Final Design Report

EML 4551C – Senior Design – Fall 2011 Deliverable

Team # 10

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Project Sponsor(s)

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Executive Summary

The purpose of our project involves the design and construction of a remote-controlled aircraft which fulfills the 2011-2012 regulations and mission requirements for submission to the SAE Aero Design East competition to be held in Marietta, Georgia. In order to be considered successful, the aircraft must lift as much weight as possible while observing requirements governed by the SAE Aero Design East committee. Furthermore, the aircraft must accomplish the specified mission while embracing the integrity of the design as defined in the technical report.

Our team’s work is different from other teams in various aspects. The primary difference involves design for a competition rather than specific customer needs; although this may seem easier allowing us to design what we like, difficulties arise to meet requirements of competition as well as the increased stress to perform in competition. Another significant difference in our team is the diversity, incorporating Brazilian and American exchange students to learn more about other cultures, spread knowledge of engineering and aeronautics, and to work around potential difficulties in communication.

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Introduction

In recent years, unmanned air vehicles (UAVs) have become part of an increasingly prominent field of study and application. The implementation of UAV's in the armed forces is considered the future for military aviation. UAV's can perform the same tasks as a normal aircraft controlled by an onboard human pilot without the risk of putting the pilot's life in danger. The practicality of UAV's can be seen in many applications such as: militant target and decoy missions, reconnaissance, real-time combat, logistics preparation, research/development and also can be actualized in a small, but growing number of civil applications. Flight International reported nearly 8000 unmanned air-vehicles (UAVs) worth $3.9 billion [US$], will be produced worldwide between 1994 and 2003.

The proposed project is to design and build a cargo UAV fulfilling the 2011-2012 regulations and mission requirements as provided and defined by the SAE Aero Design East committee. This design must be documented by means of a technical report and a project presentation given to a panel of judges composed of aeronautical engineers. According to Dr. Leland M. Nicolai (Lockheed Martin engineer), "*The student needs to understand that the analysis and performance of the R/C model is identical to a full scale airplane such as a Cessna 172. The only differences between the R/C model and the full scale airplane are the wing loading, Reynolds Number and the moments of inertia*".

The SAE Aero Design competition is intended to provide undergraduate students with real-life engineering endeavor. It is essential to the success of the project to perform trade studies and make compromises to arrive to a design solution that will optimally meet the mission requirements while conforming to the configuration limitations. The emphasis on interpersonal communication skills, often overlooked by engineers, is reflected in the team's overall score. A completely unique dynamic is evident within our team due to the international collaboration between Brazil and the United States. A strong, developed communication basis will be crucial to the success of the project since a high percentage of our score is devoted to the design report and the oral presentation required for the competition.

With regards to competition guidelines, the design project is to be structured around three critical phases: a technical report, a technical presentation/inspection, and the physical flight competition. The technical report functions as a means by which the design team can convey how their aircraft is most suited to complete the mission requirements. It details the methods, procedures and calculations (where applicable) used to arrive at the final product. The design report will be an integral part of the total competition score encompassing 50 points subdivided in the following manner: Report – 40 points, Plans – 5 points, and Payload Prediction Graph – 5 points. Prior to the technical presentation, a timed demonstration of the payload loading/unloading of the aircraft will be performed in order to confirm the ability to complete said tasks in one minute respectively. The technical presentation is to be a ten minute oration of the content presented within the technical report delivered in the same manner a “pitch” to an industry customer would occur. The design team will focus on providing detailed explanations as to why certain design configurations were chosen and present the results of any pertinent analysis/testing performed during the conception of the design choice. The oral presentation is to be scored out of a maximum of 50 points.

Product Specifications

The product specifications in our design project revolve around the rules and regulations legislated by the SAE Aero Design East board committee. With regards to competition guidelines, the design project is to be structured around three phases: a technical report, a technical presentation and inspection, and the physical flight competition.

Competition Constraints

There are plenty of constraints in this project. Some constraints are determined by the rules and other is inherent to aircraft design. Therefore, we have been facing trade-offs and design constraints since the beginning of this project. The main constraint should be related to the wing design; if we desire a high payload weight capability we need to increase the wing area. By increasing the wing area we must improve its structure (wing spar and ribs), hence adding weight again. The balance of such factors and the complication of a larger wing will be carefully considered by means of analytical equations and computational methods. One way to solve this issue is to find lighter materials with greater strength. The logical choice would be to use composites materials. However, this class of materials is forbidden in the rule book.

Customer Needs

- Aircraft has a maximum combined length, width, and height of **225 inches**
- Aircraft weighs no more than **55 lbs** including payload and fuel
- Team number visible on both sides of the vertical stabilizer and wing using **4 inch** decals
- Payload is not to be integrated as to affect the structural integrity of the airframe
- Payload is to be secured to the cargo bay in a manner as to not shift during flight
- Use of a 2.4 GHz radio is required for aircraft operation
- Battery pack to have a capacity of no less than 1000 mAh
- Only common grade, 10% nitro methane fuel permitted
- Fuel tank is accessible and pressurized using only stock fittings from the engine muffler
- Powered by a single, unmodified O.S 61FX engine with stock E-4010 muffler
- 1:1 propeller to engine RPM is required thus any gearbox, drives, or shafts must allow this ratio to be maintained

Regular Class Flight Score

Regular Class aircraft receives a flight score based upon the raw weight lifted, the team's prediction of the aircraft's maximum lifting capacity, and the team's Operational Availability (A_o).

The flight score is calculated by the following equation:

$$FS = RAW + PPB + EWB - TP$$

Where,

$$RAW = Raw \quad Weight \quad Score$$
$$PPB = Prediction \quad Point \quad Bonus$$
$$EWB = Empty \quad Weight \quad Bonus$$
$$TP = Total \quad Penalty \quad Points$$

The Raw Weight Score (RAW) is calculated by,

$RAW = W \times 4$ (W being the weight lifted in Pounds)

$$PPB = 20 - (P_{predicted} - P_{actual})^2$$
$$P_{Predicted} = Predicted \quad Payload$$
$$P_{actual} = Actual \quad Payload$$

Empty Weight Bonus.

EWB can only be obtained in the first flight round of competition. A 10 point Empty Weight Bonus (EWB) will be awarded if a successful flight with zero (0) payload achieved.

Total Penalty Points.

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

$$A_0 = \frac{(Successful \quad Flight \quad Round)}{(Successful \quad Flight \quad Round + Missed \quad Flight \quad Round)}$$
$$i = 1 + (A_0 - 40\%) \times .25$$
$$Final \quad Flight \quad Score = i \times (Best \quad Flight \quad Score)$$

The overall competition score is to be calculated as the sum of these individual components,

$$\boldsymbol{Overall\ Score = Design\ Report\ Score + Oral\ Presentation\ Score + Flight\ Score}$$

Design Approach

The project methodology is based on seven steps: i) the gathering of information, ii) preliminary studying, iii) conceptual and preliminary studying, iv) project development, v) building of a prototype, vi) ground testing, and vii) flight testing. The following design methodology is a compilation provided by Barros which originates from a synthesis of a methodology presented by Torenbeek (1981), Roskan (1985), Raymer (1989), Vandaele (1962), Stinton (1983), Wood (1968) and Frati (1946).

This methodology presupposes a set of mission requirements and based on these requirements, the design itself will commence. The typical parameters are: payload and type of load, range, cruise speed and altitude, take-off and landing distance, fuel reserves, rate of climb requirements, maneuverability requirements, and certifications basis (i.e. will be adopted based on the FAR part 23 regulation rules as well as the competition`s rules). The data will be collected and estimated using a combination of the competition regulations and studies based on previous designs. The team will couple this data using analytical equations that can be solved by means of an optimization tool. The results of said equations are to be plotted in a chart known as a "design chart"—extremely useful in determining the aircraft`s design point. This will provide enough information to calculate the design lift coefficient in which the preliminary design is heavily based.

The next step is to perform the empty-weight estimation, takeoff-weight buildup, and fuel-fraction estimation. Having this data, it is possible to calculate the wind loads on the aircraft. Determining these parameters will allow us to estimate the wing load which is a vital variable to couple the aerodynamic/structural equations and thus the wing geometry and its respective aspect ratio and stall speed. The design philosophy will prioritize the L/D parameter; this most likely will be done by selecting airfoils with low drag and by fairing the aircraft. The drag estimation methods at the preliminary phase will be those taken from the series of books from ROSKAM. The next step is to choose a suitable airfoil; there is a vast online database featuring several airfoils from all types of aircrafts. The team will select the airfoil that best suits our criterion. If one is not found, the team will design one using inverse methods. At this point, wind tunnel testing will be conducted. The wing design methodology will start with analytical calculations, providing a first design point which will be modeled on the software Tornado VLM that runs on MATLAB. This software will be used to refine the wing planform and to calculate the most suitable twist and dihedral angle, in order to provide good stall characteristics and control. Having determined the wing geometry and its loads, it will be possible to complete the fuselage and tail-unit sizing. Computational tools will be implemented in the stability and control derivatives evaluation, performance evaluation and cost estimation. If the results are satisfactory, the preliminary design phase will be complete. The prototype design phase will consist of more detailed calculations, CFD analysis and wind-tunnel testing. Ultimately, the final phase will consist of extensive ground and flight testing. The flowchart of the design methodology is in the appendix as diagram 1.

Tools

Due to the small scale nature of the project difficulties have arisen trying to apply information from available resources, which are for large airplanes. In many cases however we can scale down formulas to be applicable. There is also a lot of RC airplane enthusiasts that have information and resources online.

We used books on airplane design and analysis, math analysis programs, programs devolved for analysis of airplane components, and programs developed by hobbyist for analyzing RC airplanes.

Programs used include:

- ThrustHP: Propeller, thrust and horsepower analysis
- MathCAD: Unit conversions and calculations
- Xflr5: Tail sizing and stability analysis
- Profili v2.0: Wing and tail profile analysis
- Aximer: Aircraft design calculator

Project Plan

We must make sure to stay within the competition requirements and the FAR requirements at all times. This is highly important due to the fact that we can any time for not adhering to these rules. Within these guidelines we will begin thermal fluid principles required for proper lift, as well as airfoil design to coefficient. These main principles along with the competition requirements mission requirements. Our plans are shown in

Diagram 2: Gannt Chart in the appendix.

We will then move onto basic sizing of the aircraft. The length, wingspan, and height cannot exceed 225 inches; therefore we will need to take these dimension limits into consideration when designing our aircraft. The fuselage and wings will be designed first being as they are the most important. The rest of the aircraft will be based off of these two parts. We are keeping foremost in our minds that our design may change a few times during the preliminary stages. This is to be expected since there will be different ideas from all of the group members.
Our biggest obstacle will be our budget, limiting materials we will be able to use. A composite would be ideal due to its strength and low weight however more expensive. As a team we have brainstormed and concluded that additional funding may be required. We have acquired one sponsor; "High Fly Hobbies" in Daytona Beach Florida. The competition is held in Marietta, GA on April 27- 29 of 2012. Our aircraft will be there and ready to take down the competition.

Cost

Since the design of the aircraft is in a very crude state it is not possible to evaluate its total cost accurately. Several components are required in order to participate in the competition such as: registration fee, transportation, housing, etc., for the team going to competition. Airplane components that will be similar on all models can be analyzed such as: the O.S Engine, set of suitable servo-mechanisms, structure, skin, etc. During the testing of prototypes crashes are likely to happen. Therefore the team will design and build several prototypes in order to test various flying characteristics.

Our budget set by school is $3000. To be prepared for the worst and have a larger budget, there is a necessity for the team to get sponsorship. A hobby store in Daytona Beach called "High Fly Hobbies" will sponsor use by selling us parts at shop cost. Cost analysis is shown in table 3 in appendix. With about $600 in parts and $600 for competition registration, we are left with just over half for competition expenditures and anything extra that may need to be ordered. This estimation is rough and will get better as time gets closer to time to order parts.

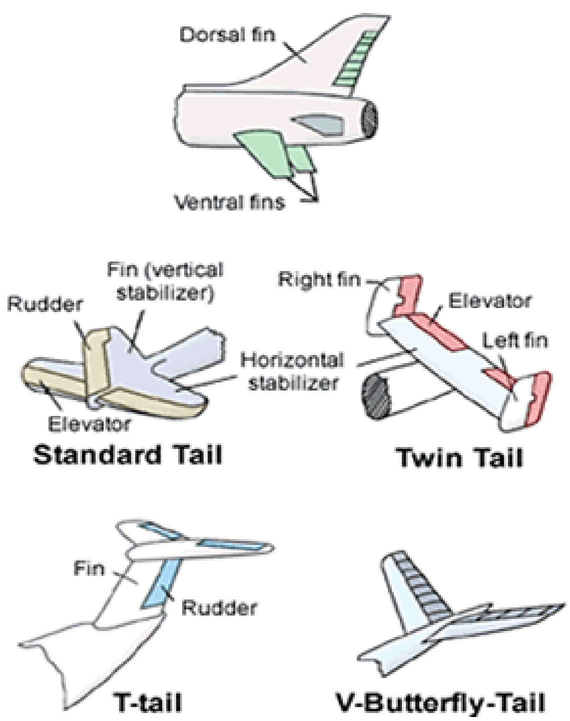
Concept Generation

The general product specifications call for a lightweight, fixed-wing remote-controlled aircraft possessing heavy payload lifting capacity. The aircraft must be able to takeoff in less than 200 feet, ascend, turn completing a 360° lap and finally land in a designated landing zone of 400 feet while carrying its payload. Analyzing and converting the customer needs to product specifications, we have determined the following are desired characteristics for our aircraft: high L/D ratio, high structural efficiency factor, maneuverability, and a high aspect ratio. It is important to attempt to incorporate all of these factors while maintaining a lightweight wing construction as surely this is of utmost importance in our design.

Concept 1: Conventional Design

The conventional aircraft design layout is exactly what its name insists, conventional. This has been the chosen design for flight since the early 1900's. The design has stood the test of time for several key reasons. One reason is because of its durability. The central fuselage allows for a sturdy back bone for the aircraft to be based on. It also allows adequate room for cargo, pilots, and passengers without disturbing the overall air foil dramatically. Possibly it's most important trait is its stability. In most configurations the conventional style aircraft design is extremely stable allowing ease of flight and control. Within the conventional design there are several possible tail layouts that have their own flight characteristics. Several tail layouts are pictured below, tail selection is shown in diagram 4 in the appendix.

Figure 1: Several types of tail configurations



Concept 2: “Flying Wing” Design

A clean flying wing is theoretically the most aerodynamically efficient design configuration for a fixed wing aircraft. It also offers high structural efficiency for a given wing depth, leading to light weight and high fuel efficiency. Because it lacks conventional stabilizing surfaces or the associated control surfaces, in its purest form the flying wing suffers from the inherent disadvantages of being unstable and difficult to control. These compromises are difficult to reconcile, and efforts to do so can reduce or even negate the expected advantages of the flying wing design, such as reductions in weight and drag. This concept will required a special airfoil that makes the aircraft stable without a tail.

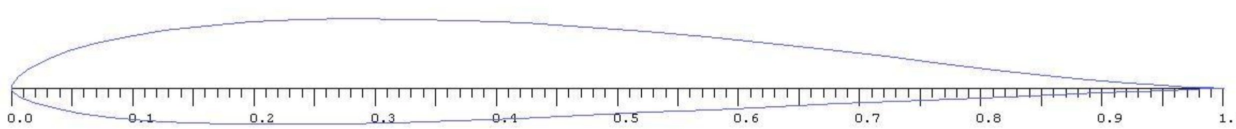


Figure 2- Flying wing examples with Airfoil

Concept 3: Minimalist Design

The minimalist design is intended to minimize the amount of material used to construct the aircraft while maintaining the integrity of a structurally sound, maneuverable airplane. Constructing an aircraft in this manner facilitates the possibility for creating a lightweight fuselage and airframe. These factors are important because minimizing the weight of the airframe gives one the ability to allocate more material to constructing a larger wing. A larger wing therefore provides more lift surface area for an optimized lift force. Many minimalist designs incorporate a “boom pole” style airframe rear which attaches to the aircraft’s aft. Not only does this reduce the total weight of the aircraft but it also minimizes the drag induced on the aircraft by the free flow air stream while in flight. It is plausible to use carbon composite tubing in combination with either a conventional tail or H-tail, in order to compensate for the possible loss in flight stability, to ensure the lightest weight while maintaining control of the aircraft. Some issues that may arise with this design option are the doubt in the aircraft’s ability to attain high wing load configurations in the presence of heavy wind gusts. Lacking uniformly distributed mass inhibits this capability thus the strength of the overall aircraft becomes of concern when weighed against variables that may not be in our control such as weather conditions.

Figure 3: UFPR aircraft implementing two carbon fiber tubes connecting the aft to the airframe

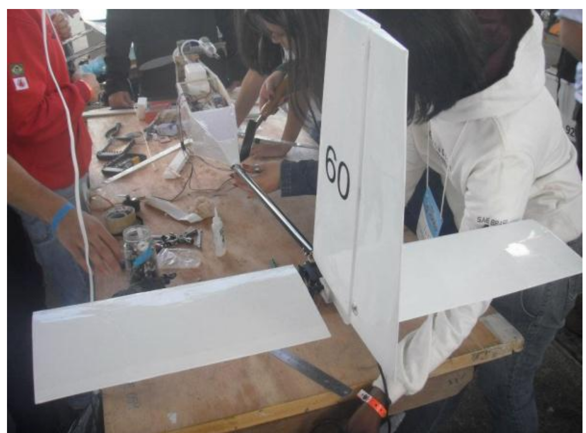


Figure 4: Lightweight, minimalist design featured at SAE Brazil Aerodesign competition

Concept 4: Canard Wing Design

Canard wing design is an application to aircraft that is not widely used. The basic idea behind the design is a two-wing application where the front wing is smaller than the back wing. On some designs, the front wing is almost as large as the rear wing. The main reason for this design is to increase lift on the aircraft. While this is accomplished by the unique wing layout, there can be negative effects, such as airflow disruption from the front wing to the back wing. When designing a canard wing system, it is very important to choose the appropriate length for the canard. There exists little room for error in this selection. The smallest change in length can drastically alter the flying performance of the aircraft. Throughout the years, many different types of planes have successfully adapted the canard wing design. From private use to military jets, canard wing design can be found in almost every type of application. Pictured below are some of the more successful designs.

Figure 5: Solo aircraft with a Canard-style wing

Figure 6: Commercial jet using Canard style wing

Concept 5: Bi-Plane Design

A bi-plane is an aircraft with two fixed main wings. The bi-plane dominated aviation history for the first 30 years following the Wright brothers' Wright Flyer design. This wing structure influenced the Wright brothers from a civil engineer and his concepts in bridge building. Early airfoils were thin requiring external bracings, therefore the bi-plane is perfect as its arrangement and truss-like bridge structure provides for more structural efficiency than an externally braced monoplane.

Bi-planes are assumed to lift twice as much as a similar chord monoplane; however this is not the case. The wings actually interfere with the aerodynamics of one another, reducing lift and increasing drag. A simple alteration is seen in the case of tandem wing, when the bottom wing is placed at the front of the aircraft and top at the back, giving a advantage of 20% more lift than a single wing but also gives higher tip vortex drag than the equivalent monoplane. Bi-planes typically have a shorter wingspan however, giving greater maneuverability. Now with thicker stronger airfoils, the bi-plane is mainly used for recreation.

Figure 7: Bi-Plane design seen at the Brazil Aerodesign competition

As for creating a RC bi-plane for competition, the advantages to the flight score look slim to none as drag is increased and lift is decreased to a standard monoplane, and any advantages to an alteration to the bi-plane (tandem) will be time consuming and difficult to perfect. The large size and structure of the biplane maybe costlier in terms of material costs and build time. Advantages will come in form of lightweight and strong wings wing structure and greater maneuverability.

Concept Selection

The monoplane model was adopted because of its low drag compared to a biplane configuration. The high-wing configuration gives a better aerodynamic efficiency and a higher lateral stability. The wing planform has a trapezoidal format, which can reach an Oswald factor of 0.99 by proper positioning and taper ratio selection. This aircraft also has an engine with a tractor configuration.

Concept Analysis

Aerodynamics

The aerodynamic analysis consisted in evaluating the lift and drag of each aircraft part. This made possible to find an initial configuration that satisfy the mission profile. The next step consisted in several interactions in order to refine the wing designed. All equations are found in the Pullin reference.

Profile Selection

This competitions main flight purpose is to carry as much payload as possible. As Raymer points out the “airfoil is the heart of the airplane”. It is reasonable to start the design by analyzing existing airfoils. The first step is to determine which classes of airfoils are more appropriated for the mission profile, since each flow regime has its own issues. The fastest and most reliable way is to calculate flow regime is with Reynolds number. The reference length was chosen to be a typical value of chord l = 0.40 m, standard conditions for temperature and pressure (dry air density ρ is 1.293 kg/m^3, air viscosity μ is 1.78 $\times 10^{-5}$ kg/(m*s)) and a reference speed V = 10 m/s were assumed.

$$Reynolds = \frac{\rho V}{\mu} = 2.906 \times 10^5$$

Therefore, the Reynolds number regime chosen was 3E5. We can conclude that we have to work on a low Reynolds regime which is predominately dominated by laminar flow and inclined to the formation of laminar bubbles on the upper camber. Using the database the airfoils design for high-lift at low Reynolds number were selected to be studied: Liebeck LD-X17A, Selig 1223, Selig 1223 RTL, Wortman FX-74-CL5 1223. The analysis was conducted in XFOIL which uses free transition (e^n) method with NCrit = 9.

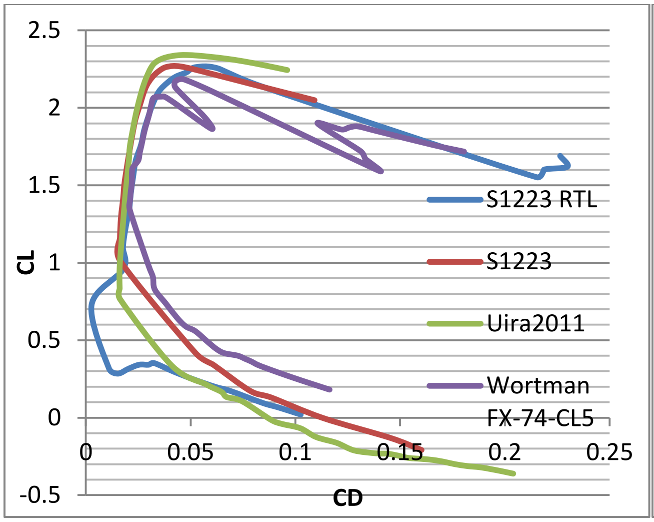


Figure 8: Coefficient of lift vs. Coefficient of drag

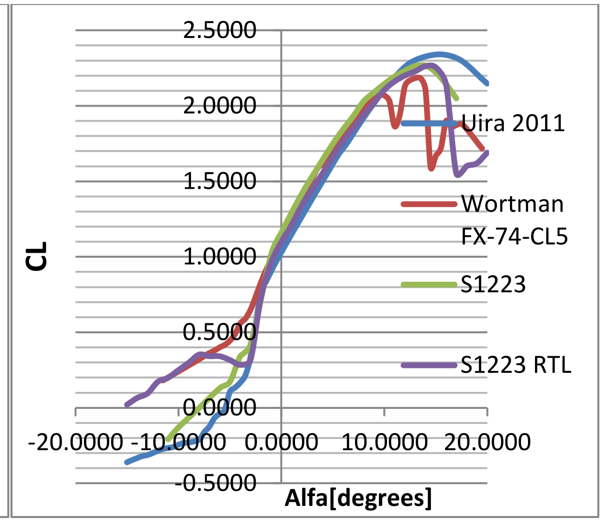


Figure 9: Coefficient of lift vs. Angle of attack

Profile Description

The airfoil chosen has being renamed to Uira2011. It was designed to operate at low-Reynolds regime, providing smooth stall capabilities. Its main data are summarized below:

Airfoil data calculate for Cl_max:

- Lift Coefficient = 2.34
- Drag Coefficient = 0.048
- L/D = 48.8
- Moment Coefficient = -0.202

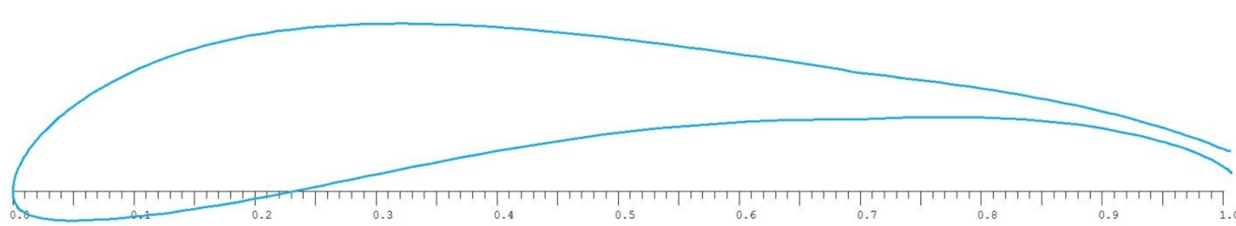


Figure 10: Uira2011 Airfoil

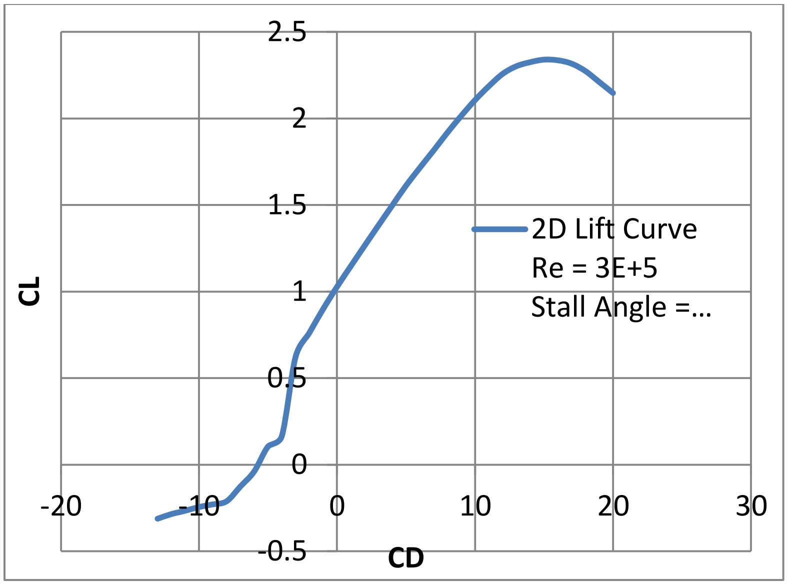


Figure 11: Drag Polar

Drag Polar

The drag polar is represented by a graph. The total drag is the sum of the parasite drag and induced drag caused by the aircraft`s lift.

$$C_D = C_{D0} + C_{Di}$$

The induced drag is given by $\frac{C_L^2}{\pi eAR}$, substituting in the equation above we have:

$$C_D = C_{D0} + \frac{C_L^2}{\pi eAR}$$

Wing Lift Calculation

From the thin airfoil theory, it is possible to estimate the lift slope for an airfoil. This method is used here to a finite wing. We approximate the 3D wing to several stations. The average lift slope then can be found

$$a_0 = \sum_{i=1}^{n} \frac{S_t a_{0t}}{S}$$

This value makes possible to calculate the lift-slope of the wing by using:

$$a = \frac{a_0}{1+\frac{a_0}{\pi eAR}} \qquad \text{and} \qquad C_L = \frac{a}{a_0} C_l$$

Wing Drag

The parasite drag and induced drag should be considered:

$$C_{D0} = C_d \frac{S_e}{S}$$

$$C_{Di} = \frac{C_L^2}{\pi ARe}$$

Tail Lift & Drag

By the definition of lift, only the elevator generates lift, therefore:

$$C_{Lelevator} = \eta \frac{a}{a_0} C_l$$

Tail unit drag calculation (Horizontal and vertical) are givin with:

$$C_{D0} = C_d \frac{S_{tailunit}}{S}$$

$$C_{Dt} = \frac{C_{Ltailunit}^2}{\pi ARe}$$

Fuselage Drag

The fuselage drag is estimated by the following equation found in [X]:

$$C_{D0} = C_{wf} C_f \left(1 + \frac{60}{(l_f/d_f)^3} + 0.0025(l_f/d_f\right) \times \frac{S_{wet}}{S}$$

Miscellaneous Drag Calculation

Consulting [5] we can estimate that the aircraft total drag with a fixed landing gear will be around 0.428. The team considered this number a little over exaggerated. Further analysis will be carried out.

We guess that we should sum up 10% on the drag to account for miscellanea drag. This would account for antenna`s drag, protuberances and surface roughness differences.

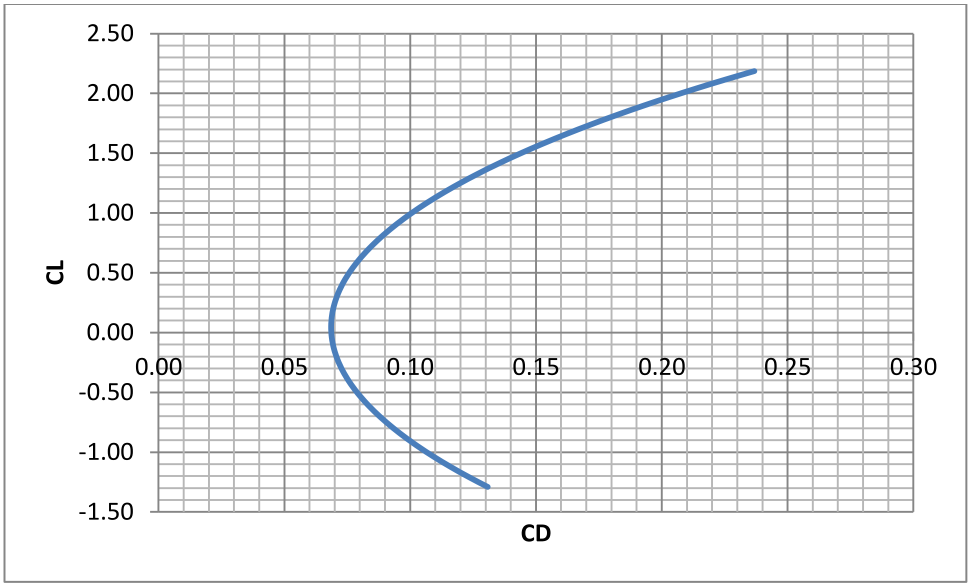


Figure 12: Coefficient of lift to Coefficient of drag for Uira2011

Wing Design

The method utilized to evaluate the wing aerodynamic properties was VLM(Vortex Lattice Method) implemented in XFLR5 and in CEA-VLM. This was chosen since it provide reliable data in short-time, being a great tool for optimization procedures. This optimization consisted in running several iterations varying the following parameters: A. Wingspan, B. Wing root and chord, C.Taper ratio and its position. Its overall consequences to the wing weight, wing lift and drag were considered. The process was monitored by the Oswald‘s factor. The final result is summarized in the table and in the graphs below:

Table 1: Wing Data

Wingspan	2.7 m
Root Chord	0.32 m
Tip Chord	0.16 m
M.A.C	0.28 m
Tip Twist	-2 degrees
Wing Area	0.728 m²
Aspect Ratio	10
Taper Ratio	2
Profile	Uira 1540

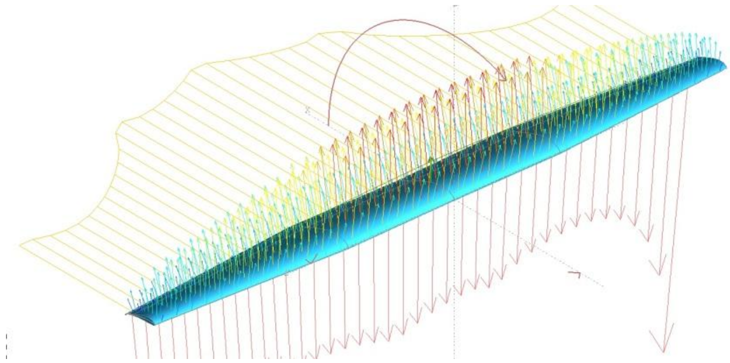


Figure 13: Bending moment and Lift coefficient along wing

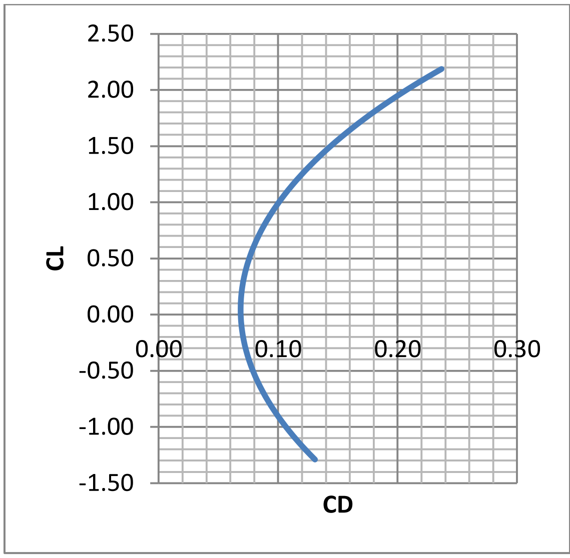


Figure 14: Wing lift vs. drag coefficient

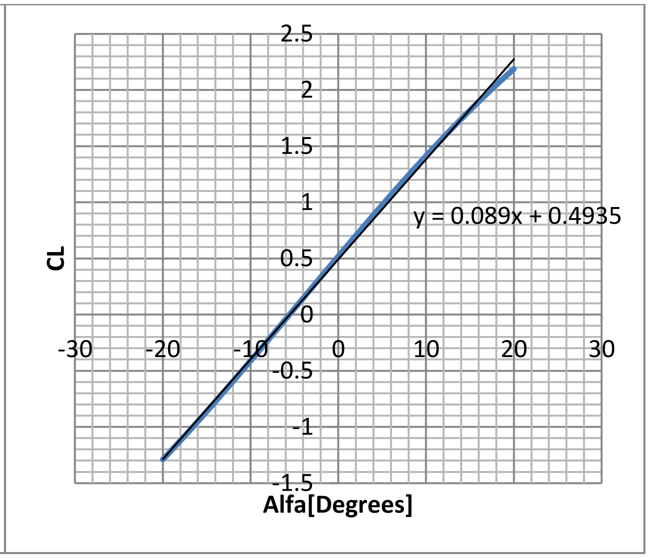


Figure 15: Wing lift coefficient vs. Angle of attack

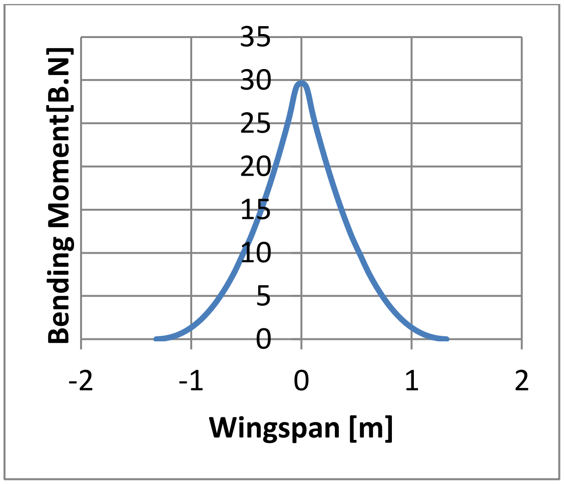


Figure 16: Bending moment along wingspan

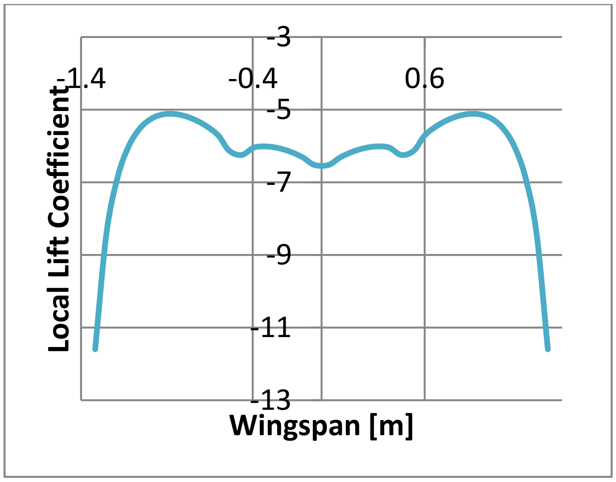


Figure 17: Coefficient of lift along wingspan

Stability and Control

Introduction

Aircrafts are not naturally stable. They must be designed to fly in a stable manner where when disturbed they will return to their original state within a set amount of time and with little to no pilot input for correction. The plane can be modeled dynamically as a spring-damper system like a car but with a few more directional variables. Conventional aircraft layouts gain the majority of their stability from the horizontal and vertical stabilizers mounted on the tail of the fuselage. The horizontal stabilizer contains the elevator which controls the planes pitch and pitch characteristics as well as trims out unwanted steady climb or descent. The vertical stabilizer controls the planes yaw and helps straighten the aircraft during landing without having to use the ailerons.

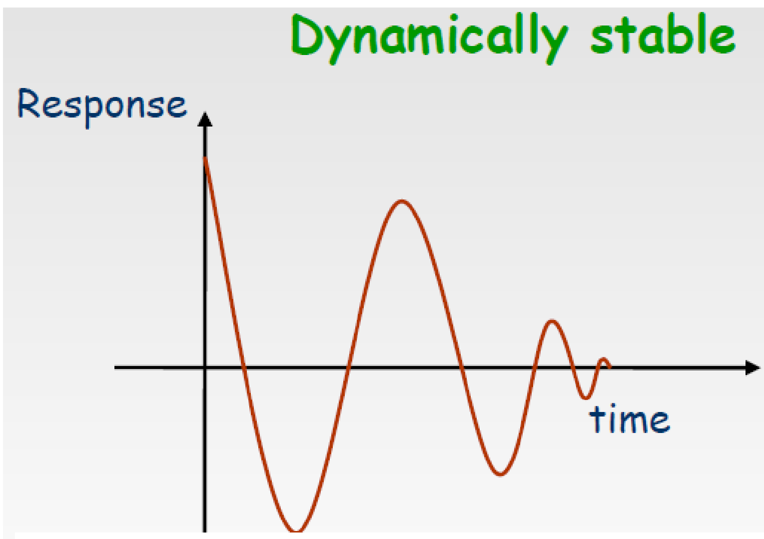


Figure 18: Standard time/response graph of an under damped spring-damper system

Trim

Due to center of gravity shift and properties of different airfoils, natural aircraft flight produces pitching moments. The moments can be reduced through simulation analysis although the simulations are not 100% accurate to real world results. There will almost always be a small pitching moment that will need to be adjusted for in-flight. This can be done using the elevator and a function in almost all radio controllers called trim; which moves the natural placement of the elevator to a position that creates a counter moment on the center of gravity. The expense of this is reduced lift, higher drag, and lower efficiency. This is why it is important to configure the aircraft's center of gravity and tail configuration in a way that produces the lowest magnitude pitch moment possible.

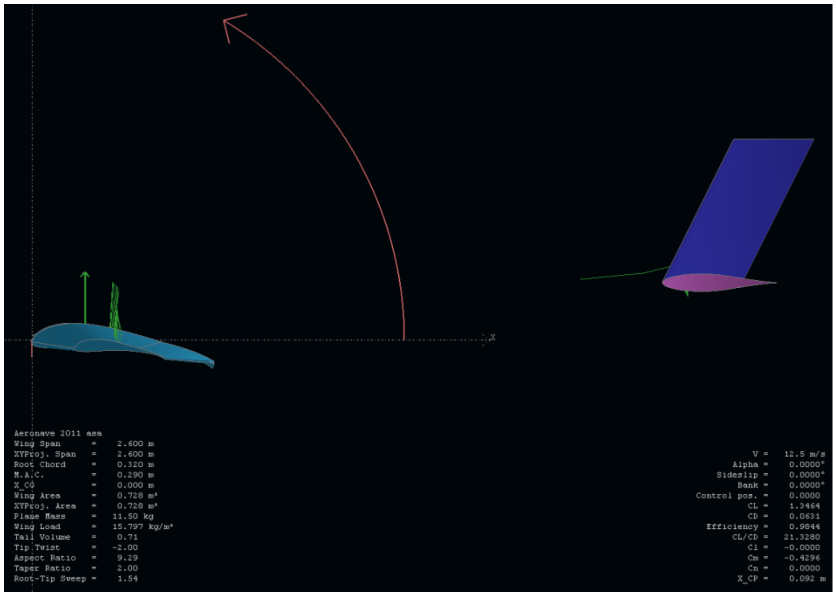


Figure 19: Initial moment magnitude before tail adjustment

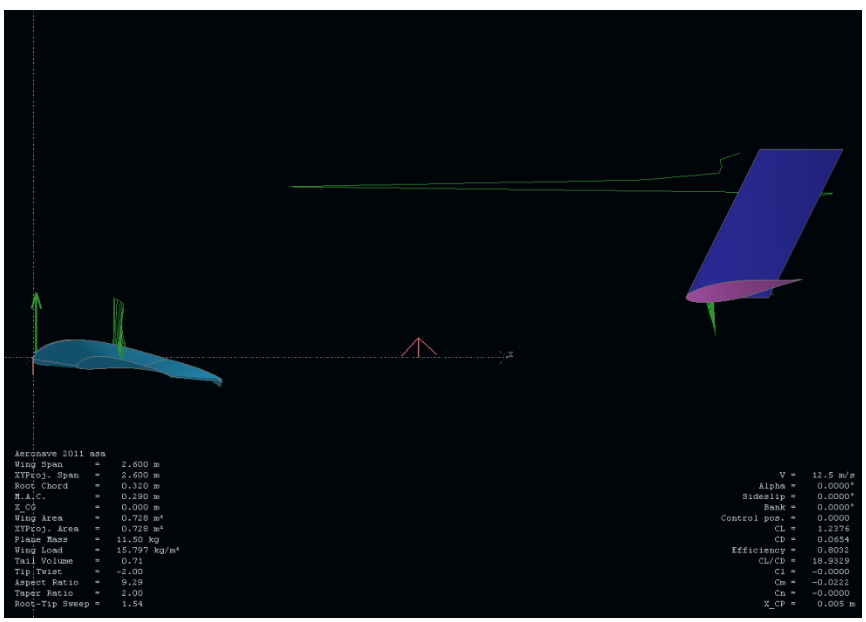


Figure 20: Moment magnitude greatly reduced after tail tuning

Stability

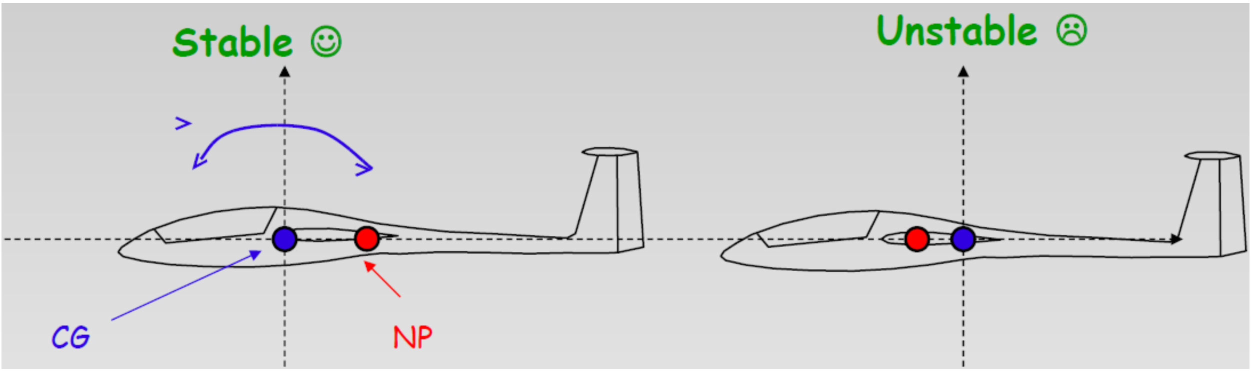


Figure 21: Stable and unstable aircrafts with a center of gravity in front of and behind the neutral

Performance

Competition regulations limit the motor used; therefore with the OS 61 FX we are given 1.9 bhp from the motor owner's manual. The engines purpose is to reliably and efficiently provide thrust to propel the aircraft. Brake horsepower is a measure of the horsepower before losses in power from components in the motor. The propeller generates thrust corresponding to the aerodynamic lift generated on the rotors, with drag from friction, form, induced and wave. The trust available is created by the OS61FX engine.

Thrust-to-Weight Ratio (T/W)

The thrust to weight ratio directly affects the aircraft's performance. An aircraft with a higher T/W ratio exhibits higher acceleration rates, climb rates and has the ability to reach higher maximum speeds while sustaining an optimum turn rate/radius. The T/W ratio is calculates in terms of sea-level and standard-day conditions for transport aircraft. For our calculation purposes we assumed both sea-level and standard day conditions. Furthermore, the take-off distance requirement of 200 feet (61 m) was implemented as a maximum in order to calculate T/W using the following equation,

$$s_g = \frac{1.21 * \frac{W}{S}}{g * \rho_\infty * C_L * \frac{T}{W}}$$

where s_g represents the take-off requirement of 200 feet, g is the gravity constant 32.2 ft/s^2, W/S is wing loading of 6.03 lb/ft^2, ρ is the air density at sea-level of 0.002377 slugs/ft^3, and C_L is the coefficient of lift of 2.34. Rearranging the equation to solve for T/W yields the following,

$$\frac{T}{W} = \frac{1.21 * 6.03}{32.2 * 0.002377 * 2.34 * 200} \approx 0.204$$

Power Required (P_R)

Having calculated the thrust-to-weight ratio we are now able to determine the required power (P_R) at takeoff which is designated by the following formula,

$$P_R = \frac{T}{W} * W_o * V$$

where W_o is the maximum gross weight of our aircraft including our maximum design payload of 35 lbs. and *V* is the cruise velocity represented by 70% of the liftoff velocity (V_{LO}) where liftoff velocity is approximated by $V_{LO} = 1.1V_{stall}$. Obtaining V_{Stall} from the spreadsheet in appendix diagram 5, we can determine the *V* and derive required power as the following,

$$P_R = 0.204 * 47lbs * 35.8435\frac{ft}{s} = 343.67\frac{lb*ft}{s}$$

This value represents the required power to take-off with a gross weight of 47 lbs. within the distance requirement of 200 feet at the specified cruise velocity. Since the power required must be equal to the available power this implies that the propeller is operating at some efficiency which according to literature has a general value of 0.85. Thus, we can now verify that our motor is able to offer the appropriate power for our given payload and velocity conditions using the equation,

$$P = \frac{P_R}{n_{prop}}$$

This yields an available power of 404.315 $\frac{lb*ft}{s}$ which if converted to horsepower yields 0.735 hp and reveals the Magnum XL 0.S 61 FX engine is powerful enough to provide the appropriate thrust for take-off at the given conditions.

Propeller Selection

This propeller drag is a loss mechanism robing the engine of net power output for thrust; thus available power is always less than the engine power. The efficiency of the propeller at producing thrust can be calculated based on the change in velocity before and after the rotor. Propeller efficiency improves as the diameter gets larger, as more mass flow of air is processed: however there are constraints that include tips clearing the ground and tips speeds less than the speed of sound. It should be optimized to convert the engine power by adjusting the diameter and number of blades.

Propellers can be sized with simple formulas that depend on the number of blades. For 2-blades:

$$D = 22 * hp^{0.25}$$

Table 2- Recommended propellers: estimated RPM, static thrust, and coefficient of thrust.

Recommended Sport Props				
Diameter (in)	Pitch (in)	RPM	ST (lb)	C.t
12	6	11675	8.48	0.029
12	7	11100	7.66	0.026
12	8	10600	6.99	0.024
13	6	10500	9.44	0.033
13	6	10500	8.91	0.031
13	7	10000	8.57	0.03

Blade helical speeds is the resultant of the blade tip speed and the flying speed, and ideally is designed under the speed of sound and below a critical speed dependent on the material which, in small cases, is negligible. Comparing our answer with our horsepower given to typical research on blades for the engine, this gives a larger that recommended diameter. Online research recommends "MasterScrew 13x6" rotor, giving an actual rotation of about 11,000 rpm.

Given on the motor manufactures website this engine should be combined with a 12-13" diameter and 6-8" pitch for sport purposes. Using ThrustHP to input: diameter, pitch, blade count, type (chose APC); we approximated values of the RPM to match the power available, estimated power of motor for thrust at 80% efficiency to about 1.42 bhp) recording the RPM to be used in propeller analysis. Varying the type in the program showed that APC had a higher coefficient of thrust than Master Airscrew. Cost for the APC is $4 however compared to $3.

Wing Loading (W/S)

The wing loading is the weight of the aircraft divided by the area of the reference wing. The wing loading directly affects stall speed, climb rate, turn performance, and take-off and landing distances. The sizing of the wing is heavily influenced by the wing loading—if the wing loading is reduced, the wing is larger. The wing loading and thrust-to-weight ratio must be optimized together in order to ensure the tradeoff between better aerodynamic performance and increases in drag and weight is not detrimental to the functionality of the aircraft. Wing loading (W/S) can be found using the following equation,

$$\frac{W}{S} = 0.5 * \rho_{\infty} * V_{stall}{}^{2} * C_L = 6.03\frac{lb}{ft^2}$$

Thrust vs. Cruise Speed

In our analysis we were able to obtain a graph of drag and cruise thrusts over a range of velocities from the spreadsheet in appendix diagram 5. Conventional versions may appear different from that of our own but this can be attributed to the fact that the Reynold's number we are working in is purely laminar thus the air velocities represented in the graph are not entirely realistic for our particular application.

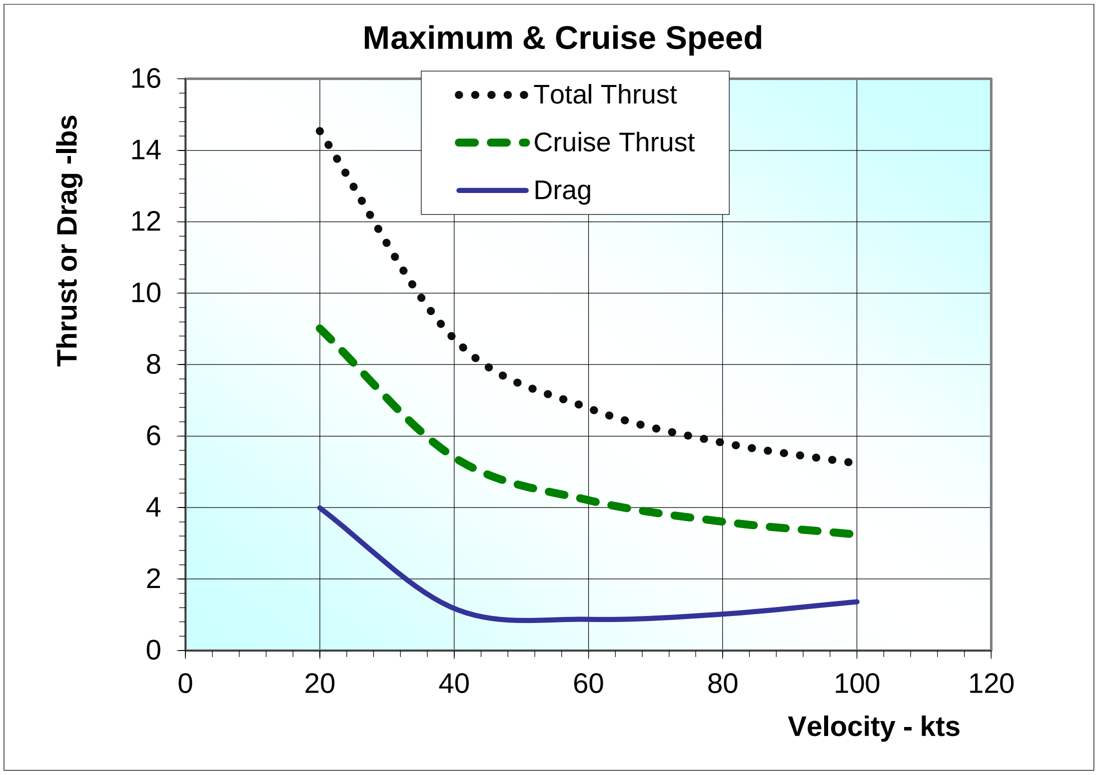


Figure 22: Thrusts and drag distribution over range of velocities

As seen in the graph, the drag is initially high and gradually decreases as the aircraft lifts off and begins to achieve its appropriate cruising speed where the weight of the aircraft equals the lift force thus resulting in stable flight conditions. Also, note the drag begins the increase as the velocity continues increasing. At that point the aircraft begins to experience other forms of drag as it transitions from purely laminar boundary layer over the wing profile to a profile experiencing turbulence thus higher drag coefficients.

Climb Rate

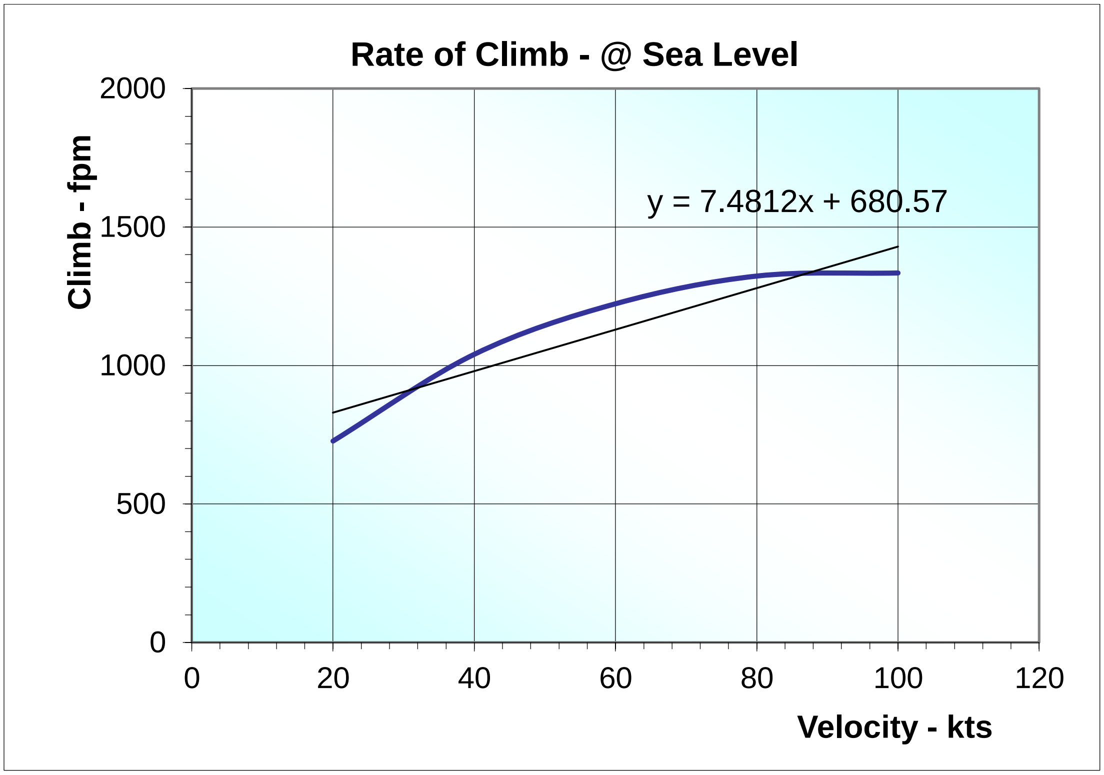


Figure 23: Climb rate vs. Velocity

The rate of climb is a vertical velocity which characterizes how rate at which your aircraft can shift to from a given altitude to a higher altitude. The graph above was generated using the analysis spreadsheet and exhibits a fairly gradual climb rate followed by an asymptotic level off at higher values of velocities. The leveling off the climb rate demonstrates the concept of a maximum ceiling which means the climb gradient has become nearly zero or in more practical terms level flight can be achieved for the given altitude. Our design parameters were structured around an altitude of 3000 feet which is an overshot value just for our preliminary design purposes thus the leveling off occurring at less than 1500 feet is logical. The climb rate can be altered if the angle of attack is adjusted for a given wind speed and must be controlled at takeoff because too quick of a climb could result in instability during the ascent to cruise altitude.

Load Factor (N)

The load factor is a ratio of the lift of an aircraft to its weight and represents a global measure of stress to which the structure of the aircraft is subjected. By calculating the lift at the cruise velocity where the aircraft would achieve stability we determine the lift to be approximately 27.87 lbs of force we can use the following equation to determine the load factor (n),

$$n = \frac{L}{W_{empty}} = \frac{27.78}{12} = 2.315$$

With regards to tuning performance, it is advisable to design your aircraft with the maximum possible load factor as this factor determines the turning performance of your aircraft. The following equation can be used to calculate the maximum load factor for our design preliminary design constraints,

$$n_{max} = 0.5 * \rho_{\infty} * {V_{\infty}}^{2} * \frac{C_L}{\frac{W_{empty}}{S}} = 0.5 * 0.002377 * 35.8435^2 * \frac{2.34}{1.54} \approx 2.322$$

The maximum load factor can be used to calculate the maximum bank angle the aircraft can safely assume without banking into a crash landing. The following expression is used to find the maximum bank angle,

$$\cos(\theta_{max}) = \frac{1}{n_{max}}$$

Rewriting the equation and applying the inverse cosine reveals a maximum bank angle of about 64.5°. This implies that our aircraft has decent stability making turns at cruising speeds of about 35.8 fps. Increasing velocity values will decrease the range of angles in which stability can be achieved during a banking turn.

Environment & Safety

Environment

The primary environmental concern with remote control fuel airplanes is the exhaust fumes that are expelled from the internal combustion engine that gives it its thrust. Most remote controlled aircraft engines run on 10-30% nitro methane fuel. Nitro methane requires less air per unit of fuel to burn compared to gasoline so each combustion stroke will burn more fuel than a comparable gasoline engine. Nitro methane offers higher cylinder pressures compared to gasoline though which requires less nitro methane to be used than gasoline. OS .61 engines similar to the Magnum XL 0.61 engine required for this design competition has a fuel consumption rate of about 1.5 oz./min. The total time our engine will be run including break-in time, prototype testing, and competition should be roughly 6 hours or more. That means about 540 oz. (39.6 lbs.) of fuel total could potentially be burnt. The competition requires us to use 10% nitro methane so only 54 oz. (4.0lbs) will be actual nitro methane. Nitro methane, when combusted creates carbon dioxide gas, nitrogen gas, and water vapor; as shown in the reaction equation below:

$$4CH_3NO_2 + 3O_2 \rightarrow 4CO_2 + 6H_2O + 2N_2$$

With carbon dioxide being a major greenhouse gas produced in the reaction. If there was complete combustion every time, around 4 or more pounds of CO_2 gas would be released into the atmosphere over the course of the spring semester. The average passenger car gives off 0.916 lbs. of carbon dioxide per mile; thus the average car would reach our semester long total of CO_2 produced in 0.61 engine with less than 5 miles. This proves that our plane will not produce a significant contribution to impact the environment.

Safety

The primary safety concerns when flying a remote controlled airplane are propeller strike with fingers, nitro methane inhalation, and being hit by a flying aircraft. Some safety procedures that can be practiced to avoid injuries include:

- Always keep fingers clear of a running engine

- When revving up, hold engine from vertical stabilizer, not behind engine or on wing leading edge
- Always refuel the aircraft in a well-ventilated area
- Keep fuel away from outside ignition sources
- All members of team keep an eye on the flying aircraft at all times
- Never fly more than one plane at a time
- When possible, wear hardhats when in the fly zone

References

http://xflr5.sourceforge.net/docs/XFLR5_and_Stability_analysis.pdf

Online research recommends "Master Airscrew 13x6"
http://www.youtube.com/watch?v=S_805JeISdE

[1] PULLIN, D., “Apostila de Aerodinâmica do Avião”, UFMG, Belo Horizonte, 1976.
[5] ROSKAN, J. “Airplane Design: Preliminary Sizing of Airplanes”, Outtowo, Kansas: Roskam Aviation and Engineering Corporation, 1985.
[X]Database: http://www.ae.illinois.edu/m-selig/ads/coord_database.html

Appendix

Diagram 1: Design Methodology

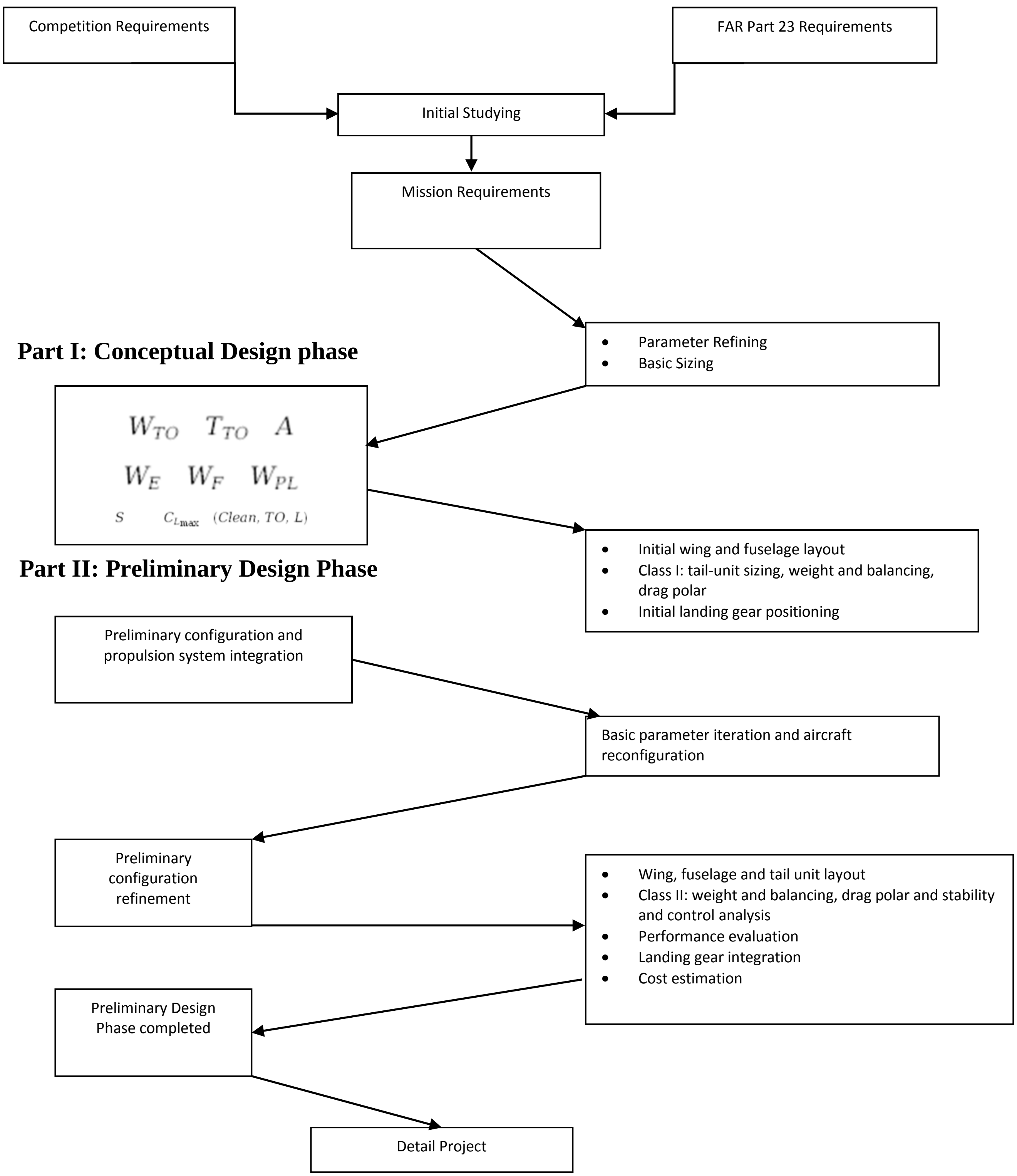
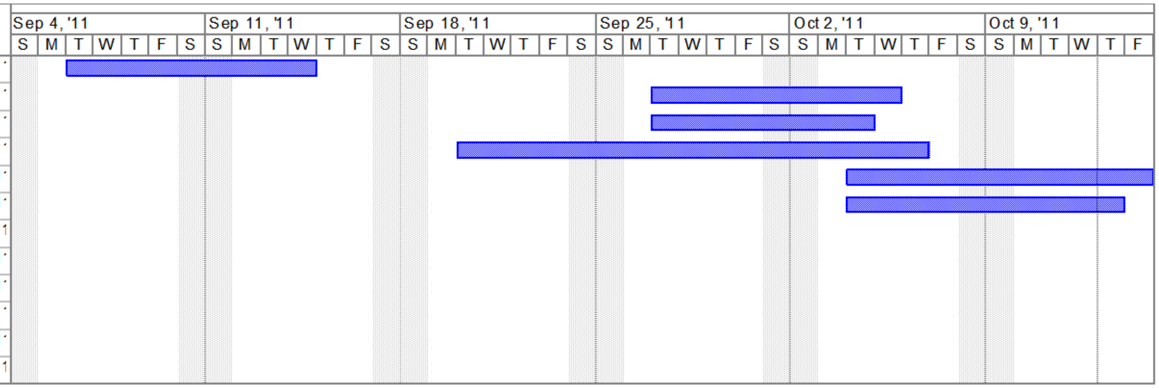


Diagram 2: Gannt Chart

ID		Task Name	Duration	Start	Finish
1		Ice Breaker	7 days	Tue 9/6/11	Wed 9/14/1
2		Code of Conduct	7 days	Tue 9/27/1	Wed 10/5/1
3		Rules Research	6 days	Tue 9/27/1	Tue 10/4/1
4		Needs Assessment/Project Scope	13 days	Tue 9/20/1	Thu 10/6/1
5		Register with SAE Aero East	55 days?	Tue 10/4/1	Mon 12/19/1
6		Product Specification Project Plan	8 days	Tue 10/4/1	Thu 10/13/1
7		Design Research	40 days?	Mon 10/17/1	Fri 12/9/11
8		Wing Design Testing	5 days?	Mon 10/17/1	Sun 10/23/1
9		Fuselage Design Testing	5 days?	Mon 10/24/1	Sun 10/30/1
10		Controls Design Testing	5 days?	Mon 10/31/1	Sun 11/6/1
11		Materials Testing and Selection	5 days?	Mon 11/7/1	Sun 11/13/1
12		Order Parts	5 days?	Mon 12/5/1	Fri 12/9/11



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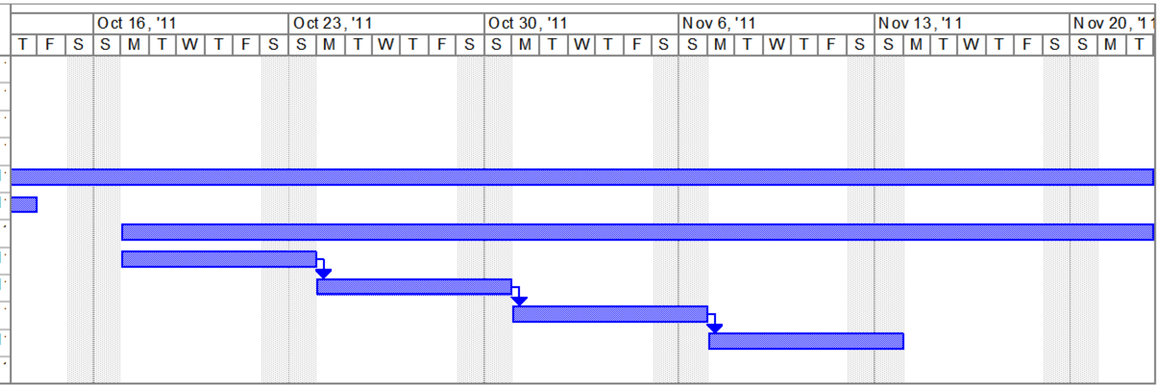

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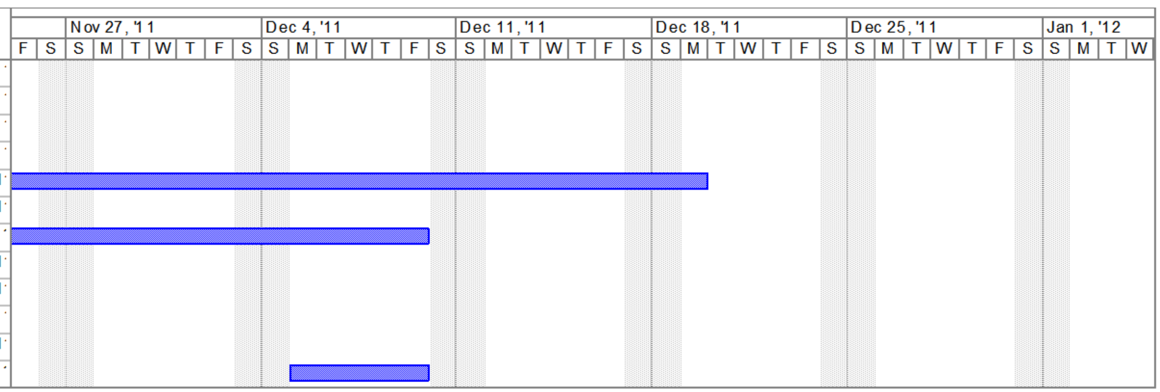

Diagram 3: Cost Analysis

Item	Description	Quantity	Cost
Engine	Magnum xls 61	1	$99
Balsa Wood	Structure of aircraft, various lengths and shapes	~50 ft.	$100
Monokote	Skin around structure	~50 sq. ft.	$60
Servos	Controls flaps (elevator, aileron, rudder, etc.)	5	$125
Fuel Tank	Holds fuel within fuselage	1	$5
Battery	Powers servos and receiver	1	$15
Radio and receiver	Radio controller for the plane and the receiver to send control functions to servos	1	$0
Miscellaneous Items	Wheels, pushrods, hardware, engine mounts, propeller	TBD	$75-$150
Shipping	Will be Shipping supplies from high fly hobbies located in Daytona Beach, FL	2-3	$14.95(per box)
Total		*estimate	*$509-$600

Diagram 4: Tail Design Decision Matrix

Figure of Merit	Weighting factor	Conventional	T-tail	H-tail
Drag	0.20	3	2	1
Ease of Build	0.10	5	3	2
Maneuverability	0.15	3	4	5
Stability	0.35	4	4	5
Weight	0.20	4	4	3
Total	1.00	3.75	3.5	3.5

Diagram 5: Aircraft Design Analysis Spreadsheet

Daniel Raymer Aircraft Design Spreadsheet

	Inputs			Calculated Values		
Wing Loading	Stall speed	(kts)	27.58	Stall speed	(ft/sec)	46.6
	Takeoff air density	(slugs/ft^3)	0.002377	Dynamic pressure	(psf)	2.6
	Wing CLmax		2.34	Wing loading (W/S)	(psf)	6.03
	power loading	(lb/hp)	24.737			
Wo -known engine	*If sizing to a range requirement, ignore this input for now but enter it later when Wo is calculated and engine is selected*			*You cannot enter Wo! Engine power and power loading are multiplied to calculate Wo. If sizing to a range requirement, do calculation below, read Wo from graph, and select an engine that gives the desired Wo=P*P/W*		
	Engine Power	(hp -each)	1.9	Wo	(lb)	47.0
	Number of Engines		1	Wing Area	(sq ft)	7.8
Wo Sizing to a range requirement (engine is not yet selected)	Swet/Sref		2.056			
	Cfe		0.002423	Cdo		0.0050
	Aspect ratio (A)		10	K (=1/piAe)		0.0424
	Cruise air density	(slugs/ft^3)	0.00218	W/S cruise		5.9
	Cruise velocity	(kts)	33	Cruise velocity	(ft/sec)	55.7
				Dynamic pressure	(psf)	3.4
				L/D cruise		12.96
	Engine SFC	(lb/hour /bhp)	1.971	Engine SFC	(lb/sec /bhp)	0.0005475
	Prop Efficiency (cruise)		0.85			
	Range	(nmi)	0.4	Range	(ft)	2430.4
				Breguet Exponent		0.0002
				Wf/Wo		0.0252
	Fuel allowance	(%)	2	Wf/Wo with allow.		0.0257
	Empty Weight constant "a"		0.91			
	Weight - crew	(lbs)	0			
	Weight - Passengers	(lbs)	0			
	Weight - payload	(lbs)	35	See Sizing Graph sheet for Wo Results		
Wing Geometry	Wing taper ratio		2	Wing Span	(ft)	8.83
				Root Chord	(ft)	0.59
				Tip Chord	(ft)	1.18
				Mean Chord	(ft)	0.92
Tail Sizing	Horizontal tail arm	(ft)	1.5	Tail areas:		
	Cht (volume coeff)		0.6	Sht (horizontal)	(sq ft)	2.85
	Vertical tail arm	(ft)	0.67			
	Cvt (volume coeff)		0.015	Svt (vertical)	(sq ft)	1.54