SAE Aero Regular

Final Report

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Project Sponsor: Professor David Willy

DISCLAIMER

EXECUTIVE SUMMARY

The team was tasked with designing a Remote Control (RC) aircraft in accordance with the SAE Aero Regular competition rules. The aircraft must be limited to 1000 Watts of power with a wingspan of 120 inches or less and a weight of 55 lbs. or less while carrying a removable size 5 soccer ball. The aircraft must then be able to take off in 100 ft., fly in a loop, and land within 400 ft.

During the design process, the team started with a glider style design. Eventually this design was entirely changed in favor of a pusher bi-plane design with enhanced lift characteristics over the initial design. This design had an approximately similar weight and would be crafted with fiberglass instead of balsa wood. After further lift characteristic evaluations, the second wing was deemed unnecessary for successful flight and was left out from the final design as the team was far behind schedule at the time.

The aircraft ended up being well within the weight and wingspan constraints as well as meeting all the other competition pass/fail criteria. The aircraft also contained the required safety arming switch and a removable soccer ball.

During the testing process the team was not able to meet all the requirements for a successful flight as per the SAE Aero competition rules. The team's final aircraft was too unstable and never achieved lift off speeds. After dealing with issues regarding the balance of the aircraft and the direction of the landing gear, the aircraft was able to move in a straight line, but once sufficient lift began to be generated, the aircraft would roll and crash. However, the aircraft's structure was resilient enough to survive six or more such roll overs without substantial damage, requiring only the replacement of one servo and re-attachment of one other. Liftoff speeds maxed out at approximately 24 ft./s, where the required lift was achieved at 37.5 ft/s. with the single wing design. Had the team continued with the biplane design, the craft would have achieved liftoff at about 30 ft/s with the increased weight.

For future work, the team would improve the final landing gear design. The landing gear tended to bend whenever the craft rolled over. This resulted in constant adjustments to the landing gear. The fixture of the landing gear to the frame of the aircraft would also be improved, as this component was not rigid enough. The aircraft would also be better fiberglassed or a different material such as the original balsa wood design. This would increase the build quality and reduce the weight of the craft. The team would also increase the lifting area of the wings to increase lift at lower speeds and include the second wing. Due to time and budget constraints, this was not achievable at this time but would be done in future work.

ACKNOWLEDGEMENTS

The team would like to acknowledge the assistance of Professor David Willy for all of his help and flexibility over the course of the semester, as well as his willingness to sponsor the project after the previous client left with little notice. The team also would like to acknowledge the help of student Gia Neve with all the challenges utilizing the new laser cutter for various components and providing the team with that learning opportunity. Finally, the team would like to acknowledge the help of the NAU purchasing staff, Shanay Barkley and Bryce Greenberg, who were always in contact with the budget liaison helping the team acquire purchased parts.

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1 BACKGROUND

1.1 Introduction

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

1.2 Project Description

The team's original sponsor, Dr. Oman, gave the following description to the team in preparation for the project:

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

2 REQUIREMENTS

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

2.1 Customer Requirements (CRs)

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

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

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

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

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

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

Cargo capacity and weight are the final two customer requirements rated at 2 and 7 respectively. This is because the other flight characteristics are more important to the team and the competition than the overall cargo capacity. The aircraft must only be able to carry a minimum payload, and anything extra would lead to a higher score in the overall competition. Weight is rated higher due to the constraints on the power allowed on the aircraft. To have enough power to maintain desired flight characteristics for the aircraft, the overall weight must be minimized so that the power available can be allocated effectively for the entire aircraft.

Customer requirements are unchanged from the previous semester as the fundamental project remains the same. All requirements come from the SAE Aero rules, and those rules remain the same as previously assessed, as have the needs of the client, even with the change in client.

Table 1: Table of CR and the ranking of impotence

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

2.2 Engineering Requirements (ERs)

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

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

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

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

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

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

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

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

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

2.3 Functional Decomposition

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

2.3.1 Black Box Model

In this section, the team will review the black box model for the team's RC plane design. This is to help the team visualize the main process of our project. This helps identify the inputs and outputs of the design.

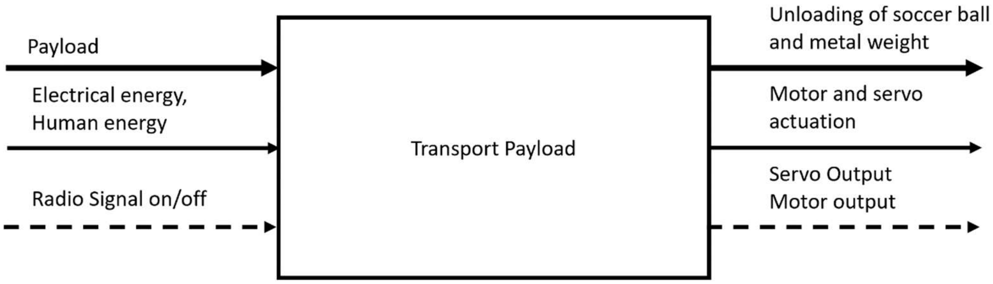


Figure 1: Black box model

The main goal designated by the competition is to transport a payload. As such, it is the focal point of the team's black box model. The only input and output of the system is the payload (soccer ball, steel weight). The payload is the only material that is fully added and removed from the system before and after use. The energy inputs include electricity and human energy. Electricity is supplied by batteries to both the aircraft and the transmitter, and human energy is used to actuate the transmitter controls. Finally, the only signal input and output is the radio signal from and to the transmitter. This black box allowed the team to better understand how to construct a proper functional model for this device.

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

The functional model is a way for the team to see what is going on within the aircraft. This model provides a visual representation of how all the inputs and outputs stated in the black box model enter the system, change, and interact with each other before leaving the system.

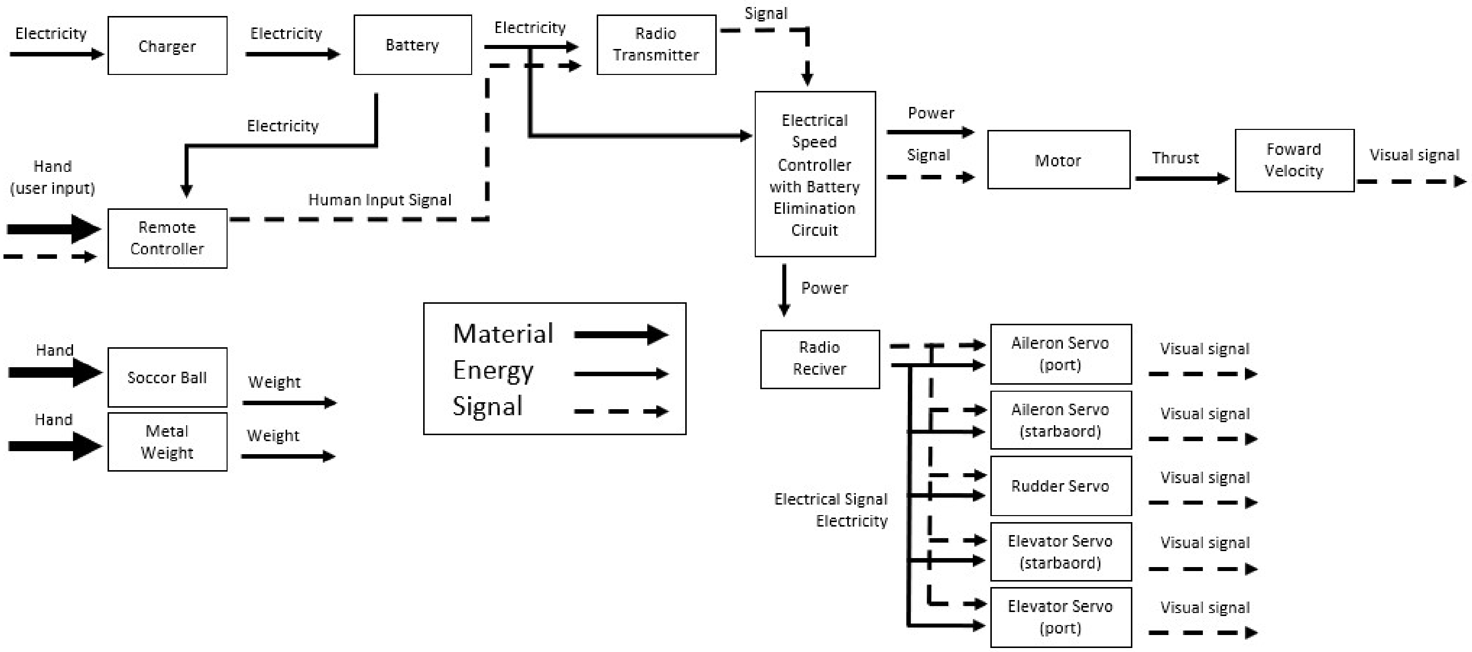


Figure 2: Functional Model

2.4 House of Quality (HoQ)

The house of quality, seen below in Appendix A, helps rate the customer requirements against the engineering requirements. It also helps relate engineering requirements to other engineering requirements. This is helpful as the team needs to evaluate how to relate the CR to the ER and by visually looking at them, and it makes sure the team can validate and focus on the ones that are more important than others. While all are important, there are always tradeoffs and you cannot always get one thing without sacrificing something else. The HoQ allows for a much easier and quicker visual as the team works on other parts of the project.

2.5 Standards, Codes, and Regulations

There are not specific standards or codes that the team had to adhere to during the building process of the aircraft due to the hobby nature of building an RC aircraft. However, referencing previous teams and rules of the SAE Aero Regular competition rules, the team complied the following standards [2] [1]. The only other applicable standards or codes would be the NSPE Engineering Code of Ethics, which is applicable to all engineering projects.

Table 2:Standards of Practice as Applied to this Project [2]

Standard Number or Code	**Title of Standard**	**How it applies to Project**
ANSI-Y14.5 M 1994	Dimensioning and Tolerancing	Proper schematics of the aircraft with dimensions.
SAE J429	Mechanical and Material Requirements for Externally Threaded Fasteners – Standard	Aircraft nuts and bolts must be strong enough for takeoff, flight and landing.
SAE J452	Composite manufacturing standard	This standard talks about composites which applied to our project using fiberglass
IEEE 750-1947	AIEEE Report on Aircraft Electric System Guide	This standard is loosely used for how to wire the aircraft

3 DESIGN SPACE RESEARCH

This section of the report will cover relevant research the design team performed to evaluate and develop an aircraft design for the SAE Aero Competition. This research will consist of reviewing the previous competition designs including previous Northern Arizona University design teams and other colleges as needed.

3.1 Literature Review

During the literature review process, the team learned the basic fundamentals of flight and aircraft design necessary to designing a small aircraft. The team learned how to analyze airfoils and how to compare standard airfoil shapes. The team also reviewed extensively the SAE Aero rules as well as the fundamentals behind designing proper landing gear. The team members also investigated the principles of control surfaces and remote-control electronics. The team also researched previous competition designs and the materials from the previous NAU SAE Aero team.

3.2 Benchmarking

During the design process of the aircraft, the team took into consideration previous team designs as well as other school designs. Due to the rules set forth by t SAE Aero there are not commercial RC aircraft that fit the parameters. Because of this most of the benchmarking is form other aircraft while inspiration for other designs comes from commercial aircraft.

3.2.1 System Level Benchmarking

This section will discuss the designs of other successful and unsuccessful aircraft to help the team understand what is needed from the team's design to allow it to reach peak performance. The team will investigate previous designs by looking at other SAE Aero teams from both NAU and from other schools. The team will also look at commercial aircraft that are well equipped to carry large payloads.

3.2.1.1 Existing Design #1: Pondarosa Pilots (NAU's 2020 Team)

Figure 3: Pondarosa's final design for aircraft [2]

This aircraft from last year's SAE Aero team at NAU has a few characteristics that are worth mentioning. They had an extremely light aircraft due to the construction materials. They used foam to produce the fuselage, wings and tail of the aircraft. They found the final weight of the aircraft to be 9.5 pounds unload with no payload on board. They also kept the wingspan to a minimum of 60 inches to better help their flight score during competition. All in all, they created a very light small aircraft for competition. While these attributes were beatifical to the aircraft, in the performance area there were a few downsides and flaws to this design. During testing, the team found that the wings were not generating enough lift during takeoff. This issue they resolved be changing the landing gear configuration. Another issue that they faced was due to the low speeds the aircraft inflight, it did not have enough horizontal authority during flight to control the aircraft. To remedy this issue, they enlarge the elevator control surface however this fix did not really solve the problem. The team also mentioned in their final report that while the lift to span ratio was satisfactory and they would not change it they would change the landing gear durability the control authority and the propeller optimization [3]. They went on to mention how the worst one was the control authority. These are all important things to keep in mind when working on our design [3].

3.2.1.2 Existing Design #2: Skyjacks (NAU's 2019 Team)

The second design to consider is the Skyjacks. This team that worked on the SAE Aero competition had a different set of parameters, so while it will be useful to look at their design it is important to keep in mind that the payload requirements and length of flight were different. Last year, in 2020, the competition changed the rules form carrying tennis balls to a soccer ball. This is the biggest difference but there are other. With this said their design consisted of a very large wingspan of 120 inches which is the max for competition [4]. The aircraft weighed empty at 18.6 pounds and fully loaded 28.3 pounds [4]. These parameters would not be helpful to duplicate as the way competition is scored has changed and the wingspan would be the biggest hinderance. Regardless they did some very insightful test on propeller to find the most thrust possible. The team ended up going with a propeller 18 inches in diameter with a pitch of 8 inches. They calculated with this design they would get a rough speed of 56.8 miles per hour [4]. While their design criteria were different information such as propeller size and thrust, calculations are something we can use as they electrical criteria have not changed.

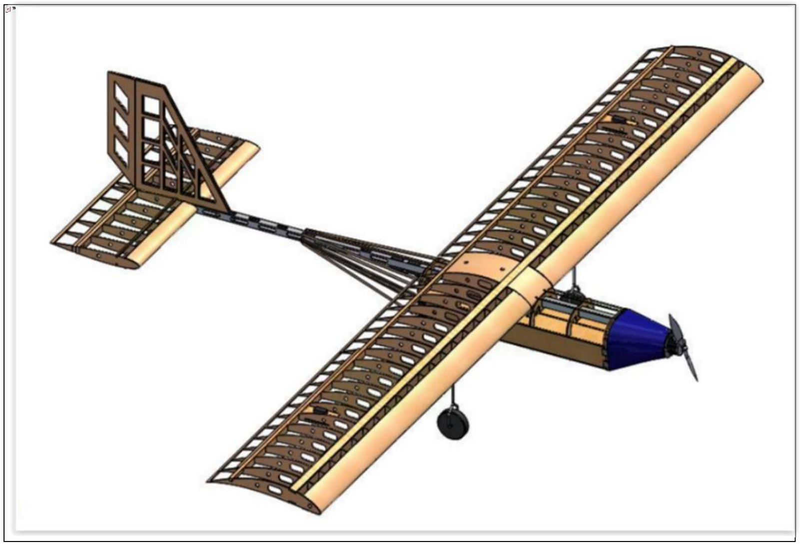


Figure 4: Skyjacks' final design without monokote [4]

3.2.1.3 Existing Design #3: In Thin Air (NAU’s 2018 Team)

Once again just like the previous design the competition rules were different, and while there will be pieces of the project, one can see there are different payload requirements. Regardless, the aircraft they created was able to carry 34 tennis balls, giving them a large cargo bay￼￼￼￼ [5]￼￼. The aircraft had a wingspan of 141.5 inches and empty weight of 33.6 pounds￼￼￼￼ [5]￼￼. Fully loaded, the aircraft came in at 52 pounds. Once again, the team went with a very large propeller of 16 inches in diameter with a pitch of 6 inches￼￼￼￼ [5]￼￼. They calculated the static trust to be 16.7 pounds which gave them an inflight speed of 36.67 miles per hour￼￼￼￼ [5]￼￼. Due to the length of the cargo area there was a lot of increases drag on the aircraft due to the increase in surface area. This is something to consider when creating the new aircraft as the team is going to have a very large cargo bay to fit a soccer ball that will increase the amount of drag on the airframe. Regardless this design has a few things worth evaluating when designing our aircraft.

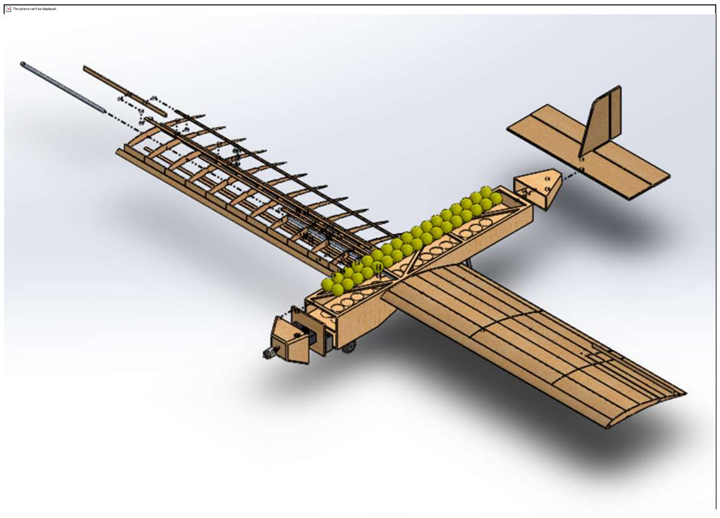


Figure 5: In Thin Air's final design [5]

3.2.1.4 Existing Design #4: Airbus Beluga

When benchmarking, the team wanted to look at products that are already on the market that fulfill the large payload constraint that the team is faced with. One aircraft that has a very interesting shape and payload capacity is the Airbus Beluga. This aircraft was created to serve the purpose of moving other airplane components around Europe for final assembly of Airbus's planes. The reason the company needed this plane was to create more economic method of move the cargo. The company has leading-edge spars being produced in the United Kingdom while also making lower wing skin in Spain and all these components need to merge together in France for final assembly. Due to the fact that this aircraft is carrying large payload and oddly shaped cargo at time the aircraft has a shape that resembled the head of a beluga whale hence its name.

Figure 6: Beluga XL aircraft inflight [7]

This aircraft was an outside the box idea to what the aircraft could look like and something that is not your typical airframe set up. Even though this aircraft has only a few ever produced and flighting the idea is still something to keep in mind as the team tries to load abnormally large payload on a small airframe. To better illustrate this idea the following image is an airplane fuselage being loaded into the aircraft for travel.

Figure 7: Beluga being loaded with fuselage of another aircraft [7]

3.2.1.5 Existing Design #5: Icon A5

The next aircraft that is being benchmarked is the Icon A5. This aircraft has a unique design that the team looked at when doing concept generations. This aircraft has a nonconventional pusher propeller instead of a puller propeller. While there are other aircraft that have this design there are very few in production today with the design. One of the reasons the designer probably when with this design is to allow for the aircraft to be amphibious and having a propeller that would strike the water on landing would be a hazard. By placing the propeller where they did it limits the potential of hitting water during take of or landing. This aircraft also has winglets that turn down on the wing tips to decrease tip vortices. Based on the wind design and the slow flight characteristics this aircraft is made to go low and slow which is one attribute we will need to have in our design. This aircraft also has a large forward section where there is plenty of room for payload while decreasing surface area as you form stern to aft. This is a good way to reduce surface drag on the aircraft, however you do have a large front cross section that affects the airflow around the aircraft. Nevertheless, an interesting design that is worth considering.

Figure 8: Icon A5 aircraft [7]

3.2.1.6 Existing Design #5: C-5 Galaxy

Another aircraft the team looked at is a heavy lift cargo plane called the Super Galaxy. This aircraft is similar to the beluga from airbus however this aircraft is operated by the military. Regardless, it has some incredible lift characteristics and payload ability, and therefore we looked at it. Our team is tasked with finding a way to carry a very load payload that is not very heavy, and you can see that something like a fuselage as cargo is similar. It has weight but mostly it is just big and filled with air. In the picture down below, you can see a C- 130 cargo plane fuselage being loaded into the C-5 Galaxy and this just show how big the cargo can be.

Figure 10: C-5 being loaded with a C-130 fuselage [7]

Figure 9: C-5 unloading an Apache Helicopter [7]

The other picture on the right side is a full helicopter being unloaded from the cargo bay and this once again give use an idea of how much this plane can carry. This image also helps better depict how we might want the cargo door to open to access the cargo inside as part of our rules for competition are to be able to access the cargo quickly.

3.2.2 Subsystem Level Benchmarking

3.2.2.1 Subsystem #1: Landing Gear

This subsystem absorbs the landing forces from impact with the ground. It will prevent the fuselage from impacting the ground and will elevate the aircraft during takeoff and landing. Allows aircraft to safely land without damage to the aircraft.

3.2.2.1.1 Existing Design #1: Tricycle Wheels

The tricycle design has three wheels placed in a triangle with wheels mounted on both wings and one in the nose of the aircraft. This design has an average weight and if designed properly can have large amounts of strength and is very common on large aircraft. It provides stability and low resistance while on the ground. This would allow for shorter takeoff and landing procedures, and the small size would minimize effects of friction and drag.

3.2.2.1.2 Existing Design #2: Tail Dragger

This design has two primary wheels mounted on the wings of the aircraft and a tail mounted wheel that is typically halfway inside the fuselage of the aircraft. This design produces faster takeoff speeds and generates more lift on the ground at low speeds, which is important to the team as this will be a critical time for the team's aircraft as this is a scored event. This design weighs less than the tricycle wheels design and is as good at absorbing impact forces.

3.2.2.1.3 Existing Design #3: Floats/Skis

This existing design uses floats instead of wheels to support the aircraft during landing and takeoff. Typically applied to water landing aircraft, it can be utilized to a degree by other aircraft as well, in the proper conditions. This is the least effective existing design for the team's evaluation because the team will not be performing a water landing, and the floats will increase drag and friction across a solid earth surface. The strength of the floats during landing would be high, but weight and resistive forces would also be increased.

3.2.2.2 Subsystem #2: Fuselage

The fuselage is the main body of the aircraft where the payload and most of the electrical components are held. Without this component, there is nothing to hold the other subsystems together or to hold the payload and other contained components. The payload, a soccer ball and a varying number of metal weights in this case, must be fully enclosed by the cargo bay of the fuselage during transport according to the competition rules. However, there are no other restrictions to the fuselage dimensions other than that the fuselage may only have a single cargo bay, which may hold as many payloads as desired. There also is nothing in the competition rules that defines where the fuselage begins and ends, so the team will go forward assuming the fuselage begins at the tip of the nose and ends where the tail or tail-adjoining beam begins, depending on the final design of the aircraft. A few basic, potential designs for the fuselage are depicted below in Figure 11.

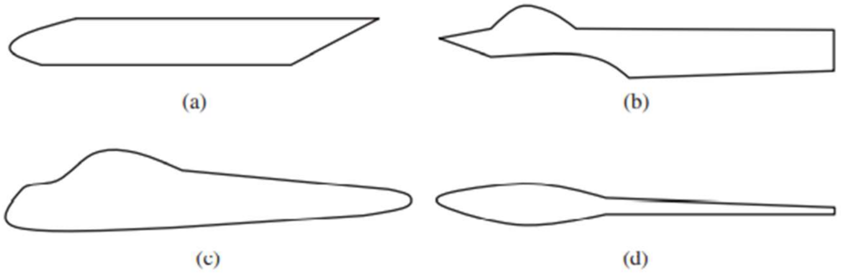


Figure 11: Basic Fuselage Design [6]

The fuselage is also typically the greatest source of drag in any aircraft, making the component one of the team's main hindrances. As the drag coefficient of the aircraft increases, the overall velocity of the plane will decrease, leading to less lift. If drag becomes too great, the aircraft may not be able to achieve lift at all. This subsystem must be as aerodynamic as reasonably possible while still meeting all the requirements stated above. The fuselage will also be where most of the aircraft's weight resides since it holds the payload, most of the electrical components, and will likely take up the most volume in the final design. As such, it is imperative that the weight of the fuselage be reduced as much as possible by using light materials and structuring the inside in a way that decreases material while maintaining a strong enough structure.

3.2.2.2.1 Existing Design #1: Commercial Design

The commercial design, shown above in Figure 11, is the typical design used by major airline companies for transporting passengers and cargo. The design excels in its ability to transfer cargo but is much heavier than other designs. This type of aircraft could be imperative to the team's goals if they decide to focus on transporting multiple or heavier payloads.

3.2.2.2.2 Existing Design #2: Light GA

The light general aircraft, or light GA, is a smaller and simpler design used commonly by hobby pilots and remote-control aircraft flyers and builders. This fuselage design is easier to manufacture and repair than other designs. However, it cannot transport as much cargo as the commercial and as not as light aa the glider design, discussed in the next section. The light GA is ideal due to its simple design and build process, decreasing build time and allowing more time to develop and test prototypes.

3.2.2.2.3 Existing Design #3: Glider

The glider is a design that uses its lightweight fuselage to allow for lift without the use of a motor. The glider is more complex to design, manufacture, and repair, but is ideal for the team's applications. The glider is meant to glide along a long loop with a few tight turns without any tricky maneuvers. The main drawbacks include the previously stated complexity and the lack of a motor. However, the design can likely be redesigned to include a motor and propeller.

3.2.2.3 Subsystem #3: Wings

The wings assembly is a highly important subsystem of the team's aircraft as it would generate the most amount of lift while minimizing drag. Wings also contain most of the control surfaces of the aircraft such as flaps, spoilers and ailerons. There are countless predefined airfoils that the team can choose from, and the team decided on using a NACA 4-series airfoil in our design. The camber, thickness, chord length and pitch of the airfoil directly relates to the aircraft performance and should be fine-tuned to achieve maximum lift and efficiency. Initially, a NACA 0004 (symmetric) airfoil was selected and simulated under different Reynolds numbers and Mach numbers. However, after further inspection, the team decided on using a thicker airfoil than NACA 0004 for ease of fabrication and maintainability. Therefore, a NACA 0010 airfoil will be tweaked to meet our design criteria. The airfoil selection is further explained in *Section 5* of this report. The wings generally have 3 main mounting positions. They are,

1. Low wing configuration
2. Mid wing configuration
3. High wing configuration

These configurations are further explored below.

3.2.2.3.1 Existing Design #1: Low-wing configuration: American Curtiss P-40 Kittyhawk

A low wing configuration tends to make the aircraft more maneuverable while increasing the phenomenon of ground effect that tends to make the aircraft float farther before landing. In retrospect, this reduces the take-off distance of Low-wing aircraft. The visibility is also generally higher. However, visibility is not an issue in the team's design as it will be unmanned and radio-controlled. The main cons of this configuration include the low center of lift and reduced ground clearance. The center of lift can be tweaked however the ground clearance cannot be tweaked. Having a low ground clearance means low debris protection and this could damage the wings and would require additional maintenance.

3.2.2.3.2 Existing Design #2: Mid-wing configuration: Brewster SB2A Buccaneer

Mid-wing aircraft usually have a larger control surface area and maximizing control surface area is a direct engineering requirement of the team's design. This configuration is very balanced as the wings are placed exactly at the midline of the airplane. However, this configuration requires additional spar structures for reinforcement and can reduce the fuselage volume right by the aircraft's center of gravity.

Mid wing aircraft are highly maneuverable but can be unstable compared to other wing configurations. Due to this reason, many aerobatic aircraft utilize this configuration. Since the team's aircraft FCS does not facilitate complex maneuvers, stability is the most important aspect. Mid wings attached to the rear side of a fuselage causes the center of mass to shift towards the rear side of the fuselage and this issue can be countered by using counterweights. However, minimizing weight is a direct requirement and adding extra weight to compensate for the aircraft itself poses a disadvantage.

3.2.2.3.3 Existing Design #3: High-wing configuration: Lockheed C-130 Hercules

In this configuration, wings are attached to the upper surface of the fuselage or on top of it. This configuration is ideal for cargo and military transport aircraft. High wing aircraft does not require wing dihedrals for stability either. The ground effect is much reduced, but these aircraft tend to be very stable at slower speeds. Therefore, this is the perfect configuration for our team's design.

4 CONCEPT GENERATION

4.1 Full System Concepts

4.1.1 Full System Design #1: Glider-Inspired Design with Mid Wings

The first full design in mind is a glider-inspired fuselage with straight wings and taildragger landing gear. The wings are in the middle of the fuselage. The glider-inspired design provides a lightweight fuselage with a low surface area, allowing for less drag in flight and a lower velocity required to achieve lift. The glider design also works well with the team's objective, as it is specifically for slow gliding without any special maneuvers. The straight wings are simpler to design and build than other types of wings as discussed below in Section 4.2.3. The taildragger design will allow the team to adjust the aircraft's angle of attack on the runway, allowing for simple testing of the takeoff sequence. This design is depicted below in Figure 45 under Appendix B.

The design is relatively complex overall, making designing, manufacturing, testing, and repair more difficult than other designs. The glider uses splines to lower aerodynamic drag, and while lower drag is beneficial to the aircraft, the splines are generally more difficult to build with. The mid wing design also introduces issues with weight and manufacturing. Mid wings are typically heavier than other wing positions and more difficult manufacture in terms of overall aircraft structure.

4.1.2 Full System Design #2: Light GA with High Wings

The second design, shown in Figure 46 under Appendix B, is a simple GA fuselage with low, straight wings and taildragger landing gear. This design has most of the advantages of the glider inspired design. However, it trades out the lighter weight and aerodynamic splines of the fuselage for a simpler design that is easier to manufacture. Simpler building will allow for more time to prototype and test the design, potentially making for a better final design. High winds will also allow for more lift during flight and are slightly lighter than mid wings.

However, the light GA fuselage is longer and heavier than the glider-inspired fuselage, which will take away from the team's score during competition. The high wings also have less lift during takeoff and have a greater frontal surface area, producing more drag in the design.

4.1.3 Full System Design #3: Icon A5 Inspired

The final design, found below in Figure 47 under Appendix B, is heavily inspired by the Icon A5 Light Sport Aircraft in Figure 8, which has a short fuselage that is similar to the light GA and high wings with taildragger landing gear. The design has most of the advantages of the previous design, but with a short fuselage that will reduce point deduction at the competition.

However, the Icon A5 is primarily for sport and made with tricks and maneuverability in mind, making it slightly over-designed for the team's objectives and applications. The aircraft does not need to, and is in fact prohibited from, make certain extreme maneuvers, such as loops. The design is interesting and would set the team apart at the competition, but it was not made with the goals the team has in mind.

4.2 Subsystem Concepts

4.2.1 Subsystem #1: Landing Gear

4.2.1.1 Design #1: Tail Dragger

This design for the landing gear subsystem has three primary components consisting of two wing mounted wheeled landing gear and one rear mounted skid wheel or dragger. The purpose of this design is to allow the team to change the angle of attack of the aircraft while the aircraft is on the ground, providing for an easier takeoff in a shorter distance. This is important as it allows the team to optimize the airfoil design for flight characteristics and to modify the angle of attack so that the airfoil can generate enough lift at low takeoff speeds. This design also has a slightly higher cruising speed than a tricycle design [4]. The pros for this design include the ability to vary angle of attack, low complexity, easily replaceable parts, and low cost. Cons for this design include lower control on the ground, potential difficulty when landing (if slider, not rear wheel), and wheel height controls angle of attack.

4.2.1.2 Design #2: Rear Steer

The rear steer concept involves two wing mounted wheels with one steering rear wheel at the rear of the aircraft. This is similar to the tail dragger concept but has a steerable rear wheel at the tail of the aircraft instead of a sliding skid or wheel. This increases the ability to control the aircraft on landing and takeoff as there is a wheel that can orient the movement of the aircraft. Pros of this design include the ability to steer the aircraft directly on the ground, relatively low cost, and good landing force absorption. Cons of the design include increased complexity, increased electrical demand, and increased weight.

4.2.1.3 Design #3: Skis

The final subsystem design utilizes skis similar to snow skis. This design would decrease the rolling resistance of the aircraft on the ground. These skis would be mounted via a shaft to the frame of the aircraft and would be mounted on both wings and at the nose of the aircraft. This design would help the aircraft with an uneven or imperfect landing as well as to increase the area that landing forces are applied to. This design would require additional adaptation and fabrication, increasing complexity of building the aircraft relative to the other landing gear options. Pros of this design include increased landing area, reduced frictional forces, low complexity, and durability of landing gear. Cons include increased weight, high-cost relative to other options, reduced control, and additional custom fabrication work.

4.2.2 Subsystem #2: Fuselage

4.2.2.1 Design #1: Glider-Inspired Design

The first design considered for the fuselage is a design that is heavily inspired by traditional glider aircraft. The basic idea of this design is displayed above in Figure 11d. Gliders are designed to glide along long distances without the use of a motor. The design minimizes drag in the fuselage by reducing the overall volume of the cargo bay and curving the body with splines in a way that makes it lighter and more aerodynamic than other types of aircraft. By doing this, the glider does not need a large velocity to achieve lift and sustain flight with less lift than other potential fuselage designs. This type of fuselage is ideal for the team's aircraft as it solves many issues the team is currently facing. The required power limiter and 1:1

motor-to-propeller gear ratio are making it difficult to maintain enough velocity to hold a net positive weight. The current solution is to decrease weight as much as possible, which the glider-inspired design allows the team to do. This design is also ideal for the team's objective, which is essentially to glide around a loop with an enclosed payload.

The main issue with the glider design is that the heavy use of splines in the fuselage makes the design difficult to manufacture and repair. The design also traditionally does not have a propeller or motor to maintain flight. However, the team believes the design can be reworked enough to allow a motor and propeller to be installed.

4.2.2.2 Design #2: Light GA

The next design the team considered is the light general aircraft (light GA). This is the traditional type of design that is most often seen in hobby aircraft designs. The light GA, seen above Figure 11c, is much simpler and easier to manufacture than the glider. The design is reliable, with many iterations to draw inspiration from, making the designing and manufacturing processes much shorter and easier than other designs. However, this design also has a long fuselage, which will count against the team's score in competition.

4.2.2.3 Design #3: Icon A5 Inspired Design

Another design considered is a design based on the Icon A5 Light Sport Aircraft. This design is essentially a light general aircraft design, except the design has been cut short, making the fuselage shorter and lighter. The Icon A5 also uses a pusher propeller to gain velocity instead of a traditional propeller, so the aircraft pushes itself instead of pulling itself. This potential fuselage could work well with the team's objective because of the lighter weight and shorter fuselage. As discussed earlier, the team's aircraft will be scored on many factors of the design, including the length of the fuselage. As such, it is imperative to minimize the length of the fuselage to maximize the team's score.

Although the Icon A5-inspired design is promising, it is not entirely what the team is looking for in an aircraft design. The Icon A5 is primarily a sport aircraft made to perform tight turns and tricky maneuvers, which is far from our objective. The team's design only needs to fly the distance and is restricted from performing some maneuvers, such as loops, by the competition rules. This design is also an amphibian craft made for both land and water, which is unnecessary for the team's design. Finally, the Icon A5 has a newsworthy history of crashes, and although these events are found to be mostly the fault of the pilots, it is still something the team is wary of.

4.2.3 Subsystem #3: Wings

4.2.3.1 Design #1: Straight Wings

The first wing type considered for the team's design is the straight wing design. Straight wings, displayed below in Figure 12**Error! Reference source not found.**, are the simplest to design and manufacture [. As such it costs the least and is the easiest to repair should the need arise.

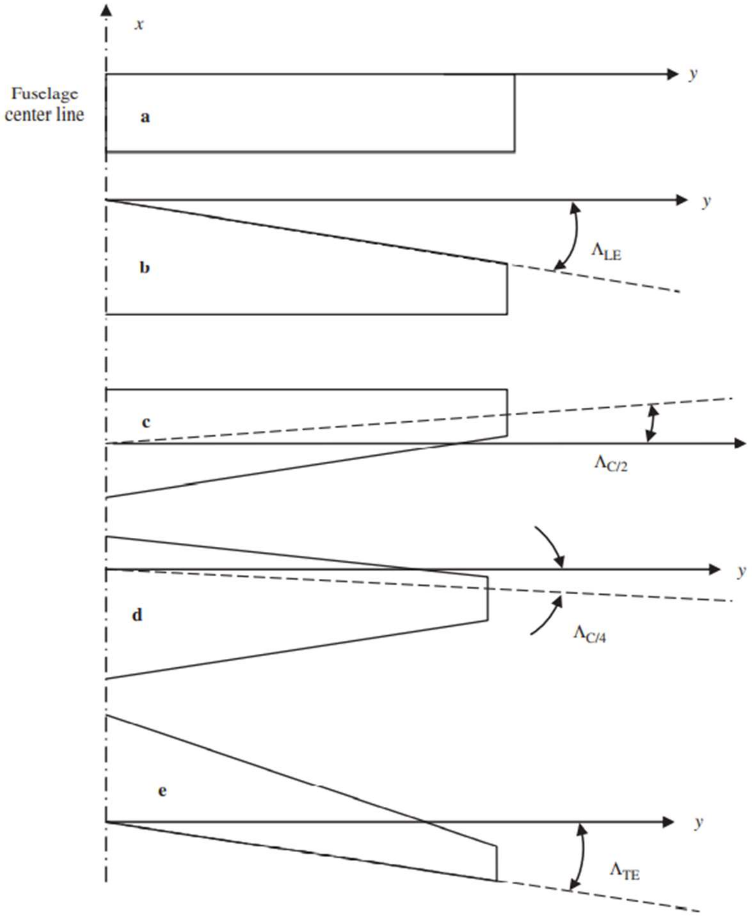


Figure 12: Wing Designs

4.2.3.2 Design #2: Swept Wings

The next wing types the team considered are wings with leading and swept angles, shown above in Figure 12. All these wing types are seen below in. Typically, these are useful for improving aerodynamic effects, such as the lift, drag, and pitching moment around the body of the aircraft. However, they are also all more difficult to manufacture and only have practical use at "transonic, subsonic, and hypersonic speeds", which are all unreasonable for the team's purposes.

4.2.3.3 Design #3: Wing Number

The number of wings and wing positions are also to be considered. Generally increasing the number of wings increases the amount of lift the aircraft can get by increasing the surface area of the wings while maintaining a small wingspan [6]. However, having more wings also decreases the distance between wings' surface areas, forcing airflow through smaller areas. If these cross-sectional areas between wings become too small, turbulence can become a major issue.

4.2.3.4 Design #3: Wing Positions

The three wing positions currently being considered are the high wing, low wing, and mid wing. The high wing typically allows for the bottom of the fuselage to be more aerodynamic and produces a more laterally stable flight [6]. However, the wing will also usually have a greater frontal surface area, increasing drag, and less lift during takeoff. The low wing has greater lift during takeoff, has less drag during flight, and is typically lighter than the high wing as it is more structurally sound [6]. But the wing also has less lift during flight. The mid wing finds a healthy middle between the high wing and low wing, and typically the most major drawback is that the wing is typically due to lack of structural integrity.

5 DESIGN SELECTED – First Semester

The team had a different design selected for the aircraft at the beginning of the semester. This aircraft consisted of a glider approach instead of the current design with a forward mounted motor and propellor. This design was composed of balsa wood construction. It was a lighter design with less lift and less capacity for payload. Analysis of the design as well as CAD and implementation plans will be provided.

5.1 Design Description

5.1.1 Improvements from the previous CAD model

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

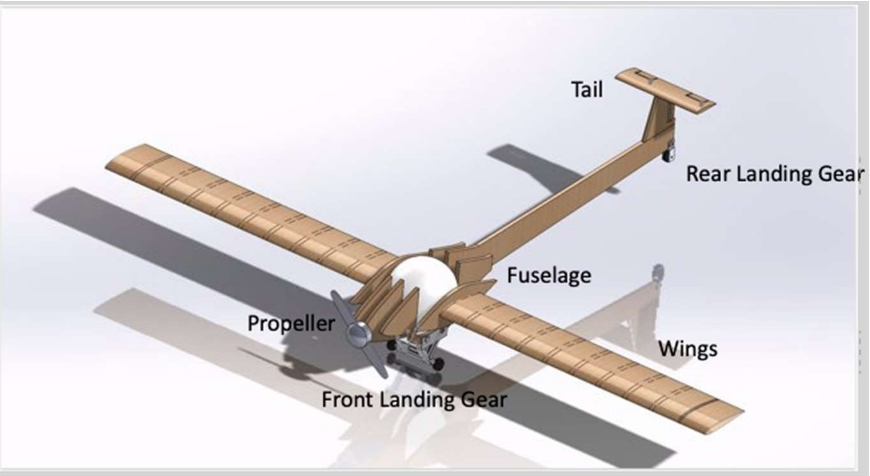


Figure 13:Current CAD model

5.1.2 Current CAD Assembly – Detailed Description

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

5.1.3 Airfoil Selection Process and Engineering Analysis

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

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

Airfoil Wingspan: 1 meter(s)

Chord Length: 0.2 meter(s)

Reynolds Number: 107 000

Mach Number: 0.044

Ambient Temperature: 20 deg. C

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

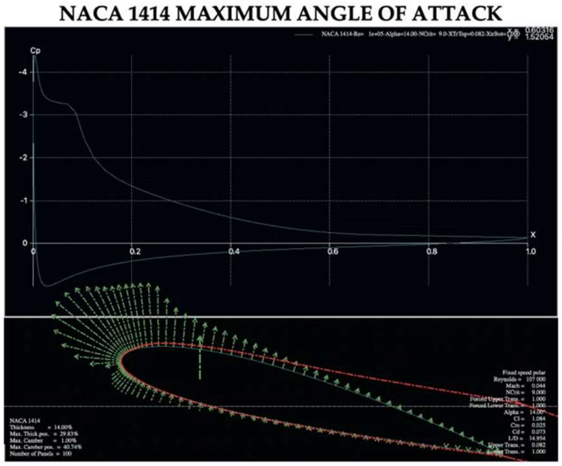


Figure 14: NACA 1414 Pressure forces

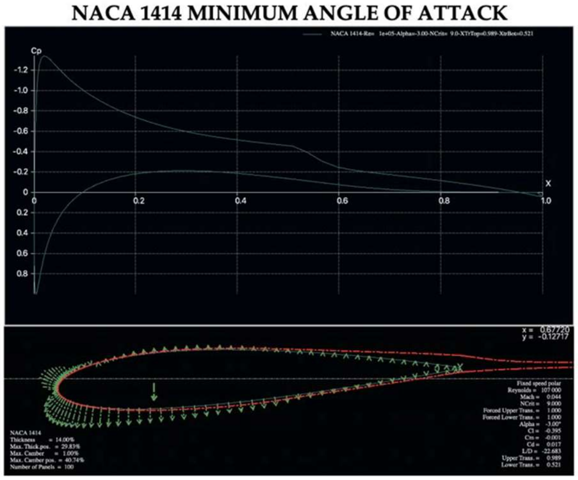


Figure 15: NACA 1414 Pressure forces

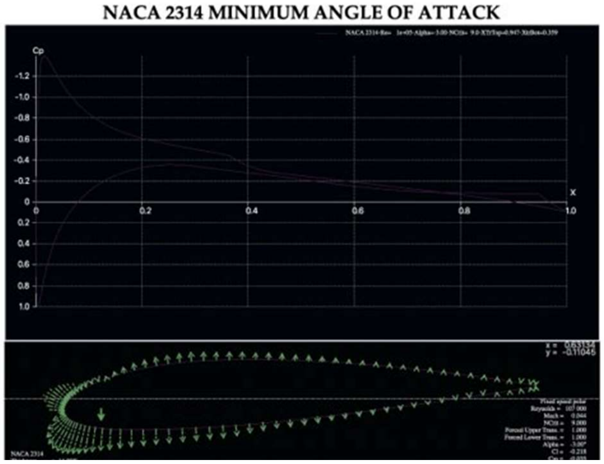


Figure 17: NACA 2314 Pressure forces

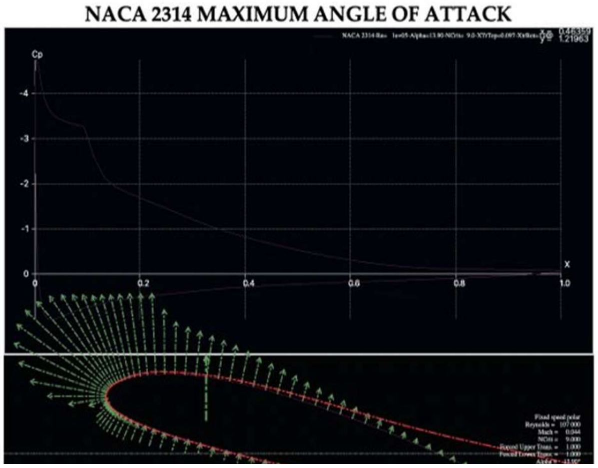
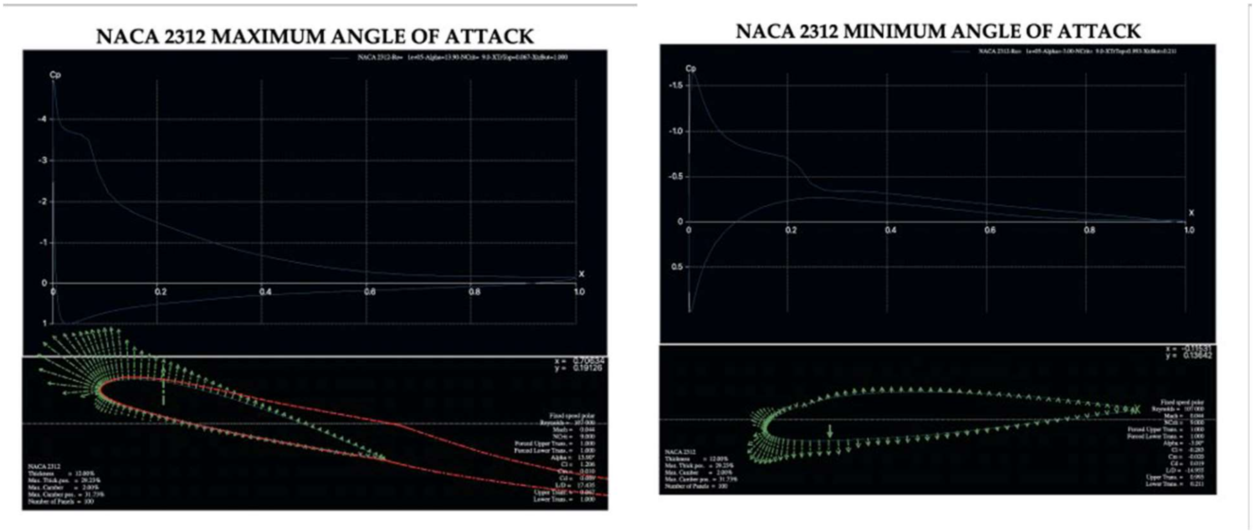


Figure 16: NACA 2314 Pressure forces



NACA 2312 MAXIMUM ANGLE OF ATTACK

NACA 2312 MINIMUM ANGLE OF ATTACK

Figure 18:NACA 2312 Pressure forces

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

Table 3: Data imputed into XFLR5

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

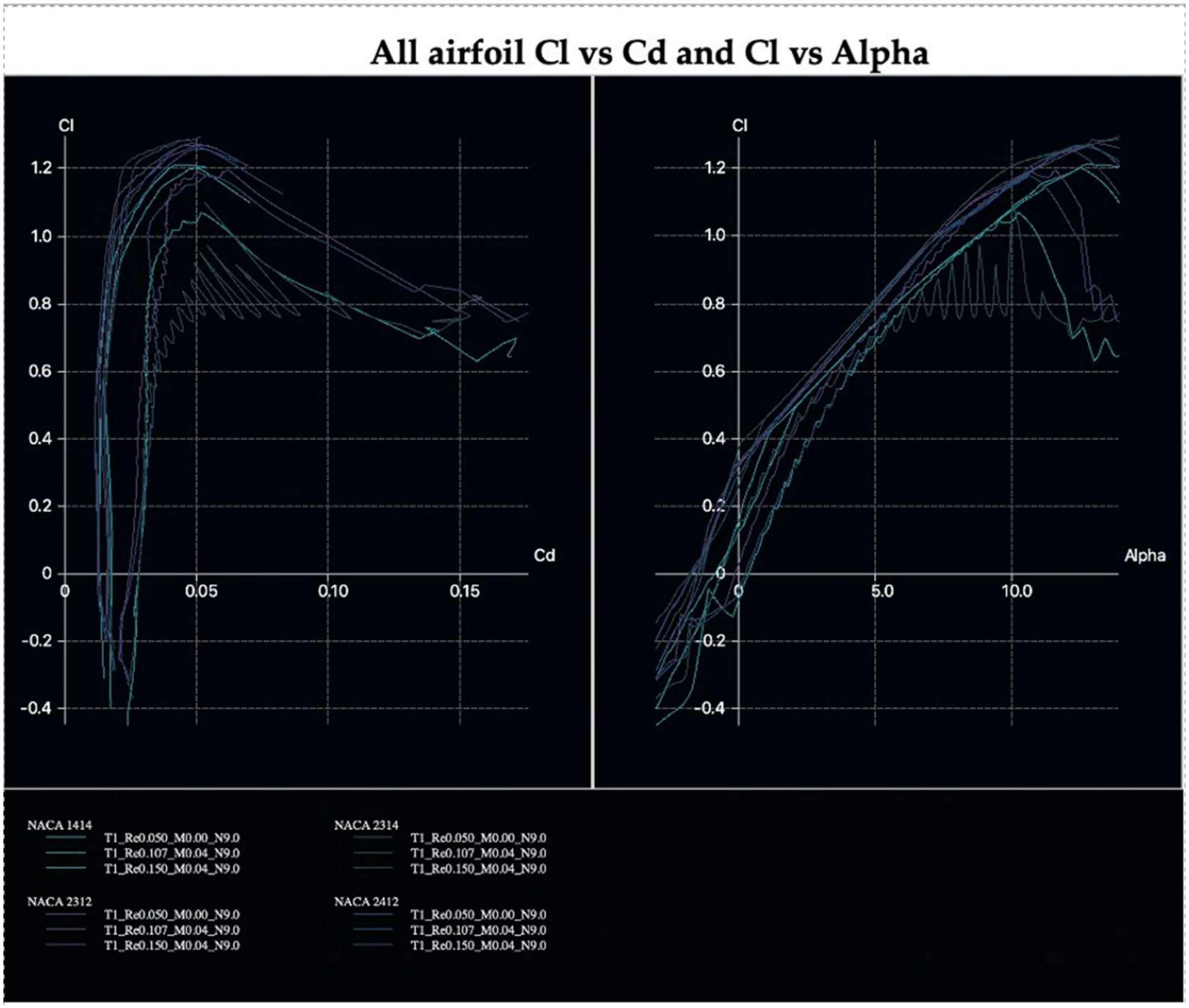


Figure 19: Cl vs Cd and Cl vs Alpha

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

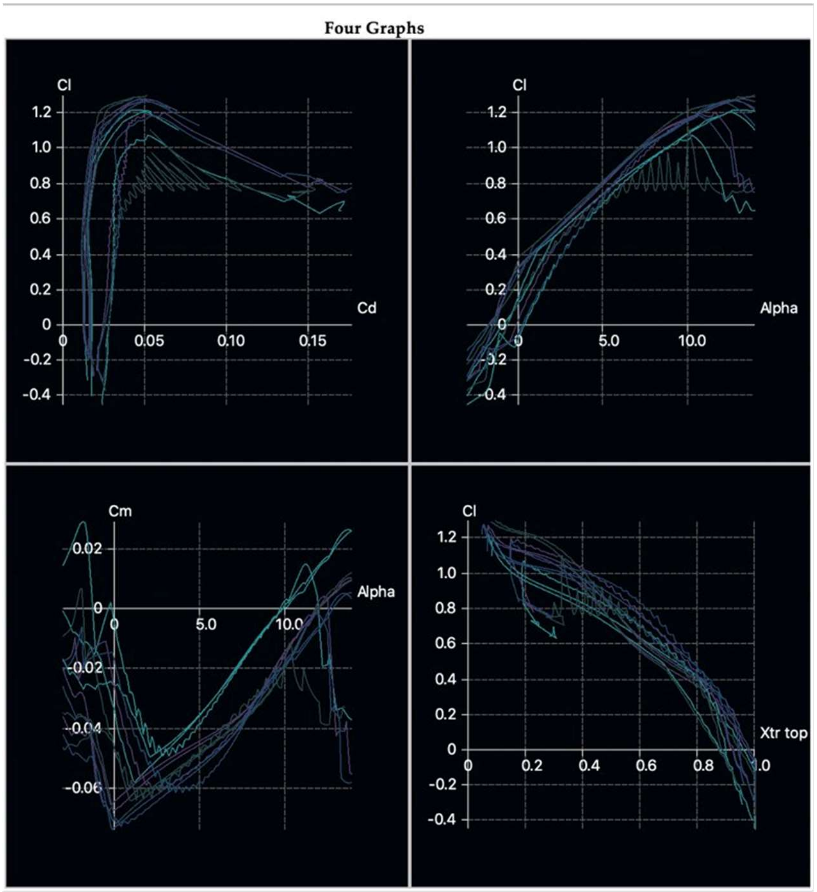


Figure 20: Graphs of Cl, Cd, Cm, Alpha

All Graphs

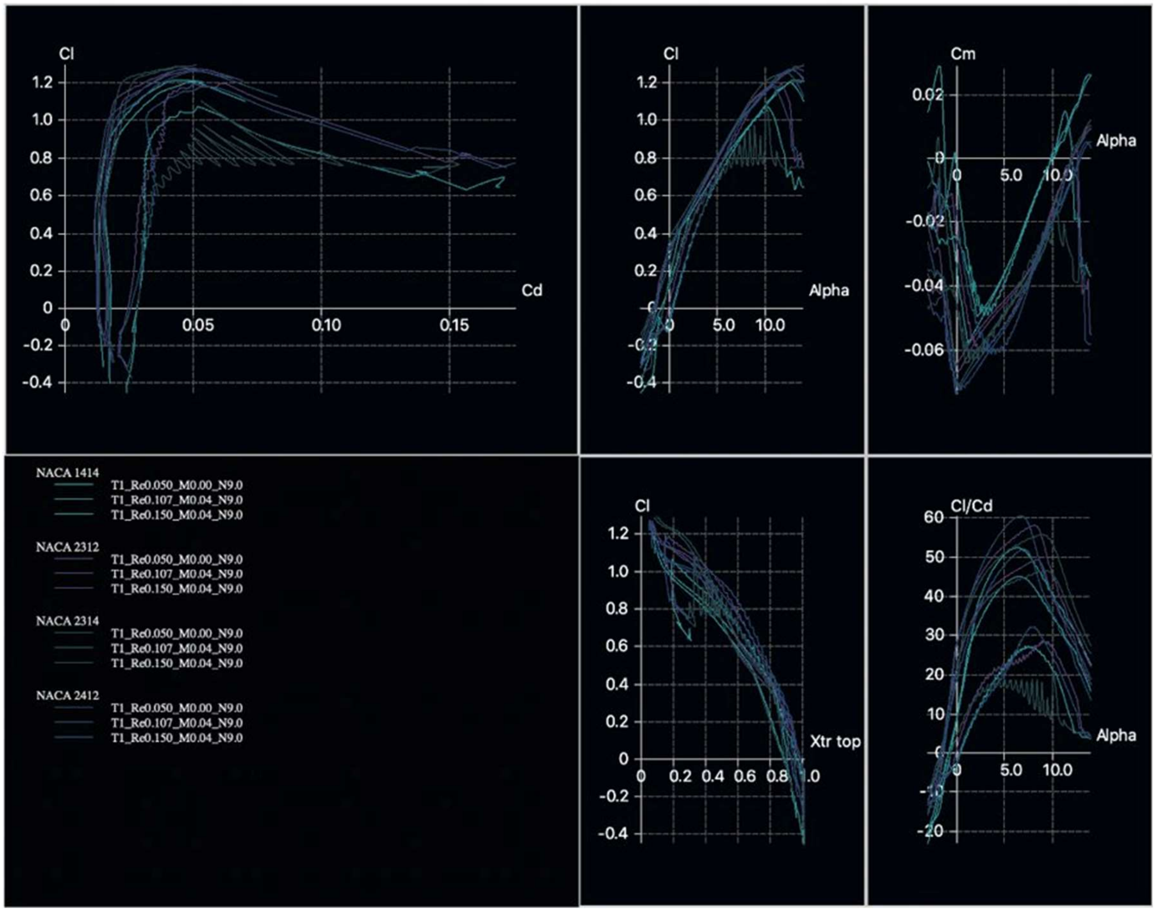


Figure 21: Graphs of Cl, Cd, Cm, Alpha

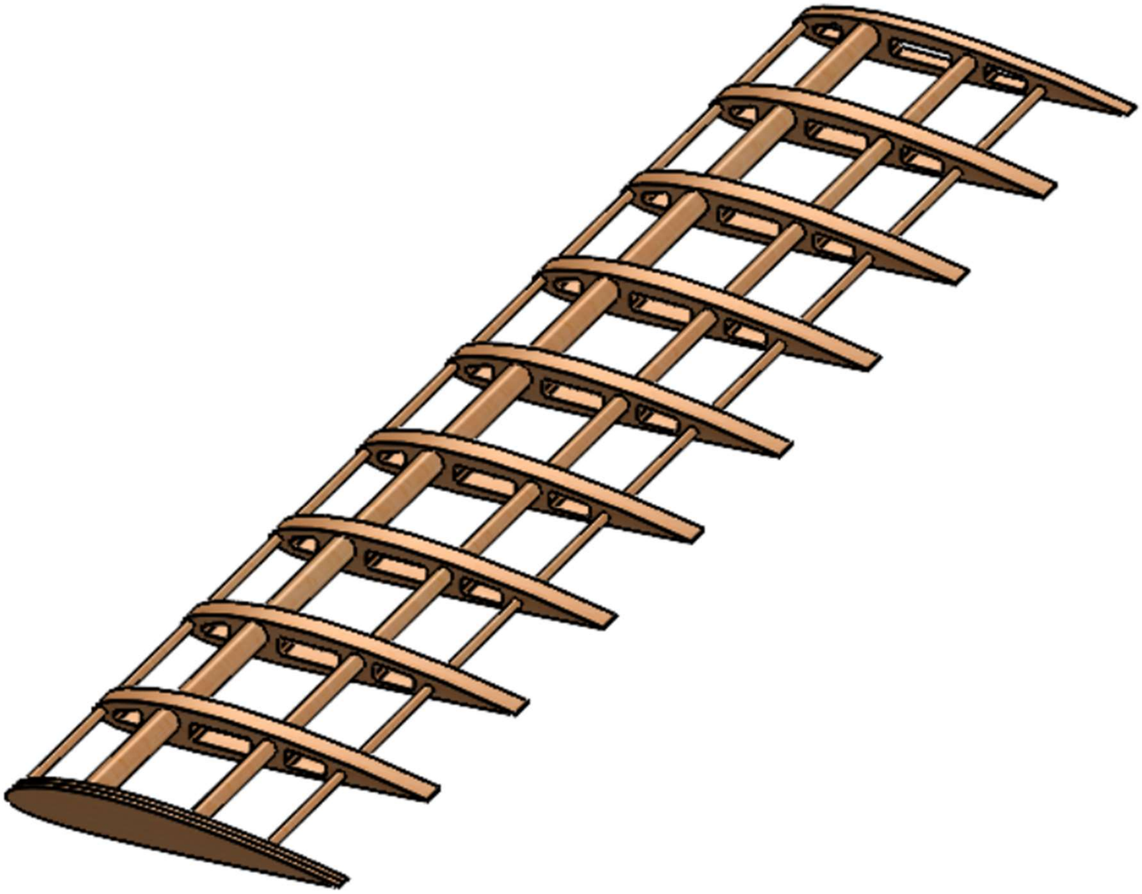
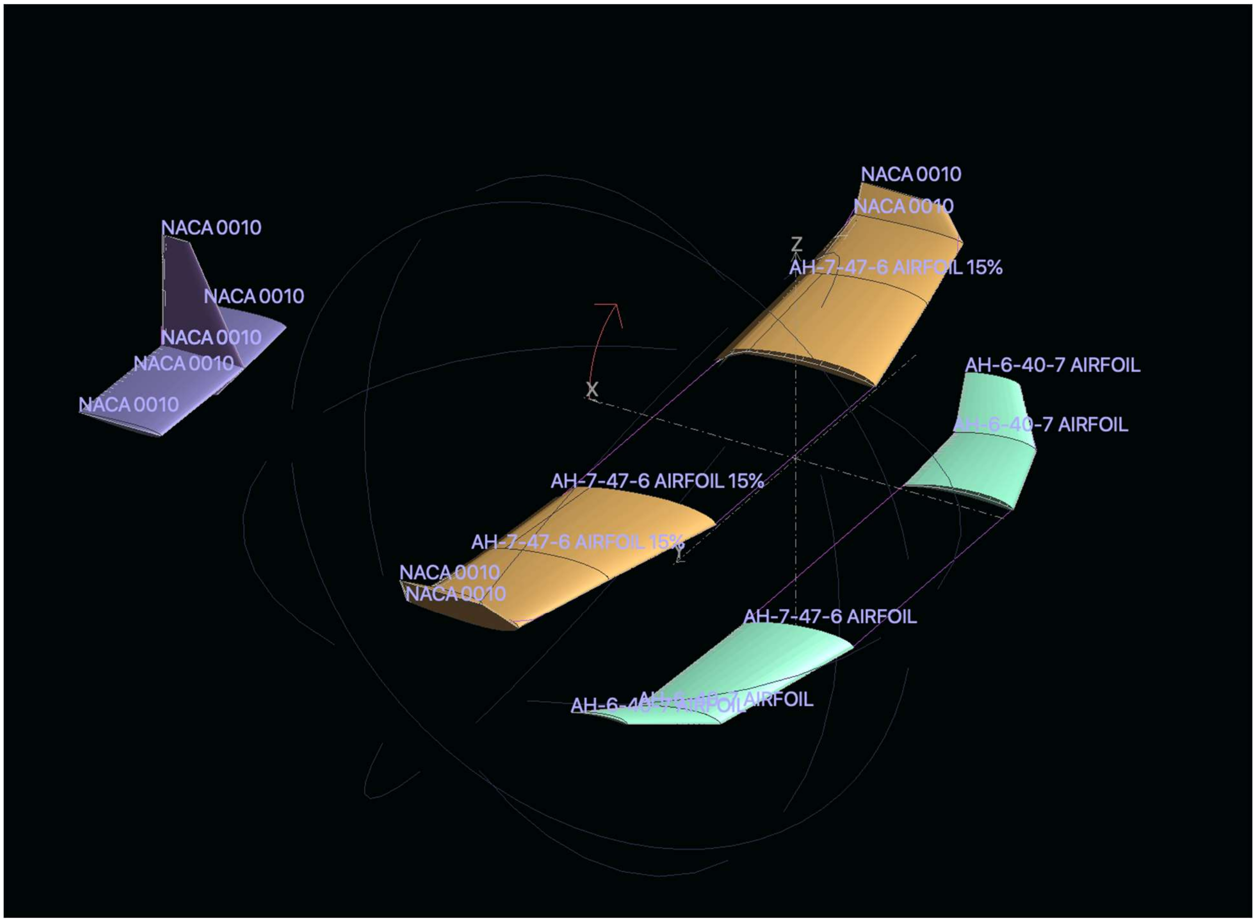


Figure 22: Airfoil design

During the second semester, after the initial batch analysis has been done, the team decided on using two different airfoils in the XFLR5 model of the final assembly. The airfoils included NACA 0010 and AH 7-47-6. A schematic of this is illustrated below. `



Airfoil placement on the XFLR5 model

You can observe that the geometry has changed with the design shifting from a single, midplane wing design to using two sets of wings instead. This is due to the team's calculations proving that the current design provides higher lift than the original single wing design. The difference between the lift and drag calculations of the previous design and the new design is tabulated below, and the mathematical background will be explored below.

Table 4: Single wing design lift/drag

Speed (mph)	Speed (ft/s)	Lift (lb.)	Drag (lb.)	Weight of Soccer ball
6.82	10.00	0.64	0.00	-0.79
10.22	15.00	1.45	0.01	0.01
13.63	20.00	2.57	0.02	1.14
17.04	25.00	4.02	0.04	2.58
20.45	30.00	5.79	0.09	4.35
23.86	35.00	7.88	0.16	6.44
27.27	40.00	10.29	0.27	8.85
27.95	41.00	10.81	0.30	9.37
28.63	42.00	11.34	0.33	9.91
29.31	43.00	11.89	0.36	10.45
29.99	44.00	12.45	0.40	11.01
30.67	45.00	13.02	0.43	11.59
34.08	50.00	16.07	0.66	14.64

Table 5: Dual wing design lift/drag

Speed (mph)	Speed (ft/s)	Lift (lb.)	Drag (lb.)	Weight of Soccer ball
6.82	10.00	1.72	0.01	0.28
10.22	15.00	3.86	0.04	2.43
13.63	20.00	6.87	0.12	5.44
17.04	25.00	10.73	0.30	9.30
20.45	30.00	15.46	0.61	14.02
23.86	35.00	21.04	1.13	19.60
27.27	40.00	27.48	1.94	26.04
27.95	41.00	28.87	2.14	27.43
28.63	42.00	30.29	2.35	28.86
29.31	43.00	31.75	2.58	30.32
29.99	44.00	33.25	2.83	31.81
30.67	45.00	34.77	3.10	33.34
34.08	50.00	42.93	4.72	41.50

From the above tables you can observe that the current wing design is much more robust with an average lift of 35 lbs of cargo at a flight speed of 31 mph compared to the meagre 6.5 lbs of cargo at a flight speed of 31 mph, with the previous design.

XFLR5 calculates lift and drag via two main methods. Those methods are,

1. Vortex Lattice Method
2. 3D Panel Analysis using nonlinear LLT (Lifting line theory)

LLT hypothesis notes that (1) a lifting wing (airfoil) can be replaced by a lifting line, and the magnitude of the trailing vortices (*linear, along the direction of free- stream velocity)* is proportional to the rate of change of the lift along the span. This makes the effective angle of attack for every section of the wing is different from the geometric angle of attack of the airfoil in question. IE, (2) the effective α should be related to the 2D (NACA) lift data for each wing section. LLT denotes that both the above conditions should be satisfied to accurately calculate the lift in the wing. With the lift curves being linear, this relationship can be reduced to a single equation and the lift distribution Is calculated. Also, it's important to note that with the linear relation $Cl = f(\alpha)$, the classic LLT is linear. IE, viscous drag, and wake effects are ignored. To override this limitation and to compensate for faulty lift/drag calculations at high angles of attack, XFLR5 uses a non-linear compensated LLT based on NACA technical databases. By using these methods, the coefficients of lift and drag for various angles of attacks were calculated and they are tabulated below.

$\alpha = 0\ deg,\ v = 52\ ft/s$

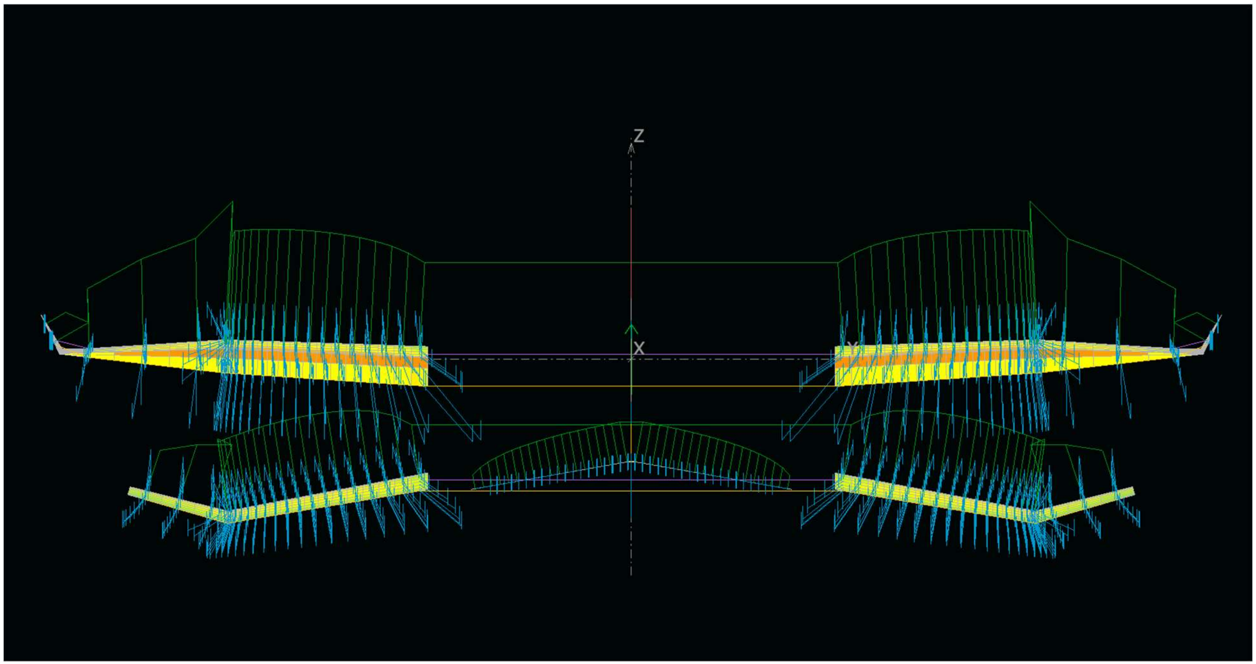


Figure 03: Visualization I

Cl/Cd	*Coeff. of Lift (Cl)*	*Coeff. of Drag (Cd)*
8.578	*1.166*	*0.136*

$\alpha = -5\ deg,\ v = 52\ ft/s$

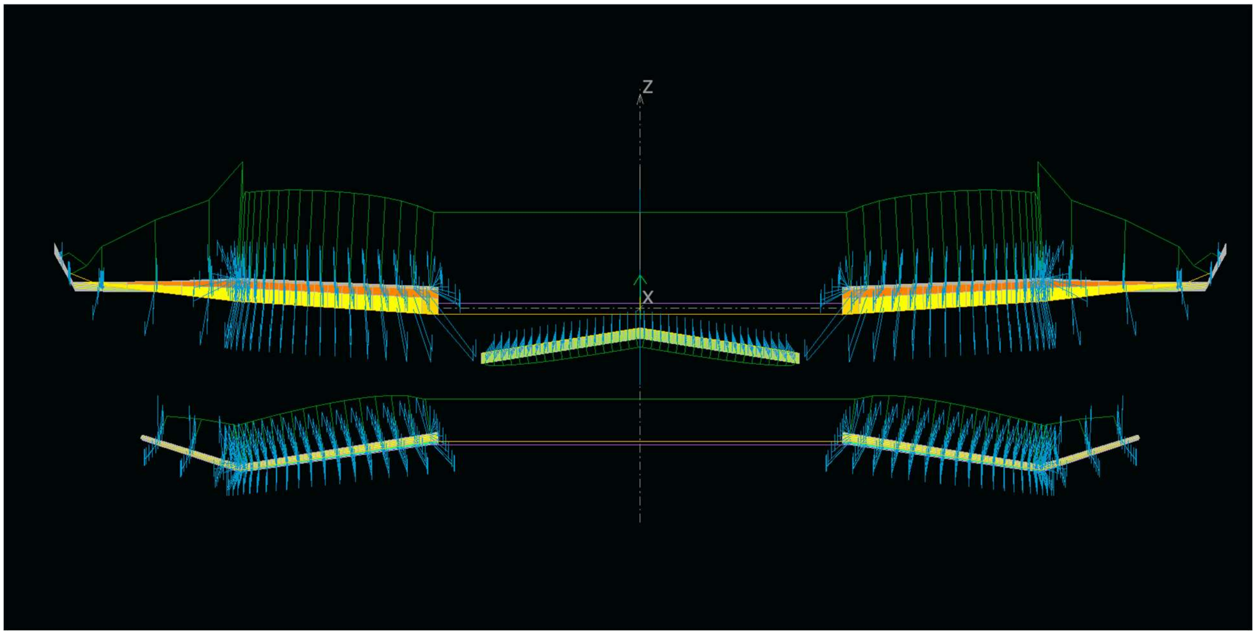


Figure 04: Visualization II

Cl/Cd	*Coeff. of Lift (Cl)*	*Coeff. of Drag (Cd)*
10.123	*0.743*	*0.073*

$\underline{\boldsymbol{\alpha = 5\ deg,\ v = 52\ ft/s}}$

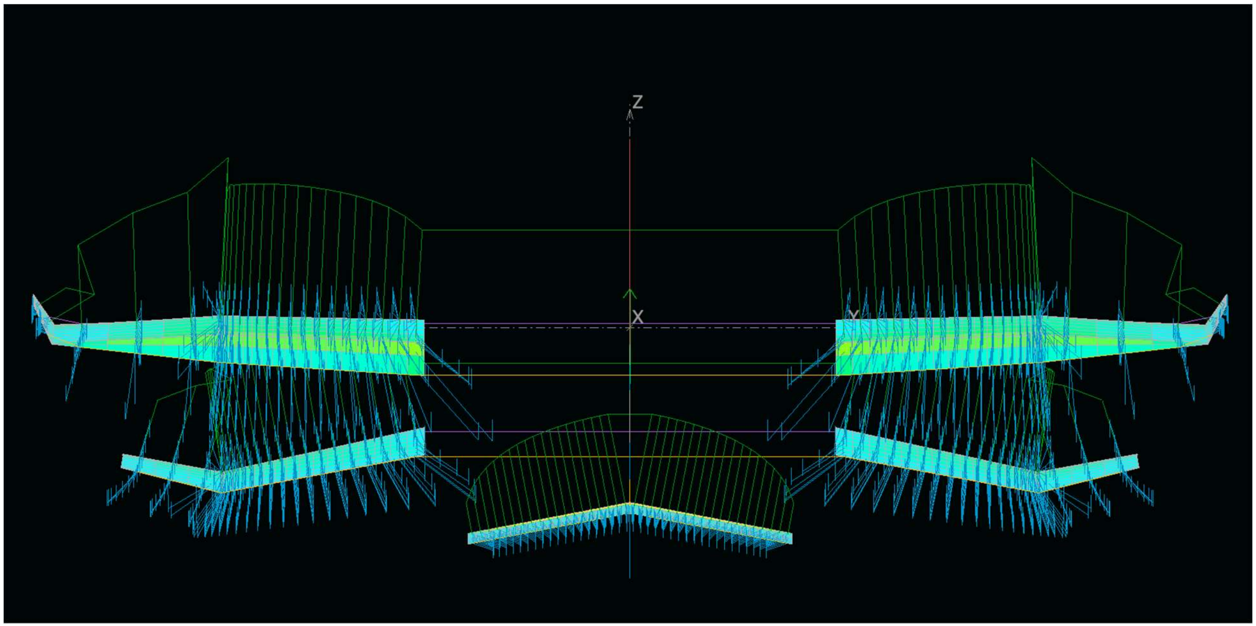


Figure 05: Visualization III

Cl/Cd	*Coeff. of Lift (Cl)*	*Coeff. of Drag (Cd)*
7.049	*1.567*	*0.222*

$\alpha = 10\ deg,\ v = 52\ ft/s$

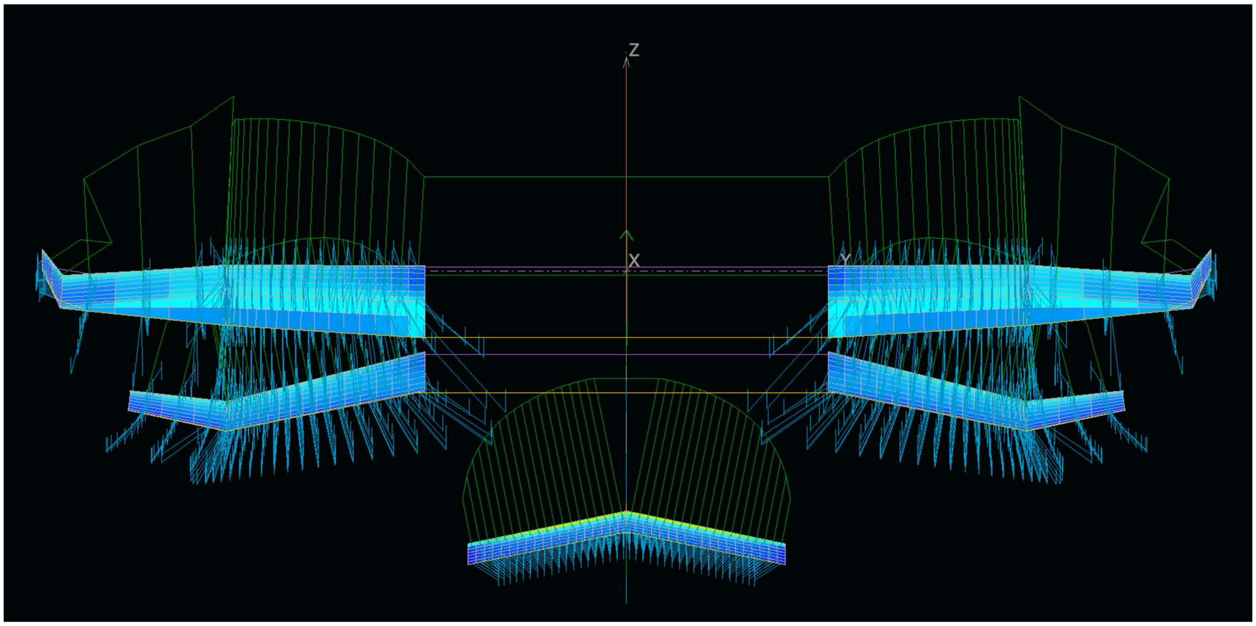


Figure 06: Visualization IV

Cl/Cd	*Coeff. of Lift (Cl)*	*Coeff. of Drag (Cd)*
5.910	*1.937*	*0.328*

$\alpha = 13\ deg,\ v = 52\ ft/s$

The picture can't be displayed.

Figure 07: Visualization V

Cl/Cd	*Coeff. of Lift (Cl)*	*Coeff. of Drag (Cd)*
5.384	*1.937*	*0.328*

Finally, the lift/drag coefficient values are tabulated below for the various angles of attacks.

α ***(deg)***	*Cl/Cd*	*Coeff. of Lift (Cl)*	*Coeff. of Drag (Cd)*
-5	*10.123*	*0.743*	*0.073*
0	*8.578*	*1.166*	*0.136*
5	*7.049*	*1.567*	*0.222*
10	*5.910*	*1.937*	*0.328*

13	*5.384*	*2.141*	*0.398*

Table 03: Tabulated Results

Mathematical Calculation of Lift and Drag

The main governing equation [1] for the calculation of lift and drag would be the Reynolds number calculation, given below. This is important as this value will determine whether the flow is laminar or turbulent based on the ratio of inertial forces and viscous forces.

$$Re_L = \frac{\rho U_\infty L}{\mu}$$

Equation 1: Reynolds Number at Length [1]

Where:
ρ = density
μ = dynamic viscosity
U_∞ = freestream velocity
L = Length

The next important equation is the free stream velocity, which is calculated by the equation [2] , [3] below.

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With the free stream velocity and Reynolds number calculated, the lift and drag calculations [4a], [4b] will be determined. Lift coefficients are experimentally found and tabulated [1.1] and these values can be used to validate the mathematical calculations.

With these calculated coefficients the actual lift and drag forces can be found by using the below equations [5], [6].

$$F_L = \frac{C_L}{2}\rho V^2 A_p$$

Equation 5: Force of Lift [1]

$$F_D = \frac{C_D}{2}\rho V^2 A_x$$

Equation 6: Force of Drag [1]

Where:
A_p = Planform Area (Parallel to Flow)
A_x = Cross-Sectional Area (Perpendicular to Flow)

Per the results obtained above, it was observed that the best lift to drag ratio is achieved at a 5-degree angle, and at level flight, the value was still applicable at a good 8.578.

Further, the performance of NACA 0010 airfoil was experimentally tested using a subsonic wind tunnel. This was done by sampling a portion of the airfoil to find a scaled value of Cl/Cd. First, a test model was generated.

XFLR5 Direct Airfoil Design: NACA 0010

First, a standard NACA 0010 airfoil was drafted on XFLR5. The operating points in Selig format coordinates are tabulated below.

Table 1: NACA 0010 Selig format Coordinates

x	y
1	0.00105
0.95	0.00672
0.9	0.01207
0.8	0.02187
0.7	0.03053
0.6	0.03803
0.5	0.04412
0.4	0.04837
0.3	0.05002
0.25	0.04952
0.2	0.04782
0.15	0.04455
0.1	0.03902
0.075	0.035
0.05	0.02962
0.025	0.02178
0.0125	0.01578
0	0
0.0125	-0.01578
0.025	-0.02178
0.05	-0.02962
0.075	-0.035
0.1	-0.03902
0.15	-0.04455
0.2	-0.04782
0.25	-0.04952
0.3	-0.05002

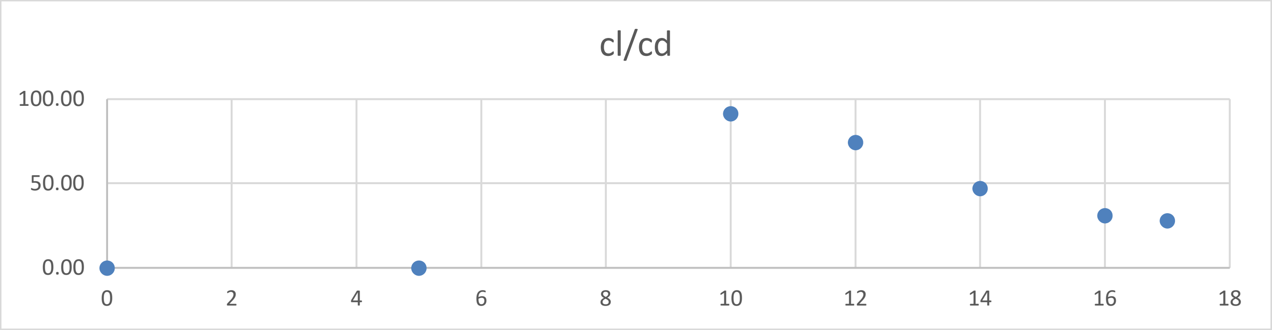
0.4	-0.04837
0.5	-0.04412
0.6	-0.03803
0.7	-0.03053
0.8	-0.02187
0.9	-0.01207
0.95	-0.00672
1	-0.00105

From these values a CAD model was generated, and 3D printed. Observe the slat in the airfoil that was used to mount the airfoil to the model positioning system to measure normal force, axial force and pitch moment.

The picture can't be displayed.

3D printed NACA 0010 with slat

Lift and drag values were calculated for multiple angles of attack until the airfoil reached stall angle at steady velocity. The observations are graphed below.



Cl/Cd at increasing angles of attack

It was observed that the NACA 0010 airfoil reaches stall between 10-12 degrees, and this experimental data validates the batch analysis findings from above.

5.1.4 Landing Gear Forces and Factor of Safety

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

The picture can't be displayed.

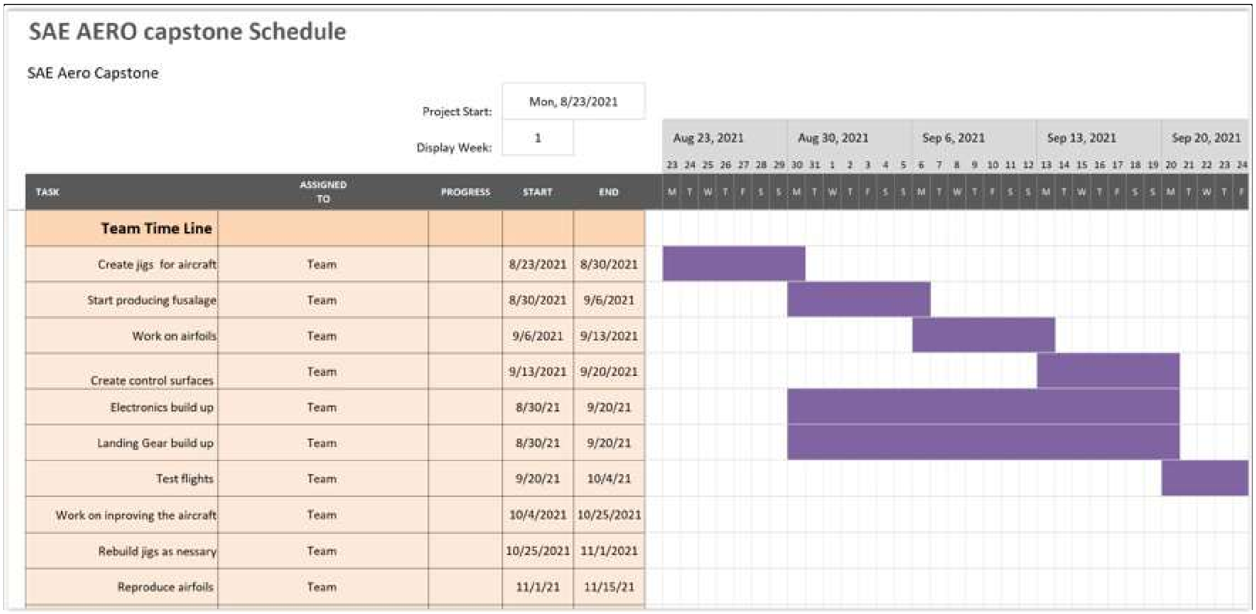
Figure 23:Screenshot of Matlab Landing gear analysis

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

5.2 Implementation Plan

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

The Gantt Chart below in Figure 24 displays the current projected schedule for next semester. This schedule shows that the team will start the next semester by making the jigs and cutouts for the aircraft and start producing the fuselage. After, the team will spread out to creating the airfoils for the wings and tail, start implementing the electronics that control the propeller and the ailerons and "tailerons". The team will then work on adding the control surfaces, making the landing gear, and implementing the steering electronics and controls and in the back wheel. Finally, the team will begin flight testing around the end of September and fix and improve any aspects and issues as necessary before finalizing the final design.



SAE AERO capstone Schedule

SAE Aero Capstone

Project Start: Mon, 8/23/2021
Display Week: 1

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

The picture in Figure 28 shows what the current proposed design should look like, while the next picture below in Figure 25 shows an exploded view of the model. This view shows how all the parts should fit together as the team assembles the parts.

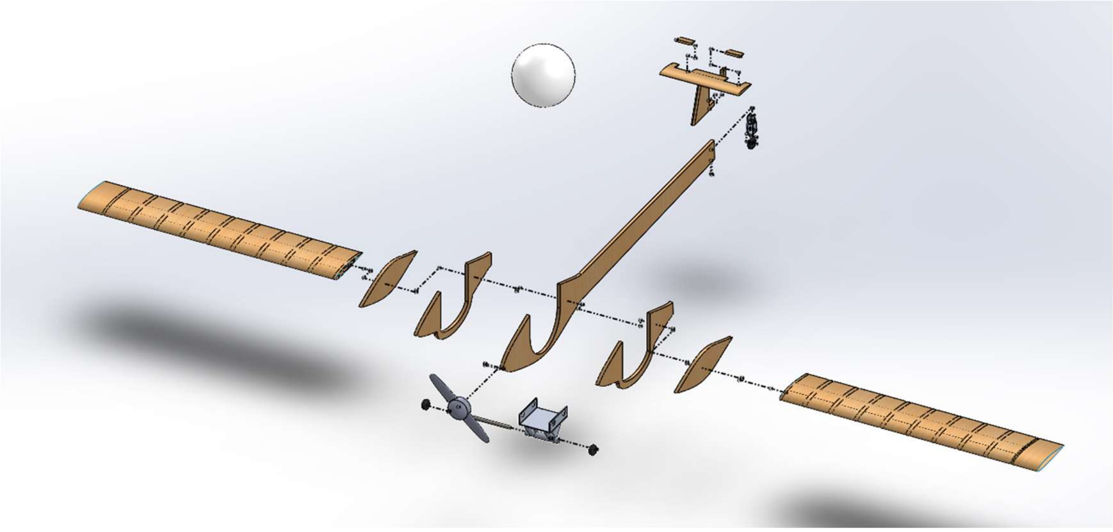


Figure 25: First semester expanded view of aircraft

Below is a rough prototype of the design. This design will be revised.

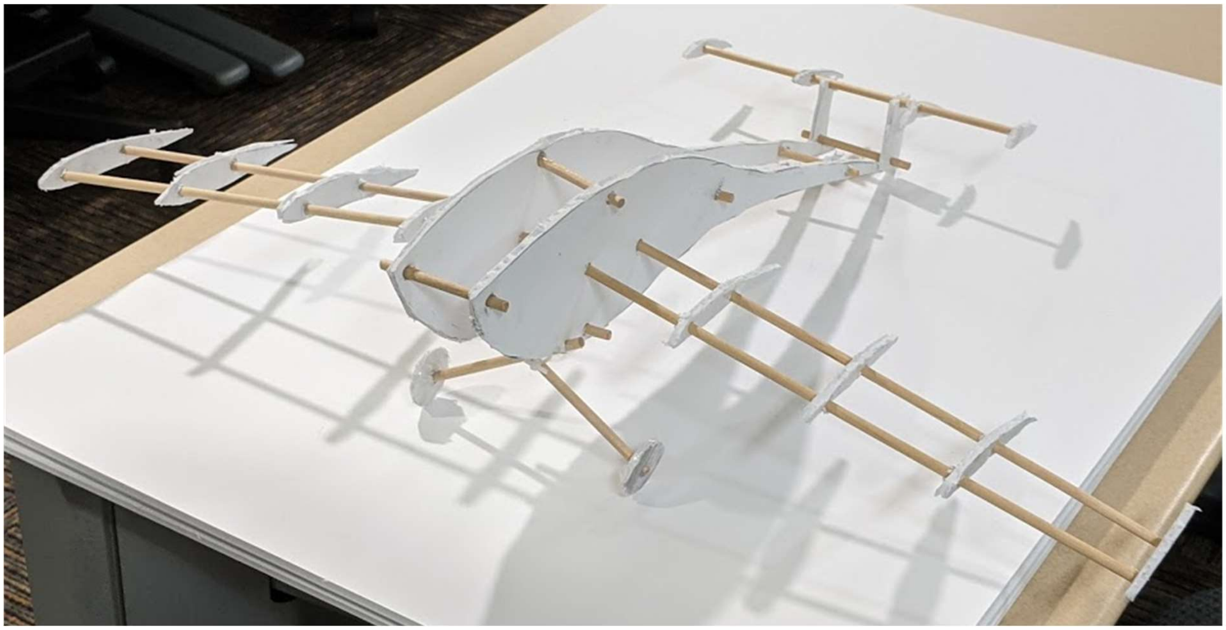


Figure 26: First Prototype

6 IMPLEMENTATION – Second Semester

During the second semester of capstone there were many changes to the design. List below are the final design changes but there were many iterations in between the previous version and the version we finished with.

6.1 Versions of the aircraft

6.1.1 Version 1

Version one of the aircraft was present previously but due to the difficulty manufacturing this design this version was scraped.

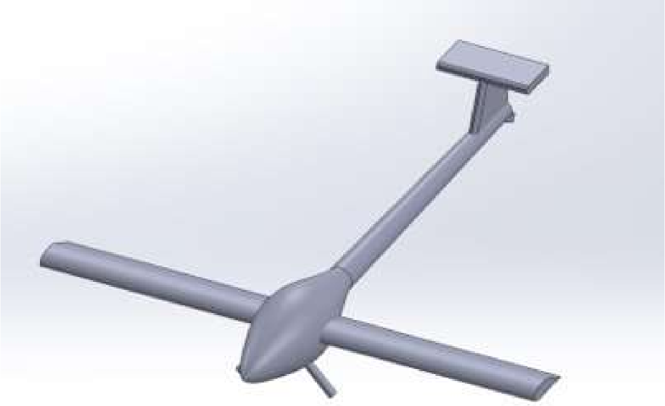


Figure 27: Version 1 of aircraft

6.1.2 Version 2

The second version of the aircraft was a more refined version of the first version but due to manufacturing issues this aircraft was scraped.

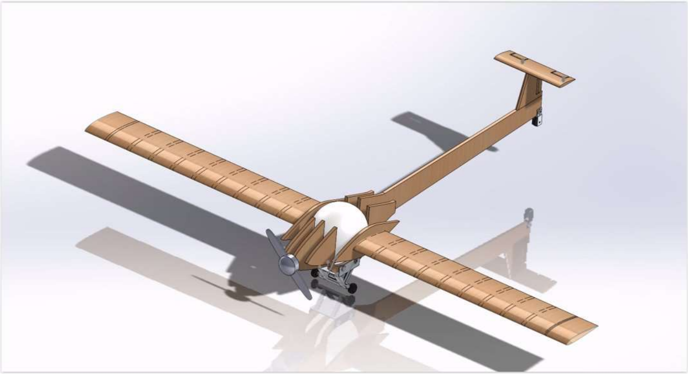


Figure 28: Second Version of aircraft

6.1.3 Version 3

The next version of the aircraft was heavily based on the laser cutter and due to some issues getting access to the equipment the team chose not to peruse this path as it was not feasible to get the plane built with the time restraints the team had. Due to this the design was never finished but below shows what the aircraft was starting to look like.

Figure 29: Third iteration of aircraft

6.1.4 Version 4

The fourth iteration of the aircraft was to have parts cut out of wood and sandwich foam in between the plates in order to create molds for the aircraft to be fiber glassed.

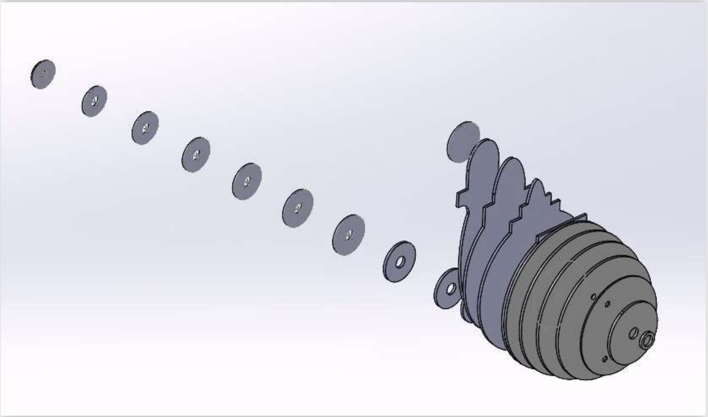


Figure 30: Version 4 of the aircraft

6.1.5 Version 5

The next version of the aircraft was a continuation of version 4 but with the addition of wings.

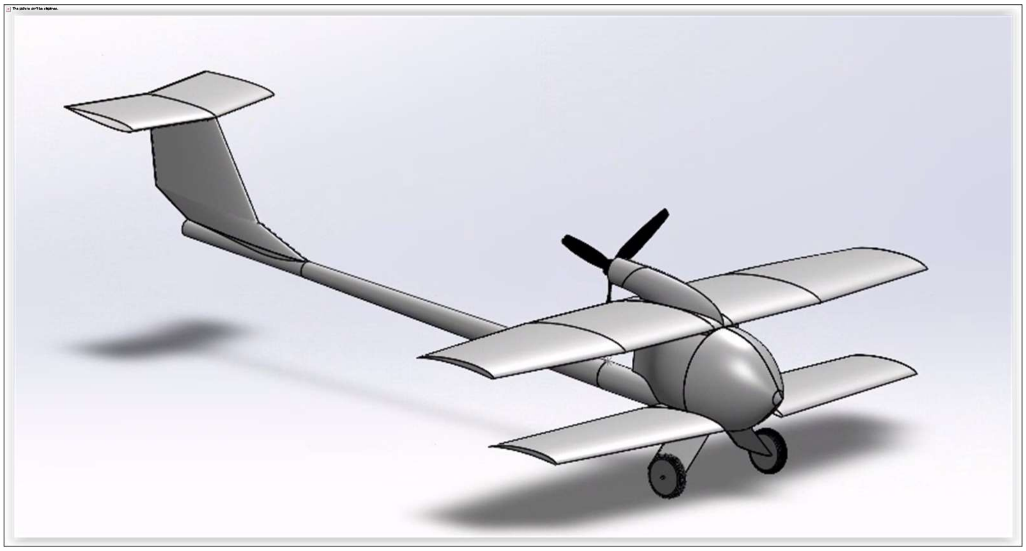


Figure 31: Fifth version of the aircraft

6.1.6 Version 6

As the team worked on getting version 5 created the deadline was getting closer and the team reverted to only going with 1 wing but using the mold and fiberglass idea.

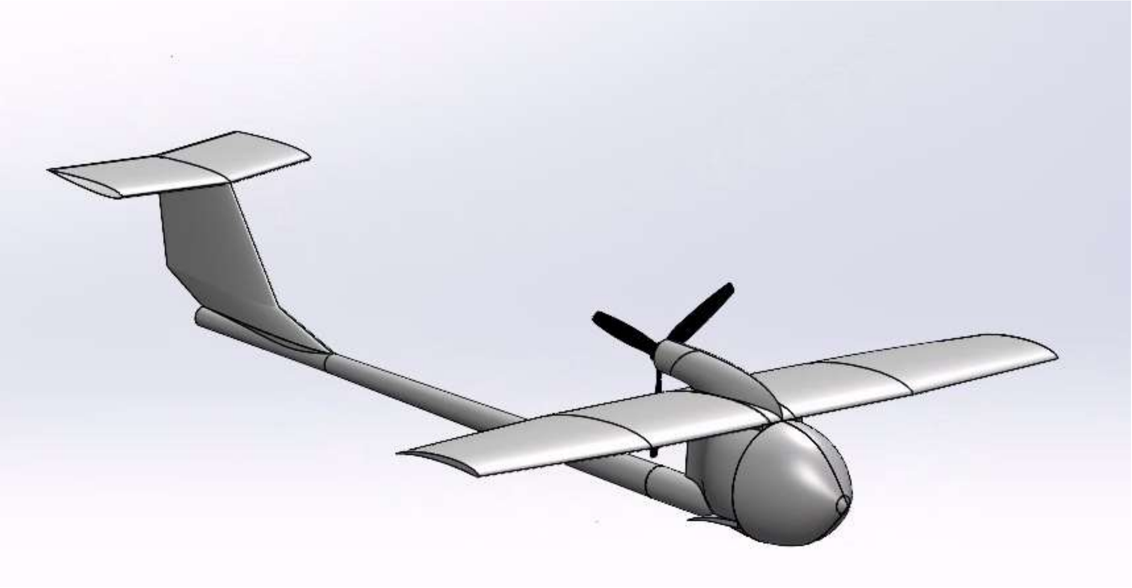


Figure 32: Final CAD of the aircraft

The final built aircraft can see below. This aircraft had lots of flaws but generally looked like the cad model of the aircraft.

Figure 33: Build aircraft

6.2 Design Changes in Second Semester

6.2.1 Design Iteration 1: Change in Propeller and Fuselage Design

The design following through the first semester of the capstone process was a more simple and typical aircraft design, detailing a propeller on the nose cone, fuselage, wings mounted on the midsection of the fuselage, and a T-tail. Toward the beginning of the second semester, the propeller was moved behind the fuselage and wings to reduce the effects of slipstream. One fault of the previous team's design was that the plane was too easily influenced by strong winds and had the tendency to flip during flight. Although this was mostly due to how light the design was, slipstream likely also played a factor. Slipstream is essentially when air turns due to the motion of the propeller and pushes against the wings and drags against the fuselage, causing the plane to torque. Moving the propeller to a pushing position behind the wings reduces the effects of slipstream.

6.2.2 Design Iteration: Change in Wing Design

During the first semester, the aircraft had the wings placed in the center of the fuselage to find a balance between takeoff lift and takeoff turbulence. Although mid-plane wings are harder to sully structure and attach to the fuselage, they provide a solid balance between maximum lift on takeoff and the amount of turbulence the plane experiences from air flowing across the ground into the wings. During the second semester, however, the team decided to make a biplane with larger wings mounted on top of the fuselage and smaller wings on the bottom. Although this introduces more turbulence on the lower wing set, the biplane design produces significantly more lift. However, during the build process, the team decided to remove the bottom set of wings because of how long the build process took, especially due to the amount of time it took to create the molds and fiberglass the parts. After recalculating with one set of wings and the new airfoil design, the plane should have still been able to achieve liftoff, but not able to carry as much weight.

As mentioned above, the team also changed the shape of the airfoils during the second semester. The original airfoil shape, the NACA 2412, generated much less lift than the new airfoil shape, the xf-ah7476-il-100000.

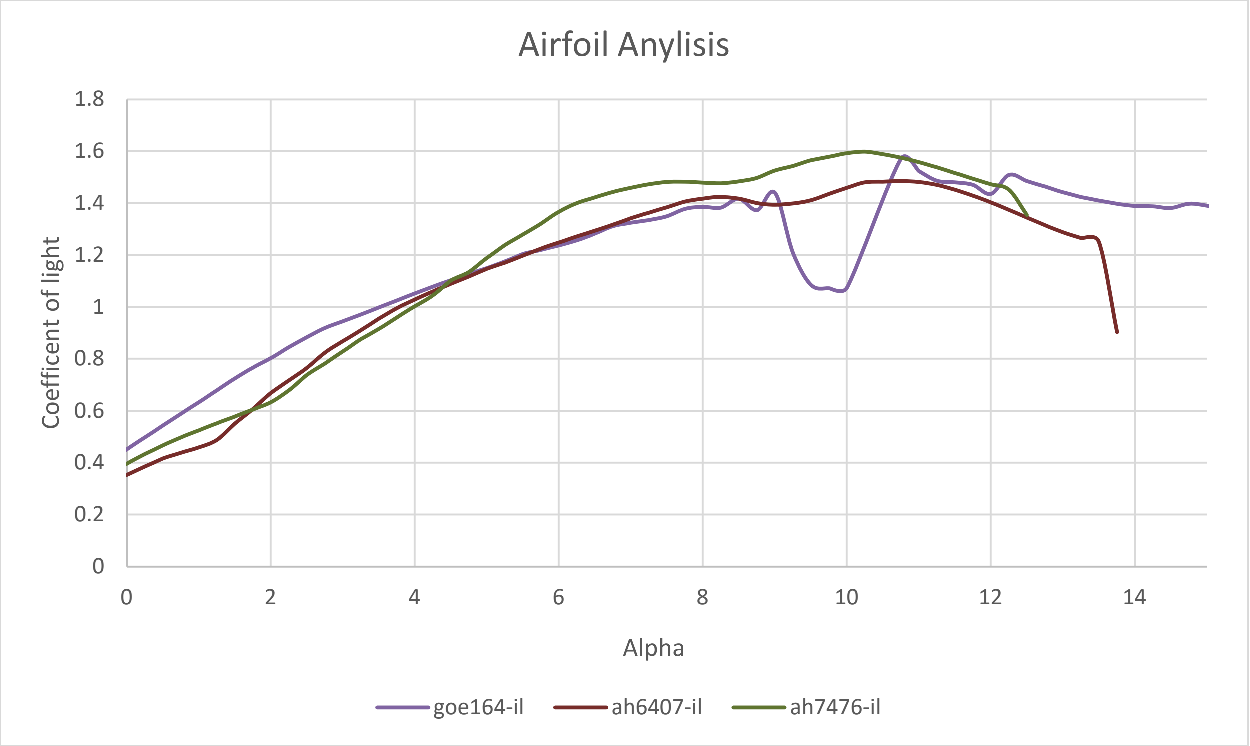


Figure 34: Graph of the top three airfoils the team had considered

6.2.3 Design Iteration 1: Change in Aircraft Material

Finally, the team changed from the use of balsa wood as the main structural material to fiberglass. Fiberglass reinforced with isophthalic resin has an ultimate tensile strength of about 117.5 MPa, whereas the ultimate tensile strength of balsa wood is only about 14.9 MPa. Although fiberglass with resin is heavier than balsa wood, being 0.0328lb/in^3 compared to 0.00578lb/in^3, the strength of fiberglass and resin would make up for it by allowing the team to use much less material.

The price of balsa wood has also increased drastically recently due to current events. Typically, balsa wood is very useful due to its price and light weight, but the price of balsa wood now rivals the price of fiberglass. This means the only downside to using fiberglass and resin is that fiberglass is more difficult to work with. At the time, the team had not considered the intense time and effort to use fiberglass, but the price and strength made fiberglass more considerable than balsa at the time.

7 RISK ANALYSIS AND MITIGATION

This section will discuss potential failure modes established in the first semester of the design project and how they were mitigated during the testing process as well as how failure modes were limited. The team considered each potential failure during the testing process and took steps to avoid them. Safety of all team members was of the utmost importance during all stages of the process.

7.1 Potential Failures Identified First Semester

Ten critical failure modes were identified in the first semester of the project. The critical failures all involved individual aircraft components failing at some point during the testing phase of the project. They are as follows: fuselage breach, fuselage hatch failure, structural rib failure, control surface failure, flight control systems failure, structural failure of wings, landing gear yielding, damaged fuselage, poor control surface assembly, and thrust. All the above failure would be considered critical failures resulting in a strong likelihood of destruction/heavy damage to the aircraft. A detailed list will be included in the appendices of this report.

7.2 Potential Failures Identified This Semester

The failure modes remained the same as the previous semester's FMEA, with the exception of one item. Steering failure was the new failure mode. During the aircraft testing, it became clear that the steering systems were ineffective at steering the aircraft, and the landing gear assembly caused some problems with the ability of the aircraft to steer straight. However, the landing gear was fixed, but the steering systems failure was not.

7.3 Risk Mitigation

Risk mitigation is one of the team's highest priorities and we are excited to share that no team members were badly hurt in the process of working on this project. Main areas of concern during the building process were the health hazards from the products being used. Due to the chemicals in the products, we were using we chose to do a lot of work outside where we could let the natural breeze help mitigate the harmful solvents. Some products like bondo, spray primer and fiberglass resin were on the list of high concern. But as previously mentioned these products were used in well ventilated spaces. The design change from balsa wood to fiberglass did increase the safety the team took during the construction process.

Aircraft safety during test flights. Our aircraft was equipped with both a kill switch on the aircraft as well as a kill switch on the remote control which allowed the aircraft to stop the motor from continuing to spin. This increases safety as the aircraft could safely be worked on without worry of the aircraft turning on. Other risk mitigation was standing a short distance away from the aircraft in case it happened to malfunction during testing.

Our team properly mitigated risk as not team members were hurt in the process of building or testing this aircraft.

8 ER Proofs

The following section discusses how the team measured whether the established engineering requirements were met by the final product.

8.1 ER Proof #1 – Power (1000W)

The power running throughout the aircraft is restricted to 1000 Watts by the power limiter required by SAE Aero. As such, there is no need to formally measure the power in the system so long as the circuit is functional. The power limiter runs directly from the battery to the rest of the system, so if the power limiter does not function, the electricity will not run to the rest of the system.

8.2 ER Proof #2 – Weight (30lbs)

The team measured the weight of the final aircraft with a simple mechanical scale meant for a person. The team weighed one team member, recorded their weight, weighed the same member again while they were carrying the plane, and found the weight of the plane by subtracting the weight of the team member from the combined weight of the member and the plane. At the end of this process, the plane weighed about 15 lbs.

8.3 ER Proof #3 – Cost ($1500 or less)

The budget was handled by the budget liaison in excel. The final budget spent on the aircraft came out to $1731.48. Although this would have originally been over budget, the extra cost over is actually due to a mistake made by the university on the team's order of fiberglass. A mix-up in purchasing resulted in the school spending $640.10 on FibreGlast, the company the team used to acquire their fiberglass, instead of the projected $358.46. However, because this was the fault of the university, the team's budget was increased by $302.50, bringing the actual allowed budget to $1802.50. As a result, the team is about $71.02 under budget. A full breakdown of the budget can be found in Appendix C.

8.4 ER Proof #4 – Takeoff Distance (100ft)

The takeoff distance would have been estimated by having one member stand further down the runway far away from the plane's path for safety, having that person mark approximately wear the aircraft achieved full liftoff, and measuring from there to the initial starting point with tape measures. However, the plane, unfortunately, did not achieve liftoff at all during testing, so there was no need to measure.

8.5 ER Proof #5 – Lift

To estimate the lift of the aircraft, the team planned on running the aircraft several times with gradually increasing amounts of weight to approximate the maximum lift. When the aircraft could no longer gain altitude, the team would note the weight added to the aircraft and consider that the maximum lift. The only forces working in the y-direction on any aircraft are the weight and lift, so measuring the added weight on top of the aircraft's initial weight would give lift. The team had calculated about 35lbs of lift at 45fps. However, the aircraft never achieved liftoff, so the team could not attempt to measure the lift this way.

The team measured the speed of the craft by measuring the speed of the air impacting the nose of the craft with a pitot tube and recording it with an Arduino.

8.6 ER Proof #6 – Payload Capacity

The team would have measured the payload capacity the same way they measured the lift of the aircraft. The maximum lift would also signal the maximum payload capacity of the aircraft. The team aimed to carry about 20lbs, but, since the aircraft never achieved liftoff, the aircraft was determined to not be able to carry a payload.

8.7 ER Proof #7 – Amperage

The team is required by the SAE Aero Regular Class competition to use a battery labeled at least

3000mAh. The team chose a battery at 3200mAh, just above the requirement, because it was the lightest battery the team could use that meets the requirements of the competition and the needs of the team's aircraft.

8.8 ER Proof #8 – Voltage (22.2V)

The aircraft battery was required to be 22.2 volts or greater. The team chose a Spektrum battery that stores 22.2V in 6 cells.

Figure 35: Battery purchased from project [7]

8.9 ER Proof #9 – Wingspan (<120 inches)

The wingspan was required to be 120 inches or less. During the testing phase, the team used a tape measure and measured the wing to ensure that the design met the requirements, even though in the CAD modeling the wing was well within parameters. The wings ended up slightly larger than the designed 60 inches due to the way the wings were mounted with fiberglass. The wings measured in at 61.375 inches which is well within the allowable parameters of the competition.

8.10 ER Proof #10 – Cargo Capacity

For the design of the aircraft, it must be able to hold a size 5 soccer ball at a minimum in an enclosed space. During the testing of the aircraft, a size 5 soccer ball that was fully inflated was inserted into the nose cone of the aircraft, and the nose cone closed fully while containing the payload. The fuselage was hollow behind the nose cone, so the craft could contain additional payload in the form of weight if desired. This was not done during the testing of the aircraft. Below are two images depicting how the soccer ball was enclosed into the aircraft.

Figure 37: Soccer ball Placed in cargo bay

Figure 37: Soccer ball enclosed in cargo bay

8.11 ER Proof #11 – Speed

From the pitot tube testing data, the hypothetical 37.5 ft/s velocity was not achieved before the aircraft would ultimately crash on the ground. Below are six different attempts to achieve flight. The aircraft best run had a max speed of just shy of 25 ft/s. This was 12 ft/s slower than the team was aiming to achieve during takeoff. As mentioned previously the aircraft would begin to lift off the ground but had too much drag on one of the wings and would cause a turning motion which led to the aircraft rolling. While flight was never achieved this information leads the team to believing that the aircraft was generating more lift then previously calculated in models. Another factor that affected this was the angle of attach of the wing was greater during testing then during the models. While revising the theoretical model would be beneficial the fact the aircraft never generated enough lift to fly means the aircraft would need to be rebuilt prior to changing the theoretical models to confirm this hypothesis. This ultimately is not possible due to time constraints which is why we will leave this difference in values alone.

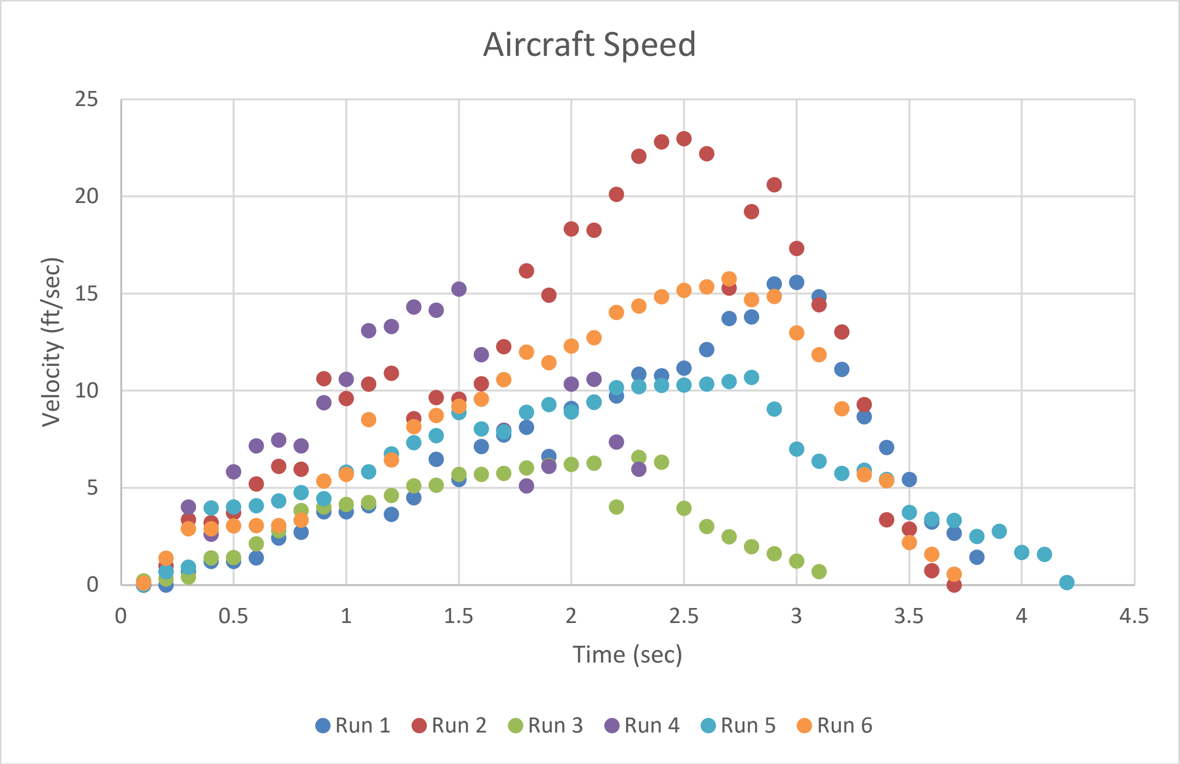


Figure 38: Aircraft speed during testing

8.12 ER Proof #12 – Lift greater than weight

The lift must be greater than the weight of the aircraft to fly. For testing the required lift would be approximately 15 lbs. of lift. During testing the aircraft never managed to achieve flight. The aircraft would generate enough speed and once one wheel began to lift off the ground, the craft would roll over and fail to achieve takeoff. The team believes this failure to be due to instability in the design and components not being parallel, manufacturing issues. This resulted in an unequal lift being generated by the craft, causing it to begin to roll and then that roll leading to a rollover of the aircraft. Based on the airfoil data the team calculated the required velocity for a 15 lb. aircraft, needed to achieve a takeoff velocity of approximately 37.5 ft/s.

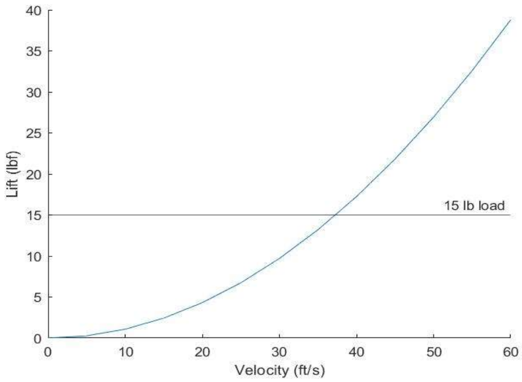


Figure 39: Velocity required to achieve lift

While our aircraft did not fare well in the air below is proof that the aircraft did get off the ground and created enough lift to overcome weight.

8.13 ER Proof #13 – Thrust greater than drag

During testing the aircraft did move which shows the aircraft had more thrust than drag, but to prove these the next three photos are is succession of the aircraft as it moves across the field.

Figure 41: Aircraft starting from rest

Figure 40: Aircraft moving away from observer

Figure 42: Aircraft farther away from observer

9 LOOKING FORWARD

The future with our aircraft is very bleak. From the team's perspective the aircraft needs to be rebuild from the ground up, while the electronics are reusable. Most of the aircraft has lots of manufacturing flaws and therefore is not worth salvaging, nor worth keeping.

9.1 Future Testing Procedures

9.1.1 Testing Procedure 1: Weight

9.1.1.1 Testing Procedure 1: Objective

The objective of weighting the aircraft is to simply get the empty weight. This value allows the team to better understand the hypothetical payload and max takeoff weight.

9.1.1.2 Testing Procedure 1: Resources Required

This test is very simple all one needs to do is get a scale and simply get the aircraft on it. Due to the size of our aircraft, it was easier to have a team member stand on the scale and use that as the datum then add the aircraft on and the person. From these two numbers the weight of the aircraft can be calculated.

9.1.1.3 Testing Procedure 1: Schedule

This test takes less than 10 minutes and can be done at home.

9.1.2 Testing Procedure 2: Test flight

9.1.2.1 Testing Procedure 2: Objective

With doing test flight the validation of a lot of ERs can be crossed off the list. Therefore, this one test really encompasses all of our work.

- Lift > weight
- Thrust > Drag

- Take off distance
- Landing distance

9.1.2.2 Testing Procedure 2: Resources Required

All that is needed is the final aircraft, a tape measure and the proper electronics for the aircraft.

9.1.2.3 Testing Procedure 2: Schedule

Testing the four parameters before, by starting at a line and measuring 100 ft away then starting the aircraft and running at full throttle, you can see if the aircraft if off the ground in the distance. For landing it is the optimist as the aircraft is going from air to land you will need to mark out a two-line 400ft away from each other and land the aircraft in that zone.
If the aircraft takes off, then the lift is greater than the weight and the thrust is greater than the drag.

9.1.3 Testing Procedure 2: Electronics

9.1.3.1 Testing Procedure 2: Objective

The ERs that have to do with the battery are easy to test individual and can be connected to multimeters and other devices to get the proper values with that said as a team we are more interested in the system as a whole.

9.1.3.2 Testing Procedure 2: Resources Required

To test how long the aircraft can fly for the electronics can be placed either in the aircraft or on a test bench. Starting with a full battery the system is turned on and ran a full power with all of the electronics including servos being actuate. Using a stopwatch form the start of this experiment the time it takes for the battery to run out can be determined and therefore the run time.

9.1.3.3 Testing Procedure 2: Schedule

This experiment takes some time to get set up and run but once it is going the system will drain out in under an hour so with set up and testing time you are looking at roughly an hour per trail. After one trial is complete the battery would need to be recharged for the next test which will add about an hour to this time. So three trials will take about six hours.

9.2 Future Work

Future teams should learn from our mistakes. There were a lot of ideas that were brilliant but the skills and time to execute them were not always up to par. The idea of fiberglass was a great idea. However, the team ran into many issues with this. Some issues included weak fiberglass due to much resin being applied, not having a space on campus to work with the product, which led to using the outdoors which was problematic when the weather started to cool down as it was fall. Other issues include not having the design finalized in the first semester. This issue stemmed from Covid-19 and the lack of team participation in the first semester. The team also found this project to be hard from the lack of manpower available. The tried-and-true method of balsa wood is probably better than fiberglass. Our team had issue getting access to on campus laser cutter which pushed us to using other materials, when you run into this issue have your professor advocate for you to get access to the spaces you need. With a few of the many errors covered here, God speed to you.

10 CONCLUSIONS

The team did not complete all the team goals and the project was ultimately unsuccessful. The final aircraft was unable to fly. This was a failure, and the craft was incapable of completing the testing procedures and the competition. The team did learn a large amount from the final design, however. The team was not expecting many of the difficulties encountered in the second semester of the project, which contributed to the overall unsatisfactory result. While the project was not successful, it provided the team with an excellent learning opportunity.

10.1 Reflection

Throughout the project the team had communication problems that were never resolved that led to tensions between team members and frequent miscommunications and repeat work/conversations. The engineering principles applied worked well in the design section to meet the requirements of the client in a safe fashion, however this did not translate into the actual constructed design. Every component was designed so that it would meet the requirements for each category. Factors of safety were used to ensure that the landing gear would be able to survive the absolute worst-case conditions, however that was not seen in the final design as the team didn't have the time and resources to integrate the designed landing gear in the final design so materials that were already available and inadequate were used instead. Safety and welfare were the most important considerations in our project. The design was able to meet these in theory from the engineering principles. Control surfaces were implemented to increase safety and welfare, but they did not make it into the final design the way that the team had envisioned so they were mostly non-existent. The team did regard safety highly and did nothing to endanger others and ensured that all testing was performed in a controlled and safe manner. The team never took any risks with the aircraft and didn't even do any testing before ensuring that the aircraft could do what was expected of it before attempting a full speed flight. The team killed any test run as soon as the aircraft began to lose control to ensure the safety of everyone present and nearby.

10.2 Postmortem Analysis of Capstone

The biggest problem with last semester was the lack of access to facilities due to COVID-19. Analytically, the team was very successful last semester as well as this semester. However, it's apparent that no amount of analytical validation would solve design problems that occur during the fabrication process. This semester, there were problems with miscommunication and the team suffered from scheduling issues with most of the team members having to work and their schedules not fitting the limited time slots the machine shop offered. Also, the client of the capstone changed from Dr. Sarah Oman to Mr. David Willy. Mr. David Willy was already our capstone coordinator. This sudden change during the second semester decreased the morale of the team even though our capstone coordinator (new client) tried his hardest to support the team.

10.2.1 Contributors to Project Success

There were a lot of factors in this project that tore the team down, but the most recent morale loss was when we crashed the plane. While the aircraft did not perform overly well the enjoyment of seeing our design on the field actually attempting to do the thing, we set out to do was a huge morale booster. Throughout this project the team has had issue after issue and due to this it is hard to say a lot of good things however, the team is glad the semester is almost over but during the semester what really got things rolling was when a new box would come in with parts and the team was pretty excited to put them together. The team also got new bursts of energy when a new design was on the drawing board making the project better iteration after iteration. All in all, the learning experiences were good, we enjoyed to project we picked and wish it came out better but at the end of the day we tried our best with the circumstances at play.

10.2.2 Opportunities/areas for improvement

The biggest area for improvement in this project is manpower during fabrication as well as facilities to do said fabrication. If more resources were provided such as space to work on, this capstone would have been more success. Our team also did not have a finalized design until almost halfway through the second semester and that did not help things either. In retrospect, while we needed the iterations, we really need the plane to start being built, although the design was great on paper, we didn't have the time to execute in real life and that hindered us.

Other areas of improvement would include better access to machinery on campus, we changed our design due to logistical issues and in retrospect this change should not have happened but at the time it was the right call for the team. Issues with purchasing was also high on the list as NAU purchasing department order over $300 more fiberglass than the team requested. While not directly the teams' fault being more clear on the purchasing order would have eliminated this issue.

While the timeline was already mentioned here, we definitely got down to the wire and this issue is simple to fix but at the time we just got delayed. This lesson is beneficial though as members form our team oversee projects in the future.

11 References

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[3] P. Pilots, "Final Report," NAU Capstone Team, Flagstaff, 2020.

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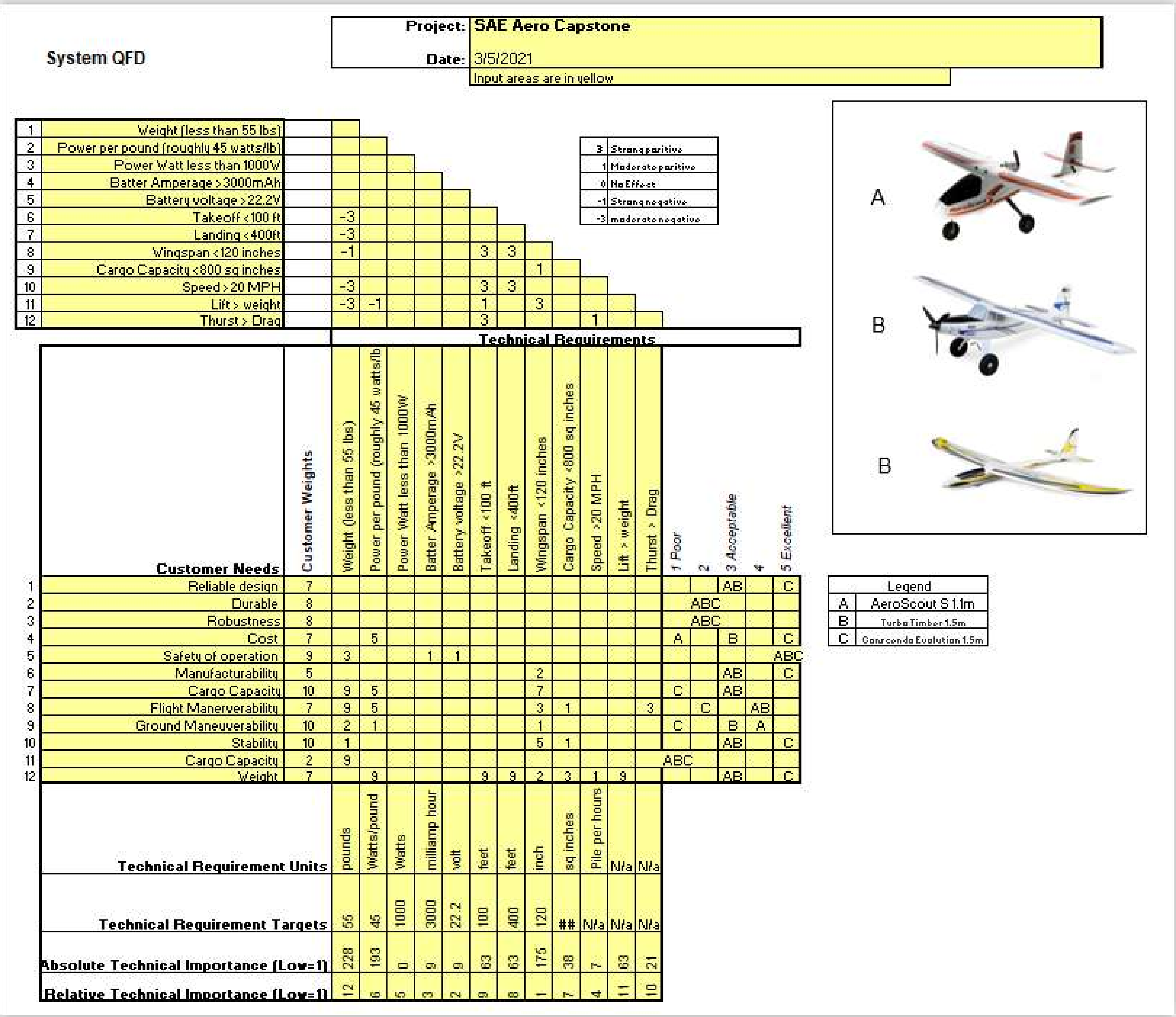
[5] In Thin Air Team 034, "2018 SAE Aero Design West Competition," NAU Capstone Team , Flagstaff, 2018.

[6] M. H. Sadraey, "AIRCRAFT DESIGN," in *A Systems Engineering Approach*, Nashua, Wiley A John Wiley & Sons, Ltd., Publication, 2013, p. 800.

[7] NAU Flight Division, "Prelim Report".

12 APPENDICES

12.1 Appendix A: House of Quality



System QFD

Project: SAE Aero Capstone

Date: 3/5/2021

Input areas are in yellow

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

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

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

Legend	
A	AeroScout S 1.1m
B	Turbo Timber 1.5m
C	Conscenda Evolution 1.5m

Figure 43: House of Quality

12.2 Appendix B: Design Concepts

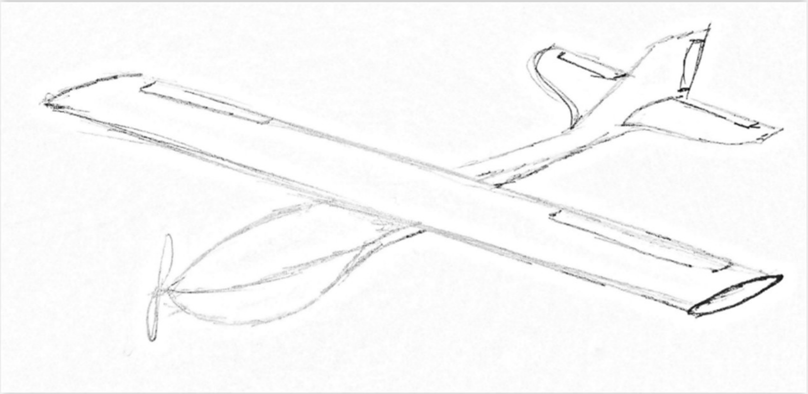


Figure 46: First design concept

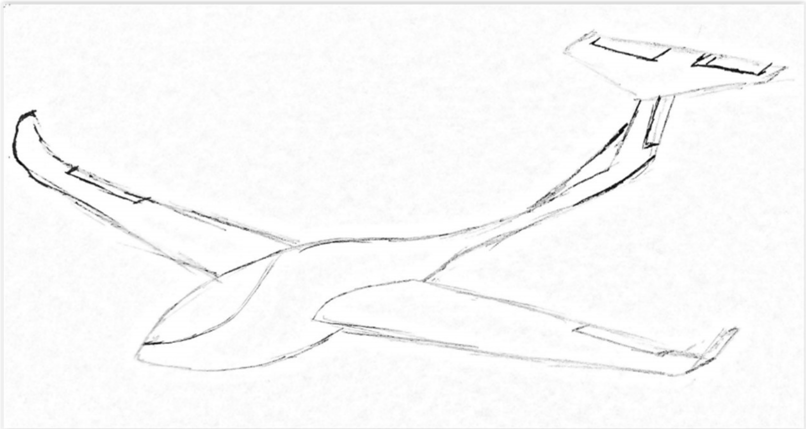


Figure 45: Second design concept

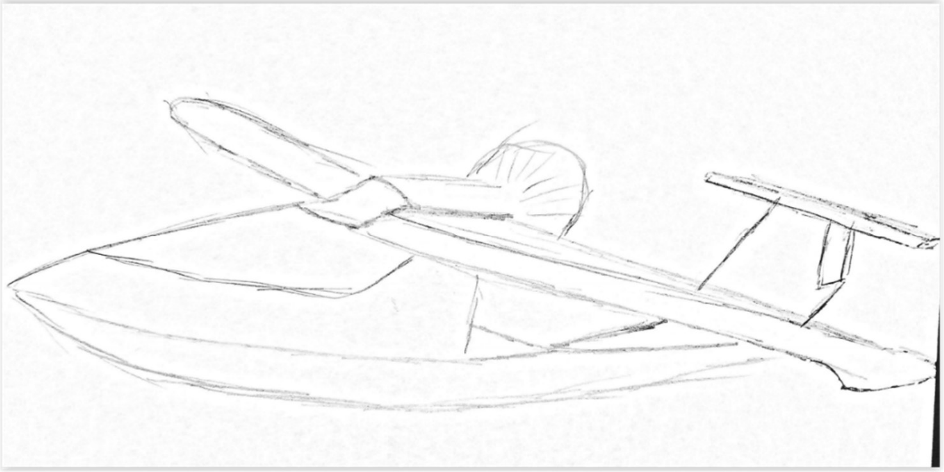


Figure 44: Third design concept

12.3 Appendix C: Budget

Table 6: Break down of what was purchased by company

Purchases	Expected Cost	Actual Cost		Projected Budget	
Horizon hobby	$ 419.88	$ 458.43		$ 1,500.00	original
Amazon	$ 49.32	$ 36.43		$ 302.50	compensation for error
FibreGlast	$ 660.96	$ 640.10		$ 1,802.50	
Adafruit	$ 76.01	$ 70.14			
Mcmaster Carr	$ 24.56	$ 23.12			
Reimbursement 1	$ 401.16	$ 401.16			
Reimbursement 2	$ 102.10	$ 102.10			

Total	$ 1,733.99	$ 1,731.48		$ 1,802.50

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Difference	$ 2.51	Remaining	$ 71.02

12.4 Appendix C: Continued

Table 7: Table of products purchased and where they came from

Vendor Name	Item or Catalog #	Size/Color	Quantity	Discount Code	Cost	Tax	Shipping	Total Cost
Horizon Hobby	SPMAR620	n/a	1		$ 49.99	$ -	$ -	$ 49.99
Horizon Hobby	SPMX32006S30C	n/a	1		$ 84.99	$ -	$ -	$ 84.99
Horizon Hobby	HRC57417	n/a	1		$ 15.97	$ -	$ -	$ 15.97
Horizon Hobby	SPMXC1080	n/a	1		$ 99.99	$ -	$ -	$ 99.99
Horizon Hobby	EFLM4060B	n/a	1		$ 126.99	$ -	$ -	$ 126.99
Amazon		Size 5	1		$ 12.00	$ -	$ -	$ 12.00
Amazon		n/a	1		$ 10.99	$ 2.54	$ 5.99	$ 19.52
FibreGlast	241	yards	25		$ 5.75			$ 143.75
FibreGlast	90/69-A	Gallons	1		$ 83.95			$ 83.95
FibreGlast	582-C	5 yards	1		$ 59.95	$ 20.86	$ 49.95	$ 130.76
Horizon Hobby	MAS1610TP	n/a	2		$ 18.98	$ -	$ 3.99	$ 41.95
Amazon		n/a	1		$ 10.38	$ 1.43	$ 5.99	$ 17.80
Adafruit	169	n/a	9		$ 5.95	$ 4.33	$ 18.13	$ 76.01
McMaster-Carr	9314A831	25	1		$ 8.94	$ -	$ -	$ 8.94
McMaster-Carr	93181A411	100	1		$ 4.50	$ 1.40	$ 9.72	$ 15.62

Reimbursements

Home Depot		2		$ 25.06			$ 50.12
Home Depot		2		$ 4.27			$ 8.54
Home Depot		2		$ 5.28			$ 10.56
Home Depot		1		$ 12.97			$ 12.97
Home Depot		1		$ 12.97			$ 12.97
Home Depot		2		$ 4.97			$ 9.94
Home Depot		3		$ 6.97			$ 20.91

Home Depot		3		$ 6.97			$ 20.91
Home Depot		2		$ 7.75			$ 15.50
Home Depot		1		$ 31.98			$ 31.98
Home Depot		1		$ 24.88			$ 24.88
Home Depot		1		$ 6.47			$ 6.47
Home Depot		1		$ 10.97	$ 15.68		$ 26.65
Amazon		1		$ 5.99	$ 0.62		$ 6.61
Amazon		3		$ 24.92			$ 74.76
Amazon		1	2.24	$ 13.99	$ 8.98		$ 22.97
9 volts batteries		1		$ 13.99			$ 13.99
3/4 dowel		4		$ 3.64			$ 14.56
3/8 dowel		4		$ 1.93			$ 14.66
Bondo		1		$ 16.47			$ 38.20
3/8 dowel		4		$ 1.93			$ 14.66
Home Depot		1		$ 10.97	$ 15.68		$ 26.65

12.5 Appendix C: Continued

Table 8: The different purchase and cost associated

Order 1	**Received**	**Actual Value**
$ 409.45		$ 437.73
Order 2	Received	
$ 358.46		$ 358.46
Order 3	Received	
$ 135.76		
Home Depot 1	Approved	
$ 252.40		$ 252.40
Amazon	Approved	
$ 102.10		$ 102.10
Home Depot 2	Approved	
$ 43.21		$ 43.21
Autozone 1	Approved	
$ 38.20		$ 38.20
Home Depot 3	Approved	
$ 18.48		$ 18.48
Digikey 1	Approved	
$ 48.87		$ 48.87
	Actual Total	$ 1,299.45
	Remaining	$ 200.55