Micro-Aircraft Design for SAE 2022 AeroDesign Competition

A Major Qualifying Project Report
Submitted to the Faculty of the
WORCESTER POLYTECHNIC INSTITUTE
in Partial Fulfillment of the Requirements for the
Degree of Bachelor of Science
in Aerospace Engineering

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Abstract

The goal of this project was to design, build and fly a micro remote-controlled aircraft to participate in the 2022 SAE Aero Design West Competition. The competition imposes challenging design constraints on the aircraft which must carry large or small cargo boxes and payload weight while being limited to a 48 inch wingspan, 450 watts of engine power, and an 8 foot takeoff distance from a raised platform. The final design configuration used large wing control surfaces that extended beyond the wing trailing edge to serve as both flaps and ailerons and a movable wing to increase stability. Although the aircraft experienced stability issues on take-off at the SAE micro class competition, the team placed third overall due to high design report and oral presentation scores.

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Professor David Olinger

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Professor Zhangxian Yuan

Flight Test Pilot at SAE Aero Design West Competition:

Mark Thomas

SAE Competition

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Table of Authorship

Section	Writing	Work
Abstract	DVS	n/a
Introduction and Background	DVS	n/a
1.1	DVS	All
1.2	DVS	All
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Design and Analysis		
2.1	DT	DT
2.2	CM, DVS, SP	CM, DVS
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Summary, Conclusions, Recommendations, Broader Impacts		
5.1	DVS	n/a
5.2	DVS, DT	DVS, DT, CM
5.3	DVS, DT, CM	DVS, DT, CM
5.4	DVS, DT	All
Appendix A	n/a	n/a
Appendix B	n/a	JS
Appendix D	CM	CM

CC = Christian Chadwick, CM = Connor Miholovich, SP = Sam Pitkowsky, JS = Justin Schoepke, DT = David Tomer, DVS = David Van Sickle

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1. Introduction

The goal of this Major Qualifying Project is to design a micro-aerial vehicle (MAV) that could be remote controlled (RC) and flown in the SAE Aero Design West competition, an annual aeronautical design competition held by the Society of Automotive Engineers (SAE). The goal of this competition is to challenge student groups by having them design, build, test, and, ultimately, fly an aircraft according to specific design specifications. Overall, this competition allows students to apply what they have learned in their classes and put theory to the test by designing an aircraft with real world applications. (Society of Automotive Engineers)

The main goal of the competition is for the designed aircraft to carry the largest payload, while maintaining the lowest weight fraction, and fastest takeoff time possible. In addition to this, there are specific rules/requirements that need to be followed that must be considered when designing the aircraft, primarily dealing with aircraft materials, payload, and size.

The project group is made up of 6 undergraduate students and is divided into 4 specific subgroups. These subgroups are made up of Aerodynamics, Propulsion, Stability and Controls, and Structures and Fabrication. Each group would be responsible for specific research and analysis related to aircraft analysis and construction. Despite the subgroups, all members of the group would work together through general decision making and design processes to gain a comprehensive understanding of the aircraft.

The objectives of this MQP are to perform both theoretical and practical design analysis of the aircraft. This broad analysis can be broken down into the mechanical design, structural analysis, and flight analysis of the designed aircraft, as well as the redesign period, all adhering to a specific set of rules and regulations.

1.1 Background Literature Review

Based on multiple available reports from Worcester Polytechnic Institute (WPI), we were able to review past micro aircraft MQP reports (Celaj et al, 2019) that described aircraft that were flown in the past. While the specific rules varied for different years of the competition, the reports were an integral part in helping the team understand the full process of planning, designing, and competing in the competition.

In addition to WPI teams, we examined various winners from past years of the SAE Aero Design Competition, notably Georgia Tech's design (Georgia Tech, 2021) as the winner of the 2021 competition. This competition winner was important as the rules of the 2021 competition were most similar to that of our competition. In past years, including the WPI competition, one of the most prominent rules was that the aircraft was to disassemble and fit into a specific sized box. This rule was not present for our competition or the 2021 competition, so the design and flight videos were more relevant for our design process. The Georgia Tech team focused on acceleration after takeoff, which further solidified our need for a high thrust to weight ratio(*Design build fly team dominates at the SAE Aero Design East Competition*.). For shaping the technical design report, past teams with high scoring design reports in SAE competition were reviewed to understand what judges may have prioritized when awarding more points.

1.2 Project Goals

This MQP aimed to achieve the following goals:

- Design a Micro Air Vehicle (MAV) to fly in the 2022 SAE Aero Design West Competition. Complete SAE AeroDesign rules can be found in Appendix A.
    - Maximize payload plate and box storage

    - Minimize aircraft weight
    - Maximize aircraft lift and thrust/weight ratio
    - Aircraft can take off from a 4’ x 8’ launch platform and remain airborne
    - Successfully fly the aircraft course
    - Unload payloads in less than 1 minute
- Use prior knowledge of aeronautical theory including aerodynamics, structures, stability and controls, and propulsion to analyze, design, reiterate, and develop a MAV.

1.3 Project Design Requirements, Constraints, and Other Considerations

The 2022 SAE Aero Design West Competition provided the team with a set of rules that would aid the team in designing the aircraft and in turn, maximizing the amount of points the team could potentially score. The competition rules that most heavily guided the team’s decision making can be found in Table 1.0 below.

Table 1.0 Primary Competition Rules

Flight Considerations	**Payload/Weight Considerations**	**Power Considerations**
Aircraft must take off from a 4’ x 8’ x 2’ platform	Payload must fit within a single payload bay	Power limited to 450 W
Aircraft must make two 180 degree turns	Payload located on exterior of plane is not ideal	Aircraft limited to total of 4 LiPo cells
300 ft. timed portion from takeoff to first turn	Plane must carry minimum of 1 payload plate to score	Motor must generate adequate thrust output
Aircraft must be able to fly unloaded; Max wingspan of 48”	Stability over maneuverability	Battery life must last for the flight duration

Less impactful competition design rules can be found in Appendix A. Another important component the team needed to understand before designing our aircraft was the scoring rubric. This scoring rubric was provided in 2022 SAE Competition Rules, with the overall flight score being determined by the total of 3 flight scores. Each flight score is dependent on the total payload weight multiplied by a bonus factor, divided by the time it takes the aircraft to reach the first turning point in the circuit. The bonus factor is dependent on the number of payload boxes flown. The specific equations that determined the overall score are shown below:

Overall Scoring Equation:

$$Final\ Flight\ Score = FSS = FS1 + FS2 + FS3 \tag{1.1}$$

Where:

$$Flight\ Score\left(FS\right) = 80 * \sqrt{\frac{\left(W_{payload} * Bonus\right)}{T_{Flight}}}$$

$$Bonus = 0.5 + (1.0 * N_{Large}) + (0.4 * N_{Small}) \tag{1.2}$$

N_{Large} = *No. of Large Boxes Flown*

N_{Small} = *No. of Small Boxes Flown*

$W_{Payload}$ = *Payload Plate Weight (lbs.)*

T_{Flight} = *Flight Time from Take-off to First Turn (s)*

In the early phase of design, the team made several graphs to determine how individual flight scores are affected by variables such as flight time, the number of small and large delivery boxes carried, and the weight of the payload plates according to the formulas provided in the rulebook. This allowed us to look at designs that would maximize our score at the competition. Using the data from the graphs,we determined that after a given number of boxes, weight is more advantageous in the form of payload weight than in delivery boxes, while also taking up less space. Additionally, without payload plate weight or a successful flight time, it is impossible to score any points using the scoring equation. As such, these factors were prioritized during plane design, while maintaining the ability to carry a single payload box.

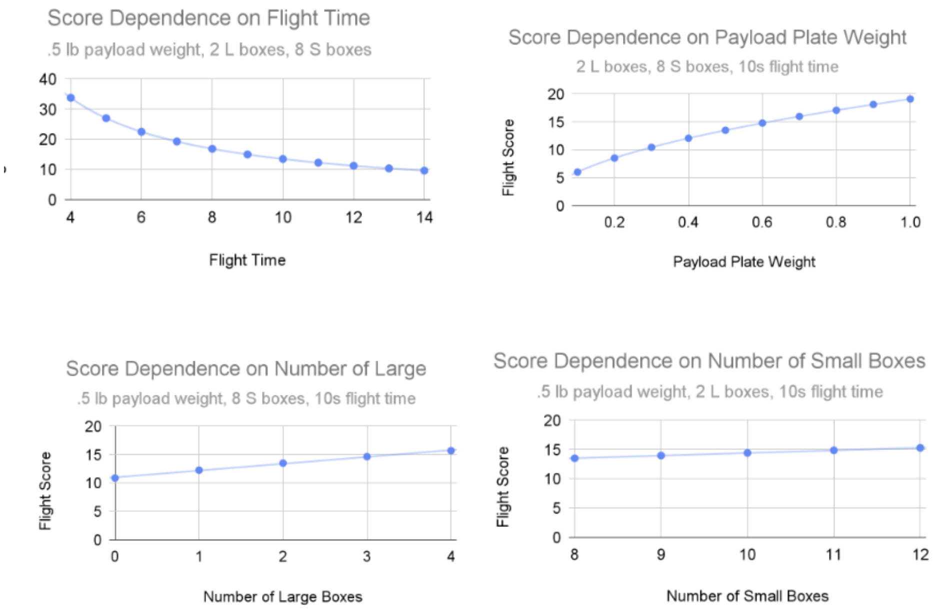


Figure 1.0 Flight Score Graphs

Outside of SAE competition design requirements, the team was limited by a departmental budget of 1500 dollars to use on this MQP. This budget was considered when buying electronic components, materials, and other relevant goods for the project.

1.4 Project Management

The project team was split into 4 distinct groups to divide the workload and create a specific team for each of the main subject areas listed in our objectives. These groups were made up of aerodynamics, propulsion, stability and controls, and structures and fabrication. The aerodynamics group consisted of Sam Pitkowsky and David Van Sickle. The primary responsibilities of this group were to examine the lift and drag characteristics and performance of the airfoil, wing, tail, and any other relevant aircraft appendages. The propulsion team included Chrisitan Chadwick who was primarily responsible for selecting a motor and propeller, analyzing the thrust and drag output, and evaluating power requirements. The stability and controls team consisted of Connor Miholovich, who was responsible for evaluating the static and dynamic stability of the aircraft, developing control systems, developing aircraft electronics, and performing trim analysis. Additionally, both the aerodynamics team and stability/controls team would work in conjunction to determine the feasibility of aircraft modifications. The structures and fabrication group were made up of David Tomer and Justin Schoepke who were responsible for the structural design, analysis, and reinforcement of the aircraft as well as the CAD modeling. Despite the fact the teams had separate objectives, each group would interact and simultaneously work together on various problems and design considerations to ensure that each member had a comprehensive understanding of any design changes to the aircraft. Detailed interactions between these subsystems can be found in Table 1.1 below:

Table 1.1 Major Design Subsystem Interactions

Subsystems	**Major Design Interactions**
Aerodynamics and Propulsion	Changes to motor selection, affecting lift and thrust.
Aerodynamics and Stability/Controls	Changes to control surfaces, moments and aircraft flight control
Aerodynamics and Structures/Fabrication	Changes to aircraft shape (nose, fuselage, tail, etc.), affecting drag, lift performance

Propulsion and Stability/Controls	Changes to acceleration and moments during takeoff; in flight controls
Propulsion and Structures/Fabrication	Imposes restrictions on size and shape of nose; nose must be able to handle thrust force
Stability/Controls and Structures/Fabrication	Aileron/elevon modifications must be feasible for fabrication

The SAE competition required that a technical presentation be presented prior to competition attendance. The presenters for this presentation consisted of Connor Miholovich, Justin Schoepke, David Tomer, and David Van Sickle. Due to budgetary constraints, the team was able to send three team members to the competition. The team members that attended the competition were Connor Miholovich, David Tomer, and David Van Sickle, accompanied by Professor Olinger.

1.5 MQP Objectives, Methods and Standards

Throughout this MQP, there were various tools and software that would help assist the team in performing detailed analysis of the aircraft and other vital calculations, as well as achieve the objectives listed in Section 1.2. Specifically, software was used to analyze the structure, model the aircraft components, stability matrices, and other factors that were beneficial to specific project groups.

1.5.1 Tools/Software Used for Analysis, Modeling, and Fabrication

1.5.1.1 MATLAB

MATLAB was a very useful program for performing more complex and tedious calculations for areas such as stability and controls. The program has many uses, primarily for our project it is used for computation and data analysis. MATLAB provided the team with the ability to solve for stability characteristics, simulate environments, and generate graphs if needed.

1.5.1.2 XFLR5

XFLR5 is an analysis tool that can be used for airfoils, wings, and planes operating at lower speeds. The wing design and analysis uses lifting line theory, the vortex lattice method, and a 3D panel method to generate detailed analyses of aerodynamic interactions. This software was particularly useful for the aerodynamic group for modeling both individual NACA airfoils to determine performance characteristics as well as 3D wing designs. Because our aircraft is fixed wing, XFLR5 also can determine certain stability characteristics that can be cross referenced with other calculations for verification.

1.5.1.3 Solidworks

Solidworks is a computer aided design software program that is able to develop mechatronic systems from beginning to end, and can be used to design parts, assemblies, and drawings. This type of program was integral for structures and fabrication, as the team would be able to visualize both individual components and the aircraft structure using the program.

1.5.1.4 InkScape

Inkscape is a 2 dimensional drawing tool. It was used to import .dxf files onto a computer and to generate custom plots to send to the laser cutter.

1.5.1.5 MotoCalc8

MotoCalc8 is a software used to create pairings between motor, battery, and propeller combinations under specific circumstances. User settings can define desired aircraft performance settings, such as thrust, weight, electric power, and battery size to streamline the motor/battery/propeller selection process for the propulsion team.

1.5.1.6 RCbenchmarkGUI

The RCbenchmark user interface software was paired with the RCbenchmark 1585 thrust stand to visualize and report out measured data for static and dynamic thrust testing. In absence of a power limiter, the software allowed desired cutoff values to be set on stand testing, such as a 450 watt power limit. This software was integral to collecting and graphing thrust stand data to confirm theoretical motor/battery/propeller thrust and power outputs.

1.6 MQP Tasks and Timetable

Table 1.2 Project Gantt Chart

Month	08		09				10				11				12				01				02				03				04	
Week	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
Background Research	🟩	🟩																														
SAE Rules Evaluation		🟩	🟩																													
Competition Registration				🟥																												
Design Process			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																			
Preliminary Design Testing/Analysis								🟩	🟩	🟩	🟩	🟩	🟩	🟩																		
Design Modifications															🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩										
Powered Flight Testing																							🟩	🟩	🟩	🟩	🟩	🟩				
Final Prototype Design/Fabrication																							🟩	🟩	🟩							
Report Writing																						🟩	🟩	🟩	🟩	🟩						
Submit Design Report																										🟥						
Submit Virtual Inspection																													🟥			
Presentation Preparation																											🟩	🟩	🟩			
Technical Presentation																														🟥		
SAE Competition																																🟥

2. Design and Analysis

2.1 Aircraft Configuration Design

Three criteria were initially considered when selecting an aircraft configuration: the type of aircraft, the number and type of delivery boxes we would attempt to carry, and how difficult the aircraft would be to build and fly. The team immediately recognized that the aircraft type was heavily influenced by the amount of payload boxes carried, so these two criteria were partially evaluated together. These brainstorming sessions yielded three aircraft configurations that we investigated further; a delta wing aircraft, a flying wing, and a traditional airfoil and fuselage design. (Lennon, A.)

Table 2.0 Aircraft Configuration Design Evaluations

	Payload Configuration	**Stability & Controls**	**Structural Complexity**	**Fabrication Complexity**	**Required AOA**	**Total Score**
Delta Wing	3	1	1	2	1	8
Flying Wing	2	1	1	2	2	8
Traditional Wing	1	3	3	3	3	13

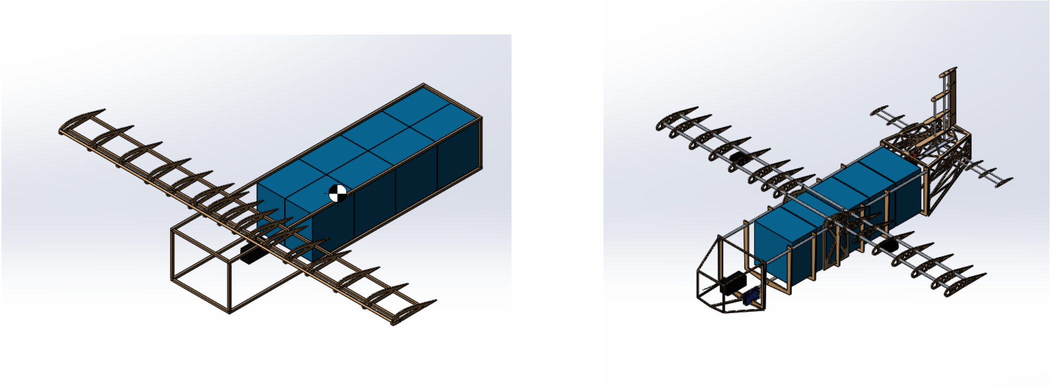


Figure 2.0 Initial Aircraft Configurations

Table 3.1 shows a design matrix we used to evaluate different aircraft configurations. Our team researched delta wing, flying wing, and traditional wing aircraft in the early stages of our design process. The design matrix shows 5 primary criteria we assessed each configuration with. The delta wing aircraft had the highest scoring payload configuration of the three aircraft types, with moderate build complexity. However, the delta wing falls short when it comes to stability and controls, structural complexity, and required angle of attack. Both the controls and structure were complex and the required angle of attack did not make sense for the scale of the competition. The flying wing also faced the same issues with stability, controls and structure complexity. The flying wing was a better choice than the delta wing in the other three categories. The traditional wing aircraft excelled past the other two aircraft in every category but payload configuration. Stability, controls, structure, fabrication, and angle of attack were all very feasible for our team and the competition. The traditional wing aircraft had the lowest point potential for its respective payload configuration, however the team prioritized ease of stability and control to higher payload capacity. The total score of each aircraft reflected the team's aptitude towards selecting a desired configuration, with the fixed wing clearly outperforming the other aircraft in multiple fields that the team prioritized, and was thus chosen as the aircraft configuration.

2.2 Aerodynamics

2.2.1 Airfoil Selection

The team designed the airfoil so that it would operate at low Reynolds numbers, while being able to generate necessary lift to equal the weight of the plane at cruise conditions. The airfoil had to be structurally sound and easy to manufacture. For example, airfoils with extremely thin trailing edges often cause fabrication issues, such as the Selig 1223. An estimated total aircraft weight (including payload plate and boxes) of 3 pounds was determined by the team's intended payload and anticipated weights for propulsion and structural components. The aircraft would have to generate a lift of 13.34 Newtons at cruise conditions (Equation 3.2). The team assumed an aircraft flight speed of 15 m/s (33.5 mph) , an approximate chord length of 16.5 cm and a flight altitude of 236 m above sea-level to determine a Reynolds number of 210,000 (approx). The required lift coefficient was then calculated by equating the weight of the loaded wet aircraft to the lift needed to generate the required amount of thrust, showin in Equation 3.1. (Anderson, J)

$$C_{Lreq} = \frac{W}{\rho V^2 A} * \left(1 + \frac{a0}{\pi AR}\right) = 0.249 \text{ at 0 AOA, Wet Mass} \tag{2.1}$$

$$W = mg = 1.36\, kg * 9.81 m/s^2 = 13.34 \text{ N} \tag{2.2}$$

From the C_{Lreq} In Equation 3.1 we can see that our airfoil selection is sufficient for the plane to takeoff where the Cl of the NACA 4412 is .467 at 0 degrees AOA as shown in Figure 3.4.

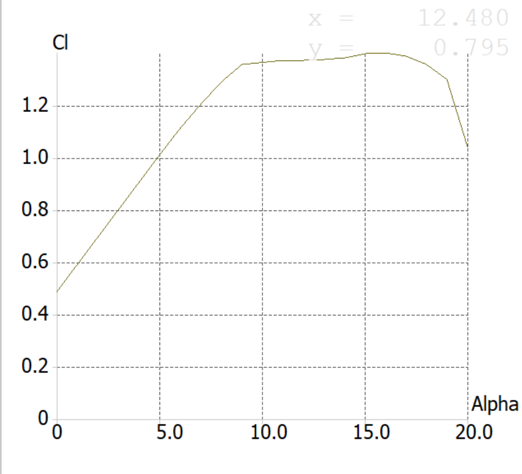


Figure 2.1 Lift Coefficient to AOA for NACA 4412 Airfoil at Re of 210,000

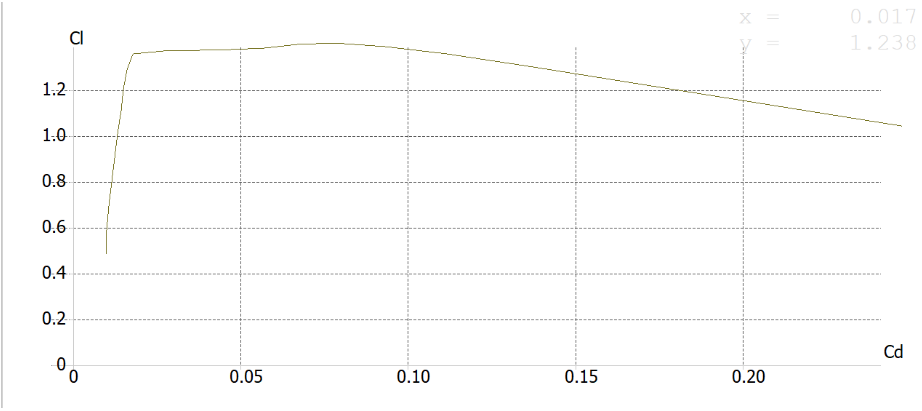


Figure 2.2 NACA 4412 2D performance (C_l vs C_d) for Reynolds numbers of 210,000

With the final iteration of our aircraft: our landing gear configuration caused the aircraft to sit at roughly 5 degrees angle of attack. The non-zero angle of attack was caused by the tail landing gear being mounted on the angled section of the tail, making it sit lower vertically on the aircraft than the main landing gear. The angled configuration allowed for our aircraft to produce greater lift at the takeoff through the wing not being positioned at a zero degree angle of attack. Our new Cl of the NACA 4412 is approximately 1 instead of the Cl of .467 for the NACA 4412 at 0 degrees angle of attack. The new Cl at 5 degrees angle of attack is more than sufficient to satisfy our design constraint of the C_{Lreq} in Equation 3.1. (Anderson, J)

2.2.2 Aspect Ratio

Our team wanted to have a high aspect ratio for our airplane to decrease induced drag and increase the roll stability of our aircraft due to a larger span. By selecting a wingspan of 116.84 cm (46 in) and a chord of 16.51 cm (6.5 in) we are able to calculate our aspect ratio to be: 7.3846 by using Equation 3.3.

$$AR = \frac{S}{c} \text{ where } S = span,\ c = chord \tag{2.3}$$

By having a larger wingspan the moment of inertia about the longitudinal axis is increased, which causes the required moment that needs to be overcome by our control surfaces to be larger. Decreasing the span would allow for a higher roll angular acceleration, which while increasing maneuverability would decrease the stability of the aircraft. Due to the simplistic flight pattern required for the competition the team valued stability over maneuverability in order to increase the potential for competition points. Furthermore, the higher aspect ratio and rectangular wing design allow for maximized wing area for the design constraint for the wingspan.

2.2.3 Wing Planform

The final wing planform shape is a 46 in. by 6.6 in. rectangle. The rectangular shape was chosen over others such as a delta wing due to its larger wingspan making it more stable. The rectangular platform greatly simplified the fabrication process compared to elliptical or swept wing designs. The rectangular wing's airfoil ribs remain the same size and shape across the wingspan and the carbon fiber support rods don't need to be angled. Due to the traditional wing style of the aircraft, the airfoil does not need to feature a reflexed edge due to the presence of the tail wing. With our wing planform and assumed wet weight, the team calculated a wing loading of 19.38 oz. per sq. ft. (0.0084 psi), or a wing cube loading of 12.3, calculated with equation 3.4:

$$W/S = (Wet\ Weight\ in\ oz.)/(S^2/144)^{1.5} \tag{2.4}$$

2.3 Structures

Our team selected typical RC building materials and building strategies to design our aircraft structure. The fuselage and airfoil are designed with carbon fiber stringers along the lengths, and balsa wood ribs placed intermittently. These structures are then wrapped in Monokote heat shrink wrap. Balsa wood is an excellent choice for its extremely lightweight properties, as well as low cost. It is readily available and easy to build with. It is especially receptive to laser cutting operations for precision shaped parts such as the airfoil ribs. We selected carbon fiber for the structure stringers not just for its lightweight properties, but also for its extremely high yield strength. The stringers in the airfoil will be supporting much of the weight and wing load so it is important that they resist deformation. Monokote heat shrink wrap was an obvious choice as an outer shell for our aircraft due to its lightweight, ease of application and repair, and conformity to curved shapes. Additionally we used 3D printing to manufacture our more intricate parts. 3D printing allowed us to make complicated parts precisely while still using a lightweight material such as ABS plastic. 3D printing also allows manipulation of density and wall thicknesses to more easily control a part’s structural properties and weight.

2.3.1 Fuselage/Cargo Bay Configuration

Figure 2.3 shows 2 possible design configurations that were investigated. Both designs allow for space to carry small delivery boxes, the first allowing for 8 and the second for 12. The team quickly eliminated the “fuselage 2” option due to the large cross sectional area and predicted consequential parasitic drag. Therefore, “fuselage 1” design became the basis for the team’s first full aircraft design. Figure 2.4 shows the first iteration of our aircraft, intended for proof of concept glide tests, including 5 small delivery boxes and control surfaces, excluding payload plates and a motor. The team realized that our initial design containing 8 delivery boxes underestimated the space needed for structural and electronic components, so we decided to attempt 5 boxes instead. A series of various tests were completed and are described in depth in Section 6. These tests informed the decision to proceed with the final payload and delivery box configuration shown in Figure 2.3.

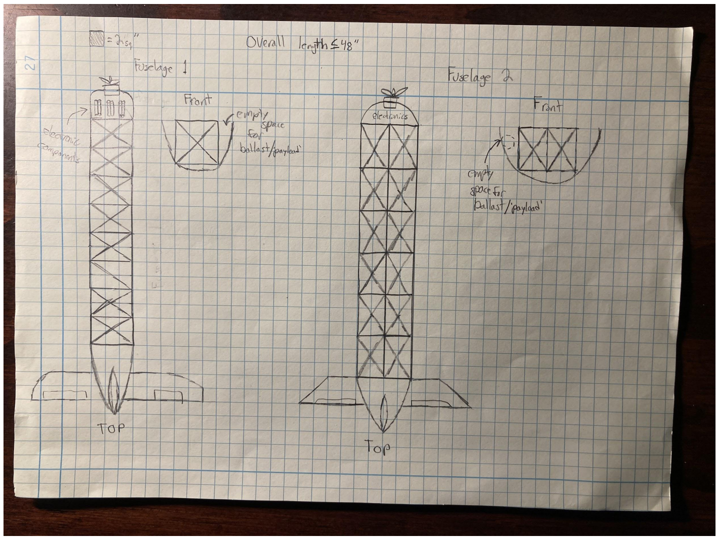


Figure 2.3 Fuselage Design with Alternative Payload Storage Options. Fuselage 1 (left); Fuselage 2 (right).

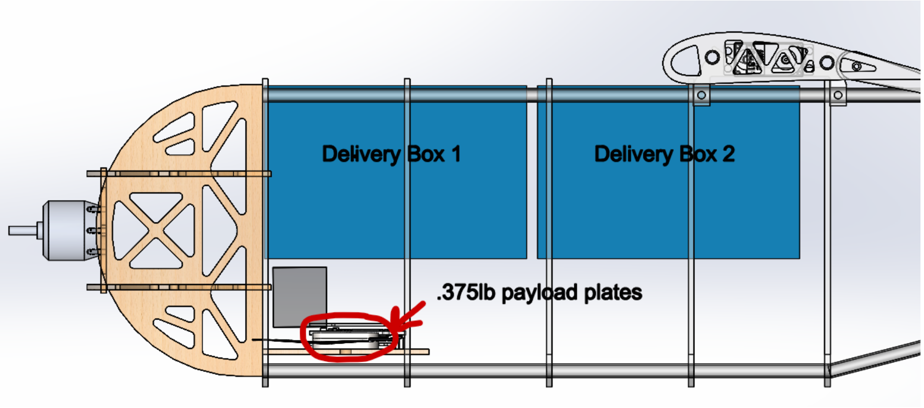


Figure 2.4 Final Fuselage Configuration Carrying Payload Boxed.

2.4 Propulsion System

The team considered various candidates for the aircraft motor, propeller and battery. Due to the short takeoff requirement, the team opted for an outrunner motor. Outrunner motors contain electromagnets around the rotor, and permanent magnets outside of these. This provides magnetic forces further from the center of the motor, resulting in higher torque and less time to reach full speed. The required thrust at cruise was determined by determining the total aircraft drag developed at 15 m/s cruise speed for our aircraft design. This calculation showed that 1.4 lbs of thrust is required to overcome drag at the estimated flight speed of 15 m/s. This thrust value yields a thrust to weight ratio T/W = .467. However, the team decided to increase the required thrust value to T = 3 lbf to achieve a thrust to weight ratio of T/W = 1.0 that is generally used for RC aerobatic aircraft. The power to weight ratio P/W = 150 watts/lb that results also meets 'rule of thumb' power requirements given in (*The Watts Per Pound Rule for Electric RC Planes*).

Candidate motors were initially selected from the MotoCalc 8 motor/propeller software database. The motor selection was heavily influenced by competition design constraints, primarily a 450 watt power limit. The team narrowed down two possible electric motors: a Scorpion HK 3226 1600 kV motor and a Flash Hobby D3536 1250 kV motor. The team decided to choose the Flash Hobby motor over the Scorpion motor due to it’s lighter weight with a higher power efficiency that ensured a high thrust to weight ratio was produced.

With a motor selected, the team was limited by the SAE rules to a commercially available 4 cell Lithium Polymer battery. The team designed the aircraft to fly at maximum throttle for at least 2 minutes. Based on the time of flight Equation 3.5:

$$TOF = ((LiPo\ Capacity/Discharge\ Rate) * 60)/1000 \tag{2.5}$$

The team found a battery that would allow the aircraft to fly for 2.5 minutes at full throttle. The team chose a 2200 mAh 4S LiPo with a 50C discharge rate. This high discharge rate ensured the battery could ramp up to maximum thrust quickly during takeoff and climb. The team was given access to an RCbenchmark 1585 Test Stand that allowed the team to measure thrust outputs, power, current, vibration and could even set cutoff values to these outputs. This thrust stand was vital to evaluate different thrust and power characteristics to determine the most efficient motor and propeller combination.

2.5 Control System Design

To design the wing, the most important feature to evaluate is the control surfaces. In the first iteration of our design the team chose to use two wing ailerons and a rudder, with a horizontal tail to produce the necessary moments about the center of mass for static stability (but no control surfaces). The control system of the plane now features two wing ailerons, a single tail rudder, and a single tail elevator (non-differential). The design was based on STOL bush planes to optimize performance of the plane at takeoff. The largest design constraint for the controls section is designing a plane that can take off from the competition's short runway.

To control the roll, the team elected to use two ailerons on the main wing. An aileron was placed to the either side of the fuselage on the trailing edge of the wing. To control the yaw of our aircraft, the team elected to use a rudder placed on the tail of the plane. The rudder was located on the trailing edge of the vertical stabilizer and was able to rotate in order to yaw left and right. To control the pitch of the plane, the team used a single elevator located on the trailing edge of the horizontal stabilizer. The non-differential system was designed for the purpose of generating lift and controlling the pitch, not contributing to roll.

Table 2.1: Shows the ratio of the surface area that the control surface is mounted to the surface of the control surface.

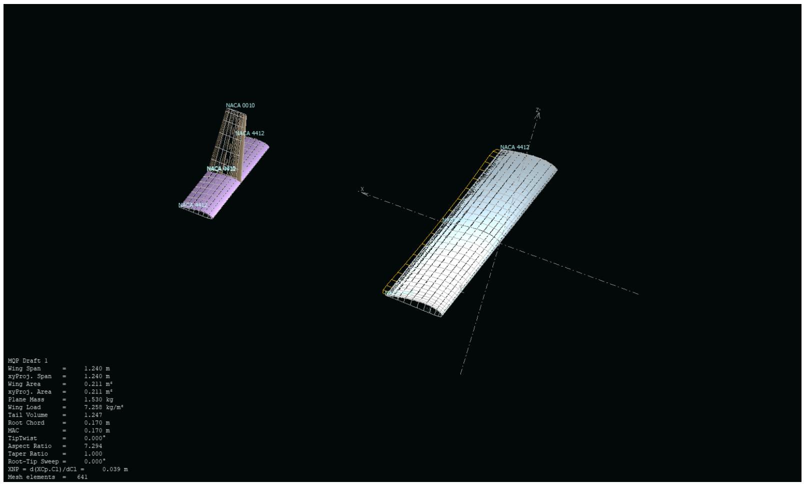
Total Aileron Area/Wing Area Ratio	Total Rudder Area/Vertical Tail Area	Total Elevator Area/Horizontal Tail Area
10.51 %	41.67 %	33.00 %

Each of the control surfaces mentioned in Table 2.1 are controlled by a closed-loop PID (Proportional, Integral, Derivative) controller that takes sensor feedback from our flight controller. The choice of using a PID controller was based on ease of implementation and overall performance benefits. The PID controller features a more robust and easy to integrate closed loop system. Furthermore, our flight controller has a built in PID controller through mission planner that only needs to be tuned to fit the aircraft. This allowed our team to spend more time on other aspects of the plane design rather than writing software to implement a more advanced controller that would only provide minimal benefits.

3 Aircraft Performance Analysis

3.1 Wing and Airfoil Simulation

In order to effectively determine the drag acting on the aircraft we used XFLR5 to simulate the aircraft in a controlled setting (no environmental conditions such as wind). The goal of the simulation and testing is to lower the drag acting on the aircraft by finding points on the plane that decrease aerodynamic efficiency. (Deperrois, A.)



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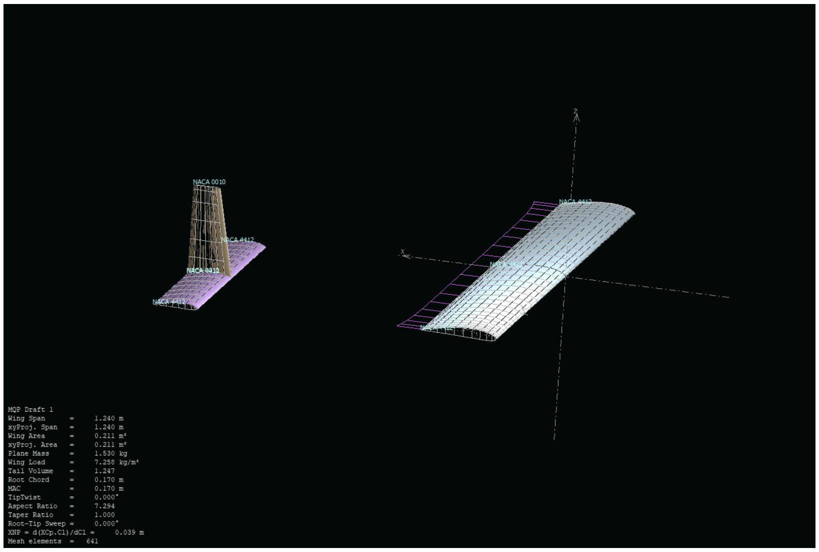
MQP Draft 1
Wing Span      =     1.240 m
xyProj. Span   =     1.240 m
Wing Area      =     0.211 m²
xyProj. Area   =     0.211 m²
Plane Mass     =     1.530 kg
Wing Load      =     7.258 kg/m²
Tail Volume    =     1.247
Root Chord     =     0.170 m
MAC            =     0.170 m
TipTwist       =     0.000°
Aspect Ratio   =     7.294
Taper Ratio    =     1.000
Root-Tip Sweep =     0.000°
XNP = d(XCp.Cl)/dCl =     0.039 m
Mesh elements  =   641
```

Figure 3.0 XFLR5 Simulation Induced Drag acting on wing at 0 degrees AOA.



```
MQP Draft 1
Wing Span      =     1.240 m
xyProj. Span   =     1.240 m
Wing Area      =     0.211 m²
xyProj. Area   =     0.211 m²
Plane Mass     =     1.530 kg
Wing Load      =     7.258 kg/m²
Tail Volume    =     1.247
Root Chord     =     0.170 m
MAC            =     0.170 m
TipTwist       =     0.000°
Aspect Ratio   =     7.294
Taper Ratio    =     1.000
Root-Tip Sweep =     0.000°
XNP = d(XCp.Cl)/dCl =     0.039 m
Mesh elements  =   641
```

Figure 3.1 XFLR5 Simulation of Viscous Drag Acting on Wing at 0 degrees AOA.

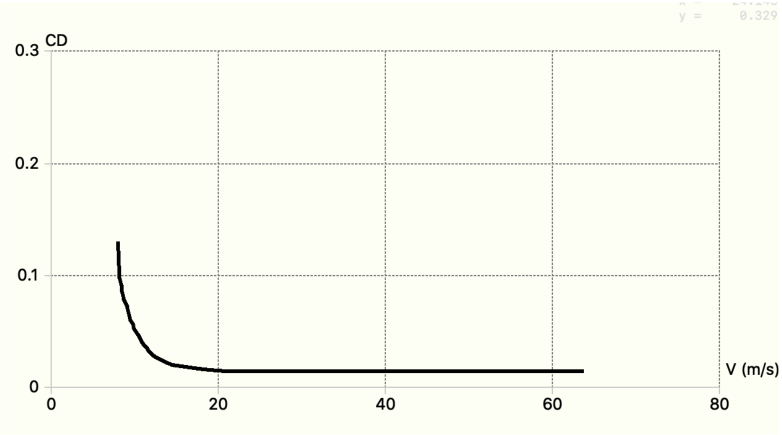


Figure 3.2 XFLR5 plot of drag coefficient vs velocity.

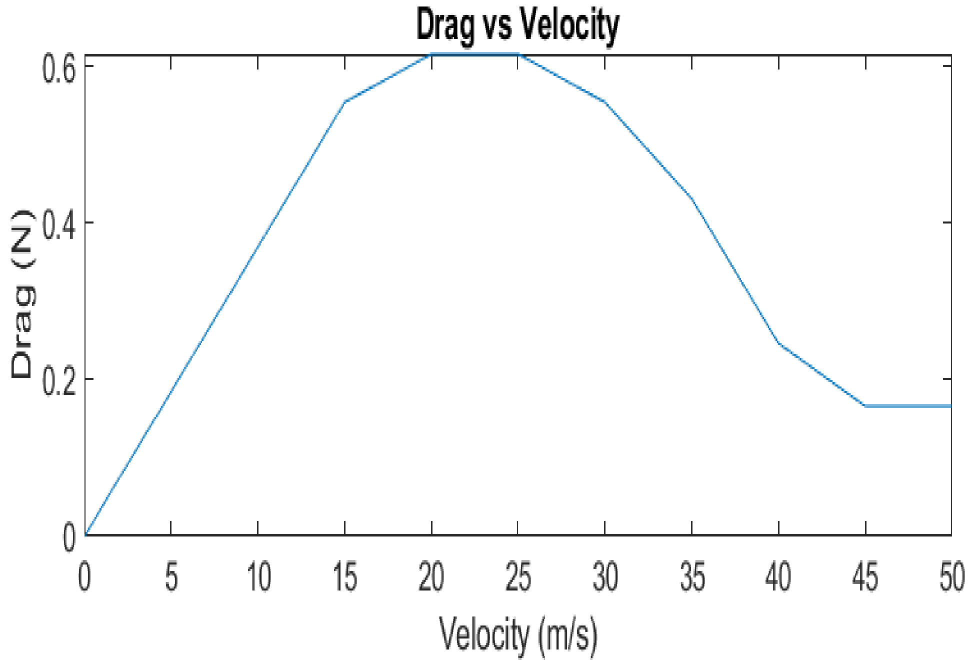


Figure 3.3 Matlab plot of drag vs velocity.

After analyzing the data from the XFLR5 simulation we were able to make several distinct observations about the aircraft's performance and effects of drag. XFLR5 shows that the airfoils are efficient in producing lift with a low drag (per AOA) at cruise conditions. The team's XFLR5 drag analysis using XFLR5's aircraft mode only included the wing, horizontal tail and vertical tail components as shown in Figures 3.0 and 3.1. The fuselage was not included in the analysis since the XFLR5 aircraft mode showed convergence issues when the fuselage was included. We later performed wind tunnel tests on a 3:1 scale model of the WPI 319-2022 design to obtain additional drag data. This testing is described later in Section 6.1.

3.2 Structural Analysis

In order to ensure that the aircraft would be able to withstand the forces anticipated during flight, we conducted simulations (static simulations in SolidWorks) on specific parts, subassemblies, and the main assembly to determine how they would respond to applied forces and locate problem areas for design improvements.

The first tests ran were to check individual parts we thought could be potential breaking points during normal operations, primarily the 3D printed clips used to connect the main airfoil to the fuselage. The points of concern were features 1, 2, and 3 as labeled in Figure 3.3 below. The assembly utilized “stand-in parts” with contact interactions so that it would behave similarly to when it is actually in flight on the aircraft. The stand-ins for the airfoil rods located at feature 3 were set as fixed geometry (parts that can’t move during simulation), and a 5 lbf downward force (conservative overestimate of expected weight/lift forces) was applied to the stand-in for the fuselage rod located at feature 2. From the simulation, we were able to determine that the part would be able to withstand the required forces without breaking (maximum stress experienced due to the applied force was about 780 psi whereas the ultimate tensile strength/breaking point of PLA is about 7080 psi), as well as determining that the feature with a higher risk of breaking was feature 3 rather as opposed to features 1 and 2, shown in Figure 3.4 below. A simple hand-calculation was done as a way to verify the amount of stress found in the simulation using Equation 4.1 for both points of concern experiencing the full force of 5 lbf across their total area, 0.0074 in^2 for sections between features 1 and 2, and 0.0423 in^2 for feature 3, resulting in stresses of around 675 psi and 118 psi respectively. While the hand calculated stresses were lower than those found in the simulation, they were able to provide an important comparison to determine if the simulation was working properly (i.e. no stresses multiple times the value of the breaking point). Similarly, a simulation of the 3D printed tail piece was also run using the same applied force as used for the airfoil clips as shown in Figure 3.5 and found that the points of high stress were around the holes for the fuselage rods, and that the stresses did not exceed the breaking point of the material. The fixed geometry was set along the holes meant for where the carbon fiber rods from the fuselage connect to the tail. The tail showed signs of stress along the carbon fiber attachment points (where the fixed geometry was set) and along the servo mounting areas. The stresses simulated in Figure 3.5 are simulating the forces from the horizontal tail wing to simulate the stresses acting on the component in flight from the lift.

$$\sigma = \frac{Force\ (lbf)}{Area\ (in^2)} \tag{3.1}$$

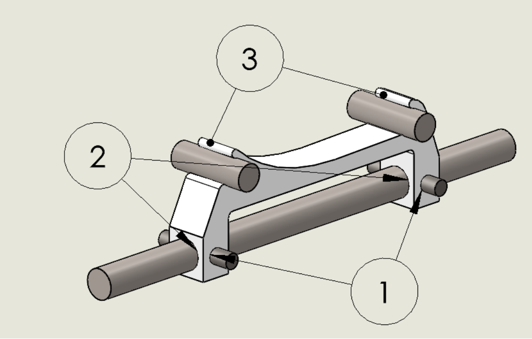


Figure 3.4 Solidworks model of 3D printed wing attachment part for stress analysis. 1- set screw holes, 2- fuselage rod holes, 3- airfoil rod clips.

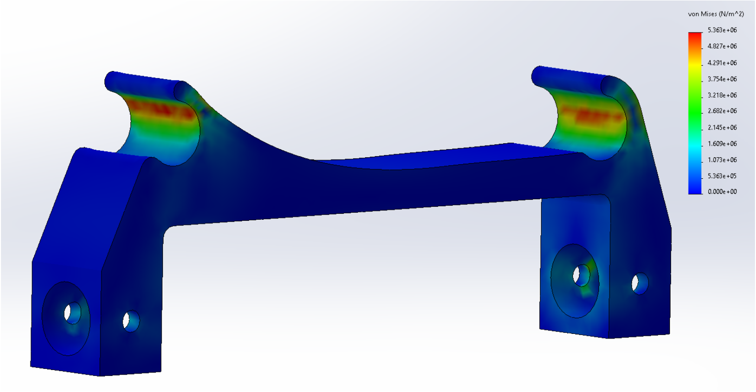


Figure 3.5 Wing attachment piece stress test results (Blue = low/no stress;red = high stress).

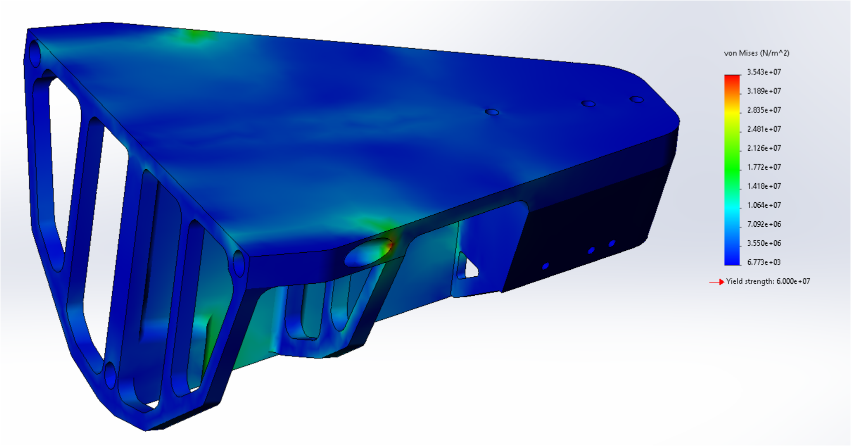


Figure 3.6 3D printed tailpiece stress test results (Blue = low/no stress;red = high stress).

3.2.1 Mass Properties & Balance

Table 3.0 below was used to compile relevant component masses and center of gravity (CG) positions relative to a datum located at the front most point of the aircraft. It allowed the team to keep track of component masses' contributions to the total mass of the aircraft and their effect on the aircraft CG, facilitating the process of making changes to component masses and positions in order to move the aircraft CG.

Table 3.0 Component weights and horizontal positions.

Item of interest	Weight (lb)	Percentage of Aircraft Weight	Position (in)
Motor	0.31875	10.625	1.1
Battery	0.55125	18.375	6.66
Electronics	0.14512	4.837	8.10
Structure	1.7349	57.829	26.97
Payload	0.25	8.333	7.71
Empty CG	n/a	n/a	19.16
Loaded CG	n/a	n/a	17.33
Total	3	n/a	n/a

3.3 Static and Dynamic Thrust

The team initially performed static thrust testing using the RCbenchmark 1585 test stand to measure the static thrust of the Scorpion HK 3226 motor paired with various propellers to measure thrust output. The test stand software allowed the team to cut off power to the motor should it exceed 450 watts, which the team did to ensure we were within the competition specified power constraints. These test results can be seen in Figure 3.6. The team then measured the static thrust of the Flash Hobby D3536 motor, which had a maximum power rating of 500 watts, compared to 1550 watts for the Scorpion motor. The team tested the motors on the thrust stand with 9 x 6E, 11 x 5.5E, and 10 x 4.5E propellers, and the combinations that generated the highest thrust were chosen for the figures. The results shown in Figure 3.7 show that the Flash Hobby motor was able to generate much more thrust than the Scorpion motor within our given power constraints, and was chosen as our desired motor for the aircraft, due to its lighter weight and higher thrust to power efficiency. (*The Watts Per Pound Rule for Electric RC Planes*)

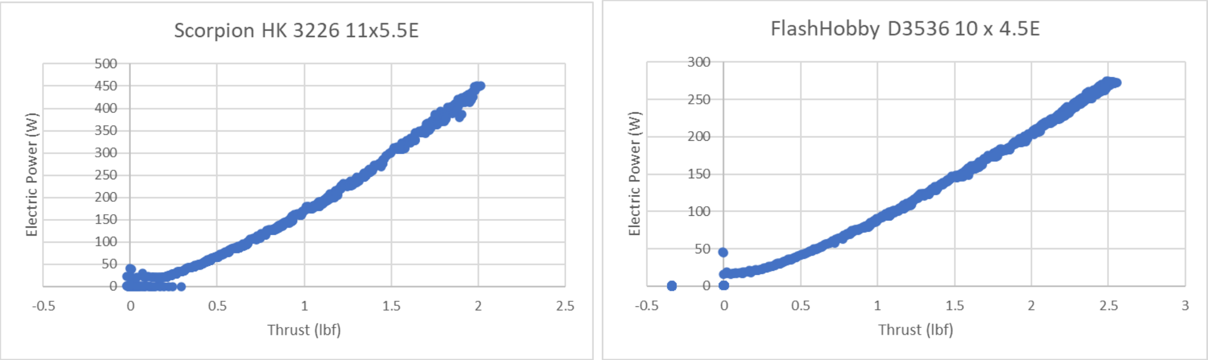


Figure 3.7 Scorpion vs FlashHobby Motor Static Thrust.

Following static thrust testing, the team measured the dynamic thrust of the FlashHobby D3536 Motor in the WPI Aerodynamics Test Facility which is a wind tunnel with 2 foot x 2 foot x 8 foot test section and 55 m/s maximum test section velocity. The following results were taken with an airspeed of 22 miles per hour, half of the team's cruise speed, and 45 miles per hour.

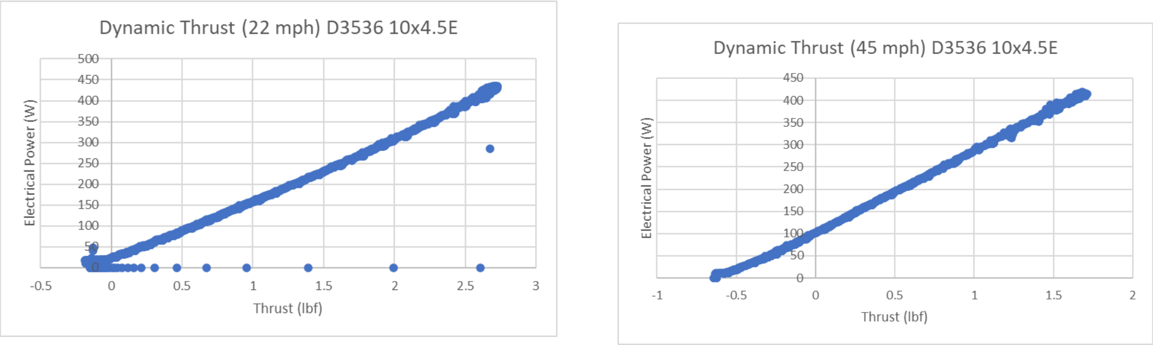


Figure 3.8 FlashHobby 22mph and 45 mph Dynamic Testing.

The motor propeller combination was able to generate 2.7 lbs of thrust before reaching the power limit at 22mph, compared to 1.6 lbs at 45 mph. This was lower thrust at the cruise speed than the team anticipated, however it was still deemed acceptable for competition flight. (Hall, N.)

3.4 Static and Dynamic Stability

Our XFLR model of the plane shows that our neutral point is at 46.2 cm (18.5 in) and our center of gravity on the x axis is at 43.5 cm (17.14 in). From the relationship between neutral point and center of gravity we can conclude that our plane is stable because our neutral point is behind our center of gravity. Figure 3.8 further validates the stability of our aircraft where our moment coefficient versus angle of attack plot shows a negative slope. We can conclude that our aircraft is statically stable through our evaluation of the static margin in Equation 4.2, our Moment Coefficient slope in Figure 3.8, and our glide testing results. (Deperrois, A.)

$$Static\ Margin = \frac{Xnp-Xcog}{c} = 16.3\% \tag{3.2}$$

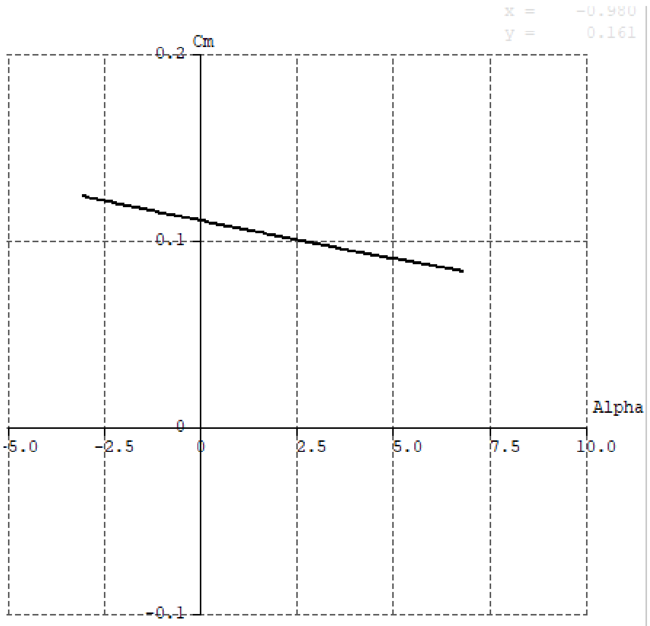


Figure 3.9 Moment Coefficient vs AOA for the XFLR5 plane model.

A stability analysis was done using Matlab by inputting the known physical parameters of our plane and the moments of inertia as calculated by solidworks. Our aircraft underwent several iterations before the team was satisfied with the stability. From our static margin Equation 3.2 and comparing the results to the moment coefficient plot in Figure 3.8, we can see that our plane is statically stable with a static margin of 16.3%. To further improve the stability (longitudinal and lateral) of our plane we used a flight controller with a tuned PID controller to improve the response of the aircraft, the tuning values can be seen in Table 3.3. When simulating dynamic responses and controls in XFLR5 the Short and Modal Responses failed. The failure of the dynamic responses allows us to conclude that our aircraft is not dynamically stable, so some form of control system or stabilization is required to fly the aircraft. (Robert C. Nelson)

Table 3.1 Longitudinal Dimensional Stability Derivatives.

Stability Derivative	XFLR5 Value	Matlab Value
Xu	-0.00024265	-0.1248
Xw	0.023189	0.8285
Xq	0	0
$X_{\overset{\frown}{w}}$	0	0
Zu	-0.10339	-4896.2
Zw	-12.525	-12.744
Zq	7.9377	-0.7939
$Z_{\overset{\frown}{w}}$	0	-0.0254
Mu	-1.3312e-7	0
Mw	9.7942	-0.3623
Mq	-8.6253	-0.4167
$M_{\overset{\frown}{w}}$	0	-0.0153

Table 3.2 Lateral Dimensional Stability Derivatives.

Stability Derivative	XFLR5 Value	Matlab Value
Yv	-0.26475	-0.7644
Yp	0.020427	-0.0556
Yr	0.019498	0.3157
Lv	0.003407	-0.2676
Lp	-0.7095	-0.8613
Lr	0.01429	0.1759
Nv	0.010442	0.1954
Np	-0.0074515	-0.0550
Nr	-0.00096087	-0.1814

When designing the control algorithm for the aircraft we wanted to model a system that could easily be input to most flight controllers. We elected to use a closed loop PID controller that would take sensor feedback from our IMU's. We then modeled the system in Matlab and Simulink using the stability derivatives and equations of motion of our physical aircraft. In our Simulink model we made a PID controller for heading of the aircraft, pitch of the aircraft, and roll of the aircraft. We then plotted the elevator, rudder and aileron responses. In using the plots we were able to tune our PID controller (shown in Table 3.3) to get the theoretical responses and settling times that we wanted. Equation 3.3 shows the PID controller equation used to create our Simulink model. (Prof. Jonathan P.)

$$PID\ Controller\ u(t) = K_p e(t) + K_i \int e(t)dt + K_p \frac{de}{dt} \tag{3.3}$$

Table 3.3 Shows the tuning parameters for the aircraft.

PID Gain	Roll	Pitch	Yaw
Proportional (Kp)	0.1600	0.4000	0.3000
Integral (Ki)	0.0003	0.0007	0.0001
Derivative (Kd)	0.0200	0.0350	0.0100

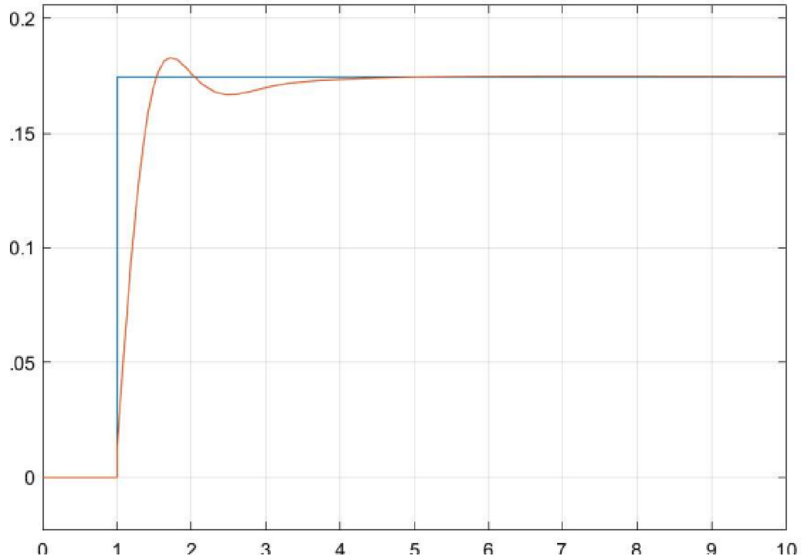


Figure 3.10 The aircrafts simulated PID response to pitch responses from 0 to 10 degrees.

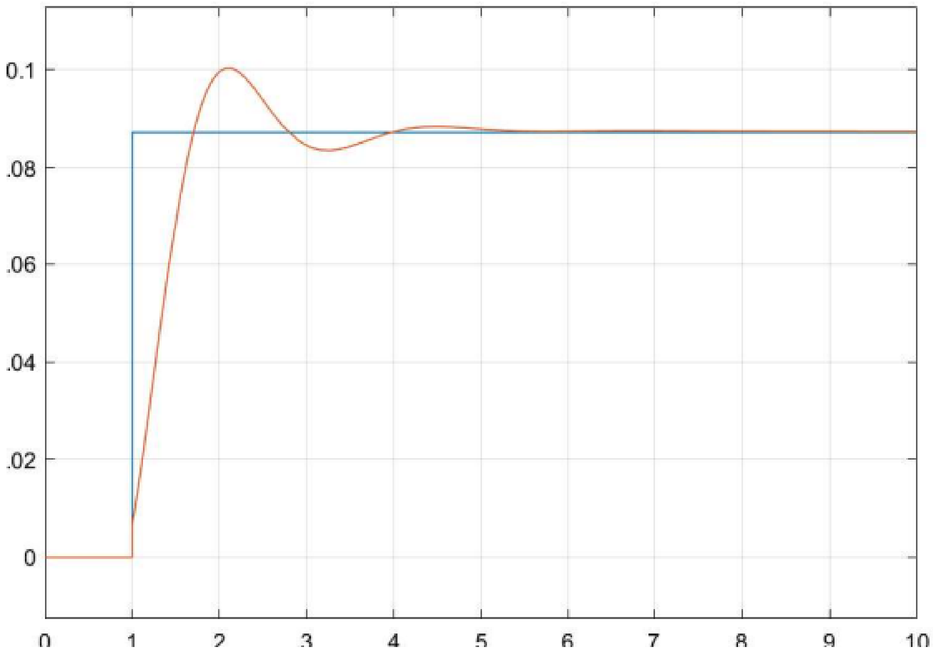


Figure 3.11 The aircrafts simulated PID response to roll responses from 0 to 5 degrees.

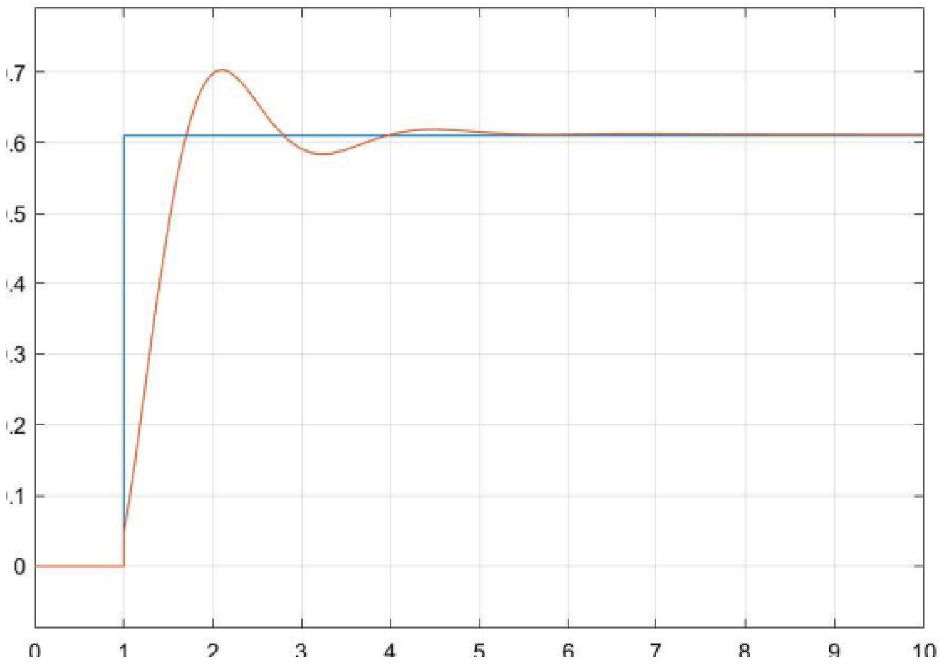


Figure 3.12 The aircrafts simulated PID response to yaw responses from 0 to 35 degrees.

Due to competition regulations we utilized the gyroscopic stability augmentation from the Frsky S8R to improve the control response of the aircraft. The PID controller developed for the project simulates the response of the Frsky S8R where the goal of the S8R is to smooth the flight path by reverting the aircraft to a level orientation (make the aircraft nonrotating/fly the aircraft at zero degree AOA). The PID controller takes a nonzero initial condition and plots the control response and angular response of the system as the PID controller attempts to level the aircraft to zero degrees (level flight).

3.5 Flight and Maneuver Performance

During our flight testing the team noticed that the roll authority was not responsive. To compensate for the lack of control authority the team redesigned the ailerons to be longer to increase the force produced by the control flaps. During the flight tests, the team noticed that the yaw control was responsive but slow. To improve the performance of the rudder the team extended the control surface by 1.5 times the original length and noticed a significant increase in the control response time. Our team noticed that the pitch control performed well during takeoff using the two ailerons on the main wing. However, during the flight, the pitch authority was aggressive rather than smooth. To increase the control authority the team elected to add a single non-differential elevator on the tail to improve the performance.

3.6 Take-Off and Climb Analysis

To simulate the takeoff from the elevated runway the team used the aircraft parameters and control parameters in a Python Runge-Kutta method which is shown in Figure 3.12. The Runge-Kutta method uses a series of differential equations of motion and integrates them with respect to time. The vertical displacement is calculated using Equation 3.9 and the system of equations is calculated using Equations 3.4-3.8. In Equation 3.9 h is defined as the step to loop through, in this instance time is used as h over the interval of 0 - 8 seconds. (S, J.)

$$\frac{dy}{dt} = f(t, y), y(t_0) = y_0 \tag{3.4}$$

$$k_1 = hf(t_0, y_0) \tag{3.5}$$

$$k_2 = hf(t_0 + \frac{h}{2}, y_0 + \frac{k_1}{2}) \tag{3.6}$$

$$k_3 = hf(t_0 + \frac{h}{2}, y_0 + \frac{k_2}{2}) \tag{3.7}$$

$$k_4 = hf(t_0 + \frac{h}{2}, y_0 + k_3) \tag{3.8}$$

$$y_i = y_0 + \frac{h}{6}(k_1 + 2k_2 + 2k_3 + k_4) \tag{3.9}$$

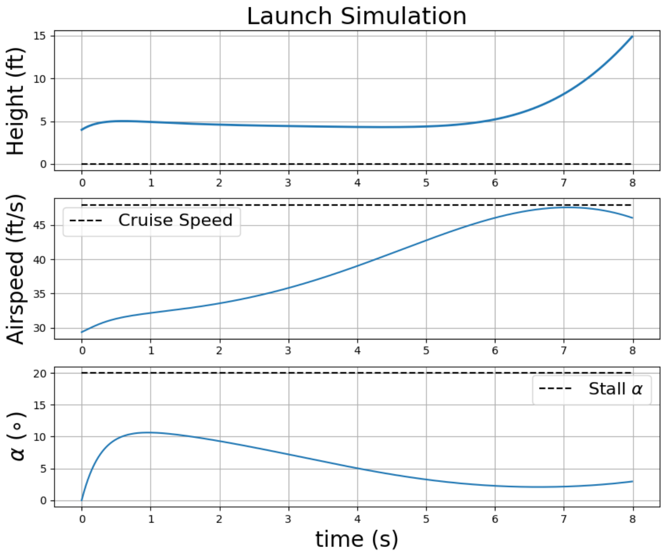


Figure 3.13 Launch simulation results from Python Runge-Kutta numerical integration.

Our takeoff simulation shows that our aircraft will be able to hold altitude until it reaches its cruise speed where it will be able to climb.

4 Construction and Testing

4.1 Fabrication

Laser cutting was a critical tool in the construction of the aircraft. It allowed parts such as the airfoil and fuselage ribs to be fabricated out of ⅛” balsa wood quickly and precisely to achieve the desired shape. Some of the laser cut components can be seen in Figure 4.0. 6 foot carbon fiber rods were ordered in bulk and cut by the team to save on costs. Payload plates were machined on a 3-axis CNC mill out of mild steel. This process was the easiest and quickest way to work with such a tough material while ensuring the plates were identical to one another. The tail base and airfoil clips were both 3D printed out of PLA plastic. 3D printing was appropriate for these components because it allowed us to manufacture unique geometries out of a light material for a low cost. All components were mated to one another using cyanoacrylate glue.

Figure 4.0 Laser cut structural components

4.2 Assembly

4.2.1 Fuselage and Airfoil

The airfoils, fuselage, and vertical tail were all assembled using a similar process. The carbon fiber stringers are cut to length, and then the ribs for the particular assembly are glued along the carbon fiber at the desired spacing. It is important to note that the 3D printed airfoil clips must be assembled concurrently between the correct ribs as the fuselage is built because once the ribs are glued into place, the clips cannot be removed. An assembled fuselage and airfoil can be seen in Figure 4.1. The vertical tail and horizontal tail are assembled onto the 3D printed tail base along with the control surface servo motors. The tail subassembly slides onto the fuselage carbon fiber stringers and then is glued in place. The nose components are designed to interlock with each other and the fuselage. These components are glued together and to the fuselage. The motor is mounted to the nose, servo motors mounted to the airfoil, and the rest of the electronics are wired together. The flight controller and esc are set into a piece of foam that is secured to the fuselage to protect them during flight. Finally, all components are covered in Monokote heat shrinking wrap. Figure 4.2 shows the fully wrapped glider prototype.

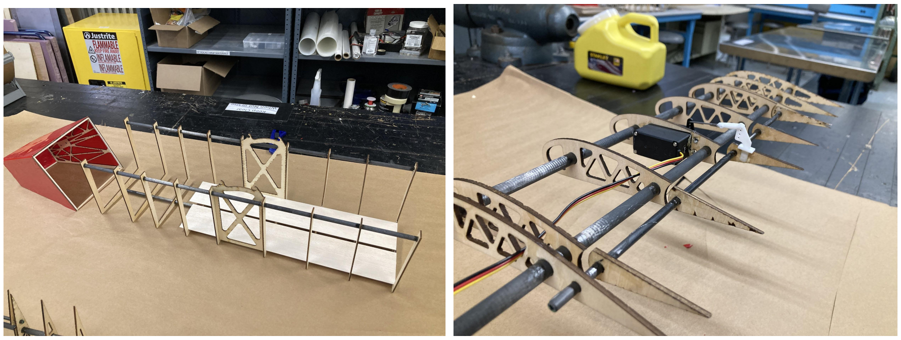


Figure 4.1 Assembled fuselage and airfoil.

Figure 4.2 Fully assembled and covered glider prototype.

4.2.2 Electronics

The competition required us to follow a strict electronic wiring setup consisting of a battery, 450W power limiter, electronic speed controller, receiver, and arming plug. Servo and DC motors had no restrictions other than the wiring to the electronics which is shown in Figure 4.3. Figure 4.4 shows the actual wired setup for our aircraft.

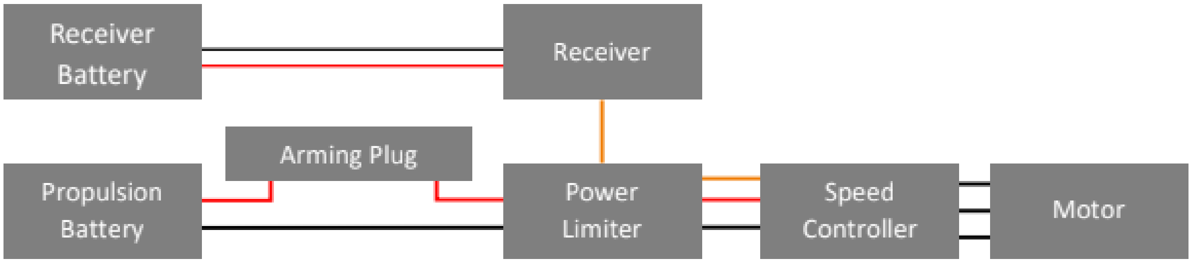


Figure 4.3 Electronic configuration as regulated by SAE.

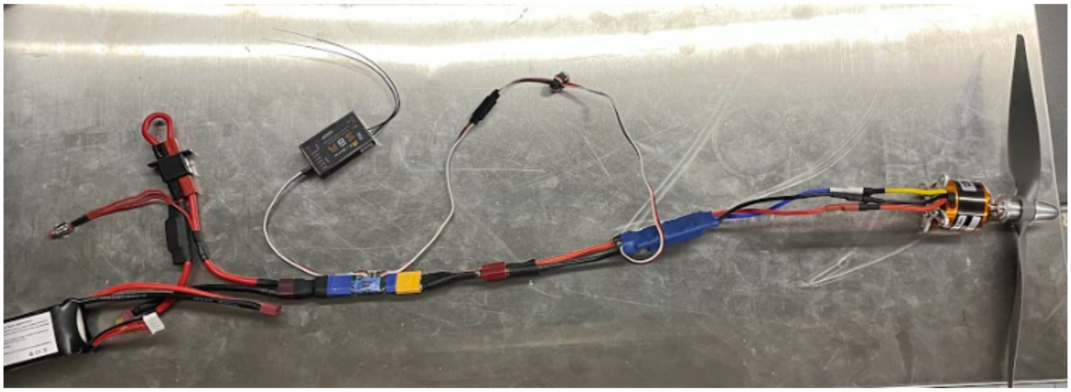


Figure 4.4 Actual electronic setup as used in the competition.

4.2.3. Shipping

The aircraft was shipped to the competition via UPS Ground in a box 48” x 24” square. This was more than enough volume to fit our aircraft, spare parts, and a box of tools. The box was purchased from a local U-Haul store.

4.2.4 Complications

Monokote can be difficult to work with; there were several instances of the wrapping tearing on sharp corners. This issue was resolved by being conscientious of how much heat was being applied and not using too much. Similarly, as the Monokote shrank, it tended to warp some of the ribs in the direction of the shrinking. ⅛” balsa rod was added between some of the ribs to prevent this.

4.3 Testing

4.3.1 Wind Tunnel Testing

Used a 3D printed 3:1 scale model of our aircraft (with no control surfaces) in a Engineering Laboratory Design (ELD) Force Balance (first usage at WPI). The testing consisted of using a calibrated lift and drag sensor and changing the AOA of the aircraft. The calibration process included using known masses (5kg and 2.5kg) that were hung from a pulley system to adjust the readings of the thrust and drag sensors. The initial model showed that there was a large amount of drag for the amount of lift acting on the scaled aircraft. To compensate for the drag the team redesigned the nose to be more aerodynamic by making the nose more round to give the aircraft body a streamlined shape.

4.3.2 Glide Testing

The team decided to perform a series of unpowered glide tests to determine the structural capabilities of the aircraft as well as control responses. The prototype designed for this test included wing aileron and rudder control surfaces, and used weights to simulate aircraft components within the fuselage. Figure 4.5 shows an indoor site with a balcony that was approximately 15 feet above ground where the aircraft could be thrown into level flight and control responses could be observed (without disturbances from environmental conditions). During glide testing, the aircraft responded to pitch control inputs well, but was less responsive in roll and yaw. The pitch response of the plane was somewhat sluggish during glide testing.

However, the slow pitch response was presumed to be the fault of the aircraft moving below the predicted airspeed during the short glide test duration. The glide test yielded an average velocity of 12.3 m/s when the predicted airspeed was 20 m/s. The average velocity was calculated from the distance traveled and the 2.13 second flight time.

Figure 4.5 Glide Testing Setup

Design changes that resulted from the first glide tests included increasing the rudder chord to increase rudder area. This change only mildly improved the yaw response and did not improve the roll response. To improve the roll response, gaps between the wing and aileron surface were reduced by extending wing monokote. Following these modifications, the team opted to test aircraft control responses on a fully powered, structurally enhanced aircraft.

4.3.3 Flight Testing

Table 4.0 summarizes the team's flight testing both before and during competition. Important findings and results from the flights are also noted in Table 4.0. Figure 4.6 shows a picture from our flight testing. The Table 4.0 also notes notable failures or success of the aircraft which strongly influenced changes the team made on the design of the aircraft in order to improve flight.

Table 4.0 Flight Test Details

Date	Test	Results/findings
11/10/2021	Glide Test	Successful glide; some pitch but little to no roll or yaw control
2/15/2022	Powered Flight	Aircraft capable of takeoff under its own power; poor roll and yaw control
4/6	Powered Flight	Aircraft can take off from 8’ table, glides down to ground, lift not adequate (50% throttle)
4/7	Powered Flight	Aircraft can take off from 8’ table; roll, yaw, and pitch all respond as expected; elevators clipped ground and right elevator broke, elevators do not appear to produce adequate lift
4/9	Powered Flight at SAE Competition	Trim ailerons down 5 degrees to add additional lift, too much payload carried for headwind, plane nose-dove (only broken landing gear).
4/9	Powered Flight at SAE Competition	Box placement moved CG, causing the plane to roll over and crash.
4/9	Powered Flight at SAE Competition	Ailerons re-trimmed to account for unbalanced CG. Plane elevators do not seem to be producing enough lift -> must use max throttle.
4/10	Powered Flight at SAE Competition	Main wing separated from the right side of the fuselage and the plane landed safely.
4/10	Powered Flight at SAE Competition	Elevator servo failed, plane did a backflip due to the servo being locked at max positive pitch.

Figure 4.6 Powered Flight Testing

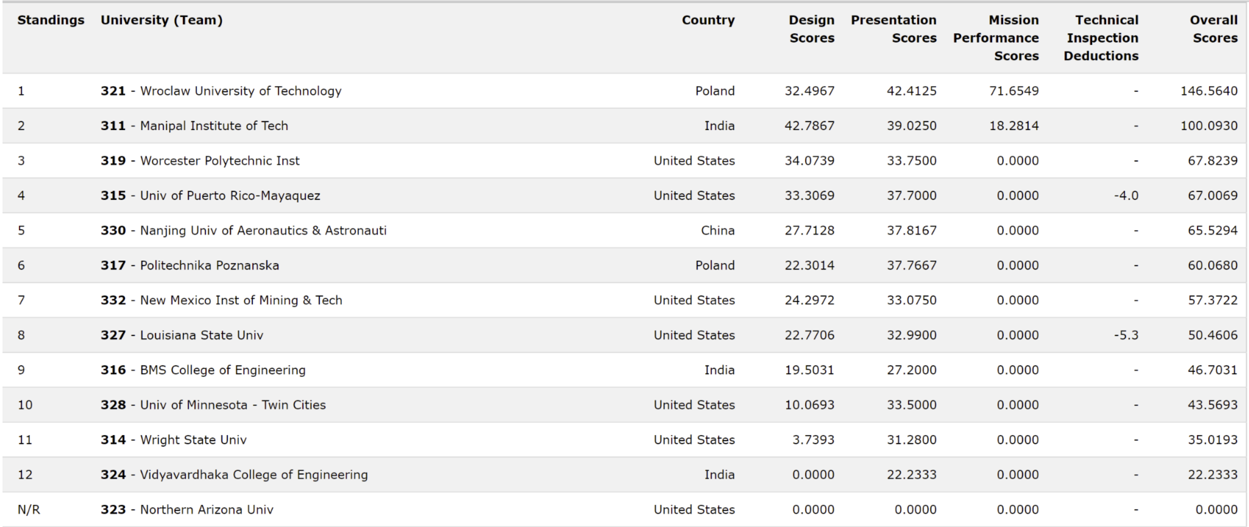
5 Summary, Conclusions, Recommendations, Broader Impacts

5.1 Summary

The team designed the WPI “Bad Larry” Aircraft to compete in the 2022 SAE Micro Aircraft Competition. The aircraft is a single motor, high wing monoplane design constructed from balsa wood, carbon fiber rods, PLA 3D printed material and monokote. The aircraft was designed to have an empty weight of 1.5 lbs consisting of structural and propulsive components, a maximum predicted take-off weight of 3 lbs, and a 3 minute flight time. The payload consists of metal payload plates and small “Delivery Boxes”, supplied by the competition. There were a number of design constraints which the team had to abide by. During this competition, the team placed third within the micro class, and achieved second place in technical design report writing scoring. While the team’s aircraft did not fly successfully, a high technical design report and presentation performance within the field assured that the team secured a place on the competition podium. The team gained greater insight into the technicalities concerning aircraft design with restrictive constraints, and was proud of our achievements within the competition.

5.2 Conclusions

The competition was held at a recreational airfield in Encino, CA over three days of flying between micro, regular, and advanced class competition aircraft. We arrived at the competition with a handful of improvements we wanted to make based on our powered flight testing mentioned previously. We made what changes we could without having to take a point deduction for an ECR (Engineering Change Request) which mostly included some fine tuning of our trim on our control surfaces. Over the three days, the team attempted 6 total flights, all with increasing levels of success. Although we never got a full scorable flight, we saw improvements each time. The overall competition standings can be found in Figure 5.1 which shows that we placed 2nd in the Design Report score and 6th in the Presentation score and 3rd place in the Overall score.



Standings	University (Team)	Country	Design Scores	Presentation Scores	Mission Performance Scores	Technical Inspection Deductions	Overall Scores
1	**321** - Wroclaw University of Technology	Poland	32.4967	42.4125	71.6549	-	146.5640
2	**311** - Manipal Institute of Tech	India	42.7867	39.0250	18.2814	-	100.0930
3	**319** - Worcester Polytechnic Inst	United States	34.0739	33.7500	0.0000	-	67.8239
4	**315** - Univ of Puerto Rico-Mayaquez	United States	33.3069	37.7000	0.0000	-4.0	67.0069
5	**330** - Nanjing Univ of Aeronautics & Astronauti	China	27.7128	37.8167	0.0000	-	65.5294
6	**317** - Politechnika Poznanska	Poland	22.3014	37.7667	0.0000	-	60.0680
7	**332** - New Mexico Inst of Mining & Tech	United States	24.2972	33.0750	0.0000	-	57.3722
8	**327** - Louisiana State Univ	United States	22.7706	32.9900	0.0000	-5.3	50.4606
9	**316** - BMS College of Engineering	India	19.5031	27.2000	0.0000	-	46.7031
10	**328** - Univ of Minnesota - Twin Cities	United States	10.0693	33.5000	0.0000	-	43.5693
11	**314** - Wright State Univ	United States	3.7393	31.2800	0.0000	-	35.0193
12	**324** - Vidyavardhaka College of Engineering	India	0.0000	22.2333	0.0000	-	22.2333
N/R	**323** - Northern Arizona Univ	United States	0.0000	0.0000	0.0000	-	0.0000

Figure 5.0 Final Competition Standings

5.3 Recommendations for Future Work

At the onset of the project, the team realized that several members had little to no experience with electric powered aircraft of this scale. The team recommends that future teams gain a better understanding of the difference between principles of smaller RC aircraft compared to full scale airplanes and conduct research on proven flight designs, rather than experimental ones.

The team could have made several changes to the overall project management and subsystem interactions to enhance greater collaboration and design coordination. The team found themselves behind schedule during the later stages of the design process, often due to inability to coordinate schedules and issues arising from fabrication challenges. This was increasingly noticeable when it came time for powered flight testing, which occurred several weeks beyond the anticipated initial test date. If the team had followed a more strict schedule and coordinated our individual schedules better, we may have been able to save precious time later in the testing process. This may have given the team ample time to make necessary design changes prior to competition that could have given the team a better chance at successful competition flights.

In addition, the team realized after conducting preliminary designs and constructing gliders that there were several unintended consequences between certain design changes which had not been communicated between different team subsystems. A great benefit early on in the project, after preliminary aircraft design research has been conducted, would be to create a flowchart detailing subsystem interactions. This would ensure that whenever a subsystem was considering a design change, they would be able to track the effects of this change across the entire aircraft design, and would be able to discuss further changes with any other affected subsystem(s).

Mentioned earlier, the aircraft was unsuccessful in completing the flight course in competition. There were a number of design changes that were realized during the competition which could not be changed, but provide greater insight into our team's design flaws. The lack of stability due to the aircraft's tail was most evident. A larger chord length on the tail would have resulted in more stability, which was clearly needed after unsuccessful flight attempts at competition. In addition, another tail modification that would enhance the aircraft's stability would be to extend the elevator chord length. This was initially considered in the aircraft design prior to competition, but was avoided due to penalties associated with design changes occurring close to the competition.

The team faced issues with the aircraft's loaded center of gravity during competition, and despite the aircraft gaining lift, it was often too late, and found the aircraft pitching up and landing on its tail. The aircraft was more tail heavy than anticipated in our theoretical calculations, which was likely due to the 3D printed tail bracket introduced later in the design phase. Concerning the overall aircraft design, the team received praise at the competition for keeping a conventional aircraft design rather than an experimental one. This is generally recommended for teams, as it simplifies the aircraft stability/controls and fabrication processes that are vital for creating an aircraft that is relatively simple to build and fly.

During powered testing, the team faced issues of certain vital components of the aircraft fracturing, rendering control surfaces inoperable and crippling structural components. A recommendation for the structure/fabrication team is to make the aircraft modular wherever possible. If multiple parts can be laser cut/printed and swapped out following a damaging crash, this would save the fabrication team a significant amount of time which would be better spent performing testing than waiting for glued parts to set. To further improve flight dynamics and ensure that the aircraft has high performance metal geared servos and paying attention to servo temperature. It was noticed that the gears on the plastic servo would melt or wear down quickly with heavy use.

5.4 Project Broader Impacts

Despite the fact that the SAE competition imposes specific design rules leading to a niche aircraft design, there are certain practical applications of this aircraft design. Certain aspects of society could benefit from such a design, through its ability to carry sizable payload, takeoff quickly, and do so consuming minimal power.

One of the primary goals of this aircraft per design requirements was to create an aircraft that could takeoff in a short distance, similar to a bush plane. The ability for an aircraft to take off in such a small distance could have many practical applications in difficult terrain where a long distance runway isn't feasible. This could have applications for various payload delivery devices, both for military application and private industry usage.

Additionally, the team designed the aircraft to minimize empty weight wherever feasible to optimize aircraft payload delivery for this short runway. Numerous civilian and military applications rely on this weight reduction for optimizing payload to weight ratios. Various payloads could be used, such as containers holding medical devices, imaging equipment for surveillance, and even a modified payload bay to drop care packages. Overall similar aircraft to our designs have the ability to emphasize smart and quick payload delivery to targets in environments which would be unsuitable for traditionally designed aircraft to navigate in and out of.

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Appendices

Appendix A. Complete SAE AeroDesign Rules

2022 Collegiate Design Series
SAE Aero Design Rules

Version 2022.0

Forward

Welcome to SAE Aero Design 2022! Our mission is to provide students with real-world engineering experience through aircraft design challenges.

This year we continue to face additional challenges from the global COVID-19 pandemic. The SAE student competition community is working together to develop an operational plan that will maintain our mission and account for participant's health and complying with local laws and best practices. As we continue to adapt, several elements of the 2021 competition season will be carried over into our operations. For example, we will continue the virtual presentations, which has allowed us greater freedom in scheduling. Our goal is to leverage virtual tools to provide a meaningful competition experience for all teams and do our best to execute a safe flyoff for teams who will be able to participate.

Our goal for this year's changes to the Advanced class is to promote trade studies and model-based system engineering on a technical project that will challenge teams to explore the design space using model-based system engineering and modelling techniques. The mission for 2022 is modeled on combatting wildfires in remote locations, assisting the firefighting crews on the ground. This year, in the spirit of moving toward greater autonomy, teams will deploy powered aircraft carrying parts for a ground rover to autonomously land in designated landing zones. To encourage dependence on model-based systems engineering techniques, teams will influence their own scoring by providing a landing accuracy probability distribution function. The primary aircraft acts as an airborne water resupply. At the end of the competition, the teams who have delivered full ground vehicles will participate in a demonstration event to transport all of the water flown by the primary aircraft across an obstacle course for more points.

Regular class continues with the same mission from 2019-2020: a bush plane to deliver outsized spherical cargo as well as regular boxed cargo, while using short runways. The tradeoff between the two payloads and their follow-on impact to performance provides a wide range of challenges and potential solutions.

Micro class rules remain unchanged, whereby micro class aircraft deliver boxes and weights when launch from a small, raised platform and speed-run to the first turn. This encourages trades between static and dynamic thrust as well as narrow structural margins in favor of scoring potential.

The Rules Committee is looking forward to the evolution of the competition that this year will bring. Each year we review your feedback from the post-event surveys, forums, and in-person comments to guide our decision making, especially now. Please read these rules carefully. Please watch the website and SAE Aero Design App for announcements on operations. Finally, please make use of the Aero Design question and answer forum to resolve questions.

Everyone at SAE Aero Design wishes all teams the best of luck for Aero Design 2022!

- *SAE Aero Design Rules Committee*

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1 COMPETITION REQUIREMENTS

1.1 INTRODUCTION

Official Announcements and Competition Information

The SAE Aero Design competition is intended to provide undergraduate and graduate engineering students with a real-world design challenge. These rules were developed by industry professionals with a focus on educational value and hands-on experience. These rules were designed to compress a typical aircraft development program into one calendar year, following the early development phase of system engineering and requirements derivation. This competition will expose participants to the nuances of conceptual design, manufacturing, system integration/test, and verification through demonstration.

SAE Aero Design features three classes of competition—Regular, Advanced, and Micro.

1. **The Regular Class** is an all-electric class intended to develop a fundamental understanding of aircraft design.
2. **The Advanced Class** is an all-electric class designed to inspire future engineers to take a systems approach to problem solving, at the same time, exposing them to explore the possibilities of autonomous flights.
3. **The Micro Class** is an all-electric class designed to help students balance trades studies between multiple conflicting requirements. e.g. carrying the highest payload fraction possible, while simultaneously pursuing the lowest empty weight possible.

Other SAE Aero Design Competitions:

SAE BRASIL http://www.saebrasil.org.br

1.2 SAE AERO DESIGN RULES AND ORGANIZER AUTHORITY

General Authority

SAE International and the competition organizing bodies reserve the rights to revise the schedule of any competition and/or interpret or modify the competition rules at any time and in any manner, that is, in their sole judgment, required for the efficient and safe operation of the event or the SAE Aero Design series.

Penalties

SAE International and the competition organizing bodies reserve rights to modify the points and/or penalties listed in the various event descriptions; to accurately reflect the operations execution of the events, or any special conditions unique to the site.

Rules Authority

The SAE Aero Design Rules are the responsibility of the SAE Aero Design Rules Committee and are issued under the authority of the SAE Collegiate Design Series. Official announcements from the SAE Aero Design Rules Committee, SAE International or the other SAE International Organizers shall be considered part of and have the same validity as these rules. Ambiguities or questions concerning the meaning or intent of these rules will be resolved by the officials, SAE International Rules Committee or SAE International Staff.

Rules Validity

The SAE Aero Design Rules posted at www.saeaerodesign.com/go/downloads and dated for the calendar year of the competition are the rules in effect for the competition. Rule sets dated for prior competition years are invalid.

Rules Compliance

By entering an SAE Aero Design competition, the team members, Faculty Advisors and other personnel of the entering university agree to comply with, and be bound by, the rules and all rules interpretations or procedures issued or announced by SAE International, the SAE Aero Design Rules Committee and other organizing bodies. All team members, Faculty Advisors and other university representatives are required to cooperate with and follow all instructions from Competition Organizers, officials, and judges.

Understanding the Rules

Teams are responsible for reading and understanding the rules in their entirety for the competition in which they are participating. The section and paragraph headings in these rules are provided to facilitate reading: they do not affect the paragraph contents.

Loopholes

It is virtually impossible to anticipate a comprehensive design space that covers all possibilities and potential questions about the aircraft's design parameters or the conduct of the competition. Please keep in mind that safety remains paramount during any SAE International competition, so any perceived loopholes should be resolved in the direction of increased safety/concept of the competition. When in doubt, please contact the SAE Aero Design Rules Committee, using the FAQ forum, early to avoid design impacts at competition.

Participating in the Competition

Teams, team members as individuals, Faculty Advisors and other representatives of a registered university who are present on-site at a competition are considered to be "participating in the competition" from the time they arrive at the event site until they depart the site at the conclusion of the competition or earlier by withdrawing.

Visa--United States Visas

Teams requiring visas to enter to the United States are advised to apply at least sixty (60) days prior to the competition. Although most visa applications seem to go through without an unreasonable delay, occasionally teams have had difficulties and, in several instances, visas were not issued before the competition.

AFFILIATED CDS STUDENT TEAM MEMBERS WILL HAVE THE ABILITY TO PRINT OUT A REGISTRATION CONFIRMATION LETTER FOR THE INDIVIDUAL EVENT(S) THAT THEY ARE ATTENDING. ONCE A STUDENT TEAM MEMBER AFFILIATES THEMSELVES TO THEIR TEAM PROFILE PAGE UNDER THEIR INDIVIDUAL EDIT SECTION, THEY WILL HAVE THE OPPORTUNITY TO PRINT OUT THEIR

PERSONALIZED LETTER WITH THE FOLLOWING INFORMATION: STUDENT'S NAME, SCHOOL'S NAME, THE CDS EVENT NAME, OFFICIAL DATES AND LOCATION(S).

Letters of Invitation

Neither SAE International staff nor any Competition Organizers are permitted to give advice on visas, customs regulations or vehicle shipping regulations concerning the United States or any other country.

Certificates of Participation

SAE International and Competition Organizers do not create any Participation Certificates outside of the auto-generated certificate on your team profile page at sae.org.

Certificates are available as soon as students are affiliated to the current competition's team. Certificates will not be available once that competition year closes.

Violations of Intent

The violation of the intent of a rule will be considered a violation of the rule itself. Questions about the intent or meaning of a rule may be addressed to the SAE International Officials, Competition Organizers or SAE International Staff.

Right to Impound

SAE International and the other competition organizing bodies reserve the right to impound any on-site vehicle/aircraft at any time during a competition for inspection and examination by the Competition Organizers, officials, and technical inspectors.

1.3 SOCIETY MEMBERSHIP AND ELIGIBILITY

Society Membership

Individual team members must be members of SAE International or an SAE International affiliate society. Proof of membership, such as a membership card, is required at the event. Students may join online at: https://www.sae.org/participate/membership/join

Teams are also required to read the articles posted on the SAE Aero Design News Feed (www.saeaerodesign.com/go/news) published by SAE International and the other organizing bodies. Teams must also be familiar with all official announcements concerning the competition and rule interpretations released by the SAE Aero Design Rules Committee.

Team Pilots

Team pilots are not required to be students or SAE International members; however, all pilots must be current members of the Academy of Model Aeronautics or the Model Aircraft Association of Canada (AMA has an agreement with MAAC). Valid AMA membership cards must be presented at the flying field prior to flying any team's aircraft. Non-US pilots can obtain a discounted AMA Affiliate membership that covers flying activities while in the US by going to the AMA web site and submitting the following form: https://www.modelaircraft.org/files/902.pdf.

1.4 LIABILITY WAIVER AND INSURANCE REQUIREMENTS

All on-site participants and Faculty Advisors are required to sign a liability waiver which is part of their Fast-Track Registration Form that can be printed off their team registration page. Individual medical and accident insurance coverage is the sole responsibility of the participant.

1.5 RINGERS PROHIBITED

In order to maintain the integrity of the competition, the Faculty Advisor must prohibit ringers. A ringer is someone that has exceptional skills related to the competition (e.g., a professional model builder) that cannot be a legal member of the team but helps the team win points.

1.6 DESIGN AND FABRICATION

The aircraft must be designed and built by the SAE International student members without direct involvement from professional engineers, radio control model experts, pilots, machinists, or related professionals. The students may use any literature or knowledge related to R/C aircraft design and construction and information from professionals or from professors, as long as the information is given as discussion of alternatives with their pros and cons and is acknowledged in the references in the design report. Professionals may not make design decisions, nor contribute to the drawings, the report, or the construction of the aircraft. The Faculty Advisor must sign the Statement of Compliance given in the Appendix.

1.7 ORIGINAL DESIGN

Any aircraft presented for competition must be an original design whose configuration is conceived by the student team members. Photographic scaling of an existing model aircraft design is not allowed. Use of major components such as wings, fuselage, or empennage of existing model aircraft kits is prohibited. Use of standard model aircraft hardware such as motor mounts, control horns, and landing gear is allowed.

1.8 OFFICIAL LANGUAGES

The official language of the SAE Aero Design series is English. Document submissions, presentations and discussions in English are acceptable at all competitions in the series.

Team members, judges and officials at Non-U.S. competition events may use their respective national languages for document submissions, presentations and discussions if all the parties involved agree to the use of that language.

1.9 UNIQUE DESIGNS

Universities may enter more than one team in each SAE Aero Design competition, but each entry must be a unique design, significantly different from each other. If the aircraft are not significantly different in the opinion of the Rules Committee and Organizer, then the university will be considered to have only a single entry and only one of the teams and its aircraft will be allowed to participate in the competition. For example, two aircraft with identical wings and fuselages but different empennage would likely not be considered significantly different. For guidance regarding this topic, please submit a rules question at www.saeaerodesign.com.

1.10 AIRCRAFT CLASSIFICATION/DUPLICATE AIRCRAFT

1. **One Team Entry per Class**
   A university is limited to registering one team per class.
2. **Backup Aircraft**
   When a team has an identical aircraft as a back-up, the back-up aircraft must go through inspection with the primary aircraft.

1.11 AIRFRAME ELIGIBILITY

Airframes will only be allowed to compete during a ***single academic year***. An airframe may be entered in both SAE Aero Design East and SAE Aero Design West during the same *calendar year*, but that same airframe may not be used in either competition during the following year. Entering the same airframe in SAE Aero Design West one year and SAE Aero Design East the next year is not allowed.

An airframe is considered entered to competition during an academic year once documentation on the design is submitted. If the airframe does not fly at competition during that same academic year, the airframe is not eligible for competition during future academic years.

The airframe must have been designed within eleven (11) months of competition and constructed within nine (9) months of competition. The airframe is defined as the fuselage, wings, and tail.

1.12 REGISTRATION INFORMATION, DEADLINES AND WAITLIST

Teams intending to participate in the 2022 SAE Aero Design competitions must register their teams online per the open registration schedule shown in Table 1.1.

Table 1.1 Open Registration Schedule

Event	***Start (Open)***	***End (Closed)***
Registration Window	September 13, 2021 10:00 AM EDT	November 1, 2021 11:59 PM EST

The registration fee is non-refundable and failure to meet these deadlines will be considered a failure to qualify for the competition. Separate entry fees are required for the events.

Team/Class/University Policy

A university or college can only have one aircraft registered per class. A university cannot register more than one team per class. The registration fees indicated on the website must be paid within 48 hours of registration to be eligible.

Individual Registration Requirements – ACTION REQUIRED

A team member must be enrolled as degree seeking undergraduate or graduate student in the college or university of the team with which they are participating. Team members who have graduated during the seven-month period prior to the competition remain eligible to participate.

All participating team members and Faculty Advisors must be sure that they are individually affiliated to their respective school / university on the SAE International website (www.sae.org) Team Profile page.

If you are not an SAE International member, go to www.sae.org and select the “Membership” link. Students will need to select the “Student Membership” link and then follow the series of questions that are asked. Please note: all student participants must be members of one of the organizations listed in Section 1.3 to participate in the events.

Faculty members who wish to become SAE International members should choose the “Professional Membership” link. Please note: this is not mandatory for Faculty Advisors.

All student participants and Faculty Advisors must affiliate themselves to the appropriate team(s) online.

The “Add New Member” button will allow individuals to access this page and include the necessary credentials. If the individual is already affiliated to the team, simply select the Edit button next to the name. Please be sure this is done separately for each of the events your team has entered.

All students, both domestic and international, must affiliate themselves online prior to the competition.

Each team member may participate for only one team. If the university or college is entering multiple classes, team members must choose only one team to affiliate with and participate in the competition with. For example, students cannot compete as part of a Micro class team and an Advanced class team.

Pre-Registration Information

SAE will not be utilizing the pre-registration process for 2022. Teams who wish to participate should be prepared to register during the normal registration window.

****NOTE: When your team is registering for a competition, only the student or Faculty Advisor completing the registration needs to be linked to the school. All other students and faculty can affiliate themselves after registration has been completed; however, this must be completed no later than two weeks before the competition start date.**

1.13 WAITLIST

Once an event reaches the venue’s capacity, all remaining registered team(s) will be asked to be placed on a waitlist. The waitlist is capped at 40 available spaces per event and will close on the same day as registration closes. Once a team withdraws from an event, an SAE International Staff member will inform your team by email (the individual who registered the team to the waitlist) that a spot on the registered teams list has opened. You will have 24 hours to accept or reject the position and an additional 24 hours to have the registration payment completed or process for payment begun. Waitlisted teams are required to submit all documents by the deadlines to be considered serious participants and any team that does not submit all documents will be removed from the waitlist.

1.14 POLICY DEADLINE

Failure to meet deadlines

Teams registering for SAE Aero Design competitions are required to submit several documents prior to the competition including a Design Report and Technical Data Sheet that the event judges use to evaluate the team during the competition. When these documents are not submitted, judges cannot accurately assess the team. Additionally, teams that do not submit required documents typically do not come to the competition. Teams that do not notify us that they are withdrawing create the following problems:

- They are included in the static event schedules and judging time is wasted.
- Their unused registration slot cannot be offered to a team on the waitlist. Additionally, failure to submit the required documents is a clear violation of the rules.

Late Submission Penalty

Late submission or failure to submit the Design Report by the deadline will be penalized five (5) points per day. If your required documents are received more than five (5) days late, the documents will be classified as “Not Submitted” and your team will not be allowed to participate. Additionally, the automatic withdrawal policy will be in effect.

Automatic Withdrawal Policy

Failure to submit the required Design Report, Technical Data Sheet, and Drawings within five (5) days of the deadline will constitute an automatic withdrawal of your team. Your team will be notified before or on the 4th day of no submission that we have not received your documents and after the 5th day your team’s registration will be canceled, and no refund will be given.

1.15 FACULTY ADVISOR

Each team is expected to have a Faculty Advisor appointed by the university. The Faculty Advisor is expected to accompany the team to the competition and will be considered by competition officials to be the official university representative. Faculty Advisors may advise their teams on general engineering and engineering project management theory but may not design any part of the vehicle nor directly participate in the development of any documentation or presentation. Additionally, Faculty Advisors may neither fabricate nor assemble any components nor assist in the preparation, maintenance, or testing of the vehicle. In brief, Faculty Advisors may not design, build, or repair any part of the aircraft. Faculty Advisors that are not eligible student team members may not participate in flight operations during competition weekend except as noted.

1.16 QUESTIONS, COMPLAINTS AND APPEALS

Questions

Any questions or comments about the rules should be brought to the attention of the Rules Committee by submitting a rules question at https://www.saeaerodesign.com.

General information about hotels and other attractions in the area, as well as a schedule of events, will be posted on the SAE International website according to the competition in which you are competing: https://www.sae.org/attend/student-events/

Complaints

Competition officials will be available to listen to complaints regarding errors in scoring, interpretation, or application of the rules during the competition. Competition officials will not be available to listen to complaints regarding the nature, validity, or efficacy of the rules themselves at the competition. In other words, the Organizer will not change the rulebook at the field, unless the safety of the competition requires updates.

Appeal / Preliminary Review

A team can only appeal issues related to scoring, judging, venue policies, and/or any official actions *regarding their own team*. Team Captain(s) and/or Faculty Advisor must bring the issue to the Organizer's or SAE International staff's attention for an informal preliminary review before filing an official appeal.

A team cannot file an appeal to cause harm to another team's standing and/or score.

Cause for Appeal

A team may appeal any rule interpretation, own-team scoring or official actions which the team feel has caused some actual, non-trivial, harm to own-team, or has had a substantive effect on their score.

Teams may not appeal rule interpretations or actions that have not caused the team any substantive damage.

Appeal Format

If a Faculty Advisor or Team Captain(s) feel that their issue regarding an official action or rules interpretation was not properly addressed by the **event officials**, the team may file a formal appeal to the action or rules interpretation with the Appeals Committee.

All appeals must be filed in writing (see Appendix D) to the Organizer by the Faculty Advisor or Team Captain(s) only.

All appeals will require the team to post twenty-five (25) points as collateral. If the appeal is successful and the action is reversed, the team ***will not*** forfeit the twenty-five (25) collateral points. If the appeal is overruled, the team will forfeit the twenty-five (25) collateral points.

All rulings issued by the Appeals Committee are final.

Appeals Period

All appeals must be submitted within thirty (30) minutes of the end of the flight or other competition event to which the appeal relates.

Appeals Committee

When a timely appeal is received, the committee will review the claims. All contentions or issues raised in the formal appeal will be addressed in a timely manner. The consideration in each review is whether the actions in dispute were just and in-line with the intent of the rules. Once the review is completed, a new order will be issued affirming, reversing, or modifying the original determination.

All rulings issued by the Appeals Committee are final.

The Appeals Committee must consist of a minimum of three members: the Organizer or delegate, SAE International representative, and either the Chief Steward, the Chief Judge, the Air Boss and/or Rules Committee member.

1.17 PROFESSIONAL CONDUCT

Unsportsmanlike Conduct

In the event of unsportsmanlike conduct by team members or a team's Faculty Advisor, the team will receive a warning from a Competition Official A second violation will result in expulsion of the team from the competition and loss of any points earned in all aspects of the competition.

Arguments with Officials

Arguments with or disobedience toward any competition official may result in the team being eliminated from the competition. All members of the team may be immediately escorted from the grounds.

Alcohol and Illegal Material

Alcoholic beverages, illegal drugs, firearms, weapons, or illegal material of any type are not permitted on the event sites at any time during the competition. Any violations of this rule will result in the immediate expulsion of all members of the offending school, not just the team member(s) in violation. This rule applies to team members and Faculty Advisors. Any use of illegal drugs or any use of alcohol by an underage person must be reported to the local law enforcement authorities for prosecution.

Organizer's Authority

The Organizer reserves the exclusive right to revise the schedule of the competition and/or to interpret the competition rules at any time and in any manner required for efficient operation or safety of the competition.

Ground Safety and Flight Line Safety Equipment

- No open toe shoes allowed. All team participants, including Faculty Advisors and pilots, are required to wear CLOSED toe shoes during flight testing and during flight competition.
- Smoking is prohibited. Smoking is prohibited in all competition areas.
- Personal Protective Equipment required. All students involved in flight-line launch and recovery operations for all aircraft classes must wear safety glasses.
- Laser Pointers are prohibited. No visible light laser pointers may be used for any reason.

1.18 SAE TECHNICAL STANDARDS ACCESS

A cooperative program of SAE International's Education Board and Technical Standards Board is making some of SAE International's Technical Standards available to teams registered for any North American CDS competition at no cost. The Technical Standards referenced in the Collegiate Design Series rules, along with other standards with reference value, will be accessible online to registered teams, team members and Faculty Advisors.

2 GENERAL AIRCRAFT REQUIREMENTS

2.1 AIRCRAFT IDENTIFICATION

Team number as assigned by SAE International must be visible on both the top and bottom of the wing, and on both sides of the vertical stabilizer or other vertical surface.

1. Aircraft must be identified with the school name, mailing address, and email address either on the outside or the inside of the aircraft.
2. Team numbers on Regular aircraft shall be a minimum of 3 inches in height.
3. Team numbers on the Advanced Class primary aircraft shall be a minimum of 3 inches in height. Team numbers on the Advanced Class Powered Autonomous Delivery Aircraft (PADA) shall be a minimum of 1 inch in height.
4. Team numbers on Micro Class shall be a minimum of 1 inch in height.
5. The University name must be clearly displayed on the wings or fuselage.
6. The University initials may be substituted in lieu of the University name provided the initials are unique and recognizable.

The assigned aircraft numbers appear next to the school name on the "Registered Teams" page of the SAE Aero Design section of the Collegiate Design Series website at:

SAE Aero East: https://www.sae.org/attend/student-events/sae-aero-design-east

SAE Aero West: https://www.sae.org/attend/student-events/sae-aero-design-west

2.2 PROHIBITED AIRCRAFT CONFIGURATION

Competing designs are limited to fixed wing aircraft only. Lighter-than-air aircraft, rotary wing aircraft such as helicopters or auto-gyros and steerable parafoil aircraft are not allowed to compete.

2.3 EMPTY CG DESIGN REQUIREMENT AND EMPTY CG MARKINGS ON AIRCRAFT

All aircraft must meet the following Center of Gravity (CG) related requirements:

1. All aircraft must be flyable at their designated Empty CG position (no payload, ready to fly) on the submitted 2D aircraft drawing.
2. All aircraft must have the fuselage clearly marked on both sides with a classic CG symbol (Figure 2.1) that is a minimum of 0.5 inches in diameter centered at the Empty CG position +/-0.25 inches, per the submitted 2D drawings. (Wing type aircraft may place the two CG markings on the bottom of the wing.)
3. The Empty CG location will be verified during Technical and Safety Inspection.
4. No empty weight flight is required.

Figure 2-1 – Center of Gravity Symbol

2.4 GROSS WEIGHT LIMIT

Aircraft gross take-off weight may not exceed fifty-five (55) pounds.

2.5 CONTROLLABILITY

- All aircraft must be controllable in flight.
- If an aircraft is equipped with a wheeled landing gear, the aircraft must have some form of ground steering mechanism for positive directional control during takeoffs and landings. Aircraft may not rely solely on aerodynamic control surfaces for ground steering.

2.6 RADIO CONTROL SYSTEM

The use of a 2.4 GHz radio control system is required for all aircraft. The 2.4 GHz radio control system must have a functional fail-safe system that will reduce the throttle to zero **immediately** if the radio signal is lost. Teams may have to reset the default on the fail-safe to meet this requirement.

2.7 SPINNERS OR SAFETY NUTS REQUIRED

All powered aircraft must utilize either a spinner or a rounded model aircraft type safety nut. Nylon-insert Lock-Nuts are prohibited. See Figure 2-2 for examples of acceptable hardware.

Figure 2-2 - Spinners and Safety Nut

2.8 METAL PROPELLERS

Metal propellers are not allowed.

2.9 LEAD IS PROHIBITED

The use of lead in any portion of aircraft (payload included) is strictly prohibited.

2.10 PAYLOAD DISTRIBUTION

The payload cannot contribute to the structural integrity of the airframe, meaning, the airframe must be able to fly without the payload installed.

2.11 STATIC PAYLOAD PLATE ATTACHMENT

All static payload plates must be secured with metal hardware that penetrates all payload plates. Payload plates must also be secured to the aircraft structure with metal hardware as a single mass inside the designated payload bay, as defined by each class.

2.12 AIRCRAFT BALLAST

Aircraft ballast is allowed. Ballast cannot be in the payload bay and must be properly secured.

2.13 CONTROL SURFACE SLOP

Aircraft control surfaces and linkages must not feature excessive slop. Sloppy control surfaces lead to reduced controllability in mild cases, or control surface flutter in severe cases.

2.14 SERVO SIZING

Analysis and/or testing must be described in the Design Report that demonstrates the servos are adequately sized to handle the expected aerodynamic loads during flight.

2.15 CLEVIS KEEPERS

All control clevises must have additional mechanical keepers to prevent accidental opening of the control clevis in flight.

2.16 STORED ENERGY RESTRICTION

Aircraft must be powered by the motor on board the aircraft. No other internal and/or external forms of stored potential energy allowed to include rubber bands and pressure vessels like CO2 cartridges.

2.17 BATTERY PACK RESTRICTIONS

- All Batteries must be commercially available. Homemade batteries are not allowed.
- All batteries in the aircraft must be positively secured so that they cannot move under normal flight loads.
- The battery bay or location in the aircraft must be free of any hardware or other protrusions that could penetrate the battery in the event of a crash.

2.18 POWER LIMITER

Some classes require the use of a third-party electronic device to limit the amount of power the propulsion system can use. The official supplier for this part is Neumotors.com. The supplier has agreed to ship worldwide to any team. The limiters are only available at the follow link:

https://neumotors.cartloom.com/storefront/category/student-contests-sae-dbf

- Repair and/or modifications to the limiter are prohibited.
- The limiter must be fully visible and easy to inspect.
- Only battery, receiver, speed control, arming plug, and limiter are allowed within the power circuit.

2.19 RED ARMING PLUG

All electric powered aircraft MUST use a discrete and removable red arming plug to arm and disarm the aircraft propulsion system. This red arming plug must be integrated into the electrical circuit between the battery and the electronic speed controller (ESC).

1. The red arming plug must be located on the positive (**RED**) wire between the battery and the power limiter.
2. The red arming plug must be located on top of the aircraft at least 12" behind or in front of the rotational plane of the propeller for Regular and Advanced class Primary Aircraft and at least 6" behind or in front of the rotational plane of the propeller for Micro class and Advanced class PADAs. This allows arming and disarming the aircraft at a safe distance from the propeller. Reaching through the arc of the propeller at any time is strictly prohibited.
3. The red arming plug must be located on top of the fuselage or wing and external to the aircraft surface.
4. The location of the red arming plug must be clearly visible.
5. The non-removable portion of the arming plug interface may not have more than one male lead.
6. Disconnecting wiring harnesses to arm and disarm a system will NOT be allowed.

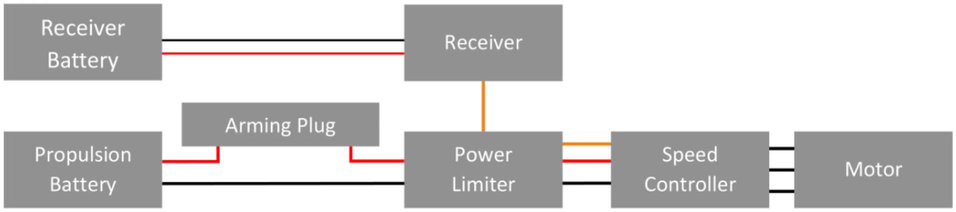


Figure 2-3: Example diagram of propulsion system with Arming Plug and Power Limiter. Note, different classes may have additional requirements, or allow for alternative configurations.

2.20 REPAIRS, ALTERATIONS, AND SPARES

1. The original design of the aircraft as presented in the written and oral reports must be maintained as the baseline aircraft during the competition.
2. In the event of damage to the aircraft, the aircraft may be repaired provided such repairs do not drastically deviate from the original baseline design. All major repairs must undergo safety inspection before the aircraft is cleared for flight.

2.21 ALTERATION AFTER FIRST FLIGHT

Minor alterations are allowed after the first and subsequent flight attempts.

1. A penalty will be assessed ONLY if 2/3 of the ruling committee (Event Organizer, Head scoring judge and/or SAE staff judge) agree that there were significant modifications made from the baseline configuration.
2. If the ruling committee determines that the changes are a result of safety-of-flight, the changes will not incur penalty points. Alteration must be reported utilizing Engineering Change Request (ECR) Appendix B.

3 MISSION REQUIREMENTS AND SCORING

3.1 AIR BOSS

The Air Boss is a qualified SAE event official or appointed volunteer that manages the flight line process. Their responsibilities include:

1 Ensure the safety of the flight line through maintaining an orderly and controlled runway.
2 Be the official of record for the success or failure or the aircraft's flight, including takeoff and landing.
3 Declare termination of flight at any time during the attempt.
4 Air Boss, or event organizers, may continue flight operations at their discretion in continuous winds up to 45 knots with gusts no greater than 65 knots.

3.2 PILOT STATION(S)

Pilot area will be defined at pre-competition meeting (Friday Night All-hands). All pilots must fly from designated area.

3.3 FLIGHT ATTEMPT

Teams are allowed one (1) flight per attempt. There is no fixed or guaranteed number of flights. The number of flights possible will depend on local conditions.

- **Regular and Advanced Classes:** Without violating other take-off restrictions, a team can have multiple attempts to become airborne within the team's prescribed time limit for each respective class identified in Section 3.8.
- **Micro Class:** only one launch attempt is allowed per flight attempt.

3.4 MOTOR RUN-UP BEFORE TAKE-OFF

For all competition classes the aircraft may be throttled-up/run-up for take-off, subject to the following conditions:

- One (1) team member is allowed to hold the aircraft in place prior to take-off roll.
- The aircraft holder may not push the aircraft on release.
- **Regular Class Only:** the main gear must remain on the take-off line prior to release.

3.5 AIRCRAFT CONFIGURATION AT LIFTOFF AND DURING THE FLIGHT ATTEMPT

The aircraft must remain intact during a flight attempt to receive full flight score. A flight attempt includes activities at the starting line, the take-off roll, take-off, flight, landing and recovery after landing.

A twenty-five percent (25%) deduction from the flight score will be assessed if any of the following items are observed to completely detach from the aircraft during a flight attempt.

- Stickers
- Tape
- Coverings

Except for a broken prop during landing, if any other components fall off the during a flight attempt, the flight will be disqualified.

3.6 COMPETITION CIRCUIT REQUIREMENTS

1. During departure and approach to landing, the pilot must not fly the aircraft in a pattern that will allow the aircraft to enter any of the no-fly zones.
2. No aerobatic maneuvers will be allowed at any time during the flight competition in any competition class. This includes but not limited to: loops, figure 8's, Immelmann, all types of rolling maneuvers and inverted flight.
3. Regular and Micro Class aircraft must successfully complete a minimum of one 360° circuit. See Table 3.2 for additional information.
4. Advanced Class has no specific flight pattern. (See Advanced Class rules for details concerning the releasable payload drop mission element.)

3.7 TIME LIMITS AND MULTIPLE FLIGHTS ATTEMPTS

- Multiple takeoff attempts are allowed within the class-specific time allotment as long as the aircraft has NOT become airborne during an aborted attempt. Refer to Table 3.1 for additional information regarding multiple takeoff attempts.
- If an airborne aircraft returns to the ground after being airborne and is beyond the take-off limits, the flight attempt will be disqualified.

Table 3.1: Flight Attempt Information

Class	**Time Limit (sec)**	**Can make multiple take-off attempts if:**			**Take-off Attempt is defined as the point at which:**
		Still within the Time Limit	Bounce within required take-off distance	Bounce outside the required take-off distance	
Regular	120	Yes	Yes	No	The main wheels leave the starting line
Advanced	180	Yes	Yes	No	The aircraft moves forward under its own power
Micro	60	No	No	No	Aircraft moves forward under its own power

3.8 TAKE-OFF

Take-off direction will be determined at the discretion of the Air Boss. If possible, the take-off direction will face into the wind. Changes in wind direction, in light and variable winds, may affect the take-off direction throughout the day. SAE Aero Design reserves the right to change the take-off direction at any time for weather or safety reasons.

1. Regular and Advanced Class aircraft must remain on the runway during the take-off roll.
2. Micro Class must be launched in accordance with section 9.4 from the designated launch area.
3. Distance requirements are defined in Table 3.2.
4. Making the initial turn before passing the "distance from initial start before turn" requirement will disqualify that flight attempt.

Table 3.2: Take-off Information

Class	Take-Off Distance Limits (ft.)	Distance from initial start before turn (ft.)	Description
Regular	100 ft.	400 ft.	Aircraft must be airborne within the prescribed take-off distance.
Advanced	None	None	Aircraft will have the full use of the runway.
Micro	See Section 9.4	See Section 9.6	Team may use the entire launch area per attempt to get the aircraft airborne. Only one (1) launch release per flight attempt is allowed.

3.9 LANDING REQUIREMENTS

A successful landing is defined as a controlled return to the ground. Aircraft must remain inside the specified landing zone for each class. The airplane may leave the landing zone only if given permission by the Air Boss.

The landing zone is a pre-determined fixed area for each class for the purpose of returning a flying aircraft to the ground. See Table 3.3 for class requirements.

1. The landing zones will be visibly marked at the site prior to the start of competition.
2. It is the team and team pilot's responsibility to be aware of the class-specific landing zone dimensions at the event site.
3. Any aircraft that leaves their designated landing zone or the paved runway for any reason during landing are subject to a penalty of fifty percent (50%) of any points earned during the flight prior to landing.
4. Any flight where the aircraft does not make the initial touch down for landing inside the designated landing zone is disqualified.
5. Touch-and-go landings are not allowed and will be judged as a failed landing.
6. The criterion for being within the landing zone is that no supporting part of the aircraft that is touching the ground can be outside the landing zone. For example, a

wing tip or fuselage can overhang the edge of the landing zone, as long as no supporting part of the aircraft is physically touching outside the landing zone.

Table 3.3: Landing Distance Limit

Class	Landing Distance Limits (ft.)	Description
Regular	400 ft.	Aircraft must land in the same direction as take-off and stop within the designated landing zone.
Advanced	Available Runway	Aircraft must land in the same direction as take-off and stop within the designated landing zone.
Micro	200 ft.	Aircraft must land in the same direction as take-off and stop within the designated landing zone.

3.10 GROUNDING AN AIRCRAFT

1. An aircraft will be grounded if it is deemed non-flight-worthy or not in compliance with class rules by any SAE official, event official or a designated technical/safety inspector.
2. Until the non-flight-worthy or out of compliance condition has been addressed and has been cleared by re-inspection, the aircraft will not be allowed to fly in the competition.

3.11 NO-FLY ZONE

Each competition will have venue-specific **no-fly zones**. The no-fly zones will be defined during the all hands briefing at the event and during the pilot's briefings.

1. At no time will an aircraft enter the no-fly zones, whether under controlled flight or uncontrolled.
2. The first infraction for crossing into the no-fly zone will result in an invalidated flight attempt and zero points will be awarded for that flight.
3. A second infraction will result in disqualification from the entire event and loss of all points.
4. It is the team and team pilot's responsibility to be aware of the venue-specific no-fly zones and to comply with all venue specific rules.
5. If a team is unable to directionally control their aircraft and it is headed towards or is in a no-fly zone, the Judges and/or Air Boss may order the pilot to intentionally crash the aircraft to prevent it from endangering people or property. This safety directive must be followed immediately, if ordered by the officials.

3.12 FLIGHT RULES ANNOUNCEMENT

Flight rules will be explained before the flight competition begins, either during the pilots' meeting or during activities surrounding the technical inspections and oral presentations.

3.13 FLIGHT RULES VIOLATIONS

1. Violation of any flight rule may result in the team being eliminated from the competition.
2. All members of an eliminated team may be escorted from the grounds.

3.14 LOCAL FIELD RULES

In addition to competition rules, the local flying club may have additional rules in place at the event flying field.

1. Club rules will be obeyed during the flight competition.
2. If club rules conflict with competition rules, it is the responsibility of the Team Captain(s) and/or Faculty Advisor to bring attention to the conflict and follow the appeals process to resolve the conflict.

3.15 COMPETITION SCORING

A team's final, overall score is composed of scores in the following categories:

1. Technical Design Report (Design, Written and Drawing)
2. Presentation
3. Flight Score
4. Penalties

Any Penalty Points assessed during the competition will be deducted from a team's overall score.

3.16 AIRCRAFT EMPTY WEIGHT DEFINITION

All aircraft parts that are not payload, as defined in the relevant class's section, contribute to the empty aircraft weight, including, but not limited to: airframe, receiver, electronics, batteries, hardware, brackets, straps and other associated features.

4 DESIGN REPORT

The Design Report is the primary means in which a team conveys the story of how their aircraft is the most suited design to accomplish the intended mission. The Design Report should explain the team's thought processes and engineering philosophy that drove them to their conclusions.

Some topics that are important to cover are: selection of the overall vehicle configuration, wing planform design including airfoil selection, drag analysis including three-dimensional drag effects, aircraft stability and control, power plant performance including both static and dynamic thrust, and performance prediction. Other topics should be included as appropriate. See the SAE Aero Design Report Guidelines available at www.saeaerodesign.com/go/downloads for additional comments, suggested topics, and a suggested outline. For more information regarding performance prediction, a white paper by Leland Nicolai is also available at http://www.saeaerodesign.com/go/downloads

4.1 SUBMISSION DEADLINES

The Technical Design Report, 2D drawing, and supplemental Tech Data Sheet (TDS) must be electronically submitted to www.saeaerodesign.com no later than the date indicated on the Action Deadlines given on the SAE International Website:

https://www.sae.org/attend/student-events

Neither the Organizer nor the SAE International is responsible for any lost or misdirected reports, drawings, or server routing delays. The SAE International will not receive any paper copies of the reports through regular mail or email outside of the emergency submissions email.

4.2 ORIGINAL WORK

The Technical Design Report shall be the team's original work for the current competition year. Resubmissions of **previous and current** year's design reports will not be accepted. Recitation of previous year's work is acceptable **if and only if** appropriately cited and credited to the original author(s). Plagiarism is a forbidden industry and academic practice. All references, quoted text, and reused images from any source shall have appropriate citation within the text and within the Technical Design Report's Table of References, providing credit to the original author and editor.

Reports may be checked against **previous and current** years submissions to determine if re-use, copying, or other elements of plagiarism are indicated.

For the purposes of the SAE International Aero Design Competition, plagiarism is defined as any of the following:

1 Use of information from textbooks, reports, or other published material without proper citation

2 Use of sections or work from previous SAE Aero Design competitions without proper citation

If plagiarism is detected in the written report, a team will be given 24 hours to make a case to SAE and the SAE Aero Design Rules Committee. If the report and/or case is found to be insufficient, the team will receive zero score for the report. The team will be allowed to compete in all remaining categories of the competition but will not be eligible for awards. SAE also reserves the right to notify the University of the situation.

If plagiarism is detected in the oral presentation, team will receive zero score for the presentation. The team will be allowed to compete in all remaining categories of the competition but will not be eligible for awards. SAE also reserves the right to notify the University of the situation.

The SAE Aero Design Rules Committee & SAE International has the sole discretion to determine whether plagiarism is indicated, and the above rules are enacted. The above rules may be implemented at any time before, during, or for up to six (6) months after the competition event.

4.3 TECHNICAL DESIGN REPORT REQUIREMENTS

Technical Design Report will be 50 points (pts) of the competition score as broken down in Table 4.3.1.

- The Technical Design Report shall not exceed thirty (30) pages, including the certificate of compliance, 2D Drawing, and the Supplemental Datasheet for each class. If the design report exceeds thirty (30) pages, the judges will only score the first thirty (30) pages.
- The Technical Design Report shall include a Cover Page with Team Name, Team Number, and School Name and Team Member Names.
- The Technical Design Report shall include a Certificate of Compliance signed by hand by the team's Faculty Advisor.
- The Technical Design Report shall be typewritten and double-spaced. Tables, charts, and graphs are exempt from this. For single-spaced reports, only the first fifteen (15) pages will be scored by judges. All other content sections will receive a zero (0).
- The report font shall be 12 pt. proportional; or 10 char/in. non-proportional font.
- The report margins shall be: 1" Left, 0.5" right, 0.5" top, and 0.5" bottom.
- Each page, except the Cover Page, Certificate of Compliance, 2D Drawing and Technical Data Sheet (TDS) shall include a page number.
- All report pages shall be ANSI A (81/2 x 11 inches) portrait-format.
- The Technical Design Report shall include a Table of Contents, Table of Figures, Table of Tables, Table of References and Table of Acronyms.
- The Technical Design Report shall be single-column text layout.
- The Technical Design Report shall include one Technical Data Sheet (TDS) appropriate for the team's competition entrant class. The Technical Data Sheet (TDS) must include the Team Name, School Name, and Team Number.

Table 4.3.1 Technical Design Report

	Page Count	Regular Class	Advanced Class	Micro Class
Cover Page	1	40 pts	40 pts	40 pts
Certificate of Compliance	1			
Design Report	26			
2D Drawing	1	5 pts	5 pts	5 pts
TDS: Payload Prediction	1	5 pts	-	-
TDS: Powered Autonomous Delivery Aircraft 2D Drawing	1	-	5 pts	-
TDS: Vehicle Performance	1	-	-	5 pts
Total	**30**	**50 pts**	**50 pts**	**50 pts**

4.4 2D DRAWING REQUIREMENTS

2D Format and Size

The 2D drawing must be one (1) ANSI B sized page (PDF) format (11 x 17 inches).

1. For teams outside North America that cannot submit an ANSI B size drawing, page format size must be the closest size available to ANSI B.

Markings Required

The 2D drawing must be clearly marked with:

1. Team Number
2. Team Name
3. School Name

Views Required

Drawings shall include at a minimum, a standard aeronautical 3-view orthographic projection arranged as described:

1. **Left** side view, in lower left, with nose pointed left.
2. **Top** view, above and aligned with the left side view, also with nose pointed left (wing-span break-view permitted).
3. **Front** view aligned to side view, located in the lower right (projection view non-standard movement as noted by projection view arrows in accordance with ANSI-Y14.5M 1994).
4. **(Regular Class Only)** Regular Class shall include an additional view, separate from the basic aircraft, illustrating the fully loaded Cargo Bay with both Spherical Cargo and Regular Boxed Cargo. The longitudinal length of the Cargo Bay (Lcargo) must be detailed on the drawing.

Dimensions Required

Drawing dimensions and tolerance shall be in English units, decimal notation accordance with ANSI-Y14.5M 1994 to an appropriate level of precision to account for construction tolerances (allowable variation from analyzed prediction to account for fabrication) (i.e. X.X = ± .1 in; X.XX = ± .03 in; X.XXX = ± .010 in).

The minimum required dimensions/tolerances are: Aircraft length, width, and height.

Summary Data Required

The drawing shall contain a summary table of pertinent data to include but not limited to:

1. Wingspan
2. Empty weight
3. Battery(s) capacity
4. Motor make and model
5. Motor KV
6. Propeller manufacturer, diameter, and pitch
7. Servo manufacturer, model number and torque specification in ounce-inches for each servo used on the aircraft. Identify servo being used at each position on the aircraft.

Weight and Balance Information

The 2D drawing shall contain the following weight, balance, and stability information:

1. A clearly marked and labeled aircraft datum
2. A weight and balance table containing pertinent aircraft equipment. Each item listed must show its location from the aircraft datum in inches (the moment arm), the force, and resultant moment. See www.saeaerodesign.com/go/downloads for additional information. The minimum list of pertinent equipment includes:
   a. Motor
   b. Battery(s)
   c. Payload
   d. Electronics
3. Aircraft mean aerodynamic cord, stability margin and Center of Gravity (CG) information listed below must be clearly shown on drawing.
   a. Aircraft mean aerodynamic cord
   b. Stability margin for loaded CG and empty CG
   c. Empty CG location (flightworthy)
   d. Fully loaded CG (flightworthy, with payload, if applicable)

4.5 TECH DATA SHEET: PAYLOAD PREDICTION (REGULAR CLASS ONLY)

Regular Class must include a total payload prediction curve as part of the technical report. The graph represents an engineering estimate of the aircraft's lift performance based on density altitude.

1. Graph of payload weight shall be linearized over the relevant range.
2. The linear equation shall be in the form of:

$$y = mX + b$$

Y = Payload weight (lbs.)
X = Density Altitude (feet)
m = Slope of the linear line
b = y-intercept.

3. Only one line and one equation may be presented on the graph. This curve may take into account predicted headwind for local conditions, rolling drag, inertia, motor and propeller performance, or any other factors that may affect take-off performance. All these factors are allowed components of the prediction curve, but only one curve will be allowed; multiple curves to account for varying headwind conditions will not be allowed.
4. The team must provide a brief explanation of how the line was generated in the body of the report. The section of the report containing this information must be noted on the payload prediction curve.
5. Graph axes shall be in English units, decimal notation.

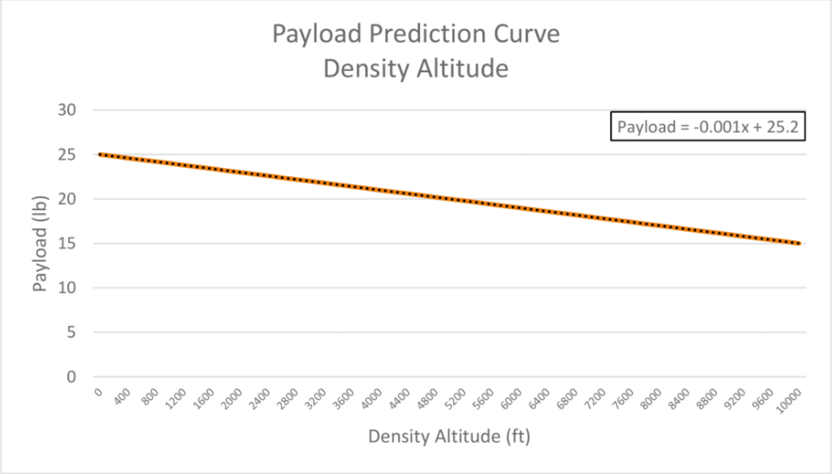


Figure 4-1: Example Regular Class Payload Prediction Curve

4.6 TECH DATA SHEET: POWERED AUTONOMOUS DELIVERY AIRCRAFT (ADVANCED CLASS ONLY)

An additional 2D drawing must be provided as an Appendix for Powered Autonomous Delivery Aircraft (PADA). This 3-view must be ANSI B sized page (PDF) format (11 x 17 inches) and follow the same requirements as the primary aircraft 2D drawing.

1. Drawings shall identify the location of the loaded CG.
2. Team shall provide a list of avionics and equipment.
3. Teams shall provide a prediction of landing accuracy for the PADA a landing zone. This shall be a histogram of the results of simulated landings by the PADA, binned in one-foot increments.
4. Teams must provide a standard deviation assuming a mean of 0ft to be used in the calculation of their PADA Landing Bonus.

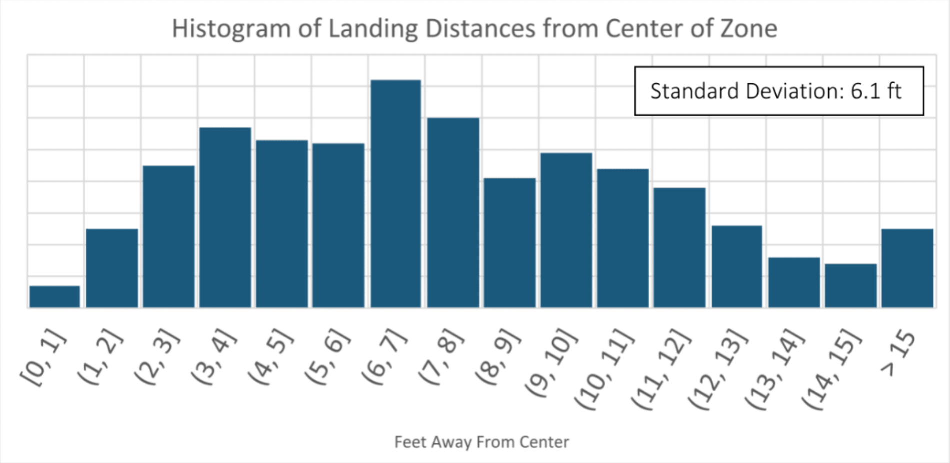


Figure 4-2: Example of Advanced Class Landing Distance Histogram

4.7 TECH DATA SHEET: AIRCRAFT PERFORMANCE PREDICTION (MICRO CLASS ONLY)

The Micro Class must include two figures describing the predicted flight performance of their aircraft between the start of takeoff and the beginning of the first turn. Both plots should be on the same page.

1. One figure must show the predicted ground distance vs time.
2. One figure must show the predicted altitude vs time.

5 TECHNICAL PRESENTATION

Like all professionals, engineers must possess a well-developed ability to synthesize issues and communicate effectively to diverse audiences. The technical presentation portion of the aero-design competition is designed to emphasize the value of an ability to deliver clear, concise, and effective oral presentations. Teams can obtain a maximum technical presentation score of fifty (50) points. The presentation score shall be comprised of scores based on the presenter's delivery technique and the judges' evaluation of technical content, empirical analysis, and visual aide.

5.1 TECHNICAL PRESENTATION REQUIREMENTS

1. Technical presentation shall last ten (10) minutes and be followed by a seven (7) minute "Question and Answer" (Q&A) period.
2. Technical presentation shall be delivered in English.
3. Technical presentation shall address, but are not limited to, trade studies performed, design challenges, and manufacturing techniques.
4. Technical presentation is limited to student team members only. Non-team member pilot, Faculty Advisors, and/or parents can attend the technical presentation but are prohibited from participating in the setup, delivery, and/or the Q&A.
5. Assistance in the use of visual aids is advisable; Film clips, if used, may not exceed one-minute total duration; Film clips may not be accompanied by recorded narration.
6. During the Q&A section, the teams shall display a single page marketing/promotion piece to further detail aircraft's feature, capabilities, and unique design attributes.

5.2 TECHNICAL PRESENTATION PROCESS AND PROCEDURES

Each presentation room shall have a lead judge with the responsibility to ensure compliance with competition rules and schedule. The lead judge will identify a timekeeper.

1. With agreement from the speaker, the timekeeper will give the speaker a one (1) minute warning prior to the ten (10) minute limit.
2. If the team exceeds the ten (10) minute limit, the team will be assessed a five (5) point penalty for going over the time limit.
3. The presentation shall be stopped at the eleven (11) minute mark.
4. A team shall have seven (7) minutes for Q&A immediately following the presentation. Questions may be asked by any judge on the panel.
5. Any time remaining or exceeding the ten (10) minutes shall be added to or subtracted from the seven (7) minute Q&A.
6. Presentation Time Breakdown:

Time (Minutes)	Description
2	Setup presentation
10	Perform Technical Presentation
7	Questions & Answers
1	Close down presentation

6 TECHNICAL INSPECTION AND AIRCRAFT DEMONSTRATIONS

Technical and Safety inspection of all aircraft will be conducted using the published Technical and Safety Inspection checklists for each class for the current year. The checklists can be found at www.saeaerodesign.com/go/downloads.

Technical and Safety Inspection is the process of checking all aircraft for:

- Compliance with all general aircraft requirements.
- Compliance with all aircraft configuration requirements for their class.
- Overall safety and airworthiness.

All aircraft must pass the Technical and Safety Inspection to compete. **Per the Statement of Compliance, teams are required to present a fully completed Inspection checklist for their aircraft that is signed by the Faculty Advisor or Team Captain.** Teams cannot begin the inspection process without meeting this requirement. Technical and Safety inspectors at the event will confirm that the team has fully inspected their aircraft.

All required Aircraft Demonstrations will be performed at designated locations.

- **Regular Class** will demonstrate the ability to unload their aircraft within two (2) minutes per the requirements of Section 7.5. This will be demonstrated each time a team unloads the aircraft at weigh in, after each successful flight.
- **Advanced Class** will demonstrate that their aircraft has proven operational ability by providing a video showing the aircraft successfully taking off, releasing a PADA, the PADA flying for 10 seconds, and landing per the Section 8.1.
- **Micro Class** will demonstrate the timed unloading of their aircraft per the requirements of Section 9.4. This will be demonstrated each time a team unloads the aircraft at weigh-in, after each successful flight.

6.1 AIRCRAFT CONFORMANCE TO 2D DRAWING

During Technical Inspection, the aircraft will be inspected and measured for conformance to the 2D drawing presented in the Design Report.

1. At a minimum, aircraft length, wingspan and height dimensions will be measured and compared to the 2D drawing.
2. All teams must have a hard copy of their design report present during technical inspection.
3. Aircraft will have the actual empty CG compared to the empty CG presented in the design report 2D drawing.
4. Advanced Class must show longitudinal and lateral C.G. positions or provide a table for each payload configuration.

6.2 FAILURE TO REPORT DESIGN CHANGES

Failure to report any design changes incorporated after Design Report submission and prior to Technical Check-in will incur a one (1) point penalty for each unreported design change discovered during technical inspection.

6.3 DEVIATIONS FROM 2D DRAWING

Any deviation in construction of the aircraft from the submitted 2D drawing, after submission of the Design Report, must be reported in writing. **For Advanced and Regular Class aircraft, there is no need to report deviations in the length (L), width (W), and height (H) of the aircraft, if the following is satisfied, where dimensions are in inches:**

$$|L_{actual} - L_{drawing}| + |W_{actual} - W_{drawing}| + |H_{actual} - H_{drawing}| \leq 3\ inches$$

1. Each design change must be documented separately using the Engineering Change Request (ECR) – a physical copy of which must be brought to the Technical and Safety Inspection.
2. Only one (1) design change may be submitted per ECR form.
3. Penalty points for design changes will be assessed in accordance with the penalty guidelines in Appendix C, subject to the judges' final determination.

6.4 SAFETY AND AIRWORTHINESS OF AIRCRAFT

Technical and Safety Inspection will also be used to assess the general safety and airworthiness aspects of each aircraft by seeking any problems that could cause an aircraft to depart controlled flight. This assessment includes, but is not limited to:

1. Unintentional wing warps
2. Control surface alignment
3. Correct control surface response to radio transmitter inputs
4. Structural and mechanical soundness

6.5 INSPECTION OF SPARE AIRCRAFT AND SPARE AIRCRAFT COMPONENTS

1. All spare aircraft and spare aircraft components (wings, fuselages and tail surfaces) must be presented for inspection.
2. Teams may submit up to two (2) complete aircraft at Technical Inspection on Friday.
3. Additional spare aircraft and parts beyond two (2) sets may be submitted for inspection during the event on Saturday and Sunday.

6.6 AIRCRAFT MUST MEET ALL INSPECTION REQUIREMENTS THROUGHOUT THE COMPETITION.

1. All aircraft must meet all Technical and Safety Inspection requirements throughout the competition.
2. Any official may request that an aircraft be re-inspected if a general, class configuration, or safety requirement problem is seen on an aircraft at any time during the event.
3. This includes any errors or omissions made by officials during inspection.

6.7 TECHNICAL AND SAFETY INSPECTION PENALTIES

No points are available to be scored as a result of the Technical and Safety Inspection: teams may only lose points as a result of errors and problems encountered during the inspection process. Any penalties assessed during Technical Inspection will be applied to the overall competition score.

7 REGULAR CLASS DESIGN REQUIREMENTS

The objective of Regular Class is to design an aircraft that can operate from short runways to carry outsized cargo as well as regular cargo. Payload will consist of large spherical storage containers, represented by Soccer Balls, and Regular Boxed Cargo, represented by payload weights, which must be carried on each flight. Accurately predicting the lifting capacity of the aircraft is an important part of the airplane design.

7.1 AIRCRAFT DIMENSION REQUIREMENT

Regular Class aircraft are limited to a maximum wingspan of 120 inches.

7.2 MATERIAL AND EQUIPMENT RESTRICTIONS FOR REGULAR CLASS

Fiber-Reinforced Plastic (FRP)

The use of Fiber-Reinforced Plastic (FRP) is prohibited on all parts of the aircraft. Fiber-Reinforced Plastic includes duct tape. Exceptions to this rule include: commercially available FRP motor mount, propeller, landing gear and control linkage components. Exploration of alternative materials is encouraged.

Rubber bands

Elastic material such as rubber bands shall not be used to retain the wing or payloads to the fuselage.

Stability Assistance

All types of gyroscopic or other stability assistance are prohibited.

7.3 AIRCRAFT SYSTEM REQUIREMENTS

Electric Motor Requirements

The aircraft shall be propelled by a single electric motor (no multiple motors). There are **no restrictions on the make or model of the electric motor.**

Gear boxes, Drives, and Shafts

Gearboxes, belt drive systems, and propeller shaft extensions are allowed if a one-to-one propeller to motor RPM is maintained. The prop(s) must rotate at motor RPM.

Aircraft Propulsion System Battery

Regular Class aircraft must be powered by a commercially available Lithium-Polymer battery pack. Minimum requirements: 6 cell (22.2volt), 3000 mAh, 25c.

Power Limiter

All Regular Class aircraft must use a 2019 V2 or newer version 1000-watt power limiter from the official supplier (Neumotors.com) as described in Section 2.18.

Radio System Battery and Switch

If a separate battery is used for the radio system, the battery pack must have enough capacity to safely drive all the servos in the aircraft, taking into consideration the number of servos and potential current draw from those servos.

1. The radio system must use a battery pack with a minimum capacity of 1000 mAh.
2. The battery pack must be a LiPo or LiFE type battery.

3. Battery voltage regulators are allowed.
4. The battery pack must be controlled by a clearly visible and properly mounted on/off switch on the external surface of the aircraft, located at least 12" from the prop.

7.4 PAYLOAD REQUIREMENTS

Types of Cargo

Regular Class payload shall consist of two types; (1) Spherical Cargo and (2) Regular Boxed Cargo, which must both be carried internally to the aircraft. Both types of Payload must be designed for ease of access. Reference Section 7.5 for demonstration details.

Cargo Bay Requirements

Regular Class aircraft shall have a single fully enclosed Cargo Bay for carrying Spherical Cargo and Regular Boxed Cargo (see Section 7.4.3) with the following additional requirements:

1. The Cargo Bay shall fully enclose the Spherical Cargo and the Regular Boxed Cargo. Spherical Cargo may not be exposed to airstream at any point in flight.
2. The Cargo Bay has no restriction on size or shape.
3. Only one Cargo Bay is allowed in a Regular Class aircraft.
4. The length of the Cargo Bay (Lcargo) must be detailed on the drawing for Technical Inspection. The drawing must also include a schematic of the aircraft fully loaded. The length of the Cargo Bay is measured from the foremost location of any payload to the aft most location of any payload.

Regular Boxed Cargo Support Requirements

Regular Boxed Cargo shall consist of a support assembly and payload plates with the following additional requirements:

1. There is no required configuration for the payload plates, other than as defined by Section 2.10 and 2.11.
2. Teams must provide their own payload plates.
3. Tape, Velcro, rubber bands, container systems and friction systems alone may not be used to retain the support assembly and/or payload plates.

Spherical Cargo Payload Definition

The Spherical Cargo payload must consist only of unmodified Size 5 Soccer Balls. Each team must provide their own. The specifications on these Soccer Balls are:

- A circumference of not more than 28 inches and not less than 27 inches
- A weight not more than 16 ounces and not less than 14 ounces
- A pressure of 8.5 psi to 15.6 psi. While the standard says 8.5 psi, SAE Aero Design, requires a minimum of 9 psi.

Additional details can be found at:

“International football association board Rules of the Game, Law 02: the Ball”

Spherical Cargo Carriage Requirements

Regular Class aircraft must position all Spherical Cargo in the Cargo Bay.

1. The Cargo Bay must accommodate a minimum of one (**1**) Spherical Cargo for each flight attempt.
2. There is no configuration requirement for the Spherical Cargo inside the Cargo Bay.

7.5 REGULAR CLASS PAYLOAD UNLOADING

To complete a successful flight for score, the post flight activities of unloading Spherical Cargo and Regular Boxed Cargo must be accomplished within one (**1**) minute. This demonstration will be performed at the weigh station after the completion of each successful flight.

The demonstration will start with all Spherical Cargo and Regular Boxed Cargo loaded, secured, and the aircraft configuration unchanged from the most recent successful flight.

This is a timed activity and shall be performed by no more than two (**2**) members of the team within the following time constraints:

- Any Regular Boxed Cargo successfully unloaded from the aircraft will be weighed and recorded for scoring that flight attempt.
- Any Spherical Cargo successfully unloaded from the aircraft will be recorded for scoring that flight attempt.
- Any Spherical Cargo or Regular Boxed Cargo that fails to be unloaded in one (**1**) minute will not be used in the scoring equation.

7.6 REGULAR CLASS SCORING

To participate in the flight portion of the competition, each team is required to have submitted AND received a score for their Design Report and Oral Presentation.

The team's Final Flight Score is the sum of the top three (3) flight scores the team achieves during the competition (FS_1, FS_2, and FS_3) and the Payload Prediction Bonus.

Scoring Equation:

$$FFS = \ Final\ Flight\ Score = \ FS_1 + FS_2 + FS_3 + PPB$$

Where:

$$FS = Flight\ Score = 120 * \frac{\mathbf{3} * S + W_{Payload}}{b\ + L_{cargo}}$$

$$PPB = Payload\ Prediction\ Bonus = 10 - (A - P)^2$$

$S = Number\ of\ Spherical\ Cargo\ Carried\ on\ a\ Flight$

$W_{Payload} = Regular\ Boxed\ Cargo\ Weight\ (lbs)$

$b = Aircraft\ Wingspan\ (inches)$

$L_{cargo} = Length\ of\ Cargo\ Bay\ (inches)$

$A = Actual\ Payload = W_{Payload} + 0.9375 * S$

$P = Predicted\ Payload$

The predicted payload, P, is determined from the payload prediction curve the teams provide in the Technical Data Sheet (Section 4.5) and the density altitude measured at the event.

The Payload Prediction Bonus will be calculated for each of the top three (3) flights that are counted for score. Only the highest of these calculated bonuses will be applied to the team's final flight score.

All Payload Prediction Bonus (PPB) less than zero (0) will default to zero (0).

Penalty Points

Any penalty points assessed during the competition are now deducted from a team's overall score.

8 ADVANCED CLASS DESIGN REQUIREMENTS

The objective of Advanced Class is to design a suite of systems that can support the fight against wildfires through the delivery of water and parts for a ground vehicle. This class is focused on mission success through understanding of diverse requirements, system-level engineering, and robust execution.

8.1 VIDEO DOCUMENTATION OF PROVEN OPERATIONAL ABILITY FOR ADVANCED CLASS

All Advanced Class teams are required to bring a video documenting the proven operational ability of their Advanced Class aircraft to Technical and Safety Inspection. The hard deadline for video submission is 8AM Saturday morning of the competition weekend.

1. The video must show the following activities accomplished successfully with their competition aircraft: A take-off, a successful release of a PADA, a PADA in stable flight for at least 10 seconds, and a landing of the Primary Aircraft (PA) without damage to the PA. A successful release of the PADA means that the PADA is in a flyable configuration after release.
2. The video will be reviewed by SAE officials in the Technical Inspection area.
3. Advanced Class aircraft will not be inspected or allowed to compete without the video documentation of proven operational ability.
4. Teams must provide a device to play the video for the officials at a screen size that allows the officials to clearly see both aircraft.
5. Videos should be no more than 1.5 minutes in length. Edited video will be accepted if the video is of the same flight.

8.2 AIRCRAFT DIMENSION REQUIREMENT

Advanced Class aircraft are limited to a maximum wingspan of **120 inches**.

8.3 AIRCRAFT SYSTEM REQUIREMENTS

Electric Motor Requirements

The Primary Aircraft shall be propelled by one or more electric motors. There are no restrictions on the make or model of the electric motor.

Gear boxes, Drives, and Shafts

Gearboxes, belt drive systems, and propeller shaft extensions are allowed.

Aircraft Propulsion System Battery

Advanced Class Primary Aircraft shall be powered by a single commercially available Lithium-Polymer battery pack. Minimum requirements: 6 cell (22.2volt), 3000 mAh, 25c.

Power Limiter

All Advanced Class Primary Aircraft shall use a single 2018 or newer version 750-watt power limiter from the official supplier (Neumotors.com) as described in Section 2.18.

8.4 RADIO SYSTEM BATTERY

The radio system battery pack must have enough capacity to safely drive all the servos in the Primary Aircraft, taking into consideration the number of servos and potential current draw from those servos. If the radio system battery also supplies DAS or other power needs, the radio system battery must be large enough for these power requirements as well.

1. The radio system must use a battery pack with a minimum capacity of 1000 mAh.
2. The battery pack must be a LiPo or LiFE type battery.
3. Battery voltage regulators are allowed.
4. The battery pack must be controlled by a clearly visible and properly mounted on/off switch on the external surface of the PA, located at least 12" from the prop.

8.5 RUBBER BANDS

Rubber bands shall not be used to retain the wing to the fuselage.

8.6 PRIMARY AIRCRAFT STATIC PAYLOAD REQUIREMENTS

Water Storage Container Requirements

Each team shall provide at least two (2) storage containers. At least one (1) main storage container to hold all the water carried as Static Payload by the primary aircraft. At least one (1) destination storage container to hold all the water delivered by the Ground Transport Vehicle (GTV).

1. After each successful mission, the Static Payload will be impounded into the team's main water storage container(s). Teams will not have access to this water until the GTV demonstration.
2. Containers must be clearly marked with team name and number.
3. Containers should have a sealable lid to prevent spilling.
4. Any evaporation, leakage, or other loss of water is the team's responsibility.

Static Payload Requirements

1. The primary aircraft shall carry a static payload of water.
2. Static payload bay(s) shall have no restriction on size or shape.
3. Teams must be able to unload Static Payload into the main water storage container at the weigh station after the flight in three (3) minutes or less.
4. Any water not unloaded during the time limit shall not be counted for score.
5. Total Static Payload weight will only be measured at the conclusion of all flight activities.

8.7 POWERED AUTONOMOUS DELIVERY AIRCRAFT (PADA) REQUIREMENTS

Teams are responsible for delivering a Ground Transport Vehicle (GTV) safely to the ground through a powered and autonomously guided aircraft. The following requirements apply to the PADA:

1. Total weight of each fully loaded PADA must be not more than 16.0 oz
2. PADA must be a fixed wing aircraft and is subject to requirements in Section 1 and 2.

3. The team may have multiple PADAs, but only one (1) can be mounted and flown on the primary aircraft per flight.
4. The PADA must have a propulsion system, consisting of at least a propeller, motor, battery, and speed controller.
5. The PADA must use a separate battery pack or battery eliminator circuit (BEC) to power the receiver. The red power wire from the ESC must not be connected to the receiver.
6. The center of gravity must be clearly marked on each PADA according to Section 2.3.
7. Payload may be carried internally or externally. Any internal payload bay(s) shall have no restriction on size or shape.
8. The PADA shall be considered a structural part of the Primary Aircraft prior to the intentional release and separation towards the target landing zone. The entirety of the PADA is considered as payload after release. Section 3.5 will be observed if the PADA loses parts while attached to the Primary Aircraft. Structural components will result in a disqualification of the flight attempt. Non-structural components will result in a 25% penalty.
9. Powered taxi of the PADA is prohibited.

8.8 LANDING ZONE

The PADA will be required to land in a designated landing zone, which will be randomly selected prior to takeoff.

1. Each zone will have a diameter of 30 ft, with the center marked by a solid-colored sign of at least 24” in diameter laying flat on the ground.
2. There will be at least 3 zones, located on the far side of the runway.
3. The location of each zone may be changed at any point during the competition.
4. Teams will **not** be allowed access to the field to obtain GPS coordinates at any time during the competition.
5. Only PADAs that land in the target zone selected for that flight attempt will be counted for score.

8.9 GROUND TRANSPORT VEHICLE (GTV) REQUIREMENTS

The payload for the PADA shall consist of components for a ground vehicle, which teams shall assemble and demonstrate at the conclusion of all flight activities. The following requirements apply to the GTV:

1. Other than the water payload and transmitter (if used), the entire GTV system, and everything necessary to construct, operate and maintain it, must be delivered as payload via PADA flights. This includes but is not limited to wheels, batteries, motors, the receiver, fasteners, tools, tape, water funnel, etc.
2. After each successful PADA landing, any desired GTV components shall be unloaded and placed in an impound box, where they will remain until the GTV demonstration.
3. Teams shall provide their own impound box which shall be a rectangular prism with a removable lid and be marked with the team’s name and number.

4. The payload for the GTV during the demonstration shall be water. The water payload must be drawn from the team's main water storage container filled by the Primary Aircraft. The water shall be delivered to the destination water storage container.

8.10 GYROSCOPIC AND OTHER STABILITY AUGMENTATION

Gyroscopic assist or other forms of stability augmentation are allowed in Advanced Class.

8.11 AUTONOMOUS FLIGHT

Autonomous flight systems that cause the Primary Aircraft to navigate without direct pilot control input are prohibited. Autonomous flight for the PADA is required, subject to the following rules:

1. Teams must provide at least one fully functional PADA that meets all requirements herein.
2. In addition to the motor, the PADA shall have an active navigation system, controlling at least 2 degrees of freedom, that guides the PADA toward the target landing zone following its release from the Primary Aircraft.
3. Teams must have a manual override for control over the PADA through a dedicated secondary transmitter. This shall be a switch on that transmitter to select between autonomous and manual flight modes.
4. The team must have a dedicated pilot for the PADA who will use the secondary transmitter if manual override is used. This pilot will stand with the Primary Aircraft pilot near the Airboss or designated representative.
5. Manual override may be used at the discretion of the team. Any use of the manual override shall result in a score reduction in accordance with the score equation.
6. If the PADA is flying in an unsafe manner, the Airboss may order grounding of the PADA as per Section 3.11.5. The PADA flight shall be considered unsuccessful.

8.12 DATA ACQUISITION SYSTEM (DAS)

Advanced Class Primary Aircraft must have a Data Acquisition System (DAS) that shall record altitude and be used by the team to locate the appropriate target landing zone. All communication between the payload specialist and any pilot must be in English.

1. Using a ground receiver station, the team must display the real-time altitude of the aircraft to the Payload Specialist and the flight judge in at least 1.0" text.
2. Team must automatically record, and immediately display in at least 1.0" text, the altitude (ft) at the moment of release for the PADA. The indicator must remain visible for the remaining duration of the flight.
3. The DAS recording must be performed on the ground station and must support play back for review on demand.
4. Altitude must be measured in feet with display precision of at least one (1) ft. and an accuracy error of less than ten (10) ft.
5. DAS system must use a discrete and removable Red arming plug to apply power to the DAS system. The DAS arming plug must be located on top of the Primary Aircraft

at least 12 inches behind or in front of the rotational plane of the propeller. Reaching through the arc of the propeller at any time is strictly prohibited. One Red arming plug can be used for both DAS and FPV. If the DAS and Aircraft Propulsion System Arming plugs are different, both must be removed upon landing to minimize interference with other teams.

6. DAS equipment may also have a reset switch, if desired. If a manual reset switch is used, it must be located externally at least 12 inches behind the propeller in the longitudinal direction. A wireless DAS reset system is allowed.
7. DAS systems shall not use the same 2.4 GHz channel as the flight control system, unless the telemetry being used is part of the radio control system being used. A DAS built into the radio control system must meet all DAS rules requirements.

8.13 FIRST PERSON VIEW SYSTEM (FPV)

FPV is no longer required for Advanced Class. For teams that wish to use an FPV system for operational reasons, the following conditions apply:

1. Teams will be required to sign up for one of 12 discrete commonly used FPV frequencies. The frequency list will be provided by SAE Aero Design.
2. There will be a frequency sign-up process communicated to teams via the event newsletters.
3. If more than 12 Advanced Class teams choose to use an FPV system, some team's frequencies may have more than 1 team using them. Frequency control procedures will be in place at the event to prevent conflicts.
4. The primary pilot must fly visually only (no FPV goggles or ground station reference).
5. FPV systems CANNOT use the same frequency as the flight control system. Use of 2.4 GHz for FPV video is prohibited.
6. The FPV system must use a discrete and removable Red arming plug to apply power to the FPV system. This arming plug is subject to the requirements in Section 2.19. One Red arming plug can be used for both DAS and FPV.

8.14 DAS FAILURES

Any DAS failure during the flight attempt is considered a missed flight attempt and receives zero (0) points.

Example: A team has flown four (4) times successfully and on the 5th attempt the Primary Aircraft takes-off successfully, makes a successful release, but the DAS altitude reading malfunctions. The flight attempt will NOT be considered a qualified flight and the team will receive zero (0) credit for PADA or static payload for flight 5.

8.15 PAYLOAD SPECIALIST

The Payload Specialist is responsible for releasing the PADA from the Primary Aircraft.

1. The Payload Specialist must be a single team member. The Payload Specialist should not count on having a line-of-sight view to the aircraft.

2. Neither the primary aircraft pilot not the PADA pilot may have access to or activate any PADA release, and the release cannot be connected to the pilot's R/C transmitters in any way.
3. The PADA release must be manually activated by the Payload Specialist or by an automatic release system that is part of the Primary Aircraft electronics.
4. If an automatic release system is used, it must have a manual override controlled by the Payload Specialist.
5. Teams may activate the payload release system using a second 2.4 GHz radio system or some other method based on their DAS or telemetry system.

8.16 POWERED AUTONOMOUS DELIVERY AIRCRAFT RELEASE PROCEDURES

1. Release of the PADA must be at least 200 feet away from the center of the runway, measured parallel to the runway.
2. Teams must release the PADA at an altitude of no greater than 50 ft.
3. Teams have as many passes as needed, so long as the PADA is released within 5 minutes of throttle-up, lands within 6 minutes of throttle-up, and the Primary Aircraft comes in to land as soon as the PADA is released.
4. A single PADA shall be successfully launched during each flight attempt. Failure to launch a PADA successfully and intentionally shall disqualify the entire flight attempt. A successful launch is defined as:
    - Being within 5 minutes of primary aircraft throttle-up
    - Complying with Section 8.16.1 and 8.16.2 as shown in Figure 8-1.
    - The PADA must attain stable flight after release.

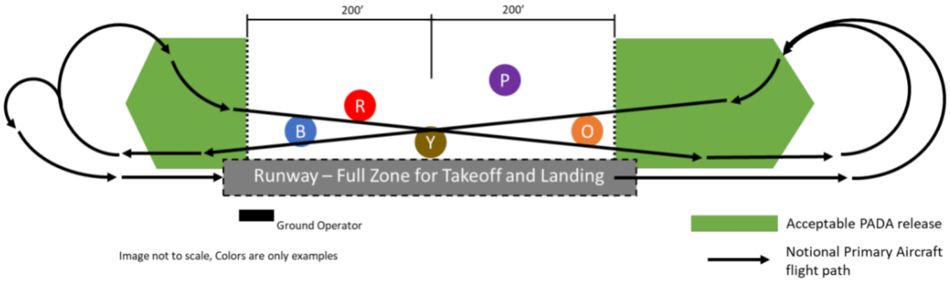


Figure 8-1 – Notional PADA Release Diagram. Not to scale.

8.17 GROUND TRANSPORT VEHICLE DEMONSTRATION EVENT PROCEDURE

At the conclusion of all flight activities, before the award ceremony, teams shall have 8 minutes to demonstrate their GTV's ability to transport water in the following manner:

1. Each team will be set up in a designated area of the runway with sufficient separation from other teams to avoid interference.
2. On one side of the demonstration zone will be the unassembled GTV in its impound box and the team's main water storage container(s). Stationed on the other side of

the zone (approx. 30 feet away) shall be the team's empty destination water storage container(s). Containers shall be positioned approximately as shown in Figure 8-2.

3. No more than three (3) team members may take part in the assembly and demonstration, including the manual driver. Teams may split personnel between the start and destination sides of the area however they choose, but no team member may switch sides during the demonstration.
4. When the demonstration begins, the team shall assemble their GTV, load it with water from the main water storage container and navigate it to the other side of the runway. Once the GTV has completely passed the finish line, the team member(s) on the other side of the runway shall unload the water into the destination storage container(s). Only water that has crossed the finish line with the GTV will be counted for score.
5. Teams may handle the water storage containers, but neither the main nor destination water storage containers may be moved during the demonstration.
6. Multiple trips across the demonstration zone are allowed.
7. Team members on the starting side may only refill the GTV after it has completely left the demonstration zone.
8. The GTV may be autonomous or manually controlled. If the team controls the GTV via a transmitter when it is within the demonstration zone, the GTV shall be considered manually controlled for the entirety of the demonstration. Teams may touch, control, or manipulate an autonomous GTV when it is outside of the demonstration zone and the GTV shall still be considered autonomous. Touching the GTV while it is within the demonstration zone is prohibited under all circumstances.
9. Obstacles will be placed in the demonstration zone approximately as shown in Figure 8-2. The obstacles may be up to 3 inches in height.
10. No additional water may be placed in the destination water storage container(s) once time is over.
11. Only the water successfully delivered by the GTV shall be measured for score.

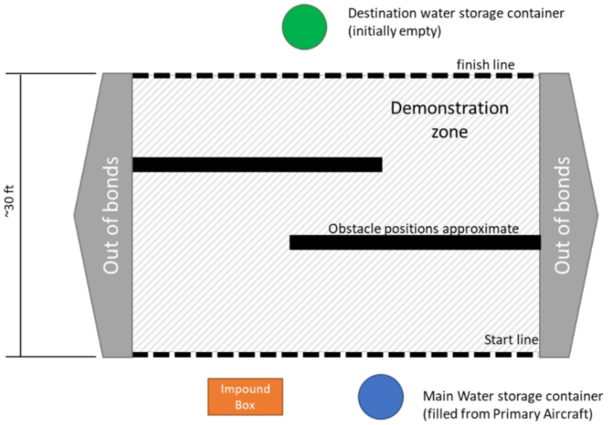


Figure 8-2: Notional Diagram of GTV Demonstration Event. Not to Scale.

8.18 ADVANCE CLASS SCORING

To participate in the flight portion of the competition, each team is required to have submitted AND received a score for both Design Report and Oral Presentation.

The final flight score is based on the team's performance over the entire event. First, teams are given points based on the amount of water the primary aircraft successfully carries each flight. Second, teams are given a flat score every time a PADA successfully lands in the designated landing zone, with a bonus for distance to the center derived from the team's predictions. Finally, the teams who delivered enough parts via PADAs to assemble a working GTV will have the opportunity to score points by transporting the water carried previously by the primary aircraft in a demonstration event.

Scoring Equation:

$$Final\ Flight\ Score = \frac{W_{payload} + A_{GTV} * W_{delivered}}{4} + 4 * \sum_{1}^{N_{PL}} (A_{PADA} + B_{PADA})$$

Where:

$$B_{PADA} = PADA\ Landing\ Bonus^{*} = 5 * \left(\frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{d^2}{2\sigma^2}} \right)$$

**Note, this is the normal probability density function with mean of 0*

$W_{payload} = Total\ Water\ (lbs)\ Successfully\ Flown\ During\ the\ Competition$

$W_{delivered} = Total\ Water\ (lbs)\ Delivered\ by\ GTV\ During\ Demonstration$

$A_{GTV} = GTV\ Autonomy\ Multiplier{:}\ 2\ if\ autonomous, 1.5\ if\ manual$

$N_{PL} = Total\ Number\ Successful\ PADA\ Landings\ During\ the\ Competition$

$A_{PADD} = PADA\ Autonomy\ Multiplier{:}\ 1.5\ if\ autonomous, 0.25\ if\ manual$

$d = Distance\ of\ PADA\ to\ center\ of\ landing\ zone, rounded\ down\ to\ nearest\ ft$

$\sigma = Team\ supplied\ Standard\ Deviation\ from\ TDS$

Penalty Points

Any penalty points assessed during the competition are now deducted from a team's overall score.

9 MICRO CLASS DESIGN REQUIREMENTS

The objective of the Micro Class is to challenge engineering students to design a small, light-weight, all electric aircraft to overcome various conflicting design and performance requirements such as short take-off, max-speed, external payload carriage, internal payload carriage, and rapid unloading of the payloads.

9.1 AIRCRAFT DIMENSION REQUIREMENTS

Micro Class aircraft are limited to a maximum wingspan of 48"

9.2 AIRCRAFT SYSTEMS REQUIREMENTS

Propulsion Requirements

Micro Class aircraft are restricted to electric motor propulsion only.

Propeller and Gearbox

Gearboxes on a Micro Class aircraft where the propeller RPM differs from the motor RPM are allowed. Multiple motors, multiple propellers, propeller shrouds, and ducted fans are allowed in Micro Class.

Aircraft Propulsion System Battery

Micro Class aircraft must use Lithium Polymer batteries. Micro class batteries are allowed a maximum of **4** cells.

Gyroscopic Assist Allowed

Gyroscopic assist and other forms of stability augmentation are allowed in Micro Class.

Power Limiter

All Micro Class aircraft must use a 2022 or newer version 450-watt power limiter from the official supplier (Neumotors.com) as described in Section 2.18.

9.3 PAYLOAD REQUIREMENTS

Types of Cargo

Micro Class payload shall consist of two types; (**1**) metal payload plates and (**2**) delivery boxes. The metal payload plates shall be carried internally to the aircraft in a cargo bay.

Cargo Bay Requirements

Micro Class aircraft shall have a single Cargo Bay for carrying payload plates with the following additional requirements:

1. The Cargo Bay shall fully enclose the payload plates.
2. The Cargo Bay has no restriction on size or shape.
3. Only one Cargo Bay is allowed in a Micro Class aircraft.

Payload Plate Support Requirements

Payload Plates shall be secured with a support assembly subject to the following additional requirements:

1. There is no required configuration for the payload plates, other than as defined by Section 2.10 and 2.11.
2. Teams must provide their own Payload Plates.
3. Tape, Velcro, rubber bands, container systems and friction systems alone may not be used to retain the support assembly and/or Payload Plates.

Delivery Box Definition

Two sizes of delivery boxes (Large and Small) are utilized in Micro Class.

1. Both boxes are rectangular prisms with specifications consistent with the table:

Type	Length (in)	Width (in)	Height (in)	Wt (oz)
Large	12±0.25	12±0.25	2±0.25	5.5±0.5
Small	6±0.25	6±0.25	4±0.25	2.5±0.5

2. Delivery boxes will be **supplied by SAE**.
3. Teams must attempt to carry at least one (1) box
4. There is no configuration requirement for the Delivery Boxes.
5. Boxes may not be modified by the team. No holes or mounting hardware are permitted on the boxes.
6. The delivery boxes must remain intact throughout the duration of the flight to receive full score. Damaged boxes shall count for 50% score. Destroyed boxes shall be disqualified.

Intact: Box geometry and dimensions remain unchanged throughout the duration of the flight.

Damaged: Box Interior of the box is not exposed (no punctures, tears etc.) AND All box dimension deviates from specification by less than 0.5"

Destroyed: Interior of the box is exposed by a rip/tear/puncture (box no longer airtight) OR Any box dimension deviates from specification by more than 0.5"

9.4 PAYLOAD UNLOADING

To complete a successful flight for score, the post flight activities of unloading delivery box(es) and unloading static payload must be accomplished within one (**1**) minute. This demonstration will be performed at the weigh station after the completion of each successful flight.

The demonstration will start with all Delivery Box(es) and Payload Plates loaded, secured, and the aircraft configuration unchanged from the most recent successful flight.

This is a timed activity and shall be performed by no more than two (2) members of the team.

- Any Payload Plate(s) successfully unloaded from the aircraft will be weighed and recorded for scoring that flight attempt.

- Any Delivery Box(es) successfully unloaded from the aircraft will be recorded for scoring that flight attempt.
- Any Delivery Box(es) or Payload Plate(s) that **fails** to be unloaded within one (**1**) minute will not be used in the scoring equation.

9.5 MICRO CLASS AIRCRAFT LAUNCH

The Micro Class aircraft must accomplish a take-off from a designated 4-foot by 8-foot take-off platform that is elevated at a minimum of 24-inches above the ground. The take-off area will be approximately level.

- The pilot and one (1) team member may be at the take-off area.
- The aircraft must be only held and released by one (1) team member. Release of the aircraft by the pilot is prohibited.
- The weight of the aircraft must be supported by the landing gear while on the platform. All landing gear, and aircraft ground contact points must be in contact with the surface of the platform. The rear of the aircraft may overhang the platform.

9.6 MISSION REQUIREMENTS

Aircraft Take-off and Circuit

Micro Class Take-off is defined as the point at which the aircraft moves forward under its own power. Micro Class aircraft are required to perform the following operations, referenced in Figure 9-1:

1. Take-off as described in Section 9.4. The Flight Timer is started at the moment of forward aircraft movement.
2. Remain airborne and fly past a designated turn point 300-ft from the take-off before turning approximately 180-degrees in heading. The Flight Timer is stopped when the aircraft is indicated to have crossed the designated turn point.
3. Fly past a second designated turn point, turning 180 degrees in heading.
4. Land within the 200-ft designated landing zone. Micro Class aircraft must be prepared to land on either a paved or unpaved landing zone.
5. Take-off direction will be determined by the Air Boss, and normally selected to face into the wind.

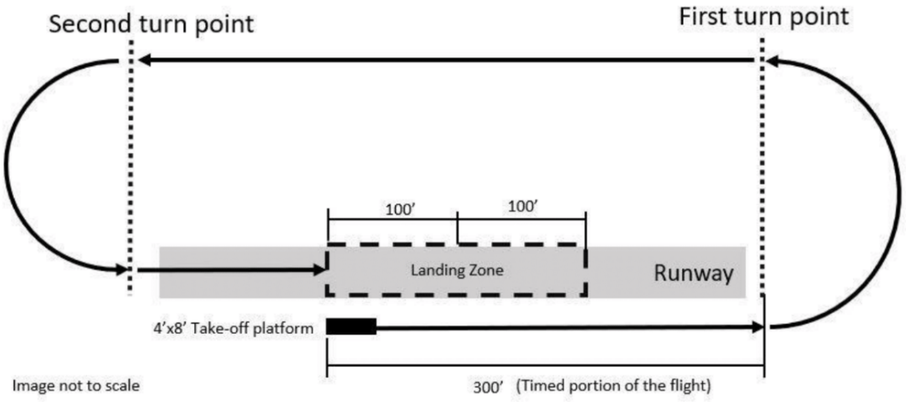


Figure 9-1 – Notional Micro-Class Flight Circuit

9.7 MICRO CLASS FLIGHT SCORING

To participate in the flight portion of the competition, each team is required to have submitted AND received a score for both Design Report and Oral Presentation.

The team’s Final Flight Score is the sum of the top three (3) flight scores the team achieves during the competition (FS_1, FS_2, and FS_3).

Scoring Equation:

$$Final\ Flight\ Score = FSS = FS_1 + FS_2 + FS_3$$

Where:

$$Flight\ Score = FS = 80 * \frac{\sqrt{W_{Payload} * Bonus}}{T_{Flight}}$$

$$Bonus = 0.5 + \left(1.0 * N_{Large}\right) + (0.4 * N_{Small})$$

$N_{Large} = Number\ of\ Large\ Boxes\ Flown$

$N_{Small} = Number\ of\ Small\ Boxes\ Flown$

$W_{Payload} = Payload\ Plate\ Weight\ (lbs)$

$T_{Flight} = Flight\ Time\ from\ Take-off\ to\ First\ Turn\ (s)$

Penalty Points:

Any penalty points assessed during the competition will be deducted from the team’s overall score.

APPENDIX A

STATEMENT OF COMPLIANCE

Certification of Qualification

Team Name	______________________	Team Number	__________
School	______________________		
Faculty Advisor	______________________		
Faculty Advisor's Email	______________________		

Statement of Compliance

As faculty Adviser:

______ (Initial) I certify that the registered team members are enrolled in collegiate courses.

______ (Initial) I certify that this team has designed and constructed the radio-controlled aircraft in the past nine (9) months with the intention to use this aircraft in the 2022 SAE Aero Design competition, without direct assistance from professional engineers, R/C model experts, and/or related professionals.

______ (Initial) I certify that this year's Design Report has original content written by members of this year's team.

______ (Initial) I certify that all reused content have been properly referenced and is in compliance with the University's plagiarism and reuse policies.

____ (Initial) I certify that the team has used the Aero Design inspection checklist to inspect their aircraft before arrival at Technical Inspection and that the team will present this completed checklist, signed by the Faculty Advisor or Team Captain, to the inspectors before Technical Inspection begins.

______________________	______________________
Signature of Faculty Advisor	Date
______________________	______________________
Signature of Team Captain	Date

Note: **A copy of this statement needs to be included in your Design Report as page 2 (Reference Section 4.3)**

Appendix B

Engineering Change Request (ECR)

Team Number:				
School Name:				
Team Name:				
Discovery Method	☐Tech Inspection ☐Safety Inspection ☐Test Flight ☐Design Analysis	System Affected	☐Wing (area +/-) ☐Fuselage (area +/-) ☐Horiz. Stabilizer (area +/-) ☐Vertical Tail (area +/-) ☐Engine Mount assembly	☐Mechanical ☐Landing System ☐Structural ☐Electronics (avionics) ☐Cargo Bay Assembly
Surface Area	AREA ADDED:____________ AREA REDUCED:______________ *If surface area was impacted by the modification, specify total area added or reduced. Show calculations:*			
Dimensions Modified	*Original Dimension:* ____________ Modified Dimension: ___________________			
Describe the Modification				
Reason for Modification				
Other Considerations				
*** OFFICIAL USE ONLY ***				
ECR #				

APPENDIX C

Penalty Chart Guidelines

These charts provide guidelines to possible assessment of penalty points for different design changes. Final assessment of penalty points is subject to the judges' determination.

Table D1: Penalties guidelies for for wing surface changes

Dimension	Add	Remove
Span	2pts per inch	1pt per inch
Chord	10pts per inch	5 pts per inch

For Advanced and Regular Class aircraft, there is no penalty for deviations in the length (L), width (W), and height (H) of the aircraft, if the following is satisfied, where dimensions are in inches:

$$|L_{actual} - L_{drawing}| + |W_{actual} - W_{drawing}| + |H_{actual} - H_{drawing}| \leq 3\ inches$$

Table D2: Penalty guidelines by category and size of change

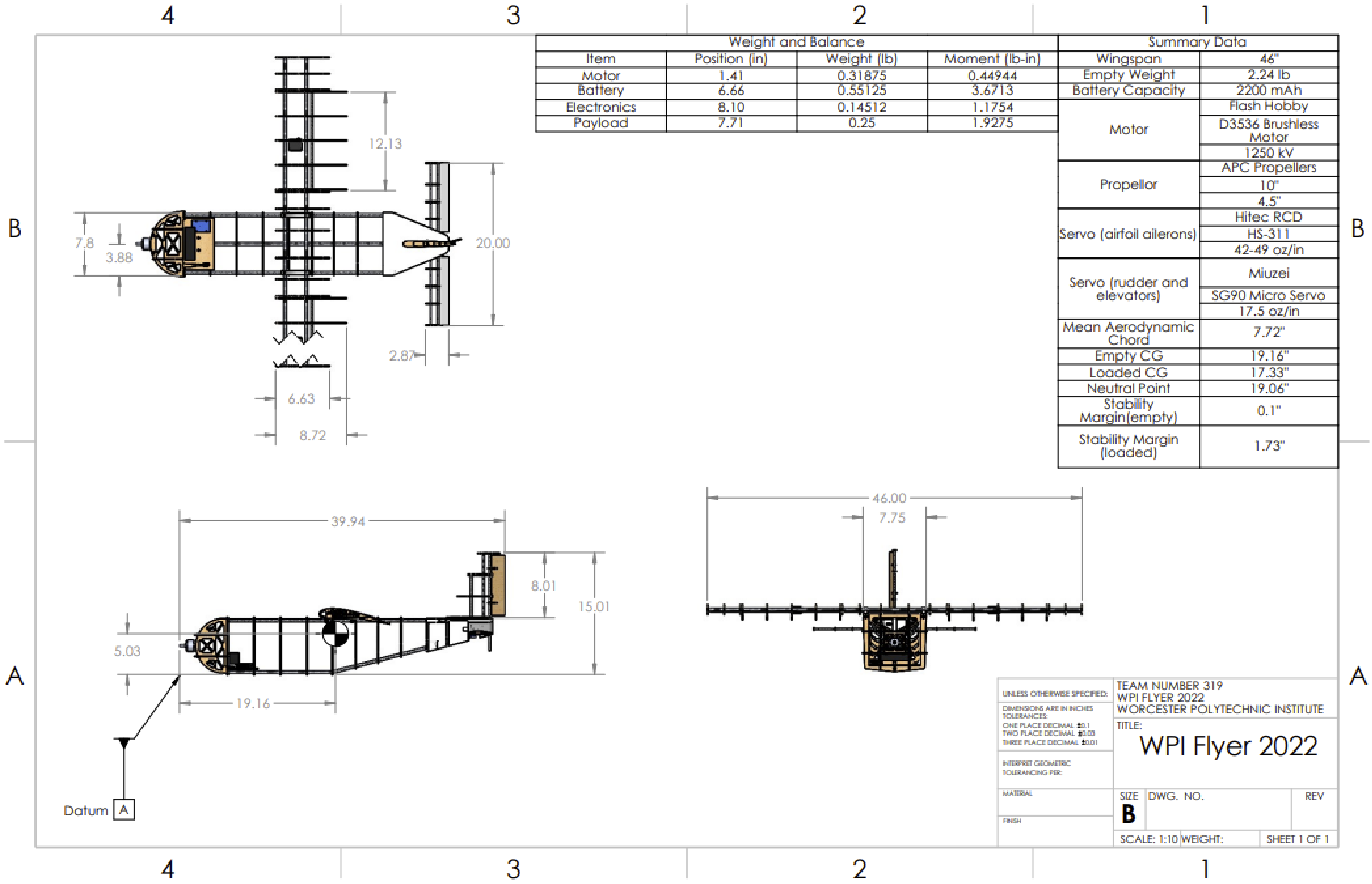
Type	Small	Medium	Large
Structural	2pts	4pts	6pts
Mechanical	2pts	4pts	6pts
Electronics	1pts	2pts	3pts
Miscellaneous	1pts	3pts	5pts

APPENDIX D

APPEALS

Team Name	
Team Captain	
Collateral Points	*All appeals will require the team to post twenty-five (25) points as collateral. If the appeal is successful and the action is reversed, the team will not forfeit the twenty-five (25) collateral points. If the appeal is overruled, the team will forfeit the twenty-five (25) collateral points* Collateral Points: 25 Sign if Agree: ____
Reason for this Appeal	
Rule Reference	*List the section(s) in the official rule that is (are) in conflict with the action(s) taken by competition official* Section:____________ Section:____________ Section:____________ Section:____________
Desire outcome	

Appendix B. Aircraft Technical Drawing



Weight and Balance			
Item	Position (in)	Weight (lb)	Moment (lb-in)
Motor	1.41	0.31875	0.44944
Battery	6.66	0.55125	3.6713
Electronics	8.10	0.14512	1.1754
Payload	7.71	0.25	1.9275

Summary Data	
Wingspan	46"
Empty Weight	2.24 lb
Battery Capacity	2200 mAh
Motor	Flash Hobby D3536 Brushless Motor 1250 kV
Propellor	APC Propellers 10" 4.5"
Servo (airfoil ailerons)	Hitec RCD HS-311 42-49 oz/in
Servo (rudder and elevators)	Miuzei SG90 Micro Servo 17.5 oz/in
Mean Aerodynamic Chord	7.72"
Empty CG	19.16"
Loaded CG	17.33"
Neutral Point	19.06"
Stability Margin(empty)	0.1"
Stability Margin (loaded)	1.73"

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Appendix C: Simulation Code

```
alpha = 0;
b = 1.2192;%meter
c = 0.1651; %meter
AR = b/c;
```

```
AR = 7.3846
```

```
e0 = 0.832; %assumed
rho = 1.225;%kg/m
V = 20;%m/s ~60mph
q = (0.5*rho*V^2);
```

```
q = 245.0000
```

```
S = (b^2)/AR;
```

```
S = 0.2013
```

```


%for NACA 4412
Cl = 0.467;
Cd0 = 0.014;
```

```
Cd0 = 0.0140
```

```
Cd =Cd0+((Cl^2)/(pi*e0*AR));
```

```
Cd = 0.0253
```

```
Cm = -0.104;
L = Cl*q*S;
```

```
L = 23.0306
```

```
D = Cd*q*S;
```

```
D = 1.2476
```

```
L_D = L/D;
```

```
L_D = 18.4594
```

```
k = 1/(pi*AR*e0);
```

```
k = 0.0518
```

```
%W1 = 1.36078*9.81 %N
W1 = .5*rho*V^2*Cl*S;
```

```
W1 = 23.0306
```

```
T_W = D/W1;
```

```
T_W = 0.0542
```

```
Clmax = sqrt((Cd0*pi*AR*e0)/3);
```

```
Clmax = 0.3001
```

```
Vstall = sqrt((2*(W1/S))/(rho*Cl));
```

```
Vstall = 20
```

```
W_S_stall = .5*rho*Vstall^2*Clmax;
```

```
W_S_stall = 73.5309
```

```

% S = 280/10.764; %m^2
% c = 6.5*0.3048; %m
% b = 46*0.3048; %m
% %using cruise high conditions
% h = 20000*0.3048;
% M = 0.434;
% V = 450*0.3048;
rho_star = 1.225;
% q = 6.1382;%kpa
% Xcg = 0.16;
g = 9.81;
% alpha = 1.1*(pi/180); %degrees
u_star = V*cos(alpha);
m = 11000/2.205; %kg
Ixx = 5135.47*703;%kgm^2
```

```
Ixx = 3.6102e+06
```

```
Iyy = 4087.17*703; %kgm^2
```

```
Iyy = 2.8733e+06
```

```
Izz = 1519.26*703; %kgm^2
```

```
Izz = 1.0680e+06
```

```
Ixz = 342.43*703; %kgm^2
```

```
Ixz = 2.4073e+05
```

```
%steady state
Cl1 = 0.467;
Cd1 = Cd;
Cm1=0;
CTx1 = 0.0298;
CmT1 = 0;
%stability derivatives
Cdu = 0;
Cda = 0.131;
CTxu=-0.0596;
Cl0 = 0.201;
Clu = 0.02;
Cla = 5.143;
Cla_dot = 2.5;
Clq = 3.9;
```

```
Cm0 = -0.015;
Cmu = 0;
Cma = -0.89;
Cma_dot = -9.1;
Cmq = -12.4;
CmTu = 0;
CmTa = 0;
%control derivatives
% CDde/CDiH == 0/0;
% CLde/CLiH == 0.6/1.35;
% Cmde/CmiH == -2/-4.1;
%stability derivatives
Clb = -0.089;
Clp = -0.47;
Clr = 0.096;
CYb = -0.31;
CYp = -0.037;
CYr = 0.21;
Cnb = 0.065;
CnTb = 0;
Cnp = -0.03;
Cnr = -0.099;
%Control Derivatives
Clda = -0.178;
Cldr = 0.0147;
CYda = 0;
CYdr = 0.187;
```

```
CYdr = 0.1870
```

```
Cnda = -0.053;
Cndr = -0.0657;
Clde = 0.009578*(pi/180);
Cmde = -0.01209*(pi/180);
Cdde = 0.000173*(pi/180);
Cldf = 0.01572*(pi/180);
Cmdf = -0.003280*(pi/180);
Cddf = 0.000351*(pi/180);
Ctu = 1;
Ct_dot = 0.1;
%Longitudinal Stability
Zu = -2*(((m*g)*cos(alpha))/V)-((1/2)*rho_star*V*S*(Clu + 2*Cl1));
Xu = 2*(((m*g)*sin(alpha))/V)-((1/2)*rho_star*V*S*(Cdu + 2*Cd1));
```

```
Xu = -0.1248
```

```
Xw = (1/2)*(rho_star*V*S*(Cl1 - Cda));
Zw = -0.5*rho_star*V*S*(Cd1 + Cla);
Zq = -0.25*rho_star*V*S*c*Clq;
Zw_dot = -(1/4)*(rho_star*S*c*Cla_dot);
```

```
Zw_dot = -0.0254
```

```
Mu = 0.5*(rho_star*V*S*c*Cmu);
Mw = 0.5*(rho_star*V*S*c*Cma);
```

```
Mw_dot = .25*(rho_star*S*(c^2)*Cma_dot);
Mq = .25*(rho_star*V*S*(c^2)*Cmq);
M_prime = Mw_dot/(m - Zw_dot);
Xde = -0.5*rho_star*(V^2)*S*Cdde;
Zde = -0.5*rho_star*(V^2)*S*Clde;
Mde = 0.5*rho_star*(V^2)*S*c*Cmde;
Zdp=0;
Mdp = 0.5*rho_star*(V^2)*S*c*Cmde;
Xdp = 0.5*rho_star*(V^2)*S*(Ctu+2*Ct_dot);
%Lateral Stability
Yv = .5*rho_star*(V)*S*CYb;
Yp = .25*rho_star*V*S*b*CYp;
Yr = .25*rho_star*V*S*b*CYr;
lv = .5*rho_star*V*S*b*Clb;
lp = .25*rho_star*V*S*(b^2)*Clp;
lr = .25*rho_star*V*S*(b^2)*Clr;
Nv = .5*rho_star*V*S*b*Cnb;
Np = .25*rho_star*V*S*(b^2)*Cnp;
Nr = .25*rho_star*V*S*(b^2)*Cnr;
Yda = .5*rho_star*(V^2)*S*CYda;
Ydr = .5*rho_star*(V^2)*S*CYdr;
lda = .5*rho_star*(V^2)*S*b*Clda;
ldr = .5*rho_star*(V^2)*S*b*Cldr;
Nda = .5*rho_star*(V^2)*S*b*Cnda;
Ndr = .5*rho_star*(V^2)*S*b*Cndr;

Jx_prime = (Ixx*Izz-(Ixz^2))/Izz;

Jz_prime = (Ixx*Izz-(Ixz^2))/Ixx;

Jzx_prime = Ixz/(Ixx*Izz-(Ixz^2));
A_longitudinal_matrix = [Xu/m Xw/m 0 -g*cos(alpha) 0;
    Zu/(m-Zw_dot) Zw/(m-Zw_dot) (Zq+m*u_star)/(m-Zw_dot) (-m*g*sin(alpha))/(m-Zw_dot) 0;
    (Mu+M_prime*Zu)/Iyy (Mw+M_prime*Zw)/Iyy (Mq+M_prime*(Zq+m*u_star))/Iyy (-M_prime*m*g*sin(al
    0 0 1 0 0;
    -sin(alpha) cos(alpha) 0 -u_star*cos(alpha) 0]
```

```
A_longitudinal_matrix = 5×5
   -0.0000    0.0002         0   -9.8100         0
   -0.9815   -0.0026   19.9997         0         0
    0.0000   -0.0000   -0.0000         0         0
         0         0    1.0000         0         0
         0    1.0000         0  -20.0000         0
```

```
B_longitudinal_matrix = [Xde/m Xdp/m;
    Zde/(m-Zw_dot) Zdp/(m-Zw_dot);
    (Mde/Iyy)+(Mw_dot*Zde)/(Iyy*(m-Zw_dot)) (Mdp/Iyy)+(Mw_dot*Zdp)/(Iyy*(m-Zw_dot));
    0 0;
    0 0]
```

```
B_longitudinal_matrix = 5×2
   -0.0000    0.0119
   -0.0000         0
   -0.0000   -0.0000
         0         0
         0         0
```

```
A_lateral = [Yv/m (Yp/m) (-V+(Yr/m)) g*cos(alpha) 0 0;
    (lv/Jx_prime)+(Jzx_prime*Nv) (lp/Jx_prime)+(Jzx_prime*Np) (lr/Jx_prime)+(Jzx_prime*Nr) 0 0
    (Nv/Jz_prime)+(Jzx_prime*lv) (Np/Jz_prime)+(Jzx_prime*lp) (Nr/Jz_prime)+(Jzx_prime*lr) 0 0
    0 1 tan(alpha) 0 0 0;
    0 0 sec(alpha) 0 0 0;
    1 0 0 0 V*cos(alpha) 0]
```

```
A_lateral = 6×6
   -0.0002   -0.0000  -19.9999    9.8100         0         0
   -0.0000   -0.0000    0.0000         0         0         0
    0.0000   -0.0000   -0.0000         0         0         0
         0    1.0000         0         0         0         0
         0         0    1.0000         0         0         0
    1.0000         0         0         0   20.0000         0
```

```
B_lateral = [Yda/m Ydr/m;
    (lda/Jx_prime)+(Jzx_prime*Nda) (ldr/Jx_prime)+(Jzx_prime*Ndr);
    (Nda/Jz_prime)+(Jzx_prime*lda) (Ndr/Jz_prime)+(Jzx_prime*ldr);
    0 0;
    0 0;
    0 0]
```

```
B_lateral = 6×2
         0    0.0018
   -0.0000   -0.0000
   -0.0000   -0.0000
         0         0
         0         0
         0         0
```

```
%part 2.4
%eigenvalues of matricies

A_longitudinal_eigenvalues = eig(A_longitudinal_matrix)
```

```
A_longitudinal_eigenvalues = 5×1 complex
   0.0000 + 0.0000i
  -0.0232 + 0.0244i
  -0.0232 - 0.0244i
   0.0219 + 0.0243i
   0.0219 - 0.0243i
```

```
A_lateral_eig = eig(A_lateral)
```

```
A_lateral_eig = 6×1 complex
   0.0000 + 0.0000i
   0.0000 + 0.0000i
   0.0041 + 0.0075i
   0.0041 - 0.0075i
  -0.0084 + 0.0000i
  -0.0000 + 0.0000i
```

```

Phugoid_eigenvalues1 = A_longitudinal_eigenvalues(3,1)
```

```
Phugoid_eigenvalues1 = -0.0232 - 0.0244i
```

```
Phugoid_eigenvalues = A_longitudinal_eigenvalues(4,1)
```

```
Phugoid_eigenvalues = 0.0219 + 0.0243i
```

```
%
short_period_eigenvalues1 = A_longitudinal_eigenvalues(1,1)
```

```
short_period_eigenvalues1 = 0
```

```
short_period_eigenvalues = A_longitudinal_eigenvalues(2,1)
```

```
short_period_eigenvalues = -0.0232 + 0.0244i
```

```

sprial_mode = A_lateral_eig(4,1)
```

```
sprial_mode = 0.0041 - 0.0075i
```

```
dutch_roll_mode1 = A_lateral_eig(2,1)
```

```
dutch_roll_mode1 = 0
```

```
dutch_roll_mode = A_lateral_eig(3,1)
```

```
dutch_roll_mode = 0.0041 + 0.0075i
```

```


state_s = ss(A_longitudinal_matrix, B_longitudinal_matrix, zeros(5,5), zeros(5,2));
[natural_freq_long, damping_ratio_long] = damp(state_s);

u_ts = abs(4/real(A_longitudinal_eigenvalues(1)))
```

```
u_ts = Inf
```

```
w_ts = abs(4/real(A_longitudinal_eigenvalues(2)))
```

```
w_ts = 172.1768
```

```
q_ts = abs(4/real(A_longitudinal_eigenvalues(3)))
```

```
q_ts = 172.1768
```

```
theta_ts = abs(4/real(A_longitudinal_eigenvalues(4)))
```

```
theta_ts = 182.2986
```

```


u_damp = abs(damping_ratio_long(1))
```

```
u_damp = 1
```

```
w_damp = abs(damping_ratio_long(2))
```

```
w_damp = 0.6703
```

```
q_damp = abs(damping_ratio_long(3))
```

```
q_damp = 0.6703
```

```
theta_damp = abs(damping_ratio_long(4))
```

```
theta_damp = 0.6901
```

```


%beginning of controls section 3
Q_long = 0.1*eye(5);
R_long = 10;
Klong = lqr(A_longitudinal_matrix, B_longitudinal_matrix, Q_long, R_long, zeros(5,2))
```

```
Klong = 2×5
10^5 ×
   -0.0000   -0.0000   -1.2379   -0.0000   -0.0000
    0.0002   -0.0000    0.2476    0.0001   -0.0000
```

```

A_control = (A_longitudinal_matrix-(B_longitudinal_matrix*Klong))
```

```
A_control = 5×5
   -0.2084    0.0223 -293.7456   -9.9096    0.0012
   -0.9815   -0.0026   19.7952   -0.0000   -0.0000
    0.0000   -0.0000   -0.0001    0.0000   -0.0000
         0         0    1.0000         0         0
         0    1.0000         0  -20.0000         0
```

```
controlled_eigenvalues_long = eig(A_control)
```

```
controlled_eigenvalues_long = 5×1 complex
  -0.1042 + 0.0000i
  -0.0529 + 0.0915i
  -0.0529 - 0.0915i
  -0.0005 + 0.0017i
  -0.0005 - 0.0017i
```

```

% controlled_eigenvalues_lat = eig(Alat)

% A = A_longitudinal_matrix
% B = B_longitudinal_matrix
% C = eye(4);
% D = zeros(4,1);
x0 = [10; -0.8; 0; 3*pi/180; 200];
t = 400;
% initial(A-B*Klong,B,C,D,x0,t)


% E = A_lateral;
% F = B_lateral;
% G = eye(4);
% H = zeros(4,2);
% initial(E-F*Klat,F,G,H,x_ref,t)

theta_0 = 1.86*pi/180;
A_lat = [A_lateral]
```

```
A_lat = 6×6
```

```
   -0.0002   -0.0000  -19.9999    9.8100         0         0
   -0.0000   -0.0000    0.0000         0         0         0
    0.0000   -0.0000   -0.0000         0         0         0
         0    1.0000         0         0         0         0
         0         0    1.0000         0         0         0
    1.0000         0         0         0   20.0000         0
```

```
B_lat = [B_lateral]
```

```
B_lat = 6×2
         0    0.0018
   -0.0000   -0.0000
   -0.0000   -0.0000
         0         0
         0         0
         0         0
```

```

Q_lat = diag([1 1e-3 1e-3 1e-3 1 1e-3])
```

```
Q_lat = 6×6
    1.0000         0         0         0         0         0
         0    0.0010         0         0         0         0
         0         0    0.0010         0         0         0
         0         0         0    0.0010         0         0
         0         0         0         0    1.0000         0
         0         0         0         0         0    0.0010
```

```
R_lat = eye(2)
```

```
R_lat = 2×2
     1     0
     0     1
```

```
K_lat = lqr(A_lat, B_lat, Q_lat, R_lat, zeros(6,2) )
```

```
K_lat = 2×6
10^4 ×
   -0.0003   -2.5898   -0.0758   -0.1150   -0.0059   -0.0000
    0.0000    0.4327   -0.3088    0.0082   -0.0014    0.0000
```

```
K_lat = [K_lat(:,1:5) [0;0]]
```

```
K_lat = 2×6
10^4 ×
   -0.0003   -2.5898   -0.0758   -0.1150   -0.0059         0
    0.0000    0.4327   -0.3088    0.0082   -0.0014         0
```

```
x_ref = [0; 0; 0; 0; 5*pi/180; 0];

```

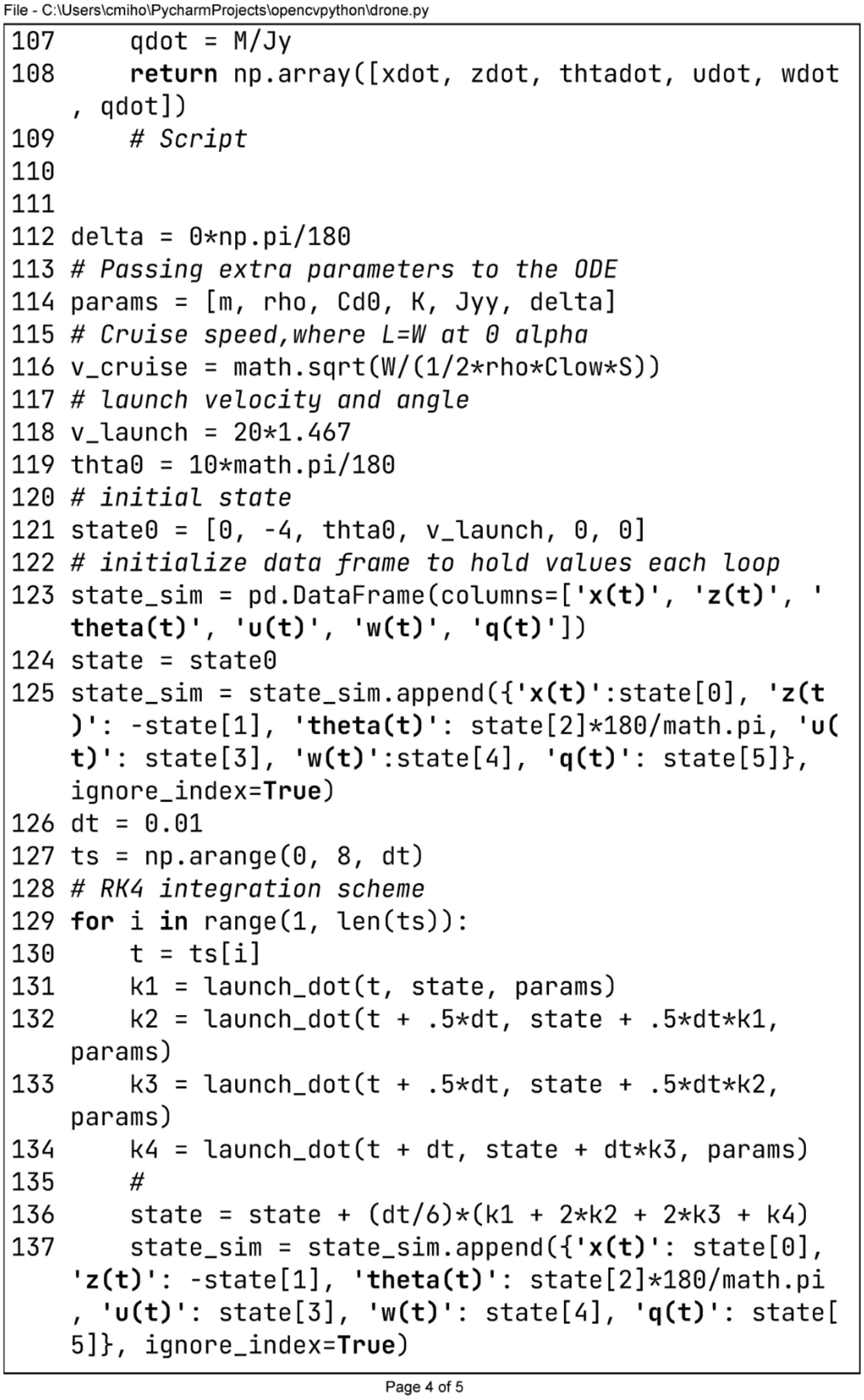
```python
import numpy as np
import math
import matplotlib.pyplot as plt
import pandas as pd
h_cg = 0.3636
hac = .25 # aerodynamic center
a = 4.796 # wing lift slope
at = 3.625 # tail lift slope
ae = 3 # elevator effectiveness
S = 2.0763 # wing area
St = .53 # tail area
lt = 25.5/12 # distance between aerodynamic center
sc = 6.5/12 # wing chord
de_dalpha = .1919 # downwash derivative
it = -6.77*np.pi/180 # tail incidence
e0 = 0 # initial downwash
alpha_stall = 20 # stall angle, degrees
Cmac = -0.23124 # natural wing moment
Clow = .7401 # wing lift at 0
W = 4.2 # weight
rho = 0.0023769 # air density
g = 32.26 # gravity accel
m = W/g # mass
Cd0 = .014 # Drag coeff
AR = 7.38 # Aspect Ratio
K = 4/3*1/(math.pi*.9*AR) # induced drag coeff
Jyy = 10 # moment of inertia

def stability_derivs(h, hac, a, at, ae,S, St, l, c, de_dalpha, Cmac, Clow, it, e0):
    '''
    Computes static stability derivatives for aircraft
    :param h: chord-fraction position of CG
    :param hac: chord-fraction position of aerodynamic center
    :param a: wing lift slope
    :param at: tail lift slope
    :param ae: elevator effectiveness
    :param S: wing area
    :param St: tail area
```

```python
    :param l: distance from tail to wing aerodynamic center
    :param c: wing mean chord
    :param de_dalpha: downwash derivative
    :param Cmac: natural wing moment
    :param Clow: lift at 0 alpha
    :param it: tail incidence angle
    :param e0: initial downwash
    :return: Stability derivatives CL_0, CL_alpha, CL_delta, Cm_0, Cm_alpha, Cm_delta
    '''
    Vh = l/c * St/S
    Cl_0 = Clow + St/S*at*(it-e0)
    Cl_alpha = a + at*(1 -de_dalpha)*St/S
    Cl_delta = St/S * ae
    Cm_0 = Cmac + Clow*(h-hac) -at*(it-e0)*Vh * (1 -(h -hac)*c/l)
    Cm_alpha = (a + at * St/S * (1 -de_dalpha))*(h-hac) -at*Vh*(1-de_dalpha)
    Cm_delta = Cl_delta *(h-hac) -ae*Vh
    return [Cl_0, Cl_alpha, Cl_delta, Cm_0, Cm_alpha, Cm_delta]


def launch_dot(t, state, params):
    '''
    :param t: time
    :param state: 2 position values, 2 velocity values, 2 angular values
    :param params: additional parameters for state transition
    :return:
    '''
    #State Variables
    x = state[0] # x position, ground-fixed
    z = state[1] # z position, ground-fixed
    thta = state[2] # flight path angle
    u = state[3] # x velocity, body fixed
    w = state[4] # z velocity, body fixed
    q = state[5] # angular velocity of flight path angle, body fixed
```

```
    #Stability derivatives
    stability_vals = stability_derivs(h_cg, hac, a, at, ae, S, St, lt, sc, de_dalpha, Cmac, Clow, it, e0)
    Cl_0 = stability_vals[0]
    Cl_alpha = stability_vals[1]
    Cl_delta = stability_vals[2]
    Cm_0 = stability_vals[3]
    Cm_alpha = stability_vals[4]
    Cm_delta = stability_vals[5]
    # other params
    m = params[0] # mass
    rho = params[1] # air density
    Cd0 = params[2] # constant drag term
    K = params[3] # Induced drag coeff
    Jy = params[4] # moment of inertia
    delta = params[5]
    # Thrust interpolation
    V = math.sqrt(u**2 + w**2)
    T = 1.907 -.01105*V # linear fit from MotoCalc data, regression of ~.98
    alpha = math.atan(w/u) # calculate angle of attack to make sure it does not exceed stall
    # Force Calcs
    Cl_total = Cl_0 + Cl_alpha * alpha + Cl_delta * delta
    Cm_total = Cm_0 + Cm_alpha * alpha + Cm_delta * delta
    Cd_total = Cd0 + K*Cl_total**2+.08
    L = 1/2*rho*u**2 * S * Cl_total
    M = 1/2*rho*u**2 * S * sc * Cm_total
    D = 1/2*rho*u**2 * S * Cd_total
    # summing aerodynamic force
    X = T - D
    Z = -L
    # State derivative
    xdot = u*math.cos(thta) + w*math.sin(thta)
    zdot = -u*math.sin(thta) + w*math.cos(thta)
    thtadot = q
    udot = X/m -g*math.sin(thta) -q*w
    wdot = Z/m + g*math.cos(thta) + q*u
```



File - C:\Users\cmiho\PycharmProjects\opencvpython\drone.py

```python
    qdot = M/Jy
    return np.array([xdot, zdot, thtadot, udot, wdot, qdot])
    # Script


delta = 0*np.pi/180
# Passing extra parameters to the ODE
params = [m, rho, Cd0, K, Jyy, delta]
# Cruise speed,where L=W at 0 alpha
v_cruise = math.sqrt(W/(1/2*rho*Clow*S))
# launch velocity and angle
v_launch = 20*1.467
thta0 = 10*math.pi/180
# initial state
state0 = [0, -4, thta0, v_launch, 0, 0]
# initialize data frame to hold values each loop
state_sim = pd.DataFrame(columns=['x(t)', 'z(t)', 'theta(t)', 'u(t)', 'w(t)', 'q(t)'])
state = state0
state_sim = state_sim.append({'x(t)':state[0], 'z(t)': -state[1], 'theta(t)': state[2]*180/math.pi, 'u(t)': state[3], 'w(t)':state[4], 'q(t)': state[5]}, ignore_index=True)
dt = 0.01
ts = np.arange(0, 8, dt)
# RK4 integration scheme
for i in range(1, len(ts)):
    t = ts[i]
    k1 = launch_dot(t, state, params)
    k2 = launch_dot(t + .5*dt, state + .5*dt*k1, params)
    k3 = launch_dot(t + .5*dt, state + .5*dt*k2, params)
    k4 = launch_dot(t + dt, state + dt*k3, params)
    #
    state = state + (dt/6)*(k1 + 2*k2 + 2*k3 + k4)
    state_sim = state_sim.append({'x(t)': state[0], 'z(t)': -state[1], 'theta(t)': state[2]*180/math.pi, 'u(t)': state[3], 'w(t)': state[4], 'q(t)': state[5]}, ignore_index=True)
```

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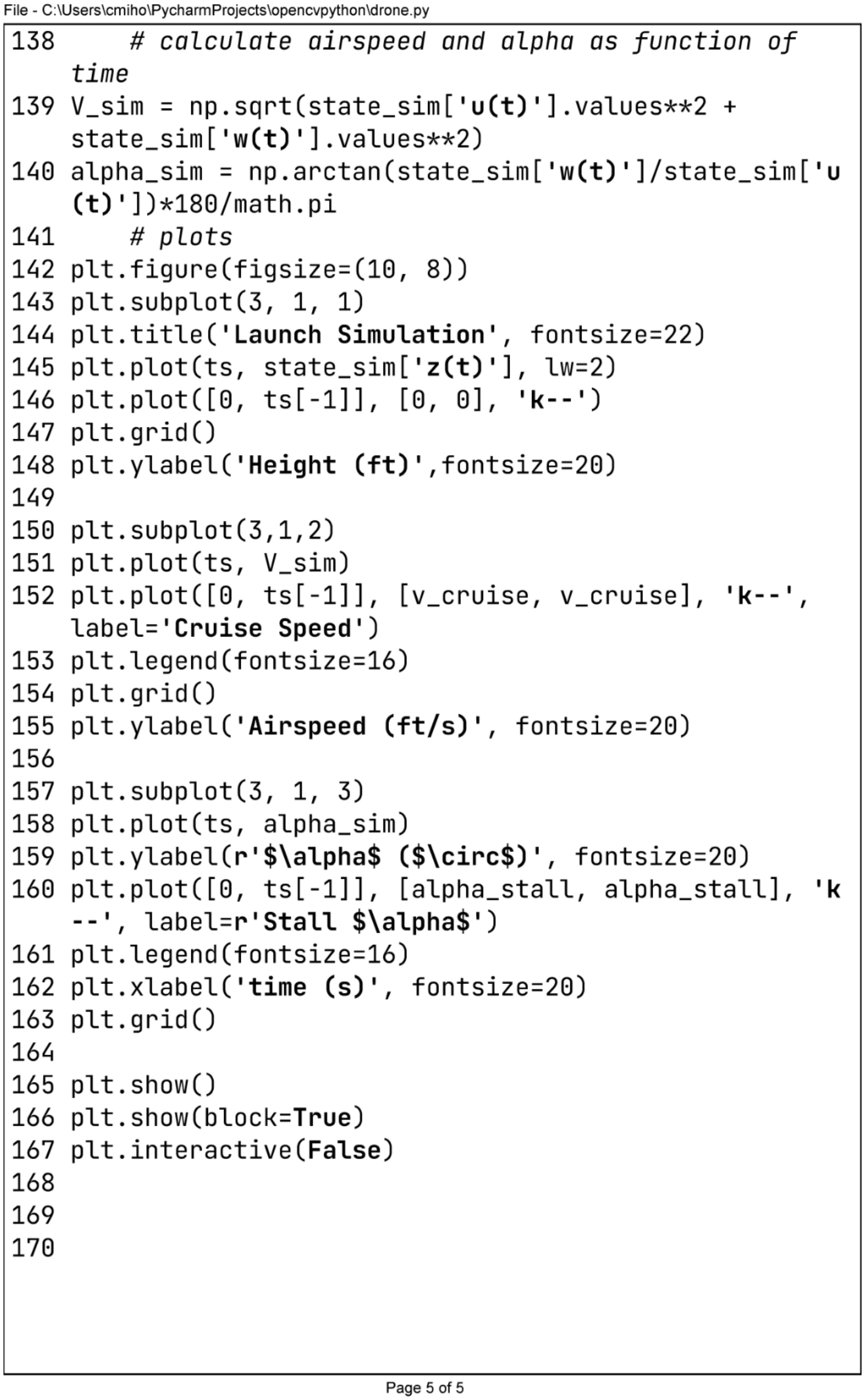

File - C:\Users\cmiho\PycharmProjects\opencvpython\drone.py

```
    # calculate airspeed and alpha as function of time
V_sim = np.sqrt(state_sim['u(t)'].values**2 + state_sim['w(t)'].values**2)
alpha_sim = np.arctan(state_sim['w(t)']/state_sim['u(t)'])*180/math.pi
    # plots
plt.figure(figsize=(10, 8))
plt.subplot(3, 1, 1)
plt.title('Launch Simulation', fontsize=22)
plt.plot(ts, state_sim['z(t)'], lw=2)
plt.plot([0, ts[-1]], [0, 0], 'k--')
plt.grid()
plt.ylabel('Height (ft)',fontsize=20)

plt.subplot(3,1,2)
plt.plot(ts, V_sim)
plt.plot([0, ts[-1]], [v_cruise, v_cruise], 'k--', label='Cruise Speed')
plt.legend(fontsize=16)
plt.grid()
plt.ylabel('Airspeed (ft/s)', fontsize=20)

plt.subplot(3, 1, 3)
plt.plot(ts, alpha_sim)
plt.ylabel(r'$\alpha$ ($\circ$)', fontsize=20)
plt.plot([0, ts[-1]], [alpha_stall, alpha_stall], 'k--', label=r'Stall $\alpha$')
plt.legend(fontsize=16)
plt.xlabel('time (s)', fontsize=20)
plt.grid()

plt.show()
plt.show(block=True)
plt.interactive(False)



```

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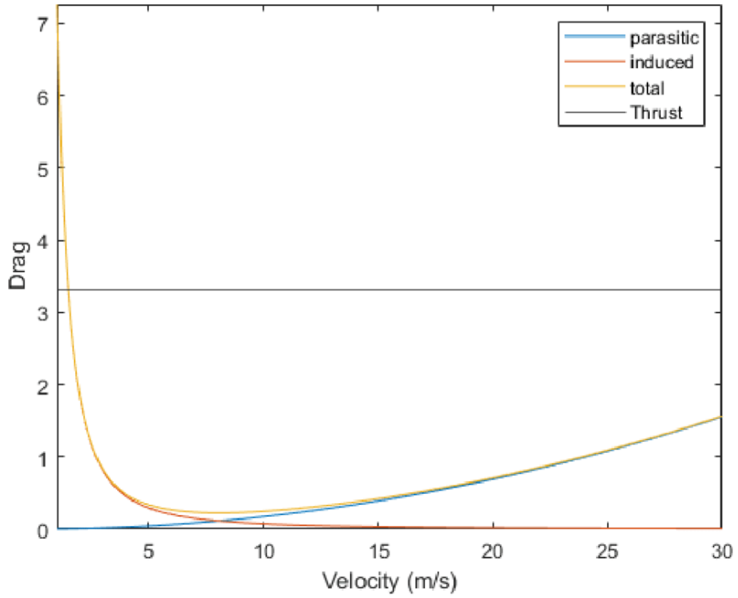
```
clc; close all; clear variables;

alpha = 0;
b = 1.2192;%meter
c = 0.1651; %meter
AR = b/c;
e0 = 0.0891; %assumed
rho = 1.225;%kg/m
syms f(x) h(x) g(x) x
v = 15;
%q = (0.5*rho*v^2)
S = (b^2)/AR;


%for NACA 4412
Cl = 0.467;

dragcoeff = [0.014,0.02];
for i = 1:length(dragcoeff)
    Cd0 = 0.014;
    Cd =Cd0+((Cl^2)/(pi*e0*AR));
    W =1.36;
    q = 0.5*rho*x^2;
    f(x) = q*S*Cd0;
    g(x) = q*S*(((W/(q*S))^2)/(pi*AR*e0));
    h(x) = q*S*Cd0+(W^2)/(q*S*pi*AR*e0);

    T= Cd*(0.5*rho*15^2)*S;
end
%Cd0 = 0.014

% Cm = -0.104;
%L = Cl*q*S
% D = Cd*q*S
% L_D = L/D
% k = 1/(pi*AR*e0)
%W1 = 1.36078*9.81 %N
%W1 = .5*rho*V^2*Cl*S
% T_W = D/W1
% Clmax = sqrt((Cd0*pi*AR*e0)/3)
% % Vstall = sqrt((2*(W1/S))/(rho*Cl))
% W_S_stall = .5*rho*Vstall^2*Clmax

figure(1);
fplot(f(x),[1 30])
hold on
fplot(g(x),[1 30])
hold on
fplot(h(x),[1 30])
hold on
yline(T)
xlabel("Velocity (m/s)")
ylabel("Drag")
```

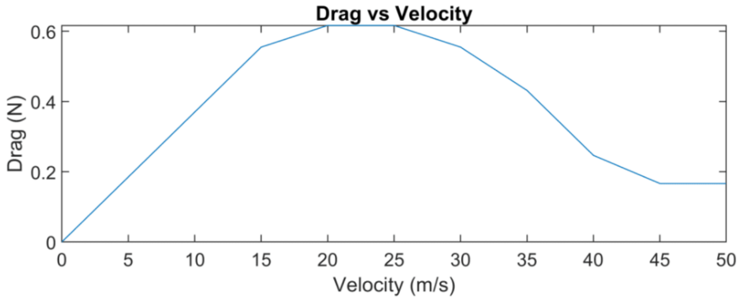
```
legend("parasitic","induced","total","Thrust")
```



```
clc; close all; clear all;

dt = 0.1;

v = 0;
x_t = 0;
v_1 = 50;
n_time_pts = v_1 / dt +1
```

```
n_time_pts = 11
```

```
t_record = zeros(1, n_time_pts); % zeros makes an array of zeros which is a way of allocating s
x_record = zeros(1, n_time_pts);
b = 1.219;
c = 0.1651;
AR = b/c;
S = (b^2)/AR;

t_record(1, 1) = v;
x_record(1, 1) = x_t;
column_number = 1;
while (v < v_1)
    column_number = column_number + 1;
    v = v + dt; % new time
    if(v < 20)
        x_tplusdt = (v)*.5*1.225*.3*S;
    elseif(v<25)
             x_tplusdt = (v)*.5*1.225*.25*S;
    elseif(v<30)
             x_tplusdt = (v)*.5*1.225*.2*S;
    elseif(v<35)
             x_tplusdt = (v)*.5*1.225*.15*S;
    elseif(v<40)
             x_tplusdt = (v)*.5*1.225*.1*S;
    elseif(v<45)
           x_tplusdt = (v)*.5*1.225*.05*S;
    elseif(v<50)
         x_tplusdt = (v)*.5*1.225*.03*S;

    end

    x_t = x_tplusdt; % x_t is the state at time t

    t_record(1, column_number) = v;
    x_record(:, column_number) = x_t;
end

subplot(211)

plot(t_record, x_record(1,:));
title("Drag vs Velocity");
xlabel('Velocity (m/s)'); ylabel('Drag (N)');
```


Drag vs Velocity
Drag (N)
0
0.2
0.4
0.6
0
5
10
15
20
25
30
35
40
45
50
Velocity (m/s)