SAE AERO REGULAR

Preliminary Proposal

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DISCLAIMER

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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 to create and produce a prototype aircraft to improve on the previous models. In previous years Northern Arizona University Aero Club (Skyjacks) has participated in this competition. Our Capstone team has been tasked with looking at these previous models and ideas that have been done and to improve them. We need to identify some of the flaws and as well as identify some of the strengths of some of these designs. In doing so we are going to create an aircraft we deem to out compete the previous iterations, by producing a prototype and testing it.

1.2 Project Description

Our sponsor, Dr. Oman gave the following description to the team in preparation for the project, here's the description.

"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's 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."

1.3 Original System

The original system for the SAE Aero Capstone team's project was the 2019-2020 team's project. This aircraft was relatively compact. this aircraft was successful at completing some of the tasks required of the design competition. Many details of the performance characteristics are not listed [1]. The team was not able to test the design in competition due to the COVID-19 pandemic. The overall system that existed from the previous design team will be discussed in this section of the report. The aircraft is pictured in Figure 3 of this report.

1.3.1 Original System Structure

The original system was an aircraft with a 10-inch cargo bay designed to enclose one size 5 soccer ball. It can carry another 6.25 lbs. of payload, if required [1]. The team used large 18-inch chord S1223 airfoils to provide lift for their aircraft [1]. The final design utilized a tail dragger style of landing gear, while initial prototypes utilized other forms of landing gear, such as a three wheeled design. These will be discussed in detail later in this report. It utilized a single prop to provide thrust to the aircraft [1]. The aircraft was successful at completing the takeoff and landing tasks as well as carrying the required cargo.

1.3.2 Original System Operation

The original system operated effectively as required by the competition rules. The previous design team published in their report that the aircraft would be able to carry a maximum of 6.25 lbs. of additional cargo at Flagstaff elevation (7000ft) [1]. The team determined that the aircraft would always have enough lift. The previous team's design operated with a remote-control system not described in their report, with many servos actuating their design's control surfaces. The team powered the aircraft with the minimum capacity battery [1].

1.3.3 Original System Performance

The original system is described as having performed the required tasks [2] adequately without excessive difficulty. No details are provided if the team performed well enough to have passed the competition expectations. The team did state that the flights were successful, and the aircraft could carry an additional 6.25 lbs. of payload in addition to the one required size 5 soccer ball [1]. The team states that the aircraft could perform the liftoff and takeoff tasks required in the competition [2] [1].

1.3.4 Original System Deficiencies

The previous design was the first iteration of the Capstone design teams with new SAE Aero Competition rules [2]. The client wants the team to redesign the aircraft to be more effective in the competition. This is difficult to quantify because the previous design team was not able to participate in a competition due to the active COVID-19 pandemic that began during their capstone project. The team thus has no metric to score directly against. The current capstone design team is aiming to improve on the design so that it will score better in the competition, even if there is no physical competition. The previous design was only able to carry one size 5 soccer ball, the current team aims to increase the overall cargo capacity while maintaining the same overall length dimensions to maximize the score to be more competitive in the competition. The client wants the design team to create an aircraft that has all components inside the aircraft, rather than the existing design's external component. Client and engineering requirements will be explained in detail in section 2 of this report.

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 maintain positive control over the aircraft at all times.

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.

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 [2]. 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.

Commented [DM2]: citation for rulebook

Power in watts is the next requirement. The team has a limit of 1000W for the entire aircraft [2]. 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 [2]. 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.

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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 [2]. 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 [2]. 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.

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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 House of Quality (HoQ)

The house of quality for space purposes has been placed in the appendices as appendix A.

The house of quality help rates the customer requirements to the engineering requirements. It also helps relate engineering requirements to other engineering requirements. This is created in a matrix that allows for the comparison of two different things. This is helpful as the team needs to evaluate how to relate the CR to the ER and by visually looking at them, 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 can not 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. We can but this up and look to see if we change the wingspan how that could affect everything else in our system. While the HoQ takes time to set up due to the complex thinking of interconnected subcomponents it is useful and has and will be beneficial to the team as we continue to design and prototype our project.

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. This research will also consist of learning about general aircraft design and required component systems.

3.1 Literature Review

The literature review section will contain reviews of multiple sources from each student. It will include previous designs, journals, books, and other source types. Each source will be summarized as it is discussed. All sources will be related to an application of the project. The literature review will contain a minimum of 5 unique sources for each team member. Sources will be related to benchmarking and the design space for the project.

3.1.1 Student 1 (Aiden Hudson)

Before approaching the design of the wings and fuselage, the team needed a firm understanding of what they contribute to the aircraft and how to approach their design processes. Each part of the aircraft is crucial to successful flight, so the team needs to understand how each individual part operates and allows for a successful and stable flight.

Chapter Two of the second edition of R. C. Nelson's Flight Stability and Automatic Control [3] discusses in detail how the wings, tail, and fuselage contribute to the overall stability of the aircraft. Section 2.3 of the textbook discusses how the different parts contribute to the airplane's static stability, the craft's tendency to return to a state of equilibrium after experiencing a disturbance. This section also provides many equations that simplify how to find moments and the different coefficients involved in the aircraft design. The section also provides many detailed figures that show all the factors that go into these equations.

The figures presented in this source provide simple, visual representations of each individual part with all the variables involved displayed over-top the figures. The equations can then be used in a mathematical program, like Matlab or Excel. This, in combination with other programs, like Xfoil and OpenVSP, will allow us to determine the dimensions of the aircraft's components.

Fuselage Aerodynamic Prediction Methods from Volume 555 of Aerospace Science and Technology, by Nicolosi et. al [4], goes into further detail on the aerodynamic characteristics. The article discusses different methodologies for estimating the aerodynamic coefficients of the fuselage. The article also provides equations and figures for estimating these values.

These equations can be used to estimate the coefficients of drag and skin friction for the fuselage of the team's aircraft. Although this article is mostly for commercial aircraft, the equations can likely be rewritten to work for the team's aircraft.

Design of Light GA Aircraft for Agricultural Purpose by Bereket Sitotaw Kidane [5] discusses the full process, from preliminary design to final product, of an aircraft made for agriculture. This means that the aircraft is mostly for low flying above crops. The aircraft does not need to perform any striking maneuvers; it only needs to cruise at a low altitude for the purpose of dusting crops.

This is very applicable to the team's project because this describes exactly what the team's aircraft needs to do. The process discussed in the handbook will likely be very similar to the process being performed by the team.

Tun Lin Htet's Structural Analysis and Topology Design Optimization of Load Bearing Elements of Aircraft Fuselage Structure [6] is a study that uses SolidWorks and Ansys to analyze stress in the fuselage of an aircraft due to pressure differentials. The article discusses how the use of different materials and structural ribs inside the fuselage can reduce the overall weight of the aircraft. The paper also provides the equation for the climb performance, which calculates the climb speed using the weight of the craft and the angle and velocity of attack.

This paper will prove to be very useful to the team's design as weight is currently a major issue being considered in the team's aircraft. The power limiter is proving to be an issue that will severely limit the weight of the aircraft, so being able to reduce the weight while maintaining a strong structure is ideal.

Chapter 12 of General Aviation Aircraft Design: Applied Methods and Procedures by Snorri Gudmundsson [7] is another chapter from a textbook that explores fuselage design. This chapter discusses different designs for the fuselage and their effects on the overall aircraft. It also explains some methods for estimating the geometry of the fuselage.

This source will help the team fully decide on a design for the fuselage and understand how to begin estimating the dimensions incorporated.

3.1.2 Student 2 (Dylan Morgan)

The technical aspects that this student focused on for the project so far are landing gear, control surfaces, and some benchmarking of a previous NAU SAE Aero Design team.

Source 1 is the fall NAU 2019 Capstone team. The specific documentation reviewed was the team's final report [1]. The focus was on the landing gear and control surfaces. During the design process for the previous team, they discovered that using a tail dragging landing gear allowed for different angles of attack at takeoff and thus allowed for varying angles of attack. This is an area of concern for the team's project currently. They also used SolidWorks flow simulations to determine if the control surfaces located on the wings would be adequate for the design to maintain control under various conditions in flight. This could be a valuable technique for my design team as it is a way to evaluate if a given control surface will be able to control the aircraft before the team makes the control surfaces on the wings, reducing the potential waste materials and overengineering that may occur.

Commented [DM5]: citation

Source 2 is from Science Direct on control surfaces. Presented in the source are numerous equations that relate to the evaluation of control surface designs [8]. The article discusses how to mathematically evaluate the effectiveness of a control surface and provides various parameters for coefficients that are common for effective control surfaces, as well as ranges that are unlikely to be effective. This will be directly applicable to the design process as the team settles on final airfoil designs for the wings as it will allow us to evaluate the control surfaces mathematically to determine if they are effective and then to apply the results to iterate through control surface designs until the team can achieve success with the control surfaces. These control surfaces are key to the success of the project, so it will be valuable to understand various parameters as they relate to the project.

Source 3 is on designing landing gear [9]. The article discusses considerations for designing landing gear for an aircraft. This component has been known to fail from previous capstone teams and the SAE Aero Competition. That will be very important throughout the team's design process because the team could decide to engineer the landing gear as a failure point or could design it to withstand repeated landing. It also discusses how landing gear geometry with struts and supports are important to the strength of the gear as well. This provides a strong general baseline understanding of elements to be considered and things that the team should be aware of while designing the aircraft to ensure that the landing gear will be successful.

Source 4 is an article on an experimental landing gear design. This article contains guidelines for different kinds of landings, as well as many of the forces involved in an aircraft landing [10]. It includes a number of equations used in the evaluation of a strut and shock-based design. Many of these equations will be able to be simplified or the design process can be used for the team's landing gear design. The team's design will be much less complex so many of the calculations will not be used, but the process will be valuable as well as knowing many of the considerations that are important to landing gear design, which are discussed in detail in this report. This is directly applicable as some of the components the team has investigated for the landing gear contain damping components similar to shocks.

Source 5 is an article on finite element analysis of light aircraft landing gear [11]. This article uses finite element analysis to evaluate the stresses on an aircraft's landing gear during the landing and takeoff process. This is useful to the team in the design process because it is both a tool for analysis of the team's design, and also provides likely locations and expectations for failure points on the team's own aircraft design. It also reveals that for a given impact speed on an aluminum aircraft system, the actual impact loads are relatively low with a light aircraft, and deflection of the design under stress should be a consideration during the design process. Stresses may also be high during landing, so the team learns from this that the team should ensure that either the landing gear can absorb the shock loads and reduce the stress or be able to deflect without deformation and also take the stresses involved in the landing process. These are important considerations and concepts the team learned from the article as it relates to their design process.

3.1.3 Student 3 (Ryan Stratton)

The technical aspect that I focused on was the electrical components of this aircraft and to better understand the propeller and thrust that our aircraft can protentional make. I also wanted to look at some general research to better understand our project better and to have the ability to help some of the other team leads with their decision.

3.1.3.1 First source: Norther Carolina Agricultural documentation

For the first source I looked at the North Carolina Agricultural and Technical State University 2019 technical report. This team scored 6th place in the 2019 competition for the advanced class. While this class has some different parameters then the regular class that the team would be competition most of the data from the report, I found to be useful form an electronics point of view as the requirements are basically the same.

The motors that they were using have a Kv rating of 515 which is a little higher than the current engine the team is modeling with right now. The Kv rating is the measurement of revolutions per minute (rpm) with 1 volt on the motor with no load. This means that the team is making the power limiter the limiting piece of their aircraft. What I mean is the motor can not be supplied more than 1000 watts of power and with an amperage rating of 59 amps and a batter voltage of 22.2 volts they will need 1300 watts to run the motor at full power. However, the limiter will stop it at 1000 watts. This is important to me as they wanted to oversize the components verse under sizing the components. By doing this they make sure that the aircraft can always hit the red line or max out the rpm. This might sound great but this does mean they are carrying more weight to over compensate for this issue.

Another pieces of the literature that was interesting was the propeller or prop that they are using is 22 x 8 which means 22 in diameter and 8 inches of pitch. This is a very large propeller for such a small motor and is defiantly not rated from the manufacture for such a large diameter of prop, but this is one way to increase thrust on the aircraft. By having a higher pitch and a larger area the propeller is able to move more air and this once again goes to show that the team seems to be over sizing components to make sure that this is not the limiting factor of the aircraft.

3.1.3.2 Second source: Electric Rc Aircraft Guy

Before we get into what this resource is, I would like to bring up the fact that this data was not published by any kind of organization. The gentleman that came up with the equations that will be displaced later was just a guy in his garage that was wondering the same information that I was wondering. While this data has not been peer reviewed or published in any formal publication there are a lot members in the RC community that recommend this recommendation. I have not seen anyone validate this information as it would require lots of instrumentation and calculation that hobbyist is not going to spend the time doing. Regardless I am using this information as a base line to help with the calculations for our project.

This resource relates the static thrust to the dynamic force with real empirical data calculation. The person that wrote the article mentioned that he was interceded in this field and wanted to see if he could easily approximate the thrust based on the diameter the pitch and the rpm of the engine. He came up with the following formula [12].

$$F = 1.225 * \frac{\pi * (0.0254 * diameter)^2}{4}\left[\left(RPM_{prop} * 0.0254 * pitch * \frac{1\ min}{60\ sec}\right)^2 - \left(RPM_{prop} * 0.0254 * pitch * \frac{1\ min}{60\ sec}\right) * V_0\right] * \frac{diameter}{(3.29546 * pitch)^{1.5}} \tag{1}$$

This equation is universal and what I mean by this is the units that you use will get you a force that you want, so you my calculations are in British units but if you were to use other units it would work out just fine.

Now how do I know that this equation works. The author did not want to make you just trust him he gave the following image of empirical data that he collected, and it shows the calculated thrust form this equation compared to the empirical data taken. I am not sure what his test set up was but I he does hint that he used a scale.

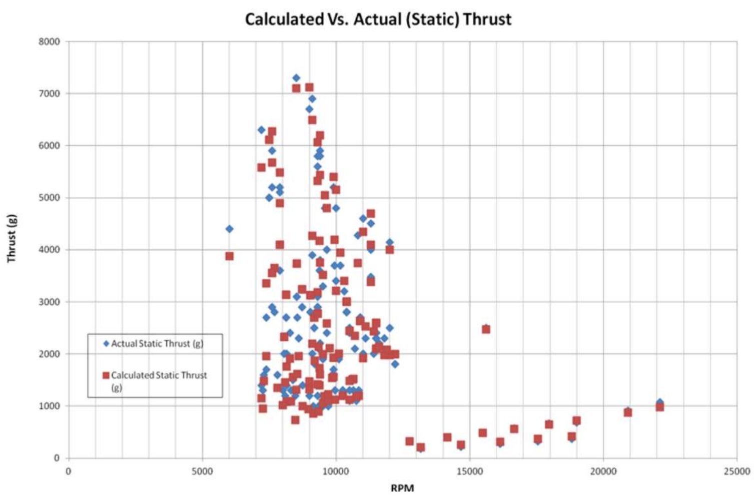


Figure 1: Empirical thrust verse calculated thrust [12]

From this date you can see that the calculated is lower in most cases and that were are time that this is not the cae bit the diffrence in trust is noramlly less than 500 grames of thrust. This is a small error in consideration to the overall calulation of the aircraft. The author does go on to talk about the reasons why there are diffrences in the 149 data points he took [12]. The prop sizes that he anylises are limited to 5x5 to 17x8 so that is impartant to remember [12]. Also this eqation does not take in to consideration into air desity or humididty any condidtions like these [12]. He comments that at most the thurst is 30% higher then the actul thurst and at worst 40% less than te acttual so when doing calulations keeping a 30% buffer room is propelly worth while [12]. He does metion that 68% of the props has less and a 13% error between calculated and emperical, so this show that must of the time this eqation is accuate [12].

To take this one step further he worked with Ohio State University and ploted the eqation for thrust verse the actuall of a 10x6 propeller at full throttle and here are the results.

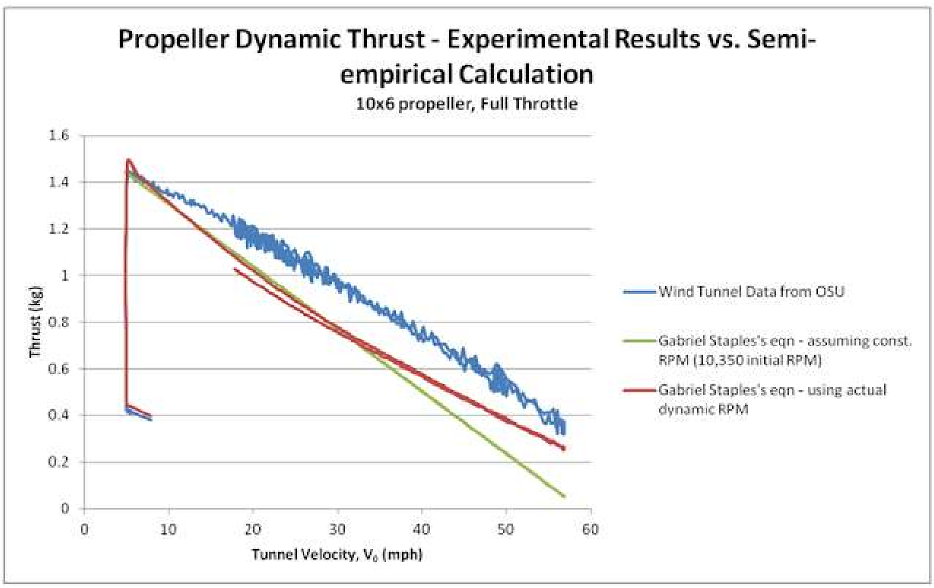


Figure 2: Dynamic thrust wind tunnel data vs. estimates using the equation [12]

Oddly enough this is an under estimate for this type for prop now this is only for the 10x6 prop but if the data is extrapolate it means that his equation is acutely not what you are going to get and underestimating is better than over estimating.

All in all, I found this work very useful and insight full as we work to find a propeller that meets our requirements. While there are more calculations to be done this equation seems like one worth using to validate answers and for preliminary calculation.

3.1.3.3 Third source: Aircraft Design

The next source that I will be looking at is a textbook tiled aircraft design and the name pretty much says it all. This book brakes down the fundamentals of flight the wing designs the tail design. Basically, every aspect of a plane this book talks about. For this part I am going to focus on the propulsion system design. This is chapter 8 from the book and while I have looked over the other chapters the propeller has quickly become one on my higher concerns and due to this, I have been looking into this much mor thoroughly.

The propulsion chapter even has a sub chapter where the author discusses the electrical propulsion of aircraft. While this is not used in general aviation (GA) due to the fact that electric planes have batteries and batteries have limited life and this is not suitable for aircraft when human life is at risk [13]. That is why the most applicable use is for RC aircraft. The author comments that aircraft less than 30 kilograms (66 pounds) are good candidate for electric power [13]. Also, this kind of propulsion is good for low speeds, less than 60 knots, low range, less than 50 kilometers (31 miles) and low endurance, typically less than an hour of flight time. From these guild lines you can see our aircraft actually makes a good candidate to be electric [13].

The information gained from this book help validate the idea of an electric system and gave information to consider when determining parts and components, as to which are important for my electrical contribution of the project. Below are two graphs from the book and the first one I found interesting. It rates altitude verse the max speed and interestingly enough electric does better than I was expecting. To help show the electrical option I have highlighted it in yellow for easier viewing.

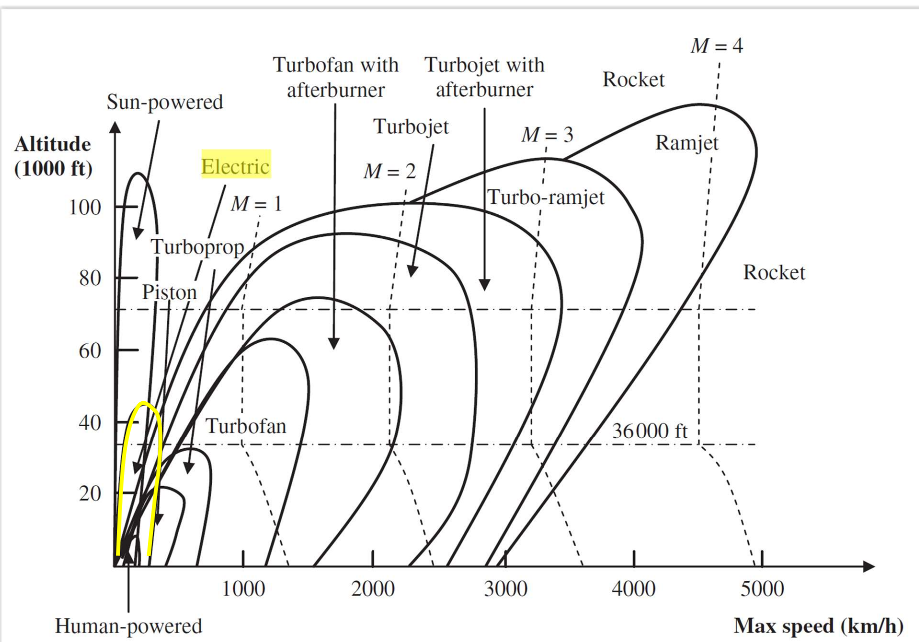


Figure 3: Altitude verse max speed for different types of propulsion [13]

The other image is the efficiency of propeller and while I talked about the electronics form the book they propeller calculations are going to come in very useful and this graph illustrated how we can get more efficiency out of our propeller design and for this reason I wanted to add the image here.

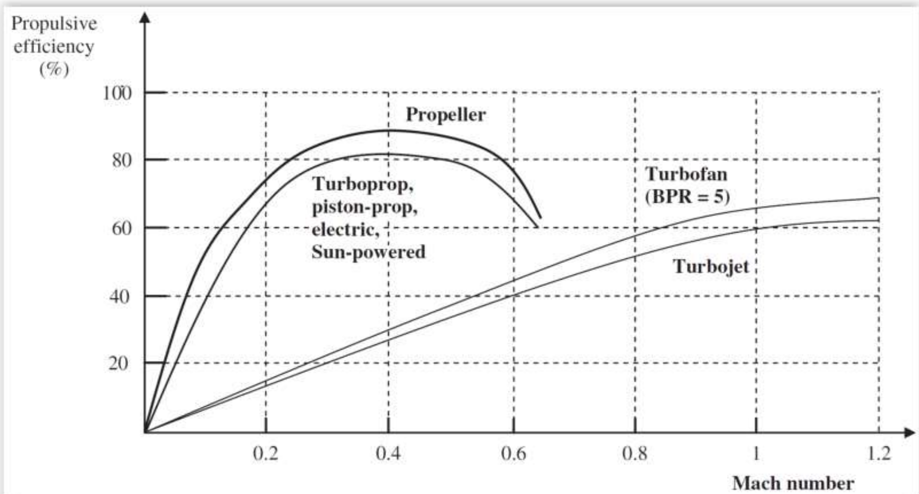


Figure 4: Type of efficiency for aircraft [13]

3.1.3.4 Fourth source: Radio Controlled Airplane

For the fourth source I will be looking at a research paper that talks about the how to build and calculate parts of an RC plane. This is in hopes to help fellow peers get into the hobby. I will be looking at their electronics part of their paper. This paper gives a good brief overview of what is needed and was a paper I started with when first looking at when trying to figure out what electronics make an RC plane fly.

The paper goes over what is this propeller dimensions and what do they mean. For example, the diameter is relatively easy it is the diameter of the propeller but what about pitch? They related it to a screw and screws have a diameter and a pitch of the threads. If a screw was ¼ by 1 that would mean that is 0.25 inch in diameter and 1 means that for ever rotation that the screw does it moves 1 inch in to the material [14]. The same is true with propellers, for example 10x8 means 10 inches in diameter and in theory during 1 revolution of the prop you would move 8 inches [14]. This was a huge help relating it to a screw that is something very tangible and easy to see.

Next they talked about Kv and this is the most confusing term and I still have to look it up every now and then but it means that for every volt of power you give the motor you will get that many revolutions per minute. For example, a 580Kv with a 22.2-volt motor will have an rpm of 12876 rpm. But this value is with no load so you will not get this much out of it in real life once you add a load [14].

Next, they move on to electric speed controllers (ESC), this is essentially the throttle to the motor if you need more power it provides more power if you need less it decreases. This unit also can have a battery elimination circuits (BEC) which can save weight on the aircraft but only have one battery on board instead of two and this BEC powers the receiver. The receiver allows the person on the ground to talk to the plane in the sky. Due to this the receiver take the commands from the ground and controls the servos and ESC, which translate into control surface control as well as speed.

Finally, this paper was very helpful as I have never designed the electronic for a plane before let allow had to make a plane so learning the terms and the components of the plane was helpful and this paper was short and gave you everything you needed but nothing more.

3.1.3.5 Fifth source: Speed Control of Brushless DC Motors

The fifth source that I will be looking at is speed control on brushless motors. The reason why is that for our aircraft and most of the RC community the motors have gone to brushless and while I have heard this term before I needed to better understand how they work to better understand the calculations on them later in the project.

The paper I found has a lot more information in it then what I was looking for but the it watered off with a good description into why brushless motors need electronics to control them. The general idea is that the a brushed motor has direct connection form the electrical source to the motor and therefore by varying the voltage you can vary the speed but a brushless motor is a little different. By the stator to the outside of the system this allows for the lightning of the interior and better rpm rate. Even though this is good you need to know where the stator is in respect to the permeate magnets and that is where a hall effect sensor comes in. The hall effect sensor allows the motor to now where the components are to allow for the cycling of power on stator [15]. Below is what that design looks like.

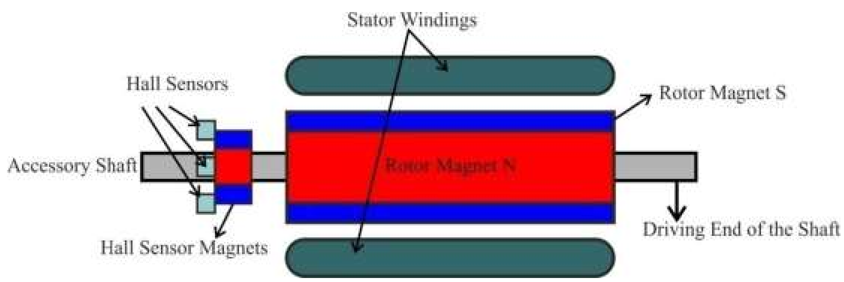


Figure 4: Brushless motor internal components [15]

This design is an improvement as it saves weight, something important for our aircraft. However, there is a downside were the ESC needs to be able to handle this type of motor adding to the complicity of the ESC. Regardless these motors produce a higher rpm which means more thrust that we will get from them is work the extra complexity on electronics the aircraft will have to carry. While this paper had more in it than what I needed the base explanation as to what is going on with brushless motors as well as what the electrical components that make it work are helpful when designing the electrical system.

3.1.4 Student 4 (Gajaba Wickramarathne)

The technical aspects that I focused on were the wing/airfoil design and selection and flight control systems. By conducting a literature review on the above topics, I was able to better understand the lift and drag calculations that goes with aircraft wing design. The airfoil selection process was also understood with a better understanding of the reasoning behind selecting different airfoils. It was proven that it’s always budgets friendly to start working from a pre-existing airfoil category such the NACA series before additional adjustments are made. Designing a custom airfoil by itself has its own pitfalls because the experimental data is not given. In this case, you are sacrificing the accuracy of your lift and drag calculations for uniqueness.

3.1.4.1 First source: Chapter 01: Fundamentals of Aerodynamics (McGraw-Hill 2016)

For the first source, section 1.5 and 1.6 from the book Fundamentals of Aerodynamics [23] were selected. These sections explore the general aerodynamic forces and moments acting on airfoils and aircraft. The first section explains that “no matter how complex the body shape may be, aerodynamic forces and moments on the body are due entirely to two basic sources” [23]. Those two primary sources are *Pressure distribution over the body surface* and *Shear stress distribution over the body surface.* The figure below illustrates the above statement.

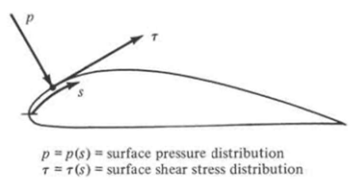


Figure 5: Illustration of pressure and shear stress on an aerodynamic surface. [23]

By this knowledge, one can simplify the complex forces acting on an aerodynamic surface into two primary sources. This is the first step towards selecting and/or modifying an airfoil for the team’s design.

The section goes on to define lift be the *component of R perpendicular to V_infinity* and drag to be the *component of R parallel to V_infinity.* Chord length ‘c’ is defined as the linear distance from the leading edge to the trailing edge of the body. Normal force is the *component of R perpendicular to c* and the Axial force is the *component of R parallel to c.*

The angle of attack, *alpha* is defined as the angle between c and V_infinity. The geometrical relation between those components is as below. [23]

$$L = N\cos\alpha - A\sin\alpha$$
$$D = N\sin\alpha + A\cos\alpha$$

The above relations are illustrated below for further understanding.

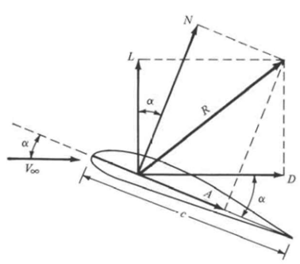


Figure 6: Resultant aerodynamic force and the components into which it splits.[23]

The section goes on to explain the detailed integration process of the pressure and shear stress distributions to obtain the aerodynamic forces and moments.

Section 1.6 explores the center of pressure of airfoils. Normal and axial forces on an aerodynamic body are due to distributed loads imposed by pressure and shear distributions. Therefore, there is a moment generated about the leading edge by those forces. This illustrated below.

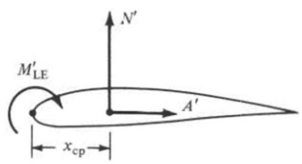


Figure 7: Center of pressure for an airfoil.[23]

3.1.4.2 Second source: Chapter 04: Fundamentals of Aerodynamics (McGraw-Hill 2016)

For the second source, the same book was used. This is due to the expansive nature of this book and each chapter is a great source. Chapter 4 [24] further explains the aerodynamic forces and theories that apply to the team's airfoil design. As the team's aircraft is cruising at low-speed and low-altitude conditions at all times, it is safe to assume that only *incompressible flow* conditions apply to the team's airfoil. Phenomena such as oblique shock and expansion waves do not occur as the aircraft would not reach sonic flow velocities. This chapter is *very* important in the design process as it explains how to calculate the airfoil properties such as lift, drag and moment coefficients as a function of angle of attack. In the instance of creating an airfoil, there are experimental measurements that have been calculated and documented in the past 100 years for different airfoils in the industry. This information gives you a practical understanding as to how airfoils behave. The chapter applies the *thin airfoil theory* to theoretically predict the lift. This theory was developed in Germany during World War I [24] and according to the source it's by far the most tractable means of obtaining analytical solutions for lift and moments on an airfoil. The problem is the thin airfoil theory holds on for thin airfoils at small angles of attack. However, this is not a problem for the team's design as our airfoil will be relatively thin and cruise at very small angles of attack. There are two approaches to low-speed airfoil theory. The first one is the *classical thin airfoil theory* developed during 1910-1920. The other one, is the *modern numerical approach for arbitrary airfoils using vortex panels [24].* The way airfoil drag is calculated by the above two methods is illustrated below, where the left-hand branch correlates to the modern approach and the right-hand side correlates to the classical approach.

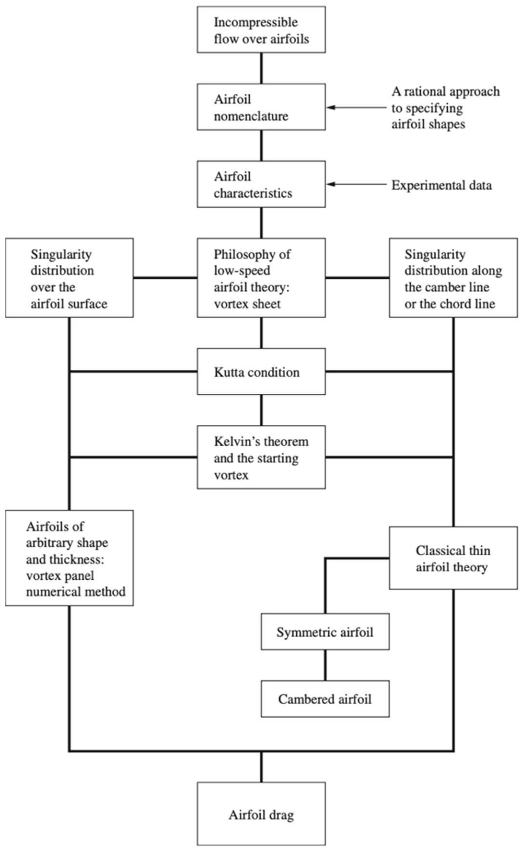


Figure 8: Airfoil drag calculations via Classical and Modern approaches [24]

Airfoil nomenclature (illustrated below) is a very important factor, and this chapter follows the nomenclature established by the NACA. It is noted that the NACA identified different airfoil shapes with a logical numbering system that has a format of **NACA ####.** The first digit is the maximum camber in hundredths of chord, the second digit is the location of max camber along the chord from the leading edge in tenths of chord, and the last two digits give the max thickness in hundredths of chord. It's important to note that the NACA has 5-digit and 6-digit series as well. For the team's design, those series are irrelevant as a NACA 4-digit series airfoil will be selected in the design process.

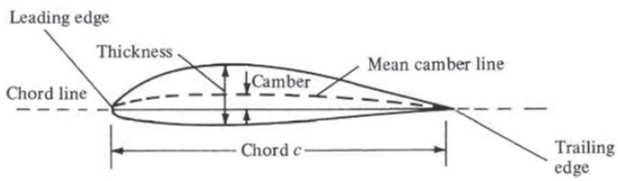


Figure 9: Airfoil nomenclature [24]

The results of calculations with the thin airfoil theory is as below [24].

Results of thin airfoil theory:

Symmetric airfoil

1. $c_l = 2\pi\alpha$.
2. Lift slope = $dc_l/d\alpha = 2\pi$.
3. The center of pressure and the aerodynamic center are both at the quarter-chord point.
4. $c_{m,c/4} = c_{m,\mathrm{ac}} = 0$.

Cambered airfoil

1.
$$c_l = 2\pi \left[\alpha + \frac{1}{\pi}\int_0^{\pi} \frac{dz}{dx}(\cos\theta_0 - 1)\, d\theta_0\right] \tag{4.57}$$
2. Lift slope = $dc_l/d\alpha = 2\pi$.
3. The aerodynamic center is at the quarter-chord point.
4. The center of pressure varies with the lift coefficient.

Figure 10: Results of thin airfoil theory [24]

3.1.4.3 Third source: Comparison of the Aerodynamic characteristics of the NACA 0010, 0010-64 airfoil sections at high subsonic Mach numbers

This report presents an investigation to determine the lift, drag and pitching moment characteristics of the NACA 0010 and 0010-64 airfoil sections at Mach numbers up to 0.91 and for a range of Reynolds numbers [25].

For the team's design, the team is leaning towards building the airfoil based on a NACA0010 airfoil due to its dimensions. This report gives valuable information about how the airfoil acts under aerodynamic stresses/factors. Since the team's design is guaranteed to run at subsonic speeds, this report is perfect for our scenario.

NACA 0010 SECTION

Upper and lower surface	
Station	Ordinate
0	0
1.250	1.578
2.500	2.178
5.000	2.962
7.500	3.500
10.000	3.902
15.000	4.455
20.000	4.782
25.000	4.952
30.000	5.002
40.000	4.837
50.000	4.412
60.000	3.803
70.000	3.053
80.000	2.187
90.000	1.207
95.000	.672
100.000	.105
L.E. radius, 1.10 percent c	

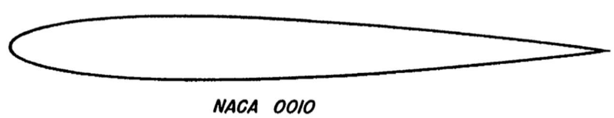
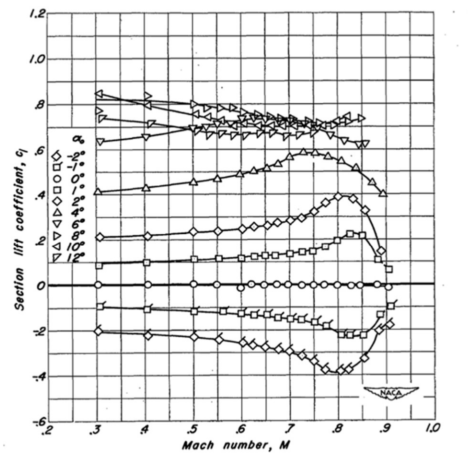
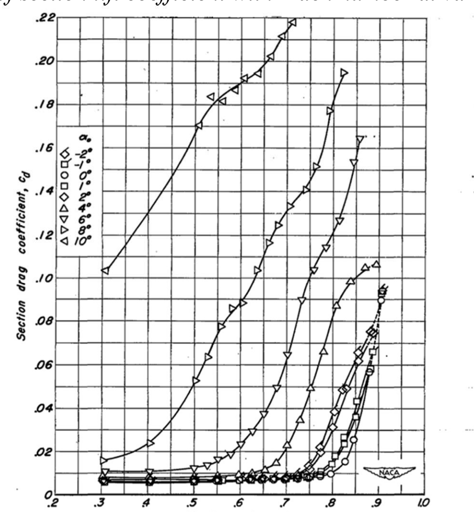


Figure 11: Coordinates and the profile of NACA 0010 airfoil tested [25]



(a) NACA 0010 airfoil section.

Figure 12: Variation of section lift coefficient with Mach number at various angles of attack.



(a) NACA 0010 airfoil section.

Figure 13: Variation of section drag coefficient with Mach number at various angles of attack.[25]

By analyzing the above experimental findings [25], it's clear that the NACA 0010 series will perform well under the aerodynamic forces acting on the team's design.

3.1.4.4 Fourth source: Flight control systems – an overview

Manual flight control systems use a collection of mechanical parts such as pushrods, tension cables, pulleys, counterweights etc. to transmit the forces applied to the cockpit controls directly to the control surfaces. This paper notes that flight control systems must be designed to prevent jamming and also to have overrides and disconnects to minimize or eliminate the effect of a jammed system [26]. For our situation, the explanations about aircraft control systems given in this paper is of utmost importance.

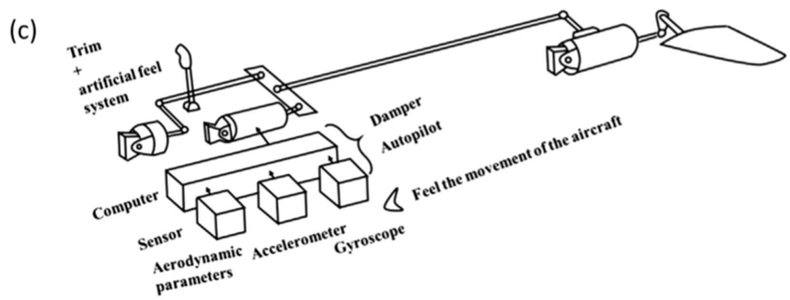


Figure 8: Reversible booster control system [26]

The team's design will include a similar control system, minus the booster. A booster is irrelevant to the design as we will be propelling our aircraft with an electric motor driven prop. There's no stability augmentation or fly-by-wire in the flight control system illustrated above.

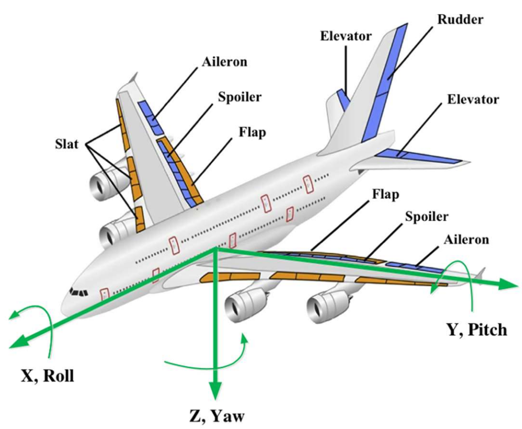


Figure 14: Primary flight controls of conventional aircraft [26]

According to this report, the primary flight controls of conventional aircraft is as above. Our design will not include hydraulics (unlike commercial aircraft) as it will be unnecessary and will be purely driven by servos due to the low altitude, low velocity conditions. The report illustrates the control surfaces of an Airbus-A320 aircraft [26], as given below. The team's design will not have as many or as complicated control surfaces. However, this gives us a good understanding about how the team's design's control surfaces should be placed.

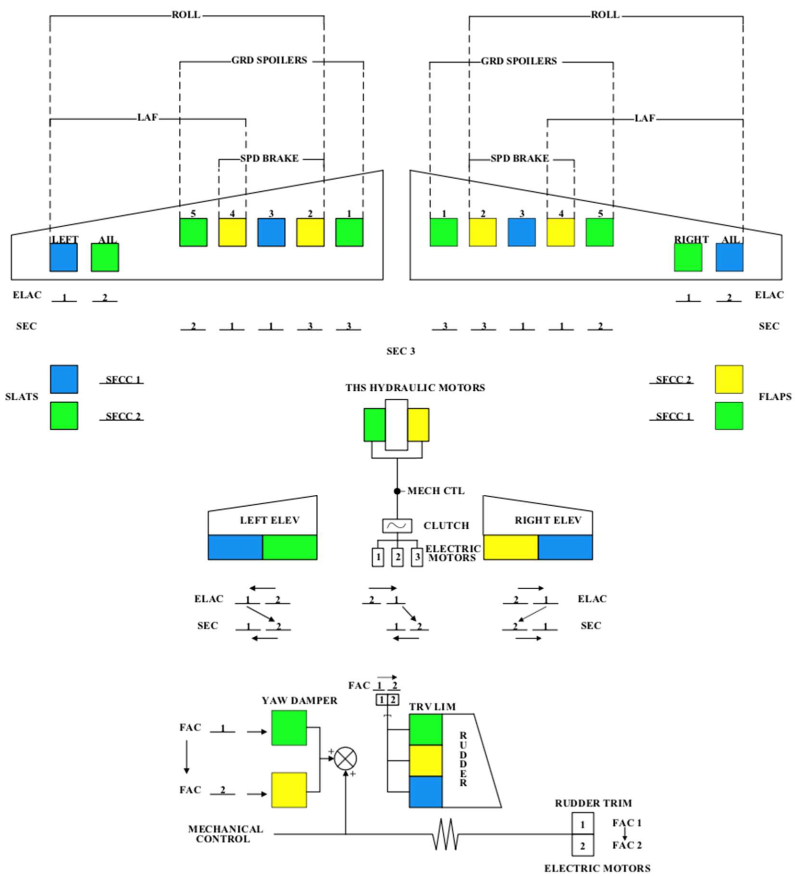


Figure 15: A320 aircraft flight control surfaces [26]

The report mentions 3 different actuation systems. They are,

1. Simple mechanical/electrical signaled, central hydraulic supply powered
2. Multiple redundant electrohydraulic actuation
3. Simple electrical signaled, distributed hydraulic supply powered

By further studying this report, it's understood that the team should focus on a simple mechanical/electrical signaled actuation system for the FCS of the team's aircraft. In conclusion, the report notes that the stability of a FCS is the precondition of the aircraft whereas the actuator's operational stability is the most important requirement for FCS stability and that the structure design of an actuator should be as simple as possible to ensure aircraft safety, reliability and maintainability [26].

3.2 Benchmarking

3.2.1 System Level Benchmarking

System benchmarking, in this section we are going to be looking at other successful and unsuccessful aircraft, to better understand what is needed form our design to help use better preform. In this section we are only going to look at the big picture. Due to this we are going to investigate previous designs by looking at other SAE Aero teams from both NAU and form other schools, we will also be looking at commercial aircraft that are well equipped in the ability to more large cargo.

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

First, let's look at last year's NAU SAE Aero entry to see what they created, what went well and what didn't go so well.

Figure 16: Pondarosa's final design for aircraft [16]

The aircraft that was designed has a few characteristics that are worth mentioning, one is 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 [16]. They even 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 [16].

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

Second, 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 [17]. The aircraft weighed empty at 18.6 pounds and fully loaded 28.3 pounds [17]. 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 [17]. 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.

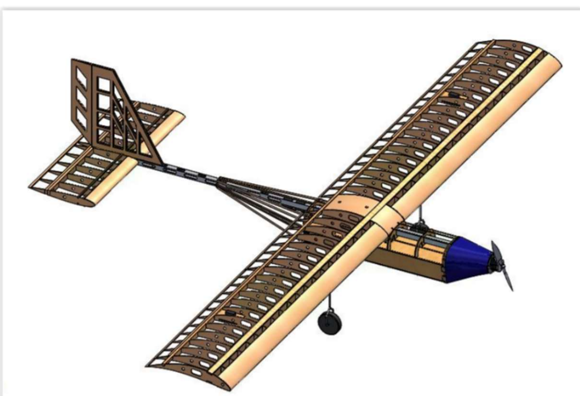


Figure 17: Skyjacks' final design without monokote [17]

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 we can look there are different payload requirements. Regardless the aircraft they crated was able to carry 34 tennis balls and this created a really large cargo bay, however the cargo bay did not need to be super tall to accommodate the cargo [18]. The aircrafts had a wingspan of 141.5 inches and empty weight of 33.6 pounds [18]. Fully load 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 [18]. They calculated the static trust to be 16.7 pounds which gave them an inflight speed of 36.67 miles per hour [18]. 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 our aircraft as we are 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.

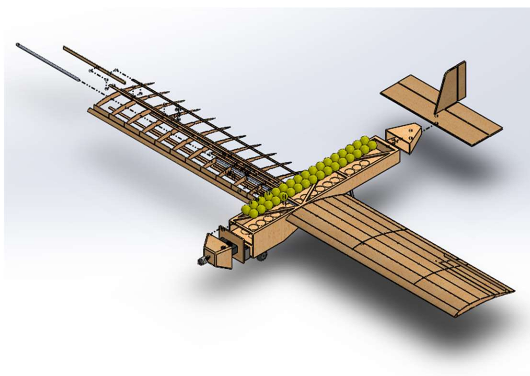


Figure 18: In Thin Air's final design [18]

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 our 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 they company needed this plane was it was a more economical way of move the cargo then but truck where the load would be oversized. 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 19: Beluga XL aircraft inflight [19]

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 our 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 20: Beluga being loaded with fuselage of another aircraft [19]

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

Figure 21: Icon A5 aircraft [20]

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.

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 23: C-5 being loaded with a C-130 fuselage [22]

Figure 22: C-5 unloading an Apache Helicopter [21]

The other picture to on the right side is a full helicopter being unloaded form 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 24.

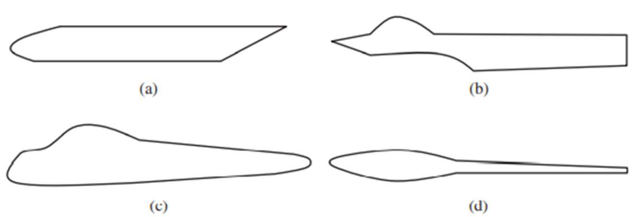


Figure 24: Basic Fuselage Design [13]

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 24, 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 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 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 tend 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 is 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 as 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 doesn't 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.

3.3 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.

3.3.1 Black Box Model

In this section we will be reviewing the black box model for our teams RC plane design. This is to help the team visualize the main process of our project. This helps identify what is the inputs and what are the outputs.

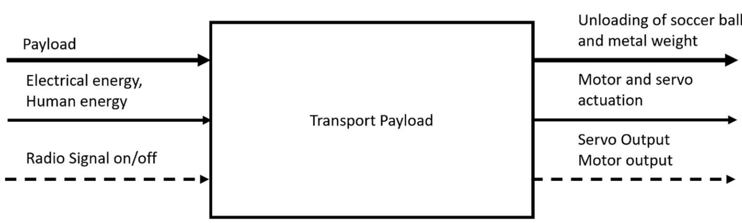


Figure 25: Black box model

We pick transport payload as the main idea as this is really the main goal of the competition. We want to pick up a payload and move it and by doing this successfully you complete the requirement for competition. With this as the overarching idea we need to know what it will take to make that happen. For materials in and out of the system they are relatively easy, we are going to add payload (soccer ball, steel weight) and then after a flight will be taking these materials out of the aircraft. For energy, there is a little more. The whole system run on electricity, so we need to include that. There is also Human energy of the person on the ground having to control the aircraft. Finally, there is signal and the signal from the transmitter on the ground will control the aircraft moving the servos and motor. All in all, this black box allowed the team to better understand what we need to do to make the aircraft work from a very overarching point of view.

3.3.2 Functional Model

The functional model is a way for the team to see what is going on with our aircraft. It gives a good visual to if this happened than this will happen and allows for the team to easier see what computes to make our project to work. Our function model also demonstrated what needs to go into our system in order to get the responses we want.

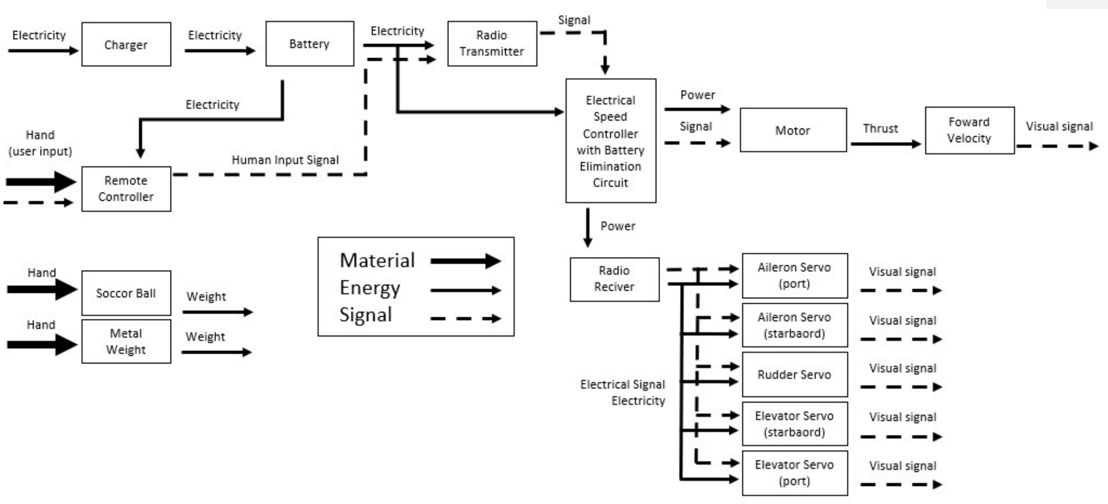


Figure 26: Functional Model

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 39 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 38 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 35 under Appendix B, is heavily inspired by the Icon A5 Light Sport Aircraft in Figure 21, 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 24d. 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 24c, 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 27a, are the simplest to design and manufacture [. As such it costs the least and is the easiest to repair should the need arise.

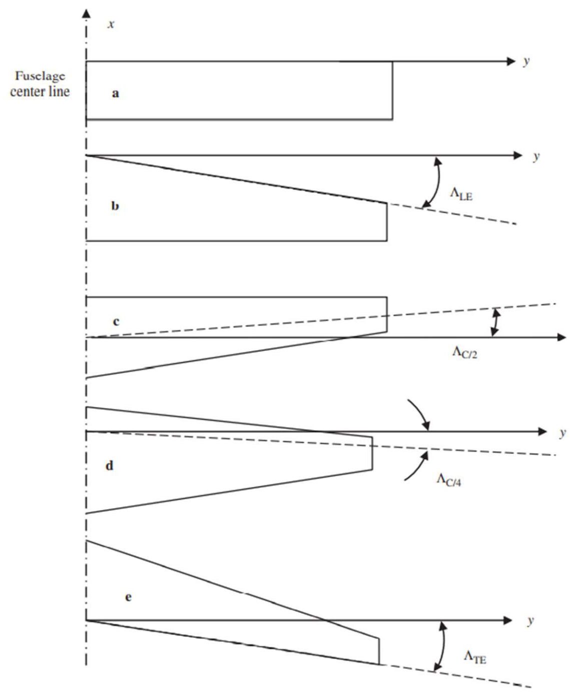


Figure 27:Wing Designs

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 27b-e. 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 [13]. 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 [13]. 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 [13]. 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 DESIGNS SELECTED – First Semester

The team has settled on the glider-inspired design with mid mounted straight wings and taildragger landing gear, described under Section 4.1.1. The glider fuselage is the most applicable to the team's goals and applications. The mid mounted wings find a middle ground between the advantages and disadvantages of the high and low mounted wings. Although they tend to be heavier than the other two types of wings, the team believes they can minimize this weight since this is not a full-size aircraft. The taildragger design, as discussed before, will allow the team to adjust the front wheel strut length, and thus the angle of attack of the full aircraft, making testing on the runway much simpler. The taildragger landing gear also allows for greater control on the runway. A rough CAD model of the design made in Solidworks is shown below in Figure 28. This CAD model assumes a rough aircraft length and wingspan of 60 in. This, however, is not a solid measurement based on calculations and is only a temporary placeholder to assist in weight comparisons under Section 5.2.

Figure 28: Rough CAD Model

5.1 Technical Selection Criteria

The weight of the aircraft is currently one of the most important factors in the design because of the underlying issue of the competition: the power limiter. The power limiter presents an interesting problem in that it severely limits the weight of the aircraft. The design is already restricted to 55lbs due to the competition guidelines [2], but the power limiter requires the team to reduce the weight as much as possible to ensure the aircraft can achieve lift. Currently, the goal for the aircraft is about 15lbs, to meet a power-to-weight ratio of 45Watts/lb.

Weight is determined by the addition of the weights of each individual component of the aircraft, including the fuselage, motor and propeller, electronics, wings, tail, and landing gear. As such, one of the major goals in the design is to reduce the weight of each of these components while ensuring the aircraft can still achieve and maintain lift while maintaining structural integrity. Doing this will require that the team use the right structures inside the fuselage, wings, and tail, as well as determine the best materials, all while accounting for the cost of the materials.

The forces that the landing gear experience will be a critical element of the team's design. This design component is affected by the speed of the aircraft and the weight of the aircraft primarily. The landing gear forces are going to be minimized by the design process while making the landing gear as lightweight and compact as possible. The team wants to minimize the drag on the landing gear as well. These were the considered factors in the Pugh Chart and Decision Matrix. Landing gear were ranked on their ability to absorb the impact forces, minimize weights, reduce drag, and potential to create a different angle of attack at takeoff. These requirements were based on the customer/engineering requirements in section 2 of this report. Weight, speed, takeoff/landing distance, and drag were the key considerations.

5.2 Rationale for Design Selection

Depicted below in Figure 29 and Figure 30 are a basic frame of the current design for the aircraft and a cutout of the mass properties of the frame. This frame is based on the CAD model shown above and assumes the use of a 1060 aluminum alloy and is made using ½ in. pipe in the weldments tool since that tool works with standardized stocks in mind (the team would have used round tubing instead of pipe if it were an option in weldments. The mass properties show that this frame is about 7.5lbs., about half of the desired 15lbs. If this type of frame were to be created using the other considered designs, the frame would likely be heavier, leaving less room for the weight of other components, showing that the current design is likely the best in terms of weight.

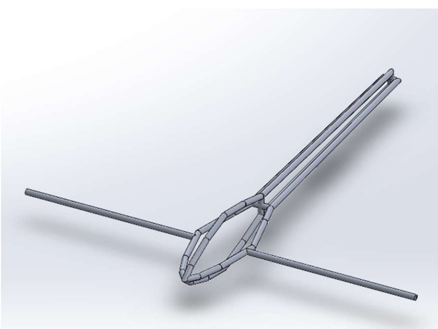
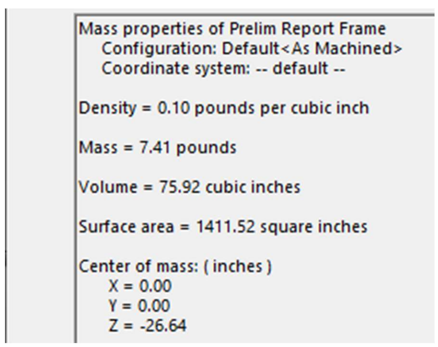


Figure 30: Rough Frame Model



Mass properties of Prelim Report Frame
Configuration: Default<As Machined>
Coordinate system: -- default --

Density = 0.10 pounds per cubic inch

Mass = 7.41 pounds

Volume = 75.92 cubic inches

Surface area = 1411.52 square inches

Center of mass: (inches)
X = 0.00
Y = 0.00
Z = -26.64

Figure 29: Mass Properties of Frame Model

The landing gear for both aircraft were deemed to be within the acceptable parameters. The enlarged belly design would use the rear steer for the landing gear. The glider design would use the tail dragger landing gear. After performing an approximate calculation using the momentum equations of dynamics, the maximum force experienced would be expected to be 194 lbf, assuming landing results in a 10% change in velocity on impact with the ground. The calculations are available in Appendix F for review. With our max weight of 18 lbs. and max velocity of 22.5 MPH, both landing gear systems would be able to support the worst-case impact forces. This is important because it means that because the two-wing mounted landing gear would be the same for both designs, and if the team uses the shock absorbing landing gear, assuming it extends the impact durations from 0.01s to 0.1s, the force will become 19.4 lbf, which is approximately the same as the static loading, so both designs would easily be able to handle the impact forces. This resulted in the glider design scoring slightly higher in categories affected by the landing gear because of the tail dragger system allowing for modification of angle of attack on the ground, resulting in better takeoff characteristics. Otherwise, the two systems of landing gear were determined to be equally effective.

For the wing design, lift and drag coefficients were calculated at a low velocity and Reynolds number. It's important to note that these numbers were calculated for a NACA 0004 airfoil. Currently, the team is analyzing a NACA 0010 airfoil instead. The lift and drag coefficients are yet to be calculated. However, the methodology of calculating these values are the same.

Figure 31: Airfoil dimensioning

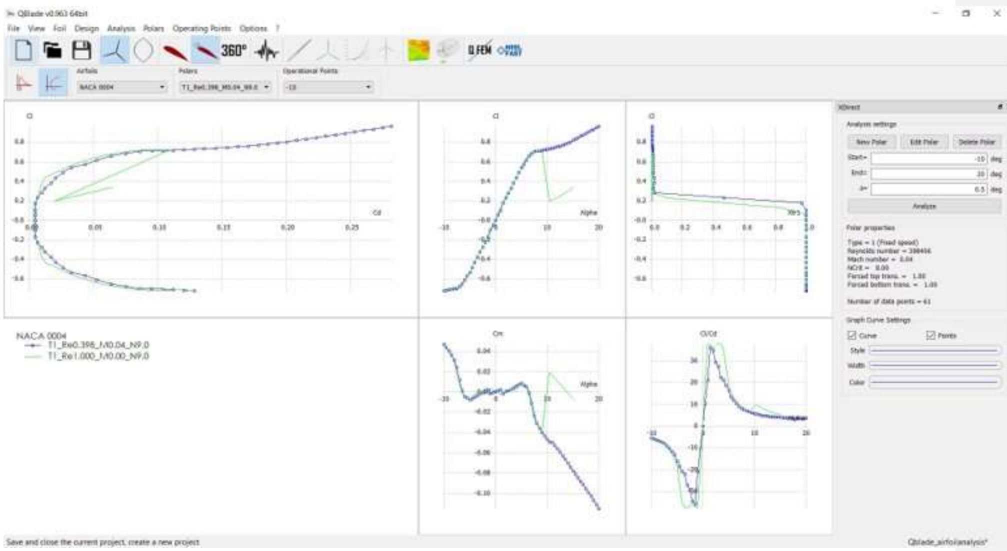


Figure 32: Lift and drag coefficients - Simulated

After the simulation, the team realized that a NACA 0004 airfoil is too thin to be used on our design. Therefore, a thicker airfoil series was explored. This led the team towards analyzing and tweaking a NACA 0010 series airfoil instead.

5.3 Additional back of the envelope calculation

The electrical calculations just do not seem to fit in other section and due to this there is this new section to house the back of the envelope calculation for propellers and electronic requirements. The reason that these do not fit in to the technical selection criteria is that they are off the shelf parts and the team has options as to which ones to pick but not really option at to how to change them as they are store bought components.

When analyzing electronical system of the aircraft there are a lot of rules in place from the competition hand book for example we must use a power limiter of 1000W [2]. There is a specific one and there is only one, so this part is required and predetermined. However, the team needs to figure out how big of a motor to go with and that is why this section was created.

The motor selection is the only thing the wattage effects, so to determine what is the best motor we need to do some calculation. In the table below I have three different motors with three different Kv values and ultimately the Kv is how motors are sold. Kv values are not helpful in this application however so using data from Horizontal Hobbies, we are able to get the amperage of the motor during normal load and burst mode. Burst mode is simply full throttle.

Table 1: Table for Kv of motor compared to wattage

Power Outrunner Motors	Input Watts	Idle Current	Continuous Current	Max Burst current
Power10BL,1100Kv	375W	2.10A	30A	38A
Power15BL,950Kv	425W	2.00A	34A	42A
Power25BL,870Kv	550W	2.40A	32A	44A
Power32BL,770Kv	700W	2.40A	42A	60A
Power46BL,670Kv	800W	3.90A	40A	55A
Power60BL,400Kv	1200W	2.70A	40A	60A

From the data in the table above you can see that as the Kv value decreases the current increases. There is also the correlation that as the Kv decreases the wattage goes up and this is important as the competition does not allow use to go over 1000 watts or power.

What does this all mean? The team could go with a smaller less wattage motor, but this is a downside as the motor would not have the torque to turn the propeller. The team could go to the opposite side of the spectrum and get a motor that has a low Kv and high wattage, but this too is a downside as this decease the rpm of the engine. For our application we want to almost max out the wattage parameter but not quiet as we want the most rpm out of the motor as possible while making sure we have enough torque to run a propeller that is larger than the manufacturer recommendation. This does two things for use, it gets a really high rpm out of the motor and get a lot of air moving due to the large propeller and this is much better than the other two option. As of right now the team is looking at the 670 Kv motor as the burst wattage is above the 1000 W limit.

With regards to the other components, the servos, ESC, and receiver do not have any other parameters on them. However, the battery does. For the regular class the battery must at a minimum have 6 cells, 22.2 volts, and 3000mAh and 25c. While the team can go with an oversized battery as of right now the team does not see any reason to go this route as all it will do is at weight to the aircraft that could be used for payload. As of right now we will go with the minimum batter back which will give ample time complete the flight with power to spare as we are only allowed 120 seconds of flight time.

Now that we have a motor that is decently specked out, we can turn our attention to the propeller and start working on size as well as what our thrust forces on the aircraft are going to be. In this table below shows some of the preliminary calculations to how fast the aircraft could be, as well as the max thrust that there can be.

Table 2: Propeller calculations

Diameter	Pitch	
10	4	
870	Kv	
22.2	Volts	
19314	rpm	
44	Max amps	
976.8	Watts	

Possible speed of aircraft		
Prop Diameter	10	
Engine RPM	19314	RPM
Tip Speed	606767.2	in/min
Tip Speed	574.5902	mph
Outside temp	32	°F
	491.67	°R
Speed of sounds in MPH	1086.825	ft/s
	740.8485	mph
Prop Tip speed in Mach	0.775584	Max performance = .8-.92
Theoretical speed Calculator		
Pitch	4	inch
Engine RPH	1158840	Revolutions per Hours
Inches per Hour	4635360	IPH
	73.15909	Miles per hour
Aircraft Drag	0.75	
Forward Velocity	54.87107	mph
True airspeed	47.68166	knots
Airspeed in ft/s	80.47758	ft/s
Barometer (inHg)	29.92	
Pressure	14.69548	psi
Density	0.0807	lbm/ft^3

From the data in the table with a prop of 10x4 and a motor of 870 Kv and an estimated drag of 25% on the aircraft the max speed comes out to roughly 54 miles per hour. This value seems to be in range for other documentation the team has seen. This number is also important as it allows the team to get more accurate Reynolds numbers as well as time it will take to get airborne.

6 References

[1] N. F. 2. Capstone, "NAU SAE AERO Regular 2019-2020," [Online]. Available: https://www.ceias.nau.edu/capstone/projects/ME/2019/19F12_SAEAeroRegular/index.html. [Accessed 31 Jan 2021].

[2] "SEA Aero Design - Rules," SAE Aero Design, [Online]. Available: https://www.saeaerodesign.com/cdsweb/gen/DocumentResources.aspx. [Accessed 24 Jun 2021].

[3] R. C. Nelson, "Static Stability and Control," in *Flight Stability and Automatic Control*, Singapore, McGraw-Hill, 2010, pp. 35-95.

[4] F. Nicolosi, P. D. Vecchia, D. Ciliberti and V. Cusati, "Fuselage Aerodynamic Prediction Methods," *Elsevier,* vol. 55, pp. 332-343, 2016.

[5] B. S. Kidane, "Design and Analysis of LIght GA Aircraft for Agricultural Purpose," University of Turkish Aeronautical Association, Turkey, 2016.

[6] T. L. Htet, "Structural Analysis and Topology Design Optimization of Load Bearing Elements of Aircraft Fuselage Structure," *IOP COnference Series: Materials Science and Engineering,* vol. 1, pp. 1-7, 2020.

[7] S. Gudmundsson, "The Anatomy of the Fuselage," in *General Aviation Aircraft Design: Applied Methods*, Waltham, MA, Elsevier, 2014, pp. 521-545.

[8] "Control Surfaces," *Science Direct,* 2012.

[9] Meng Zhang, A.Y.C. Nee, "Landing Gear," *Science Direct ,* 2016.

[10] D.Carr, "Prototype Landing Fear Conceptual and Embodiment Designs," *Ideal Exchange.*

[11] P. Sonowal, S. Das, D. K. Mishra, and K. M. Pandey, " Stress analysis of Landing gear of light Unmanned Aerial Vehicle," *Journal of Physics: Conference Series,* vol. 1455, p. 012019, 2020.

[12] G. Staples, Electric RC aircraft Guy , 16 July 2013. [Online]. Available: https://www.electricrcaircraftguy.com/2013/09/propeller-static-dynamic-thrust-equation.html. [Accessed 20 Febuary 2021].

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

[14] Omkar Bhosle Rohit Varpe Mahesh Pula, "Radio Controlled Airplane," *International Journal for Scientific Research & Development|,* vol. 3, no. 2, pp. 89-94, 2015.

[15] E. V.-S. a. J. G.-G. José Carlos Gamazo-Real, "Position and Speed Control of Brushless DC Motors Using Sensorless Techniques and Application Trends," *MDPI,* vol. 10, no. 7, pp. 6901-6947, 2010.

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

[17] Skyjacks Team 045, "SAE AERO," NAU Capstone Team , Flagstaff , 2019.

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

[19] T. Pallini, "Airbus's massive new cargo plane that looks like a whale is now fully operational," Business insider, 15 January 2020. [Online]. Available: https://www.businessinsider.com/airbus-beluga-xl-cargo-plane-a330-2018-7. [Accessed 2 March 2020].

[20] T. MOYNIHAN, "What It's Like to Fly—And Stall—In the Icon A5 Plane," Wired, 28 09 2015. [Online]. Available: https://www.wired.com/2015/09/like-flyand-stallin-icon-a5-plane/. [Accessed 2 March 2021].

[21] B. B. F. Staff, "C5 Galaxy Delivers Apache Helicopters to Europe," Blog before flight , 23 February 2017. [Online]. Available: https://www.blogbeforeflight.net/2017/02/c5-delivers-apache-helicopters-to-europe.html. [Accessed 4 March 2021].

[22] J. Trevithick, "Air Force Now Wants to Get Sidelined C-5 Galaxy Transports Back In the Air," The Drive , 31 May 2017. [Online]. Available: https://www.thedrive.com/the-war-zone/11014/air-force-now-wants-to-get-sidelined-c-5-galaxy-transports-back-in-the-air. [Accessed 28 February 2021].

[23] J. D. Anderson, "Fundamentals of Aerodynamics," in *Fundamentals of Aerodynamics*, Mcgraw-Hill Education, 2016, pp. 19-33.

[24] J. D. Anderson, "Fundamentals of Aerodynamics," Mcgraw-Hill Education , 2016, pp. 321-413.

[25] P. P. Polentz, "Comparison of the Aerodynamic Characteristics of the NACA 0010 and 0010-64 Airfoil Sections at High Subsonic Mach Numbers," UNT Libraries Government Documents Department , 1949.

[26] Anderson, "sciencedirect.com," 2016. [Online]. Available: https://www.sciencedirect.com/topics/engineering/flight-control-systems. [Accessed 01 02 2021].

7 APPENDICES

7.1 Appendix A: House of Quality

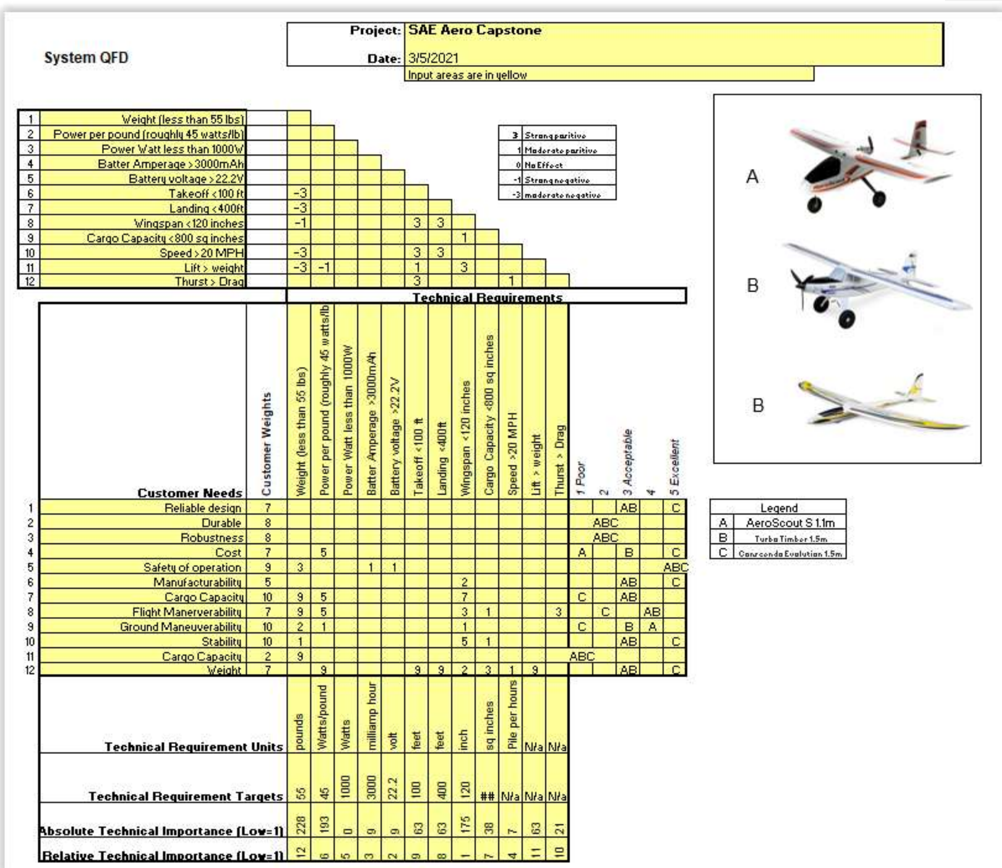


Figure 33: House of Quality

7.2 Appendix B: Design Concepts

Here are the three design concepts that the team was considering for the decision matrix

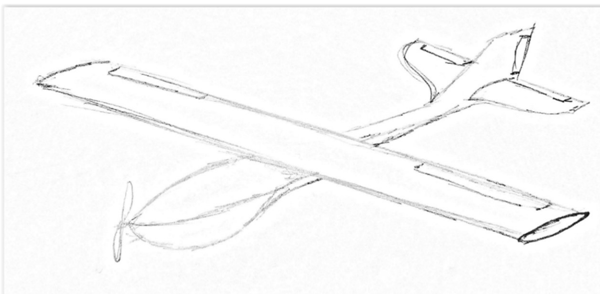


Figure 38:Light GA Design

Figure 34: First design concept

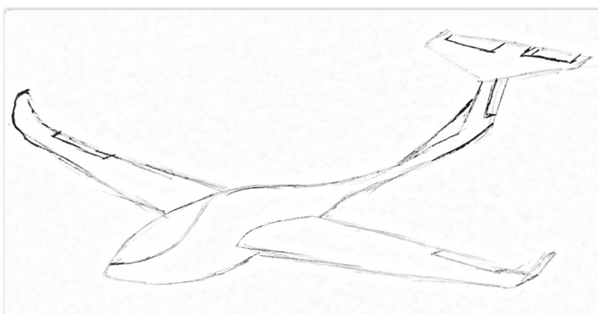


Figure 37: Second design concept

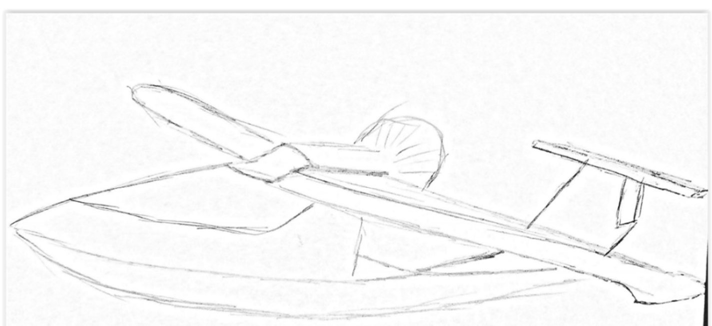


Figure 36: Third design concept

Figure 35:Icon A5 Inpsired Design

7.3 Appendix C: Budgeting

Here is the Teams budget and while there is not much in here these are to cost allications we are planing on appling to the different catagoires of our projcet.

Table 3: Budget

Total Budget	$1,500
60% Electrical Components	($900)
22.5% Fuselage and Wings	($337.50)
5% Landing gear	($75)
12.5% Prototyping	($187.50)

7.4 Appendix D: Pugh Chart

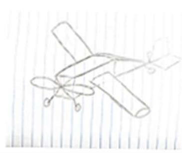
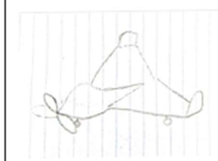
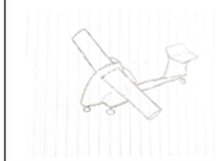
	Design 1	Design 2	**Design 3 (Datum)**	Design 4	Design 5
Criteria					
Reliability	+	+	[redacted]	-	-
Durability	+	+		-	-
Cost	-	-		-	+
Safety	+	+		+	-
Manufacturability	+	-		-	+
Flight Maneuverability	-	+		+	+
Ground Maneuverability	+	+		-	-
Lightweight	-	+		+	+
Stability	+	+		+	+
Cargo Capacity	+	+		+	+
Σ+	7	8		5	6
Σ-	3	2		5	4
ΣS	0	0		0	0

Figure 40: Pugh chat

7.5 Appendix E: Decision Matrix

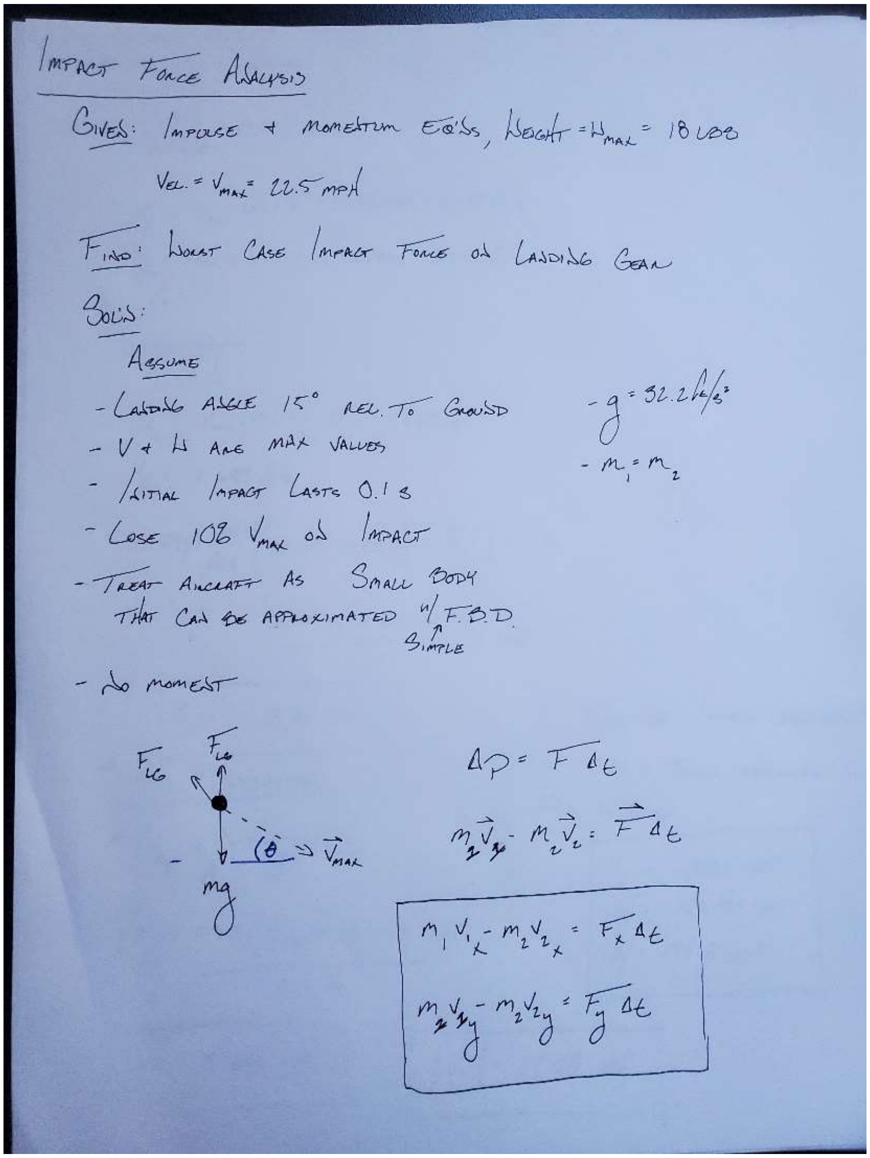
Design Matrix for SAE AERO

Criteria	Discription	Weight	Pushing Prop	Enlarged Belly for oversized cargo	Glider Design	
These are requirements from the competition rules. Ultimately to make the customer happy we need to perform well, and we do that by getting a good flight score at competition.	This better explains the criteria	How important is each criteria				
Wing span (under 10 ft)	Want to decrease for better score in competition	10	6	4	4	100
Increase Payload (max 55lbs)	The more payload we can carry the better the score	4	8	6	6	40
Soccer ball Payload	The more soccer balls we can carry the better our score	3	4	8	8	30
Overall Weight (airframe weight - max 55lbs)	The lighter the airframe to more cargo we can carry, and the better out flight score will be	7	1	6	7	70
Taking off (less than 100 ft)	Probability that we can get this aircraft off the ground in less than 100 ft	10	4	4	4	100
Speed	While we will not be able to make something fast a sleek design will increase speed	6	9	3	7	60
Cargo Bay	The small our cargo bay the better our flight score	10	5	9	9	100
Easy of Construction	We plan on crashing more than once so a simple design that is easy to mass produce is more important than a complicated shape	8	3	5	9	80
Power (thrust)	Which design do we think we will get the most power out of i.e. effecentcy of the propeller	9	5	6	7	90
		Weighted average	67.16%	76.12%	91.04%	670

Score is defined as a value 1 to 10 on how well it does in this criteria 10 being the best 1 being the worst
Weighted average is defined as a mathmatical formula to illistrate the most important design alterniternative
It will be scored as =(score * weight)/(total score)

Figure 41: Decision Matrix

7.6 Appendix F: Calculations



Impact Force Analysis

Given: Impulse + Momentum Eq's, Weight = W_{max} = 18 lbs

Vel. = V_{max} = 22.5 mph

Find: Worst Case Impact Force on Landing Gear

Sol'n:

Assume

- Landing Angle 15° rel. to Ground
- V + W are max values
- Initial Impact Lasts 0.1 s
- Lose 10% V_{max} on Impact
- Treat Aircraft as Small Body that can be approximated w/ Simple F.B.D.
- No moment
- $g = 32.2\ ft/s^2$
- $m_1 = m_2$

F_{LG}, F_{LG}, θ, $\vec{V}_{max}$, mg

$$\Delta p = F \Delta t$$

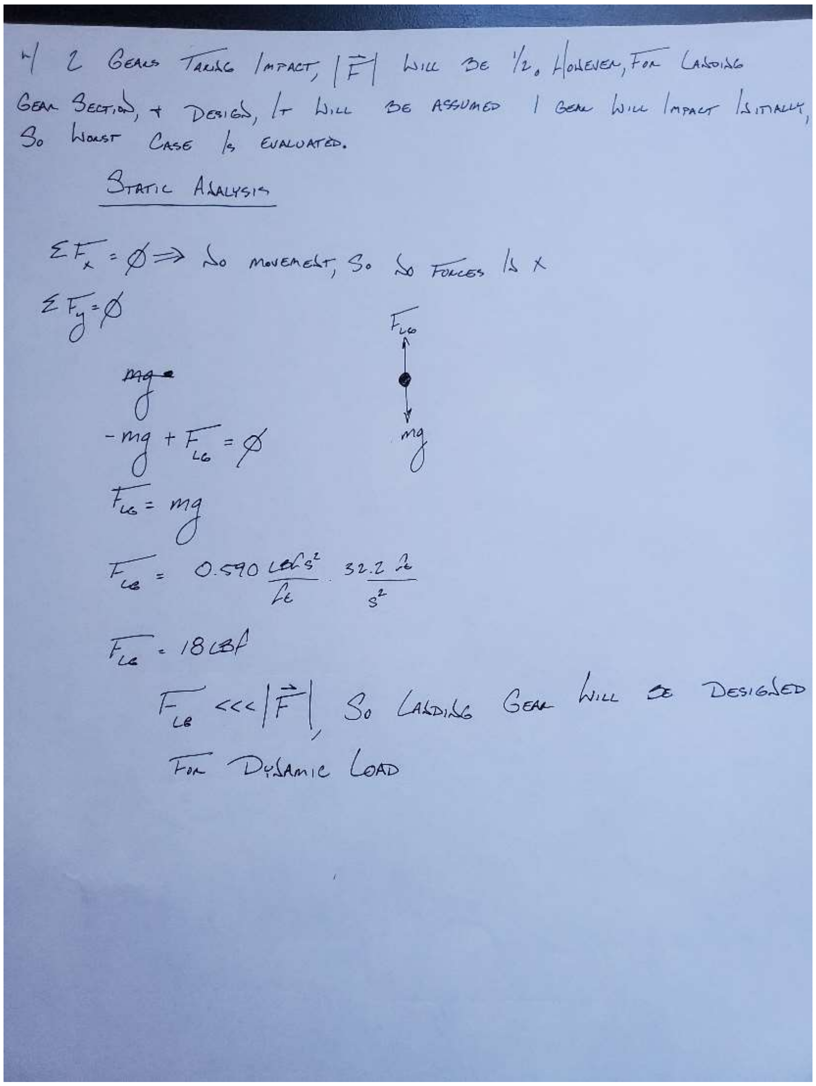
$$m_1 \vec{v}_1 - m_2 \vec{v}_2 = \vec{F} \Delta t$$

$$m_1 v_{1_x} - m_2 v_{2_x} = F_x \Delta t$$

$$m_1 v_{1_y} - m_2 v_{2_y} = F_y \Delta t$$

Figure 42: Landing Gear calculations

Appendix F: Calculations Continued



W/ 2 GEARS TAKING IMPACT, $|\vec{F}|$ WILL BE 1/2, HOWEVER, FOR LANDING GEAR SECTION + DESIGN, IT WILL BE ASSUMED 1 GEAR WILL IMPACT INITIALLY, SO WORST CASE IS EVALUATED.

STATIC ANALYSIS

$\Sigma F_x = \emptyset \Rightarrow$ NO MOVEMENT, SO NO FORCES IN X

$\Sigma F_y = \emptyset$

$$-mg + F_{LG} = \emptyset$$

$$F_{LG} = mg$$

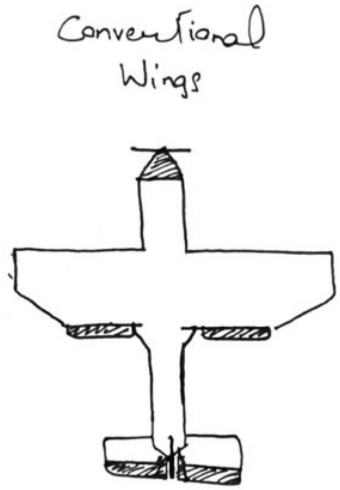
$$F_{LG} = 0.590 \frac{LBf\,s^2}{ft} \cdot 32.2 \frac{ft}{s^2}$$

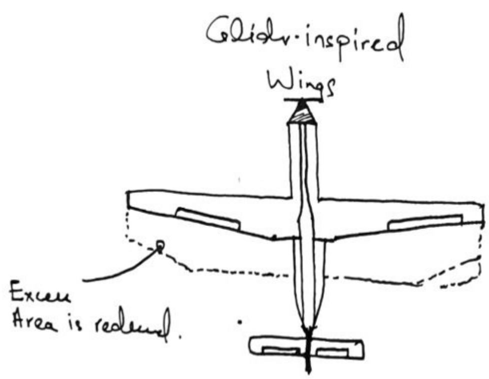
$$F_{LG} = 18\,LBf$$

$F_{LG} <<< |\vec{F}|$, SO LANDING GEAR WILL BE DESIGNED FOR DYNAMIC LOAD

Figure 43: Landing Gear calculation Continued

7.7 Appendix G: Wind Area Drawings





7.8 Appendix H: Reynold number calculations

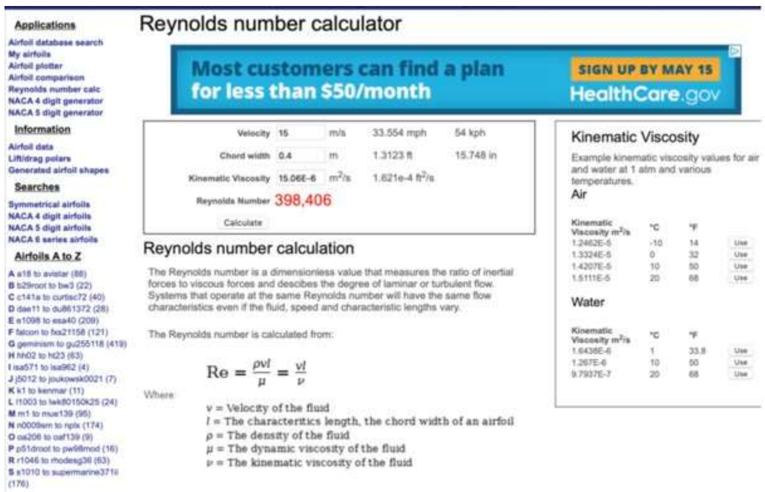


Figure 44: Mach and Reynolds number calculations

7.9 Appendix I: Wing design modifications

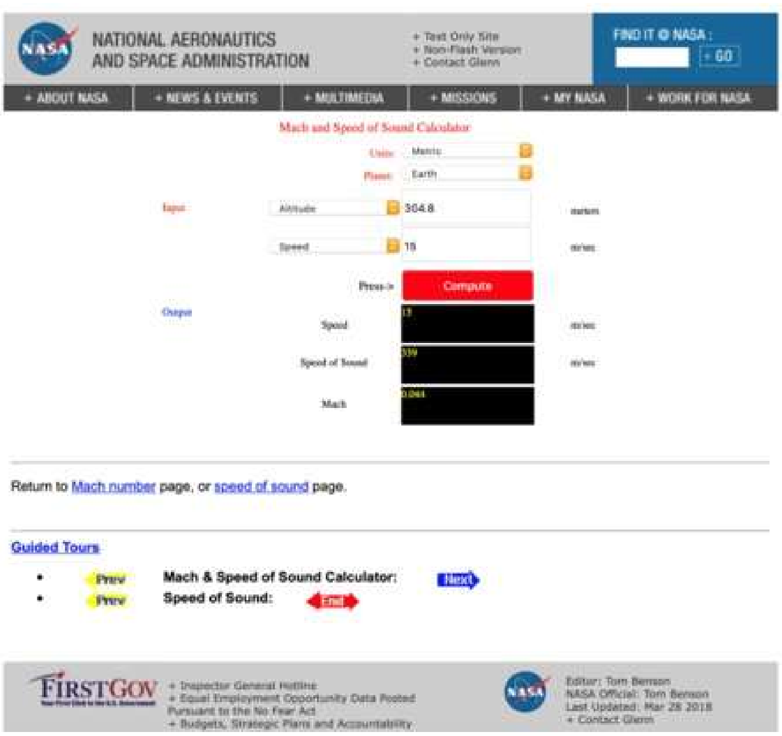


Figure 45: Wing design modifications