

Memorandum

To: Dr. John Tester

From: The Wright Stuff

Date: December 7, 2012

Re: Project Proposal

The team wants to thank you for your support of our team to participate in the SAE Aero Design Competition for our senior design project. This memo summarizes our preliminary design proposal following the end of the first semester of senior design. Currently the team has wrapped up the preliminary analysis for the aircraft design. The main approach for analysis at this point has been to identify all of the unknowns and setup the equations for them. A preliminary velocity for calculations has been chosen based upon averages from previous teams. The team is awaiting results from propulsion testing to determine the operational velocity of our aircraft. The analysis will be refined as the velocity of the aircraft is determined. One of the key components depending on propulsion analysis is the airfoil. Based upon our assumed aircraft velocity the group selected various airfoils to analyze and refine their geometries for the aircraft. The team is pursuing rapid prototyping aircraft components to help with the accuracy of the manufactured parts. The team has hypothesized that rapid prototyped parts would help make our aerodynamic analysis more accurate which would help us be more competitive against other teams. Our team is currently developing a static thrust test stand to determine the thrust and velocity of various propeller configurations on the motor. After this testing the refined airspeed will help refine our preliminary analysis. You can find a detailed report of our analysis and preliminary design on our team website (<http://www.cefn.s.nau.edu/interdisciplinary/d4p/EGR486/ME/13-Projects/TheWrightStuff/Home.html>).

Again the team would like to thank you for your support and help with the project thus far. If you have any questions regarding our current design or approach please let us know.

Cheers,

The Wright Stuff

SAE AERO DESIGN WEST

“THE WRIGHT STUFF”

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Team 10

FINAL DESIGN

REVIEW AND PROPOSAL

Document

*Submitted towards partial fulfillment of the requirements for
Mechanical Engineering Design – Fall 2012*



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1. Introduction

This team has elected to participate in the Society of Automotive Engineers' Aero Design Competition (SAE ADC) for our 2012 Capstone project. As stated by the Brian A. Czapor, the SAE Rules Committee Chair, the competition provides students with an opportunity to demonstrate their ability to apply engineering knowledge and leverage towards their career goals. For this competition, the team will design, build, and test a remote-controlled aircraft with the intent being to accurately predict a maximum payload.

For the students, this project represents the culmination of our undergraduate careers and gives us exposure to the type of situations seen in the workplace. This competition is a test of analytical, design, teaming, and communication skills. This document provides an overview of specific needs this team has identified to successfully complete this project.

2. Needs Identification

For a nontraditional project such as this, we are constrained less by customer requirements than we are by project rules and guidelines. As this team has not been tasked with a customer's specific request, the major needs for our task have come from the generalized requirements laid out by the SAE ADC.

Per SAE requirements and group consensus, we realize that at present, current remote- controlled aircraft designs are not capable of carrying sufficient payload.

3. Problem Statement

Through exquisite engineering, the goal for the SAE Aero Design project is to design, report and manufacture an RC aircraft capable of carrying a maximized theoretical payload in order to win the competition.

3.1. Goal

Design a model aircraft to meet or exceed a 25lb payload and accurately predict this performance through solid proof of concept.

3.2. Objectives

The team has developed objectives based upon its goals, each in terms of quantifiable properties. Table 1, shown on the following page, displays these objectives along with the basis and unit of measurement.

Table 1: Table of Objectives

Objective	Basis for	Units
Sponsorship/Cost	Money	\$
Maximum	Weight	lb
Minimal Weight of	Weight	lb
Aircraft	Turning radius	ft
Aircraft Take Off	Distance	ft
Aircraft Landing	Distance	ft
Safety/ Controllability	Injuries	N/A
Stability	Center of gravity	ft
Crash Durability	Broken parts	\$
Payload	Volume/time to	Ft ³ /s
Payload	Lift	lb
Propulsion	Thrust	lb

3.3. Constraints

Mission constraints

- Aircraft must accomplish a successful takeoff in at least 3 minutes.
- Aircraft must lift from the ground within a take-off distance of 200 ft (61m).
- Aircraft may not be pushed by helper during take-off other than engine run-up
- Aircraft must remain intact during takeoff and landing
- Aircraft must successfully complete one 360 degree circuit of the field
- Aircraft must touch down within the designated landing zone and remain on the runway between the landing limits of 400 ft (122m)
- Aircraft must be controllable in flight

Aircraft Class Constraints

- No lighter than air or rotary wing aircraft are allowed
- Aircraft shall not exceed a combined length, width and height of 255 inches
- Aircraft may not weight more than sixty-five (65) pounds with payload and fuel

- Aircraft must be identifiable by displaying team number on both the top and bottom of the wing, and on both sides of the vertical stabilizer or other vertical surface in 4 inch numbers
- Aircraft must clearly display the university name on the wings or fuselage.
- Aircraft engine must be unmodified O.S 61FX with E-4010 muffler or the Magnum XLS-61A
- Aircraft engine may not have any muffler extensions or headers
- Aircraft may not have a fuel pump
- Aircraft may make use of gear boxes, drives and shaft as long as a one to one propeller to engine RPM is maintained
- Aircraft fuel tank must be accessible to determine contents during inspections and may be pressurized by a stock fitting on the engine muffler only.
- Aircraft may not have any type of gyroscopic assist
- Aircraft payload must consist of a support assembly and payload plates. All payload carried for score must be carried within the cargo bay. The support assembly must be constructed so as to retain the weights as a homogeneous mass.
- Aircraft payload must be secured to the airframe to ensure the payload will not shift or come loose in flight
- Aircraft design must be capable of loading and securing payload in less than 1 minute
- Aircraft design must be capable of unloading the payload in less than 1 minute
- Aircraft is required to use a 2.5 GHz radio
- Aircraft battery pack may be no less than one thousand mah capacity
- Aircraft must utilize either a spinner or a rounded safety nut

Material Constraints

- Aircraft may not use metal propellers
- Aircraft may not contain any lead
- Aircraft may not use any Fiber-Reinforced Plastic (FRP) except in the use of a commercially available engine mount and propeller.

3.4. Test Environment

The competition will be held in Van Nuys, California on April 12-14, 2013. According to wunderground.com, historically, Van Nuys has a mean temperature of 50 degrees Fahrenheit, barometric pressure of 29.86 inches of Mercury and max wind speeds of 23 mph. This team as noted that Phoenix, Arizona holds similar air densities as the competition location and will be the most comparable site for testing.

4. Design Choices

4.1. Criteria and Criteria Tree

Establishing the prime objectives in a project is essential to success. Project objectives help provide an outline to follow by breaking down each aspect into specific criteria. Many of the project objectives are chosen to best fit the project guidelines listed by SAE ADC. To achieve a high maximum payload, a wing must be properly designed. The accurate prediction of the max payload can only be achieved by executing correct engineering analysis. As seen below, Table 2 has a detailed list of the project objectives along with the correlating criteria.

Table 2: Customer Objectives vs. Engineering Criteria

Objective	Criteria
Minimal Weight of Aircraft	Material/Design
Aircraft Control	Maneuverability
Safe Landing	Landing Gear
Propulsion	Motor and Propeller
Aircraft Shipment	Transportation
Crash Durability	Material/Design
Part Removal and Replacement	Aircraft Design
Payload Prediction Accuracy	Engineering Analysis
Sponsorship	Cost

The objectives for the project can also be broken down into a detailed design criteria tree. This criteria tree can be in figure 1 below.

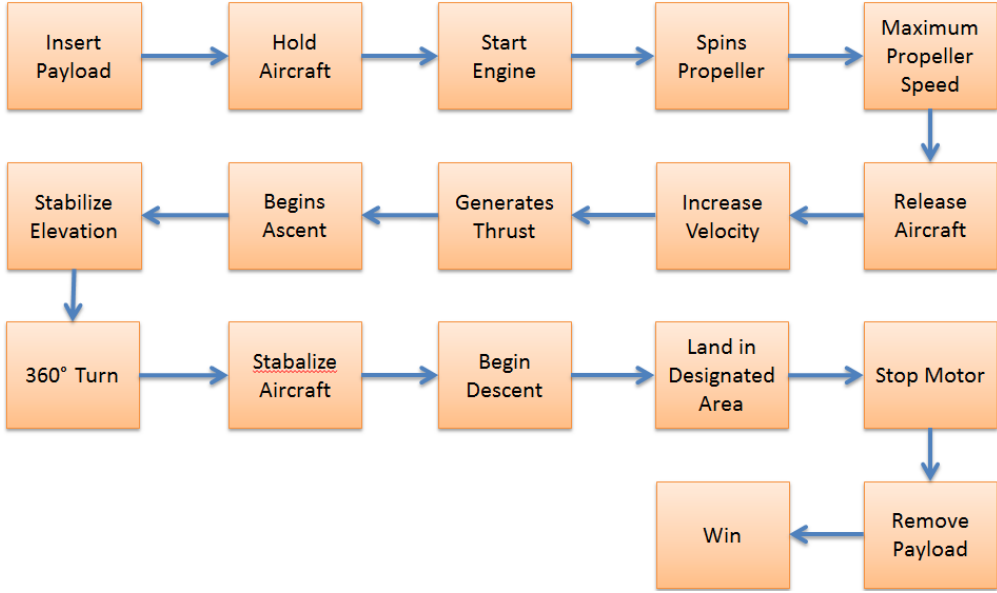


Figure 1: Aircraft Design Criteria Tree

4.2. Functional Diagram

Outlining of a project can also be assisted by detailing a step-by-step process of the test environment. Figure 2 below shows a function diagram used of the competition process expected. Each step represents a key component needed to complete a successful run within the competition.

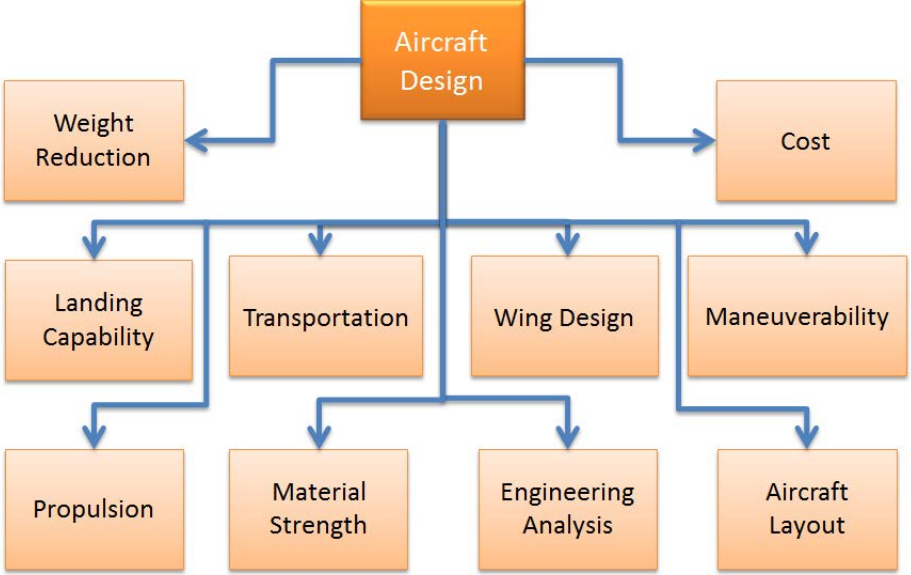


Figure 2: Functional Analysis Diagram

4.3. Quality Function Deployment with House of Quality

In order to succeed in the stated goal, it will be essential for the team to correlate the requirements laid out by the customer with concrete engineering requirements. Table 3 below presents the fundamental engineering requirements compiled for this purpose. Here, the yield strength is influential in fulfilling nearly all the customer requirements, as the aircraft needs to withstand all applied loads. The location of the center of gravity affects the ability of the aircraft to maneuver and land, thus enhancing its stability. Lift and drag considerations are fundamental to nearly all requirements, especially in the objective of carrying load. In order to generate lift and achieve takeoff, the aircraft requires sufficient thrust. The weight of the aircraft interacts directly with its load-bearing ability and its cost. The turning radius of the aircraft allows it to maneuver and remain stable. Finally, a low-cost product constitutes an inexpensive design.

Table 3: Quality Function Deployment

		Engineering Requirements						
		Yield Strength of	Location of Center of	Aerodynamic Lift and				
Customer Requirements		X		X	X	X		
			X	X			X	
		X		X	X			
		X	X	X				
		X	X	X	X		X	
				X				
		X						X
		X		X		X		X
	Units	psi	ft	lb	lb	lb	ft	\$

In Figure 3 below, correlations between key engineering requirements are drawn. Here, the team has decided that the yield strength of aircraft components positively correlates with both the aircraft weight and its cost. An accurate location of the center of gravity leads to the generation of aerodynamic lift and an adequate turning radius. Effective production of lift and reduction of drag positively affects the aircraft's turning radius, negatively correlates with its weight, and depends on thrust in a more complicated sense.

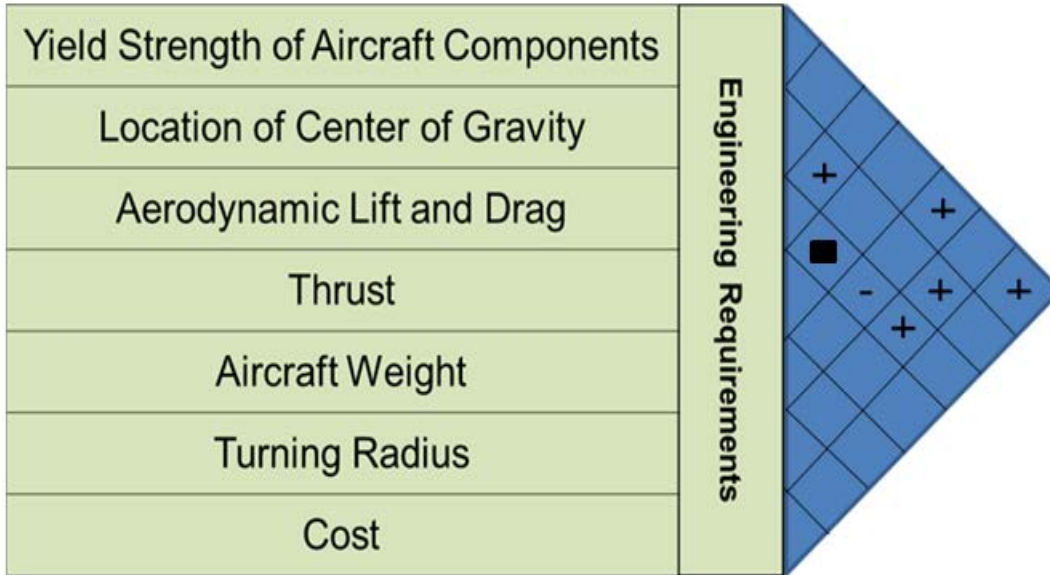


Figure 3: House of Quality

5. Configuration Selection and Analysis

The technology of high lift aircraft design is already well-understood. Therefore, this team will not seek to “reinvent the wheel” by developing a new design from scratch. Instead, the objective for this team is to optimize the system through a series of selection and configuration design processes. The success of the final product will ultimately be the result of sound analysis and precision manufacturing.

5.1. Airfoil Planform

The airfoil planform is a fundamental design consideration because it significantly impacts the performance characteristics of the aircraft in areas such as lift, drag, ease of manufacture, weight, and stability. In this category, five designs were considered, as

described below. The decision-making process constituted a decision matrix which compared the strengths and weaknesses of each design.

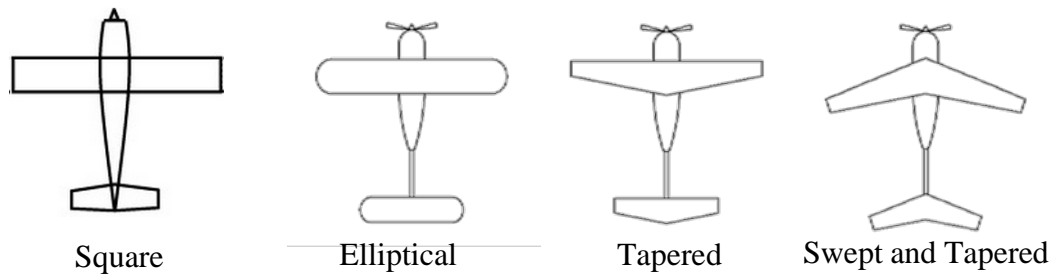


Figure 1: Common Planforms

5.1.1 Square

The square planform is advantageous because it has the largest total area, and therefore can generate the most lift. Also this type of wing is easiest to manufacture because the cross-section is uniform for the whole plane. The downsides inherent in this type of wing are the large weight and considerable induced drag due to vortex generation at the wing tips.

5.1.2 Elliptical

The major advantage to an elliptical planform is induced drag reduction, accomplished through curved wing tips. The major downside to this approach, however, is that such curved wing tips are very difficult to manufacture.

5.1.3 Tapered

Tapered wings offer similar high lift and ease of manufacture advantages of the square

planform while also reducing the induced drag. Moreover, the tapered wings perform consistently well in all categories.

5.1.4 Swept

The main advantage to a swept planform is the increased stability that results from a tail-up moment generated as the lift contributions of the wing are spread backwards toward the tail. The disadvantage of this resulting moment is that the wings must be built with more strength to withstand it. This causes an increase in weight and makes the design more difficult to manufacture.

5.1.5 Swept and Tapered

Swept and tapered wings are the industry standard for high lift aircraft today. The foremost advantages of this approach are stability and induced drag reduction. However, the difficulty of manufacture in this wing type is great, which makes the swept and tapered planform impractical for this project.

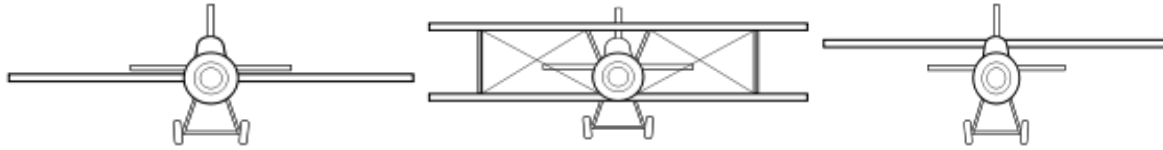
Table 4: Airfoil Planform Decision Matrix

Concept	Criteria					Score
	Lift	Drag	Ease of Manufacture	Weight	Stability	
Square	1	4	1	4	3	13
Tapered	3	2	2	2	3	12
Elliptical	5	1	5	2	3	16
Swept	1	4	4	4	1	14
Swept & Tapered	3	2	5	3	1	14

This decision matrix shows the tapered wing planform as the optimal choice, with the square planform a close second option. Further analysis throughout the design process, the group will apply specific calculations in order to make a final decision between these two options.

5.2. Wing Configuration

The wing configuration and layout is a crucial aspect of the design of the aircraft. It defines the location of the wing relative to the aircraft's fuselage. The key constraints used in finalizing the type of wing configuration include: lift, drag, manufacturability, weight, and maneuverability. The types of wing configurations we have decided upon from many of options comprise of a single high wing, single mid wing and a biplane. Refer to Figure 2 for a representation of these types of configurations.



Single Mid

Double

Single High

Figure 2: Wing Configurations

5.2.1 Double

There are many advantages with the use of a double. First, the double wing consists of two wing sets, highly increasing the lift of the aircraft which plays a crucial part in this design project. Second, because the double wing offers the large amounts of lift and travels at lower velocities, it provides tight maneuverability. However, our design does not require very much maneuverability. Given the advantages of a double wing design, it is found that the disadvantages are greater when compared to the other configurations. The multiple parts of the biplane result in large amounts of drag, weight and cost. Refer to the wing configuration decision matrix in Table 2.

5.2.2 Single Mid Wing

The single mid wing provides great characteristics in lift, drag, weight and maneuverability; however, the designing and manufacturing of the wing into the fuselage would be very challenging especially when compared to the assembling of the single high wing to the fuselage.

5.2.3 Single High Wing

This configuration allows the manufacture of a complete wing and easy assembly to the fuselage with a set of brackets. The use of the single high wing will also create a greater space within the fuselage for adding in payload in addition to having more room for maintaining the aircraft.

Table 2: Wing Configuration Decision Matrix

Concept	Criteria					Score
	Lift	Drag	Ease of Manufacture	Weight	Maneuverability	
Single High	5	1	1	1	3	11
Single Mid	4	2	4	3	3	16
Double	1	5	5	5	1	17

This decision matrix indicates that the single high wing configuration is the best for our system. As a result, the group plans to pursue this configuration as a final design.

5.3. Tail Configuration

The tail configuration and layout is an essential to the performance of the aircraft. It defines the location of the elevator on the empennage relative to the location of the main wings location. The fundamental constraints used in finalizing the type of tail configuration include: lift, drag, manufacturability, weight, and stability. The types of tail configurations we have decided upon include a T-tail, no tail and a conventional tail. Refer to Figure 3 for representations of these configurations.

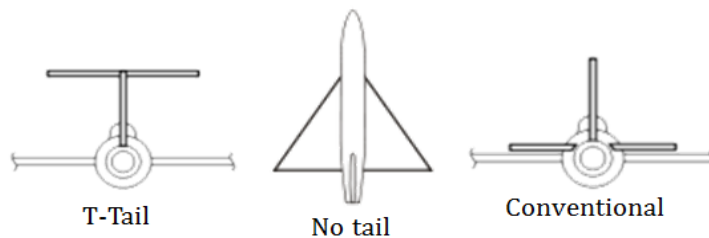


Figure 3: Tail Configurations

5.3.1 No Tail

A design which does not utilize a tail will suffer in terms of stability, since the tail allows the aircraft to maintain the optimal angle of attack. The omission of a tail, however, could be advantageous because it means the group would have one less component design, enhancing the ease of manufacture.

5.3.2 T-Tail

The T-Tail offers a larger moment arm than a conventional tail. This increased moment helps the aircraft to be more stable by keeping it level. The drawback to selecting the T-Tail is that it is more difficult to manufacture and it adds weight, as additional structural support is required to locate the airfoils above the central plane of the aircraft.

5.3.3 Conventional

The conventional tail is advantageous because it increases the lift of the overall aircraft and reinforces its stability through the addition of a moment about the center of gravity. The conventional tail requires some effort to manufacture and adds weight, but not to an extraordinary amount.

Table 3: Tail Configuration Decision Matrix

Concept	Criteria				Score
	Lift	Ease of Manufacture	Weight	Stability	
No Tail	5	1	2	5	13
T-Tail	1	4	4	1	10
Conventional	1	3	3	2	9

The decision matrix compiled for this design consideration shows the conventional tail as the optimal tail configuration, with the T-Tail as a reasonable second choice. The final tail configuration, therefore, is still pending static analysis and testing at this stage.

5.4. Spar and Rib Design

Spar and rib design is a key component to the overall quality of a wing on an aircraft. The spars within the wing represent the main support against various forces on the wing. These forces include upward bending loads generated from lift and drag. Numerous ribs are attached to the main spar to help distribute the loads evenly across the wing. Below are the three material selections identified for manufacturing the spars.

5.4.1 Polymers

Designing the spar and rib with a polymer demands the utilization of rapid prototyping, or 3D printing. 3D printing takes concepts designed from CAD, and turns them into real objects. This technique allows for great accuracy and precision in product specifications while maintaining good overall strength. Unfortunately, this process is timely and comes at a high cost.

5.4.2 Balsa Wood

The more traditional method within the SAE competition is to use balsa wood to manufacture the spar and ribs. Balsa wood allows for the aircraft to remain at an overall minimal weight. This option also is very cheap and accessible, permitting possible extra spending in other parts of the aircraft. The downside of balsa comes from its lack of precision and accuracy within the manufacturing process.

5.4.3 Light Metals

The last option explores the use of light metals such as aluminum. A light metal thrives in its ability to withstand large moments produced by lift and drag. The high capability in strength may be a positive, but the high density of the light metal is a negative. The aircraft design must maintain a reasonable overall weight, however, if light metal ribs are used, this will be compromised.

Proper assessment of the spar and rib material has been broken down into various criterions. The main criteria for the wing design are strength, weight, workability, and cost. Table 2 below shows a detailed decision matrix weighing each of the material selections against our chosen criterion.

Table 4: Spar and Rib Decision Matrix

Concept	Criteria				Score
	Strength	Weight	Workability	Cost	
Balsa	4	1	4	1	10
Polymer	2	3	1	3	9
Light Metal	1	5	4	4	14

This decision matrix concludes that the polymer spar and ribs generated through 3D printing would be the best approach. Balsa is still a viable option, and will still be considered until the group conducts further cost-benefit and yield strength analysis.

6. Loading Scheme

Another major consideration of the aircraft’s design is to choose a payload configuration that will ensure maximum inflight stability as well as the accessibility that will enable a sixty second load and unload for the SAE oral presentation. For purposes of specific configuration selection, we’ve chosen to focus analysis towards payload accessibility and weight type.

6.1 Payload Bay Location

This design consideration discusses the location of the payload bay. This decision has a direct impact on the ease of loading the aircraft, the ability to locate the center of gravity precisely, and the location of the aircraft wings.

6.1.1 Top Loading

A payload bay located on top of the fuselage allows for very simple loading of the aircraft. Space becomes an issue with a Top loading scheme due to the wings being located at the top of the aircraft as well as the control components being located there. The idea of a one-piece wing is not compatible with a top loading scheme because access to the top of the fuselage would become restricted.

6.1.2 Bottom Loading

By loading the aircraft from the bottom of the fuselage, the issue of inverting the aircraft when loading arises. This specific disadvantage can be mitigated through either construction of a loading stand or through a well-rehearsed loading protocol. A primary advantage of this load scheme is the ability to utilize the space on the top of the fuselage for placement of the wings, which has been chosen as the optimal location in the above discussion. As a result, more space inside the fuselage is made available, which will allow the payload mechanism to be more precise in locating the center of gravity.

Table 5: Payload Bay Location Decision Matrix

Concept	Criteria			Score
	Load Speed/Ease of Loading	CG Location	Wing Location	
Top	1	2	2	5
Bottom	2	1	1	4

This decision matrix shows that the bottom location of the payload bay is the optimal choice in this design consideration.

6.2 Payload Type

This design consideration refers to the construction of the payload system, in particular the objects that will be used to add weight to the aircraft.

6.2.1 Plates

Using plate masses as payload is advantageous because their size allows the group to create fewer of them. Also, the frame that the payload would sit on is easy to integrate into the fuselage structure. However, since these masses are so much larger, the adjustability of the center of gravity is decreased with this type of system.

6.2.2 Washers

A loading scheme that utilizes washers allows the center of gravity to be placed more accurately, since the individual weights are smaller. However, the infrastructure required to implement this system is more difficult to manufacture and also decreases the group's ability to load the aircraft with speed and ease.

Table 6: Payload Type Decision Matrix

Concept	Criteria			Score
	Load Speed/Ease of Loading	Adjustability of CG Location	Ease of	
Plates	1	2	1	4
Washers	2	1	2	5

This decision matrix shows that the method of loading the aircraft with plates is the preferred choice, though the difference between the two is small. This decision will likely be solidified once the fuselage is built and the materials are purchased.

7. Propeller Selection

Model aircraft propellers use a specific numbering system to classify the various propeller types. Aircraft propellers are specified by “Diameter X Pitch” given in inches, (an example of this would be a 12 X 5 propeller, which would have a diameter of 12 inches and a pitch of 5 inches). Pitch is defined as the distance a propeller would advance in a solid medium if turned one revolution. Below are the two configurations that are under consideration for this project; Low diameter high pitch and high diameter low pitch.

7.1 Low Diameter High Pitch

The first option of using a low diameter high pitch offers a lower thrust with a higher airspeed of the plane. The high airspeed of this configuration has a negative impact of the maneuverability of the aircraft and due to the restricted airspace for the turning of the plane. This is an important characteristic to consider.

7.2 High Diameter Low Pitch

The concept of a high diameter low pitch configuration offers a higher thrust with a low airspeed. Thrust is an important trait to consider for takeoff because it’s important in generating lift for the aircraft. Due to the low airspeed of this configuration Maneuverability is much easier for the aircraft.

Table 7: Propeller Selection Decision Matrix

Concept	Criteria			Score
	Thrust	Airspeed	Maneuverability	
Low Diameter, High Pitch	3	1	3	7
High Diameter, Low Pitch	1	2	1	4

The design matrix above helped in determining that a high diameter low pitch configuration would best fit the design criteria for this project. The analysis and testing of a number of configurations of the High diameter low pitch will determine the final propeller for the aircraft.

8. Modeling and Analysis

Building on the concept design detailed above, this section will cover static analysis, theoretical design with emphasis on aerodynamics, propulsion systems, and, spar analysis. Matlab codes and detailed calculations can be found in Appendix A and Appendix B at the end of this report.

8.1 Static Analysis

An important initial step of designing an aircraft is ensuring static equilibrium of the body during level flight. To meet this condition, the weight of the plane must be balanced by the lift generated by the airfoils and the resulting drag must be overcome by thrust. This can be accomplished through adequate balance of the lift produced by the wings in relation to the lift due to the tail. In addition, the moments about the center of gravity of the plane must also sum to zero to maintain static equilibrium. Placing the tail accordingly will ensure this balance of moments. By defining a term called the Lift Ratio as the lift from the wings divided by the lift from the tail and conducting the static analysis, the result is a system of equations relating these parameters in a way that guarantees level flight. The resulting equations and a figure used to derive these equations are shown below in Figure 1 and Equations 1, 2, and 3.

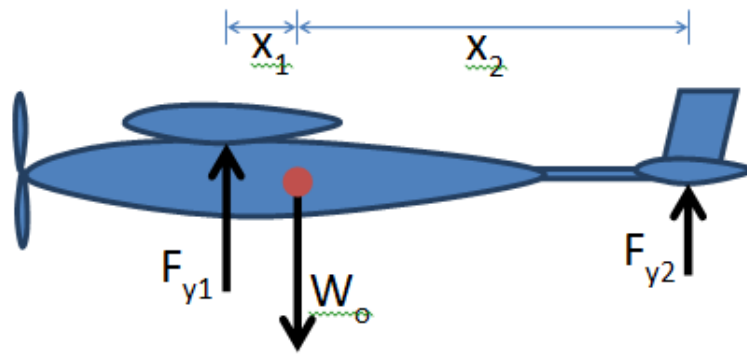


Figure 3: Static Analysis

$$x_2 = LR \times x_1 \quad (1)$$

$$F_{y1} = \frac{LR}{LR+1} \times W_o \quad (2)$$

$$F_{y2} = \frac{1}{LR+1} \times W_o \quad (3)$$

8.2 Aerodynamic Systems

In designing an aircraft, it is crucial to know the environmental characteristics such as air density, temperature, and aircraft velocity. Using historic values from our competition location and estimated velocities of the aircraft, we determine a Reynolds number range between 282,000 and 450,000. Knowing that our aircraft will be operating below a Reynolds number of 500,000 is important because it lays out the fundamental characteristic for the type of aircraft we will have; Reynolds numbers below 500,000 represents laminar flow. Flying in laminar flow determines the types of drag that are crucial. For these parameters, pressure drag will be significantly more than the skin friction. This is highly important in determining the type of airfoil the aircraft will be utilizing. In addition, induced drag will play a significant role in the competition, where determining the type of planform geometry is vital. Another key characteristic is the Mach number. For any Mach number below 0.3, the flow is assumed to be incompressible. Our Mach number is calculated to be about 0.053, much below 0.3, therefore, aerodynamically, our aircraft will be designed to fly in laminar and incompressible flow.

8.3 Airfoil selection

Once the flow characteristics were defined, it was found that in determining the type of airfoil, a high lift and minimal drag type of airfoil will be needed; because the pressure drag is most significant, an airfoil with minimal pressure drag will be needed while simultaneously providing the high lift characteristics of a cambered airfoil. This is

imperative because the type of airfoil will have to reduce the flow separation (minimize the boundary layer) while still having the lift characteristics of a high cambered airfoils that that produced large coefficients of lift in addition to having minimal pressure drag. There are many options for airfoils to choose from that have already been designed by NACA, Eppler and Selig for low Reynolds numbers and incompressible flow characteristics. Some airfoil considerations include:

- NACA 2408
- NACA 2412
- E174
- E180
- S1223

In addition, the aircrafts planform geometry will be designed to minimize the lift induced drag. Lift induced drag is produced by the wing tip vortices (high and low pressure above and below the wings) causing drag to increase and also reducing the effective angle of attack for the wings. Lift induced drag is defined by the following equation:

$$C_{D,i} = \frac{C_L^2}{\pi AR} (1 + \delta) \quad (4)$$

Equation 4 shows that the lift induced drag is highly a function of the aspect and taper ratios for the wing design. Aspect ratio is defined by Equation 5 below:

$$AR = \frac{b^2}{S} \quad (5)$$

Where “b” is the wingspan of the wings and “S” is the planform area. For example, if there was a very large wingspan with very short chord length, the aspect ratio is increased. Having a large aspect ratio results in very minimal lift induced drag.

Figure 2 below displays the calculations for determining delta in finding the lift induced drag. For a give taper and aspect ratio, delta can be found and inserted into Equation 1. The taper ratio is defined by the chord at the tip of the wing divided by the chord at the root of the wing.

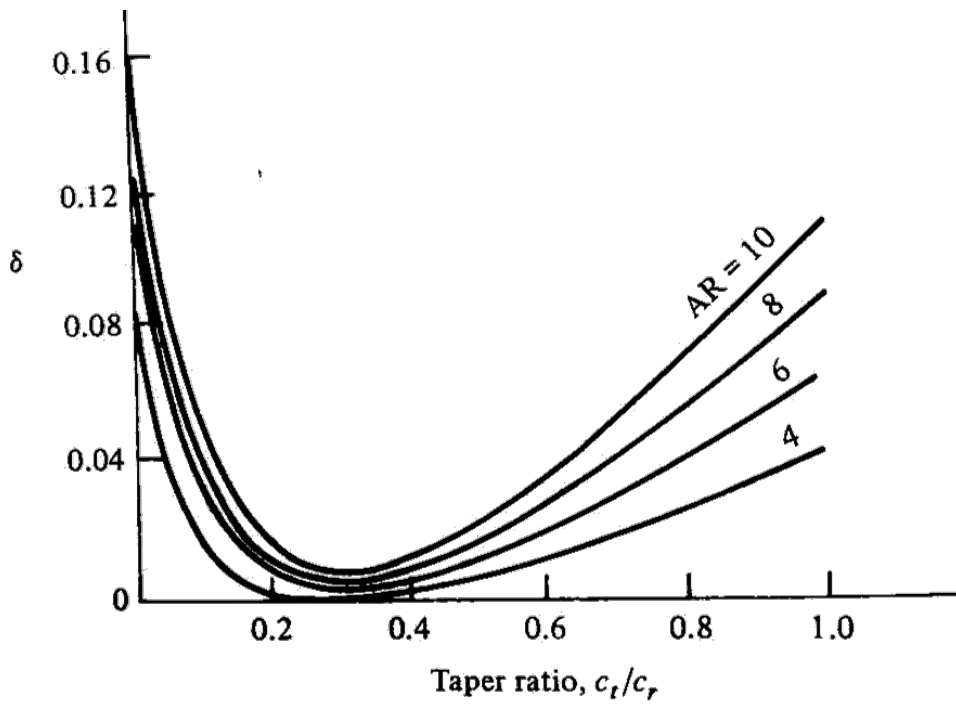


Figure 4: Drag coefficients as a function of the taper ratio and aspect ratio

Figure 2 ultimately demonstrates the importance of using the optimal taper ratio, for instance, using a taper ratio of 0.3 will result in the minimal delta (δ).

Using Equation 4 and Figure 2, Figure 3 displays an optimization surface plot from Matlab for an array of taper and aspect ratios. This allows the team to design the wings with minimal induced drag.

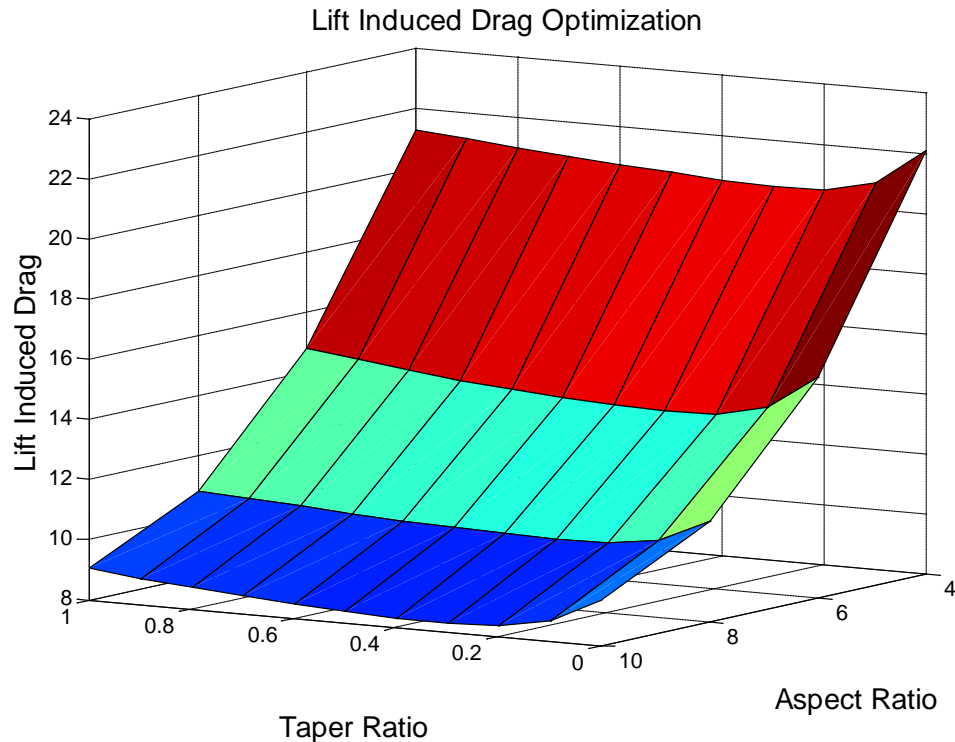


Figure 5: Lift induced drag optimization surface plot

Figure 3 suggests that for a taper ratio of about 0.3 and maximum aspect ratio of about ten, the optimal lift induced drag may be achieved.

8.4 Theory of Wing Design

Once the airfoil is determined, it can be subject to multiple software programs for analysis. The first program was made in Matlab in a previous semester's aerodynamics class with Dr. Tom Acker. This method of analysis is called the vortex panel method where the airfoil geometry is discretized into a number of panels defining its cross-sectional shape. By inputting the airfoil geometry, chord length, angle of attack and some environmental conditions such as air density and the velocity of the aircraft, the vortex at each panel can be calculated and the program will output the lift and pressure coefficients per unit span. The program can also generate the coefficients for a sequence of angles of attack which will be useful in determining the optimal lift and drag angles for the airfoil.

The second piece of software is called XFOIL and "it is an interactive program for the design and analysis of subsonic isolated airfoils" [6]. It was first designed by a Professor at MIT, Mark Drela and then advanced with Harold Youngren. This program is very similar to the Matlab script that the team has developed however XFOIL provides many

more opportunities. Not only does it produce the coefficient of lift and pressure, it also provides the drag coefficient as a function of pressure and viscous forces for a multiplicity of angles of attack.

Using the output from these two programs allows the design of the wings to be defined and optimized. This process was performed using the Matlab script as shown in Appendix A.

By defining the dynamic pressure of the system, q_{inf} , as shown in Equation 6, it can be employed with the lift coefficient produced from the programs developed from the S1223 airfoil, Equation 7 calculates the "prime" lift for a given chord length. The airfoil chord has been defined as 1 ft (0.3048 m).

$$q_{inf} = \frac{1}{2} * \rho * V^2 \quad (6)$$

$$L' = cl * q_{inf} * C \quad (7)$$

For a predetermined value of lift that we have defined as 80 Ib (355.8 N) to be able to provide enough lift for a maximum aircraft weight of 65 Ib (289.1 N) as required by the SAE AERO Design West Competition, is labeled as L_{square} below in Equation 8.

$$b = \frac{L_{square}}{L'} \quad (8)$$

Using Equation 8, the wingspan, b , is determined for the aircraft to provide the lift necessary for the payload goal in the competition.

Given that the necessary lift from a square planform, the wing designed is tapered to reduce the lift induced drag as described above and as shown in Figure 3. This requires the integration of the lift about the length of the wing for the tapered planform in order to calculate the fractional lift of the wing as defined by the following equations:

$$L_{fraction} = 1 - \frac{(b*(C-C_{Tip}))}{(2*b*C)} \quad (9)$$

$$L_{Tapered} = L_{fraction} * L_{Square} \quad (10)$$

Now that the wings are defined by the previous analysis, the lift has been calculated using Equation 9. The planform area, S , can now also be calculated by simply calculating the area of the rectangular portion of the wing in addition to the triangular sections as defined by Equation 11 below.

$$S = b * C_{Tip} + (C - C_{Tip}) * \left(\frac{b}{2}\right) \quad (11)$$

Now the primary lift coefficient, C_L , can be calculated as defined by the following equation:

$$C_L = \frac{L_{Tapered}}{q_{inf} * S} \quad (12)$$

The validity of the results will be tested by performing wind tunnel experiments for the aircraft's wing design. The wind tunnel experiment will be measured for similar Reynolds numbers to calculate both the lift and drag forces for the designed wing and these results will be compared to the theoretical solutions from the computer programs.

8.5 Methodology for Wing Design

The method employed for aerodynamic analysis relies on the use of XFOIL software, a Matlab code written by the team, and wind tunnel testing for validation purposes. XFOIL, a free two-dimensional software program that relies on the vortex lattice method, determines the performance characteristics of an airfoil per chord and wingspan. The Matlab program then accepts these characteristics from XFOIL simulations as well as environmental conditions and geometry estimates. Subsequently, this program computes the resulting wing shape and dimensions and determines the actual lift and drag produced by utilizing the theory described above in Section 2.2. These results are output into the command window of Matlab in an output table. The .m file used in this analysis is attached in [Appendix A](#) of this document.

1. Input airfoil geometry into XFOIL bin folder in .data format
2. Input Reynolds number, Mach number, and a range of angles of attack into XFOIL
3. Record XFOIL outputs of c_l , c_d , and c_m occurring at the optimal angle of attack where c_l/c_d is a maximum
4. Input into Matlab code the desired chord length at the wing root [ft], desired taper ratio, c_l and c_d from xfoil, and delta from Figure 1
5. Tabulate important outputs from Matlab code, such as: chord at the wing tip (c_{tip}), wingspan (b), wing planform (S), aspect ratio (AR), lift generated by tapered wings ($L_{tapered}$), coefficient of induced drag ($c_{D_{induced}}$), coefficient of 3D skin friction and pressure drag ($c_{D_{3D}}$), overall coefficient of drag ($C_{D_{total}}$), and resulting drag (D)
6. Repeat steps 1-5 for a variety of airfoil shapes, operating conditions, and wing geometries until the optimal shape is determined
7. Validate numerical simulations with wind tunnel tests in which a scale model of the wing with accurate taper and airfoil cross section is tested for lift, drag, and moment production

8.5.1 Preliminary Results of Aerodynamic Analysis

Following research on airfoil types, the team decided to pursue the S1223 airfoil for the first iteration of this analytical procedure, because of its known ability to operate well in heavy-lift applications in low Reynolds numbers.

After conducting steps 1-3 of the analysis laid out in section 2.3 using the S1223 airfoil geometry, performance characteristics such as c_l , c_d , and c_m were computed for various angles of attack. The outputs from XFOIL displaying this relevant data can be seen in Figure 4 on following page. From inspection of this graphic, the maximum c_l/c_d occurs at an angle of attack of 12 degrees. Then, a simulation is performed to demonstrate the detailed performance of this airfoil at 12 degrees; the result is shown in Figure 5 on the following page.

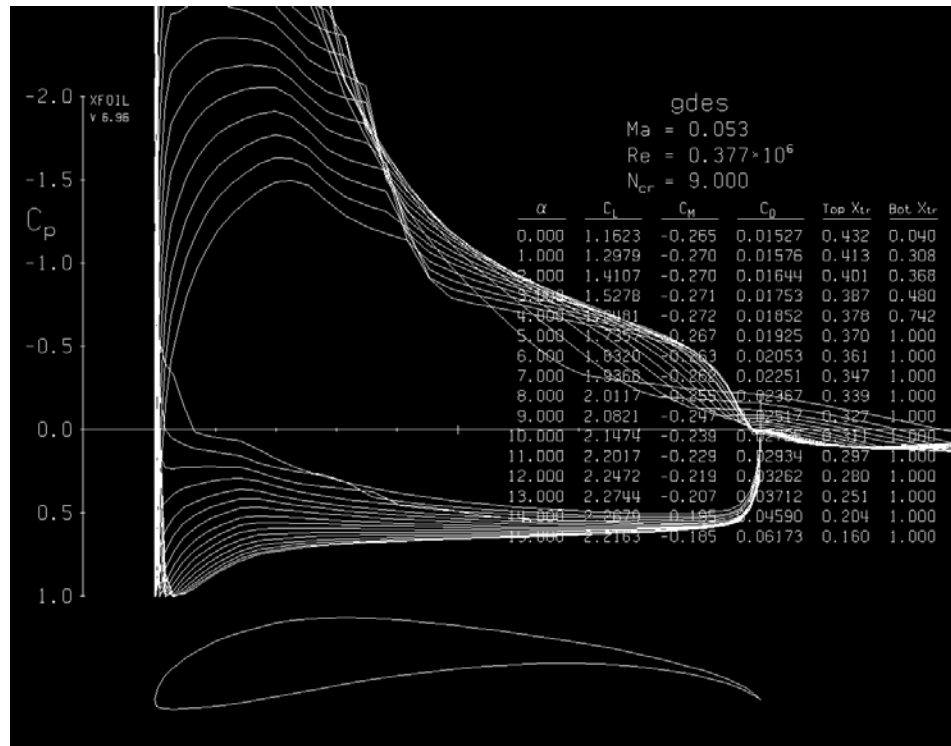


Figure 6: Sweep of angle of attack for airfoil performance (S1223)

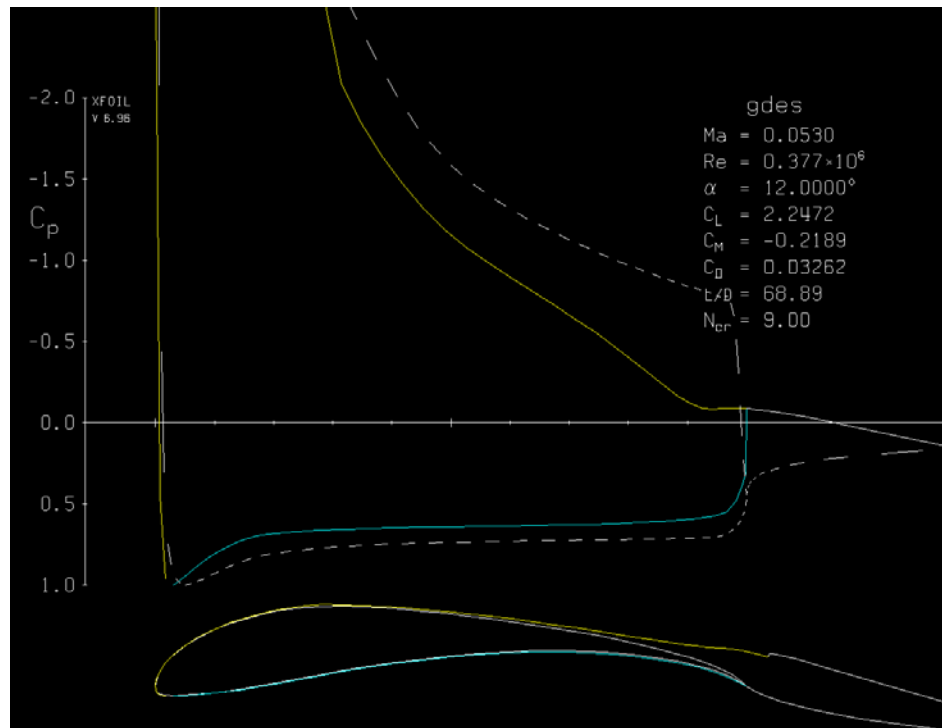


Figure 7: Airfoil (S1223) performance for 12° angle of attack

Following XFOIL analysis, a comprehensive table of geometry and performance characteristics for the wing and the tail was generated with the use of the team's Matlab code. The result can be seen below in Figure 6. These results provide an acceptable shape for the first iteration. The geometry is reasonable, the lift provided is adequate, and the drag is acceptable.

Summary of Wing Geometry						
Chord at Root	Taper Ratio	Chord at Tip	Wingspan	Wing Planform	Aspect Ratio	
[ft]		[ft]	[ft]	[ft ²]		
0.83	0.5	0.42	6.0	3.7	9.53	

Performance Characteristics											
cl	cd	delta	AoA	Flight Speed	Reynolds number	CL	cD induced	cD 3D	CD	Lift	Drag
				[m/s]						[lbs]	[lbs]
2.147	0.028	0.03	10.0	20.12	3.53e+05	2.147	0.159	0.146	0.305	40.94	5.82

Summary of Tail Geometry				
Chord	Span	Wing Planform	Aspect Ratio	
[ft]	[ft]	[ft ²]		
0.50	1.9	0.9	3.71	

Performance Characteristics											
cl	cd	delta	AoA	Flight Speed	Reynolds number	CL	cD induced	cD 3D	CD	Lift	Drag
				[m/s]						[lbs]	[lbs]
2.156	0.035	0.04	10.0	20.12	2.12e+05	2.156	0.159	0.183	0.342	10.23	1.62

Figure 8: Performance characteristics and wing geometry

Subsequent iterations of this process will attempt to improve upon this basis by fine-tuning the flight speed once that information is understood, adjusting the airfoil to perform more efficiently in known operating conditions, and finally carrying out wind tunnel tests to validate these results. Based on these specifications and the static analysis described in Section XX, the overall dimensions of the plane are determined.

8.6 Propulsion Analysis

One of the first key steps in propulsion analysis was the selection of the motor. Our group has selected the Magnum XLS .61A motor due to the ease of access over the other motor option. No modifications to motor or exhaust are allowed for this competition. The key properties for this motor can be seen in the table below.

Table 8: Motor Specifications

Magnum XLS-61A	
Displacement	9.94cc (0.607ci)
Bore	24mm
Stroke	22mm
Practical RPM	2,000 – 16,000 rpm

For the analysis of the motor, the engine displacement of .607 cubic inches and the practical rpm range of 2,000-16,000 rpm must be taken into consideration. The Top Flite propeller manufacturing company has developed the figure below. The figure plots engine displacement along the bottom axis and a curve across the plot defines the practical rpm range for the given engine displacement. From the start and endpoints of the practical rpm, the range of the propellers can be defined.

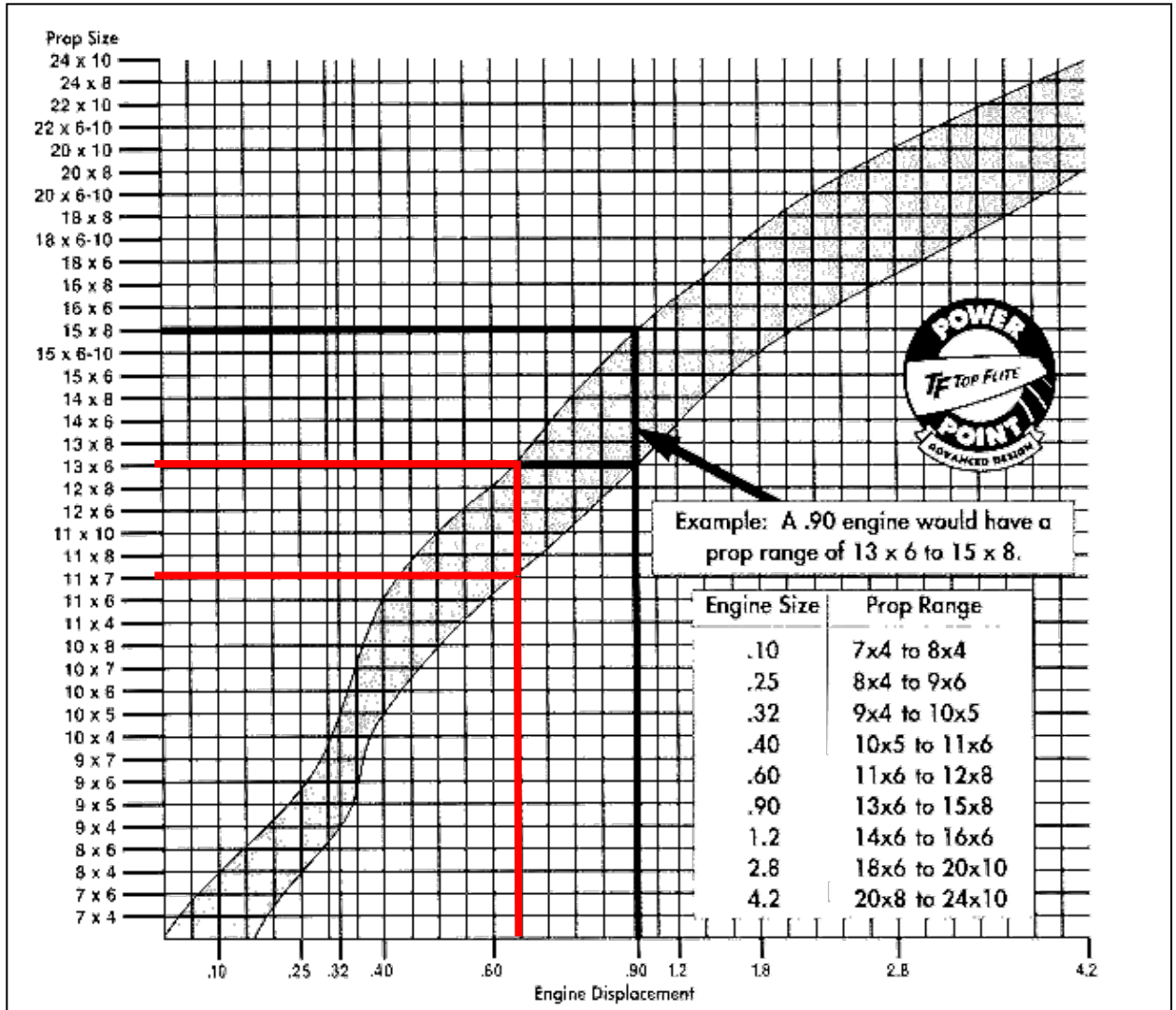


Figure 9: Prop Size Determination Criteria

Looking at the figure above and using the defined engine displacement of .607 cubic inches, the red line defines the useful range of propellers for the aircraft. Based upon the figure above, the defined propeller range for the aircraft will be 11X7 → 13X6. The 11X7 propeller falls on the lower end of the practical rpm curve. The 11X7 propeller will be used to initially break in the motor. The lower rpm will help load the motor and break in the motor for better long-term performance. This preliminary analysis is inconclusive of which propeller will be utilized for the final flight test. Physical testing needs to be performed to determine the static thrust and rpm output for given propellers. A test stand will be developed that has a thrust meter attached to the motor and propeller configuration. The motor will be fully throttled and static thrust will be measured as well

as rpm output to ensure that configuration is operating within constraints. A stand similar to the previous team's design project will be developed as seen in the figure below.

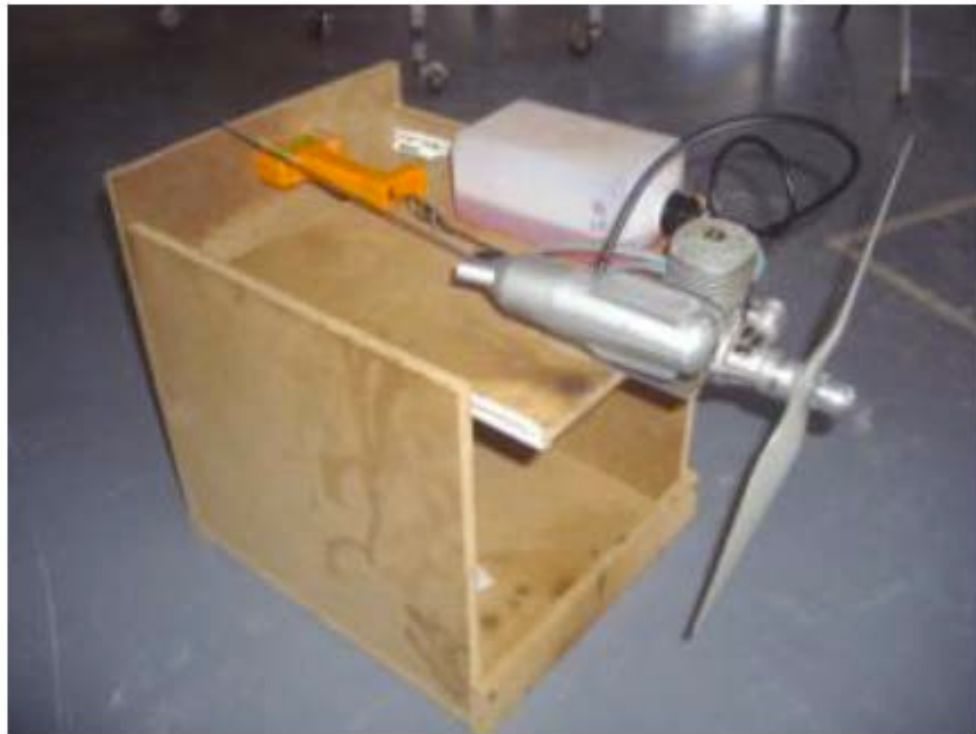


Figure 10: Test stand for static thrust analysis

As seen in the figure above a thrust meter and cable are attached to the motor and sliding drawer. As the motor is throttled the thrust will cause the drawer to slide outward measuring the thrust developed.

8.7 Material Choice

With strength to weight optimization being vital for aircraft design, this team has chosen to utilize rapid prototyping technology to construct wing ribs. This allows the airfoil to be modeled with high precision, vital to both the aerodynamics and accurate analysis of a wing. By utilizing this technology, ribs may be produced that are both significantly stronger and more exactly manufactured than if they were to be constructed of a typical model aircraft material such as balsa or bass wood.

The rapid prototyping technology available to us uses a polymer known as Acrylonitrile Butadiene Styrene P400 (ABS). Table 2 shows some of the main characteristics of ABS P400.

Table 9: ABS Properties

Specific Gravity	Tensile Strength (Mpa)	Tensile Modulus (Mpa)	Flexural Strength (Mpa)	Flexural Modulus (Mpa)
1.04	22	1,627	41	1,834

As seen above, ABS has a specific gravity of 1.04, almost five times that of balsa wood. Conversely, this polymer has high potential for impact and mechanical strengths.

Due to ABS's woven construction, these strengths extend in all planar directions, which is a significant advantage when compared to an equivalent fibrous rib (wood), whose strength is related to an applied force's orientation to the grain.

8.8 Static Spar Analysis

Modeling of the spars depends on the load distribution along the wing. This load will be provided through the aerodynamics portion of the calculations. Analysis of each spar will be communicated via a discretization of the planar-area of the wing, and the corresponding static and material analysis.

8.8.1 Wing Discretization

The wing will consist of two main supports, a front spar and rear spar. To ultimately determine the stresses acting along each, the wing must first be broken into sub elements, marking the space between wing ribs. Arranged from A_1 to A_n , this breakdown is given in Figure 7 located on the ensuing page.

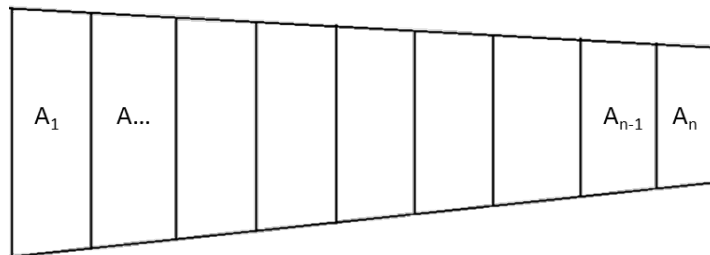


Figure 11: Discretization of Wing

Each sub element can be best modeled as a trapezoid because of the linearly tapered airfoil planform. Generalized dimensions are outlined in Figure 8 below, and calculated explicitly in Appendix B.

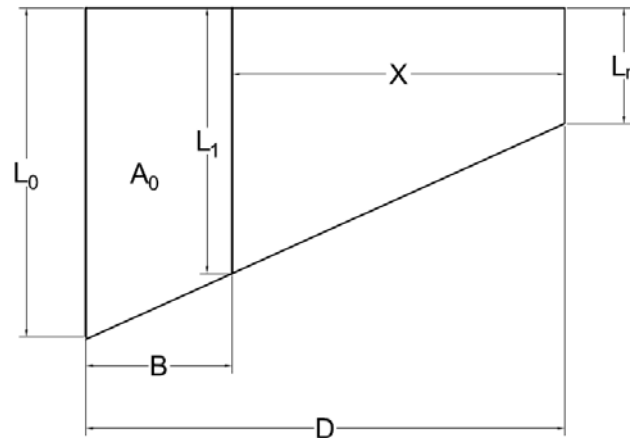


Figure 12: Wing Dimensions

This process of discretization enables the engineer to determine the percent area of the total wing area exists between individual ribs. By applying the percent planform area as a multiplied scalar to the total lift force per wing, the lift force acting over each section can be determined, as in Appendix B, Equation 1-A.

8.8.2 Representative Model/ Static Analysis

Knowing the load trends across the wing, shear force and bending moment diagrams may be constructed to determine locations where analysis should be focused towards. To build these diagrams, lift forces are considered to be acting at the same location as the center of gravity of each wing element, given in Appendix B, Equation 2.

With these diagrams constructed as seen in Appendix B, the engineer may interpolate to determine maximum forces acting along the wing; in the case of a cantilevered beam, mechanical failure is most likely to occur at the fixed end.

8.8.3 Mechanics of Materials

With shear and bending forces tabulated across the length of the wing, material analysis becomes a balancing between consideration of the torques induced about each rib, and the analysis of the spar along its length of the wing

8.8.4 Torque about ribs

Based on angle of attack and the lift force profile determined from airfoil analysis, the percent of the lift forces acting on the front and rear spars may be taken as

70% and 30%, respectively. These connected spars are related by a moment couple about the elastic center of the rib, given in Appendix B, Equation 3. This equivalent force corresponds to a torsional displacement given in Appendix B, Equation 4.

One important implication of this relation is that in-flight torque on the wings may be practically negligible if the elastic center is designed to be at the point at which the lift force resolves.

8.8.5 Spars along length of wing

With the loading of the wing known, materials and stress analysis may be performed at the fixed end, indicating the maximum stresses that the airfoil will experience.

9. Final Design

After performing conceptual design and preliminary analysis, the team has developed a finalized conceptual design and determined the overall dimensions of the aircraft. The group has constructed a solid model of the aircraft concept, which can be found in Appendix C. Based upon aerodynamic analysis, the group has decided on a tapered S1223 airfoil for the plane. The tapered wing design helps to reduce vortex shedding from the wingtips. A T-Tail configuration was chosen to maximize aerodynamic efficiency by elevating it above the wake of the upstream wings.

The group has selected the Magnum XLS .61A motor for the final design. The final propeller has not been selected yet and is awaiting results from static thrust testing. One of the key attributes of the final design is the application of ABS rapid prototyping for ribs and various aircraft components. After exploring this option, the team has hypothesized that rapid prototyping components such as airfoil ribs will help achieve precise wing shapes, which will help in predicting the system performance.

Based upon the preliminary analysis upon the current design the aircraft generates fifty pounds of lift with about six pounds of drag in steady level flight. This design meets our requirements as well as the current goal of carrying fifteen pounds of payload along with the weight of the aircraft. One of the key considerations in the current design is aircraft dimensions. The total of the height, length and width dimensions must not exceed 225 inches for the aircraft. As the airspeed is refined from static thrust testing, airfoil dimensions can be refined which in turn will help determine the rest of the aircraft dimensions.

Design constraints for the competition have been under constant consideration during the design process. Currently, the design meets all competition constraints and requirements. A breakdown of the budget for the proposed design can be found in the Financial Overview section.

10. Financial Overview

9.1 Budget

This capstone project is unique because it is an entirely self-funded student effort. In order to predict the costs that would be applicable to this project, a detailed budget was formed. The budget was broken down into three key areas: competition expenses, travel expenses, and building/miscellaneous expenses. The three areas put the grand total of our budget at \$4955. The figure below shows the breakdown of all of these areas in our total budget.

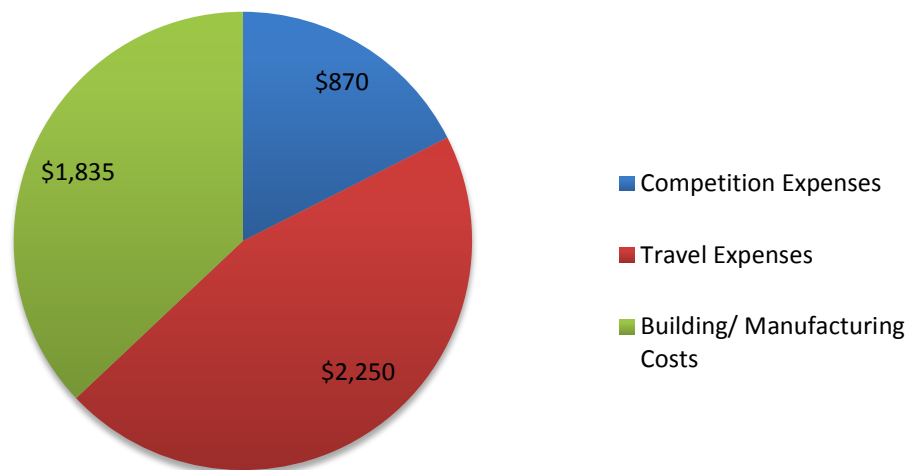


Figure 13: Pie chart of budget breakdown

Costs were derived from previous teams' expenses as well as current market values for some of the materials. With a budget of this magnitude, sponsorship was a major goal of the team. It was noted at the beginning of the semester that failure to budget adequately from previous teams caused a lot of out-of-pocket costs to occur and this was taken into consideration when developing the budget.

9.2 Sponsorship

Sponsorship was needed for this project due to the high magnitude of the budget. The team sought out companies that would be interested in supporting the team in this competition. The figure below is a pie chart showing the sponsorship breakdown for this project.

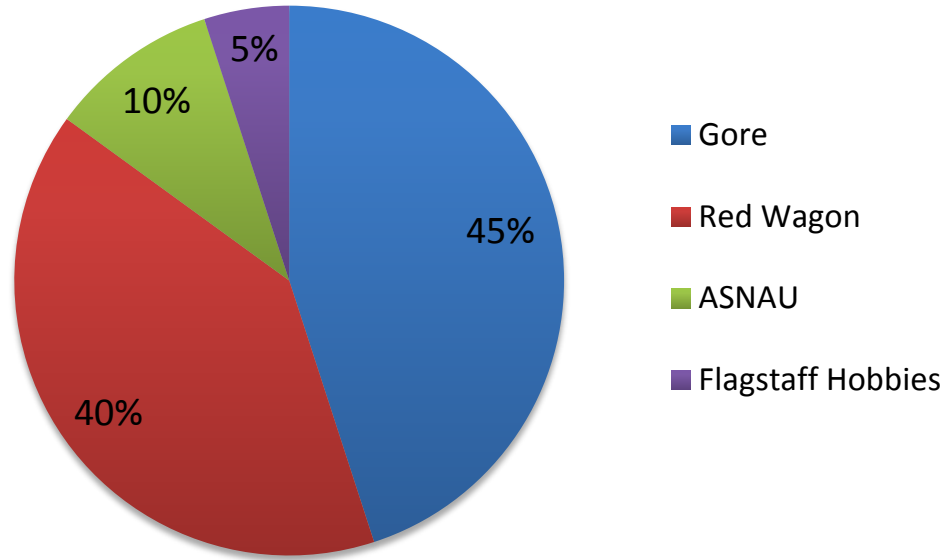


Figure 14: Pie chart of sponsorship contribution

Two of the major contributors to the group were Gore and Red Wagon. Gore funding has been donated to the capstone program and a portion of their contribution will be going to our Aero Design team. Red Wagon also made a significant contribution to the team to help with material and construction costs. The local company Flagstaff Hobbies has agreed to sponsor the team through discounted materials and waived shipping costs for all orders. The Associated Students of Northern Arizona University have been contacted for a small contribution to the team's budget as well.

11. Project Timeline

Meeting deadlines is a key component of this capstone project. The team has compiled a detailed Gantt chart of tasks and deadlines needed for the completion of the project. The team's Gantt chart can be seen in the figure below.

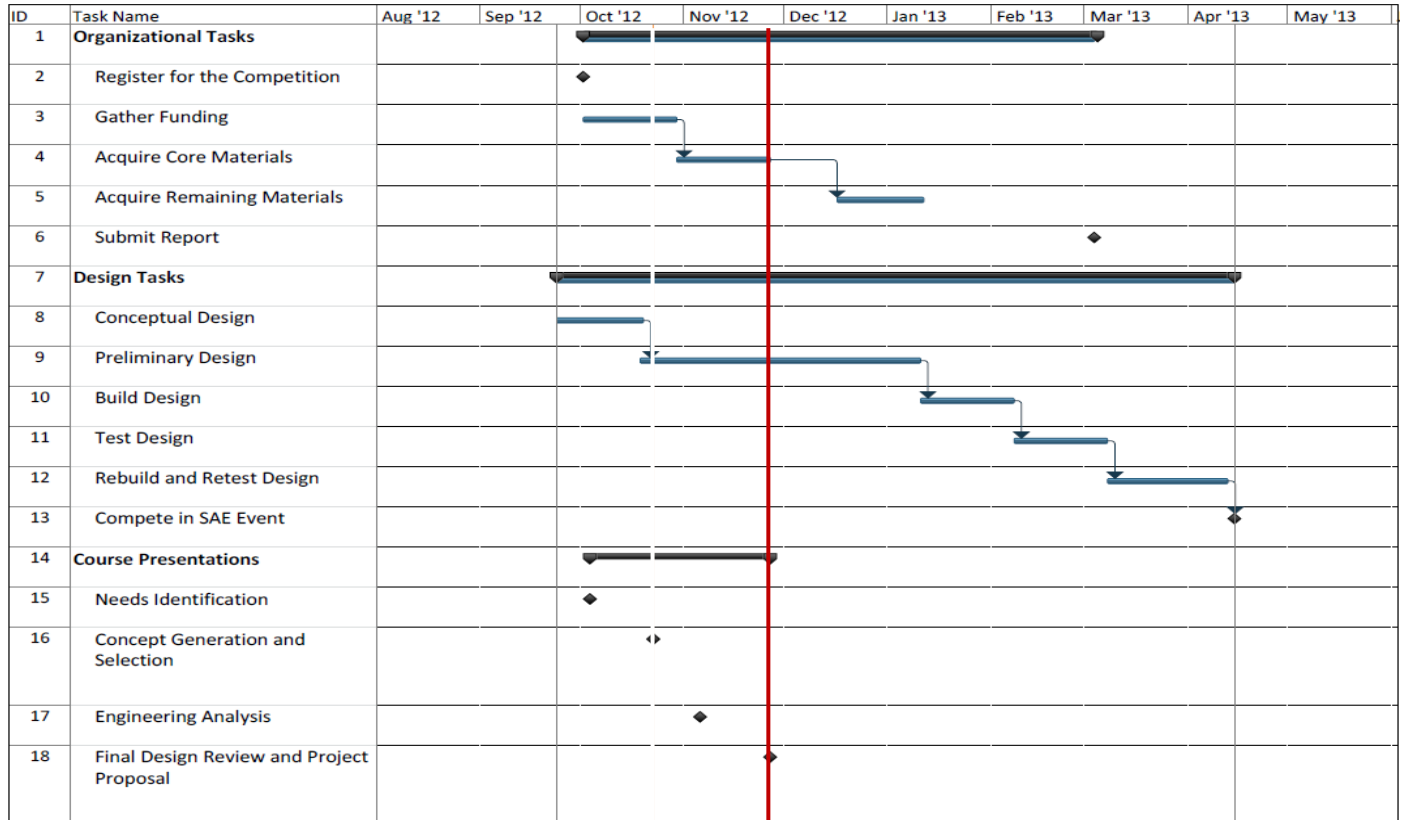


Figure 13: Project Gantt chart

Overall the team is on task with the Gantt chart and no modifications have been needed at this time. The team has approached the end of acquiring core materials and has ordered all of the components for the static thrust test stand discussed in the propulsion analysis. The preliminary analysis has refined the design of the aircraft thus far and the group is ready to begin the second half of the preliminary design phase.

12. Future Tasks

Wrapping up this semester the team has identified some key things that will be approached in the following semester. The team has been broken up into three key areas of the aircraft and the remaining tasks of each of the groups have been broken down into the following.

Aero team:

- Perform wind tunnel testing to validate numerical solutions
- Determine loading distributions and forward to structural for spar design
- Reiterate analysis once a better flight speed estimate is given
- Perform analysis to support turning and pitching (angle of attack) controls system

Structural team:

- Produce a rib in 3D printer to familiarize with the process
- Develop payload scheme
- Formulate a plan for teardrop shaped fuselage design
- Consider attachment of wings at the top
- Leave space for electronic controls
- Do calculations for spars once wing/tail information is known- determine dimensions and materials for spars

Propulsion and Controls Team:

- Build static thrust test stand
- Conduct static thrust testing for various propeller configurations
- Determine flight velocity capabilities based on plane weight estimate
- This will be done in MATLAB so it can be reiterated once aircraft mass is better known after construction
- Research controls and electrical systems
- Interface with Aerodynamics team to formulate turning and pitching controls system
- Interface with Structural team to integrate controls system into fuselage design

13. Conclusions

As stated previously, aircraft design is a well-established science. As such, the focus of this project is to optimize each component of the aircraft using selection and configuration design processes. Design matrices were developed for the airfoil planform, wing and tail configurations, spar and ribs, loading schemes, and propeller selection. These matrices helped decide some factors, but also shows further analysis is necessary for optimal design selections. Further analysis was performed on the airfoil selection, static analysis, landing gear, maneuvering mechanisms, and control systems. These design considerations are secondary concerns which are established through the base design of the aircraft. When detailed analysis is deemed adequate, formation of the final design will be determined for the aircraft.

References:

- [1] Raymer, Aircraft Design: A Conceptual Approach
- [2] Johnson, Airfield Models, <http://airfieldmodels.com/>
- [3] Anderson, Fundamentals of Aerodynamics
- [4] <https://store.amtekcompany.com/products.php?product=Dimension-Standard-ABS-Model-Material-%25252d-P400>
- [4] <http://www.rc-airplane-world.com/propeller-size.html>
- [5] Magnum XLS .61a Operating Instructions,
<http://media.globalhobby.com/manual/210770.PDF>
- [6] XFOIL, raphael.mit.edu/xfoil/
- [7] Weather Underground (www.wunderground.com)
- [8] SAE International 2013 Collegiate Design Series: Aero Design® East and West
Rules

Appendix A

%%%

% Program: Nelessen_AeroDesign.m

% Programmer: Adam Nelessen

% Institution: Northern Arizona University

% Date: Fall 2012

% Performed for: SAE Aero Design West Airplane

%%%

%% Cleanup

clear all; clc; close all;

%% Input Environmental Variables

speed_mph=30:1:50; % [mph] Predicted speeds from previous team's report

speed_mps=speed_mph*.4470; % [m/s]

speed_particular=45*.447; % [m/s]

alpha=10; % degrees

T=283.15; % [K] from wunderground avg on 4/14

p=98532.6; % [Pa] from wunderground avg on 4/14

R=287.04; % [J/kg*K] Air

rho=p/(R*T); % [kg/m^3]

mu=1.71E-5*(T/273)^0.7; % [N*s/m^2] From Power Law eqn., Table A.2, pg. 826, Fluid
Mechanics by White

a=337.4; % [m/s] at T=283K

Mach=speed_mps./a;

Mach_particular=speed_particular/a;


```

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Determine tail information from airfoil analysis%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

chord_tail_ft=.5;%input('\nInput Chord at the root in ft: \n');

chord_tail=chord_tail_ft*.3048;

cl_tail=2.1555;

Lprime_tail=cl_tail*qinf_particular*chord_tail;

L_tail=Ltapered/4;

b_tail=L_tail/Lprime_tail;

b_tail_ft=b_tail/.3048;

S_tail=b_tail*chord_tail;

S_tail_ft=S_tail/((.3048^2));

AR_tail=b_tail^2/S_tail;

CL_tail=L_tail/(qinf_particular*S_tail);

delta_tail=.04;

cDinduced_tail=(CL^2*(1+delta))/(pi*AR);

cd_xfoil_tail=0.03490;

cD_3D_tail=cd_xfoil_tail*b/S;

CDtotal_tail=cDinduced_tail+cD_3D_tail;

D_tail=CDtotal_tail*qinf_particular*S_tail;

D_tail_lbs=D_tail/4.448;

L_tail_lbs=L_tail/4.448;

```

Re_particular_tail=(rho*speed_particular*chord_tail)./mu;

% %

%%%

%%% Calculate Payload

Potential%%%

%%%

W=50;

LR=4;

Fy1=(LR/(LR+1))*W;

x1=.5;

Fy2=W/(LR+1);

x2=x1*Fy1/Fy2;

% %

%%%

%%% Input Plane

Dimensions%%%

%

%%%

max_total_dim=225/12; % ft

w=6; % ft

l=3.5;

h=3;

total_dim=w+l+h;

```
%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Output Significant
Results%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
fprintf('                Summary of Wing Geometry                \n');
fprintf('\n');
fprintf('    | Chord at Root | Taper Ratio | Chord at Tip | Wingspan | Wing Planform | Aspect
Ratio | \n');
fprintf('    |-----[ft]-----|-----|-----[ft]-----|----[ft]----|-----[ft^2]-----|-----|\n');
fprintf('    |    %.2f    |    %.1f    |    %.2f    |    %.1f    |    %.1f    |    %.2f    | \n',chordft,
taper,ctipft, bft, Sft,AR);
fprintf('\n');
fprintf('\n');
```

```
fprintf('                Performance Characteristics                \n');
fprintf('\n');
fprintf('| cl | cd | delta | AoA | Flight Speed | Reynolds number | CL | cD induced | cD 3D | CD |
Lift | Drag | \n');
fprintf('|-----|-----|-----|-----|----[m/s]-----|-----|-----|-----|-----|---[lbs]---|---[lbs]---
|\n');
fprintf('| %.3f | %.3f | %.2f | %.1f |    %.2f    |    %1.2e    | %.3f | %.3f | %.3f | %.3f | %.2f | %.2f
|\n\n', cl, cd_xfoil,delta, alpha, speed_particular,
Re_particular,CL,cDinduced,cD_3D,CDtotal,Ltaperedlbs,Dlbs);
```

```
fprintf('                Summary of Tail Geometry                \n');
fprintf('\n');
fprintf('    | Chord | Span | Wing Planform | Aspect Ratio | \n');
fprintf('    |---[ft]---|---[ft]---|-----[ft^2]-----|-----|\n');
```

```

fprintf('                | %.2f | %.1f |   %.1f   |   %.2f   |\n',chord_tail_ft, b_tail_ft,
S_tail_ft,AR_tail);

fprintf('\n');

fprintf('\n');

fprintf('                Performance Characteristics                \n');

fprintf('\n');

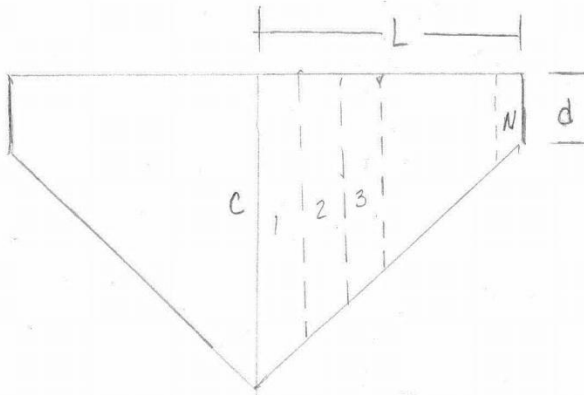
fprintf('| cl | cd | delta | AoA | Flight Speed | Reynolds number | CL | cD induced | cD 3D | CD |
Lift | Drag |\n');

fprintf('|-----|-----|-----|-----|----[m/s]----|-----|-----|-----|-----|---[lbs]---|---[lbs]---
|\n');

fprintf('| %.3f | %.3f | %.2f | %.1f |   %.2f   | %1.2e |%.3f| %.3f | %.3f | %.3f | %.2f | %.2f
|\n\n', cl_tail, cd_xfoil_tail,delta_tail, alpha, speed_particular,
Re_particular_tail,CL_tail,cDinduced_tail,cD_3D_tail,CDtotal_tail,L_tail_lbs,D_tail_lbs);

```


Appendix B



• $L = \frac{\text{WING SPAN}}{2}$

• C = CHORD

• $F_{LIFT} = \frac{F_{LIFT\ TOTAL}}{2}$

• $\alpha = \text{ANGLE}$

LIFT PER SECTION

AREA FOR EACH SUBELEMENTS

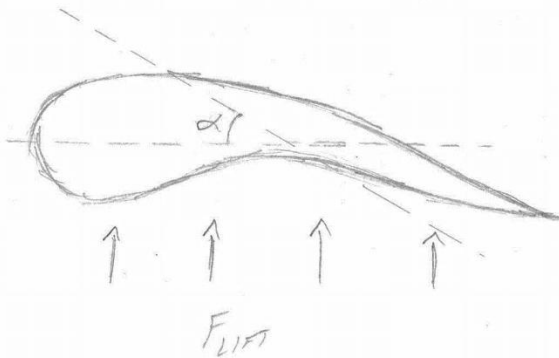
FOR $i = 1 : N$

(1) SECTION AREA (%) = $\frac{\left[\frac{d_{i-1} + d_i}{2} \left(\frac{L}{N} \right) \right]}{\left[\frac{c + d}{2} (L) \right]}$

WHERE

$d_i = \left(\frac{L i}{N} \right) \left(\frac{c - d}{L} \right)$

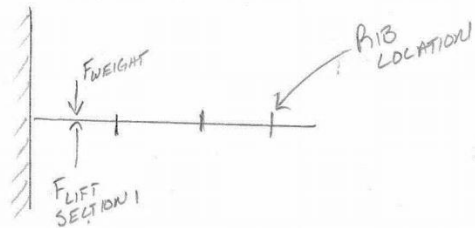
(1-A) $\Rightarrow F_{LIFT, SECTION} = (A_{SEC}) (F_{LIFT})$



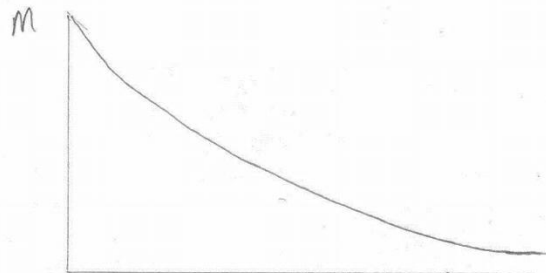
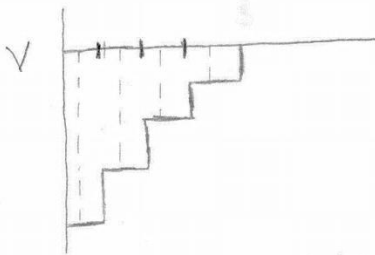
CENTER OF GRAVITY

2) $CG(x) = \frac{d_{i-1} + d_i}{3(d_{i-1} + d_i)} + L \left(\frac{i-1}{N} \right)$

• $F_{LIFT, SECTION}$ ACTS AT $CG_{SECTION}$.



V & M DIAGRAMS

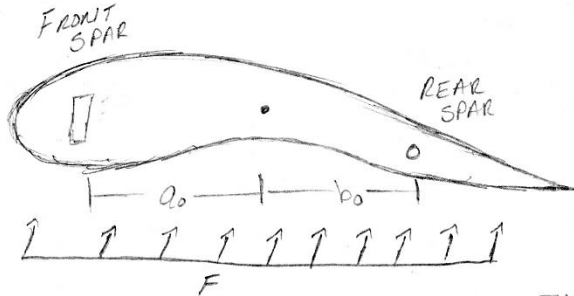


INTERPOLATE TO DETERMINE V & M AT ANY POINT.

TORQUE

ELASTIC CENTER.

(3) $E(x) = \frac{a_0}{b_0} = \frac{E_{FS} I_{FS}}{E_{RS} I_{RS}}$



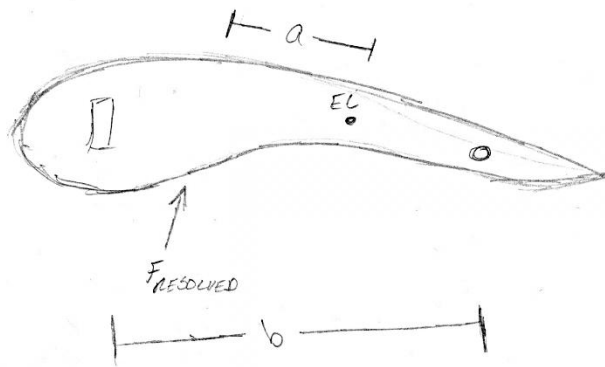
TORQUE DETERMINED BY HOW FAR THE RESOLVED FORCE IS LOCATED FROM THE ELASTIC CENTER.

(4) $\theta = \frac{FL^4}{8bA_0}$

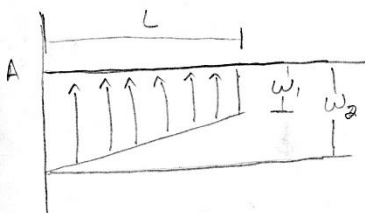
WHERE

$\frac{1}{A_0} = \frac{1}{A_F} + \frac{1}{A_R}$

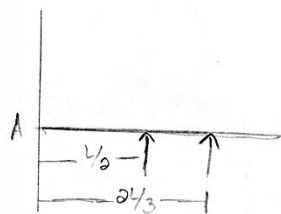
- $A_F = EI_F$
- $A_R = EI_R$



MELPHANILS OF MATERIALS



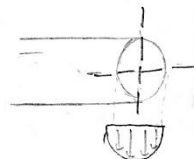
\Rightarrow



$\Sigma MA = \frac{1}{2}(w_1 L) \left(\frac{2L}{3} \right) + \frac{w_2 L}{3} \left(\frac{L}{3} \right)$

$\sigma = \frac{My}{I}$ (5)

σ IS MAX WHEN "y" ON THE TOP & BOTTOM THE SPAR



Appendix C

Technical drawing of an airplane wing section. The drawing includes a top view, a side view, and a 3D perspective view. Dimensions are provided in inches. The top view shows a total length of 72.00 inches and a hole diameter of 1.00 inches. The side view shows a thickness of 5.00 inches and a chord length of 38.00 inches. The 3D model shows the wing's position on the fuselage, with a distance of 21.71 inches from the fuselage to the leading edge of the wing.

APPLICATION		UTILS OTHERWISE SPECIFIED:		DRAWN		TITLE:	
NET ASSY	USED ON	DIMENSIONS ARE IN INCHES	DO NOT SCALE DRAWING	NAME	DATE	SAE AeroDesign	
		TOLERANCES:		AAL	12/6/12	A Aeroplane	
		FRACTIONAL: 1		CHECKED	BP	SCALE: 1:20 WEIGHT: SHEET 1 OF 1	
		ANGULAR: MACH 2		ENG APPR.			
		TWO PLACE DECIMAL: 2		MFG APPR.			
		THREE PLACE DECIMAL: 3		Q.A.			
		INTERPRET GEOMETRIC TOLERANCING PER:		COMMENTS: Front and rear wing sections modeled using a 51223 dffoil.			
		MATERIAL:					
		RINER					

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