SAE Aero Design Regular Class

Initial Design Report

William Alcorn, Project Manager & FEA analyst

Dom Belasquez, Computer-Aided-Engineering Tool Lead & SolidWorks Expert

Gavin Georgiou, Manufacturing Lead & Propulsion Engineer

Tyler Milne, Budget Liaison & Electrical Lead

Tylee Thornley, Website Developer & Aerodynamic Design Engineer

Fall 2025-Spring 2026

NAU NORTHERN ARIZONA UNIVERSITY

Steve Sanghi College of Engineering

Project Sponsor: Salt River Project (SRP), Society of Automotive Engineers (SAE), Northern Arizona University Steve Sanghi College of Engineering (SCE)

Faculty Advisor: Dr. Peter Vedaz

Sponsor Mentor: Flagstaff Flyers

Instructor: David Willy

DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such, they are not responsible for the accuracy of results or conclusions.

EXECUTIVE SUMMARY

The SAE AERO design competition looks to build engineering skills in aviation, aeronautics, and aircraft design in students participating in the competition. This year's AERO design project involves students to design a remote-controlled aircraft that will take off, cruise, and land while delivering a volumetric payload, which this year has been designated to be 2-liter, commercially available bottles. The SAE organization has also stated several rules and regulations that each team must abide by. Key design parameters are guided by SAE competition rules, emphasizing payload mass, takeoff distance, and overall mission score. The final design will achieve a takeoff within the required distance while carrying a payload with stable and controllable flight characteristics verified through ground and flight tests. The design process is driven by both engineering analysis and competition requirements, guiding key design decisions in aerodynamics, structures, propulsion, and controls. Using computational tools such as SolidWorks for structural modeling and XFLR5 for aerodynamic performance evaluation, the team optimized the airfoil selection, aspect ratio, and wing loading to achieve efficient lift and stable flight characteristics under varying payload conditions. The propulsion system was selected through thrust-to-weight analysis to ensure reliable takeoff performance within the prescribed takeoff distance limits.

After considering the rules for this year's competition, we wanted to start benchmarking against the previous year's winning designs. This allows us to understand what worked and what didn't, thus allowing for better decision making. California State University has consistently won multiple years in the past decade, while universities such as Georgia Tech, have presented various creative designs. We've also looked at remote controlled (RC) aircraft available on the market to see what these companies have perfected in terms of cost saving measures and general production. We then took all the presented information and broke into subsystems to begin concept generation. The subsystems were chosen through the use of a black box model. Initial starting with 3 functions of flight, pitch, steering and lift, then we could decompose those into smaller systems until only a basic component was left. Each component broke the aircraft into much more manageable parts to allow studying of specific aspects and determining the pros and cons of each idea. Additionally, calculations and mathematical modeling for specific systems were required to fully rank and compare the concepts effectively in our concept selection. After each criterion was fully considered we developed our preliminary CAD design to begin prototyping.

For research, our team split into various sections close to the area chosen for concept creation to better and more accurately rate the designs. Each team member was tasked with gathering at least seven literature sources, to perform research within the design space. This research revolves around setting up mathematical models to aid in the design and selection process of aircraft components. Specific areas of concern such as aerodynamic drag/lift, structural bending, thrust/weight ratio, and landing forces were the primary equations we studied, as they will be the most crucial to our preliminary development of the aircraft.

TABLE OF CONTENTS

Contents

1 BACKGROUND

This chapter reviews the background of the project being reviewed in this report. This begins with a description of the project and the AERO design competition, before moving on to the key deliverables along with the project timeline, and the matrices for achieving success in the project.

1.1 Project Description

This project entails participation in the SAE AERO 2026 design competition, which requires the design of a "regular class aircraft" whose specifications are defined in the *2026 Collegiate Design Series SAE Aero Design Rules.* The objective of the regular class aircraft is to design a cargo aircraft, utilizing electric propulsion, that can maximize flight performance associated with payload delivery. The payload itself consists of commercially available 2L cylindrical plastic bottles, which will be carried on each flight. These bottles may not be modified and may be either empty or filled. It is required that the team be able to predict the payload capacity of our aircraft, as well as be able to incrementally increase the payload that the aircraft carries in each subsequent attempt during competition.

The project schedule is portrayed with a Gantt chart, which organizes the project timeline in terms of the key deliverables for the NAU capstone and SAE AERO competition. These deliverables are broken down into the required efforts for those deliverables, which are assigned to a team member or several team members.

This year, the project was donated an initial $5000 from SRP, with a fundraising goal of an additional $5000 for the regular class aircraft, to cover extra costs from competition, travel, required documentation, software & hardware, etc. Currently, the team is relying on the GoFundMe fundraiser, which has a goal of $10,000 that will be split between the two teams participating in the AERO Design competition this year. Currently, the GoFundMe has reached 64% of its goal, at $6390.

The importance of this project lies in its mimicry of problems and scenarios present in the real-world aircraft industry. The ruleset, aircraft requirements, and competition deliverables are designed to take a typical aircraft development program and compress it into the timeframe of a single academic year. Through participation in the capstone and competition, students will be exposed to conceptual design, manufacturing processes, systems integration and testing, and verification of results & design through demonstration of the aircraft performance at the competition.

1.2 Deliverables

Major capstone deliverables for this project are in four cycles, ending each cycle with a peer evaluation. The first cycle consisted of the deliverable presentation one, which was focused on setting the project for the year. Detailing the different requirements that the project will follow, a literature review having team members become more prepared for the scope of the project, and beginning calculations, to help set up the next cycle of major deliverables. Along with this, the focus was planned by laying out a schedule for the semester by breaking out major deadlines, creating a rough budget, and anticipating fundraising options. The second cycle included an individual skill building assignment, presentation two, and the team made the requirement of building the first prototype in this cycle. Each member learning a new skill is a way for the team to have more technical specialties and do more analysis. Presentation two has the focus on design, starting with a functional decomposition identifying the important sub-systems, then creating many sub-system designs, doing calculations to finalize designs, then making a rough CAD of this full system. For the first glider prototype, the goal was to look into wing configuration and airfoil shapes, experimentally finding trends of where our designs may perform better.

For the third cycle, deliverables include report one, website check one, presentation three and prototype demo one. This cycle focuses on proof of concept of the theoretical and pushing for proving calculations through testing. Report one summarizes what has happened through the semester up to this point, compiling work. Website check one is the proof of concept of a functioning website with necessary pages and navigation features. Presentation three is making more detailed models of a final design, detailing out the different components to the project, how they will all work together, and looking into the failure points in the design. Prototype demonstration one, will consist of two prototypes, each answering important questions. A scaled physical glider prototype to test overall design, thrust/weight and lift. Then a virtual prototype in computational fluid dynamics software, looking into the sizing of important actuation surfaces like the ailerons, elevators, rudder, also finding the pressures they must withstand. Cycle four consists of the deliverables: homework four an analytical analysis, report two, second prototype demonstration, finalized CAD and bill of materials (BoM), and a second website check. This focuses on finalizing designs, and preparing for manufacturing in the second semester, with the fourth homework, having each team member focus on parts and doing full analysis on it to ensure it is suitable for a final design. Report two follows a similar summarization, but incorporating scheduling, finances, bill of materials, prototyping, failure points, and future testing. The second prototype demonstration also consists of two prototypes, focusing again will be led by guiding questions. The finalized CAD and BoM are the designs and lists guiding second semester and the manufacturing of the final product. Website check two will focus on appearance, and completeness, needing detailed documents and full galleries of the work being done so far.

Major competition deliverables in the first semester are affiliated to one team, entering the lottery, and when selected for competition, paying the registration. The important deliverables during second semester are the technical design report, and the competition itself. The technical design report will be taking our finalized CAD and submitting the drawings of this design that the final plane will be compared against. Our plane must be certified that it is compliant with rules and regulations and will be able to compete. A flight score prediction must be made to show how theoretically our plane will be able to hold. For the competition itself, safe travel of the plane will be necessary, and planning the logistics of two SAE Aero teams travel will also need to be considered. In addition, for the competition the plane will need to be in fully functioning condition ready to compete, with many back-up parts that can be used to repair as needed. Lastly, flying training is an important factor for competition, with the pilots beginning training during the first semester and early as possible.

1.3 Success Metrics

Our team has determined that success comes from competition. We want to compete and place well in competitions. To achieve this goal, we first looked at the rules of the competition and how the scoring occurred. Our final flight score at competition is based on this equation.

$$Final\ Flight\ \ Score = \frac{(FS_1+FS_2+FS_3)}{3} + PPB \qquad \textit{Equation 1}$$

Where:

$$FS = 4(Empty\ Bottles) + 15(Full\ Bottles) \qquad \textit{Equation 2}$$

$$PPB = MAX(10-(FS-PS)^2, 0) \qquad \textit{Equation 3}$$

$$PS = Predicted\ Maximum\ Flight\ Score$$

The competition determines a full bottle having a weight of 4lbs or more and an empty bottle as anything between 1-4lbs. After comparing the potential flight score of each combination of bottles compared to their specific volume (volume/weight ratio), we generated this graph.

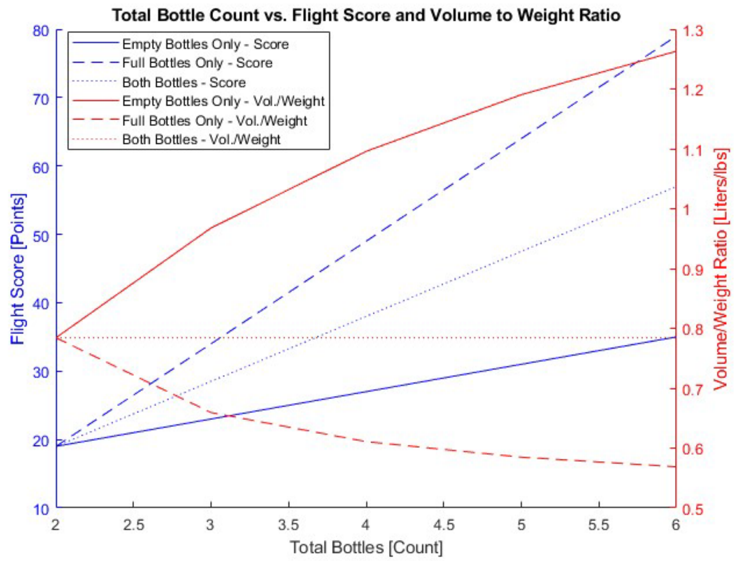


Figure 1: Flight Score Study for Varying Payloads

After analysis and planning, we have determined that we must attempt to target full bottles for our max flight score attempt to ensure we can receive the most possible points while ensuring we can hold that much weight and volume in our cargo space. The predicted maximum flight score is a factor determined by a theoretical flight score based on a "density altitude" approximation. This will be explored and calculated by the team closer to competition time so we can base our vehicle's performance on the final design. We must also look to receive zero deductions in points. These come by means of either technical or physical deductions. Late submissions of technical reports, deviations in reports, or unprofessional/unsportsmanlike actions shall result in point technical deductions. Physical deductions result from actions such as material falling off the aircraft, improper flying in designated zones, or dimensional limit violations. These will be crucial to limit, as we want to retain the maximum points possible.

2 REQUIREMENTS

This chapter of the report details the customer requirements and engineering requirements designated by the SAE organization. The customer requirements review the restrictions on mechanical and electrical components, as well as the competition & flight requirements. This is followed by the engineering requirements of the aircraft, which determine/restrict the geometric and mechanical properties of the aircraft, many of which are binary constraints. Lastly is the house of quality, where customer requirements and engineering requirements are related to each other and previous benchmarking in order to begin determining optimal design values.

2.1 Customer Requirements (CRs)

Through Quality Function Development, 16 Customer/Competition requirements were identified. These requirements, their descriptions, and corresponding weights of importance are organized and detailed below in Table 1. Weight of importance was biased towards methods of maximizing flight score.

Table 1: Customer/Competition Requirements, Weighting, and Descriptions

Customer/Competition Requirement	Weight of Importance	Requirement Description
Wingspan restriction	4	Planform wingspan must be between 72 & 120 inches
Maximum length restriction	5	Aircraft body axis length may not exceed 120 inches
Maximum weight restriction	5	Gross takeoff weight of aircraft may not exceed 55 pounds
Minimum chord length	2	Wing chord length must be greater than 4 inches
Propeller sizing restriction	2	Propellers must be either 9 inches or 12 inches
Motor count restriction	4	Aircraft may only utilize 2 or 4 electric motors for propulsion
Receiver/controls restriction	1	Receiver and controls require a separate power system and frequency
Safety requirements	1	Aircraft requires arming plugs, propeller nuts, etc.
Team Identification Vehicle Badges	1	Team number and name must be visible on aircraft wings.
Empty weight center of gravity markings	1	A marking for the center of gravity of the empty weight is required.
Steerable landing gear	2	Aerodynamic features may not be primary system used to steer
Takeoff Distance	5	Aircraft must achieve takeoff without bouncing within the takeoff distance
Flight attempt time limit	2	Aircraft must achieve takeoff within 60 seconds of being called on the runway
Landing distance	5	Aircraft must achieve landing within a certain distance without bouncing
Cargo requirement	5	Cargo must be 2L bottles that are fully enclosed within the fuselage
Propulsion system battery restriction	4	Aircraft must use a commercially available 4-cell (14.8 volt) Lithium-Polymer battery pack w/ a minimum 2200 mAh

2.2 Engineering Requirements (ERs)

For our capstone design project, it is heavily competition-based and thus all engineering requirements are derived from the 2026 SAE Aero rulebook for the regular class [1]. The competition requires that our planform wingspan is between six and ten feet. For our design, we found that the longer the wingspan, the more effective our aircraft's performance would be in lift. Thus, our target goal is to have a wingspan as close to ten feet as possible. One other factor that is very important to generate lift is wing chord length. For this competition, we are required to have our wing chord at any point along the wing be greater than 4 inches. This includes the ends of the wing if they have a taper. We are still running preliminary designs, but so far, our goal is to have the chord be greater than one foot. In future work, we will be analyzing drag values to see if a taper is required. Another requirement from SAE is that our vehicle must be under ten feet long. We initially thought that increasing our fuselage length closer to ten feet would be beneficial, however upon further analysis it was found to be incorrect. We should minimize the length to reduce weight and maintain flyability. Thus, for our design we are hoping to minimize this length, which based on our preliminary analysis in section 4.3 the length should be around four feet. Expanding upon this flyability requirement, the gross takeoff weight must be less than 55 pounds based on the rulebook. However, our preliminary calculations in section 4.3 show that we should stay around 30 pounds to stay flyable with the other competition constraints. The final major geometric constraint from the competition is that we must choose between two and four propulsion motors. This selection requires having either a 12-inch or 9-inch propeller to be used for the 2 motor and 4 motor setups respectively. From our calculations we are predicting that having two motors with 12-inch propellers would generate more effective thrust.

Along with geometric constraints, there are also extensive electrical equipment constraints that are acceptable for the competition. The first major and most limiting constraint is that our propulsion system must run off a single four cell LiPo battery that must have a capacity of at most 2200 mAh. The logical solution here was to select a battery with 2200 mAh as this will give us the most amount of operation time for high discharge rates. The next important engineering constraint is that for our controls system, receiver and servos, we must run off a separate battery that has minimum capacity of at least 1000 mAh. Our goal is to have a battery of at least 3000 mAh as this will provide additional safety in case of propulsion failure. Expanding on propulsion safety, the competition requires that we also place an arming plug that disengages the propulsion system, and it must be placed at a minimum 9-inches away from any propeller. Our goal is to have a safe competition; thus, our goal is to aim towards 12-inches. The final major electrical equipment requirement is the receiver, and transmitter must operate on a 2.4 GHz frequency band. Thus, our system will communicate at this frequency.

The rulebook also lays out some major scoring requirements for our team to score any flight points. The first major requirement is our cargo restriction. The regular class competition requires that we carry two-liter commercially available bottle cargo to earn any flight points. For our target, we initially wanted to carry six bottles (12 liters), but after our preliminary analysis, see section 4.3, it seems that we need to target four bottles (8 liters). Another requirement for our flight score is we must take off within 60 seconds of getting on the runway. Take off is defined as all wheels leave the ground completely. We are also required to take off within 100 feet of the starting location. For these requirements we are targeting 50 seconds and 80 feet respectively. Once our flight path is complete, we must also land within a 400-foot landing strip. A complete landing is defined as controlling the vehicle to the ground safely on the landing gear and coming to a complete stop. Our goal is to land within 100 feet of the end of the 400-foot landing strip. This would be the 300-foot mark on the runway.

2.3 House of Quality (HoQ)

Below is the broken-down preliminary House of Quality for our design project thus far. Our full HoQ can be found within Appendix C of this report. Table 2 is weighted with positive and negative relations represented as a + or a –, respectively. Table 3 is weighed from 1-5, representing the least and most important for increasing flight score. Table 4 is weighted as 1, 3, or 9 to show a weak to strong correlation between the customer and engineering requirements. Table 6 is weighed from 1-5, which shows poor to excellent incorporation of the respective customer requirements into those benchmarked designs.

Table 2: Engineering Requirement Correlations HoQ

Engineering Requirement Correlations													
Wingspan (6' < L < 10')													
Vehicle Length (< 10')	+												
Gross Weight (≤ 55lbs)	+	+											
Wing Chord (> 4")	+		+										
Propeller Diameter (9" or 12")													
Propulsion Battery 4 Cell 14.8V (≤ 2200 mAh)					-								
Reciever Battery LiPo or LiFE (≥ 1000 mAh)													
Arming Plug (≤ 9" from any Propeller)	-			-	-	+							
Landing Distance (≤ 400')	+	+	+	+									
Take-Off Distance (≤ 100')	+	-	-	+	+	+			+				
Flight Attempt Time Limit (≤ 60s)			-		+	+	+	+		+			
Radio Control System (2.4 GHz)						+	+				+		
Cargo Volume (2 Liter Bottle)		+	-										

Table 3: Customer Requirements of HoQ

Competition & Customer Requirements	Weight of Importance for Scoring
Wingspan Restriction	4
Aircraft Length	5
Weight Restriction	5
Airfoil Chord Length Restriction	2
Propeller Sizing Restriction	2
Motor Count (2 or 4)	4
Receiver/ Control System Restriction	1
Safety Requirements	1
Team Identification Vehicle Badges	1
Empty Weight Center of Gravity Markings	1
Steerable Landing Gear	2
Take-Off Distance	5
Flight Attempt Time Limit	2
Landing Distance	5
Cargo Requirements	5
Propulsion System Battery Restriction	4

Table 4: Engineering Requirements and ER/CR Correlations of HoQ

Engineering Requirements												
Wingspan (6' < L < 10')	Vehicle Length (< 10')	Gross Weight (≤ 55lbs)	Wing Chord (> 4")	Propeller Diameter (9" or 12")	Propulsion Battery 4 Cell LiPo 14.8V (≤ 2200 mAh)	Reciever Battery LiPo or LiFE (≥ 1000 mAh)	Arming Plug (≥ 9" from any Propeller)	Landing Distance (≤ 400')	Take-Off Distance (≤ 100')	Flight Attempt Time Limit (≤ 60s)	Radio Control System (2.4 GHz)	Cargo Volume (2 Liter Bottles)
9	3	3	1		3		3					
3	9	3	1	1			1					
3	9	9	3	1	3							
3	1	3	9	9			3					
		3		9			9					
	1	3		3			9	1	1		1	3
				1		9		1			9	
1	3		1	1	1	1	9			3	3	1
	1											
	1	1								1		9
1	1		1	3				1	9	1	1	
	3			1					9	1	1	
				1	1				3	9	1	3
1	3							9		3	1	
	9	9								1		9
		1			9	3					3	1

Table 5: Bottom Floor of HoQ

Bottom Floor														Totals
Importance Weight Score	80	190	146	45	73	66	22	86	52	73	49	42	77	1001
Importance Weight Percentage	7.99%	18.98%	14.59%	4.50%	7.29%	6.59%	2.20%	8.59%	5.19%	7.29%	4.90%	4.20%	7.69%	100.00%
Measurement Units	feet	feet	lbs	inch	inch	mAh	mAh	inch	feet	feet	seconds	GHz	liter	-
NAU Team 1 Target Value	~10	4	30	≥12	12	2200	3000	12	300	80	50	2.4	8	
2023 Georgia Tech (Advanced Class)	~11	~8	N/A	~18	~2	N/A	N/A	N/A	~30	~50	N/A	N/A	N/A	
Dynam Cessna 310 Grand Cruiser V2 Blue Twin Motor RC Scale Plane	4.25	3.67	2.65	~6	8	2200	N/A	N/A	~30	~20	N/A	2.4	N/A	
2023 California State University Northridge (Advanced Class)	~12	~3	N/A	~24	~1.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	

Table 6: Benchmarking of HoQ

Benchmarking			
2026 NAU Team 1 Target (Regular Class)	2023 Georgia Tech (Advanced Class)	Dynam Cessna 310 Grand Cruiser V2 Blue Twin Motor RC Scale Plane	2023 California State University Northridge (Advanced Class)
5	5	1	5
4	4	3	2
5	2	2	2
3	4	3	4
3	1	1	1
3	1	3	1
4	4	4	4
5	5	3	5
2	5	1	5
4	5	1	3
3	1	3	3
4	5	5	4
3	5	1	4
4	5	5	4
5	2	1	2
5	5	5	5

3 Research Within Your Design Space

3.1 Benchmarking

To get a better understanding of the type of aircraft we are trying to construct, we benchmarked against a few different models to get an idea for different components. The 2025 AERO competition, past winning aircraft, and a Dynam Cessna 310 Grand Cruiser V2 Blue Twin RC Plane are the aircraft we based our benchmarking on. From this benchmarking, goals were identified for each part performance.

3.1.1 2025 Competition

The 2025 Aero regular class competition planes were looked at to get a start on what velocity and Reynolds number we would be designing for. From a video of the competition, how long it took each plane to travel a specific distance was recorded. The velocity of takeoff, cruise, and landing were estimated and used in our calculations. The aircraft that were chosen to be in our data for the velocities were all regular class planes who took off and landed successfully. The distances were estimated based on the rules for last year's competition. [2]

3.1.2 Winning Aircrafts

Previous winning aircrafts from Georgia Tech and California State University were looked at because they won the competition in a previous year. The aircraft of these two teams were then compared against our ideal design in our QFD. These designs related very well in our QFD accept within rule requirements as the rules change yearly. By comparing the physical geometry of the plane, we may build a similar aircraft assuming this is partly why their plane was successful. [3] [4]

3.1.3 Dynam Cessna 310 Grand Cruiser

This aircraft was selected because it uses the same electronics that fit within our constraints. Understanding how this aircraft performs can help us with electronic selection. This plane performed poorly in the QFD, but that was expected due to the fact that this plane was not designed for our competition. The starting point of our electronics research and dual propeller planes came from the performance and benchmarking done from this plane. [5]

3.2 Literature Review

Each student in the Aero 1 team completed research within their chosen design category to better understand the project at hand. A list of sources and a description of how it is being used is listed below.

3.2.1 William Alcorn

[6] John D. Anderson Jr., "NACA Airfoil Nomenclature" in *Aircraft Performance and Design* 5th ed., 2012. [Online]. Available: https://soaneemrana.org/onewebmedia/AIRCRAFT%20PERFORMANCE%20AND%20DESIGN1.pdf

This section in the textbook gives insight and explanation into the geometric properties of wing airfoils. Additionally, it explains how the NACA nomenclature system communicates the airfoil geometry through the 4 digits present in the NACA designation. The ultimate intention behind using this literature piece was to expand the conceptual understanding of aircraft geometry, so that it may be further applied in mathematical modeling.

[7] Martin Simmons, "Factors affecting lift and drag", in *Model Aircraft Aerodynamics* 5th ed., 2015, pp. 27-44

This literature piece involves discussion on the factors contributing to lift and drag air reaction forces, air density, model size, velocity, angle of attack and trim, airfoils and lift coefficients, wing loading, coefficient of lift of an entire airfoil vs an airfoil section, Bernoulli's theorem, etc. This conceptual background behind lift and drag was essential in the 1st mathematical modeling process.

[8] Martin Simmons, "Airfoils: 1 Camber", in *Model Aircraft Aerodynamics* 5th ed., 2015, pp. 119-136

This reference builds off what was learned from the 1st literature review and serves the same purpose of giving insight into a specific geometric property of airfoils: camber. It was learned what camber was, how it is portrayed as a curved midline through the airfoil, and how it ultimately affected the airfoil geometry.

[9] John D. Anderson Jr., "Aerodynamic lift, drag, and moments" in *Aircraft Performance and Design* 5th ed., 2012. [Online]. Available: https://soaneemrana.org/onewebmedia/AIRCRAFT%20PERFORMANCE%20AND%20DESIGN1.pdf

This source is directed towards providing the locations of lift, drag, and resultant aerodynamic force, as well as the bending moments along a wing section. Like the previous references, the purpose of this review is to learn basic concepts surrounding aerodynamic forces, to ultimately aid in the mathematical modeling process.

[10] John D. Anderson Jr., "Lift, Drag, and Moment Coefficients: How They Vary" in *Aircraft Performance and Design* 5th ed., 2012. [Online]. Available: https://soaneemrana.org/onewebmedia/AIRCRAFT%20PERFORMANCE%20AND%20DESIGN1.pdf

This reference provides further conceptualization of the lift and drag coefficients. It gives insight into the many complexities that affect these coefficients, such as geometry, angle of attack, Reynolds number, Mach Number, etc. These concepts allowed for proper assumptions and parameters to be set for the 1st mathematical process.

[11] Sighard F. Hoerner, Henry V. Borst, "Lift Characteristics of foil sections" in *Fluid Dynamic Lift* 2nd ed., 1985. [Online]. Available: https://ia801507.us.archive.org/20/items/FluidDynamicLiftHoerner1985/Fluid-dynamic_lift__Hoerner__1985_text.pdf

This reference is focused on relating the geometric properties of airfoil sections to their lift characteristics. Ultimately, this review has the same objective as previous references: developing a conceptual understanding of wing design

[12] "NACA 0012 AIRFOILS (n0012-il)," Airfoil Tools, 2025. [Online]. Available: http://airfoiltools.com/airfoil/details?airfoil=n0012-il

This source is used as a tool in the preliminary mathematical modeling process, in which it was desired to determine the theoretical lift forces acting on the aircraft during flight. This site was used to select the NACA 0012 and determine the optimal angle of attack, which was further used for mathematical modeling.

3.2.2 Dom Belasquez

[1] SAE International, "Regular Class Design Requirements," in 2026 Collegiate Design Series SAE Aero Design Rules, 2026, pp. 31-33.

This source is the foundation of our competition as this is the Regular Class rules and competition requirements. This was essential for the creation of our HoQ and understanding how we will be scored at the competition. This source also lays out the content required for submission such as design reports, flight studies, CAD, and presentations.

[13] Aircraft Owners and Pilots Association, "Density Altitude," AOPA, 2025. [Online]. Available: Density Altitude – AOPA

One of the requirements for submission to SAE is a flight study of how our vehicle theoretically performs the best at different altitudes. This performance is based on how much cargo we can theoretically carry at certain density altitudes. Its importance is crucial in gaining additional points in the Payload Prediction Bonus section of the rulebook [8]. Thus, this source explores the theory behind density altitude for pilots and how to calculate it.

[14] A. K. Mitra, "Propeller Airplanes," in Aircraft Performance and Design - An Introduction to Principles and Practice, 2nd ed., Library of Congress, 2020, pp. 115-132

During our preliminary design phase this book provided necessary resources for our team to understand and calculate multiple critical characteristics. These include steepest climb rate, minimum power requirement, takeoff and landing ground run, angle of approach, and stall speed. These equations helped verify the quality of the MATLAB Optimization programs outputs. These equations also showed us that we will need some form of braking during landing such as electric brakes or reverse thrust capabilities.

[15] A. K. Mitra, "Static Stability," in Aircraft Performance and Design - An Introduction to Principles and Practice, 2nd ed., Library of Congress, 2020, pp. 156-174

This source provided a background on multiple important fundamentals of stability. It provides recommended static coefficients for cargo planes along with guidelines for wing and tail placement. The source also goes into the theory and how to calculate moment stability which also helped verify the content of the MATLAB Optimizer program used in our preliminary design.

[16] “Trainer Design," RCPlanes, 2025. [Online]. Available: https://rcplanes.online/design.htm

This source provides multiple helpful guidelines for designing a propeller remote-controlled aircraft. The website has a built-in calculator that recommends multiple geometric features on an aircraft based on some basic inputs of desired wingspan. As we continue to utilize the MATLAB Optimizer explained in section 3.3.2, we will use this resource to double check if the geometric features the Optimizer creates are reasonable. The source also provides some recommendations for increasing flight stability and good power to weight ratios for desired aerobatics.

[17] M. V. Cook, "Static Equilibrium and Trim," in Flight Dynamics Principles, 2nd ed., Massachusetts: Elsevier Ltd., 2007, pp. 32-57

This source extends off the static stability source previously listed and provides a more in-depth discussion of the theory behind static equilibrium. One important addition to this source is that it covers lateral stability which is essential for cargo planes since they typically do not have the power to pull out of a roll stall. This source does also cover control trims within aircraft which is not directly applicable to our design but does help understand controls stability.

[18] Omron, "Technical Explanation for Servomotors and Servo Drives," [Online]. pp. 1-19 Available: https://www.ia.omron.com/data_pdf/guide/14/servo_tg_e_1_1.pdf

Although this source is directed towards promoting its own product, it does provide essential

information for the selection criteria of servomotors. Our aircraft will have ailerons, elevators, steerable landing gear, and a rudder which will all utilize servomotors. Ensuring that we select the correct servomotor is crucial to ensuring safe and controllable flight.

[19] ASME Dimensioning and Tolerancing, ASME Standard Y.14M, 1994

This standard plays multiple important roles for our team. The competition requires that we provide an industry standard CAD drawing of our vehicle that must follow this standard. Furthermore, we will likely be partnering with the metal 3D printing team to optimize some subsystems of our design along with placing orders with the NAU machine shop and Idea Lab. All these services require we provide them with proper dimensions and tolerances.

3.2.3 Gavin Georgiou

[20] Richard Von Mises, "Propellor and Engine" in Theory of Flight, First Edition, pp. 285-309

This source served as a learning resource about the thrust to weight ratio calculation that was being conducted, including the important equations, and the variable breakdown of the different variables. Along with this the source highlighted how to interpret the results of the thrust to weight ratio calculations, giving examples of real aircrafts ranges. This source also explained how different propellor will affect design, describing benefits and drawbacks of number of blades and pitch angles.

[21] BadAss BA-2315-1480 "Performance Test Data". [Online] Available: https://innov8tivedesigns.com/pub/propcharts/BA2315-1480-Specs.htm

This specification sheet is for the BadAss BA-2315-1480 motor which initial thrust vs weight calculations were being taken against. The specification sheet outlines how the motor performs with different battery connections and with different propellers used. Using these sheets served as a check as they had thrust values, and it ensured that proper calculations were being taken place to ensure similar thrust values. In addition, it provided the necessary information to perform the thrust-to-weight ratio on the motor.

[22] Rcgroups, "Thrust to Weight Ratio". [Online] Available: https://www.rcgroups.com/forums/showthread.php?2024770-thrust-to-weight-ratio

This online forum is a conversation of RC aircraft hobbyists, discussing the different optimum thrust to weight ratio ranges they have found through their experience. The ranges that were detailed describe how fast RC planes will need to be far above 1, and slow aircraft must be, more often than not, above 0.3, as no-one seemed to find success taking off with a thrust to weight ratio below 0.3. This is important for the project as it details ranges that the project will aim for and ensure we have a successful flight.

[23] A. K. Mitra, "Thrust Required" & "Endurance" in Aircraft Performance and Design - An Introduction to Principles and Practice, 2nd ed., Library of Congress, 2020, pp. 202-228 & 293-296

This source explains thrust-to-weight ratios taken for other aircraft and details many different assumptions that can be taken to perform the calculation. This helped create the project's thrust-weight-ratio calculation, having proper assumptions. It also explained other important factors that need to be considered in the overall design, such as endurance, and how thrust vs drag will affect necessary torque from the motors, leading to less battery life for larger motors. This is important for design considerations and motor selection.

[24] A. K. Mitra, "Estimation of the Critical Performance Parameters" in Aircraft Performance

and Design - An Introduction to Principles and Practice, 2nd ed., Library of Congress, 2020, pp. 406-418

This source describes different constraint requirements and considerations that need to be considered for the overall aircraft design. These constraints assist with future constraints calculations that are performed on the aircraft and influence the overall design considerations. It details how wing area and thrust vs weight ratios can be affected by a variety of different constraints.

[25] John D. Anderson, Jr., "Effect of Aspect Ratio" in Fundamentals of Aerodynamics, 6th ed., Mc-Graw Hill, pp. 450-464

This source explained aspect ratios and how they influence the overall design of the aircraft, as the aircraft does not need to be very maneuverable, a higher aspect ratio can be used for the aircraft. This will decrease the induced drag, helping reduce the necessary thrust and lift. Which influences design considerations and equipment sizing for the aircraft.

[26] Daniel P. Raymer, “Sizing from a Conceptual Sketch" in Aerodynamic Design: A Conceptual Approach, 6th ed., AIAA Educational Series, pp. 11-31

This source details many commercial aircraft with different designs, describing the benefits and drawbacks of how these components and overall designs work together. This is beneficial to the project, as this description of benefits and drawbacks helps design considerations on what the project's design should be related to. It additionally describes many important calculations for relating a sketch and model of the aircraft to real-life conditions, which will help influence the team's design considerations and future calculations.

[27] E. Oberg, F. D. Jones, H. L. Horton, and H. H. Ryffel, "Rivets and Riveted Joints“ Machinery’s Handbook, 29th ed. New York, NY: Industrial Press, 2012. pp. 1729-1745

This source describes the standards that are in place around rivets and riveted joints. This resource will be very important during design, so the project ensures that it is following the proper standards that are in place for the different components in our project. In addition, it is important during design, so designs are created with manufacturing in mind, and are able to be connected using rivets.

3.2.4 Tyler Milne

[28] D. Chandra Shil, T. Ahmed, R. Mia, and N. Bej, “Design, Fabrication and Aerodynamic Analysis of a RC Airplane,” Radware bot manager Captcha, https://iopscience.iop.org/article/10.1088/1742-6596/2856/1/012002/meta (accessed Sep. 13, 2025).

Useful for the design factors of airplanes, such as drag and lift coefficients, remote control frequencies, stability, and angles of attack. Provides a detailed discussion on aerodynamic design parameters such as lift, drag, and stability. Includes experimental and simulated results for drag and lift coefficients. Discusses control surface configuration, remote-control frequencies, and angle of attack optimization. Useful for understanding overall RC airplane design methodology and validation approaches.

[29] D. J. Auld and K. Srinivas, “Resources,” Aerodynamics for Students, https://www.aerodynamics4students.com/aircraft-performance/take-off-and-landing.php (accessed Sep. 13, 2025).

Useful equations for takeoff and landing calculations, thrust and power formulas, as well as maneuvering methods for the aircraft. Contains fundamental equations for takeoff distance, ground roll, and climb performance. Provides thrust, power, and drag relationship formulas used in aircraft performance analysis. Offers maneuver and performance methods applicable to RC aircraft scaling.

[30] "Landing performance," https://webstor.srmist.edu.in/web_assets/srm_mainsite/files/downloads/class18-2012.pdf (accessed Sep. 13, 2025).

Explains theoretical and practical aspects of aircraft landing performance. Includes mathematical modeling for rolling resistance, braking distance, and deceleration forces. Highlights ideal landing procedures to minimize the risk of crash or instability. Valuable for simulating and validating RC aircraft landing behavior.

[31] M. H. Sadraey, "Chapter 9," in *Aircraft Design: A Systems Engineering Approach*, 1st ed, vol. 1, Chichester, United Kingdom, 2013, pp. 508–581 (accessed Sep. 13, 2025).

Covers landing gear design, structural analysis, and load distribution. Provides detailed formulas for impact force and gear reaction forces. Discusses wheel geometry, tire selection, and landing approach angle optimization. Essential for ensuring safe and efficient landing gear configuration in small-scale aircraft.

[32] A. C. Watts, V. G. Ambrosia, and E. A. Hinkley, "Unmanned Aircraft Systems in remote sensing and scientific research: Classification and considerations of use," MDPI, https://www.mdpi.com/2072-4292/4/6/1671 (accessed Sep. 13, 2025).

Reviews types and classifications of unmanned aerial systems (UAS). Discusses control and communication systems used in remote or autonomous flight. Highlights operational considerations for stability, navigation, and environmental applications. Useful for improving control architecture and exploring autonomous features for RC aircraft.

[33] A. Gupta, V. Soni, D. Shah, and A. Lakdawala, "Generative design of main landing gear for a remote-controlled aircraft - sciencedirect," ScienceDirect

Focuses on weight reduction and topology optimization for landing gear structures. Demonstrates use of generative design to enhance structural efficiency. Provides insights into materials selection and geometry refinement for small aircraft applications. Helpful for optimizing the strength-to-weight ratio in RC aircraft landing systems.

[34] "FAA regulations," FAA Regulations | Federal Aviation Administration, https://www.faa.gov/regulations_policies/faa_regulations (accessed Sep. 17, 2025).

Outlines regulations governing the operation of aircraft, including unmanned and model aircraft. Defines safety, airspace, and operational compliance requirements. Useful for ensuring adherence to legal flight standards during RC testing and competition events.

3.2.5 Tylee Thornley

[35] R. W. Fox and J. W. Mitchell, *Fox and McDonald's introduction to fluid mechanics*. Hoboken: Wiley, 2019.

This is the book I used in my fluid dynamics class. It has tables and equations for lift and drag that are relevant to aircraft design. I also used tables for properties like the density of air. This book is a useful source for equations that deal with the air around the plane.

[36] NASA, "Reynolds Number," *Nasa.gov*, 2019. https://www.grc.nasa.gov/www/k-

12/airplane/reynolds.html

NASA created this website to calculate the Reynolds number given certain information. This was used at first to find a preliminary Reynolds number that we are looking for, which helped with initial airfoil selection.

[37] SAE International, "SAE Aero Design East 2025 Flight Attempts Day 1 Sponsored by the Gene Haas Foundation," *www.youtube.com*, May 03, 2025. https://www.youtube.com/watch?v=gandHr7aDDc (accessed Sep. 11, 2025).

This YouTube video is of the competition from 2025. It was used to find the velocities of aircraft in the competition to see what we need to design for. The design of previous aircraft was also looked at to get an idea of what we wanted.

[38] C. Reyes, *RC Advisor's Model Airplane Design Made Easy*, 1st ed. Albuquerque, N.M.: Rcadvisor.com, 2009, pp. 35–53.

This book is a preliminary on how to start building an R/C aircraft. It has tips for airfoil selection and Reynolds numbers for R/C aircraft. Using this book as a reference, a preliminary airfoil was chosen for the first round of calculations.

[39] John David Anderson, Fundamentals of Aerodynamics, 5th ed. New York: Mcgraw-Hill, 2011, pp. 313–407.

This online book has several calculations that can be used in the future for lift and drag as well as thrust to weight, based on the Reynolds number.

[40] L. Nicolai, "Estimating R/C Model Aerodynamics and Performance," Lockheed Martin 7Aeronautical Company, Jun. 2019.

This paper, written by an engineer at Lockheed Martin, compares an R/C plane to a Cessna 172. This was used in research for benchmarking, as our benchmarking was done against another Cessna plane.

[41] J. G. Leishman, "Mach Number & Reynolds Number," *eaglepubs.erau.edu*, p. Ch.16, Aug. 2022, doi: https://doi.org/10.15394/eaglepub.2022.1066.n13.

Lift to drag relationship to Reynolds number

[42] C. Locke, "Amateur-Built Aircraft and Ultralight Flight-Testing Handbook," Federal Aviation Administration, Feb. 2023.

This site by the FAA lists standards for flight testing of amateur airplanes and tips for takeoff, which is crucial when researching how we will test our aircraft and what size is required to test at an airstrip.

3.3 Mathematical Modeling

Each member of the team completed calculations and modeling for different subsystems to optimize our design and compare different configurations. The process and results of our findings are listed below.

3.3.1 Wing sub-assembly – Gavin Georgiou

The first calculation is the thrust vs weight calculation; details of the motor mentioned in reference [21] were used. The equation:

$$T = K_T \rho n^2 D^4 \qquad \textit{Equation 4}$$

was used to find the theoretical thrust of the motor [20]. In this equation, T stands for thrust in newtons, K_T stands for the unitless coefficient of thrust, ρ stands for the density of the fluid, so in this case, air at ~20°C and 2,000ft of elevation, measured in kilograms per meter cubed. The variable n stands for the rotational speed in revolutions per second, and D is the diameter of the propeller in meters. This equation was then coded into MATLAB, along with a conversion to English units. After this, it was divided over a series of weights ranging from 20 to 55 lbs. Repeating this code for both the two-propeller and four-propeller configuration, a plot comparing their thrust/weight ratio to the weight of the overall plane.

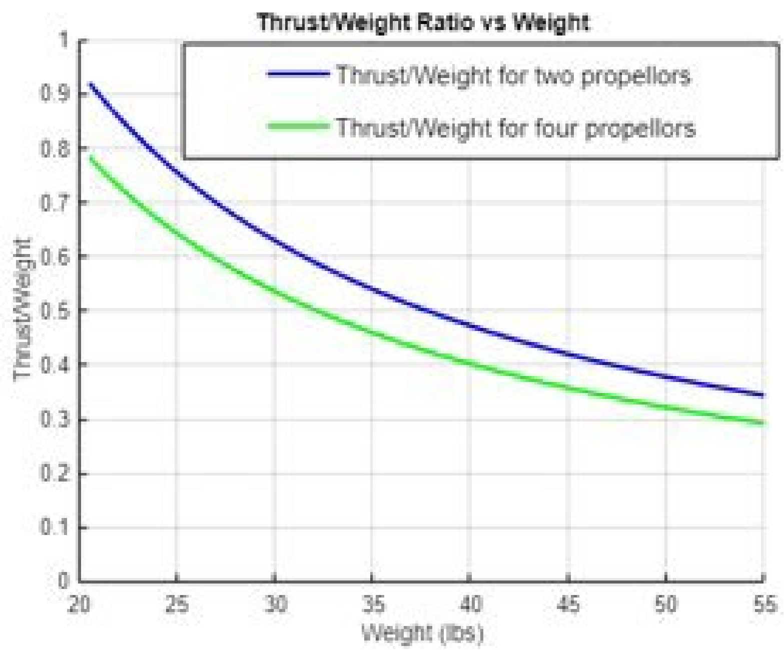


Figure 2: Thrust/Weight Ratio vs Weight Graph

The second calculation was a calibration curve, which was used to find an acceptable region for flight, on a thrust/weight vs wing loading graph. The equations used for this were the stall constraint:

$$V_s = \sqrt{\frac{2*\frac{W}{S}}{\rho*C_{L,max}}} \qquad \textit{Equation 5}$$

V represents velocity in feet per second, $\frac{W}{S}$ represents wing loading in pounds per square foot, ρ represents density in pounds per foot cubed, C_L represents the coefficient of lift. Rate of climb constraint:

$$\frac{dh}{dt} = (T - D) * \frac{V}{W} - (\frac{g}{g})(\frac{dV}{dt}) \qquad \textit{Equation 6}$$

$\frac{dh}{dt}$ represents the rate of climb in feet per second, T represents thrust in pound force, D represents drag in pound force, W represents weight in pound force, g represents the gravity constant in feet per second squared, and t represents time in seconds. Take-off distance constraint:

$$m\frac{dV}{dt} = T - D - \mu(W - L) \quad \textit{Equation 7}$$

m represents mass in pounds, μ represents dynamic viscosity in pound force second per foot squared, and L represents lift in pound force. Constant velocity turn constraint:

$$\frac{T}{W} = \frac{qC_D}{\frac{W}{S}} + k\frac{L}{W}q\left(\frac{W}{S}\right)\left(\frac{L}{D}\right) \quad \textit{Equation 8}$$

C_D represents the coefficient of drag, k represents the induced drag factor, and q represents dynamic pressure in pound force per square foot. The final equation used in the calculation was the cruise seed constraint:

$$V_{Cruise} = \sqrt{\frac{2*\frac{W}{S}}{\rho*C_{L,Cruise}}} \quad \textit{Equation 9}$$

These equations were coded into MATLAB and graphed together to find an acceptable region, as highlighted in green.

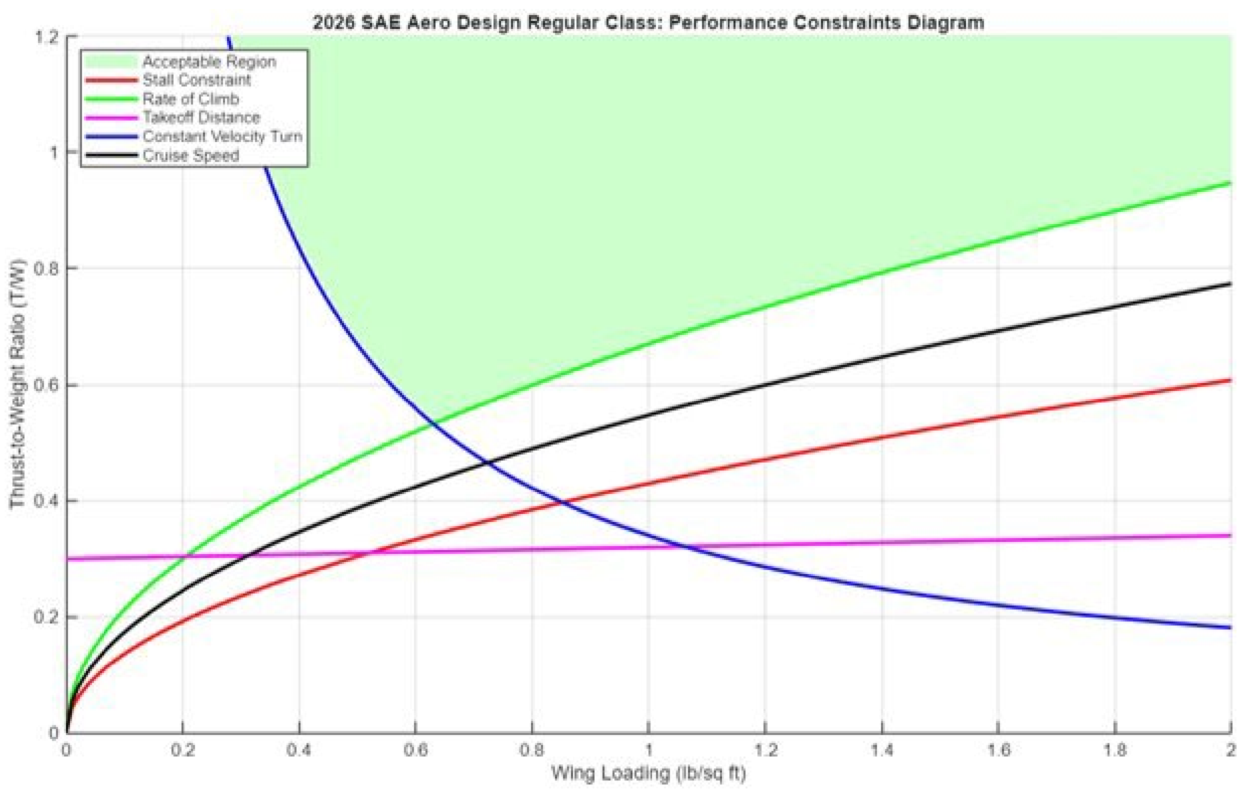


Figure 3: Performance Constraints Diagram

3.3.2 Airframe + Fuselage sub-assembly – Dom Belasquez

The engineering tools most heavily utilized for designing and studying the airframe and fuselage were ANSYS Discovery and MATLAB. The MATLAB community created an optimizer for regular class Aero competitors to utilize for their designs [43]. In the early stages of our design, we took this program and modified the code to match the competition criteria for the 2026 SAE competition. This included importing all of the engineering/customer requirements from the rulebook, along with importing some important equations. Equation (10) was imported and is the flight score calculation that will be used by SAE to find our flight score [1].

$$FS = 4EB + 15FB \qquad \textit{Equation 10}$$

Here, EB and FB are the number of empty and full bottle cargo, respectively. The next equation, equation (11), was imported was the thrust equation found above in section 3.3.1. Further review of this equation can be found above in 3.3.1.

$$T = K_T \rho n^2 D^4 \qquad \textit{Equation 11}$$

The next set of equations was important to import because these were used for calculating stability within the aircraft based on different fuselage and cargo bay setups. These are the moment of inertia equations for a hollow cylinder (12-13) and a rectangular cargo setup (14-16) [44]. We simplified the geometry of the cargo as a rectangular prism to simplify our calculations.

$$I_x = \frac{m}{8}(d_o^2 + d_i^2) \qquad \textit{Equation 12}$$

$$I_y = I_z = \frac{m}{48}(3d_o^2 + 3d_i^2 + 4l^2) \qquad \textit{Equation 13}$$

$$I_x = \frac{m}{12}(a^2 + b^2) \qquad \textit{Equation 14}$$

$$I_y = \frac{m}{12}(a^2 + c^2) \qquad \textit{Equation 15}$$

$$I_z = \frac{m}{12}(b^2 + c^2) \qquad \textit{Equation 16}$$

The m is the mass. The d_o and d_i are the outer and inner diameters. The l is the length of the cylinder. The a, b and c are the width, height and length of the rectangular prism respectively. The final major equation, equation (9), was imported into the MATLAB Optimizer, which was the landing ground run equation [45].

$$s_g = \frac{1.323(\frac{W_{LA}}{S})}{\rho g C_{L,max,LA}\{\left(\frac{T_R}{W_{LA}}\right) + \mu\}} \qquad \textit{Equation 17}$$

For this equation s_g is the ground run distance, $(\frac{W_{LA}}{S})$ is the wing loading, ρ is the air density, g is the gravity acceleration constant, $C_{L,max,LA}$ is the stall lift coefficient during landing, $\left(\frac{T_R}{W_{LA}}\right)$ is the reverse thrust to weight ratio, and μ is the rolling friction of the wheels and the ground.

For ANSYS FEA, there were no equations applied as they were already built into the program. However, it was the main tool used to analyze the main frame of the aircraft and optimize it. The material used for those designs were standard-size aluminum alloy tubes that are commercially available [46].

3.3.3 Wings and Tail Sub assembly – Tylee Thornley

To assess the different tail designs, first, a Reynolds number calculation was done. The velocities of aircraft from the 2025 competition were analyzed to find the velocity at takeoff, cruise, and landing. Ten aircraft from the regular class were looked at to get these velocities. The average velocities were 4m/s for cruise, 5.5 m/s for takeoff, and 7 m/s for landing. The average Reynolds number is around 50,000, which means an airfoil designed for a low Reynolds number is needed.

$$Re = \frac{\rho \cdot V \cdot c}{\mu} \qquad \textit{Equation 18}$$

This is the equation to find the Reynolds number based on the velocities that were found. From the Reynolds number calculations, an analysis was done using OpenVSP on the design ideas for the tails and wings. The Mach number is set to 0.014, the Reynolds number of 50,000, the velocity is 5 m/s, angle of attack varied from 0 –10, and the air density is set to 1.225 kg/m^3. The analysis done on OpenVSP as well as a qualitative analysis of each design, was used to decide which wing and tail would be selected. Equations 18, 19, 20, and 21 were used to calculate the numbers for the software. The lift and drag for each design were found and compared, and the design that generated the best lift and L/D ratio was selected. Based on this, a semi-T-tail cruciform mix and a rectangular wing will be used in our design.

$$Ma = \frac{V}{c} \qquad \textit{Equation 19}$$

$$L = Cl \cdot \frac{1}{2} \cdot A \cdot \rho \cdot V^2 \qquad \textit{Equation 20}$$

$$D = Cd \cdot \frac{1}{2} \cdot A \cdot \rho \cdot V^2 \qquad \textit{Equation 21}$$

3.3.4 Theoretical Lift/Drag + Lift Distribution Wing subassembly - William Alcorn

The calculation for theoretical lift and drag began by taking the liftoff, cruise, and landing velocities, as well as the average Reynolds number, found from Tylee’s analysis, and then applying them in the lift equation and drag equation for each stage. This was done to determine which stage of flight the maximum lift and drag forces occurred. Values of the coefficients of lift and drag were taken from airfoiltools.com, for a NACA 0012 airfoil, an average Reynolds number of 50000, and an angle of attack of 5 degrees. The wing area used was determined using the minimum chord length and maximum wing length, and the density used was the density of air at standard temperature and pressure

$$Lift = C_d \cdot \frac{1}{2} \cdot A_{wing} \cdot \rho_{air} \cdot V^2_{takeoff,cruise,landing} \qquad \textit{Equation 22}$$

$$Drag = C_d \cdot \frac{1}{2} \cdot A_{wing} \cdot \rho_{air} \cdot V^2_{takeoff,cruise,landing} \qquad \textit{Equation 23}$$

Theoretical lift and drag across all 3 flight stages were determined and plotted for comparison using MATLAB. From Figures 4 and 5, it was determined that the maximum theoretical lift and drag forces occurred during the landing stage of the aircraft flight. Additionally, it was determined that Reynold’s number and lift & drag forces had a quadratic relationship with each other.

Following this analysis, it was then desired to determine the lift distribution across 4 selected wing configurations to determine which one performed the best. The four configurations were a straight rectangular wing, a swept rectangular wing, a tapered straight wing, and a half straight half tapered wing. These configurations may be observed in Figures 12 and 13. Using XFLR 5, the performance data of the Selig 1223 airfoil, iterating from -5 to 5 degrees of attack in 1-degree increments, and iterating from 10000-90000 Reynolds numbers, was obtained.

XFLR 5 then took the performance data and applied it to the four wing configurations previously mentioned, using Prandtl’s lifting line theory and the Kuta-Joukowski theorem to determine the distribution of lift coefficient across the wingspan of each configuration. Once all 4 configurations had been analyzed, their coefficient of lift distribution data were imported into MATLAB to determine the actual lift force distribution for each wing configuration. This data was then plotted in MATLAB to compare the lift performance of each configuration, where it was finally determined from Figure 6 that the straight rectangular wing had the best performance.

$$\alpha(y_0) = \frac{\Gamma(y_0)}{\pi * \infty * c(y_0)} + \alpha_{L=0}(y_0) + 1/4\pi * V_\infty \int \left(\left(\frac{d\Gamma}{dy}\right) dy(y_0 - y) \right)^{-1} \quad \text{Equation 24}$$

$$L^{`} = \rho_\infty * V_\infty * \Gamma(y_0) \quad \text{Equation 25}$$

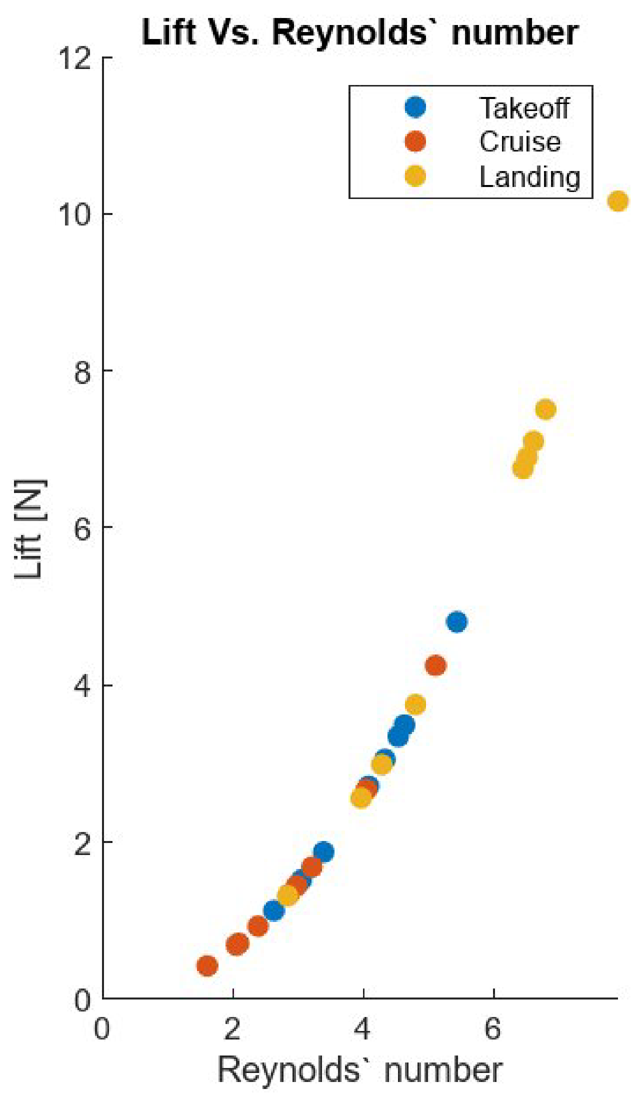


Figure 4: Lift V Reynolds number across 3 flight stages

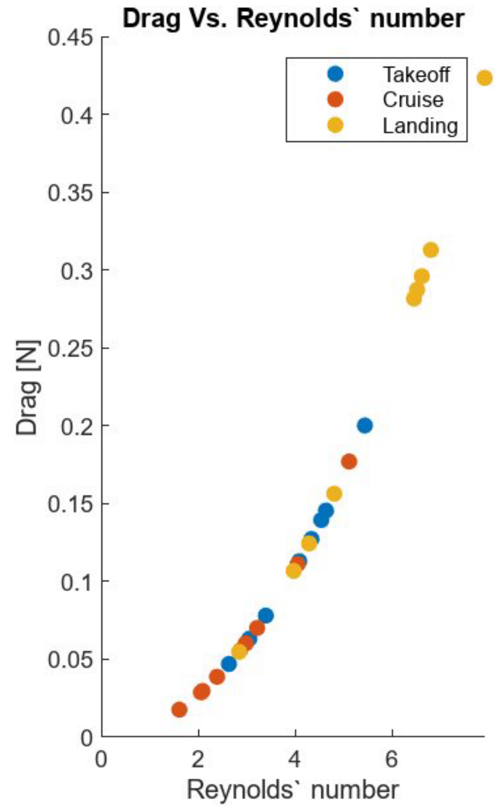


Figure 5: Drag V Reynolds number across 3 flight stages

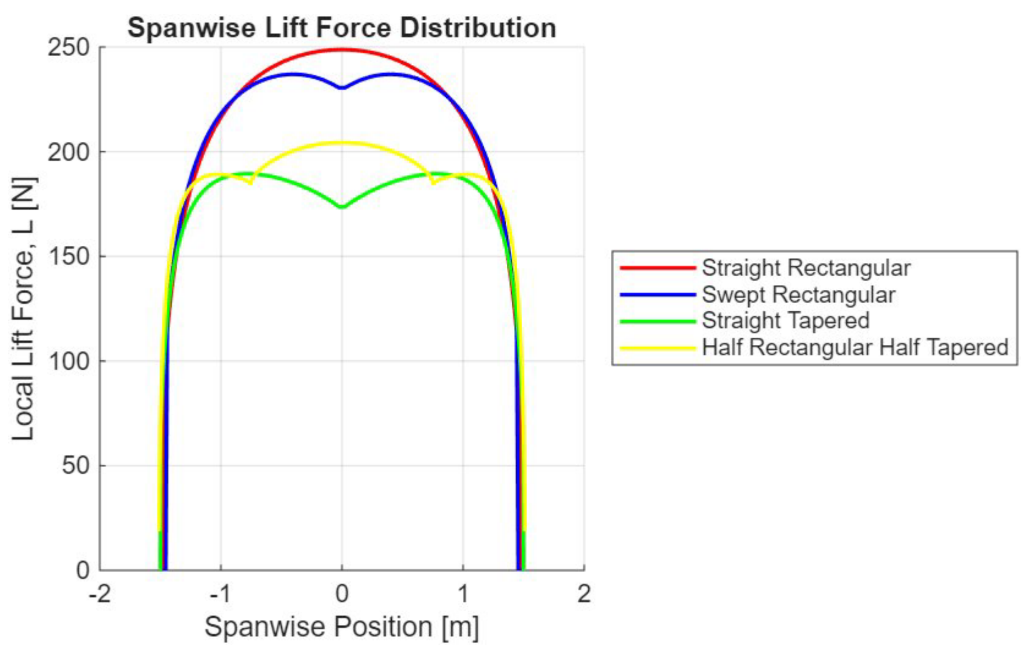


Figure 6: Spanwise lift distribution across 4 different wing configurations

3.3.5 Theoretical Landing Force Calculations – Tyler Milne

To determine the potential landing gear, we had to investigate the forces that would occur. Data such as speed was estimated by reviewing footage or last year's SAE AERO competition videos. While these may be slightly inaccurate due to the measuring system, they give a good baseline to perform calculations. The driving equations we used were based on impulse and momentum calculations

$$P = m * v \qquad \textit{Equation 26}$$

$$I = \frac{P}{t} \qquad \textit{Equation 27}$$

Where P = momentum, m is mass (total weight of aircraft), v = velocity vector (pointing toward the ground), and t represents time for the impact energy to be dispersed completely. This also assumes no dampening from springs or shocks to provide the "worst case" scenarios. We used 55lbs as the weight of the aircraft, as that is the competition's max takeoff weight, as well as using a 5-degree angle of approach relative to the ground. An angle of 3.5 degrees or more is commonly used for pilots to determine a "rough" approach. This allows us to calculate the velocity descent based on initial speeds of 3-10 m/s. Additionally, two times 0.01s and 0.1s were used to represent a fast and slow energy dissipation, respectively. The result of the test is presented in this graph.

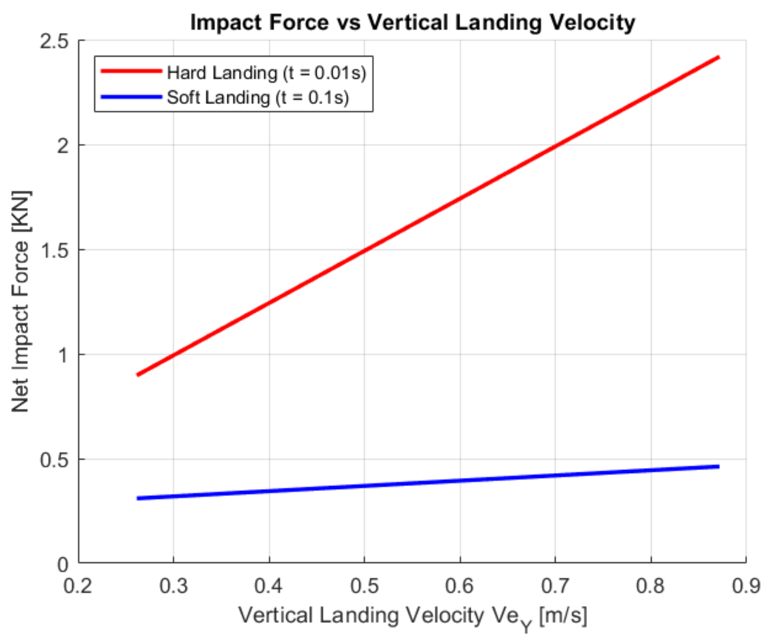


Figure 7: Hard vs Soft Landing

We would like to design for the worst possible outcomes, which means a total of 1.2kN must be supported by each wheel, landing gear and any support structures.

4 Design Concepts

This chapter looks at how we decomposed our design problem into multiple subfunctions/subsystems and generated initial concept variants for our analysis and selection.

4.1 Functional Decomposition

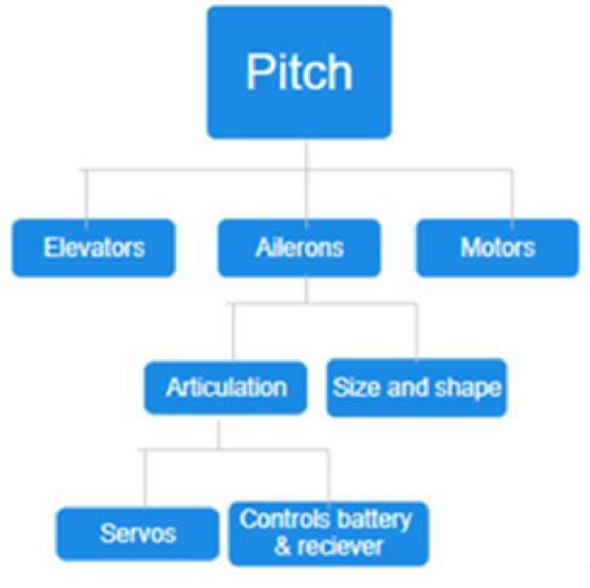


Figure 8: Pitch Functional Decomposition

Pitch is one of the three key functions of the project, as it is responsible for changing the planes' orientation, in a manner of changing the angle the plane is relative to the head wind. It is necessary for take-off and landing so the plane's orientation can be in ideal positions. Elevators being the main component to change pitch, ailerons helping to provide some pitch change, and motors being able to throttle up and down to help change the pitch.

Figure 9: Steering Functional Decomposition

Steering is another key function, as it will allow the plane to traverse on the ground with steerable landing gear, and steer in the sky with the rudder and ailerons. The main sky-steering components are both steering the plane, and inducing roll, to assist the plane in turning while in the air.

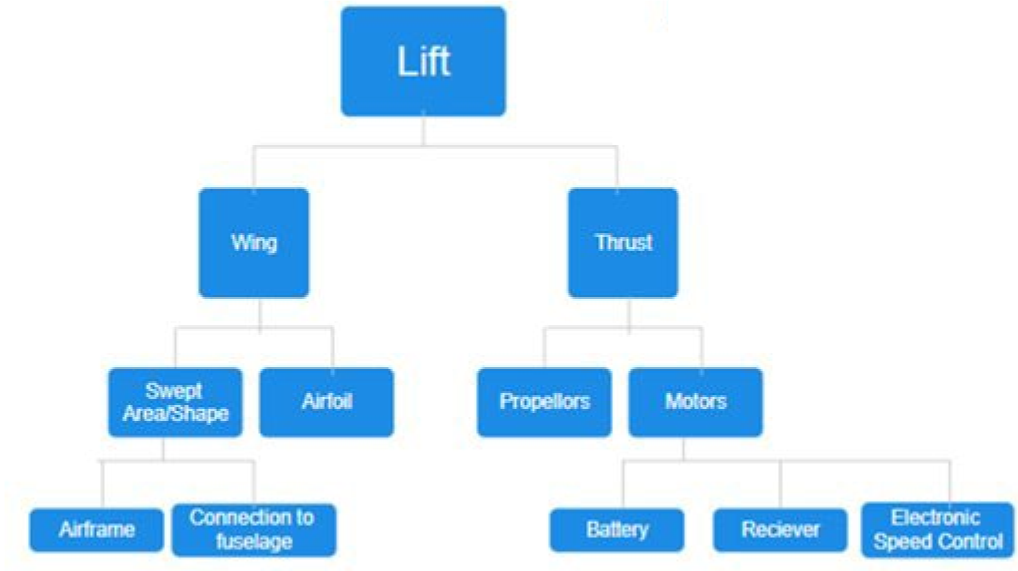


Figure 10: Lift Functional Decomposition

Lift is the last key function of the plane, with wing design and thrust being the biggest components affecting lift. Wings are important, as the swept area and placement of the wings will influence lift with the amount of area creating lift, and the wings' airfoil will influence the coefficient of lift that the wings will have. Thrust influences lift due to thrust creating a force against the headwind, allowing the plane to travel forward. The propellers will affect how much air is moving with each rotation of the motors. Motors will determine how fast the propellers spin and the amount of thrust that will then be created by the system, depending on how fast the motor is able to spin under the load of the propeller.

The functional decomposition was important to this project, as it served as the basis for concept generation, highlighting the different subsystems that the project has. In addition, it highlighted the systems that the team will need to purchase instead of manufacturing, allowing us to make specification tables of the project's different electronic components.

4.2 Concept Generation

From the functional decomposition, two subsystems were assigned to each individual to generate different concepts to review for our final design. Listed below are all the subsystems and the pros and cons of each selection.

4.2.1 Fuselage/Cargo Bay

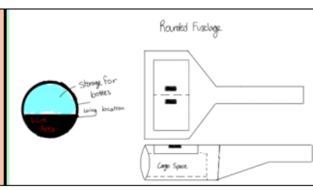
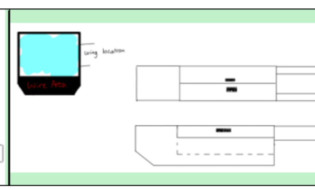
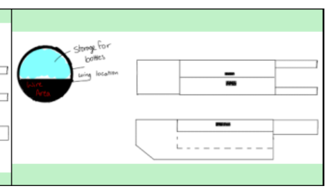
A	Fuselage/Cargo Bay			

Figure 11: Fuselage Concepts Generation

The designs for our fuselage are combinations of two different cross-sectional areas and two styles of fuselage bodies. The two cross sections are based on a circular and chamfered square. The circular design is seen in many commercial aircraft, due to its low coefficient of drag, weight, and its improved stability.

However, it has drawbacks in storage and its complexity which are both solved with the chamfer squared design. Ideally, a mix of the two designs using the chamfered square as a base, while rounding the edges, would provide a perfect balance. Additionally, we need to select either a tapered straight back design or a squared boom tail design. The design with a "boom tail" or the two straight back connectors has a very simple creation, improved stability for the rudders, and a simple storage space for the required payload. The taped design compromises on these factors by its aerodynamic efficiency.

4.2.2 Wing Configuration

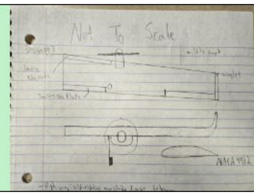
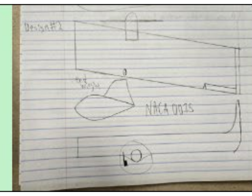
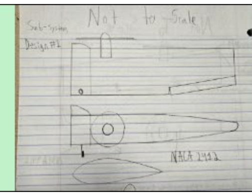
B	Wing Configuration			

Figure 12: Wing Configuration Generations

The first sketch shows a wing configuration of a converging wing, ending in a winglet, and this design consisted of ailerons, front, and back flaps. Pros of this are increased control, stability, and lift at high speeds. Its cons are the design consisting of very complex manufacturing, excessive controls, increased drag and weight, decreased lift at low speeds, and would require a much higher cost to manufacture. The second sketch is a swept wing configuration, ending in a winglet with ailerons. Pros of this design are an increased possible wing area within the competition requirements, increased ability to roll, increased stability, and it handles crosswinds better. Cons of this design are complex manufacturing, an increase in the drag, decreased lift at low speeds, increased weight, and an increase in the complexity and amount of bonding needed. The third sketch is a rectilinear wind converging from the aileron, with larger ailerons to also act as possible flaps. The pros of this are simpler manufacturing, greater lift at lower speeds, less weight, less drag, and easier bonding complexity with less required bonding. Cons of this design are a smaller wing area, decreasing the stability of the plane, with larger ailerons, roll caused by the ailerons is less significant, and this design performs worse with crosswinds.

4.2.3 Wing Geometry

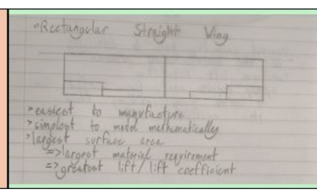
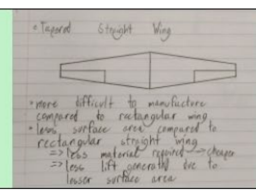
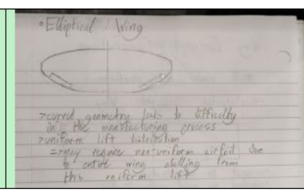
C	Wing Geometry			

Figure 13: Wing Geometry Generations

The first sketch shows a rectangular, straight wing planform geometry, with ailerons and flaps to complement. The main pros of this concept are that it is more stable than the other two considerations, as well as being very cheap and easy to manufacture. The main con, however, is that stability comes at the cost of better maneuverability and handling in flight.

The second sketch shows a straight wing with a constantly tapering airfoil profile. This wing configuration is considerably more maneuverable than a straight rectangular wing; however, this unfortunately comes at the cost of lowered stability. Additionally, it is much more complex to manufacture, and expensive to produce.

The third sketch shows an elliptical wing planform profile, which is the most difficult configuration of the three to manufacture. Additionally, elliptical wings struggle to perform at the low speeds our aircraft is expected to perform at, as they are prone to stall in the Reynolds number range at which the aircraft is expected to operate. Because of this, it was ruled out.

4.2.4 Airframe

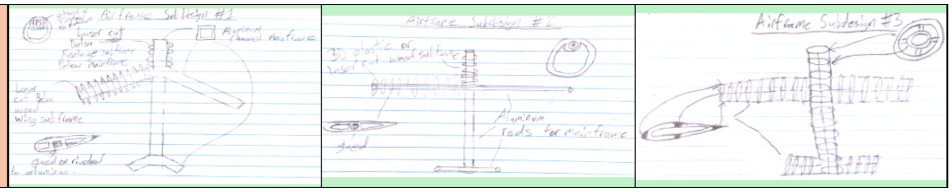
D	**Airframe**	

Figure 14: Airframe Concept Generations

For the airframe there were three major design concepts considered. The first concept on the left in Figure 14 above is a design where the wings are swept and it utilizes a square channel tube for the mainframe. For the subframe it uses laser cut balsa wood to form the structure. The next design uses another mainframe and subframe system, but the wings are not swept. The mainframe also uses round channel tubing rather than square and the subframe can also use 3D printed material. The last design, which was eliminated early on in our design process. It had no mainframe and was only to be held together from the subframe material. The reason for this elimination was because it would likely be much weaker than the other options and thus require excessive reinforcement. One pro of the first design over the second is that it can utilize more effective wingspan/area since the competition only has a restriction on the planform wingspan. Another benefit is that since it is a square channel it is much easier to mount the subframe and drill holes compared to the round channel frame. Another pro with the first design over the second is there would likely be less drag production since the wings are swept. The downside to this however is square channels require advanced and expensive equipment to properly bend compared to round channels. Another downside to the first is it would require more material for both the subframe, and the mainframe compared to the second because it has longer effective wings. This means it would be heavier by nature.

4.2.5 Rudder

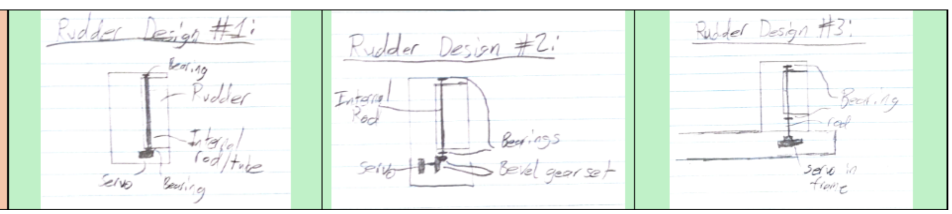
E	**Rudder**	

Figure 15: Rudder Concept Generation

For the rudder there were three systems considered for design as seen in Figure 15. The first design was the design that was eliminated early on. The reason for this elimination was because with the servo being placed in the rudder towards the trailing edge, it would require an excessively thick rudder. Also, it would limit the size of servo that could be selected. For the second design, this utilizes a bevel gear set that allows the servo to be placed in the thicker, leading-edge region of the rudder. The last design is like the first as it is also a direct drive, but the main difference here is that the servo is placed within the fuselage or mainframe of the aircraft with an extended rod. Both the second and third design allow for larger servos, but the main benefit with the third design is that it avoids another set of gears that would reduce efficiency. Gears are already in servomotors and thus already have friction and energy losses. The third design would avoid these additional losses. Another benefit the last has over the 2nd is it would be easier to mount the servo as it would have a direct connection to the mainframe. The drawback of the last design is that the servo could interfere with the mainframe rod that supports the horizontal stabilizer. Another downside is that for larger loads, since there is only a direct drive for the servo to the rudder it would likely require a large servomotor.

4.2.6 Ailerons

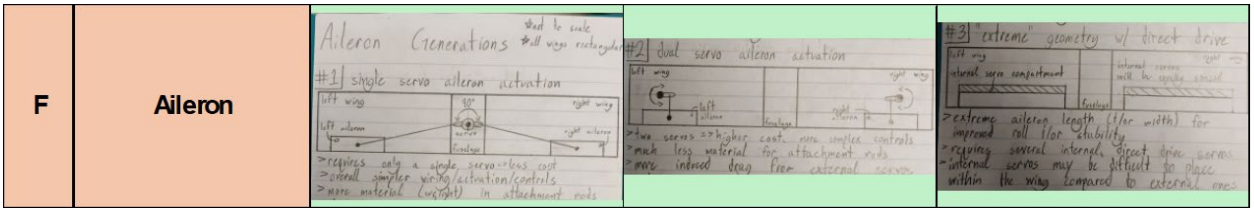


Figure 16: Aileron Actuation Concept Generation

The concern for aileron design lies mostly in the method by which they are actuated. The first concept shows a single servo extended out of the center of the fuselage, meant to actuate both ailerons simultaneously. This method is elegant in that it only requires a single servo; however, it becomes impractical in that the connector rods are quite long and will induce significant drag and extra weight. Because of this, this concept has been dropped from consideration.

The second concept utilizes two servos that serve each wing. Though more costly by requiring two servos, it is the most practical to manufacture, and requires much smaller connector rods, which will drive down weight and cost compared to the first generation.

The third concept describes an actuation system where the servos lie internally in the wing, rather than outside. These servos then directly drive the aileron, which will increase the torque applied, which thus may allow for more extreme aileron geometry, resulting in better stability. It is a complex system and expensive, though worthwhile to consider, as it may greatly improve performance.

4.2.7 Elevators

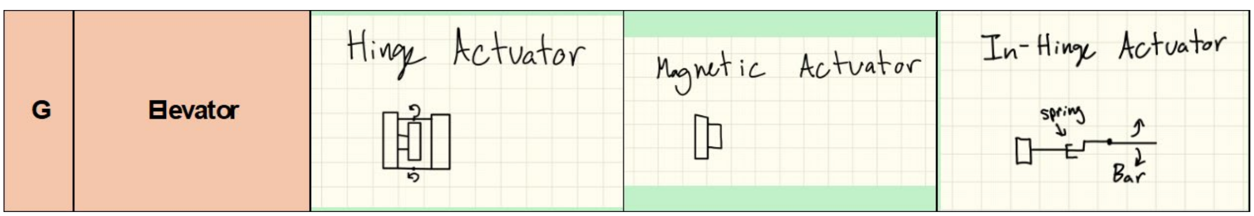


Figure 17: Hinges for the Elevator

For the design of the elevators, different hinges were looked at which would be paired with a servo to actuate. The first design is a hinge actuator that attaches directly to the elevator to actuate it. It is light weight and requires one servo per hinge. Its biggest con is that it attaches directly to the elevator increasing drag. The second is a magnetic actuator that moves the elevator using the magnet when it is activated. It requires more programming to implement and more electronic parts, making it more expensive. The last design is an in-hinge actuator that uses a bar to move the elevator. It also increases drag because it is attached to the outside of the elevator. The bar would provide direct control of the elevator, making it have a fast response time.

4.2.8 Propellers

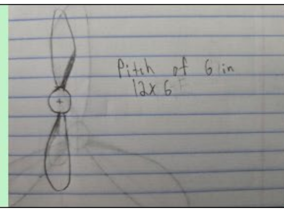
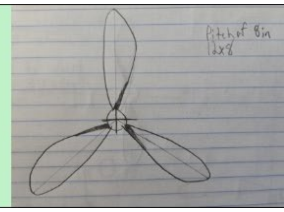
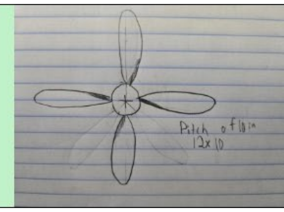
H	Propeller			

Figure 18: Propellor Configurations

The first sketch is detailing a two bladed propellor, that is twelve inches in diameter and has a six-inch pitch. The pros of this design are its lightweight, cheaper, more efficient, requires less torque, and will have faster cruising speeds. Cons for this design is that the smaller pitch requires much more rpm due to the propellor producing less thrust per rotation, due to these higher speeds, stability would decrease, and the planes rate of climb would decrease. The second sketch is detailing a three blade propellor with a twelve-inch diameter, and eight-inch pitch. Pros of this design are the higher pitch creating more thrust per rotation, this propellor has a higher rate of climb, and would help increase the planes' stability. The cons of this design are its heavier nature requires more torque, which leads to slower cruising speeds, these propellers are less efficient and are more expensive. The third sketch details a four blade propellor with a twelve-inch diameter, and eight-inch pitch. The pro of this design is the most thrust per rotation from the highest pitch, the highest climb rate and most stability. The cons of this design are the great amount of torque needed for these propellors due to their much higher weight, leading to the slowest cruising speeds, and these would be very costly propellors.

4.2.9 Landing Gear

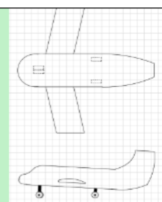
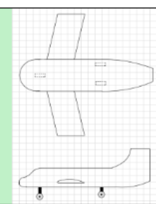
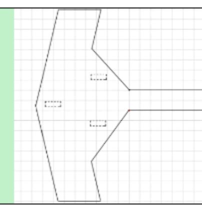
I	LandingGear			

Figure 19: Landing Gear Generations

For landing gear three various were chosen, varying in wheel count and spacing. The first design has a two-wheel front wheel design with two rear wheels close to the centered axis. This allows for the easiest ground maneuvering and connectivity to the frame fuselage. However, due to this connection point in the frame we will lose potential cargo space. The second design shares most all aspects of the first design, however, it only has one front wheel as opposed to two. This will allow for less ground friction when rolling which could be advantageous during takeoff, however, it puts much more stress on the singular front wheel. The third design attempts to push the rear wheels out farther from the center and positioned near the wing connection point. This requires more structural complexity and will create more drag; however, the landing gear can potentially distribute the load more effectively and doesn't have the drawback of cutting into potential cargo space.

4.2.10 Tail

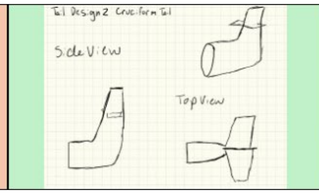
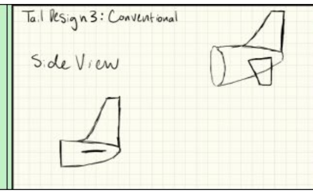
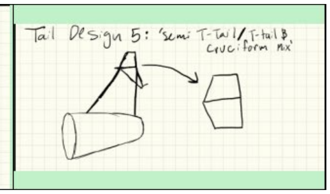
J	Tail			

Figure 20: Tail Configurations

The criterion for selecting a tail is to choose a design that was most functional and stable with our design. Since we are doing a dual propeller plane, a T-tail design was looked at for two concepts. These configurations were compared to a conventional tail design to see if they would be more useful. The first design is a cruciform tail which provides good stability but adds more weight. The second design is a conventional tail. This tail is the simplest to manufacture since the horizontal stabilizer would attach to the airframe. The biggest con of this design is that it can stall due to it being in the wake of the propellers. The final design is a mix between a T-tail and a cruciform tail. This design adds the most flexibility to optimize where the horizontal stabilizer is placed. It also has the benefits of a T-tail without added weight.

4.3 Selection Criteria

A set of quantitative design studies were run for the analysis of each of the concept subfunctions. Selection for these variants were based upon highest performing characteristics set upon by the team. The results were placed within decision tools such as decision matrices and specification charts for the final decision of these variants thus far.

4.3.1 Fuselage

With our project being rooted in maximizing our flight score, our selection criteria were clear. Choose the designs that give the best performance and allow the highest flight score. To study this, we used the MATLAB Optimizer and modified it to our competition specifications [43]. For comparing between the fuselage types, round or square, we compared this using the results of the MATLAB Optimizer. The optimizer attempts to maximize our flight score while staying within the constraints and still being a flyable plane. Below in Table 7 are the results of the two fuselage types. One of the preliminary assumptions that we had before this study was that the square fuselage would be better since a square fuselage allows for more space for cargo. For this competition, more cargo equates to more flight points. However, the results showed us that with our current constraints and weight assumptions, we will only be able to have 4 full bottles across both designs. This meant that additional parameters had to be explored.

Table 7: MATLAB Optimizer Results Between Fuselage Types

Quantity	Units	Round Fuselage	Square Fuselage
Empty Bottle Count	Count	0	0
Full Bottle Count	Count	4	4
Cargo Bay Start Location	m	0.1587	0.1016
Leading Edge Wing Location	m	0.2809	0.1899
Horizontal Tail Half Span	m	0.3428	0.25
Vertical Tail Half Span	m	0.3902	0.3048
Wing Half Span	m	1.3438	1.359
Horizontal Tail Chord	m	0.1549	0.1016
Vertical Tail Chord	m	0.1131	0.1016
Wing Root Chord	m	0.4523	0.453
Length of Fuselage	m	1.0731	0.8445
Wing Taper Ratio	m/m	0.771	1
Max Score	Points	60	60

The next step within the study was to compare the MATLAB results across additional parameters. These parameters included gross weight, take off distance, and flight score to weight ratio. The most important parameter that we agreed to study was the flight score to weight ratio because this defined the effectiveness of our design. Having a higher value for this parameter meant that we were getting more flight points for less vehicle weight. When it comes to cargo planes the most important parameter is their weight. If it is too heavy, we will be unable to fly or must excessively run our motors where we would run out of electrical fuel. This continuation of the study and its results can be found below is section 4.4.1.

4.3.2 Airframe

For analyzing the airframe, it utilized the geometric features presented in Table 7 above for a round fuselage from the MATLAB Optimizer results. Aluminum alloy was selected as the material of choice because of low density and high strength performance. We avoided any fiber composite because it is prohibited for the regular class this year [1]. Furthermore, we extended the study to include swept and non-swept wings to round channel tubes and only including non-swept square channel bars. This was because upon further investigation, round bars are much easier to bend, and the machine shop at NAU has a round tube bender. A square channel would require an additional excessively expensive purchase. For our study with the airframes, we utilized finite element analysis within ANSYS Discovery to obtain our selection criteria quantities. To stay conservative early on, we used a wing loading of 75 lbf uplift and for the horizontal stabilizer we used 15 lbf downforce. We understand that it is likely that the wing loading will be much less, but as stated, we wanted to stay conservative in the preliminary design stage.

4.3.3 Elevators

A qualitative analysis was done to figure out which type of hinge would be used. Servo selection and the electronic configuration used will also be a factor when selecting which hinge to use. A magnetic hinge is more complicated, expensive, and requires a lot of research to implement, so it will not be used. The simplest one is a hinge that connects directly onto the elevator. This one will most likely be used due to its simplistic design.

4.3.4 Tail

Different tail designs were looked at that are used in commercial aircrafts. A T-tail adds more weight and as we have a weight constraint of 55 lbs it will not be used in our design. The conventional tail is a solid option and performed well in the OpenVSP analysis but is expected to cause stalling with our dual propeller design, so it was not selected. A cruciform tail is the last option which performed similar to a conventional tail as well as is expected to work well with a dual propeller plane as it sits above the wakes generated by the propellers.

4.3.5 Wing Configuration

Final wing configuration-based designs on ease of manufacturing, weight added to the plane, necessary controls, and chord length. The first design had triple the necessary controls, to fully operate, due to triple the control surfaces that it had, with these additional controls, it adds weight in motors. Qualitatively it was determined to decrease aerodynamics due to having more surfaces, causing small gaps, and the level of manufacturing would increase to the wing's winglet. The second design helped to optimize within the allowed space, having more wing area, with this it would increase the overall weight of the plane. Qualitatively it drastically increases the complexity of the wing's manufacturing, as it will require the frame to be swept to match, also supporting a winglet at the end. The final design was chosen due to its matched simpler control complexity to design two, decreased weight in comparison to the other designs, and qualitatively it's less complex manufacturing.

4.3.6 Propellors

The different propellors were analyzed based on specification from the manufacturer, as this will be a purchased part. This analysis mainly focuses on the efficiency of the propellors and rate of climb, as these influence the overall engineering requirements the most. Efficiency is important due to the limit on battery supplying power to the motors and rate of climb is important due to the limited take-off distance. So, the two bladed propellor, while having the highest efficiency would lead to the most take-off distance. The four-bladed propeller would lead to the smallest required take-off distance but would lead to the least efficient use of the motors. So the three bladed propellor was selected due to the balance of efficiency and rate of climb that the design possesses.

4.4 Concept Selection

For our concept selection, we took each design listed in our concept generation and performed various calculations or market specification research. We compare these results to our engineering and customer requirements to determine which design was superior.

4.4.1 Fuselage

Compiling the parameters previously listed in section 4.3.1 into a decision matrix along with the MATLAB results, it was clear that in our case the round fuselage performed the best as can be seen below in Table 8. One other preliminary note is we are also assuming that a round fuselage will reduce our drag values significantly since it avoids sharp angles that could induce wakes. One extremely important discovery from this study was that we found we will need some form of reverse thrust or braking. This is because we are required to land within a 400-foot landing strip. Based on the results, our ground run is almost 4 times that distance which is completely unacceptable. Below in Figure 21, it also shows the proposed setups for the cargo within the cargo bay, which as can be seen both will have enough room for the 4 bottles. However, based on Table 8 we will continue forward with the round fuselage for additional design.

Table 8: Fuselage Decision Matrix

Decision Matrix - Based on Fuselage				
Results from MATLAB Optimizer Program				
Engineering Requirements	Units	Target Value	Concept Designs	
			A1 - Round Fuselage/ Cargo Bay	A2 - Square Fuselage/ Cargo Bay
Wingspan	Feet	<10	9.9	10
Fuselage Length	Feet	<9	3.52	2.76
Gross Weight	lbf	<50	32.13	33.27
Wing Chord	Inch	>4	17.81	16.13
Propeller Diameter	Inch	12	12	12
Takeoff Distance	Feet	<100	78.08	80
Landing Distance	Feet	<400	1585	1515
Cargo Volume (2L Bottles)	Liters	12	8	8
Flight Score	Points	Maximum	60	60
Flight Score/Weight	Points/lbf	Maximum	1.867413632	1.80342651
Choosen Fuselage Based on Matrix			Fuselage: A1 - Round Fuselage/ Cargo Bay	

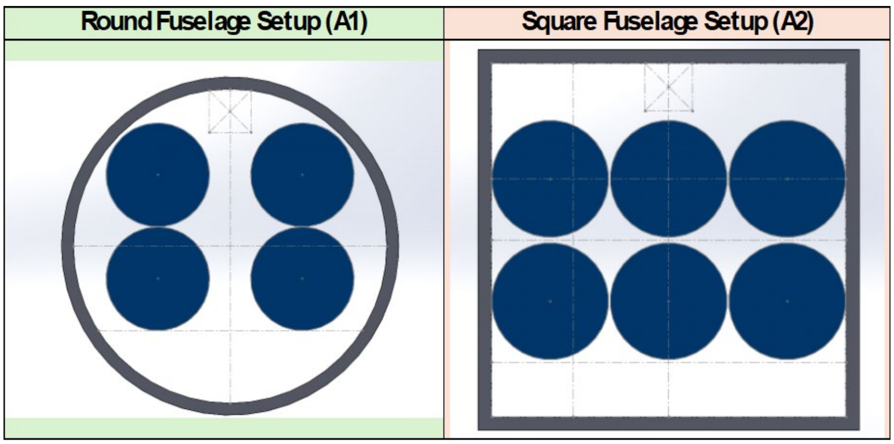


Figure 21: Fuselage Layouts with Preliminary Theoretical Cargo Setup

4.4.2 Airframe

The airframe studies can be seen summarized below in Table 9 for the airframe decision matrix. For our essential comparison criteria, we agreed that comparing a Factor of Safety to airframe weight ratio would be appropriate. This is because for our preliminary design we will likely have to optimize much further in the future which means reducing the weight of the airframe. Having a higher value for this ratio means we are allowed higher reductions without compromising the aircraft's structural integrity. From this table the square channel tube airframe performed the best with the highest factor of safety and factor of safety to weight ratio. This means for optimization, this will be the best choice for our design. One other note is that square channels allow for the easiest subframe attachment with little adhesive/reinforcement since the square shape will naturally oppose torsional bending of the subframe in all directions. Figure 22 below also displays the different frame layouts along with the selected concept for the airframe.

Table 9: Airframe Decision Matrix

Decision Matrix - Based on Airframes					
Results from ANSYS Explore FEA - 75lbf Loading on Wing, 15lbf Loading on Horizontal Tail					
Engineering Requirements	Units	Target Value	Concept Designs		
			D2 - No Sweep Round Bars	D1 - Sweep Round Bars	D2 - No Sweep Square Bars
Wingspan	Feet	<10	9.9	9.9	9.9
HTail Span	Feet	>2.5	3.33	3.33	3.33
VTail	Feet	>1.5	1.03	1.03	1.03
Fuselage Length	Feet	<9	3.52	3.52	3.52
Airframe Weight	lbf	<10	6.42	6.43	7.2
Max Deflection	inch	Minimum	2.18	2.21	1.31
Max Stress	psi	Minimum	1.73E+04	1.73E+04	1.12E+04
Material	N/A	Aluminum	Aluminum	Aluminum	Aluminum
Factor of Safety (FOS)	N/A	Minimum	2.18	2.17	3.36
FOS/Weight	1/lbf	Maximum	0.339563863	0.33748056	0.466666667
Choosen Airframe Based on Matrix			Airframe: D2 - No Sweep Square Bars		

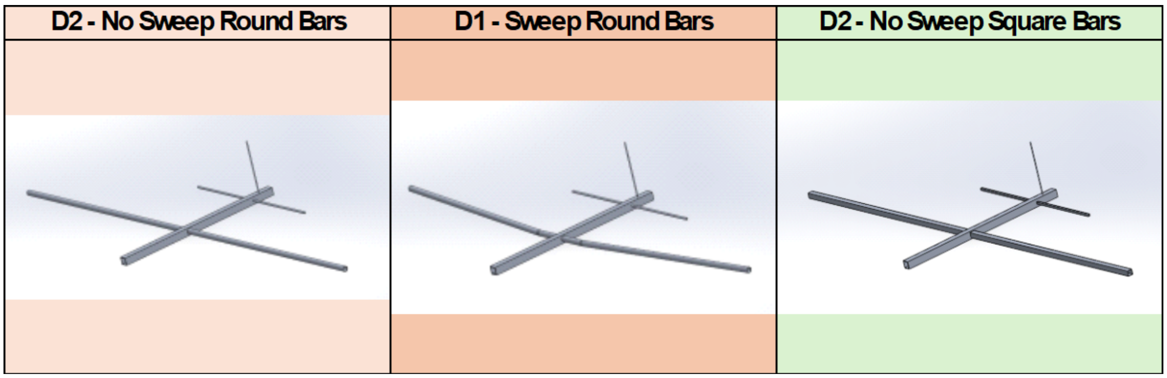


Figure 22: Airframe Layouts Involved in Study

4.4.3 Wing

The geometry and coefficients found from OpenVSP are listed in the decision matrix below. The green cells are the options that performed the best for that engineering requirement. The yellow cells are the next best option, and the red is the worst option. During this analysis it was found that the original airfoil we selected, the NACA 0012, does not produce enough lift for our design requirements. The Selig 1223 performed the best and will be the airfoil we are going to use. From the matrix design B3 and C1 are the best options with a similar rectangular wing design.

Table 10: Wing Decision Matrix

Decision Matrix - Wings Results from OpenVSP and VSPAero						
Engineering Requirements	**Units**	**Target Value**	**Concept Designs**			
			B2	**B3**	**C1**	**C2**
Wingspan	Feet	<10	9.5	9.5	9.5	9.5
Airfoil Chord Length Restriction	inches	>4	12	12	12	12
Tip Chord	inches	>4	12	7.2	12	6
Sweep	degrees	N/A	15	0	0	0.5 (local)
Wing Loading	lb/ft^2	50	7.692307692	5.767012687	5.263157895	7.26744186
Weight	lb		10	10	10	10
Wing Area		ft^2	6.5	8.67	9.5	6.88
Airfoil	N/A	N/A	NACA 0015	NACA 2412	NACA 0012	NACA 0012
Lift			0.013870134	1.726724934	0	0
Coefficient of L (max)			0.0015	0.14	0.00	0.00
Drag			0.000197313	0.031441927	0	0
Coefficient of D (max)			0.01	0.0128	0.01	0.0112
L/D			70.29	54.92	0.00	0.00
Airfoil 2	N/A	N/A	Selig 1223	Selig 1223	NACA 2412	NACA 2412
Lift	N		10.63377	14.18381	1.92581	1.47593
Coefficient of L (max)	N/A		1.15	1.15	0.14	0.15
Drag	N		1.51	1.41	0.03	0.02
Coefficient of D (max)	N/A		0.10	0.07	0.01	0.01
L/D	NA		7.03	10.04	70.29	59.07
Chosen Airframe Based on Matrix			**Wing B3 or C1**			

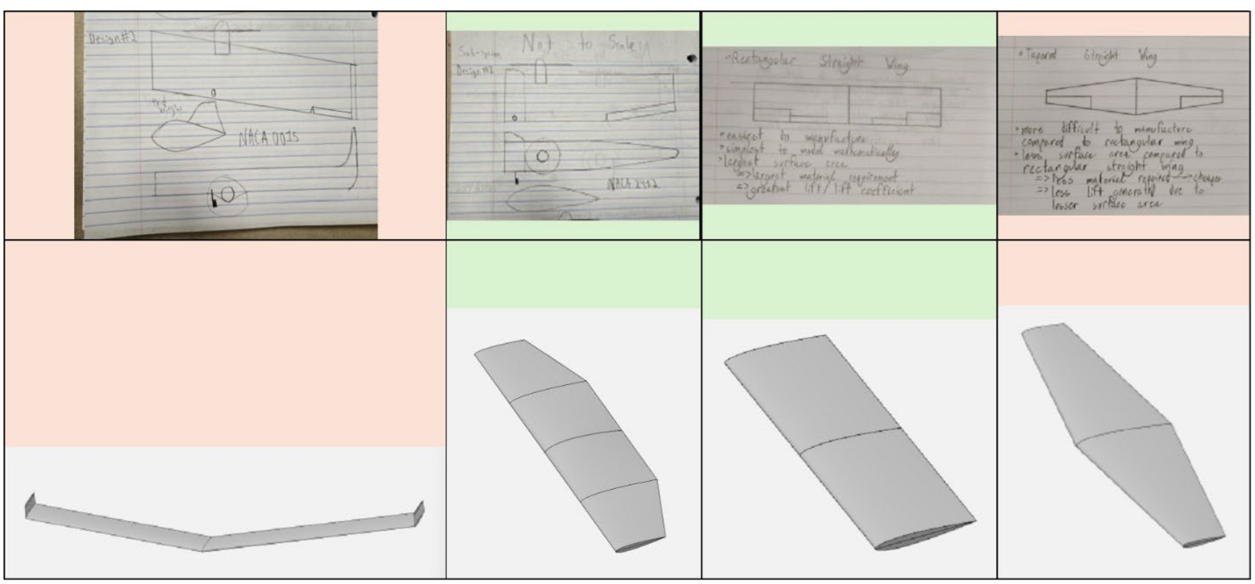


Figure 23: Wing Designs from OpenVSP (B2, B3, C1, C2)

4.4.4 Tail

The decision matrix for the tail design uses geometry and engineering requirements to compare the two designs. A NACA 0012 is used as the tail is for stability. Based on these numbers of wing loading and a qualitative analysis the J3 design was chosen as the tail design.

Table 11: Decision Matrix for the Tail

	Decision Matrix - Tails Results from OpenVSP and VSPAero				
	Engineering Requirements	**Units**	**Target Value**	**J2**	**J3**
	HTail Span	Feet	>2.5	3.33	3.33
	VTail	Feet	>1.5	1.03	1.03
	HTip Chord	inches	>4	8.4	4.8
	VTip Chord	inches	>4	6	9
	HSweep	degrees	N/A	15	30
	VSweep	degrees	N/A	30	30
	H Wing Loading	lb/ft^2	50	17.66784452	89.89572096
	V Wing Loading	lb/ft^2	50	17.66784452	64.72491909
	Weight	lb		2.5	2.5
	H Wing Area		ft^2	2.83	0.5562
	V Wing Area		ft^2	0.7725	0.7725
	Airfoil	N/A	N/A	NACA 0012	NACA 0012
	Lift			0.002938903	0.004351808
	Coefficient of L (max)			0.00073	0.0055
	Drag			0.012857614	0.025275651
	Coefficient of D (max)			0.01170	0.023
Horizontal	L/D			0.22857	0.17217
	Drag			0.013505989	0.02417671
Vertical	Coefficient of D (max)			0.01229	0.022
	Choosen Tail Based on Matrix			**Tail J3**	

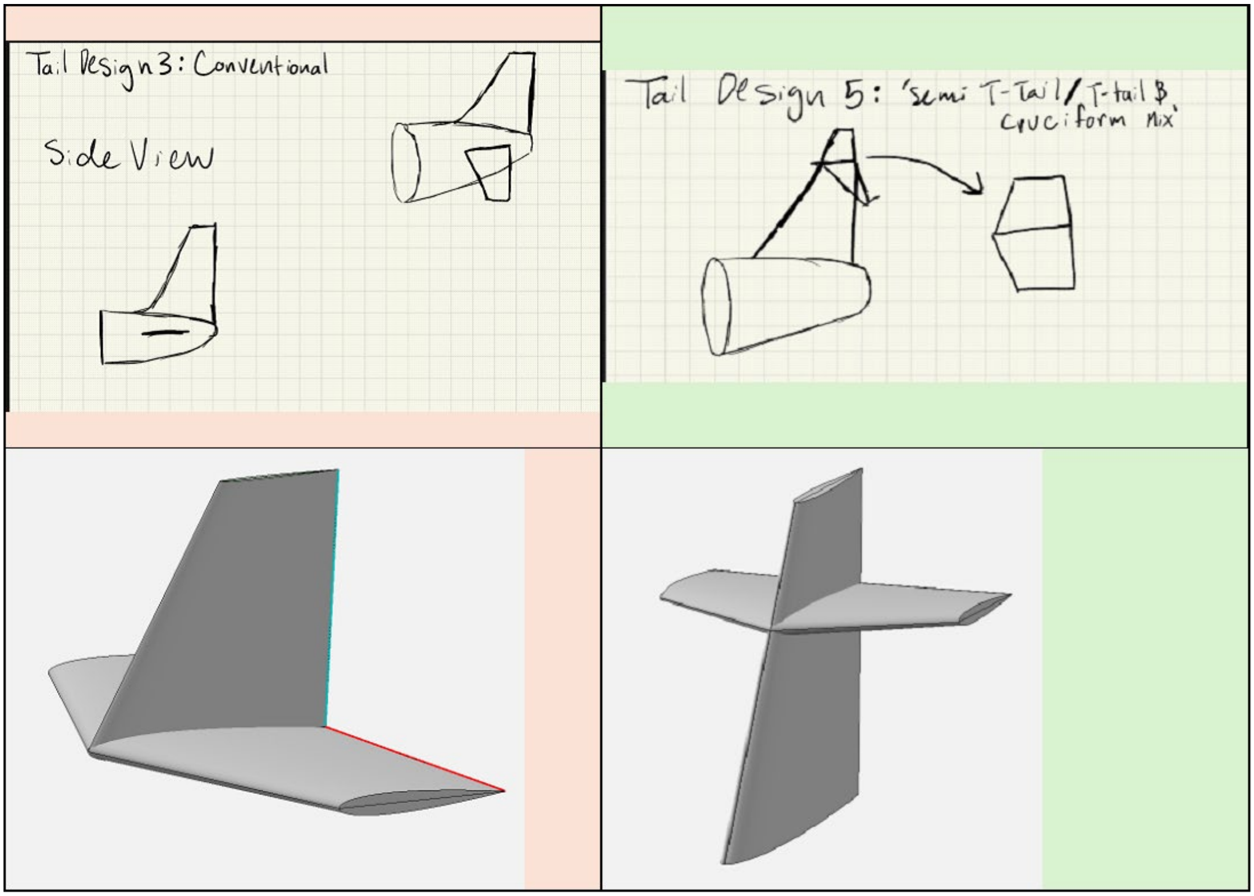


Figure 24: Tail Concept Design from OpenVSP (J2, J3)

4.4.5 Motor and Propellor

The specification tables for the motors and propellors list available information about each of the different parts. This information reflects the engineering requirements of gross weight and take-off distance, in the figure below, the highlighted sections indicate the chosen parts. The selected motor was due to its fast speeds while maintaining higher torque, potential thrust with selected propellors, and potential efficiency during flight. The propellor was chosen due to its increase to rate of climb compared to a two bladed propellor, while maintaining more efficiency than a four bladed propellor.

BadAss 4520 - 830kV Brushless Motor

Component	Value
Motor Weight	13.96 oz.
12x8 Prop	10,480 RPM
12x6 Prop	10,755 RPM
12x8 Prop	114.25 oz. Thrust
12x6 Prop	125.01 oz. Thrust
12x8 Prop	2.74 Thrust Eff. [Grams/W]
12x6 Prop	3.70 Thrust Eff. [Grams/W]

Precision Mini Drives NFP-BL2414-14.8V20.5k18W

Component	Value
Motor Weight	11.8 oz.
No-load Speed	20,500 RPM
No-load Current	0.3 A
Max Efficiency Speed	16,155 RPM
Max Efficency Current	1.15 A
Max Efficency Torque	61 g.cm
Max Efficiency Output	10.12 W

Master Airscrew - 3-Blade - 12x8 propellor

Component	Value
Propellor Weight	1.69 oz
Material	Glass Fiber R Composite

Dynamic 8 Brushless Motor 2600 kV

Component	Value
Motor Weight	12 oz.
No-load Speed	38,480
Power	2710 W
Efficiency	88%

Master Airscrew - Scimitar - 2 Blade - 12x6 Propellor

Component	Value
Propellor Weight	1.23 oz
Material	Glass Fiber R Composite

Figure 25: Motor and Propellor Specification Tables

4.4.6 Electrical CAD and Battery Life Calculation

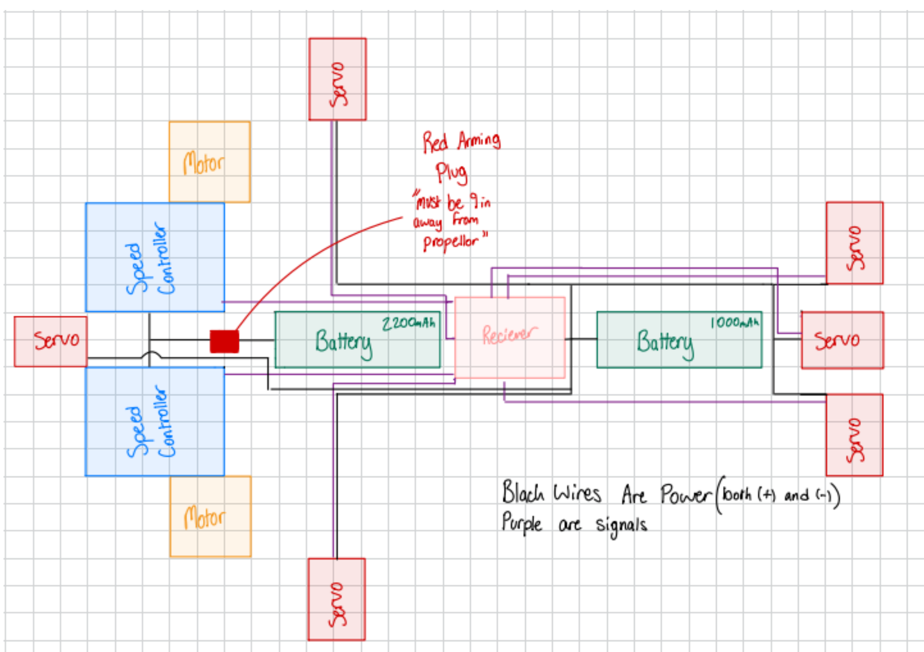


Figure 26: Electrical Engineering CAD

Our preliminary circuit diagram has been modeled with all necessary components for flight. We have 1 speed controller, 2 DC motors, with a 2200mAh 14.8V and a 1000mAh 6V LiPo battery. There will also be five servomotors to control ailerons, elevators and ruder respectively along with the receiver/transmitter housing. The 2200mAh battery will power the motors and speed controller only, while the extra 1000mAh battery will power every other component, this is required by the competition as a safety concern that would allow us in the event of emergency to return the plane to the ground without the motor systems. For our designs we need our battery to last for two minutes. This was the maximum flight time viewed of past years competitions. We used equation 28 and equation 29 to calculate the max amperage possible continuous amperage power draw.

$$I_{max} = C * 120s * \frac{1h}{3600s} \quad \textit{Equation 28}$$

$$P_{max} = I_{max} * V \quad \textit{Equation 29}$$

Where I_{max} is the max amperage draw [A], C is the batteries capacity [Ah], P_{max} is the max power output (W) and V is the voltage. We found that our max continuous power output could be no more than 976.8W for 2 minutes straight. However, we understand that our plane will not fly at 100% power for the entire duration of flight so we may be able to push past this limit temporarily for specific states of flight such as takeoff.

4.4.7 Computer Aided Drawing (CAD) of Preliminary Final Concept

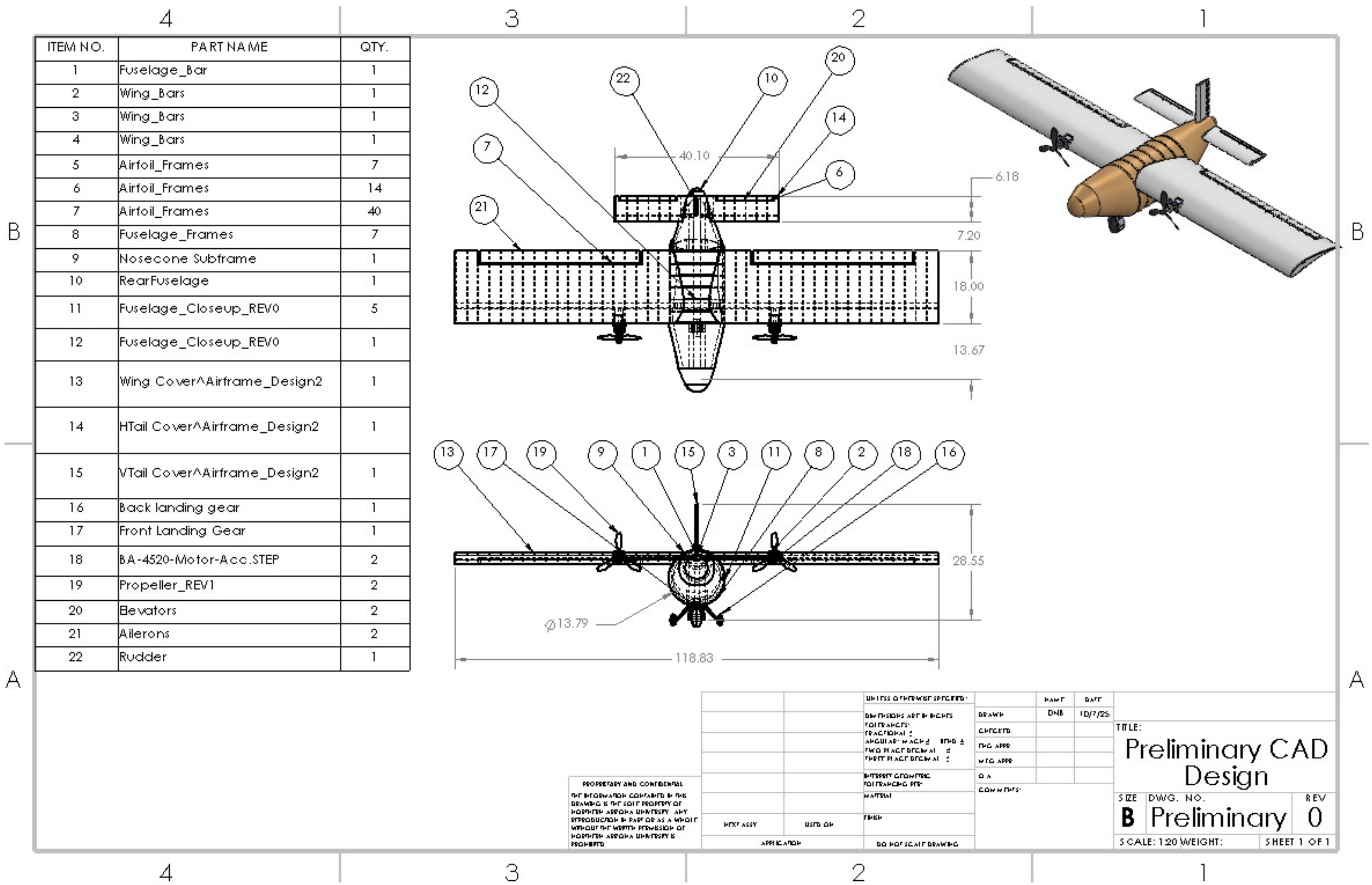


Figure 27: Preliminary Final Concept CAD

5 CONCLUSIONS

The SAE AERO regular design project entails conceptualization, design, manufacturing, and flight of an aircraft for the SAE AERO 2026 Design competition. This aircraft, classified as “regular class”, must be capable of deliverable a volumetric payload of 2-liter bottles, through an all-electric propulsion system, while displaying proper and safe flight performance. The project deliverables are binary, where there are two groups of deliverables throughout the project: Capstone deliverables and competitions deliverables. The Capstone deliverables make up the bulk of the deliverables throughout the project, consisting of presentation, reports, and website checks throughout the fall and spring semester. The single major competition deliverable is the technical design report, wherein all technical information about the project is contained. The ultimate goal of this project is to succeed in competition, where in section 1.3 it is detailed how flight scores are achieved, followed by a study on how our team can maximize our score during competition.

The regular class aircraft is also subject to several competition requirements, as well as engineering requirements. These requirements restrict, regulate, or otherwise govern design decisions our team may make. These include, but are not limited to, the geometric features of our aircraft, the allowable materials of the aircraft, the allowable batteries, takeoff and landing requirements, and other competition specific requirements. Through the use of a house-of-quality, customer requirements and engineering requirements are related to each other and the previously identified benchmarked in order to weigh the positive and negative relationships that each identified requirement has corresponding to the benchmarks.

This project requires extensive research to develop the working design decisions of the aircraft. The process of research began with literature review, in which each member of the team found, at minimum, 7 legitimate sources to develop conceptual understanding of the problem, and build mathematical models to answer the make determinations about design through the problem, such as propeller count, aircraft geometry, thrust-to-weight/propulsion characteristics, etc.

The design process began with a functional decomposition of 3 functions of the aircraft: pitch, steering, and lift. These functions were then broken down using a black box model in order to identify the components required to develop these functions successfully. Using these functional decompositions, each member of the team then generated 3 concepts for different elements and sub-components of the aircraft, such as the wings (geometry and ailerons), tail (geometry, rudder, and elevators), and fuselage (geometry). Once this was completed, the team deliberated and ruled out a single concept for each category. The remaining two concepts were evaluated through several mathematical modeling processes until a single concept for each function category remained. These final components comprise the preliminary, final design. Of course, this preliminary design will continue to be iterated on and improved as we continue our development and analysis.

6 REFERENCES

[1] SAE International, "Regular Class Design Requirements," in 2026 Collegiate Design Series SAE Aero Design Rules, 2026, pp. 31-33.

[2] SAE International, “SAE Aero Design East 2025 Flight Attempts Day 1 Sponsored by the Gene Haas Foundation,” www.youtube.com, May 03, 2025. https://www.youtube.com/watch?v=gandHr7aDDc (accessed Sep. 11, 2025).

[3] A. Sprague, “A&A's Design Build Fly team soars to new heights with historic...,” UW William E. Boeing Department of Aeronautics & Astronautics, Seattle, WA, June 14, 2024. [Online]. Available: https://www.aa.washington.edu/news/article/2024-06-14/dbf-soars-to-best-finish-ever.

[4] M. White, "Apollo XI Model Aircraft Field located at 6201 Woodley Avenue in the Sepulveda Basin," Valley Relics Museum, Facebook, Sep. 02, 2023. [Online]. Available: https://www.facebook.com/valleyrelics/posts/apollo-xi-model-aircraft-field-located-at-6201-woodley-avenue-in-the-sepulveda-b/958691826435336/

[5] Dynam Hobby, "C-310 Grand Cruiser V2 Blue Twin Motor Scale Plane," Dynam RC, [Online]. Available: https://www.dynamrc.com/products/c-310-grand-cruiser-v2-blue-dy8935bl

[6] John D. Anderson Jr., “NACA Airfoil Nomenclature" in Aircraft Performance and Design 5th ed., 2012. [Online]. Available: https://soaneemrana.org/onewebmedia/AIRCRAFT%20PERFORMANCE%20AND%20DESIGN1.pdf

[7] Martin Simmons, “Factors affecting lift and drag", in Model Aircraft Aerodynamics 5th ed., 2015, pp. 27-44

[8] Martin Simmons, “Airfoils: 1 Camber", in Model Aircraft Aerodynamics 5th ed., 2015, pp. 119-136

[9] John D. Anderson Jr., “Aerodynamic lift, drag, and moments" in Aircraft Performance and Design 5th ed., 2012. [Online]. Available: https://soaneemrana.org/onewebmedia/AIRCRAFT%20PERFORMANCE%20AND%20DESIGN1.pdf

[10] John D. Anderson Jr., “Lift, Drag, and Moment Coefficients: How They Vary" in Aircraft Performance and Design 5th ed., 2012. [Online]. Available: https://soaneemrana.org/onewebmedia/AIRCRAFT%20PERFORMANCE%20AND%20DESIGN1.pdf

[11] Sighard F. Hoerner, Henry V. Borst, “Lift Characteristics of foil sections" in Fluid Dynamic Lift 2nd ed., 1985. [Online]. Available: https://ia801507.us.archive.org/20/items/FluidDynamicLiftHoerner1985/Fluid-dynamic_lift__Hoerner__1985_text.pdf

[12] "NACA 0012 AIRFOILS (n0012-il)," Airfoil Tools, 2025. [Online]. Available: http://airfoiltools.com/airfoil/details?airfoil=n0012-il

[13] Aircraft Owners and Pilots Association, "Density Altitude," AOPA, 2025. [Online]. Available:

Density Altitude – AOPA

[14] A. K. Mitra, "Propeller Airplanes," in Aircraft Performance and Design - An Introduction to Principles and Practice, 2nd ed., Library of Congress, 2020, pp. 115-132

[15] A. K. Mitra, "Static Stability," in Aircraft Performance and Design - An Introduction to Principles and Practice, 2nd ed., Library of Congress, 2020, pp. 156-174

[16] “Trainer Design," RCPlanes, 2025. [Online]. Available: https://rcplanes.online/design.htm

[17] M. V. Cook, "Static Equilibrium and Trim," in Flight Dynamics Principles, 2nd ed., Massachusetts: Elsevier Ltd., 2007, pp. 32-57

[18] Omron, "Technical Explanation for Servomotors and Servo Drives," [Online]. pp. 1-19 Available: https://www.ia.omron.com/data_pdf/guide/14/servo_tg_e_1_1.pdf

[19] ASME Dimensioning and Tolerancing, ASME Standard Y.14M, 1994

[20] Richard Von Mises, “Propellor and Engine” in Theory of Flight, First Edition, pp. 285-309

[21] BadAss BA-2315-1480 “Performance Test Data”. [Online] Available: https://innov8tivedesigns.com/pub/propcharts/BA2315-1480-Specs.htm

[22] Rcgroups, “Thrust to Weight Ratio”. [Online] Available: https://www.rcgroups.com/forums/showthread.php?2024770-thrust-to-weight-ratio

[23] A. K. Mitra, “Thrust Required” & “Endurance" in Aircraft Performance and Design - An Introduction to Principles and Practice, 2nd ed., Library of Congress, 2020, pp. 202-228 & 293-296

[24] A. K. Mitra, "Estimation of the Critical Performance Parameters" in Aircraft Performance and Design - An Introduction to Principles and Practice, 2nd ed., Library of Congress, 2020, pp. 406-418

[25] John D. Anderson, Jr., "Effect of Aspect Ratio" in Fundamentals of Aerodynamics, 6th ed., Mc-Graw Hill, pp. 450-464

[26] Daniel P. Raymer, “Sizing from a Conceptual Sketch" in Aerodynamic Design: A Conceptual Approach, 6th ed., AIAA Educational Series, pp. 11-31

[27] E. Oberg, F. D. Jones, H. L. Horton, and H. H. Ryffel, "Rivets and Riveted Joints“ Machinery’s Handbook, 29th ed. New York, NY: Industrial Press, 2012. pp. 1729-1745

[28] D. Chandra Shil, T. Ahmed, R. Mia, and N. Bej, “Design, Fabrication and Aerodynamic Analysis of a RC Airplane,” Radware bot manager Captcha, https://iopscience.iop.org/article/10.1088/1742-6596/2856/1/012002/meta (accessed Sep. 13, 2025).

[29] D. J. Auld and K. Srinivas, “Resources,” Aerodynamics for Students, https://www.aerodynamics4students.com/aircraft-performance/take-off-and-landing.php (accessed Sep. 13, 2025).

[30] “Landing performance,” https://webstor.srmist.edu.in/web_assets/srm_mainsite/files/downloads/class18-2012.pdf (accessed Sep. 13, 2025).

[31] M. H. Sadraey, “Chapter 9,” in Aircraft Design: A Systems Engineering Approach, 1st ed, vol. 1, Chichester, United Kingdom, 2013, pp. 508–581 (accessed Sep. 13, 2025).

[32] A. C. Watts, V. G. Ambrosia, and E. A. Hinkley, “Unmanned Aircraft Systems in remote sensing and scientific research: Classification and considerations of use,” MDPI, https://www.mdpi.com/2072-4292/4/6/1671 (accessed Sep. 13, 2025).

[33] A. Gupta, V. Soni, D. Shah, and A. Lakdawala, “Generative design of main landing gear for a remote-controlled aircraft - sciencedirect,” ScienceDirect

[34] “FAA regulations,” FAA Regulations | Federal Aviation Administration, https://www.faa.gov/regulations_policies/faa_regulations (accessed Sep. 17, 2025).

[35] R. W. Fox and J. W. Mitchell, Fox and McDonald’s introduction to fluid mechanics. Hoboken: Wiley, 2019.

[36] NASA, “Reynolds Number,” Nasa.gov, 2019. https://www.grc.nasa.gov/www/k-12/airplane/reynolds.html

[37] SAE International, “SAE Aero Design East 2025 Flight Attempts Day 1 Sponsored by the Gene Haas Foundation,” www.youtube.com, May 03, 2025. https://www.youtube.com/watch?v=gandHr7aDDc (accessed Sep. 11, 2025).

[38] C. Reyes, RC Advisor’s Model Airplane Design Made Easy, 1st ed. Albuquerque, N.M.: Rcadvisor.com, 2009, pp. 35–53.

[39] John David Anderson, Fundamentals of Aerodynamics, 5th ed. New York: Mcgraw-Hill, 2011, pp. 313–407.

[40] L. Nicolai, “Estimating R/C Model Aerodynamics and Performance,” Lockheed Martin 7Aeronautical Company, Jun. 2019.

[41] J. G. Leishman, “Mach Number & Reynolds Number,” eaglepubs.erau.edu, p. Ch.16, Aug. 2022, doi: https://doi.org/10.15394/eaglepub.2022.1066.n13.

[42] C. Locke, “Amateur-Built Aircraft and Ultralight Flight-Testing Handbook,” Federal Aviation Administration, Feb. 2023.

[43] MATLAB. “Aircraft Design Optimization with the Fixed-Wing Object,” (2025). [Online]. Available: https://www.mathworks.com/help/aerotbx/ug/aircraft-design-optimization-with-the-fixed-wing-object.html

[44] R. G. Budynas and J.K. Nisbett, “Appendixes A – Useful Tables,” in Shigley’s Mechanical

Engineering Design, 11th ed., New York: McGraw Hill, 2020, pp. 1052-1054.

[45] A. K. Mitra, "Landing," in Aircraft Performance and Design - An Introduction to Principles and Practice, 2nd ed., Library of Congress, 2020, pp. 99

[46] MetalsDepot. “MetalsDepot – America’s Metal Superstore,” (2025). [Online]. Available: https://www.metalsdepot.com/#

7 APPENDICES

7.1 Appendix A: Full House of Quality

Table 1C: Full HoQ Zoomed Out

Engineering Requirement Correlations

	Wingspan	Vehicle Length	Gross Weight	Wing Chord	Propeller Diameter	Propulsion Battery	Receiver Battery	Arming Plug	Landing Distance	Take-Off Distance	Flight Attempt Time Limit	Radio Control System	Cargo Volume
Wingspan (6' < L < 10')													
Vehicle Length (< 10')	+												
Gross Weight (≤ 55lbs)	+	+											
Wing Chord (> 4")	+		+										
Propeller Diameter (9" or 12")													
Propulsion Battery 4 Cell 14.8V (≤ 2200					-								
Receiver Battery LiPo or LiFE (≥ 1000													
Arming Plug (≤ 9" from any Propeller)	-			-	-	+							
Landing Distance (≤ 400')	+	+	+	+									
Take-Off Distance (≤ 100')	+	-	-	+	+	+			+				
Flight Attempt Time Limit (≤ 60s)			-		+	+	+	+		+			
Radio Control System (2.4 GHz)						+	+				+		
Cargo Volume (2 Liter Bottle)		+	-										

Competition & Customer Requirements	Weight of Importance for Scoring	Engineering Requirements: Wingspan (6' < L < 10')	Vehicle Length (< 10')	Gross Weight (≤ 55lbs)	Wing Chord (> 4")	Propeller Diameter (9" or 12")	Propulsion Battery 4 Cell LiPo 14.8V (≤ 2200 mAh)	Receiver Battery LiPo or LiFE (≥ 1000 mAh)	Arming Plug (≥ 9" from any Propeller)	Landing Distance (≤ 400')	Take-Off Distance (≤ 100')	Flight Attempt Time Limit (≤ 60s)	Radio Control System (2.4 GHz)	Cargo Volume (2 Liter Bottles)	Benchmarking: 2026 NAU Team 1 Target (Regular Class)	2023 Georgia Tech (Advanced Class)	Dynam Cessna 310 Grand Cruiser V2 Blue Twin Motor RC Scale Plane	2023 California State University Northridge (Advanced Class)
Wingspan Restriction	4	9	3	3	1		3		3						5	5	1	5
Aircraft Length	5	3	9	3	1	1			1						4	4	3	2
Weight Restriction	5	3	9	9	3	1	3								5	2	2	2
Airfoil Chord Length Restriction	2	3	1	3	9	9			3						3	4	3	4
Propeller Sizing Restriction	2			3		9			9						3	1	1	1
Motor Count (2 or 4)	4		1	3		3			9	1	1		1	3	3	1	3	1
Receiver/Control System Restriction	1					1		9		1			9		4	4	4	4
Safety Requirements	1	1	3		1	1	1	1	9			3	3	1	5	5	3	5
Team Identification Vehicle Badges	1		1												2	5	1	5
Empty Weight Center of Gravity Markings	1		1	1								1		9	4	5	1	3
Steerable Landing Gear	2	1	1		1	3				1	9	1	1		3	1	3	3
Take-Off Distance	5		3			1					9	1	1		4	5	5	4
Flight Attempt Time Limit	2					1	1				3	9	1	3	3	5	1	4
Landing Distance	5	1	3							9		3	1		4	5	5	4
Cargo Requirements	5		9	9								1		9	5	2	1	2
Propulsion System Battery Restriction	4			1			9	3					3	1	5	5	5	5

Bottom Floor

	Wingspan	Vehicle Length	Gross Weight	Wing Chord	Propeller Diameter	Propulsion Battery	Receiver Battery	Arming Plug	Landing Distance	Take-Off Distance	Flight Attempt Time Limit	Radio Control System	Cargo Volume	Totals
Importance Weight Score	80	190	146	45	73	66	22	86	52	73	49	42	77	1001
Importance Weight Percentage	7.99%	18.98%	14.59%	4.50%	7.29%	6.59%	2.20%	8.59%	5.19%	7.29%	4.90%	4.20%	7.69%	100.00%
Measurement Units	feet	feet	lbs	inch	inch	mAh	mAh	inch	feet	feet	seconds	GHz	liter	
NAU Team 1 Target Value	~10	4	30	≥12	12	2200	3000	12	300	80	50	2.4	8	-
2023 Georgia Tech (Advanced Class)	~11	~8	N/A	~18	~2	N/A	N/A	N/A	~30	~50	N/A	N/A	N/A	
Dynam Cessna 310 Grand Cruiser V2 Blue Twin Motor RC Scale Plane	4.25	3.67	2.65	~6	8	2200	N/A	N/A	~30	~20	N/A	2.4	N/A	
2023 California State University Northridge (Advanced Class)	~12	~3	N/A	~24	~1.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	