SAE AERO-2 MICRO CLASS

Design Report 2

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DISCLAIMER

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EXECUTIVE SUMMARY

The SAE Aero Micro Class competition encompasses the process of creating a small-scale remote-controlled plane that is capable of holding a payload as well as taking off and landing in a set constraint. The goal of this competition is to complete several different aerodynamic and flight stability calculations to first prototype the plane, then later create a final design that fits within all the given requirements. This project allows team members to learn and build valuable skills in the aerospace engineering discipline.

The primary design constraints for this competition include utilizing a small (2-4ft) wingspan, being able to carry a payload of at least 67 fluid ounces of water, keeping the final design under a weight limit of 55 pounds, and being able to take off within the given 100-foot runway. To maximize the flight score, the team will need to make the plane as small as possible while still being able to stabilize during the flight.

This specific team consists of a fuselage design lead, wing design lead, electronics specialist, landing gear specialist, website developer, fundraising lead, and budget liaison. All these roles work with each other to ensure all deliverables are met, and the product is being designed to certain specifications.

Throughout the current stage of this project, the team has managed to complete several initial calculations to ensure a structural sound and viable design. These calculations include aerodynamic aspects such as choosing the best airfoils for the applications, correct plane geometries (ailerons, elevators, rudders, fuselage, and wingspan). Other calculations performed include MATLAB optimization to achieve the best possible flight scores given several initial parameters, power production, and landing gear analysis. Methods used for these calculations include FEA simulations, aerodynamic and airfoil simulations, CAD modeling, and coding optimization.

As well as calculations, many design decisions have been made during this period. These decisions were made from decision matrices based on several different concepts generated from brainstorming and research. Each subassembly was optimized during this point to create the best outcome for not only the first prototype but the final design as a whole.

Regarding prototyping and manufacturing the team is now designing our third prototype. This involves several different revisions of CAD models to ensure weight reduction throughout every part, as well as compatibility. All major subassemblies (fuselage, main wings, tail wings, and landing gear) have been redesigned for a third prototype that is built to all correct geometries and utilizes all aspects of the design rules.

The next steps throughout this project and competition include refining our individual aerospace knowledge as well as iterating the processes to create an outcome that will not only perform come competition but also achieve a high flight score and surpass the achievements throughout past NAU Aero teams.

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1 BACKGROUND

1.1 Project Description

This project presents an excellent opportunity for our team members to dive into the aerospace field and apply technical knowledge gained throughout our undergraduate education. The Aero competition challenges its participants to engage in every step of the engineering design process. It opens doors for our team to design, manufacture, test, and iterate on the engineering design process thus nurturing our team to develop quintessential professional skills such as project management, effective communication, and collaboration.

Complementing technical design and calculation is our team's budget and fundraising efforts essential to enliven our design. Large costs such as competition payment, materials required, manufacturing, and travel demand precise financial awareness and administration. To carry these needs, our team has fundraised roughly 600% of its intended goal (initial goal was 10% of donated Gore funds). This allows for relaxation in the budget and grants methods of quality manufacturing processes and purchases of advanced materials. Not only does diligent financial awareness provide funding to sustain our design process but also strengthens the team's knowledge of tangible costing methods and while pursuing economic solutions without sacrificing quality. As for the total expenses to date, the budget is still on track for our project total of just under $5500. This budget includes every projected and actual expense we thought we might occur. This includes our travel expenses, registration costs, and bill of materials for all the prototypes and final models. From our initial donation and lucrative fundraising efforts this provides our budget a decent amount of wiggle room if any unexpected costs were to occur.

The SAE Aero competition enforces the necessity of effectively designing based on constraints, budget and time, emulating the demands of aerospace engineering environments. This design projects bridges the gap between academia and real-world applications, such as small-scale UAV/drone implications.

Ultimately, the project represents a monumental steppingstone for our team members considering all of us are seeking careers in the aerospace industry. Our members are fiercely molding and refining their respective skills to contribute to the progression of technological advancement in aerospace.

1.2 Deliverables

For our understanding and measurement of the project's success, each deliverable is significant down to peer evaluations. Smaller deliverables, including timecards, meeting minutes and peer evaluations, institute the necessary structure to make our project successful. Disciplined and detailed comprehension of smaller deliverables contribute predominantly to our understanding of upcoming major deliverables such as prototypes, reports and presentations.

Major deliverables are the culmination of the project at that point in time. They are a detailed summary of the work that has been completed and a forecast of work to be completed. The major deliverables are listed in order of deadline; Website Check #1 (10/24/25), Presentation 3 (11/6/25), 1st Prototype Demo (11/13/25), Report 2 (11/26/25), 2nd Prototype Demo (12/4/25) and lastly our Final CAD and Final BoM (12/5/25).

1.3 Success Metrix

The team's overall success will be determined at the competition. If our team designs and manufactures an aircraft that completes 3 flights, each scoring roughly 16 points, our team will be successful. Detailed analysis of the flight score can be found in Section 3.3.1. This performance will serve as reassurance that the team produced a successful design. However, success can be extended beyond competition results through proper deliverable management. Every deliverable completed with thorough analysis and comprehension is essential to success in Fort Worth. Deliverables include technical reports, presentations, timecards, staff meetings, and most importantly, prototypes. Punctual submissions mirror the team's commitment and discipline to our cumulative goal.

Prototypes will be considered successful if they contribute to the advancement of our understanding and final design. Each prototype we develop will be assessed with respect to both qualitative and quantitative analysis. That being said, each prototype developed will be successful. Qualitative success includes a better understanding of manufacturing, or ease of assembly. Quantitative success can include optimizing prototypes for a larger thrust to weight ratio or analyzing an old prototype to arrive at an optimal angle of incidence regarding the wing mounting.

2 REQUIREMENTS

2.1 Customer Requirements (CRs)

The customer requirements defined throughout the engineering process relate to the rules and request found in the 2026 SAE Aero Rulebook [1]. Other requirements were derived from past team performance as well as team wants, all illustrated in Table 1.

Table 1: Customer Requirements

Requirement	Definition
Safely taxi	Utilize servo on front landing gear to allow movement while on the ground
Carry Payload	Incorporate a payload container (bladder) inside of the fuselage to carry water.
Fixed-Wing Original Design	Design must be new and innovative, while using fixed wing characteristics
Stable flight	Completing a circuit though flying
Red Arming Plug	Arming plug must be used to quickly de-arm/ shut-off the plane
Safety Nut	Must use an approved cap over the propellor for safety reasons
Electric Propulsion	Must use an electric motor powered by lithium polymer batteries
Identification	Clearly label team number as well as any large sponsors

2.2 Engineering Requirements (ERs)

Engineering requirements for this competition were found from the 2026 SAE Rulebook [1]. These are quantitative constraints that can be measured to ensure we are meeting requirements. All requirements can be seen in Table 2.

Table 2: Engineering Requirements

Requirements	Definition
Total Weight < 10lb	Plane must be lightweight and able to be transported by 1 team member, must be under 55 pounds to pass tech inspection.
Combined Power < 450 Watts	Must use a power limiter for all motors, maximum allowed power is 450 Watts
Payload Capacity > 67 fluid ounces	Payload container must be able to hold at least 67 fluid ounces of liquid water
Thrust:Weight> 0.23	Thrust to Weight ratio needs to be greater than 0.23
Takeoff Distance < 10ft	The team wants to takeoff within 10 feet to get the most possible points; needs to take off within 100 feet to count as a flight attempt
Landing Distance < 200ft	Plane must land within 200 feet to count as a flight attempt
Payload Release < 60s	We must demonstrate the payload (liquid water) being released within 60 seconds through the use of a drain plug.

2.3 House of Quality (HoQ)

In Figure 1 below, all of the customer needs are listed, and then those needs are used to create engineering requirements and specifications. These needs and engineering requirements are then compared in a matrix to ensure that all aspects are being met by at least one of our design areas. The number values listed in the areas just correspond to how much the categories relate to one another. We also used last years micro plane as a benchmark, where we rated everything the same except for the fixed-wing design and steering mechanism, as we found our design to be superior when compared to last year's plane.

	Weight Limit	Electric Motor	Thrust to Weight	Takeoff	Landing	Low Cost	Payload unload	Winspan	Chord Length	Prop Diameter	Landing Gear Strength
Weight Limit											
Electric Motor	6										
Thrust to Weight	9	9									
Takeoff	9	9	9								
Landing	3			3							
Low Cost	3	6	3	3	3						
Payload unload					9	3					
Winspan	6	3	3	9	9	3					
Chord Length	3	3		9	9	3		9			
Prop Diameter		9	9	6	3	3		6	6		
Landing Gear Strength	9			9	9	6		3	3	3	

Legend	
	No correlation
3	Small correlation
6	Average correlation
9	High correlation

		Engineering Requirements											Competition	
Customer Needs	Customer Weights (0-10)	Weight Limit	Electric motor(s)	Thrust to weight ratio	Takeoff	Landing	Lowcost	Payload unload	Wingspan	Chord Length	Propeller diameter	Landing Gear Strength	*Our Plane*	*SAE Aero Micro 2025 NAU*
Carry payload in a cargo bay	5	6					3	9					S	0
Original unique design	8	3	3				6	6	9	6	6	6	S	0
Fixed-Wing	7				9	9			6	6			+	0
Complete 360-degree circuit	10	3	6	6	9	9	3		9	9	6	9	S	0
450 W Power limiter	6		9	6	3		3						S	0
Red arming plug for propeller	6		9				3				3		S	0
Steering mechanism on landing gear	8				6	6	3					3	+	0
Saftey nut on propeller	9						3				6		S	0
Electric motor	5	6	9	6	9	6	6		3		3		S	0
Lithium polymer batteries	5	6	6	3	9	6	6		3		3		S	0
Technical Requirement Units		lbs	W	N/A	ft	ft	$	s	ft	in	in	lbs		
Technical Requirement Targets		< 15	<450	>0.23	0<x<10	0<x<200	<2,700	<60	3<x<4	8<x<15	7<x<10	2x Weight		
Absolute Technical Importance		144	267	141	309	261	240	93	234	180	210	162		
Relative Technical Importance		10	3	9	1	2	5	11	4	7	6	8		

Figure 1: House of Quality

3 RESEARCH WITHIN YOUR DESIGN SPACE

3.1 Benchmarking

System Level Benchmarking

The table below contains information about contestants from past SAE Aero Micro competitions [31]. These contestants were chosen to be used as benchmarks for our design based on their mission score and place in competition. The design produced by the Nanjiing University team will be used as the primary benchmark due to the fact that they had the highest mission score of the teams sampled.

Table 3: Benchmarking Criteria

Contestant Name	Place in competition	Mission Score
Nanjing University of Aeronautics SAE Aero Micro	1st in SAE Aero West 2025	107.5
Texas A&M SAE Aero Micro	1st in SAE Aero East 2024	54.6
University of Portland SAE Aero Micro	2nd in SAE Aero West 2025	48.9
Georgia Tech University SAE Aero Micro	1st in SAE Aero East 2023	76.5

Sub-System Level Benchmarking

While it is difficult to select a single best design due to a lack of access to performance data from previous SAE Aero Micro Teams, our team will discuss subsystem designs that have the potential to be the most advantageous based on their known aerodynamic characteristics.

- Fuselage: The design produced by the University of Portland has a fuselage shaped like an airfoil [29]. This design has several advantages. To begin, an airfoil is known to have a low drag coefficient compared to other shapes, which would help the aircraft accelerate quickly. Additionally, using an airfoil as a fuselage would enable the team to decrease the overall wingspan, thus increasing their flight score.
- Wing: The design from Nanjing University features a tapered wing with a large span and high aspect ratio [28]. This design reduces induced drag and enables shorter takeoff and landing

distances.

- Empennage: The design from Texas A&M University features a conventional tail[30]. This design has a low structural weight enables stable flight. This design also reduces flight control complexity and enables the actuation of elevators and rudders using only two servos.

3.2 Literature Review

3.2.1 Carlo Boyd

SAE Aero 2026 Rulebook [1] Section 9.3-payloads

This rulebook discusses vital information for the competition, primarily going over engineering and competition requirements as well as flight score calculations. Specifically section 9.3 allowed me to analyze what was needed out of the payload, being the minimum capacity of 67 fl oz of water and maximum release time of 60 seconds, in addition to understanding that it is up to each team if they want to fly with or without the payload.

SAE Aero 2026 Rulebook [1] Section 9.6-flight score

Section 9.6 of the rulebook elaborated on the variables that went into the flight score. With these equations I was able to translate everything into the MATLAB optimization to ensure that we were optimizing for the best possible flight score given different constraints.

Aircraft Performance & Design [2] Sections 7.3, 8.6.3, and 8.7

The specific sections in this textbook carried information regarding optimization, fuselage configuration, and weight estimate. These sections were used to understand the MATLAB optimization code, design a fuselage that worked with constraints and distance interferences, and give initial values for several parameters input into the optimization.

Aircraft Fuselage Design Study [3]

This design study illustrates different configurations for fuselage design. With this it allowed me to focus on a semi-monocoque design to eliminate any extra chords and strings that would be needed for a generic wrapped fuselage. It also discusses load distribution which will be used in further analysis to ensure all payload (payload container and electronics) will be placed in the correct spots.

MATLAB Aircraft Optimization [4]

Inside of MATLAB are predefined airplane optimization codes for design. With this code, I was able to rewrite it to follow the SAE Micro Aero flight score to optimize several different aircraft parameters to achieve the maximum flight score. The optimization also allowed for cross references to airplane stability code and checking with prandlt coefficients. (3.3.1

Aero Toolbox- Fuselage Sizing and Design [5]

This website explains different design principles of several varying types of fuselage designs. It explains how fuselages should be loaded, as well as how the diameter influences surface drag. This website is a helpful tool in checking calculations and design parameters to ensure everything will be manufactured to spec.

Model Aviation- Center of Gravity [6]

With competition requirements, our center of gravity must be easily located and marked. This website helps with providing equations to find the correct envelope for center of gravity based on chord length.

Modelling and Analysis of Fuselage [7]

This specific research journal explores more equations for stability, drag, design, and structural analysis of the fuselage. It is helpful in correcting calculations and running ANSYS finite element analysis on the fuselage structures created in CAD.

Standards that were incorporated into the respective parts of the fuselage designs include solid structures for fuselage (carbon fiber, balsa) [3,5], as well as sizing/dimensioning [4,5], and materials okay with competition [1].

3.2.2 Ryan Carberry

Aircraft Performance and Design [2]

This book is very informative to the beginner airplane modeler. I specifically read into chapter 2.9, 7.2, and 4.0. Chapter 2.9 outlined the drag polar, what it means and how it is used. Chapter 4.0 outlined the equations of motion in flight. Chapter 7.2 overviewed the phases of airplane design, which was helpful at the beginning of this project.

Introduction to XFLR5 [8]

This research paper was written in Fall of 2023 at Notre Dame. It outlines the program XFLR5 and how to use it to understand the stability and performance of RC airplanes operating at low Reynolds numbers.

Mechanics of Flight [9]

Chapter 2 and 3 of this book explain air and airflow as well as airfoils at subsonic speeds. Chapter 3 was very helpful for the study of airfoils, how they work and the different shape types. It also had explanations that helped me interoperate XFLR5 generations.

Airfoil Tools [10]

This website houses the largest database of airfoil shapes and types. As well as being able to generate simple characteristic graphs, it also is able to export airfoil shapes in the form of data points. I then can export any airfoil to SolidWorks or other programs to use that specific airfoil shape.

Aircraft Design: A Conceptual Approach [11]

Chapter 4.2 and 4.3 explains the importance of wing geometry and airfoil selection. Chapter 12 introduces aerodynamics. Chapter 12.4 dives into lift and 12.6 explains induced drag. These chapter increased my understanding of wings and how they work.

Airfoil for Aircraft – Patent [12]

This google patent was one of the first sources I looked up, and it simply solidified my understanding of what an airfoil is.

SAE Aero 2026 Rulebook [1]

> Chapter 9 overviews the design requirements for the micro class. Constraints that I took into account include wingspan (no limit), landing and take-off zones, and servo sizes so that I can incorporate that into my design.

Standards included in airfoil research include airfoil type [10, 8, 11] and wing material choices being cohesive with our requirements as well as the competition requirements (PLA filament, balsa, carbon fiber, foam, and ultracote).

3.2.3 Cale Hines

SAE Aero 2026 Rulebook [1] Chapter 1.7 – Airframe Design Requirements

> This chapter mentions purchasing existing parts or kits. The rulebook states that "Use of standard model aircraft hardware such as motor mounts, control horns, and landing gear is allowed." This simply means that we are allowed to by a landing gear.

SAE Aero 2026 Rulebook [1] Chapter 2.6 – Controllability

> This chapter mentions the requirement that we must incorporate a "steering mechanism for positive directional control." This means that we are required to have steering in some capacity in our landing gear. We are planning on placing a servo inside the fuselage to accomplish this.

"Landing gear configurations: Pilotinstitute," [13]

> This website discusses common landing gear configurations in an elementary fashion. There are a few configurations it mentions that have no application to our goal, but this was a great source to attain baseline knowledge of landing gear configurations.

Blog of Model Airplane Landing Gear Configurations [14]

> This source is an online blog for model plane enthusiasts. There are many opinions on here debating a tricycle configuration or a tail dragger configuration. Many of them prefer the tricycle simply because its maneuverability on the ground.

Aircraft Landing Gear Design Principles and Practices [15] Chapter 4.10

> This chapter in the textbook speaks about military designs for landing gears and their respective requirements. However, there is a specific stipulation that says the nose gear should be able to reach its required angle of twist without having to roll. The team believes that this is a solid requirement our craft. This will ultimately give is maximum control on the ground.

Amateur-Built Aircraft and Ultralight Flight-Testing Handbook [16] Chapter 1 – Section 8

> This source speaks about C.G. of the plane, and discusses the location of the landing gear placement based on C.G. calculations. There are numerous equations and ratios. The most important being the ratio of total weight to total moment.

Generative design of main landing gear for a remote-controlled aircraft [17]

This was a study conducted on self-manufactured rear landing gear for a tricycle configuration. It implemented multiple FEA studies to determine different stresses and loads for dynamic and static loads. This is beneficial because someone already did the work and we can analyze and use our estimated forces to design around.

Code of Federal Regulations Title 14 Subchapter C Part 23 [18]

This source identifies the standards that must be met regarding an aircrafts landing gear. There is plenty of good material in the CFR to bring to our project. Even though, or aircraft does not need to be federally authorized simply because it is classified as a hobby, key concepts can be extracted and applied.

3.2.4 Trey Cooper

2026 SAE Aero Design Rules [1]

Chapter 9 of the SAE rulebook describes the limitations on the power of our electronics. Specifically, it states that we are required to integrate a 450-watt power limiting device into our circuit. This rule determines what electronics we can purchase.

Aircraft Design: A Conceptual Approach [11]

Chapters 2 and 8 in this textbook contain equations that describe how much horsepower our motor must create for our aircraft to take off. Chapter 2 contains information about the overall design process, while Chapter 8 contains graphs and equations that helped determine our horsepower to weight ratio. This helps determine how much horsepower our motor needs to propel an aircraft of a specific weight.

SECTION 6: BATTERY BANK SIZING PROCEDURES [32]

This document contains information about how to size our battery bank. Specifically, it contains the depth of discharge equation, which enables us to calculate how much energy we have drained from our battery. If our team's depth of discharge exceeds 80%, our battery's health will be negatively impacted. Thus, this document contains information crucial to the longevity of our electronics.

MIT Electric Vehicle Team, “A guide to understanding battery specifications” [33]

This source contains our battery capacity equation. Specifically, this source states that we must multiply our discharge current in amps by our desired flight time to determine how many amp-hours of capacity we need. This source plays a critical role in determining the size of our battery

Guidelines to help you choose your Plane’s Power System [34]

This article contains additional information about selecting electronics for a remote-control airplane. It contains equations and guidelines for selecting propellers, motors, and batteries. This source provides our team with information about electronics not covered in other sources

Low-cost Expendable UAV Project [18]

This report contains information about unmanned aerial vehicle constructed by an undergraduate team at the University of Virginia. To elaborate, this document contains an example of how to do an electrical load analysis and determine how much current each device in a circuit will draw. This information will help our team size our battery by determining how much current we consume per minute.

Electrically powered aircraft, Introduction to Aerospace Flight Vehicles [19]

This source provides our group with estimates for system efficiency. Specifically, it provides figures for motor, electronic speed controller (ESC), battery, and transmitter efficiency and combines them to give a overall estimate of 90%. Our calculated battery capacity can be divided by this figure to give a total battery capacity.

Standard Specification for Batteries for Use in Small Unmanned Aircraft Systems (SUAS) [20]

This design standard provides mechanical and electrical design guidelines for batteries used in small aerial vehicles. The document provides instructions regarding how we must maintain our battery and place it within our aircraft to avoid safety hazards.

3.2.5 Luke Chandler

Principles of Flight [21]

The website outlines how flight is governed by the four aerodynamic forces; lift, weight, thrust, and drag. It goes more in depth about how lift is generated, incorporating both Bernoulli's principle and Newton's law and how all of this is influenced by angle of attack, airspeed, wing area, and air density.

Design and Analysis Notes, RC Aero Notes [22]

This is a report produced by William B. Garner on his experiences with rc airplanes. In it he brings together a range of his articles and excel tools he has used that are focused on the design and performance of rc airplanes. His notes have specific things such as drag estimates, maximizing flight time, airfoil information, and just anything that could relate to a rc aircraft.

Horizontal and Vertical Tail Design [23]

This source goes over the two main functions of the tail, the horizontal and vertical stabilizers. It also goes over the sizing for the tail volume coefficients, so approximate stabilizer areas can be calculated. Lastly, he gives practical design tips such as using symmetric airfoils for the tail, and appropriate aspect ratios for the stabilizer.

Design and Angle of Contact (AoA) analysis of Remote Control (RC) Aircraft [24]

This paper presents the design and aerodynamic analysis of a rc aircraft focusing on how angle of attack affects lift and drag. Based on aerodynamic equations, the authors found optimal design parameters for the wings, fuselage, and stabilizers. The work highlights the importance of having a balance among these variables for efficient flight performance.

ESTIMATING R/C MODEL AERODYNAMICS AND PERFORMANCE [25]

This paper, which was given on the SAE website provides a practical methodology for estimating the aerodynamic performance of rc aircraft. It explains how to adjust 2-D airfoil data in order to evaluate take-off, climb, cruise, and stall performance for R/C models.

RC Plane Wing Design: Understanding Aerodynamics [26]

This article offers a hands-on guide to wing design for rc aircraft. It goes over how wing shape, airfoil type, and other key parameters influence stability and performance. The three airfoil types are explained and how each one has a different purpose. Lastly it also introduces design parameters like aspect ratio and wing loading.

Chapter 6 Tail Design [27]

This chapter defines what the tail of the plane's roles are, which main functions are trim, stability, and control. It also describes how to size the tail with the tail volume coefficient, which links the tail size to the wing geometry. The main design topics discussed include the tail arm, aspect ratio, taper, ratio, sweep, and the airfoil selection.

Code of Federal Regulations [28]

The department of transportation has provided this document which contains a lot of necessary information with regards to any aviation regulations, which we can reference to make sure the team plane follows all safety procedures.

3.3 Mathematical Modeling

3.3.1 MATLAB Optimization- Carlo Boyd

To efficiently create feasible design values, MATLAB was used in creating an optimization code that ran several different parameters against aerodynamic functions such as flight stability and prandlt coefficients to optimize for the flight score, provided by SAE Aero rulebook [1] seen in equations 1-3. The MATLAB code was derived from the aircraft optimization code [4], then modified to work with the given constraints and parameters.

$$FS = 3 \cdot W_{Payload} \cdot M + Z \tag{1}$$

$$M = \frac{11}{(W_{Empty} - 1)^4 + 8.9} \tag{2}$$

$$Z = B_{Takeoff} - S^{1.5} \tag{3}$$

Where $W_{payload}$ is the payload weight (lbs), W_{Empty} is the empty weight (lbs), S is the wingspan (ft), and $B_{takeoff}$ is a score given when the plane takes off, seen below.

$$B_{Takeoff} = \begin{cases} 20 & 0 \le x \le 10\,ft \\ 15 & 10 < x \le 25\,ft \\ 9 & 25 < x \le 50\,ft \\ 0 & 50 < x \le 100\,ft \end{cases}$$

The initial parameters used in the code included wing shape, airfoil type, materials, dimensions, payload, velocity, and power. These parameters were then run against different constraints like stability, dimensional interference, center of gravity, and weight to optimize design variables like wingspan, weight of plane, weight of payload, and other dimensions. All optimized variables can be seen in Table 4 which also provides their optimized values based on initial guesses and parameters during the design process thus far.

Table 4: MatLab Variables

Symbolic Variable	Physical Quantity	Optimized Value	Units
P_full	Filled payload weight	1.06E-06	[lb]
X_p	Payload X location	0.1016	[m]
X_w	Wing X location	0.0969	[m]
b_ht	Horz. tail half span	0.0508	[m]
b_vt	Vert. tail half span	0.021	[m]
b_w	Wing half span	0.047	[m]
c_ht	Horz. tail chord	0.07	[m]
c_vt	Vert. tail chord	0.07	[m]
cr_w	Wing root chord	0.1663	[m]
f_weight	Fuselage weight	14.7884	[lb]
l_f	Fuselage length	0.4064	[m]
lambda_w	Wing taper ratio	0.9	
FS	Flight Score	16.8907	

As seen in

, the maximum flight score given the initial constraints and parameters came out to 16.8907. It is important to note that by flying without a payload, in this case our P_full was zero, that the score cannot be greater than 20. The P_full value being zero is a result of flight stability parameters, where we will have the best possible thrust to weight ratio at the lowest possible weight.

Overall, the MATLAB optimization was able to provide the team with crucial information for the first prototype and allow for us to narrow down our parameters and create focus on the most important aspects of the design while providing less attention to ideas that won't drastically help with the flight score, such as ignoring the payload for the first couple iterations.

3.3.2 Wing Analysis - Ryan Carberry

When designing a wing, there are multiple factors you need to consider. For a small RC plane, stability, lift/drag ratio, stall characteristics, and moment characteristics. Along with this, taking into account where the plane will be flying is very important. Our competition is located in Fort Worth, Texas, so we need to use the correct air density to calculate our Reynolds Number, which is step one of the analyses of a wing, which can be seen in equation 4.

$$Re = \frac{\rho v l}{\mu} \tag{4}$$

Where μ is the dynamic viscosity of the fluid, which is calculated through equation 5.

$$\mu = \mu_0 \left(\frac{T}{T_0}\right)^{\left(\frac{3}{2}\right)} \cdot \frac{T_0 + C}{T + C} \tag{5}$$

To estimate the velocity, I watched videos of last year's competition and averaged speeds from various teams and also considered what speeds worked well, and which speeds worked badly. Also, for this equation we need a chord length, which can be found in equation 6.

$$CL = \frac{WS}{AR} \tag{6}$$

In this equation, CL = Chord Length, WS = Wingspan, and AR = Aspect Ratio. A typical aspect ratio of an RC plane is 5-10, which makes our cord length around 1 foot. Plugging these values into equation (4), we find a Reynold's Number of around 150,000. Since weather and air density are variable, 300,000 was used for further analysis.

Diving deeper into airfoil shapes, the program XFLR5 helps immensely when looking at flight behavior. I chose two symmetrical and two unsymmetrical airfoils to study and choose from. When looking at coefficient of lift vs alpha, coefficient of drag vs alpha, and coefficient of moment vs alpha, I picked the airfoil that creates the most lift, least drag, and with a negative coefficient of moment to counteract the lift force and keep our plane stable. Along with this, a graphical shape we want to keep an eye out for is a "kneeing" shape, which indicates that stall is near. After doing a two-dimensional preliminary analysis of these four different airfoils, the team decided to move forward with the NACA 2412 airfoil. This airfoil has great flight characteristics, where it starts to stall at about a 15-degree angle of attack

Next, a 3D straight wing model was created with our dimensions of 10-inch chord length and 3-foot wingspan in XFLR5 and generated a coefficient of drag with respect to wingspan and coefficient of lift with respect to wingspan graph operating at a Reynold's number of 300,000. In Figure 2, we can look at the local drag graph, operating at a 10-degree angle of attack. This graph is great, shows a low drag coefficient throughout the wingspan, however it does spike up at the wing tips, but this is normal due to wingtip vortices.

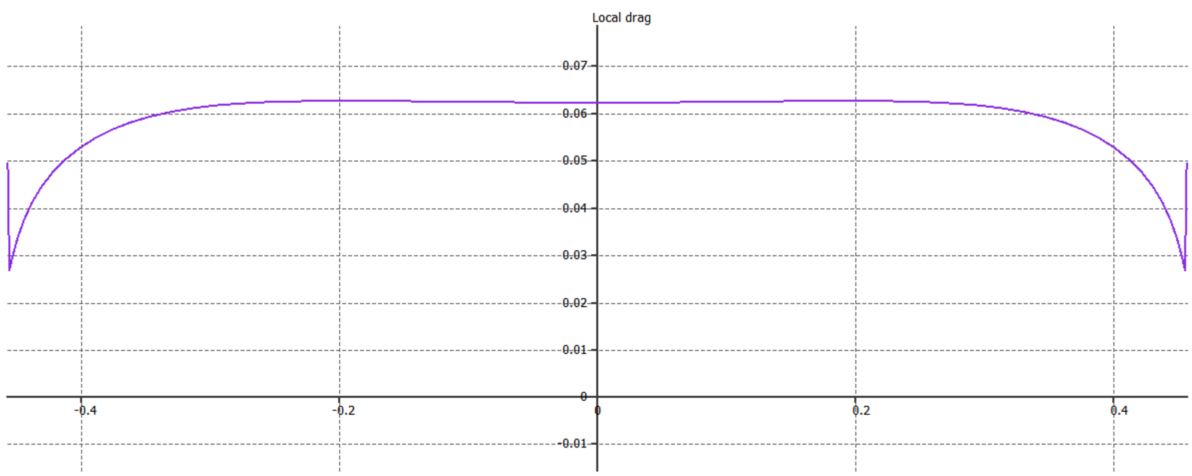


Figure 2: Local Drag Graph

Next, a local lift graph was generated to investigate how the wing will be generating lift at a 10-degree angle of attack. At first look, Figure 3 shows that the wings will generate much more lift than drag, which is preferred. The wing is going to generate more lift at the root of the wing, and less lift at each wingtip. Again, this is a very smooth graph and doesn't show any stalling characteristics even at a high angle of attack. However, we do not want to exceed 15 degrees as the aircraft become more prone to stalling.

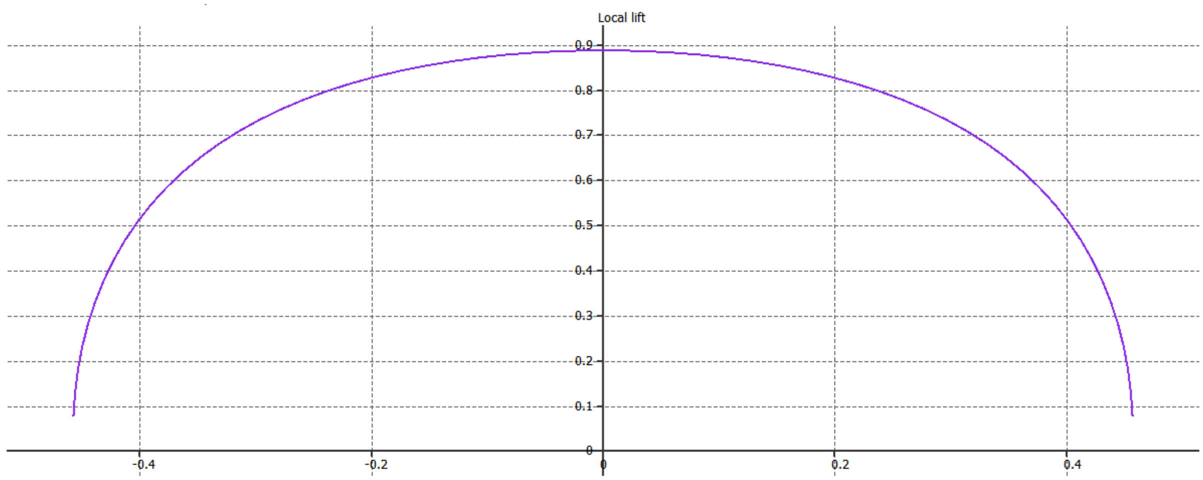


Figure 3: Local Lift Graph

Lastly, we compared coefficient of lift to drag, coefficient of moment to alpha, and Cl/Cd to alpha in three dimensions to confirm my two-dimensional analysis. In Figure 4, we can see a smooth graph that generates high lift with low drag. We also do not see any stalling behavior traits in the graph which is great for a range of alpha being -10 to 20 degrees

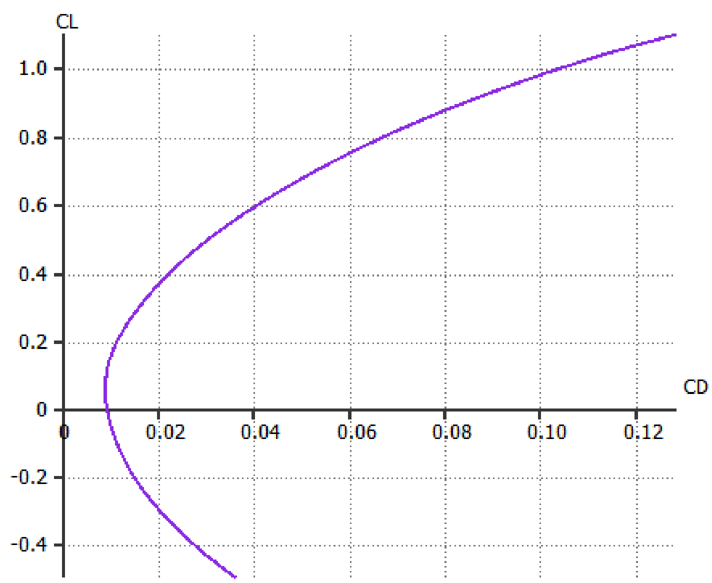


Figure 4: Coefficient of Lift vs. Coefficient of Drag

In Figure 5, we can see the coefficient of moment vs alpha graph, which shows a negative coefficient of moment at alpha greater than -5 degrees. This confirms my two-dimensional data, and also shows no stalling characteristics, because we used a more reasonable Reynold's number to generate this graph.

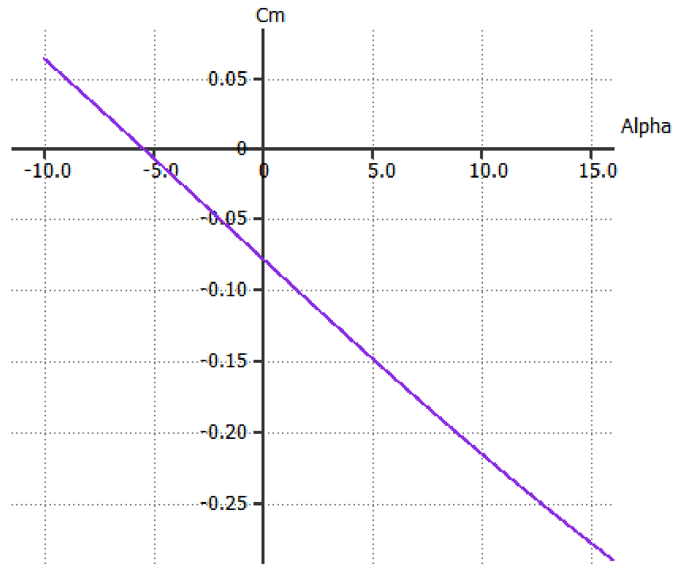


Figure 5: Coefficient of Moment vs. Alpha

In Figure 6, we generated a coefficient of lift/coefficient of drag vs alpha graph to condense the lift and drag graphs into one with respect to the angle of attack. This graph is generating large positive numbers greater than -2.5 degrees, which means the wings will be generating a great amount of lift. Again, no stalling characteristics can be seen in this graph, but if we look at larger positive and negative angles of attack, the graph starts to generate those "kneeing" shapes.

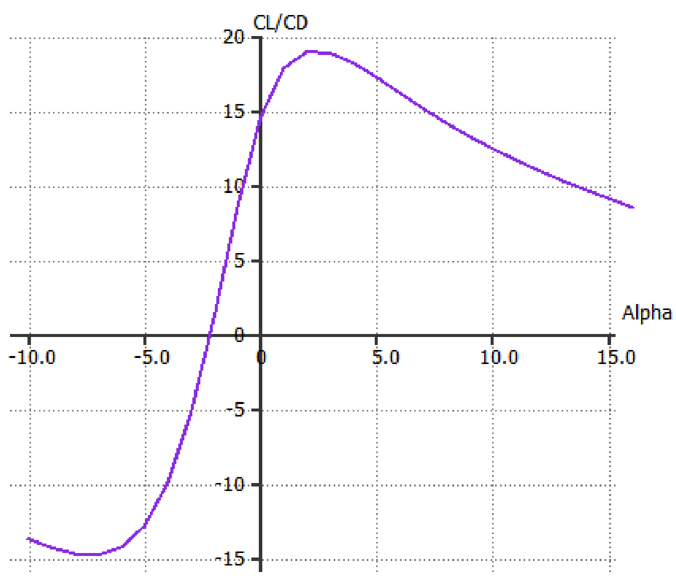


Figure 6: Coefficient of Lift/Coefficient of Drag vs. Alpha

3.3.3 Tail Wing Design- Luke Chandler

Using some of the information from the main wing design, such as the Reynolds number, this can help to make informed decisions for the tail wing too. To narrow down the selections XFLR5 is used once again. When performing the batch analysis in XFLR5 the system can calculate a stretch of Reynolds numbers, this was done as the conditions we will be flying in are uncertain and ever-changing. So, an acceptable range was input based off the previous calculations. This is what the different lines on the figure represent, the different Reynolds numbers. After doing research on tail wing design, I selected three NACA airfoils to compare the different features they had. Figure seven shows the relation between the coefficient of lift to the coefficient of drag at the angles of attack. The symmetric airfoils, 0009, and the 0012 display very similar results which only start to fluctuate at the larger angles of attack. The NACA airfoil 6409 has a camber which means it will generate higher lift at all angles of attack without producing much drag.

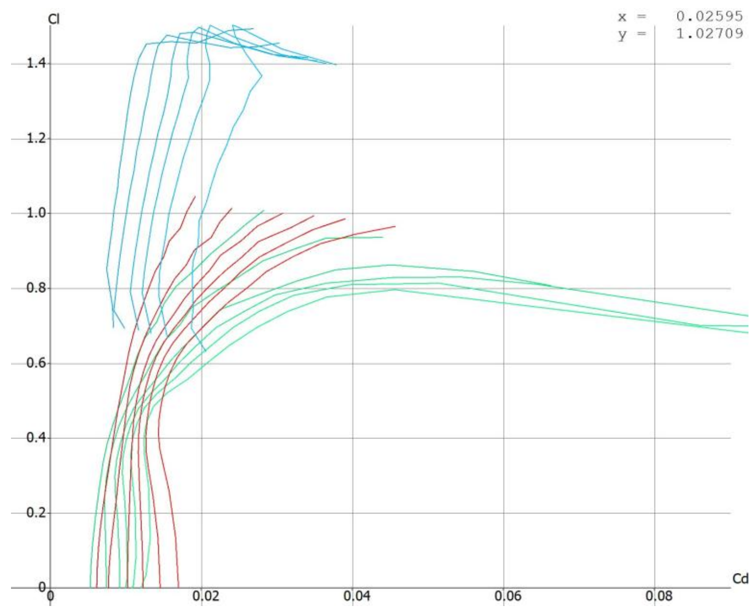


Figure 7: Coefficient of Lift vs. Coefficient of Drag

Figure 8 shows a similar trend as observed above with the fact that the cambered airfoil once again starts to produce higher lift coefficients all the way through. The worrying part about the NACA 6409 (Blue lines) and NACA 0009 (Green lines) is that at the higher angles of attack the graphs being to deviate from the linear path, which indicate signs of stalling. If we can limit the point at which stalling occurs this will allow to have a much more stable flight without the risk of crashing as easy.

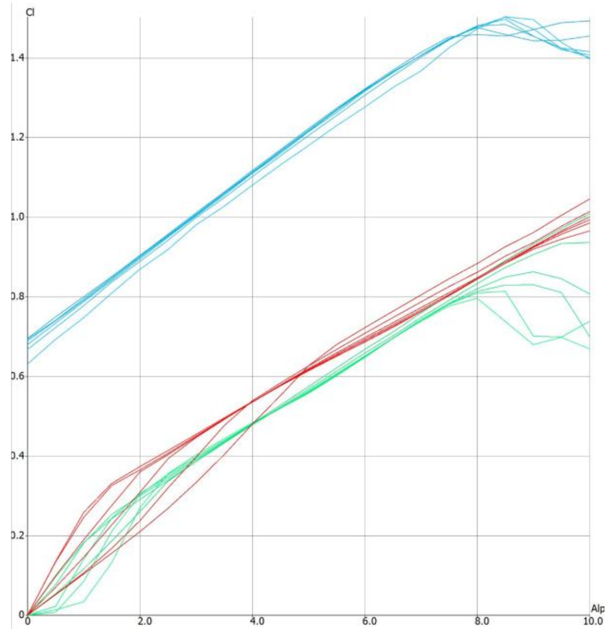


Figure 8: Coefficient of Lift Across Increasing Angles of Attack

The last area of useful information for the tail-wing is the pitching moment. After doing some research on how the pitching moment should act for the tail, it was found that symmetrical ones work the best [27]. If the tail wing is also producing a negative pitching moment it means the main wing must be able to produce excess lift to keep the aircraft level. With much larger planes this is not really a problem but because handling and stability are more sensitive for RC aircraft this would create issues. So, reducing the negative pitching moment will give more control and stability in the air. So based off the data which the graphs are giving the NACA 0012 airfoil would be selected for its ideal characteristics of, small pitching moment, linearity for lift, and small amounts of drag.

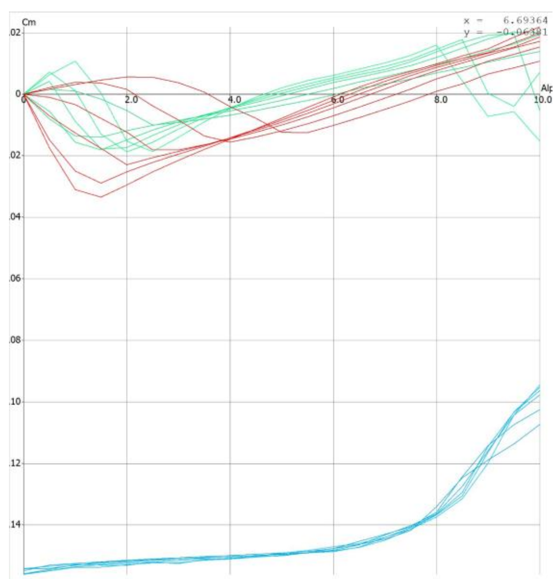


Figure 9: Pitching Moment Across Increasing Angles of Attack

3.3.4 Electronics Analysis - Trey Cooper

In order to select a motor, esc, and battery for our airplane, our team had to first answer questions related to the specifications of those devices. Specifically, our group determined how much horsepower would be required for takeoff and how much capacity our battery would need.

To determine how much power would be required for takeoff, equation 5.4 is utilized from Daniel P Raymer's Aircraft Design: A Conceptual Approach textbook [20].

$$\left(\frac{hp}{W}\right)_{takeoff} = \frac{V_{cruise}}{550 \cdot \eta_p} \cdot \frac{1}{(\frac{L}{D})_{cruise}} \cdot \frac{W_{cruise}}{W_{takeoff}} \cdot \frac{hp_{takeoff}}{hp_{cruise}} \quad (7)$$

Since our design utilizes a motor and battery, the power provided by our power plant and the weight of our aircraft does not change with altitude or time. As a result, the weight and horse power ratio terms in equation 5.4 can be neglected and set equal to 1. Our cruising speed was determined to be 18.28 m/s and our L/D ratio for cruise was determined to be 10 using Figure 3.6 from our aircraft design textbook [20]. This resulted in a hp/w ratio of 0.00415. When factoring in our desired takeoff weight of 68.37 N, the minimum required take off horsepower was determined to be 0.284 hp or 211 watts.

In order to determine the size of our ESC our team estimated the maximum current draw for each component. The current draw of each component can be found in the table below

Table 5: Total Amperage

Item	Current Draw (Amps)
Motor	30-70A
Servos	0.2A x 5 = 1A
Receiver	1A
Total	**32A-72A**

Based on the results above, our team decided to purchase an 80A ESC to ensure it can handle the most extreme loads expected.

In order to select a battery, our team calculated the minimum capacity needed, assuming an average current draw of 32 Amps and a desired flight time of 6 minutes (0.1 hours). After calculating the minimum capacity, we divided the figure by our estimated efficiency (90%) and depth of discharge figure (80%).

$$C = \frac{I_{avg} \cdot t}{\eta_{sys} \cdot DoD} \quad (8)$$

This equation helped our team determine that we need a battery with a minimum capacity of 4,444 milliamp-hours [22].

3.3.5 Landing Gear: Anticipated Force and Stress- Cale Hines

To design or purchase a landing gear, we must estimate stress on the landing gear by calculating multiple forces. Ultimately, the change in momentum will help us estimate forces given by:

$$F = \frac{m_{aircraft} \cdot \Delta v_y}{\Delta t} \tag{9}$$

However, there must be more calculations completed to find the force. It is being assumed that the magnitude of the landing velocity is 53 [ft/s]. If we assume an 8-degree angle of descent (incredibly steep) then we can calculate the velocity in the y-direction given by:

$$v_y = v_{landing} \cdot \sin(\theta) \tag{10}$$

The velocity in the y-direction is calculated to be 7.4 [ft/s]. Now we can calculate the change in momentum. Using a mass of 0.625 [lbm] (10 [lbf]) and our velocity in the y-direction, we can calculate force by plugging in multiple time values. An important note; the smaller the time value, the more intense the landing. The change in time refers to how long it takes the pilot to touchdown and completely remove vertical velocity. If we consider a time of 0.1 [s] the force is calculated to be 46.25 [lbf]. Now let us consider a time of 0.01 seconds. This is slightly unreasonable, but this way we can visualize how important landing in a controlled fashion is. If we evaluate force at a change in time of 0.01 [s], force will be 462.5 pounds. This is informative because it shows that decay in force as time increases linearly. This can be proved in Figure 10.

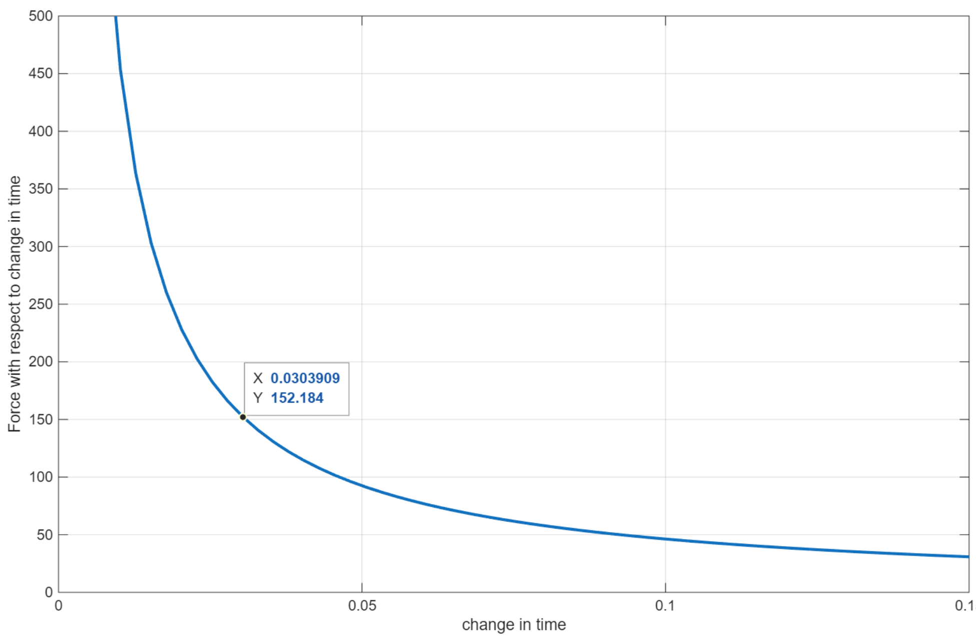


Figure 10: Change in Momentum

4 DESIGN CONCEPTS

4.1 Physical Decomposition

The physical decomposition, as seen in Figure 11 outlines the major subassemblies and their respective parts for the entire project. This decomposition is important to help not only the team but also all stakeholders and clients understand where energy and time should be focused and how everything works together. For this project in particular, it helps to show us what parts are needed to make everything work together. With this knowledge, the team can run analysis on each individual part involved to ensure it is working with the subassemblies and is a feasible solution. It also allows for each subassembly lead to understand what they need to be completing for their respective parts.

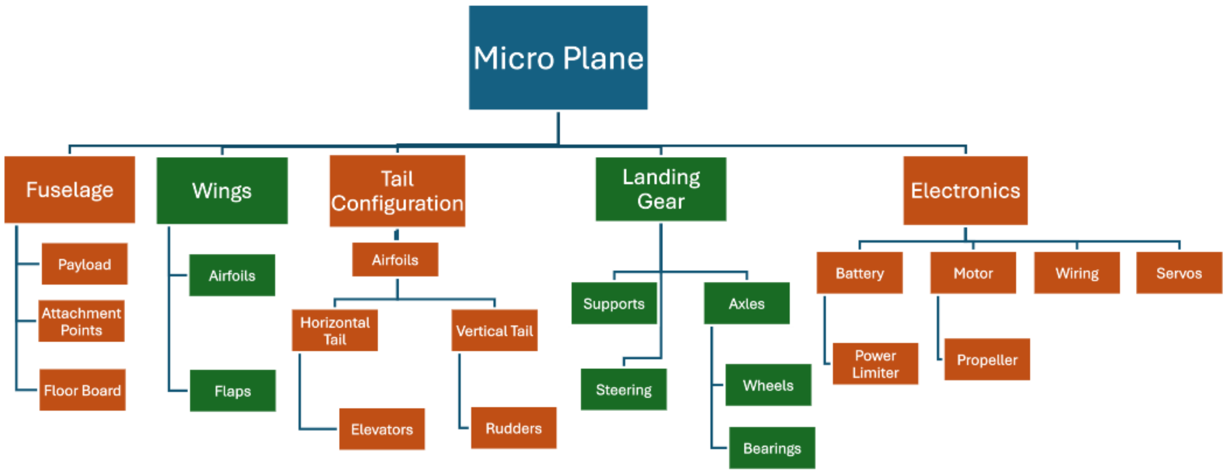


Figure 11: Physical Decomposition

4.2 Concept Generation

For a project such as this, when creating concepts, it is important to break them up into various sub-sections and rate them individually as well as how compatible they are with the other parts. Our sub-sections include fuselage, landing gear, tail wings, main wings, and motor/electronics.

Fuselage

For the fuselage, the team generated four different shapes with varying surface drag and usable space. Following this were four different types of structural design, a hollow tube with a separately connected boom both made from carbon fiber, or wrapped stringers and chords with either balsa wood or carbon fiber/ aluminum. We also looked at different inner diameters ranging from 3-6 inches, these were chosen to provide variability for weight as well as usability. Along with this, for the nose cone the concepts include a dome shape, a lifted-up shape, and a cone that converges to a sharp point. The team also considered attachment methods, including screwing the nose cone into the fuselage, a threaded attachment and using glue. Lastly, for the payload container, we considered a 3D printed cylinder or a plastic 2-liter bladder. These concept generations were then transferred into four different design options, seen in Table 4.

Table 6:Design Options for Fuselage

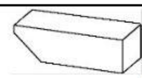
Options	Shape	Design	Diameter	Nose Cone	Attachment
1	 1	Structural Tube	4"	Sharp Point	Screw in
2	 2	Structural Tube	4"	Sharp Point	Screw in
3	 3	Structural Tube	4"	Sharp Point	Screw in
4	 4	Wrapped Stringers and chords	3"	Sharp Point	Screw in

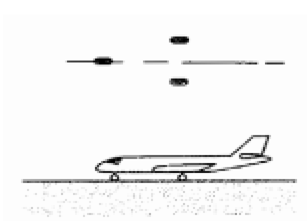
Table 7: Pros and Cons of Fuselage Designs

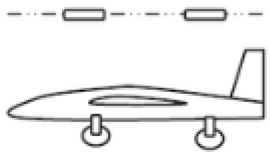
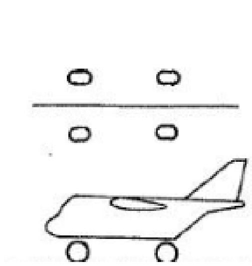
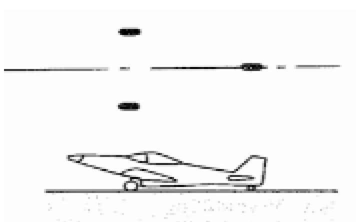
Options	Pros	Cons
1	Easy to manufacture, Less surface area. Lower Surface Drag	Needs more parts, large stress concentration at change in diameter
2	Easy to manufacture, involves 1-2 parts	More surface area, less variability, more weight
3	Aerodynamic	Difficult to manufacture, design could lead to stall out
4	Lot of mounting surfaces	Most drag, lots of parts needed

Landing Gear

The team deliberated between multiple configurations of landing gear. Those being tricycle, taildragger, bicycle and quadricycle. Configuration pictures, pros and cons can be found in Table 8.

Table 8: Pros and Cons of Landing Gear Configurations

Configurations	Pros	Cons
Tricycle 	Taxiing ability, stability upon landing, pilot controllability	Boring aesthetic, nose gear prone to failure
Bicycle	Easy to manufacture and install	Very poor stability upon landing and takeoff, generally

		used for high speed jets
Quadricycle 	Extreme stability	Redundant, difficult to install, poor taxiing ability
Taildragger 	High lift at takeoff	Poor landing stability and maneuverability

As is clearly illustrated, the tricycle landing gear configuration is triumphant primarily due to its stability upon landing and its taxiing ability on the runway. Per the SAE Aero Rulebook, the aircraft must be able to turn and have complete control on the ground to compete in competition, thus ruling the tricycle landing gear configuration superior for our application.

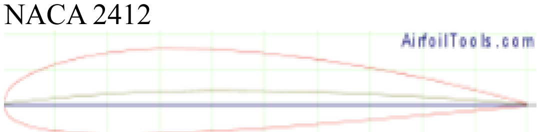
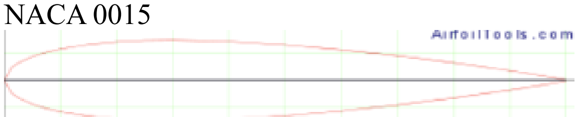
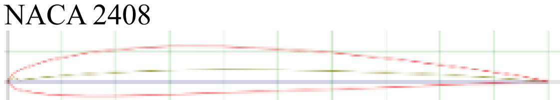
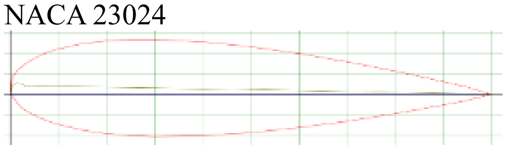
Wings

Moving onto main wings, the team generated three shapes, a straight leading and trailing edge, a tapered leading and trailing edge, and a straight leading edge with a tapered trailing edge. Along with this, generating and comparing airfoil shapes is important. The team generated the NACA 2412, NACA 0015, NACA 2408, and NACA 23024 airfoil. The materials for the wings include balsa wood sheets, UltraCote sheets, balsa wood airfoils and supports, and PLA 3D printed airfoils. When discussing these concepts, we want to look at lift/drag characteristics, stalling characteristics, ease of manufacturability, cost, and maneuverability in the air.

Table 9: Main Wing Design Options

Options	Wing Shape	Wing Material	Flap Type	Foil Type
1	Straight leading edge, straight trailing edge	Balsa wood wing Ultrakote sheet	plain flap	NACA 2412
2	straight leading edge, straight trailing	EPP foam wing	split flap	NACA 0015
3	tapered leading edge, straight trailing	Balsa wood wing Ultrakote sheet	Slotted Flap	NACA 2408
4	Tapered leading edge, tapered trailing edge	Carbon fiber sticks with Balsa wood sheet	plain flap	NACA 23024

Table 10: Pros and Cons of Wing Airfoil

Foils	**Pros**	**Cons**
NACA 2412 	Creates lift at -4 AoA, good stall characteristics, has good negative moment coefficient about leading edge	Not as much lift as other foils, could stall earlier than advanced designs
NACA 0015 	Symmetric stable and predictable behavior	Produces no lift at 0 AoA, requires a high angle of incidence to produce lift
NACA 2408 	Low drag at moderate Reynolds numbers and a light weight wing structure.	Low maximum lift coefficient, stalls earlier at high AoA, less space for structural components.
NACA 23024 	Very high lift, good performance at low Reynolds numbers, delay stall and maintain lift smoothly.	High drag at cruising speed, lower aerodynamic efficiency at high speeds, nose pitches upwards.

Tail

Next up on the concept generation are the tail wings. The shapes generated include conventional, T-tail, cruciform, and dual. The materials are going to be the same as the main wings for ease of manufacturability and a consistent center of gravity. The airfoil shapes generated include NACA 0009, NACA 6409, and NACA 0012 airfoil. When generating concepts, we want to look for elevator/stabilizer characteristics, cost and ease of manufacturability.

Table 11: Tail Wing Design Options

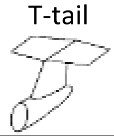
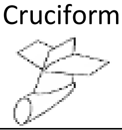
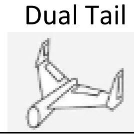
Options	Tail Type	Airfoil
1	Conventional 	Symmetrical
2	conventional	Cambered
3	T-tail 	Symmetrical
4	T-tail	Cambered
5	Cruciform 	Symmetrical
6	Cruciform	Cambered
7	Dual Tail 	Symmetrical
8	Dual Tail	Cambered

Table 12: Pros and Cons for Tail Wing Options

Designs	Pros	Cons
Conventional	Simple, lightweight, predictable stable behavior.	It can be affected by wake at high angles of attack, less effective in deep stall.
T-Tail	Tail sits above the wake, better pitch control.	Prone to deep stalling as horizontal stabilizer can be blanked by stalled wings, requires a stronger structure.
Cruciform	Compromise between	More complex structurally and

	conventional and T-tail.	still partly affected by wake.
Dual Tail	Better yaw stability, reduces single fin loads.	More complex, heavier and also increase drag.
Symmetrical Airfoil	Predictable response, no pitching moment, ideal for stability and control.	Less efficient at producing lift.
Cambered Airfoil	Produces more lift and has a smaller surface area.	Produces a pitching moment so this increases trim drag.

Motor/Electronics

The concept generation process for our electronics was carried out by conducting a search for products that met our performance requirements. The specifications and pros and cons of each motor and battery option considered are outlined below.

Table 13: Design Options for Motor

Option	Hp/W (Watts/lbs)	KV	Cost
1)D3536 Brushless Outrunner Motor	(739.1}/{102}=7.24	1450	19.99
2)FLASH HOBBY 2826 RC Brushless Motor	{342}/{50} =6.84	1000	17.99
3)FLASH HOBBY D2830 Brushless Motor	{275}/{52} = 5.28	1300	18.99

Table 14: Pros and Cons of Motor Options

Option	Pros	Cons
Option 1: D356 Brushless Outrunner Motor	- Provides the highest amount of horsepower relative to its weight	- Has the highest KV value. Higher KV values require a smaller propeller, which in turn reduces efficiency - Costs the most
Option 2: Flash Hobby 2826 Motor	- Has the lowest KV value, thus enabling larger propeller sizes and higher efficiency - Costs the least	- Provides a lower horsepower to weight ratio compared to option 1
Option 3: Flash Hobby 2830 Motor	- Offers a lower KV value and cost compared to option 1	- Provides the lowest amount of horsepower relative to its weight,

		which would likely negatively impact horse power to weight ratio of the entire aircraft

Table 15: Design Options for Battery

Option	Weight	C Rating	Cost
1) Goldbat 5000mah	0.61 lbs	50	$11
2) HRB 5000mah	0.831 lbs	120	$51
3) Ovonic 5000mah	1.79 lbs	100	$55

Table 16: Pros and Cons of Battery Options

Option	Pros	Cons
Option 1: Goldbat 5000mah battery	- Weighs the least of all options considered - Costs the least of all options considered	- Offers the lowest continuous discharge rate (C-rating), limiting the current available to the motor
Option 2: HRB 5000mah battery	- Offers a highest C rating	- Weighs more than option 1 - Costs more than option 1
Option 3: Ovonic 5000mah battery	- Offers a higher C rating compared to option 1	- Weighs the most of all options considered - Costs the most of all options considered

4.3 Selection Criteria

Fuselage

For the fuselage design, we used ease of manufacturability, cost, surface drag, and weight as the selection criteria. Ease of manufacturability and surface drag were rated the highest, this is due to the team wanting to be able to quickly produce parts and make the main body not be a big piece of drag. In reference to Table 4, it can be seen that design option 1 won. This was due to its ease of manufacturability, low surface drag, and low weight. Table 11 & Table 12 in Appendix A: Tables illustrate all part specifications for the fuselage assembly and justify why materials were chosen.

Landing Gear

For the landing gear, the team weighed stability on landing and ground control the highest predominantly because in order to score, the plane must land safely and our competition requirements state that our aircraft must be able to maneuver on the ground. The aircraft must have a steering system, that can be easily operated by our pilot. As can be seen in **Error! Reference source not found.**, the tricycle configuration scored highest in both of these categories, thus producing the majority of its points.

Wings

For the main wings, the team used lift/drag, ease of manufacturing, cost, stall characteristics, stability, weight, air resistance, and compatibility with the rest of the plane as selection criteria. The lift/drag, stall, and moment characteristics were calculated using XFLR5 software as seen in the wing analysis [section 3.3.2]. For weight, design characteristics were taken into account when designing and manufacturing, such as material, number of ribs/spars, as well as taking section cuts out of airfoils and ailerons prior to wrapping to decrease as much weight as possible. Compatibility was chosen early in the design process, as the team found it valuable to be able to change things such as wing location and angle of incidence quickly without having to redesign the fuselage. The team chose to have a top-mounted wing, with a mounting bracket under the wing so that we can change the location of this mounting bracket as well as increase the angle of incidence from 0° to larger angles easily through the use of extra washers on the leading edge. This design is strictly for ease of prototyping, and we plan to make a more sound wing mount once we find an optimal angle of incidence and location of wings about our fuselage.

Tail

Similar to main wings, the team rated lift/drag, ease of manufacturing, stability, and weight for the tail wing design. The selection for lift and drag was made using the software XFLR5. Within this, the team was able to input different parameters about the airfoils and conditions that would be experienced, such as different Reynolds numbers. The program would produce a graph of the coefficients of lift and drag for the airfoils at varying angles of attack, based on the conditions given. From looking at a stability standpoint, further analysis is still being conducted to be able to have quantifiable data and numbers. This analysis will come from fluid simulation software to understand how different configurations will behave. But for the time being all the decisions made were based on research across the sources and the use of standard industry practices.

Motor/Electronics

To select a motor for our aircraft, our team conducted a search to identify motors that could produce the minimum required horsepower for takeoff of 211 Watts. After identifying these products, our team narrowed our options by examining the horsepower to weight ratio, KV value, and cost of each motor. Other electronics such as the ESC were selected based upon the expected current draw of the motor, servos, and receiver.

After identifying batteries that met our minimum capacity requirement, our team considered factors such as the weight, c-rating, and cost of each battery to make a final purchase.

4.4 Concept Selection

Once all of the parts and different designs for the sub-assemblies had been determined, we needed to compare them against each other to determine which design would work the best for this project. Breaking into each section, everyone came up with the most important characteristics that could be used to differentiate between the different concepts. These characteristics were given a weighted value of how important this specific area was to achieve our engineering goals. From this point a number value was given to the designs based on how well they would score in the respective categories. These number values were all determined from the above calculations, research, past performance, and past experiences. The multiplier was then applied to each category, and the design with the highest overall score was then selected to be implemented into our design. All tables for these decision matrices can be seen in Appendix A: Tables.

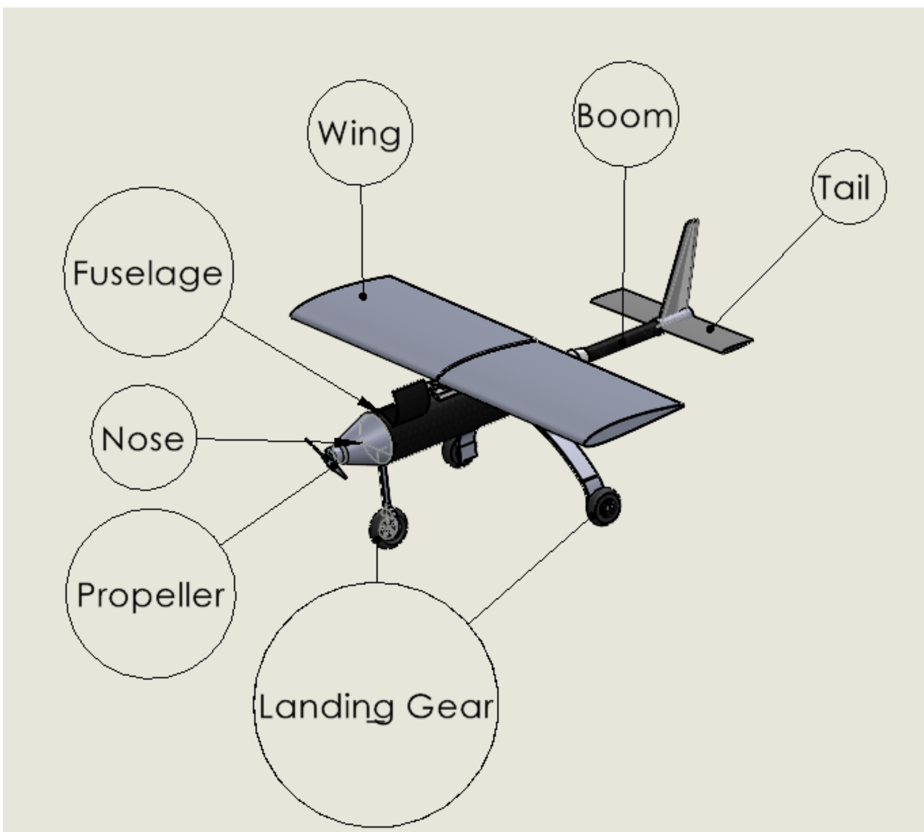


Figure 12: Final CAD Model

5 SCHEDULE AND BUDGET

5.1 Schedule

The Fall 2025 Gantt chart can be found in the appendix found at the end of this report. The team did a wonderful job of staying on track and adhering to the timeline set both by the syllabus and the project manager. However, as a team, we did very little to get ahead of schedule. We began our first prototype on October 16. There was agreement among the team to take a week away from capstone, to refresh our minds. Following the week of sabbatical, we returned behind schedule and have been playing catch up ever since. In the spring semester, the team has agreed to make capstone their first priority and meet consistently.

An outline for the Spring 2026 Gantt chart can also be found in the appendix. It is a rough blend between both the SAE timeline and the ME-486C capstone. The team is very confident that the rough draft is subject to drastic changes. The main stipulation being the hardware submittals in their relation to the SAE submittal timeline.

Both Gantt charts can be found at the bottom of Appendix B.

5.2 Budget

Table 17 just briefly summarizes any and all expenses the team will expect to incur during the course of our project. As the team continues to move through the different stages the costs are updated accordingly. These costs are then tracked in Table 18 to determine how much of the budget is remaining. For the prototypes these numbers were just rough estimates as we were at first unsure what materials would be needed. The final model was determined through the bill of materials which is listed below in the section 5.3 below.

Table 17: Project Expenses

Description	Projected Cost	Actual Cost	Difference
Cost of competition	$1650	$1650	$0
Prototype 1	$250	$256.42	-$6.42
Prototype 2	$300		
Prototype 3	$350		
Final Model	$700		
Travel Money	$1500		

Table 18: Project Balances

	Projected	Actual to date	Difference
Total Income	$10,000	$8295	-$1705
Expenses	$4750	$1906	-$2844
Balance	$5250	$6389	

5.3 Bill of Materials (BoM)

Table 19 includes everything that the team will need to complete the final design of the project. Some of these items had been donated to us from previous years teams thus no price has currently been listed.

Table 19: Bill of Materials for Final Design

Items	Description	Link	Price per Unit	Quantity	Total Price
Goldbat 5000mah Battery	Battery	Amazon.com: E-flite Nose Gear Strut Assembly Viper 70- EFL-1268 : Toys & Games	$11.24	2	$22.28
Goldbat 5000mah Battery	Motor	Motor	$19.99	2	$39.98
Carbon Fiber Filament	Print certain parts	Filament	$29.00	3	$87.00
Kevlar Core Carbon Fiber Round Tube	Fuselage	https://dragonplate.com/kevlar-core-carbon-fiber-round-tube-4-id-x-48?slug=6649-FDPT4.0*4.125*48*KC*	$312.03	1	$312.03
Braided Carbon Kevlar Round Tubing	End part of fuselage (Boom)	https://dragonplate.com/braided-carbon_yellow-kevlar-round-tubing-1-id-x-48	$151.13	1	$151.13
Electronic Landing Gear	Front wheel	Landing Gear	$23.99	1	$23.99
Carbon Fiber Landing Gear	Back two wheels	End Landing Gear	$18.99	1	$18.99
Nylon Propeller	Propeller powering flight	Propeller	$2.83	1	$2.83
Servos	Control all moving parts		Already Have	10	$0.00

UltraCote Wrap	What the plane is wrapped in		Donated	1	$0.00
Final Cost					$658.43

6 DESIGN VALIDATION AND INITIAL PROTOTYPING

6.1 Failure Modes and Effects Analysis (FMEA)

After conducting our FMEA, our team discovered over 27 potential modes of failure. The failure modes with the highest Risk Priority Number related to structural and flight control failures. We mitigated these issues by eliminating points of stress concentration such as sharp corners and controlling the placement of servos so that control surfaces deflect evenly. More details are given below in Figure 13, Figure 14, and Figure 15. The team found the best way to illustrate this data is by using snipping tool because when inserting a table of this size, the geometry of the table significantly impacts the aesthetic as well as the representation of data become distorted.

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
3. Nose Cone/Motor Mount	Motor could come loose	Loss of thrust, Flying Debris	9	*Infill of motor mount could be too low * Mount is not properly fastened to fuselage	2	Measure distance between bracket and mount	1	18	Use higher infill percentage (currently 30%, use 35%)
1. Fuselage	Yield under load	Disassemebly of aircraft	10	Stress concentration within fuselage	2	Load Test	1	20	Simulate loads in Ansys, Eliminate stress concentration points such as sharp corners in fuselage
2. Boom Adapter	Could come loose, shear in bolts	Total loss of control	10	Infill near nuts too low, too much force from tail wing	2	Load test	1	18	Slicing software for thicker infill near nuts
5. Boom	Yield under load	Disassemebly of aircraft	10	Stress concentration within boom	2	Load Test	1	20	Eliminate stress concentration points such as sharp corners in boom
24. Stabilizer Connector	Fasteners could become loose	Disassemebly of aircraft	5	Loads could exceed strength of fasteners	5	Load Test using weight hanging from tail vertically	1	25	Use additional fasteners
23. Vertical Stabilizer	Ribs could slide along stringer	Unstable flight	9	Insufficient force to keep ribs in place	5	Measure distance between outboard rib and end of stringer	1	45	Screw outboard ribs in place

Figure 13: FMEA Part 1

25. Rudder	Control surface could fail to return to neutral	Yaw to one direction	3	Servo arm moves upon activation Linkage stopper becomes loose	5	Measure distance between control surface end point and neutral point	8	120	Examine control surface prior to flight
20. Horizontal Stabilizer	Structure could cant due to being improperly fastened	Unstable flight	9	Insufficient force to keep ribs in place	5	Determine if stabilizer is level using spirit level	1	45	Examine stabilizer prior to flight
22. Elevators	Control surface could fail to return to neutral	Pitch in one direction	3	Servo arm moves upon activation Linkage stopper becomes loose	5	Measure distance between control surface end point and neutral point	8	120	Examine control surface prior to flight
8-13. Wing	Tear in wrap, struts braking	Flight instability and high likelyhood of crash	8	*wrapping too tight *large gaps in airfoils on wing skeleton *Crashing	7	Load test Experimenting with wrap	3	168	strong leading edge, eliminate wrap fludder through experimentation
6. Wing Connector Bolts	Bolts could shear or come loose in the infill	Complete loss of wings or wings becoming loosly mounted	10	*Too low of infill on 3D print *Shear force on bolts	5	Testing forces on wings before flight	2	100	Higher infill percentage or redesign
9. Ailerons	Control arm disconnecting Connection rod breaking	Loss of control surfaces on main wings, airplane only controlled from tail	8	*loose connections Servo arm moves upon activation Linkage stopper becomes loose	3	Shear Calculations, strong control arm mounts	7	168	Stronger materials for connection rod and control arm

Figure 14: FMEA Part 2

29. Motor	Thermal Fatigue Leads could break	Loss of Thrust	7	Sustained operation at high RPM	2	Measure temperature at high throttle settings using infared thermometer	2	28	Reduce the amount of time operating at high throttle settings Reduce Tension on motor leads
30. Servos	Wire could break Servo arm could become loose Servo could dismount from tray	Loss of control	9	Tension on servo wire	3	Functionality Test prior to flight	1	27	Nail servos to servo tray
31. ESC	Thermal Fatigue Leads could break	Loss of Thrust	7	Sustained operation at high RPM	2	Measure temperature at high throttle settings using infared thermometer	2	28	Reduce the amount of time operating at high throttle settings Reduce Tension on ESC leads
32. Battery	Charge could run out during flight Battery could overheat	Loss of control	10	High current draw Reduced battery capacity from wear	2	Measure battery voltage prior to flight	2	40	Introduce cooling vents into nose cone to allow airflow through fuselage
33. Receiver	Loss of signal	Loss of control	9	Physical damage	2	Functionality Test prior to flight	1	18	Store receiver away from other components
34. Propeller	Yield under load Brittle Fracture	Loss of Thrust	10	Physical damage	4	Functionality Test prior to flight	1	40	Examine propeller prior to flight
3b, 2b. Nose Cone and Boom Adapter bolts	Bolts could shear or come loose in the infill	Complete loss of power and stability	10	*low infill on 3D print *Bolts not tightened	2	Shear Calculations	3	60	*Higher infill near near the nut holders
14-19. Landing Gear	Yield under load	Damage to aircraft Flying debris	9	*Improper fastening * Material defects or damage	2	Drop test	2	36	Use strong materials such as carbon fiber

Figure 15: FMEA Part 3

6.1.1 Risk Trade-off Analysis

To perform a risk trade off analysis, our team discussed what actions we could take to mitigate risk and then discussed the trade-offs associated with those actions. To address the concern of structural failure, our team concluded that we could add additional fasteners and adhesives to weak points in our design. Although this solution would add weight to our aircraft, it would reduce the risk of structural failure.

6.2 Initial Prototyping

6.2.1 Prototype 1

Initially for prototype 1, the team wanted to answer the question: Can we manufacture a structurally sound plane with working control surfaces that we can easily control? This question was answered through creating several different 3D parts for each respective subassembly. Through this, we were able to answer the above question with a yes, being that all control surfaces worked, and the final model was structurally sound. Prototype 1 can be seen in Figure 16.

Figure 16: Prototype 1 Final Assembly

The manufacturing process for this prototype involved a lot of 3D printing and CAD models. The wings were constructed from printed airfoils that were placed on 3 Balsa square struts, with a large, printed mounting foil to connect the wings to the plane. The fuselage and boom were made from pvc pipe. The tail wing was fully 3D printed with a mounting bracket, wings, a rudder, and three elevators. To connect the tail end to the main fuselage, a 3D printed boom connector was used. The motor was bolted to a printed nose cone. All electronics were run through the fuselage and control horns were screwed into the control surface followed by a linkage rod and servos in a printed mount.

What this prototype showed the team is that certain materials chosen were too heavy and bulky, relating in a final weight around 14.2 pounds. It allowed us to shrink the size of struts, decrease infill in all 3d printed parts, and remake every model to enforce more weight reduction throughout the plane. Another large aspect that this prototype proved is that our tail wing control surface was too small to work for the size of the plane. These dimensions were then recalculated for further prototypes.

This initial prototype could not take off the ground, which was okay for the team as takeoff was not one of the original goals for prototype 1.

6.2.2 Prototype 2

The main goal for prototype 2 was to make a plane that can fly, we wanted to find out if the team was capable of such a task. For this prototype we wanted to make something as light as possible while still following rough dimensions of what we want our final model to look like. Through this, the team was able to answer the prior question with another yes, being that we were able to fly prototype 2 in the air for 3 seconds. Although this was not a long flight, it did validate some ideas for us. This prototype ensured that the center of gravity was located at the correct spot, as the plane nosed down instead of rolling or falling tail-end first. It also proved that the new wing design worked well, and the ailerons were able to provide stability control. This prototype can be seen in Figure 17.

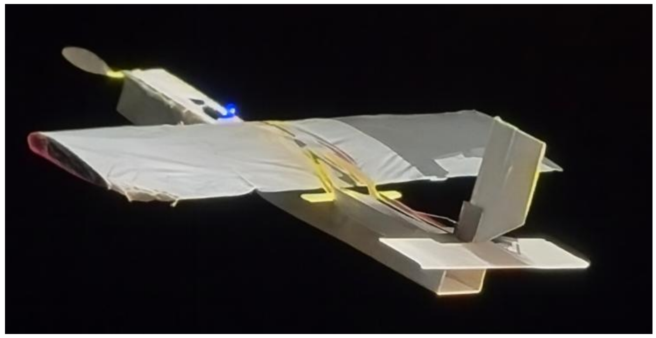


Figure 17: Prototype 2 Assembly

The manufacturing process involved the use of a lot of foam board and hot glue. The fuselage was made rectangular shaped using pieces of foam board and 90-degree brackets to create a solid structure. The motor was mounted onto another 90-degree bracket and then glued to the inside of the fuselage. Tail wings were created with foam and brackets, along with servos and control horns built into the foam. Lastly, one idea the team wanted to focus on with this prototype was out wing design. The decision was to create wings like prototype 1 as well as any future prototypes. These were made from printed airfoils that slid onto carbon fiber struts. The same type of wing adapter was used, although this one had more weight reduction. Printed servo mounts were once again used to hold the servos in place. The ailerons were increased in size to provide more of a control surface, then printed with PLA and wrapped in UltraCote. Once everything was in place, spray foam was used to create a leading and tailing edge. The wings were then wrapped in UltraCote to create the outside surface. Through this process we were able to drop 30% in the weight of the wings, from 18.7 to 13 ounces.

This prototype told us that a firmer leading and tailing edge were needed, allowing us to pick balsa for the following prototypes. It also told us that we need to focus some of our efforts on controlling a plane in the air, which we correlated to buying a trainer rc plane to get practice time in. Lastly, we found that we can make something that will fly allowing for better design with other models.

6.2.3 Prototype 3

The main goal for prototype 3 is to answer the following question: Can the team design a plane using all requirements from the SAE Aero rulebook and still be able to fly?

As we are still in progress constructing this prototype, we have not been able to answer the above question yet. Currently in this prototype we are almost done constructing the main structural sections. With this, throughout the last two prototypes, we have been able to enforce about a 30% weight reduction throughout most parts. This was done through not only redesigning all CAD models but also using a lower infill on all parts paired with a lighter weight PLA that has 40% less density than that of normal PLA. To reduce the need for nuts and bolts, which have more weight, we added two hatches into the fuselage to give us access for wiring as well as adjusting the center of gravity. With these hatches, it allows for the nose cone, boom adapter, boom, and tail wing to all be glued using either superglue or epoxy. The design is outlined in Figure 18.

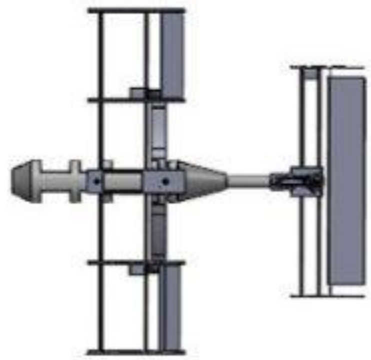


Figure 18: Prototype 3 CAD Model

6.3 Other Engineering Calculations

6.3.1 Thrust: Carlo Boyd

Since the concept selection phase, we were able to run tests on our current motor and propeller combination. The test involved using a thrust measuring stand to find the maximum static thrust that our propulsion system could produce. This value came out to 58.1 ounces, or about 3.63 pounds, seen in Figure 19. This related in a thrust to weight ratio of 0.2556:1 for prototype 1, 0.3528:1 for prototype 2, and a prospective ratio of 0.4538:1 for prototype 3.

Figure 19: Maximum Static Thrust

6.3.2 Fuselage FEA: Carlo Boyd

With the new fuselage design, there are several points where failure could occur. Because of this, we created a part in SolidWorks and uploaded the file into SimScale. The boundary conditions were set so the front and rear end of the fuselage as a fixed point. Point loads were then added to where the landing gear contacts the plane. A force of 200 pounds was used for each mounting point (front and rear). I also created a new material in the software that closely aligns with carbon fiber, although not quite as strong. With all this set, a static analysis was conducted on the fuselage, resulting in Figure 20.

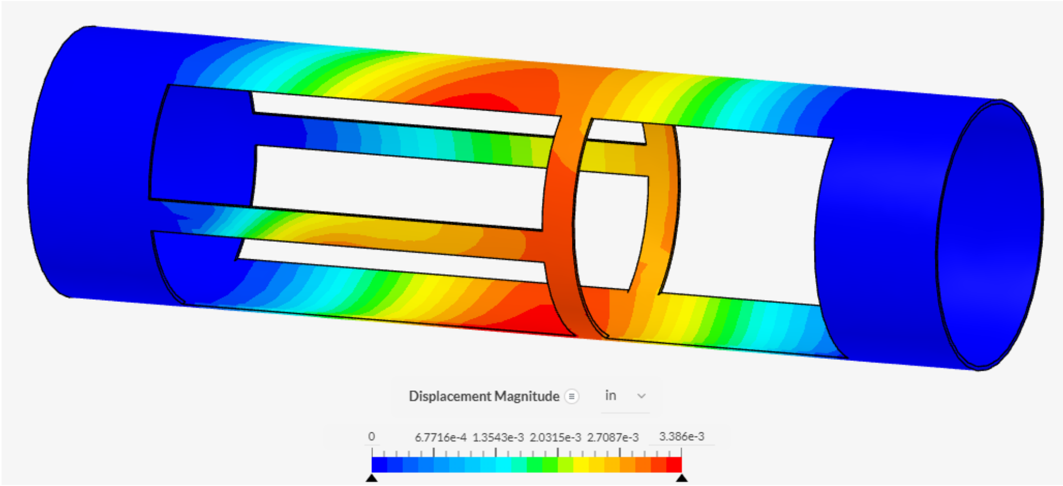


Figure 20: Fuselage FEA Displacement

This above figure shows that the maximum possible deflection is 0.003386 inches, and by looking through different tabs it is found that the maximum strain is .000549 in/in. With the strength of carbon fiber, this deflection and strain combination would not make the material deflect past the yield strength, meaning the design should work well for our specific applications. A large factor of safety is also used being that the 200 lb force used already inserts a factor of safety of 1.5, and this force most likely wouldn't be seen even on a rough controlled crash.

6.3.3 Dynamic Moment of Ailerons: Ryan Carberry

The question that the team wanted to answer through these calculations was: how effective are our ailerons?

Table 20: Variables and Values for Aileron Dynamic Moment

Variable:	Description:	Value:
$C_{l\varepsilon}$	Aileron lift increase with deflection angle (ε)	0.0124
$C_{l\alpha}$	Lift coefficient at 0° AOA	0.15
γ	Aileron chord length	2.5 [in]
$S_{aileron}$	Surface area of aileron	45 [in^2]
S_{ref}	Aileron area	315 [in^2]
$y_{aileron}$	Spanwise center of aileron (center of aileron → wing root)	13.1875 [in]
b	Wingspan	36 [in]
ε	Deflection angle	(±5, ±10, ±15)° [convert to rad]
q_∞	Dynamic pressure	0.0871 [$\frac{lb}{in^2 \times s}$]

M	Dynamic moment	(±1.07, ±2.14, ±3.21) $[\frac{lb\times in}{s}]$

Using equation (11) and *Table 20*, we first found our lift increase of 0.0124 at cruising flight (0° Angle of Attack). With this, using equation (12), we were able to find a dynamic moment at different aileron deflection angles (±5, ±10, ±15)°, which came out to ±1.07, ±2.14, and ±3.21 $[\frac{lb\times in}{s}]$.

$$C_{l\varepsilon} = C_{l\alpha} \times \sqrt{\gamma} \times \frac{S_{aileron}}{S_{ref}} \times \frac{y_{aileron}}{b} \quad (11)$$

$$M = C_{l\varepsilon} \times \varepsilon \times S_{ref} \times b \times q_{\infty} \quad (12)$$

These values seem valid because we don't want a dynamic moment that is too large, which would produce too much roll, or a value that's too little, which would produce an inadequate amount of roll. Through these calculations, we can test our roll capabilities through flight and simulation to gauge our stability in roll, as the team is required by the SAE rulebook to complete a 360° course, which makes stable and controllable flight an important aspect of our design process.

6.3.4 Tail Wing Sizing: Luke Chandler

Based off prototype one the tail wing had control surfaces that were too small, so to fix this new horizontal (S_{HT}) and vertical stabilizer (S_{VT}) areas were calculated using some updated dimensions. The main things to note from equation (13) is that c_{HT} is the volume coefficient and can be found in *Aircraft Performance and Design* [2]. Then C_{MAC} is the mean aerodynamic chord length but since the wings do not have any taper this is just the actual chord length of the main wing. L_{ht} is the distance from 75% of the main wing chord to 75% of the tail wing chord length and finally S_W is the main wing surface area.

$$S_{HT} = \frac{c_{HT} * S_W * C_{MAC}}{L_{ht}} = \frac{.7*360*10}{7.5+13.8} = 118.309 in^2 \quad (13)$$

For the horizontal stabilizer the recommended aspect ratio is between 3-5, and it has to be less than the ratio of the main wing. As the ratio of the main wing is 3.6 this forced the lowest limit to be applied when finding the span. When finding these dimensions just rough estimates are used, so then from this point the area is just divided by span to find the chord length. Using the percentages provided by John D. Anderson these were then multiplied by span and chord to find the approximate dimensions for the elevator [2]. Based off the size of the plane the highest ranges of these percentages were used because if the elevators and rudders are too small, we will not have surfaces large enough to control the plane.

$$Span = \sqrt{AR * Area} = \sqrt{3 * 118.309} = 18.83 in \quad (14)$$

$$Span_e = .9 * Span = 16.956 in \quad (15)$$

$$C_h = \frac{118.309}{18.83} = 6.28 in \quad (16)$$

$$C_E = 0.5 * C_h = 3.14 in \quad (17)$$

The main differences between the horizontal and vertical tail surface area calculations are the volume coefficients and then instead of the mean aerodynamic this equation uses the main wing span. The aspect ratio is also slightly lower when finding the span of the vertical stabilizer but besides that all the rest of the equations follow the same principles as listed above.

$$S_{VT} = \frac{c_{VT} * S_W * b}{L_{ht}} = \frac{.04*360*36}{7.5+13.8} = 24.338 in^2 \quad (18)$$

$$Span = \sqrt{AR * Area} = \sqrt{2 * 24.338} = 6.976 in \quad (19)$$

$$Span_R = .9 * Span = 6.27in \quad (20)$$
$$C_V = \frac{24.338}{6.976} = 3.489in \quad (21)$$
$$C_R = 0.5 * C_V = 1.744in \quad (22)$$

One last calculation made was just to see how much drag force the tail wing is producing by itself. This was just done by isolating the part in SolidWorks and then performing a fluid simulation similar to what we will be experiencing during flight. The drag force of this was just about a one-pound force proving the aerodynamic shapes of the tail are performing as expected and not creating unnecessary drag.

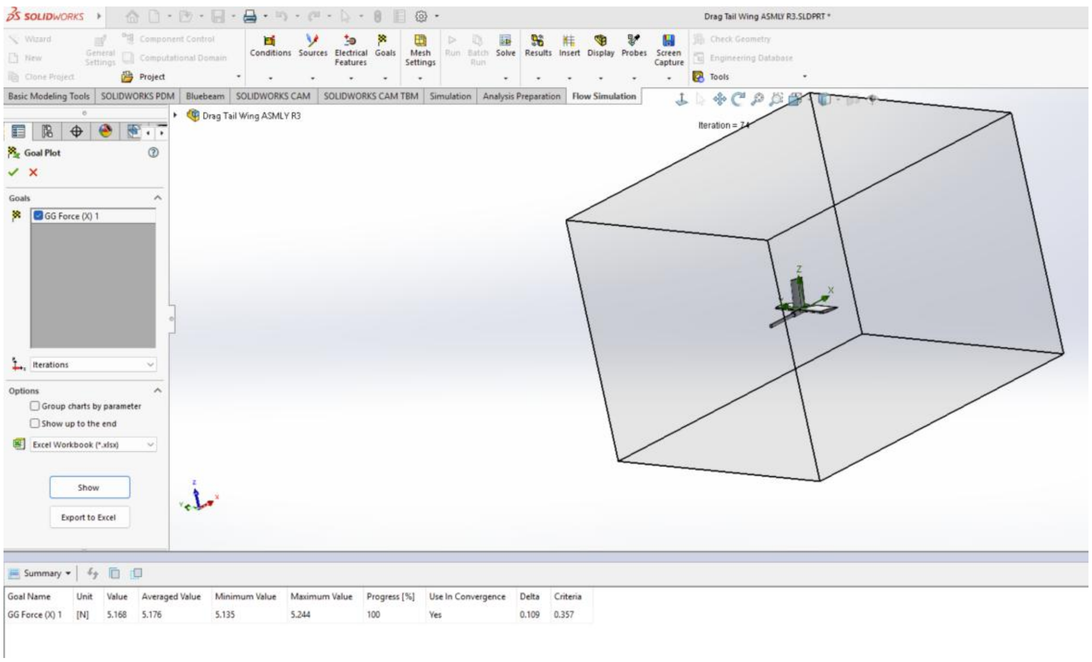


Figure 21: Drag Force on Tail wing

6.4 Future Testing Potential

The team has completed some testing procedures such as static thrust of our propellor, flying tests with our ultra-light prototype 2, some basic ANSYS Fluent simulations for pressure and velocity contours of our airfoils as well as SolidWorks analysis of surface drag of prototype 1.

Looking forward, we want to manufacture a roof mount for future prototypes to record data for dynamic thrust at various speeds. For this testing procedure, we need to improve our ability to smoothly fly our prototypes. To do this, we are planning on buying a trainer RC plane so that we can practice and improve our ability to control our planes in the air. The team also plans to do more analysis in either ANSYS Fluent, SolidWorks, or SimScale to acquire data to find our surface drag of our prototype assemblies.

Also, we will use a scale to measure our prototypes weights by measuring our sub-assemblies separately and adding the weights together, which we have been doing and plan to continue. In addition, we plan to use cones to measure takeoff and landing distances to ensure we are in the 100-foot takeoff and 200-foot landing distance requirements. Using a center of gravity stand as well as center of gravity calculations, we will test our flight ability at empty weight. Lastly, using a timer we will test our ability to drain our water container in less than 60 seconds.

Calculation wise, we need to be able to find our center of gravity, find a optimal angle of incidence, and calculate our increase of lift at different angles of our elevator control surface on the tail wing.

7 CONCLUSIONS

This report provides an overview of our project objectives and the requirements that drove our aircraft dimensions and configuration. To provide a description of our project, our team was tasked with designing a fixed-wing aircraft capable of taking off within 100 feet and landing within 200 feet while carrying a payload of 67 fl oz of water. Other key requirements include designing an aircraft with a gross weight of no more than 55lbs, a power limit of 450 watts, and the ability to drain water from a container within 60 seconds.

During our report, we discussed a number of crucial elements of our capstone proposal. First, we provided a description of our goals and highlighted the metrics we would use to measure our success. Next, we outlined the key customer and engineering requirements for project. Additionally, we provided a literature review which describes the nature of our sources and how they contributed to our design. Lastly, we provide overview of the calculations we performed to optimize the performance of our aircraft and ensure we obtain the highest flight score possible.

In order to meet the requirements of the competition, our team elected to design a single-engine, high wing airplane with a rectangular wing planform and a conventional tail. We believe this design will enable us to achieve short takeoff and landing distances while balancing other factors such as cost and ease of manufacture. While our team is still in the process of testing our prototype, we believe our design will enable us to score well if we are selected for the competition.

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9 APPENDICES

9.1 Appendix A: Tables

Table 21: Fuselage Decision Matrix

Fuselage Decision Matrix			Options			
			1	2	3	4
Selection Criteria	Weight	Multiply	(1-5)			
Ease of Manufacturability	5	x	5	5	2	2
Cost	3	x	3	3	2	5
Surface Drag	5	x	4	4	4	2
Weight	4	x	4	2	3	4
		Total Score	70	62	48	51

Table 22: Landing Gear Decision Matrix

Landing Gear configurations		Bicycle	Tricycle	Quadricycle	Taildragger
Characteristics	**Weight (1-5)**	Score (1-5)			
Stability on landing	5	1	4	3	1
Ease of manufacturing	2	3	3	1	3
ground control (taxiing)	4	1	5	3	2
Ease of take off	3	2	3	2	5
	Score	21	55	35	34

Table 23: Tail Wing Decision Matrix

Decision Matrix Tail Wing										
Criteria	Weight		1	2	3	4	5	6	7	8
Lift and Drag	2	x	2	3	3	4	2.5	3.5	3	4
Ease of Manufacturing	3	x	5	4	3	2	3	2	2.5	2
Stability	5	x	3	2	4	3	3	2	4	3
Weight	3	x	4	4	2	2	3	3	3	3
Final Scores			46	40	41	35	38	32	42.5	38

Table 24: Main Wing Decision Matrix

Decision Matrix Main Wing		Design Options:			
		1	2	3	4
Criteria:	Weight (1-5)	Weight (1-5)			
Lift/Drag	5	5	3	4	2
Ease of Manufacturing	3	4	3	2	3
Cost	4	4	5	4	2
Stall Characteristics	5	4	3	3	2
Stability	5	4	4	3	2
Air Resistance	3	3	2	4	3
Weight	3	3	4	3	4
Compatibility	4	4	2	4	4
	Total Score:	127	102	109	84

Table 25: Motor Decision Matrix

Decision Matrix Motor		Design Options:		
		1	2	3
Criteria:	Weight (1-3)	Scoring (1-3)		
Hp/W	3	3	2	1
KV	2	2	1	3
Cost	1	1	3	2
	Total Score:	14	11	11

Table 26: Battery Decision Matrix

Decision Matrix Battery		Design Options:		
		1	2	3
Criteria:	Weight (1-3)	Scoring (1-3)		
Weight	3	3	2	1
C-Rating	2	1	3	2

Cost	1	3	2	1
	Total Score:	14	14	8

Table 27: Fuselage Body and Boom Specs

Part:	Material:	ID	OD	Density	Pros:
Main Body	Kevlar Core Carbon Fiber	4"	4.125"	.048 lb/in^3	Easy to modify, lightweight, structurally sound
Boom	Kevlar Core Carbon Fiber	1"	1.09"	.048 lb/in^3	

Table 28: Other Fuselage Parts and Specs

Part:	Material:	Young's Modulus	Tensile Strength	Pros:
Nose Cone	Carbon Fiber Filament (CFN)	5138.7 MPA	48.3 MPA	Stronger than conventional PLA/ ABS
Boom adapter	Carbon Fiber Filament (CFN)	5138.7 MPA	48.3 MPA	
Floor Board	Balsa Wood	3000 MPA	14 MPA	Lightweight, Cost efficient

Table 29: Tail Wing Specs

Part:	Material:	Young's Modulus	Tensile Strength	Pros:
NACA 009 Airfoil	Balsa Wood	3000 MPA	14 MPA	Lightweight, Cost efficient
Part:	Lift Slope	Zero Lift Drag Coeff	Drag efficiency	Aerodyamic Stall AoA (deg)
NACA 009 Airfoil	0.1	0.03	0	10.5

Table 30: Prototype 1 Expenses

Item	Cost
Nuts, Bolt, Screws	$25.53
Wire	$3.79
Dowels	$0.99
Balsa Wood	$24.99
PVC for Fuselage	$25.99
PVC for boom	$4.97

Motor	$19.99
3D Filament	$24.99
Servos	$23.98
Speed Controller	$37.49
Servo Extenders	$7.99
Landing Gear	$14.97
Propellers	$15.99
Glue	$11.98
Sales Tax	$12.78
Total	$256.42

9.2 Appendix B: Figures

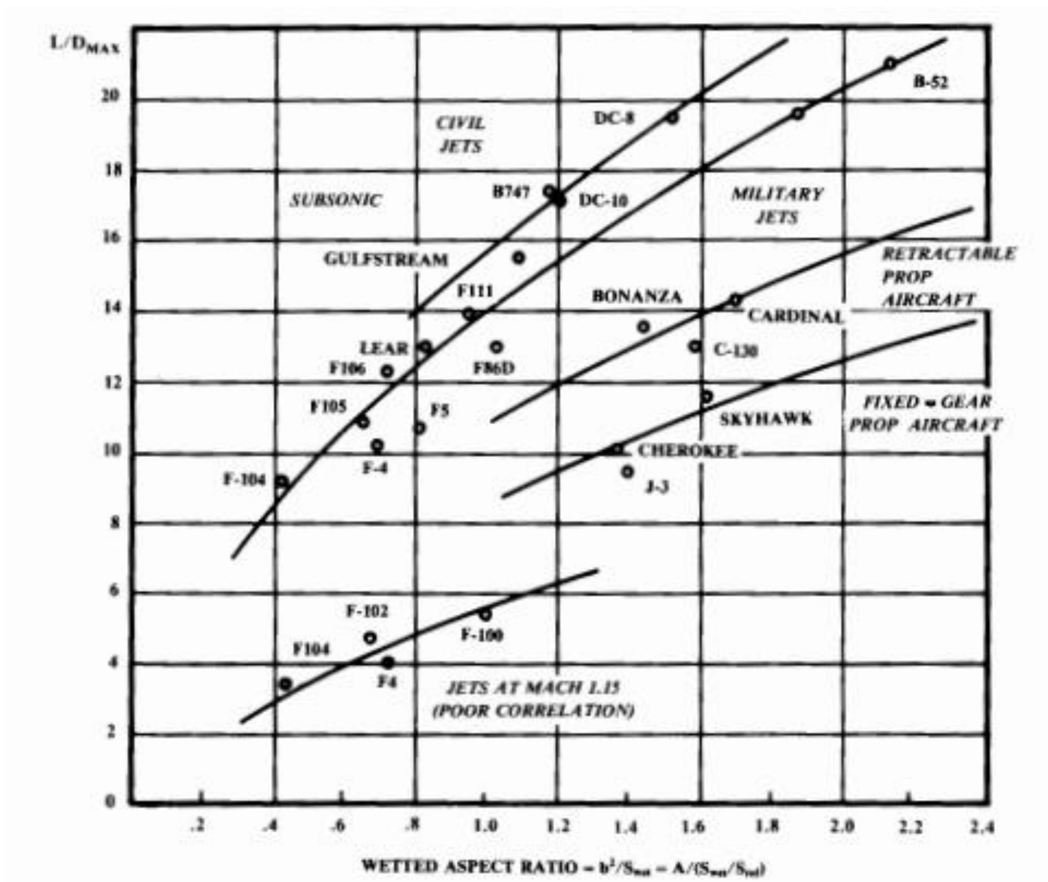

Fig. 3.6 Maximum lift to drag ratio trends.

Figure 22: L/D Ratio vs. Wetted Aspect Ratio