Wing construction

To reduce torsion on the wing webbing was placed between each rib. By placing balsa on the vertically with the direction of wood growth the wing will increase its resistance against torsion. Balsa was then used as the skin of the wing, small strings of balsa where placed along the rib to increase the area so it will make wrapping the wing with ultracote easier.

Figure 68 Wing

The tail was constructed by cutting 3/8 of balsa using the 1:1 drawing as a guide and gluing the sticks with CA. Plastic hinges where used to allow the rudders and elevator to deflect. A plywood support was used to connect the tail and the fuselage. Triangles of balsa where used at the junction between the vertical and horizontal stabilizer to increase rigidity by increasing the contact are for the adhesive.

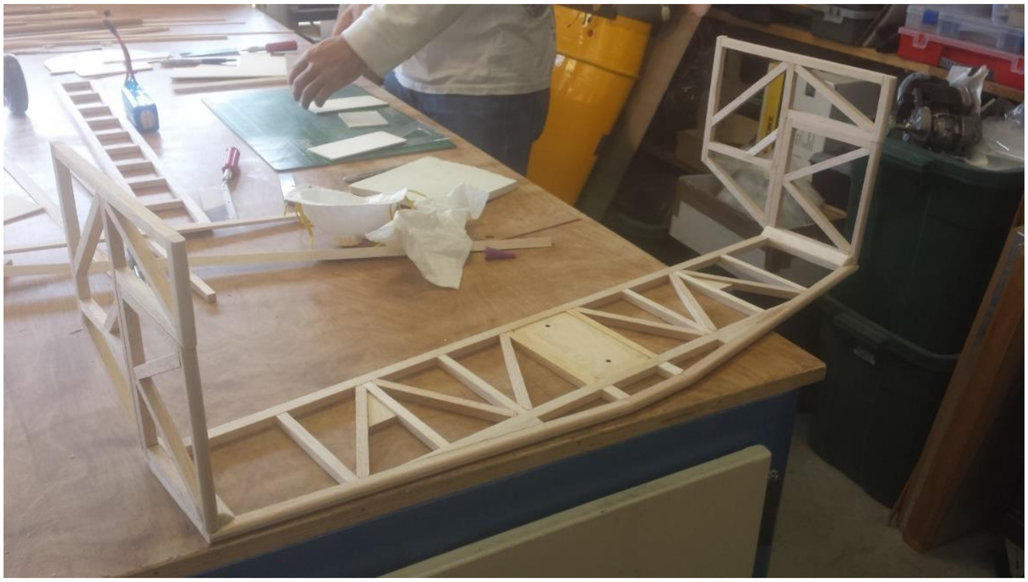


Figure 69 Tail construction

The fuselage side wall were laser cut and balsa sheets were glued on top to increase rigidity. To prevent torsion ¼ x ¼ balsa was placed diagonally. Plywood was used on the fire wall and well as where the wing will be supported. A 4x4x10 payload box was manufactured to comply with the competition requirements.

Figure 70 Fuselage Construction

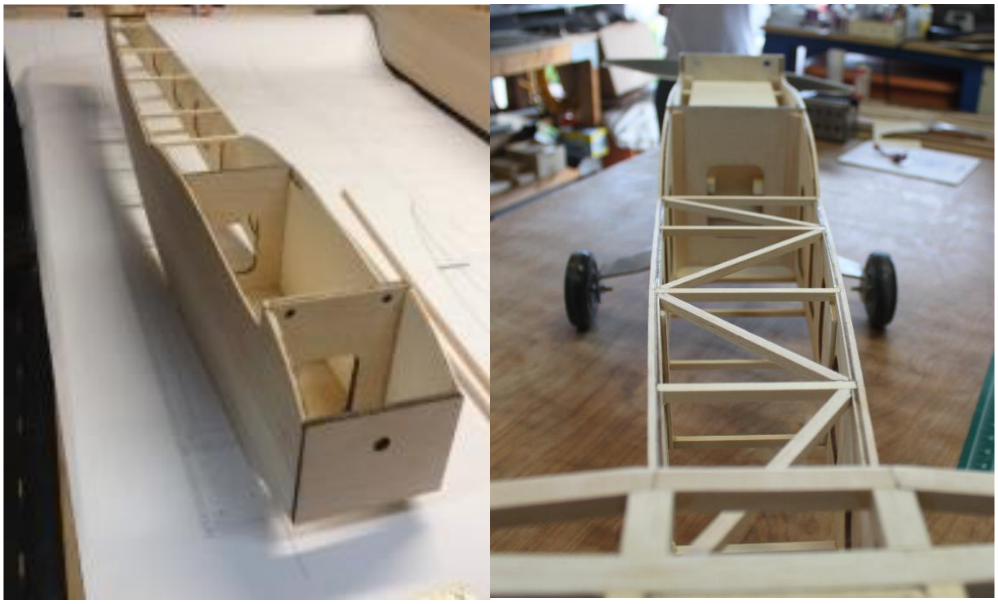


Figure 71 Fuselage

Figure 72 Payload Bay

Once all the aircraft components are constructed, everything is put together to balance the aircraft. Connections are made and servos are mounted. Then the aircraft is wrapped. Since our wing has a very thin trailing edge Ultracote is used instead of monokote to reduce chances of the wing deforming.

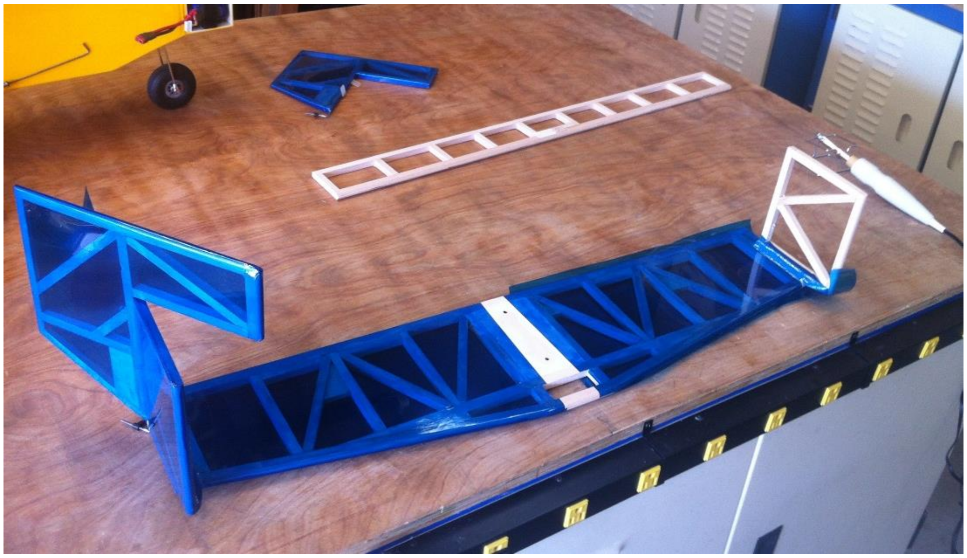


Figure 73 Tail ultracote wrapping

Figure 74 Wing ultracote wrapping

When the aircraft is completely wrapped and all electrical components are mounted the plane is balanced for the last time. Control surfaces are tested to verify their efficiency and required adjustments are made.

19. Final Design

Once the aircraft was built and assembled final adjustments are made to make it functional. Through testing our team discovered that the connection made to move both rudders with one servo was not efficient. The rudders remained a little loose which would make the aircraft unstable. Supports where added to the rudders to fix the issue but we were not successful. Two options where available. First option was to make the rudders independent and have a servo connected to each. The servos would have to be placed and the tail making the aircraft air heavy. Due to the large moment arm this would result in having to add a ballast in the airplane. Second option was to move the rudders from the ends to the support in the center and have the rudders connected together through wire. After a considering the advantages and disadvantages of each option the team decided to move the tail and have the rudders connected together. The amount of weight needed to add to the tail to have this configuration would be less than adding two servos to the tail.

Figure 75 Tail Change

After the modification was made and the rudders were tested, it was concluded that they no longer were loose and any possibility of flutter was discarded. The aircraft was now balanced and ready for test flights.

Figure 76 Final Design

20. Test Flight

The aircraft was taken to the field and tested before the competition. Three test flight were made. On the first flight our team wanted to validate the results obtained through the bench tests and the aircraft was flown with the 15x6 propeller. At the day of the maiden flight the wind speed was between 15-20 mph crosswinds. The aircraft was able to get airborne without any payload but it was very noticeable that it lacked power. The airplane almost did not move when it flew against the wind direction.

Figure 77 Maiden Flight

On the second flight the propeller was changed to the selected propeller of 18x8, the difference was incredible. The airplane lifted with no problem, on this flight a 1 pound payload was added. After validating the power provided by the power plant configuration selected, we decided to load the airplane with 7 pounds and see how it behaved. The plane got airborne at a take-off distance of around 10 feet. These results give our team a good chance of being competitive and the chance of winning the competition.

Figure 78 Successful Landing

21. Conclusion

Our team was able to successfully design an aircraft that can be competitive for the SAE Aero Design Competition. We will be competing on April 11, 2014 and hope to come back to FIU with great standing. Through this project we hope to open interest in our peers so our university can be more involved in more design competitions giving students the chance to have an on hands experience in design and give our university nationwide recognition at the events.

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Appendices

Appendix A: Competition Rules

Section 2 Requirements for all Classes

2.1 Introduction

Official Announcements and Competition Information

The Aero Design competition is intended to provide undergraduate and graduate engineering students with a real-life engineering exercise. The competition has been designed to provide exposure to the kinds of situations that engineers face in the real 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.

The importance of interpersonal communication skills is often overlooked by engineers, yet both written and oral communication skills are vital in the engineering workplace. To help teams develop these skills, a high percentage of a team's score is devoted to the Design Report and the oral presentation required in the competition.

Aero Design features three classes of competition—**Regular**, **Advanced**, and **Micro**. Regular Class ***(now all electric)*** is intended to be simpler than Advanced Class, and therefore more accessible to the Novice team. Advanced Class is intended to be less restrictive than Regular Class, thereby opening a larger potential solution set. Its lack of restriction allows teams to pursue more complex aircraft configurations, thereby encouraging greater creativity in satisfying the mission requirements. Micro Class (all electric) 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.

Other SAE Aero Design Competitions: SAE Aero Design Brazil; SAE BRASIL .http://www.saebrasil.org.br/.

SAE Aero Design Rules and Organizer Authority

Rules Authority

The SAE Aero Design Rules are the responsibility of the SAE Aero Design Rules Committee and are issued under the authority of the SAE University Programs Committee. Official announcements from the SAE Aero Design Rules Committee, SAE or the other SAE Organizers shall be considered part of and have the same validity as these rules.

Ambiguities or questions concerning the meaning or intent of these rules will be resolved by the officials, SAE Rules Committee or SAE Staff.

Rules Validity

The SAE Aero Design Rules posted on the SAE Website and dated for the calendar year of the competition are the rules in effect for the competition. Rule sets dated for other years are invalid.

Rules Compliance

By entering an SAE Aero Design competition, the team members, faculty advisors and other personnel of the entering university agree to comply with, and be bound by, the rules and all rules interpretations or procedures issued or announced by SAE, the SAE Aero Design Rules Committee and other organizing bodies. All team members, faculty advisors and other university representatives are required to cooperate with, and follow all instructions from competition organizers, officials and judges.

Understanding the Rules

Teams are responsible for reading and understanding the rules in its entirety for the competition in which they are participating. The section and paragraph headings in these rules are provided to facilitate reading: they do not affect the paragraph contents.

Loopholes

It is virtually impossible for a set of rules to be so comprehensive that it covers all possible questions about the plane's design parameters or the conduct of the competition. Please keep in mind that safety remains paramount during any SAE competition, so any perceived loopholes should be resolved in the direction of increased safety/ concept of the competition

Participating in the Competition

Teams, team members as individuals, faculty advisors and other representatives of a registered university who are present on-site at a competition are considered to be "participating in the competition" from the time they arrive at the event site until they depart the site at the conclusion of the competition or earlier by withdrawing.

Visa--United States Visas

Teams requiring visas to enter to the United States are advised to apply at least sixty (60) days prior to the competition. Although most visa applications seem to go through without an unreasonable delay, occasionally teams have had difficulties and in several instances visas were not issued before the competition.

Don't wait – apply early for your visa.

Registration Confirmation Letters (new)
Aero Design Student Team Members will have the ability to print out a Registration Confirmation Letter for the individual event(s) that they are attending. Once a student team member affiliates themselves to their teams profile page under their individual edit section. They will have the opportunity to print out their personalized letter with the following information: Student's Name, the School's Name, the SAE Event Name, Official Dates and Location(s).

Please be advised that SAE International cannot intervene with, or call or send personal letters to, the State Departments, Embassies or Consulates of the United States or other governments on behalf of any meeting or event participant.

Violations of Intent
The violations of the intent of a rule will be considered a violation of the rule itself. Questions about the intent or meaning of a rule may be addressed to the SAE Officials, Competition Organizers or SAE Staff

Right to Impound
SAE and the other competition organizing bodies reserve the right to impound any on-site vehicle/plane at any time during a competition for inspection and examination by the organizers, officials and technical inspectors.

General Authority

SAE and the competition organizing bodies reserve the right to revise the schedule of any competition and/or interpret or modify the competition rules at any time and in any manner that is, in their sole judgment, required for the efficient operation of the event or the SAE Aero Design series as a whole.

Penalties
Organizers have the right to modify the points and/or penalties listed in the various event descriptions; to better reflect the design of their events, or any special conditions unique to the site.

2.2 Team Member Eligibility

Teams are required to read the articles posted on the SAE Aero Design homepage (.http://students.sae.org/competitions/aerodesign/.) published by SAE and the other organizing bodies. Teams must also be familiar with all official announcements concerning the competitions and rule interpretations released by the Aero Design Rules Committee.

2.3 Society Membership

Individual team members must be members of one of the following societies: (1) SAE or an SAE affiliate society, (2) ATA, or (3) IMechE or (4) VDI. Proof of membership, such as a membership card, is required at the event.

Students who are members of one of the societies listed above are not required to join any of the other societies in order to participate in any SAE competition.

Students may join online at www.sae.org/students.

2.3.1 Pilots

Pilots are not required to be students or SAE members, but they must be current members of either the **Academy of Model Aeronautics** or the **national model aircraft club** in their country of origin (such as the MAAC for Canadian teams). Valid AMA membership cards must be presented at the flying field prior to flying any team's aircraft. Copies of AMA application forms will not suffice as proof of AMA membership; the actual AMA card must be presented at the event flying field.

2.3.2 Liability Waiver and Insurance Requirements

All on-site participants and faculty advisors are required to sign a liability waiver upon registration. Individual medical and accident insurance coverage is the sole responsibility of the participant.

2.4 Ringers Prohibited

In order to maintain the integrity of a fair competition, the faculty advisor must prohibit ringers. A ringer is someone that has exceptional skills related to the competition (e.g., a professional model builder) that cannot be a legal member of the team but helps the team win points.

2.5 Design and Fabrication

The airplane must be designed and built by the SAE student members without direct involvement from professional engineers, radio control model experts, pilots, machinists, or related professionals. The students may use any literature or knowledge related to R/C aircraft design and construction and information from professionals or from professors as long as the information is given as discussion of alternatives with their pros and cons and is acknowledged in the references in the design report. Professionals may not make design decisions, nor contribute to the drawings, the report, or the construction of the airplane. The faculty advisor must sign the Statement of Compliance given in Appendix.

2.6 Original Design

Any aircraft presented for competition must be an original design whose configuration is conceived by the student team members. Photographic scaling of an existing model aircraft design is not allowed. Use of major components such as wings, fuselage, or empennage of existing model aircraft kits is prohibited. Use of standard model aircraft hardware such as engine mounts, control horns, and landing gear is allowed.

2.7 Official Languages

The official language of the SAE Aero Design series is English. Document submissions, presentations and discussions in English are acceptable at all competitions in the series.

Team members, judges and officials at Non U.S. competition events may use their respective national languages for document submissions, presentations and discussions if all the parties involved agree to the use of that language.

Aero Design East	English
Aero Design West	English
Aero Design Brazil	Portuguese and English

2.8 Unique Designs

Universities may enter more than one team in each Aero Design competition, but each entry must be a unique design, significantly different from each other. If the aircraft are not significantly different in the opinion of the rules committee and organizer, then the university will be considered to have only a single entry and only one of the teams and its aircraft will be allowed to participate in the competition. For example, two aircraft with identical wings and fuselages but different empennage would likely not be considered significantly different. For guidance regarding this topic, please email CollegiateCompetitions@sae.org..

2.9 Aircraft Classification/Duplicate Aircraft

Aircraft may only compete in one class. Simultaneous entry in Advanced, Regular, and Micro Class, with the same aircraft, is not allowed. When a team has an identical aircraft as a back-up, the back-up aircraft must go through inspection with the primary aircraft. If the entire back-up aircraft is used in competition, previously earned flight points are forfeited and flight point scoring starts over.

2.10 Aircraft Eligibility

Aircraft will only be allowed to compete during a single academic year. Aircraft may be entered in both Aero Design East and Aero Design West during the same calendar year, but that same aircraft may not be used in either competition during the following year. Entering the same aircraft in Aero Design West one year and Aero Design East the next year is not allowed.

2.11 Registration Information and Deadlines

Teams intending to participate in the 2014 SAE Aero Design competitions must register their teams online starting

Tuesday, October 8, 2013 at 10:00 am EDT (75 team limit)

Registration (or is sold out) closes for both Aero Design and Aero Design West,

December 16, 2013 at 11:59 PM Eastern Standard Time.

The registration fee is non-refundable and failure to meet these deadlines will be considered a failure to qualify for the competition. Separate entry fees are required for the East and West events.

The registration fees indicated in the Appendix ($ 700) must be paid online by credit card at the time of online registration. Registration fees may not be paid by any other means.

Please note each Aero Design event will have limits on the number of teams…

75 for Aero Design East

75 for Aero Design West

Individual Registration Requirements – ACTION REQUIRED

All participating team members and faculty advisors must be sure that they are individually linked to their respective school / university on the SAE website, registration page.

If you are not an SAE member, go to www.sae.org and select the "Membership" link. Students will need to select the "Student Membership" link and then follow the series of questions that are asked Please note all student participants must be SAE members to participate in the events.

Faculty members who wish to become SAE members should choose the "Professional Membership" link.
Please note: this is not mandatory for faculty advisors.

All international student participants, or unaffiliated faculty advisors, who are not SAE members are required to complete the International Student Registration form per team found on the Registration page of the specific event (http://students.sae.org/competitions/aerodesign/west/registration.htm). Upon completion, email the form to CollegiateCompetitions@sae.org.

All student participants and faculty advisors must affiliate themselves to the appropriate team(s) online. To do this you will need to go to the Aero Design homepage and select the SAE Aero Design Series link to expand the menu. Select the event(s) that you are registered for, and once the menu expands, click on the Registration link. From here you will select the "Register Your Team / Update Team Information" link in which your team links should appear on the next page. Select the team link and scroll to the bottom of the page; the "Add New Member" button will allow individuals to include themselves with the rest of the team.

The "Add New Member" button will allow individuals to access this page and include the necessary credentials. If the individual is already affiliated to the team, simply select the Edit button next to the name. Please be sure this is done separately for each of the events your team has entered.

All students, both domestic and international, must affiliate themselves online or submit the International Student Registration form by March 7st, 2014
For additional assistance, please contact CollegiateCompetitions@sae.org

****NOTE: When your team is registering for a competition, only the student or faculty advisor completing the registration needs to be linked to the school. All other students and faculty can affiliate themselves after registration has been completed; however this must be done on or before March 7th, 2014**

2.12 Faculty Advisor

Each team is expected to have a Faculty Advisor appointed by the university. The Faculty Advisor is expected to accompany the team to the competition and will be considered by competition officials to be the official university representative.

Faculty Advisors may advise their teams on general engineering and engineering project management theory, but may not design any part of the vehicle nor directly participate in the development of any documentation or presentation. Additionally Faculty Advisors may neither fabricate nor assemble any components nor assist in the preparation, maintenance, or testing of the vehicle.

In Brief - Faculty Advisors may not design, build or repair any part of the plane.

> **NOTICE**: In the event that the number of teams registering for the competition exceeds the number of teams/participants the facilities can handle, then registration priority will be given to colleges and universities with SAE student chapters.

2.13 Complaints, Protests and Questions

2.13.1 Complaints

Competition officials will be available to listen to complaints regarding errors in scoring, interpretation, or application of the rules during the competition. Competition officials will not be available to listen to complaints regarding the nature, validity, or efficacy of the rules themselves at the competition. In other words, the Organizer will not change the rulebook at the field.

2.13.2 Protests / Preliminary Review

If a team has a question about scoring, judging, policies, or any official action, they must bring the question to the Organizer's or SAE staff's attention for an informal preliminary review before a protest is filed.

2.13.3 Cause for Protest

A team may protest any rule interpretation, score or official action (unless specifically excluded from protest) which they feel has caused some actual, non-trivial, harm to their team, or has had a substantive effect on their score. Teams may not protest rule interpretations or actions that have not caused them any substantive damage.

2.13.4 Protest Format

If a faculty advisor or team captain feels that his complaint about an official action or rules interpretation was not properly addressed by the event officials, he or she may protest. All protests must be filed in writing to the Organizer by the faculty advisor or team captain only.

2.13.5 Protest Period

All protests must be submitted within thirty (30) minutes of the end of the flight round or other competition event to which the protest relates.

2.13.6 Protest Committee

Any protests must be reviewed by the Protest Committee. The Protest Committee must consist of a minimum of three members: the Organizer, SAE Collegiate Design Series representative, and either the Chief Steward, the Chief Judge, or the Air Boss. The decision of the Protest Committee must be final. If a member of the Aero Design Rules Committee is at the competition, he or she will be in the Protest Committee.

2.13.7 Protest Resolution

In order to have a protest considered, a team will be required to post twenty five (25) points as collateral. If the protest is sustained, the appropriate correction will be applied and the team will forfeit no points. If the protest is overruled, the team will forfeit the twenty five (25) collateral points.

2.13.8 Questions

Any questions or comments about the rules should be brought to the attention of the Rules Committee via the SAE Aero Design forum at

http://forums.sae.org/access/dispatch.cgi/aerodesign_pf

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General information about hotels and other attractions in the area as well as a schedule of events will be posted on the SAE website according to the competition in which you are competing: http://students.sae.org/competitions/aerodesign/

2.14 Professional Conduct

2.14.1 Unsportsmanlike Conduct

In the event of unsportsmanlike conduct by team members or that team's faculty advisor, the team will receive a warning from a Competition Official. A second violation will result in expulsion of the team from the competition and loss of any points earned in all aspects of the competition.

2.14.2 Arguments with Officials

Arguments with or disobedience toward any competition official may result in the team being eliminated from the competition. All members of the team may be immediately escorted from the grounds.

2.14.3 Alcohol and Illegal Material

Alcoholic beverages, illegal drugs, firearms, weapons, or illegal material of any type are not permitted on the event sites at any time during the competition. Any violations of this rule will result in the immediate expulsion of all members of the offending school, not just the individual team member in violation. This rule applies to team members and faculty advisors. Any use of illegal drugs or any use of alcohol by an underage person must be reported to the local law enforcement authorities for prosecution.

2.14.4 Organizer's Authority

The Organizer reserves the exclusive right to revise the schedule of the competition and/or to interpret the competition rules at any time and in any manner which is required for efficient operation or safety of the competition.

SAE Technical Standards Access

A cooperative program of SAE's Education Board and Technical Standards Board is making some of SAE's Technical Standards available to teams registered for any North American CDS competition at no cost. The Technical Standards referenced in the Collegiate Design Series rules, along with other standards with reference value, will be accessible online to registered teams, team members and faculty advisors. To access the standards (1) your team must be registered for a competition in North America and

(2) The individual team member or faculty advisor wanting access must link to the team in SAE's system.

Access Procedure - Once your team has registered there will be a link to the technical standards titled "Design Standards" on the main registration screen where all the required onsite insurance information is added. On the technical standards webpage you will have the ability to search standards either by J-number assigned or topic of interest such as brake light.

A list of accessible SAE Technical Standards can be found in Appendix S.

Section 3 Mission Requirements

3.1 Take Off

Takeoff is defined as the point at which the main wheels leave the ground.

3.1.1 Time Limit (NEW)

- **Micro Class:** Upon a signal given by the Air Boss, a team will have 1.5 minutes to setup their launch system, if applicable, and get their aircraft airborne. Only one attempt is allowed.
- **Regular Class:** Upon a signal given by the Air Boss, a team will have three (3) minutes to accomplish a successful takeoff. Multiple takeoff attempts are allowed within the three-minute window as long as the aircraft has **NOT** become airborne during an aborted attempt.
- **Advance Class:** Upon a signal given by the Air Boss, a team will have five (5) minutes to accomplish a successful takeoff. Multiple takeoff attempts are allowed within the five-minute window as long as the aircraft has **NOT** become airborne during an aborted attempt.

3.1.2 Take-off Zone

Takeoff direction will be determined by the Air Boss, and selected to face into the wind. Aircraft must remain on the runway during the takeoff roll.
Distance requirement is defined in the Table.

Take-Off Distance Requirement

Class	Take-off Requirements	Description
Regular	200 ft. (61m)	Aircraft must lift from the ground within a take-off distance requirement.
Micro	N/A	N/A
Advanced	N/A	Aircraft shall have the full use of the runway.

3.1.3 Engine Run-up

Use of a helper to hold the model while the engine is revved prior to release for takeoff is allowed, but the helper may not push the model upon release. To stay within the takeoff zone, the main wheels of the aircraft are to be placed on the takeoff line.

3.1.4 Aircraft Configuration upon Liftoff

The aircraft must remain intact during takeoff, from release through liftoff. No parts may depart the aircraft during the takeoff process.

3.2 Competition Circuit Requirements

Regular and Micro Class aircraft must successfully complete one 360° circuit of the field. During departure and approach to landing, the pilot must not fly the aircraft in a pattern that will allow the aircraft to enter any of the no-fly zones (See Para. 20.3.4). More than one circuit of the field is allowed. During a flight, each aircraft must fly past the departure end of the takeoff zone, turn the aircraft through approximately 180° of heading, and fly past the approach end of the takeoff zone prior to landing. No aerobatic maneuvers will be allowed at any time during the flight competition in any competition class. This includes but not limited to: loops, figure 8's, immelmans, barrel rolls, etc.

3.3 Initial Turn after take-off

The pilot may begin to make the initial turn of the 360° circuit after the aircraft has passed the Take-Off Distance Requirement (see table). Making the initial turn before passing the Take-Off Distance Requirement will disqualify the flight attempt.

3.4 Landing

Landing is defined as occurring from initial touchdown to the point at which the aircraft stops moving. Initial touchdown is defined as the point at which any part of the aircraft touches the ground.

3.4.1 Landing Zone

Touch-and-goes are not allowed, and a crash-landing invalidates the landing attempt. A good landing is defined as touching down within the designated landing zone for the class, and remaining on the ground through rollout. Rolling-out beyond the landing zone is allowed, provided the aircraft touches down within the landing zone. Bouncing across the boundary at the end of the landing zone is not allowed, and will be judged as a failed landing attempt. A failed landing attempt will result in no score for the round.

During a landing, the aircraft must remain on the runaway between their landing limits to be considered a successful landing. Running off the side of the runway onto the grass is not allowed. If an aircraft crosses their respective landing limits, running off onto the grass is permitted.

Landing Distance Requirements

Class	Landing Requirement	Description
Regular	400 ft (122m)	Aircraft must land in the same direction as takeoff within a designated landing zone.
Micro	N/A	Aircraft must land in the same direction as takeoff within a designated landing zone.
Advanced	N/A	Aircraft must land in the same direction as takeoff within a designated landing zone.

3.4.2 Post-landing Condition

The aircraft must take off and land intact to receive points for the flight. All parts must remain attached to the aircraft during flight and landing maneuver, with the exception of the propeller. Broken propellers are allowed, and will not invalidate a flight attempt.

3.4.3 Flight Authority

The Organizer, Chief Judge, Air Boss, SAE Official, or other designated competition technical inspector may prohibit flight of any aircraft deemed non-flight-worthy until the non-flight-worthy condition has been repaired and the aircraft has been re-inspected by the judges.

3.4.4 Controllability

All aircraft must be controllable in flight.

3.4.5 No-Fly Zone

Each flying site will have site-specific no-fly zones. At no time is any aircraft to enter the no-fly zones, whether under controlled flight or uncontrolled. First infraction for crossing into the no-fly zone will result in an invalidated flight attempt and no points will be awarded for that flight. Second infraction will result in disqualification from the entire event and loss of all points. Flying over the pit area is not allowed at any time.

3.4.6 Flight Rules Announcement

Flight will be explained to all teams before the flight competition begins, either during the pilots' meeting or during activities surrounding the technical inspections and oral presentations.

3.4.7 Flight Rules Violations

Violation of any flight rule may result in the team being eliminated from the competition. All members of the team may be escorted from the grounds.

3.4.8 Local Field Rules

In addition to competition rules, the local flying club may have additional rules in place at the event flying field. Club rules will be obeyed during the flight competition; for example, the club may have specific frequency control procedures that must be used during the event.

3.4.9 Repairs and Alterations

The original design of the aircraft as presented in the written and oral reports must be maintained as the baseline aircraft during the course of the competition.

3.4.10 Repairs

In the event of damage to the aircraft, the aircraft may be repaired provided such repairs do not drastically deviate from the original baseline design.

3.4.11 Alteration after First Flight

Minor alterations are allowed after the first and subsequent flight attempts. Penalty will ***ONLY*** be assessed if 2/3 of the ruling committee (Event Director, Head Judge, SAE Judge) agree that there was significant modifications made from the baseline configuration. Changes due to safety will not be assessed with penalty points. Alteration must be reported as described in section 7.3.3

3.4.12 Ground Safety

NO OPEN TOE SHOES ALLOWED.

All team participants, including faculty advisors and pilots, will be required to wear CLOSED toe shoes during flight testing and during flight competition.

Smoking – Prohibited--Smoking is prohibited in all competition areas.

Section 4 (NEW) Regular Class Requirements

Design Objective:

The objective of Regular Class is to design an aircraft that can lift as much weight as possible while observing the available power and aircraft's length, width, and height requirements. Accurately predicting the lifting capacity of the aircraft is an important part of the exercise, as prediction bonus points often determine the difference in placement between competing teams.

The Regular Class will be divided into 3 phases as follows:

Phase 1: Technical report

Teams will electronically submit their proposals for competition detailing how their design has met or exceeded the design requirements.

Phase 2: Technical Presentation and Inspection

Phase 2A – Payload Loading Demonstration (timed event during Oral Presentation).

Phase 2B – Payload Unloading Demonstration (timed event during Oral Presentation)

Phase C – Oral Presentation

Phase 3: Flight Competition

4.1 No lighter-than-air or rotary wing aircraft

Competing designs are limited to fixed wing aircraft only. No lighter-than-air or rotary wing aircraft such as helicopters or autogyros will be allowed to compete.

4.2 Aircraft Dimension Requirement

Fully configured for takeoff, the free standing aircraft shall have a maximum combined length, width, and height of **175 inches**. Aircraft exceeding this design requirement will be disqualified from the competition.

Length is defined as the maximum distance from front to the aft of the aircraft. Width is the span or the maximum distance from wingtip to wingtip. Height is defined as the maximum distance perpendicular to the ground to the highest part of the aircraft (propeller not included).

Note: Modifications to the aircraft to meet the Length + Width + Height limitations during technical inspection are subjected to design change penalties.

4.2.1 Gross Weight Limit

Regular Class aircraft may not weigh more than sixty-five (65) pounds with payload and fuel.

4.2.2 Aircraft Identification

Team number as assigned by SAE must be visible on both the top and bottom of the wing, and on both sides of the vertical stabilizer or other vertical surface in 4-inch numbers. The University name must be clearly displayed on the wings or fuselage. The University initials may be substituted in lieu of the University name provided the initials are unique and recognizable.

The assigned aircraft numbers appear next to the school name on the "Registered Teams" page of the SAE Aero Design section of the Collegiate Design Series website at:

Aero East:
http://www.sae.org/students/aeroeast.htm
Aero West:
.http://www.sae.org/students/aerowest.htm

4.2.3 Name and Address

Regular Class aircraft must be identified with the school name and address either on the outside or the inside of the aircraft.

4.2.4 Material Restriction

The use of Fiber-Reinforced Plastic (FRP) is prohibited on all parts of the aircraft. The only exception is the use of a commercially available engine mount and propeller. Exploration of other materials and building methods are greatly encouraged.

In addition, the use of lead in any portion of the aircraft (payload included) is strictly prohibited.

4.3 Aircraft System Requirement

4.3.1 Electric Motor Requirements

There are no restrictions (make or model) on the electric motor. Only a single motor configuration is allowed (no multiple motors).

4.3.2 Gear boxes, Drives, and Shafts

Gearboxes, belt drive systems, and propeller shaft extensions are allowed.

4.3.3 Aircraft Batteries

Regular Class aircraft must be powered by a commercially available Lithium-Polymer battery. Homemade batteries are NOT allowed.
Required: 4 cell (14.8 volt) Lithium Polymer (Li-Poly/Li-Po) battery
Minimum requirements for Li-Po battery: 4000 mah, 25C

4.3.4 Power Limiter

All Regular Class aircraft must use a 1000 watt power limiter from our supplier (Neumotors.com). The limiter is only available at the follow link:

http://www.neumotors.com/store/page19/page19.html

This supplier has agreed to ship worldwide to any team.

4.3.5 Gyroscopic Assist Prohibited

No gyroscopic assist of any kind is allowed in the Regular Class.

4.3.6 Shunt Plug

All Regular Class aircraft **MUST** use a shunt plug to arm and disarm the electrical system. This shunt plug must be integrated into the electrical circuit between the battery and the electronic speed controller (ESC).
The shunt plug must physically be located at 40% to 60% of the aircraft length from the aircraft propeller. This is to avoid arming/disarming the aircraft without incursion through the prop arc. In addition, the shunt plug must be located on top of the fuselage and external of the aircraft surface. Please note: Disconnecting wires to arm/disarm a system will NOT be allowed.

4.4 Payload Requirements

4.4.1 Payload and Payload Support

The payload must consist of a support assembly and payload plates. All payload carried for score must be carried within the cargo bay. The support assembly must be constructed so as to retain the weights as a **homogeneous mass**. There is no required configuration for the payload plates. The design of the support assembly will depend upon the configuration of the payload plates. The payload must be secured to the airframe to ensure the payload will not shift or come loose in flight. The total payload consists of the plates plus the support assembly. It is the responsibility of each team to provide its own payload plates.

Again, no lead weights will be allowed as payload.

4.4.2 Payload Bay Limit(s)

Regular Class aircraft has a "Closed" payload bay dimensional requirements for the 2014 design year. A "Closed" payload bay is defined as having four sides, a bottom and a top. The top can be a hatch or the wing once installed on the aircraft. The payload bay must be fully enclosed within the fuselage and the aircraft must be structurally airworthy with and without the payload installed. No penetrations are allowed through the payload bay except for the payload support assembly, in which case the support assembly MUST be made removable. It must be removable so that the test block can be inserted into the payload bay during technical inspection. The removable payload support assembly will be considered as payload.

"Closed" Payload bay volume dimension shall be 4 x 4 x 10 inch +1/8, -0

- Each team is allowed only 1 payload bay per aircraft
- Teams must provide their own payload for all portions of the competition.
- During Technical Presentation (timed event) (see Section 7.2.2)
  - Team must demonstrate their design provides the capability to load and secure payload (**Ready for Flight**) in less than 1 minute.
  - Team must demonstrate their design provides the capability to unload the payload in less than 1 minute
  - **Ready for Flight** shall be defined by a completely assembled aircraft with all latches engaged and nuts/bolts tightened. NO power connected (i.e. shunt plug dis-engaged)

4.4.3 Payload Distribution

The payload cannot contribute to the structural integrity of the airframe, and must be secured to the airframe within the cargo bay so as to avoid shifting while in flight.

4.4.4 Aircraft Ballast

Aircraft ballast is allowed to be used as teams desire with the following exceptions:

1. Ballast can never be used in the closed payload bay.
2. Ballast stations must be indicated on the 2D drawings.
3. Cannot use lead as ballast.
4. Ballast must be secured so as to avoid shifting or falling off the aircraft and causing a CG problem.
5. Ballast will never be counted as payload.

4.5 General Requirements

4.5.1 Radios

The use of 2.4 GHz radio is required for all aircraft competing.

4.5.2 Spinners or Safety Nuts Required (NEW)

All aircraft must utilize either a spinner or a rounded safety nut. Prop savers are not allowed in Regular Class due to the high power propulsion system used.

4.5.3 Metal Propellers Prohibited

Metal propellers are not allowed.

4.5.4 Control Surface Slop

Aircraft control surfaces must not feature excessive slop. Sloppy control surfaces lead to reduced controllability in mild cases, or control surface flutter in severe cases.

4.5.5 Servo Sizing

Analysis and/or testing must be described in the Design Report that demonstrates the servos are adequately sized to handle the expected aerodynamic loads during flight.

4.6 Regular Class Scoring

In order to participate in the flight portion of the competition, each team is required to have submitted AND received a score for their Design Report and Oral Presentation.

4.6.1 Regular Class Flight Score

The Final Regular Class Flight Score shall comprise of total weights lifted, Max Payload Prediction Bonus and Total Penalty deduction

$$FFS = \sum_{1}^{n} R_n - \sum T + B_{n(max)}$$

$B_n = Payload\ Prediction\ Bonus\ for\ n\ round$

$B_{n(max)} = Maximum\ Payload\ Prediction\ Bonus\ earned\ for\ the\ competition.$

> *Note: $B_{n(max)}$ is NOT the summation of all the Payload Prediction Bonus earned and **shall not exceed** 20 points*

$R_n = Round\ Flight\ Score = Payload_{lb}$

4.6.2 Payload Prediction Bonus

The prediction bonus will be determined according to the following formula:

$$B_n = 20 - (P_p - P_a)^2$$

$$P_p = Payload\ Prediction$$

$$P_a = Actual\ Payload\ Carried$$

If $\boldsymbol{B_n}$ is positive, the resulting number will be applied as the prediction bonus. If the above number is negative, no bonus will be applied.

4.6.3 Total Penalty Points

Any penalties assessed during Design Report Submission, Technical Inspection, and Aircraft Modifications will be applied to the overall Flight Score.

$$T = Penalty\ Points$$

4.6.4 SAMPLE SCORE CARD

Round	R_n	B_n	T	FFS
1	10.70	0.00	5.00	
2	0.00	0.00	0.00	
3	16.40	4.00	3.00	
4	17.85	8.00	0.00	
5	18.02	19.00	0.00	
6	16.41	4.00	0.00	
SUM=	**79.38**	**19.00**	**8.00**	**90.38**

$$FFS = \sum_{1}^{n} R_n - \sum T + B_{n(max)}$$

FFS = 79.38 – 8.00 + 19.00

FFS = 90.38 pts