SAE Aero Design West-Micro Class 18F18

Flapjacks #329

Final Report

Salem Alazmi
Collin Krawczyk
Jeremy Reber

NORTHERN ARIZONA UNIVERSITY
College of Engineering, Informatics, and Applied Sciences

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Project Sponsor: SAE, Northern Arizona University, Quality Vans and Specialty Vehicles, Coconino High School Engineering Group

Faculty Advisor and Sponsor Mentor: Dr. Tester

Instructor: Dr. Trevas

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EXECUTIVE SUMMARY

The scope of this project is to design and build a micro aircraft. The Northern Arizona University micro team plans to compete a micro aircraft at the SAE Aero West competition in April 2019. The SAE Aero West competition is an international competition where universities compete to win monetary prizes and potential job offers. The micro class involves designing an all-electric and radio-controlled aircraft that focuses on minimizing weight while maximizing payload. A constraint is placed on the size of the aircraft where the entire aircraft and necessary parts must fit within a cardboard container with maximum outside dimensions of 12.125 inches x 3.625 inches x 13.875 inches. Designs that were considered included a twin-engine aircraft with a V-tail similar to a military drone, a twin-engine aircraft with a conventional straight tail, a single engine aircraft with a V-tail, and a single engine aircraft with a conventional straight tail. The design that was selected was a single engine aircraft with a conventional straight tail. This design was selected due to the simplicity to construct compared to the other designs as well as the flight dynamics and stability that would occur during flight. The selected design has a wing span of 30 inches, a wing chord length of 4 inches, an 850 mAh battery, a 7”x4” propeller, and has control surfaces that include ailerons, elevators, and a rudder. With these selected components, the aircraft has a weight of approximately 0.75 lbs. and can generate a thrust to weight ratio of 4.66:1 with a flight time of 5 minutes. The wing and tail sections will be constructed using balsa wood ribs and spars with Monokote stretched and applied over the length of the sections. The wing was be split into two 11-inch sections with one 8-inch section. The tail will have one elevator that will span the length of the 9-inch horizontal stabilizer. To prepare for competition in April, construction, testing, design iterations, and report generations that meet competition guidelines must be completed. Once competition was completed, a new design was proposed. The new design focused on the elimination of the fuselage, using a Selig 1223 airfoil, extending the chord length to 7 inches and the wing length to 44 inches, and introducing a 15^{o} dihedral. This final design was tested in Flagstaff.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. BACKGROUND

1.1 Introduction

The scope of this project is to design, manufacture, and compete an aircraft against other universities at the Society of Automotive Engineers (SAE) Aero Design West competition April 5-7, 2019 in Van Nuys, California. The aircraft is radio controlled, electric powered, and should be capable of carrying the maximum payload possible while still being able to fit within a cardboard box with maximum outside dimensions of 12.125 inches x 3.625 inches x 13.875 inches [1]. This competition represents NAU's engineering program on an international platform and by succeeding, validates the quality of the engineering program offered by the school. Being successful in this project is imperative because NAU's reputation for having a quality school of engineering would be diminished by a poor performance. The competition rules and structure focus on the engineering design, manufacturing, and sell-off through demonstration of an aircraft within a compressed time frame and require many of the same steps a design of a full-scale aircraft could require.

1.2 Project Description

The project statement from the SAE website for aero design is as follows. The SAE Aero Design competition is a real-world design challenge designed to compress a typical aircraft development program into one calendar year, taking participants through the system engineering process of breaking down requirements. It exposes participants to the nuances of conceptual design, manufacturing, system integration/test, and sell-off through demonstration [1].

The micro class is to design lightweight micro UAV style aircraft that can be quickly deployed from a small package and able to carry a large, unwieldy low-density payload [1].

1.3 Original System

This project involved the design of a completely new scale aircraft. There was no original aircraft design when this project began.

2. REQUIREMENTS

The customer requirements are requirements given by the client and the SAE Aero rule book. Engineering requirements were then created based on these customer requirements. The customer requirements will be discussed first followed by the engineering requirements.

2.1 Customer Requirements (CRs)

The customer requirements in table 1 are a combination of requirements stated by the team's technical advisor and taken from the rules document published by the SAE competition coordinators.

Table 1: Customer requirements and relative weights

Customer Requirement	Relative Weight (5 Most Important)
Fly	5
Land	3
Fly Multiple Times	5
Compact	4
Transportable	2
Durable	3
Easily Repairable	4
Battery Powered	5
Safe	5
Not Heavy	4
Easy to Assemble	4
Radio controlled	5

Starting at the top of table 1, flying is a very highly weighted requirement because if the plane does not fly, the team will not go to the competition, wasting the school's monetary resources and poorly representing the program. The second requirement of landing is weighted lower at a 3 because if the aircraft makes it to the ground in one piece and within the defined zone, there is no competition point deduction. Flying multiple times is rated at a 5 because there are multiple competition trials and the final score is the sum of all trial scores. Being compact was rated as a 4 because the entire plane must be able fit inside the box described in the project description or else the plane is not competition legal and thus, the team would not be able to compete. The transportable requirement is rated lower at a 2 because the requirement of making the plane fit in a box makes it inherently transportable, that in addition to the planes small size, makes transport easy and something that does not need to be specifically designed for. Durable is next on the list and rated at a 3 because if the aircraft is durable, it does not need to be easily repairable. The opposite is also true given the weight of 3. Easily repairable is a 4 because it is lighter to build an easy-to-repair plane than a durable one. Battery powered is rated at a 5 because that is a mandatory competition requirement. The maximum battery that can be used is a 2200mah 3c LiPo. Safe and radio controlled are also rated as a 5 because of their mandatory to competition component. The last 2 requirements are rated as a 4. Those being not heavy and easy to assemble because while they are important to performing well in the competition, they are not mandatory to compete.

2.2 Engineering Requirements (ERs)

Engineering requirements were obtained from the customer requirements. As the client provides only the description of the project, engineering requirements are the technical values of the project. These requirements will be fulfilled at the end of the project. If these requirements are not fulfilled by the end of the project, then the project will not be accepted into competition. The reason for making the engineering requirements is to quantify customer requirements with technical values to determine the success of the project. The safety requirement can be measured in terms of current to determine if the current is safe enough to handle. In the same way, the weight of the aircraft will determine if the aircraft will fly and meet the weight requirement of the constraint box not weighing over 10 lbs. Table 2 shows the engineering requirements that were generated.

Table 2: Engineering requirements

	Engineering Requirements (ER)	**Target**	**Tolerances**
ER 1	Stability [Center of Gravity (CG)]	0 inches	± 0.2 inches
ER 2	Distance from Flight to Complete Stop	200 feet	± 10 feet
ER 3	Number of Trials	8 flights	± 1 flight
ER 4	Total Volume of Aircraft	350 cubic inches	± 10 cubic inches
ER 5	Total Volume of Box	610 cubic inches	± 20 cubic inches
ER 6	Material Strength	100 psi	± 5 psi
ER 7	Time to Repair	10 minutes	± 1 minute
ER 8	Voltage	11.1 volts	± 0 volts
ER 9	Number of Technical Safety Requirements Met	10 requirements	± 1 requirement
ER 10	Mass	2 pounds	± 0.3 pounds
ER 11	Time to Assemble	2 minutes	± 30 seconds
ER 12	Frequency	2.4 GHz	± 0 GHz

2.3 Testing Procedures (TPs)

Testing procedure 1 correlates to testing the stability of the aircraft. Testing the stability or center of gravity of the aircraft was accomplished by lifting the aircraft up by the ends of the wings and visually determining if the aircraft pitches forward, backwards, or stays level. The aircraft was picked up by the team members. The center of gravity was at the correct location and was considered a successful center of gravity.

Testing procedure 2 correlates to testing the distance from flight to complete stop. Testing the distance from flight to complete stop was accomplished by landing the aircraft and measuring the distance from touchdown to a complete stop. The instruments used were a 200 ft. measuring tape. The team already has this equipment and will not have to acquire it. The test was performed by visually seeing where the aircraft touches down and measuring from this point to where the aircraft stopped. The requirement of stopping within 200 ft. will be considered a success.

Testing procedure 3 correlates to testing the number of trials of the aircraft. To test the number of trials, the aircraft was launched and landed multiple times. The instruments used were a stopwatch and the measuring tape. If the plane can complete a specified course and land within 5 minutes 8 times, the number of trials that the aircraft can complete will be considered a success. However, the aircraft was not able to fly correctly, and this testing procedure failed.

Testing procedure 4 correlates to the total volume of the aircraft. To test the volume, the aircraft was disassembled into its subassemblies and placed inside the required box. The required box from customer requirements was built out of cardboard. The aircraft was able to fit within this constraint and the constraint was considered met.

Testing procedure 5 correlates to the total volume of the box. To test the volume of the box, the box was constructed based on the constraints of 12.125 inches x 3.625 inches x 13.875 inches. A tape measure was used to verify that the box size meets this constraint. The tape measure was already acquired and did not have to be bought. The box volume met this constraint and was considered met.

Testing procedure 6 correlates to the material strength. To test the material strength of the aircraft, the aircraft was flown and landed multiple times. A visual scan will determine if any pieces or subassemblies separate from the aircraft. During flight tests, no pieces came off and this criterion was met.

Testing procedure 7 correlates to the repair time of the aircraft. Due to the materials of the wing being Monokote and balsa wood, a stopwatch was used to determine the cure time of the Monokote. Using this time as a reference measurement, a time to repair for a wing section was calculated. If the time to repair a wing section is less than 10 minutes, this requirement will be considered met. The time to repair took roughly 5 minutes each time and this meets the requirement.

Testing procedure 8 correlates to the voltage of the battery. A voltmeter was used to measure the voltage of the battery. If the voltage read from the voltmeter is less than or equal to 11.1 V, this constraint will be considered met. The voltage read was almost directly 11.1V and this requirement was met.

Testing procedure 9 correlates to the number of technical safety requirements met. The aircraft was visually inspected to determine if the aircraft meets the safety requirement constraints as given by the SAE Aero rules. If the aircraft meets all safety requirements, the safety of the aircraft will be considered a success. The aircraft passed technical inspection at competition which meets this requirement.

Testing procedure 10 correlates to the mass of the aircraft. The aircraft was placed on a scale to determine if the aircraft weight is less than 2 lbs. A scale has already been obtained and did not have to be purchased. If the aircraft weight is less than 2 lbs, the mass requirement will be considered a success. The weight of the aircraft was 0.75 lbs. meeting the requirement of being less than 2 lbs.

Testing procedure 11 correlates to the assembly time of the aircraft. The aircraft was sealed within the required box. A stopwatch was started, and the aircraft was gathered from the box and assembled. Once the aircraft was fully assembled, the stopwatch was stopped. If the time to assemble is less than 2 minutes, the time to assemble requirement will be considered a success. The time to assemble the aircraft was 3:30 minutes, which failed the requirement of less than 2 minutes.

Testing procedure 12 correlates to the frequency of the controller. A Spektrum Dx8E was used for aircraft control. Manufacturer's specifications were found online and was considered correct. The manufacturer’s specifications stated that the Spektrum Dx8E controller has a frequency of 2.4 GHz. This requirement meets the required frequency given by the SAE rules.

These testing procedures were conducted at the end of the first semester and throughout the second semester and determined if the aircraft is acceptable to fly for competition.

2.4 Design Links (DLs)

Each design link (DL) will be correlated to the engineering requirements. Design link 1 (DL1) will correlate to ER 1, design link 2 (DL2) will correlate to ER 2, and this pattern will continue until DL12.

For DL1, the center of gravity was located where predicted. This falls within the requirement of being 0 inches from the center of the aircraft. This was verified by using a CG stand as well as verifying by hand holding the aircraft. The aircraft was placed with CG stickers at the needed location

For DL2, it was uncertain if the aircraft passed this requirement. The aircraft was unable to fly correctly resulting in uncertainty in this requirement.

For DL3, the aircraft failed this requirement. The aircraft was unable to complete one full trail and resulted in crashes each attempt. This resulted in not completing this requirement.

For DL4 and DL5, each of these were successfully completed. DL5 dictated the size for DL4 and due to the aircraft successfully being contained in the required box dimension, both of these size constraints were met.

For DL6, the materials chosen were birch wood, aluminium, and monokote. Each of these materials has a material strength well over 100 psi and this requirement of material strength being over 100 psi is met.

For DL7, the time to repair the aircraft took an average of 5 minutes. The maximum time was a 10 minute repair and the aircraft needed to be repaired a total of 4 times. Three out of the four times resulted in a time under 10 minutes. However, one repair took over 10 minutes due to the cure time of the epoxy used. With three out of the four times being a success, this requirement was met.

For DL8, the voltage of the battery was 11.1 volts. This battery was a store bought battery and the voltage specified was 11.1 volts. This verified the requirement of meeting the 11.1 volt given by the SAE guidelines.

For DL9, the number of safety requirements were set by SAE. The design and construction of the aircraft were based upon these safety requirements. The team met all of the safety requirements set by SAE and this resulted in ER9 to be met.

For DL10, the total weight of the aircraft was 0.75 lbs. This is well under the 2 pound limit and this was verified using a scale. Due to this, the ER9 was considered met.

For DL11, the time to assemble was a maximum of 2 minutes. During competition, the assembly time took 3 minutes and 30 seconds. This is a minute and a half over the 2 minute time limit that was set. This resulted in this requirement not being met.

For DL12, the frequency of the transmitter was rated at 2.4 GHz. This was required by SAE and the transmitter met this requirement. This resulted in ER12 being met.

Based on the each DL, the aircraft passed 9 out of the 12 requirements, failed 2 out of the 12, and was uncertain on 1 out of the 12 requirements.

2.5 House of Quality (HoQ)

Based on the customer requirements (CR) and engineering requirements (ER), a house of quality was made to show comparisons between the two requirements. The house of quality has target values and improvement directions for ERs. The absolute technical importance (ATI) is the sum of the relative weights multiplied by the relation between CRs and ERs. The relative technical importance (RTI) is the ranking from one to twelve of each ER based on the results of ATI. Table 3 shows the house of quality.

Table 3: House of quality

Stability (Center of Gravity)											
Distance from Flight to Complete Stop											
# of Trials	+										
Total Volume of Aircraft	+										
Total Volume of Box				++							
Material Strength	+										
Time to Repair				+		++					
Voltage											
# of Technical Safety Requirements Met								++			
Mass	++	++		++	-	+					
Time to Assemble				+							
Frequency											

Legend	
1	Weak Correlation
3	Moderate Correlation
9	Strong Correlation
--	Very Weak Correlation
-	Weak Correlation
+	Strong Correlation
++	Very Strong Correlation

Benchmarking Legend	
A	MQ-1C Grey Eagle
B	NAU 2017 Micro Team
C	MIT 2018 Micro Team

Row	Relative Weight (1 - 5 with 5 being most important)	Engineering Requirements / Customer Needs	Stability (Center of Gravity)	Distance from Flight to Complete Stop	# of Trials	Total Volume of Aircraft	Total Volume of Box	Material Strength	Time to Repair	Voltage	# of Technical Safety Requirements Met	Mass	Time to Assemble	Frequency	Very Poor	Poor	Average	Good	Very Good
		Direction of Improvement Minimize (▼) Maximize (▲)	▲	▼	▲	▲	▲	▲	▼	▲	▲	▼	▼	-	**Competition Benchmarking**				
1	5	Fly	9		9	3		3		3	9	9		3		B			AC
2	3	Land	9	9	9	3		3		1	9	9		3	C		B		A
3	5	Fly multiple times			9			9	9	1	9					B			AC
4	4	Compact				9	9					3			A		B	C	
5	2	Transportable				9	9					3			A			B	C
6	3	Durable			9	9	9	9	3							B	C		A
7	4	Easily Repairable			9	9		9	9								A		BC
8	5	Battery powered								9					A				BC
9	5	Safe	9	9						3	9			9			BC	A	
10	4	Not heavy	3			9	9	3			3	9				A			BC
11	4	Easy to assemble	1			1	3						9		A			B	C
12	5	Radio controlled								1				9					ABC
	Technical Requirement Units		in	ft	#	in^3	in^3	Psi	min	V	#	lbs	min	GHz					
	Technical Requirement Targets		0	200	8	350	610	100	10	11.1	10	2	2	2.4					
	Absolute Technical Importance		133	72	180	181	129	144	90	88	174	126	36	114					
	Relative Technical Importance		5	11	2	1	6	4	9	10	3	7	12	8					

The ER that ranked first RTI was the total volume of the aircraft. The total volume of the aircraft is the sum of volumes of each part of the aircraft. The improvement direction is to maximize the total volume of the aircraft because each part should be maximized to generate the greatest lift or generate the maximum thrust. The second was number of trials. The number of trials relates to the number of times we can take off, land, and take off again. The improvement direction is to maximize the number of trails due to judging based on how fast the aircraft can complete the given number of trials. If the trials that the aircraft can complete is greater than the amount allowed at the competition, the aircraft should have a reliability greater than one. The reliability is how reliable the aircraft is compared to a base standard of simply meeting all the requirements. The third was number of technical safety requirements met. The technical safety requirements met is the amount of safety requirements the aircraft meets based on competition rules. The improvement direction is maximizing the safety requirements met because if the aircraft does not meet or exceed all the safety requirements, the aircraft will not be able to compete. The ER that was ranked last was time to assemble. The time to assemble is how fast the aircraft can be built when disassembled and contained in a box. The improvement direction is to decrease the time to assemble due to a judging score at competition being higher for a lower time to assemble. This is ranked last compared to the other ERs but is still a high importance to the competition.

Competition benchmarking was based upon the designs in section 3.2. These existing designs were compared to the customer requirements that were developed and were scored from very poor to very good. The legend in table 3 shows which existing design correlates to the letters designated in the competition benchmarking section. Most designs had a "very good" score in this section and these correlated to customer requirements such as flying, flying multiple times, easily repairable, battery powered, not heavy, and radio controlled.

The hat of a house of quality correlates engineering requirements to other engineering requirements. Table 3 shows the hat of the house of quality and can be distinguished by the double pluses, pluses, minuses, and double minuses. Mass had the biggest effect on other engineering requirements which were stability, distance from flight to complete stop, total volume of aircraft, total volume of box, and material strength. Mass can influence stability of the aircraft due to if the mass of the aircraft increased, the dynamic stability would increase. Mass can also influence the distance from flight to complete stop due to if mass increases, the distance to stop may increase during landing. More correlations can be found in the hat of the house of quality in table 3.

By using a house of quality, the team was able to prioritize tasks related to concept generation. These tasks allowed the team to focus on maximizing the amount of lift is generated over the wing, increasing the number of trials the aircraft can complete by designing reliable connecting joints and landing gear, and maximizing the number of technical safety requirements met by implementing each safety restraint given by the competition rules. The lower ranked ERs were not ignored and were still considered in the concept generation phase.

3. EXISTING DESIGNS

The task of designing an aircraft to compete at SAE Aero Design West has been done many times by many teams and the goal of the competition to carry as much payload as possible for the weight of the craft. As a result, there is a plethora of information on designs and practices used to produce such aircraft. Three existing designs were researched, and the findings are found in this section. Research was done on the Northern Arizona 2017 team, the MQ-1C military drone, MIT's 2018 team, and details on NACA 2412 airfoils, Clark Y style airfoils, and NACA 6409 airfoils.

3.1 Design Research

Benchmarking was used to research existing designs. The first design that was considered was Northern Arizona University 2017 SAE Aero Micro Team [2]. This design is a simple one motor with a straight tail. The wings have full length ailerons and the tail has a full-length elevator across the horizontal stabilizer and a full-length rudder across the vertical stabilizer. One problem the team identified was no landing gear in the tail section. This could cause rough landing and possible detachment of the tail section. Another issue was the full-length aileron. The team initially determined from this design a full-length aileron may not be as efficient as having a small aileron towards the tip of the wing. Based on this design, the team was able to concept generate several wing designs and landing gear.

The second benchmark was the MQ-1C Grey Eagle [3]. The Grey Eagle is a military drone with a complex tail section. The tail section has an inverted V-tail and a small horizontal stabilizer. The drone has a higher aspect ratio than a micro plane due to the application of being a slider. This design gave the team concepts on how to design the tail section. One issue the team noticed that may occur if this tail section was selected was the complexity of constructing this tail. The team would have to calculate the angle needed on each tail fin and then correctly construct this design.

The third benchmark was Manipal Institute of Technology (MIT) 2018 SAE Aero Micro Team [4]. This design is also a simple one motor with a straight tail section. The fuselage is box shaped and the wings appear to be telescoping. This design gave the team concepts on how to construct a compact wing and shapes of the fuselage. One problem the team identified was the box shape of the fuselage. This would create substantial drag and could cause issues in flight. Another problem the team noticed was the telescoping wings. If the team chose a design that telescopes, the telescoping would have to be forced open to ensure that it would not close during flight.

A web search of airfoils for airplanes was conducted to determine an appropriate airfoil. The first airfoil selected was the NACA 2412 airfoil based upon the Cessna 319 [5]. This airfoil is a basic airfoil used however, the lift vs drag at the Reynolds number that the aircraft would be flying at may be an issue [6]. The second airfoil is a Clark Y airfoil based upon recommendations of the airfoil used on remote controlled model aircraft [7]. This airfoil may be better due to the general application of this airfoil to generate lift from its high camber. These airfoils will be analysed further in an analytical analysis to determine the airfoil that will be used.

3.2 System Level

The team has chosen three system levels in the design of the aircraft for competition. The first is landing gear, the second is tail section, and the last is wing and propulsion. The benchmarks the team used for designing the plane can be seen below and each has a different aspect of these subsystems the team would like to adopt in the design of the competition aircraft.

3.2.1 Tricycle: Landing Gear Section

Figure 1 shows tricycle landing gear on an aircraft [8].

Figure 1: Tricycle landing gear

Tricycle landing gear is a formation of gears to land the aircraft on the ground. Landing gear is a system which controls the aircraft to land on the ground or uses for take-off as well [8]. Tricycle landing gear has a single tire at the front side and two tires on the wings to provide a better push for take-off and provide higher control during the landing phase. When the aircraft will land using tricycle landing gear, it will become easier to stabilize the aircraft and the aircraft will not misbalance.

3.2.2 MQ-1C Grey Eagle: Tail Section

Figure 2 shows the MQ-1C Grey Eagle with a unique tail design.

Figure 2: MQ-1C Grey Eagle

Tail design is an important consideration in aircraft design as it attributes to drag which negatively affects the aircraft and control which is essential to flight. The goal is to design a tail section that gives maximum control while producing the lowest possible drag. In figure 2 above the MQ-1C grey eagle, a military drone used for delivering payload at long ranges, is pictured and at the rear of the aircraft there is a type of tail called a V-tail. These tails are known for producing lower drag and being lighter weight than a conventional tail section. The reason for reduced drag is due to less wetted surface to create drag but also creates a lighter weight with this design [9]. The design the team would like to pursue is something similar being lightweight and low drag, two criteria the team is designing for.

3.2.3 MIT's 2018 Micro Team: Wing Section

Figure 3 shows MIT's 2019 Micro aircraft.

Figure 3: MIT's 2018 Micro Team

The wing design is important to the design of the aircraft due to the requirement of being able to assemble the aircraft in a specific time frame at competition. Since there are size requirements on the container that the aircraft must fit in, the wing will have to be in sections and assembled using connectors. MIT's team uses a telescoping wing that will expand when pulled and contract when pushed. This design may cause stability issues in flight due to flexing of the telescoping section of the wing. This design gave the team ideas of how to construct the wing to be collapsible into sections.

3.3 Functional Decomposition

The main function of the project is to fly a plane. The team used a black box model to visualize the material, energies, and signals required to fly a plane. The materials needed to fly a plane are airflow, controller, wing, and motor. These are then outputted as lift, drag, a controller, and a wing. The energies required are electrical and human energies. The output energy created is thrust. The signal required is a radio frequency. The output signals are noise, visual, and an on/off signal. Using this black box model, a functional model can be generated. The functional model uses these black box model inputs and outputs and visualizes the process of how each input is transformed into an output. There are two functions that are independent of each other. The first is converting airflow to lift and drag. The second is converting electrical energy to thrust. The black box model and functional model are further discussed below.

3.3.1 Black Box Model

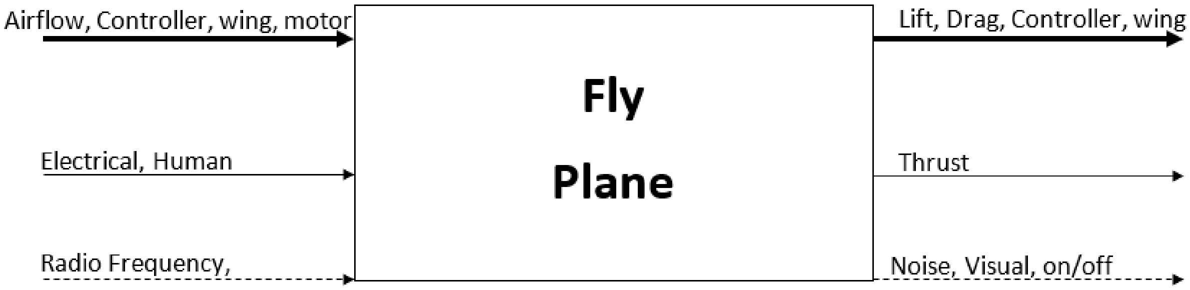


Figure 4: Black Box Model

The black box model in figure 4 above shows the goal for the design on the inside and the materials, energy, and signals going in and out of the box. The purpose of this model is to take the individual components out of the system so that it becomes possible to analyse the essential flows in and out of the system needed to make it operate. Materials going into the model above are airflow, the wing, the controller, and the motor. Those materials go into the model and leave the system as lift, drag, the controller, and the wing. Energy put into the model is electrical and human energy. Human energy is used in hand launching the plane and electricity is introduced from the battery in the plane. Those energies go through the system and leave as thrust. Lastly, radio signal goes into the system and leaves as a noise signal due to motors running and servos turning. A visual signal is produced by the plane changing direction and an on or off signal is produced by a light signalling whether the aircraft is turned on or off.

3.3.2 Functional Model

A functional model is a model which defines the complete system processing and shows the parts of the project.

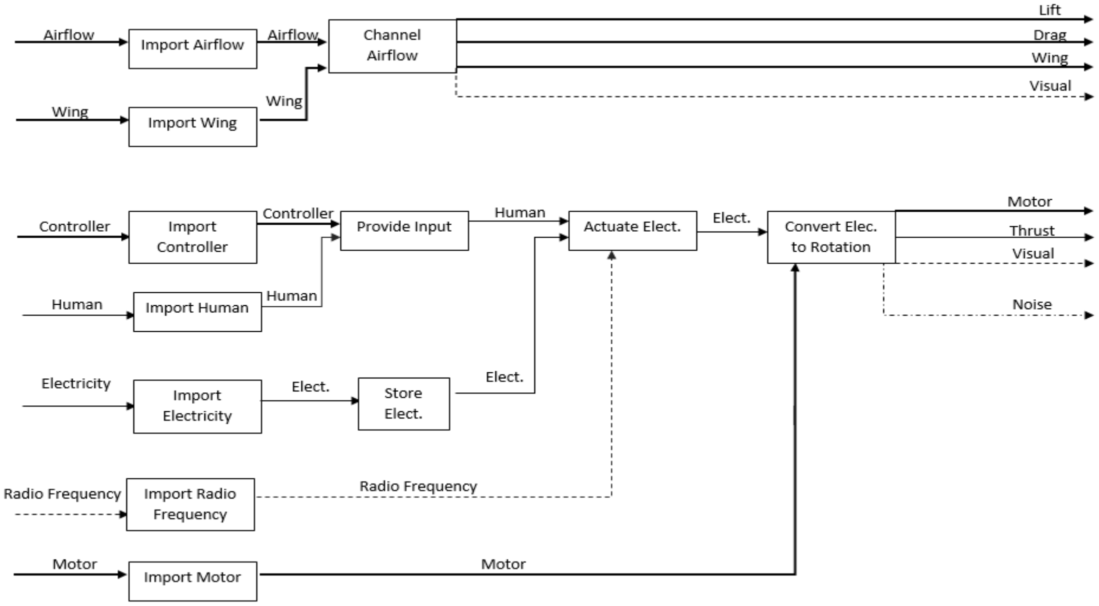


Figure 5: Functional Model

Figure 5 shows the functional model. All the subparts of the system are defined in functional decomposition. Functional decomposition explains the complete project so anyone looking at the functional decomposition model can tell how the project works. The functional model has two separate channels. The first is the airflow which uses the wing to generate lift and drag. The second is converting electricity and human energy into thrust by using the motor. The outputs of converting these energies into thrust include a noise and visual signal.

3.4 Subsystem Level

This section discusses designs considered and how they meet, or defeat customer and engineering requirements outlined for the project. The 3 major subsystems of the aircraft are flight and thrust, maneuvering, and landing. These subsystems are designed separately and then the best of each can be combined into a final system design.

3.4.1 Wing and Propulsion

The function of flight and propulsion is controlled by two things. The first being wing design and the second being motor and propeller design and placement. This category of design functions to serve in the flight, payload capacity, as well as weight and reliability, all of which are engineering or customer requirements.

3.4.1.1 Single Engine Overhead Wing

The most common small aircraft design is a single engine overhead wing design. The design offers several advantages, specifically for the requirements of this project. The first is that it is a very light weight design with only one motor and electronic speed controller needed reducing the weight of the overall aircraft significantly, while also making design and construction of the plane simple. The layout of the plane can be seen in figure 6 below.

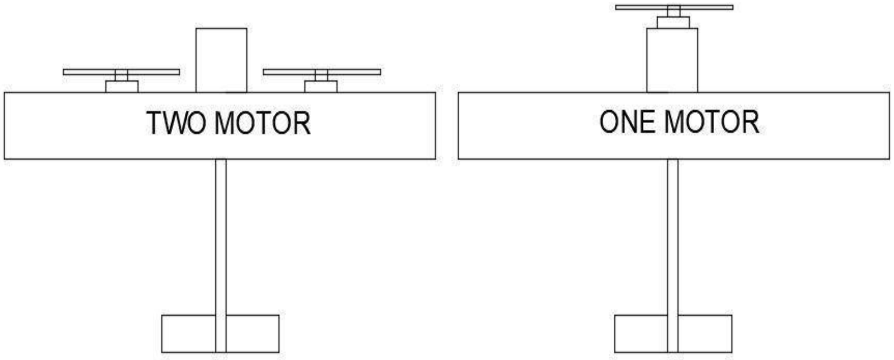


Figure 6: One vs. two motor aircraft layouts

3.4.1.2 Twin Engine Overhead Wing

The goal in this design was to maximize thrust and reliability by adding a second motor and placing one on each wing. The layout of a twin engine can be seen above in figure 6. This would provide more thrust at the cost of more weight but would also enable a V-tail, which would eliminate the need for a vertical stabilizer. More thrust would allow for more payload and the second motor would make the reliability and ability to fly multiple timers higher. However, the voltage draw would be much higher than a single motor and would reduce the battery life and in turn, flight time. In addition, repairing 2 motors would create a level of complexity that could be hard to overcome in the event of a serious repair needing to be done.

3.4.1.3 Airfoil Design

The last part of the functional model that needs to be evaluated for flight is the design of the wing. For this, three styles of designs were considered. The first a slightly cambered airfoil similar to a NACA 2415. The slightly cambered is shown in figure 7.

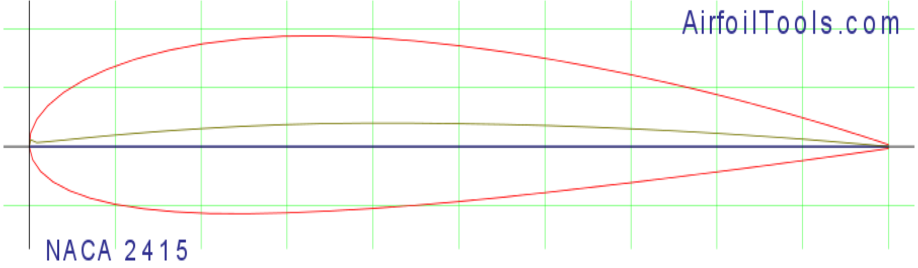


Figure 7: Low camber airfoil [10]

The second a heavily cambered airfoil which would increase lift but also drag which would tax a single motor system. The heavily cambered airfoil is shown in figure 8.

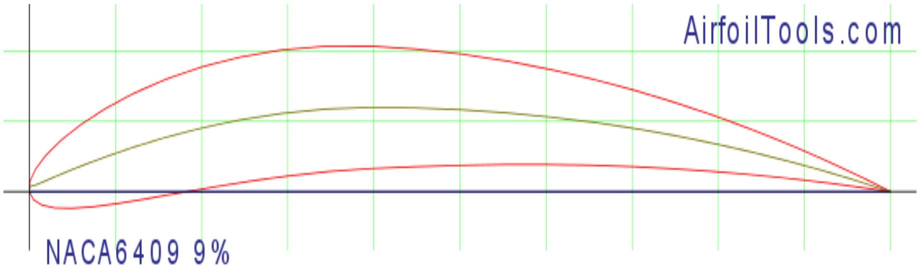


Figure 8: High camber airfoil [11]

The third is a general airfoil that is used on model aircraft. The Clark Y has a high camber for an efficient lift to drag ratio and flat bottom edge which makes the wing easier to construct [7]. The Clark Y airfoil is shown in figure 9.

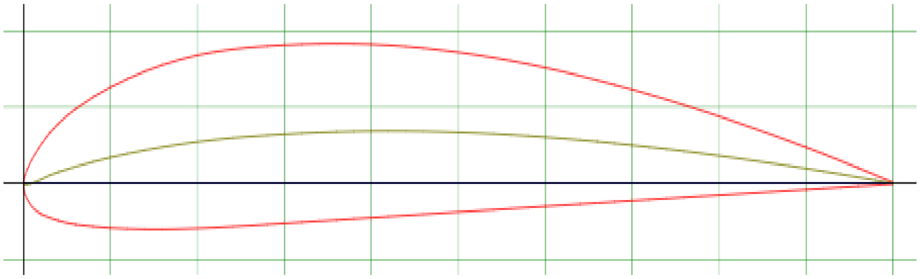


Figure 9: Clark Y Airfoil [12]

In terms of customer and engineering requirements, the advantage for payload capacity is a heavily cambered airfoil but in terms of battery life and voltage draw, a slightly cambered airfoil is more efficient. A smaller more symmetric airfoil would also consume less volume in the box for packing purposes giving additional reasoning for choosing a lower camber design. However, due to weighting of requirements and that the purpose of the design is to carry maximum payload, all three needed to be considered carefully.

3.4.2 Maneuvering Devices

The maneuvering devices for this design include radio controllers, servos, and control surface configuration. Because all radio controllers will be similar, and servos can be sized only after configuring and sizing control surfaces. This section will focus mostly on the number and configuration of control surfaces. The course described by the SAE rules is a loop and therefore maneuvering is critical to take off, landing, and maneuvering the course to complete a trial, of which there are multiple in the competition. Additionally, the controllability of the aircraft is a huge factor in safety. These effects are customer or engineering requirements making them important to design for.

3.4.2.1 Conventional Aileron, Elevator, Rudder

This design is what can be seen on many small full-scale aircraft as well as many conventional model planes shown in figure 10.

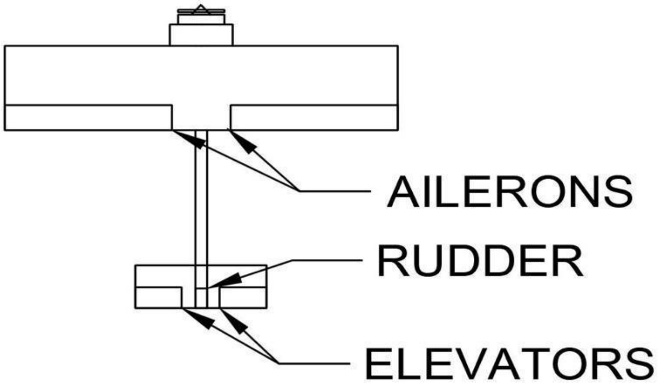


Figure 10: Control surfaces of an aircraft

The advantages are that the design has been done many times and rule of thumbs for designing this type of system are well established. However, in relation to our engineering requirements, the mass of the 4 or 5 servos required to operate these control surfaces are great and not only negatively affects payload capacity, but also increases the overall unloaded weight of the aircraft, a requirement the design will be scored upon. This makes this design while conventional, undesirable for the purposes of this design project.

3.4.2.2 Ailerons and Differential Thrust

This is the most unique of the designs considered. The purpose of the design is to have 2 motors that can supply differential thrust for yaw authority. This would then allow for a lower drag V-tail to be used and would only require 2 servos to control the elevators. In doing so, this design trades weight of servos for additional thrust. The increased thrust would translate to improved payload capacity but would also increase weight, so the trade-off needs to be considered. This design is shown in figure 11.

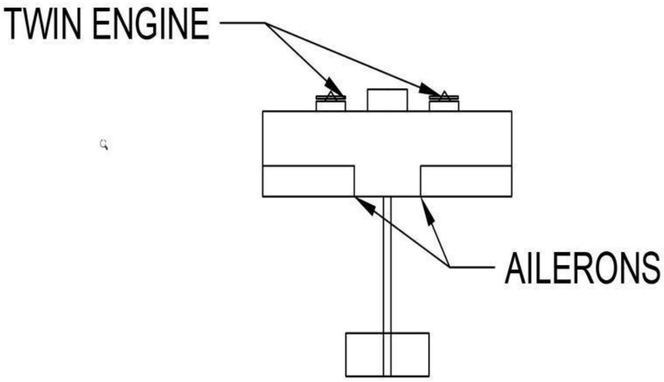


Figure 11: Differential thrust and ailerons

3.4.2.3 Rudder and Elevator

This design is based on other lightweight trainer aircrafts control systems. It utilizes one rudder and one elevator servo providing elevation and yaw. The advantages are that this system only requires one motor and 2 servos which reduces mass while maintaining control of the aircraft. Reducing mass increases payload which helps in scoring. A consideration for this design though, is when the weight of payload is added, will the aircraft remain controllable? This question needs to be answered before a final decision can be made. The design is shown in figure 12.

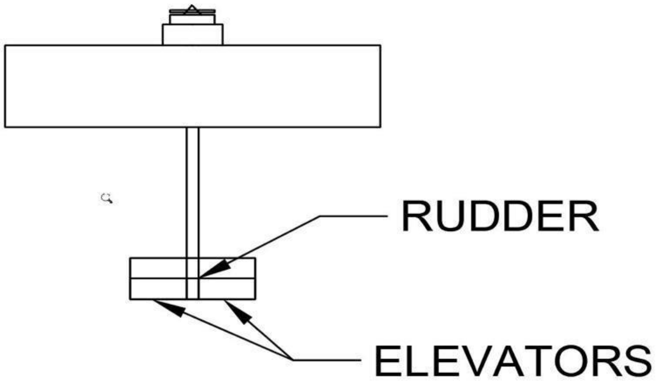


Figure 12: Rudder and elevator, 2 servo control

3.4.3 Landing Equipment

A major requirement given by the SAE guidelines is that the plane must land in a zone 200 feet long and remain in one piece. If any piece comes off during the landing or flight, the trial is scored a zero negatively affects competition results. Another SAE requirement is that any plane with wheeled landing gear must be controlled by a rudder servo. These two requirements make design challenging as servos are heavy as is landing gear. Weight and drag are the largest considerations in this subsystem.

3.4.3.1 No Gear

The lightest possible design it is possible if landing in grass to potentially have no landing gear at all as shown in figure 13.

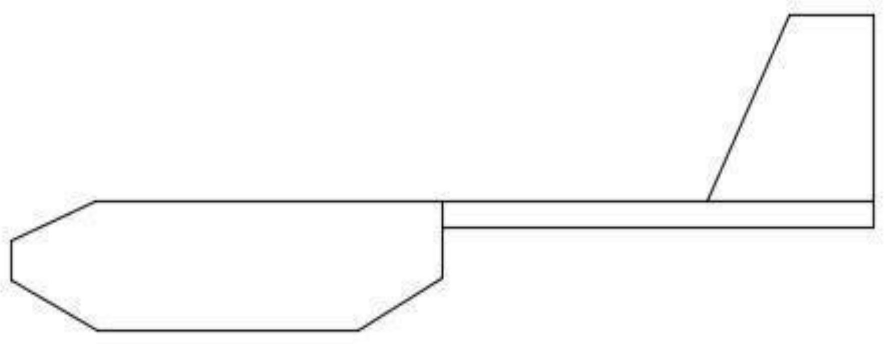


Figure 13: No landing gear

There is a risk of breaking propellers or damaging the airframe as a result of this method but from a purely weight perspective, it is the lightest option which means more payload can be carried.

3.4.3.2 Wheeled Gear

The most common design is to have 2 wheels in the front of the plane and 1 in the rear controlled by the rudder servo. This design is likely the heaviest and includes considerations for how to support the landing gear and payload on landing due to the forces involved in doing so. This meets competition safety requirements and engineering requirements for successful trials and multiple flights because the risk of damaging the aircraft is greatly reduced. The design can be seen in figure 14 below.

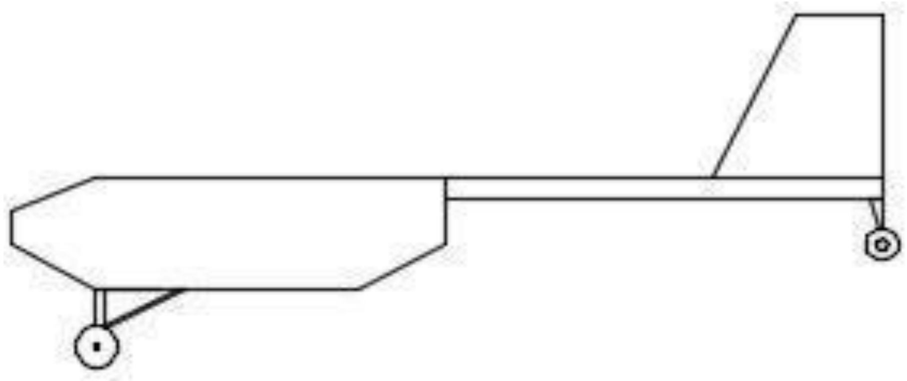


Figure 14: Wheeled landing gear

3.4.3.3 Wheeled Front Gear and Skid Rear

When considering a twin-engine design with differential thrust and no rudder servo it becomes apparent that due to rules, the design could not have wheeled rear landing gear because there would not be the required control for taxiing. To overcome this, the team designed a skid style landing gear for the tail that would aid in slowing the aircraft down as it landed while also maintaining compliance with the rules. This design, however, relies on two motors which adds weight and defeat the purpose of the customer requirements as stated. The design is seen below in figure 15.

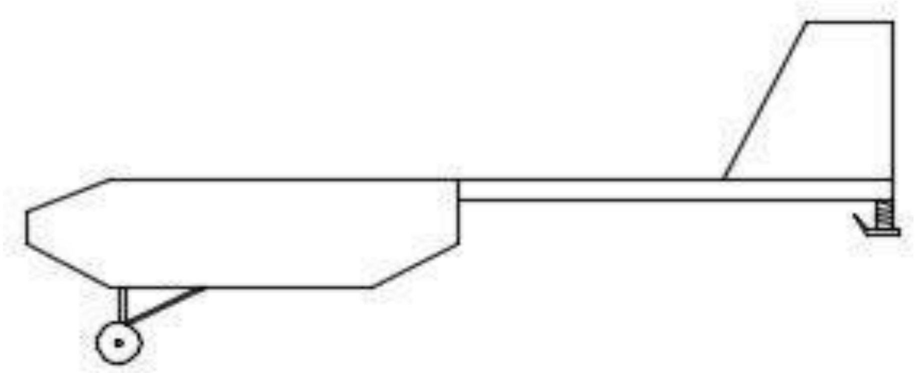


Figure 15: Wheeled gear plus skid

4. DESIGNS CONSIDERED

The team generated ten different total aircraft. The concepts were generated by combining different parts of different aircraft. The following sections detail each design and the pros and cons of each design.

4.1 Twin engine V-tail With Skid Rear Gear

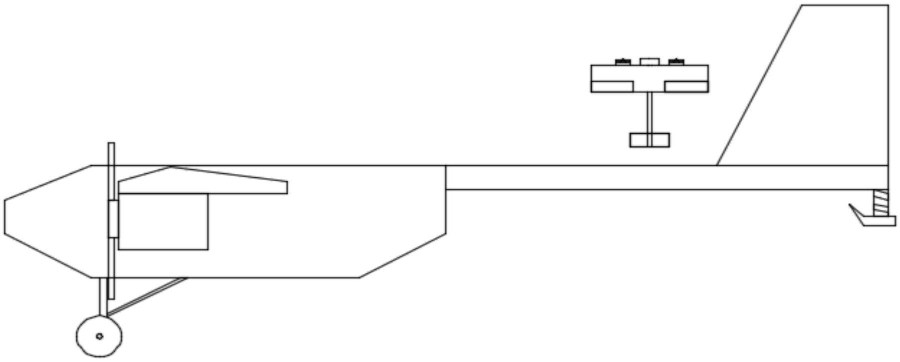


Figure 16: Twin engine; V-tail with skid rear gear

Figure 16 shows a twin-engine aircraft with a rear skid. There are two engines and ailerons on the wing, a V-tail, and a rear skid for landing. The front has two wheels due to the need to roll the aircraft. The rear skid is used to stop the aircraft during landing. A pro of this design is the safety factor with two motors. If one motor is lost, the aircraft can be controlled with one motor up to a degree. A con of this design is the complexity to construct. The manufacturing process of a V-tail is very complex to determine the angles required.

4.2 Single Engine, Conventional Control, Wheeled Gear

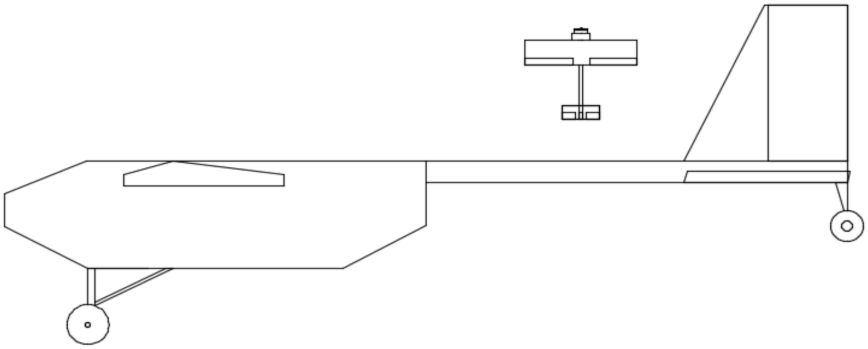


Figure 17: Single engine; conventional control; wheeled gear

Figure 17 shows a single engine aircraft with a straight tail and wheeled landing gear. The motor is mounted on the front of the fuselage and the aircraft has ailerons, elevators, and a rudder. The landing gear is all wheels. If the power to the motor is cut during landing, the wheels should be able to stop the aircraft. A pro of this design is simplicity of manufacturing. This is due to the ease of constructing a straight tail versus a V-tail. A con of this design is the non-uniqueness. This design is a conventional aircraft and does not have any unique features.

4.3 Single Engine, Elevator and Rudder Control, Wheeled Gear

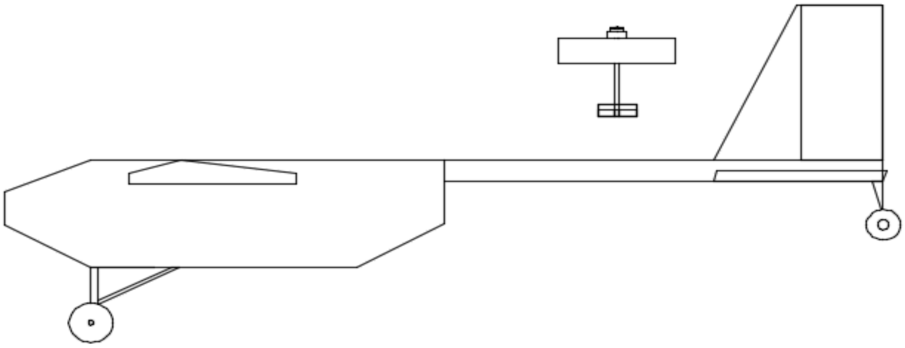


Figure 18: Single engine; elevator and rudder control; wheeled gear

Figure 18 shows a single engine aircraft with a straight tail, wheeled landing gear, and no ailerons. The motor is mounted on the front of the fuselage and the aircraft has elevators and a rudder. The landing gear is all wheels. If the power to the motor is cut during landing, the wheels should be able to stop the aircraft. A pro of this design is the elimination of two servos. The elimination of the two servos required for the ailerons eliminates weight and the aircraft can focus on payload. A con of this design is the possibility of not being able to bank during flight. The elimination of the ailerons forces the rudder to control banking and with high payloads, the aircraft may not bank.

4.4 Overhead Single Engine, Conventional Control, Wheeled Landing Gear

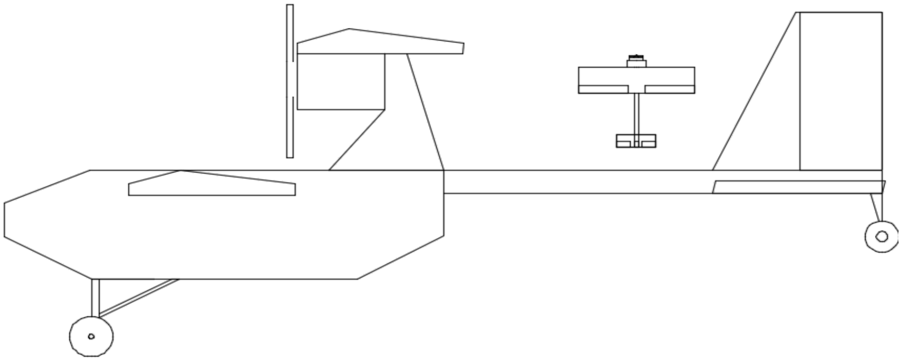


Figure 19: Overhead, single engine with ailerons

Figure 19 shows an overhead single engine aircraft with a straight tail and wheeled landing gear. The motor is mounted on top of the fuselage ailerons, elevators, and a rudder. The landing gear is all wheels. If the power to the motor is cut during landing, the wheels should be able to stop the aircraft. An advantage of this design is the uniqueness. This design has a motor on top of the fuselage creating a unique design. A disadvantage of this design is the wake generated by the engine. The wake generated by the overhead mounted single engine will cause issues with the tail section due to the flow hitting the tail being turbulent. This turbulent flow will cause issues with the rudder and elevators being able to perform efficiently.

Figures 33-38 in the appendix B show other designs considered. Figure 33 is a single motor aircraft with a straight tail and no landing gear or ailerons. This aircraft has an advantage of a single motor but has disadvantages of having difficulty to land and bank. Figure 34 is a single motor aircraft with a straight tail, front skids with a back wheel, and no ailerons. This aircraft has the advantage of being able to land quickly but has difficulty banking. Figure 35 is a single motor aircraft with a straight tail, a front skid with back wheel, and has ailerons. This aircraft has advantages of being able to land quickly and bank but would be slightly complex to construct. Figure 36 is a single motor aircraft with a straight tail, no landing gear, and has ailerons. This aircraft has the advantage of being able to bank but would have difficulty landing. Figure 37 is a two motors aircraft with a V-tail, full skid landing gear, and has ailerons. This aircraft has advantages of having two motors for thrust control and the ability to bank but it would be complex to construct. Figure 38 is a two motors aircraft with a straight tail, wheeled landing gear, and conventional controls. This aircraft has advantages of two motors for thrust control and the ability to bank but it would be very complex to construct.

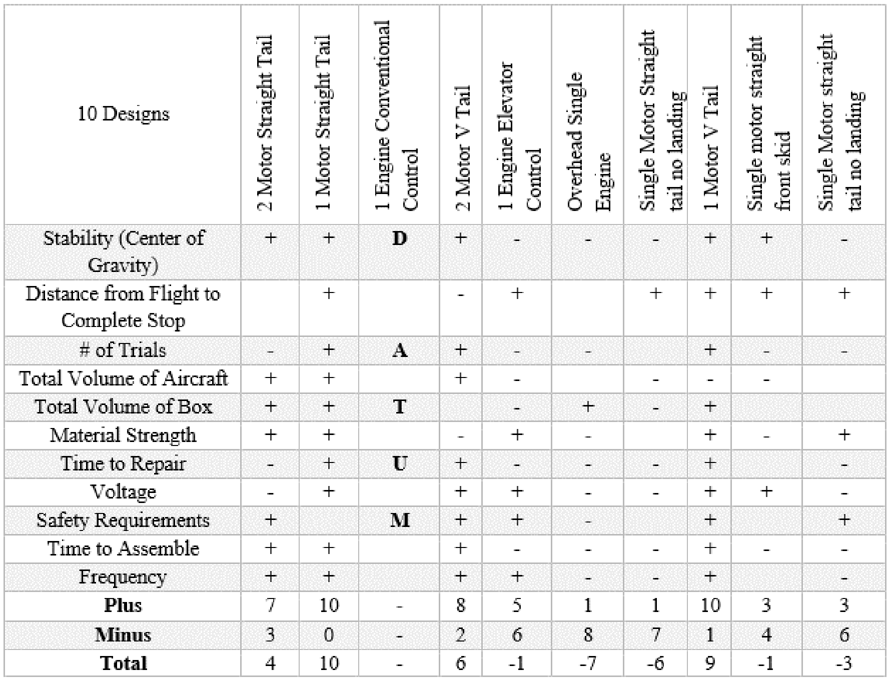
5. DESIGN SELECTED

In this is section, the best design was chosen by using a Pugh chart and a decision matrix. Weights were assigned to each category of the matrix based on customer and engineering requirements and how important each was to the overall performance of the aircraft. Below is the Pugh chart and the decision matrix analysis.

5.1 Rationale for Design Selection

A Pugh chart is a method to discriminate between the design ideas and identify the best design ideas according to certain criteria. This certain criterion can be either customer requirements or engineering requirements. A design is first considered to be the datum that the rest of the designs will be compared against. A positive or a negative sign will be assigned for each design based on the criteria. The positives and negatives will be summed up and the lowest sums will be eliminated. Table 4 shows the Pugh chart that was created.

Table 4: Pugh chart



10 Designs	2 Motor Straight Tail	1 Motor Straight Tail	1 Engine Conventional Control	2 Motor V Tail	1 Engine Elevator Control	Overhead Single Engine	Single Motor Straight tail no landing	1 Motor V Tail	Single motor straight front skid	Single Motor straight tail no landing
Stability (Center of Gravity)	+	+	**D**	+	-	-	-	+	+	-
Distance from Flight to Complete Stop		+		-	+		+	+	+	+
# of Trials	-	+	**A**	+	-	-		+	-	-
Total Volume of Aircraft	+	+		+	-		-	-	-	
Total Volume of Box	+	+	**T**		-	+	-	+		
Material Strength	+	+		-	+	-		+	-	+
Time to Repair	-	+	**U**	+	-	-	-	+		-
Voltage	-	+		+	+	-	-	+	+	-
Safety Requirements	+		**M**	+	+	-		+		+
Time to Assemble	+	+		+	-	-	-	+	-	-
Frequency	+	+		+	+	-	-	+		-
Plus	7	10	-	8	5	1	1	10	3	3
Minus	3	0	-	2	6	8	7	1	4	6
Total	4	10	-	6	-1	-7	-6	9	-1	-3

From table 4, a single engine, conventional control aircraft was selected as the datum. Each other design was rated against this design based on engineering requirements. The top four designs were the 1 motor straight tail, 1 motor straight tail, 2 motor V-tail, and 2 motor V-tail. These designs were then inputted into a decision matrix to determine the final design.

The decision matrix was created to evaluate the top four designs and choose the best one. These designs were evaluated based on the engineering requirements mentioned in section 2.2

Table 5: Decision matrix

		1 Motor Straight Tail		2 Motor Straight Tail		1 Motor V Tail		2 Motor V Tail	
Criterion	**Weight (%)**	**Score (1-100)**	**Weighted Score**	**Score (1-100)**	**Weighted Score**	**Score (1-100)**	**Weighted Score**	**Score (1-100)**	**Weighted Score**
Stability (Center of Gravity)	0.17	85	14.45	90	15.3	40	6.8	75	12.75
Distance from Flight to Complete Stop	0.1	70	7	60	6	75	7.5	65	6.5
# of Trials	0.07	50	3.5	50	3.5	50	3.5	50	3.5
Total Volume of Aircraft	0.12	40	4.8	30	3.6	60	7.2	40	4.8
Total Volume of Box	0.1	60	6	50	5	65	6.5	55	5.5
Material Strength	0.07	50	3.5	50	3.5	50	3.5	50	3.5
Time to Repair	0.07	80	5.6	30	2.1	20	1.4	10	0.7
Voltage	0.01	75	0.75	40	0.4	80	0.8	45	0.45
# of Technical Safety Requirements Met	0.15	50	7.5	50	7.5	50	7.5	50	7.5
Time to Assemble	0.13	75	9.75	40	5.2	75	9.75	40	5.2
Frequency	0.01	50	0.5	50	0.5	50	0.5	50	0.5
Total	**1**		**63.35**		**52.6**		**54.95**		**50.9**

Table 5 shows the decision matrix. Based on the results, the top result was the 1 motor straight tail design. This design is the easiest to construct and will give us the best thrust to weight ratio. This is the design that will be considered for competition and developed.

5.2 Design Description

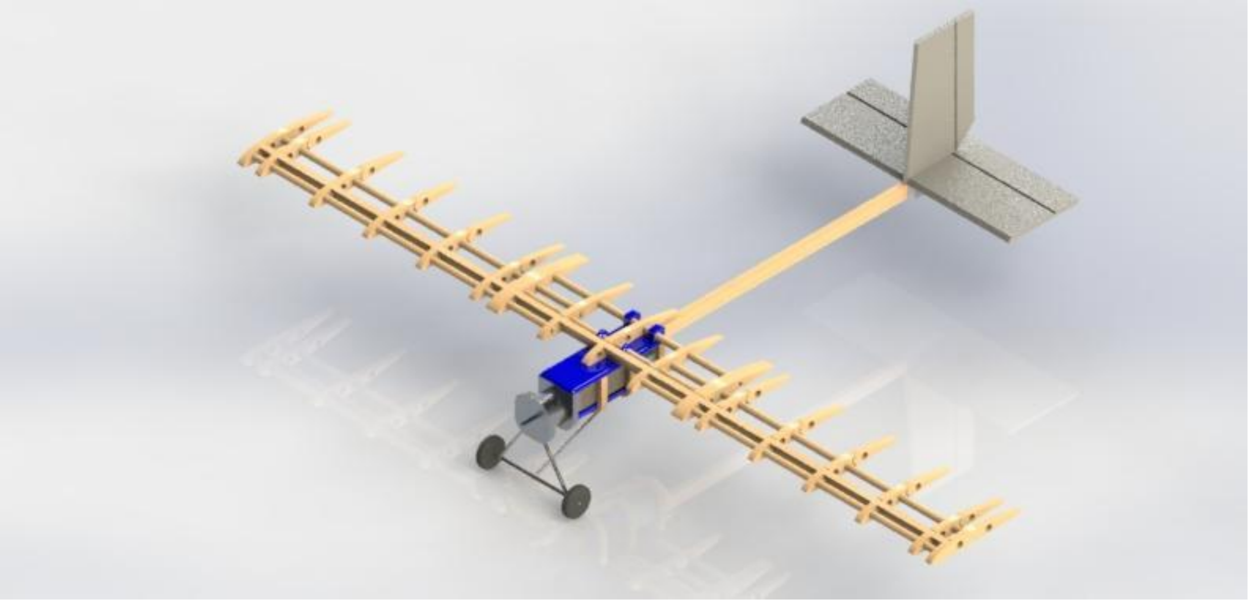


Figure 20: Design assembly

Figure 20 shows the design assembly. The materials used are primarily balsa with Dacron foam and limited 3D printed PLA components. These materials create a durable and lightweight construction. The fuselage and wing construction are modular with pieces interlocking that can then be glued in place. The interlocking features ensure that pieces will be placed in the correct position for tight tolerancing. Total assembly weight with batteries and electronics is 0.75 lbs.

5.2.1 Aerodynamics

The main wing, a Clark Y 11 airfoil, has a cambered airfoil profile and is 30-inches in length and has a 4-inch cord providing an aspect ratio of 7.5. The aspect ratio defines how maneuverable the plane will be. This aspect ratio allows for low drag while still producing high amounts of lift relative to size. The ribs will be laser cut, the spars are standard size ¼-inch dowels, and the shear web is made of balsa. This framework will then be wrapped in Monokote, a lightweight plastic that is applied as a skin, which will provide the wing shape. Then using a 3D printed part, the wing will be mounted to the fuselage using an M3 screw. Based on testing of a simulated model in RealFlight, this wing design will create adequate lift for our purposes. The wing assembly is pictured in figure 21 below.

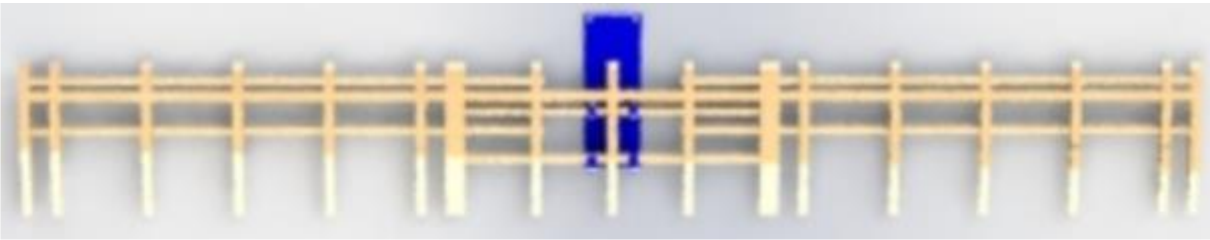


Figure 21: Wing assembly

Flight will be controlled by 4 control surfaces including two 10-inch long by 1-inch wide ailerons, a 5-inch by 1-inch rudder, and 9-inch by 1-inch elevator. Ailerons will control roll, elevators will control pitch, and the rudder will control yaw. Each control surface will be driven by 9 g HobbyKing micro servos which will provide adequate torque to safely fly the aircraft. These dimensions of control surfaces were modelled and tested using the RealFlight software and proven to be correct for the needs of this aircraft.

5.2.2 Propulsion System

The propulsion system is comprised of three components; the battery which supplies electrical energy, the motor which converts that energy to rotation, and lastly, the propeller which converts the rotation to thrust. The selected motor is a Scorpion SII-2212-1850. The selected battery is an 850mah 65c LiPo 3s battery. The selected propeller is an APC Electric E 7x4". To calculate the values that would be needed for a successful design, a subscription to online calculator built for model aircraft was used. The results were compared to find the best balance of weight to power and flight time. Based on these simulations, the motor chosen that will be used is a Scorpion SII-2212-1850kv motor. This motor, with the appropriately sized propeller, will create a 2.28:1 thrust to weight ratio assuming the plane weighs 1 lb. The plane weighs 0.6 lbs so the new thrust to weight ratio is 4.66:1 ratio. The compiled table results from the calculation are below in table 6.

Table 6: Motor sizing

Motor	Motor (kV)	Motor weight (oz)	Flight time(min)	Thrust to weight ratio
Scorpion SII-2212-1850	1850	2	5.5	2.28:1
Scorpion SII-2205-1490	1490	1.2	8.9	1.24:1
Scorpion S-1804-1650	1650	.4	8	0.98:1
Scorpion S-1805-2250	2250	.6	5.9	1.01:1

Taking that motor selection, a battery was then selected to optimize the minimum amount of weight possible for the desired flight time. Based on these calculations, an 850 mAh 65c battery was selected and the tabulated results that led to this selection can be seen in Table 7. Based on the short course required for competition, 5 minutes should be more than enough battery life to complete each trial.

Table 7: Battery size, weight, and life

Battery Size (mAh)	Battery weight (Oz)	Flight Time (min)
2200	2.2	14.4
1800	1.8	11.8
1600	1.6	10.5
1200	1.2	7.9
850	0.8	5.00

The propeller was sized using the same calculator with the selected motor and battery provided as parameters. Thrust to weight ratios were compared to cost of the propeller. Additionally, size and pitch of the propellers were compared to maximize thrust to weight ratio. Based on the calculations, a 7x4 APC Electric E propeller was the cheapest propeller that would supply the most thrust. Table 8 below shows the tabulated results.

Table 8: APX Electric E

Diameter x Pitch	Thrust to weight Ratio	Flight time (min)
6x3	1.29:1	7.2
6x3.5	1.47:1	7
6x4	1.65:1	6.8
7x3	1.84:1	5.8
7x3.5	2.08:1	5.7
7x4	2.3:1	5.6

6. PROPOSED DESIGN

The assembly shown in figure 22 is the final prototype CAD model of the design.

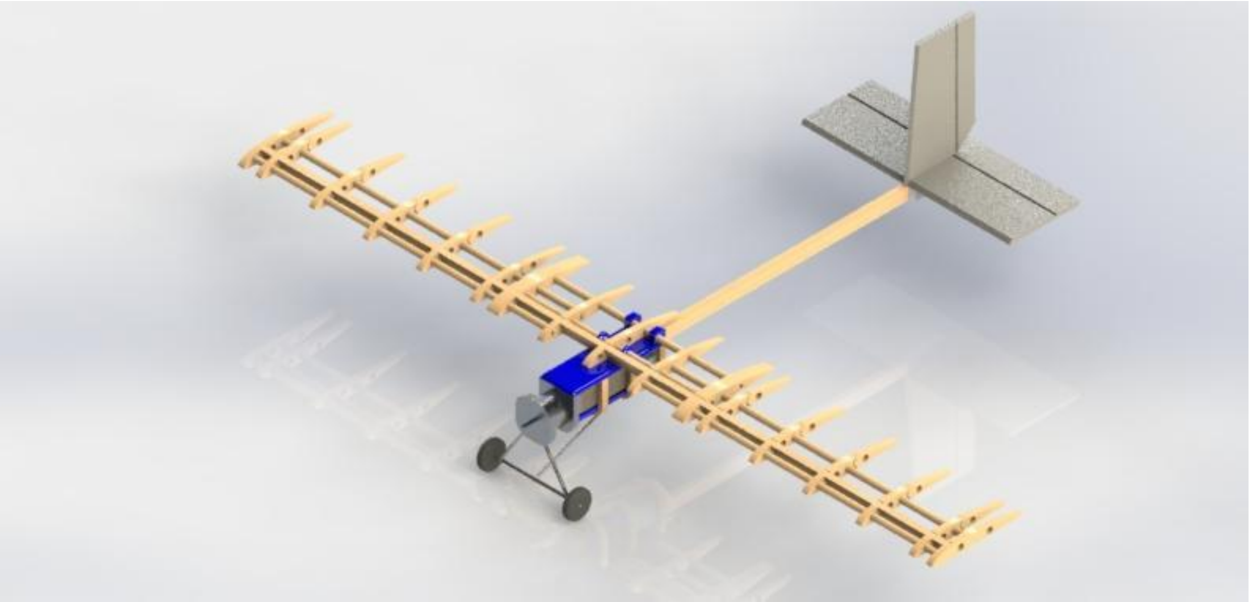


Figure 22: Assembly view

The aircraft is constructed using balsa, 3d printed PLA, and Monokote. Because balsa and Monokote are common materials used for constructing aircraft, manufacturing of this plane will follow typical practices used in the construction of model aircraft. Balsa pieces will be laser cut using a contact of Dr. Tester, who is a teacher at Flagstaff high school. Spars and ribs, as well as fuselage pieces, will be glued together using an aircraft grade wood glue. The tail assembly will be created using balsa, wood glue, and control surfaces will be fitted. After, Monokote will be applied using a Monokote iron and the assistance of the Flagstaff Flyers. Then, electronic assemblies such as motor and servos will be placed and anchored in the fuselage and receivers will be programmed. Lastly, 3D printed components will be installed, and the plane will be completed. Figure 23 shows the exploded assembly view.

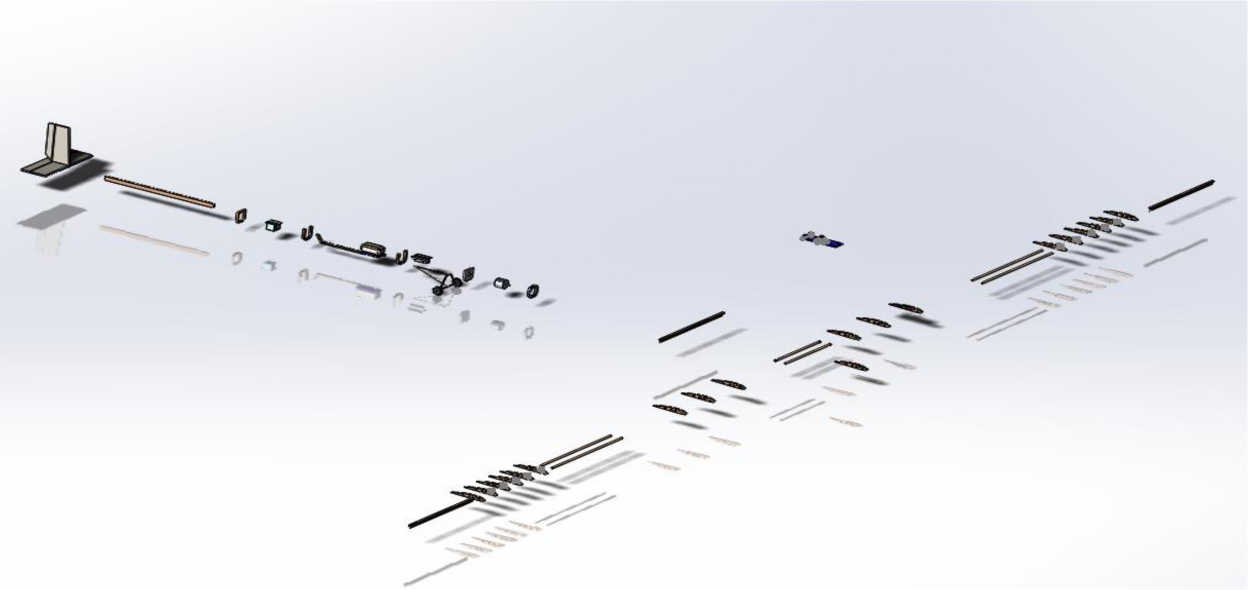


Figure 23: Exploded assembly view

Schedule for the building of the design is more accelerated than most teams and course requirements. The team expects to complete construction by the end of December and major construction milestone dates can be seen in the table 9 below.

Table 9: Construction schedule

Item	Start date	End Date
Laser cutting	12/1/18	12/14/18
Wing Frame Assembly	12/14/18	12/21/18
Fuselage Assembly	12/14/18	12/21/18
Tail Assembly	12/14/18	12/21/18
Motor Plate Machining	12/1/18	12/14/18
Monokote	12/16/18	12/22/18
Electronics Mounting	12/27/18	12/31/2019

The bill of materials needed to complete this build can be found in table 10 of appendix A. Dr. Tester has stated that the laser cutting will be free but there is an estimated cost in the BOM in the event it is not. Total cost to build the design without laser cutting is $278.40. This is well within the team's budget and will allow for the construction of an additional plane or two.

7. IMPLEMENTATION

To complete the design for the second semester, laser cutting, part ordering, and assembly. The laser cutting was completed at a local high school and assembly was completed at the machine shop on campus. The first design was the design that was taken to competition and the second design was completed once returned. The sections will be split into two parts; the first design and the second design.

7.1 Manufacturing

The manufacturing is split into the first design and second design. The first design is the design that has been talked about in the report and was taken to competition. The second design was designed after competition and the manufacturing process is discussed in 7.1.2.

7.1.1 Initial Design

The materials used for the first design included balsa and birch wood, aluminium, and 3D printed components. A laser cutter was used courtesy of the Coconino High School engineering group to cut the balsa and birch wood sheets. Figure 24 shows the laser cutter that was used with the wood pieces that were cut.

Figure 24: Laser cutter

Once the pieces were cut, the pieces were laid out to show the amount of material used for the design. Figure 25 shows all the pieces.

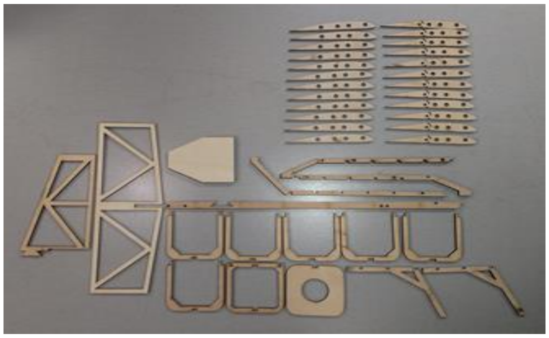


Figure 25: Pieces needed for the first design

A material called Monokote was applied over the wood which acts like heat shrink and creates a hard, semi-flexible surface. Once the pieces were laid out and glued together, the Monokote was applied across the wing, fuselage, and tail. The Monokote is the blue and yellow material that is prominent in figure 26.


Figure 26: CG testing with the blue and yellow Monokote

Aluminium inserts were created to connect the end wing sections to the middle section. This allowed the wing to be put together with minimal hardware. Figure 27 shows the aluminium inserts being machined that slide over wooden dowels within the wing sections.

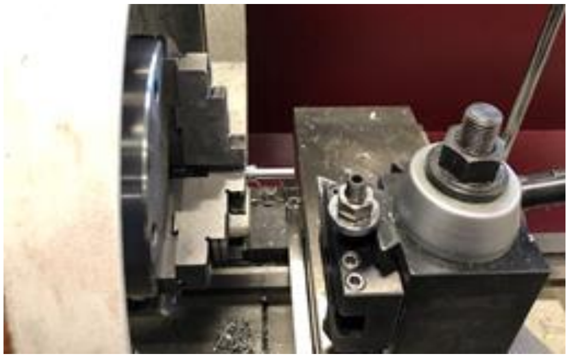


Figure 27: Aluminium inserts being turned on the lathe

Figure 28 shows the size of the aluminium inserts compared to a standard sized pen.


Figure 28: The inserts size compared to a standard pen

This initial design was tested at competition. Figure 26 shows the final design that was brought to competition. Table 11 in appendix A shows the cost for the initial design.

7.1.2 Final Design

During competition, the initial design crashed during four flight attempts. Due to the aircraft crashing at competition, new parts needed to be made. The new design is shown in figure 29.

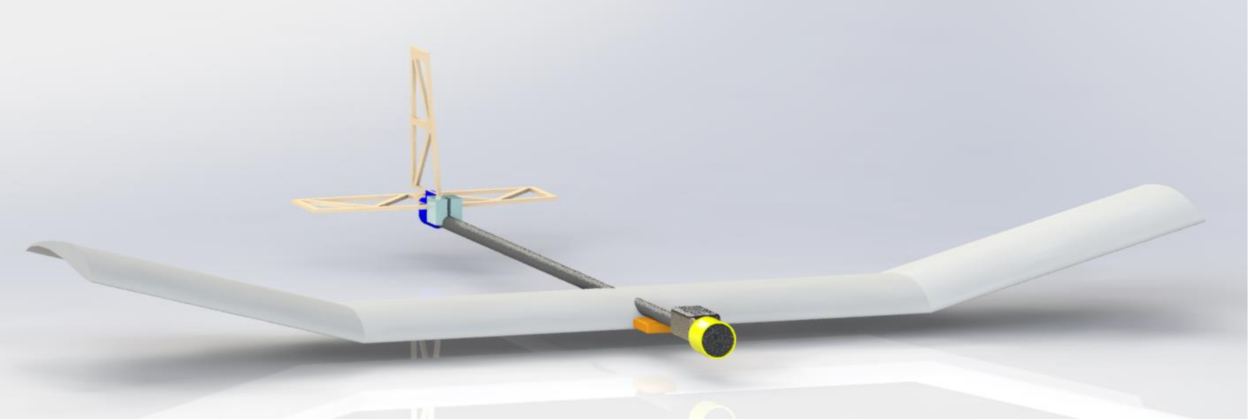


Figure 29: New design with different parts

The parts that were needed for the new plane was a boom (fishing rod), mounts (3D printed), and a wing. Manufacturing of the wing involved foam cutting sections with a saw and then applying a fiberglass mesh to increase wing strength. Initially, the plan was to cut 10.5” sections and fiberglass over these. However, due to the saw blade bending when cut on a hot wire knife, sections were cut down to 3”. A foam cut section is shown in figure 30.

Figure 30: A 3" foam cut section of the new aircraft

The new aircraft was built in approximately two weeks. The wing designed in figure 29 is a basic wing design that was observed at competition. Due to time constraints, a wing that is commercially available was used to develop a proof of concept. The aircraft was developed to provide a basis for next year’s micro team to eliminate a few problems that were encountered during the build. Tables 12, 13, and 14 show the cost for the final plane, the bill of materials for the final plane, and the total cost for the project, respectively.

7.2 Design Changes

During competition, four flight attempts were made. In each of these flight attempts, the aircraft was unable to reach the speed required for total lift. The needed 1.2 pounds of lift was only reached at 30 mph with the Clark Y airfoil. To eliminate this, a new airfoil was selected. This new airfoil was selected to generate greater lift at lower speeds. This new airfoil is a Selig S1223 airfoil that is used for high lift at low speeds. Figure 31 shows the S1223 airfoil.

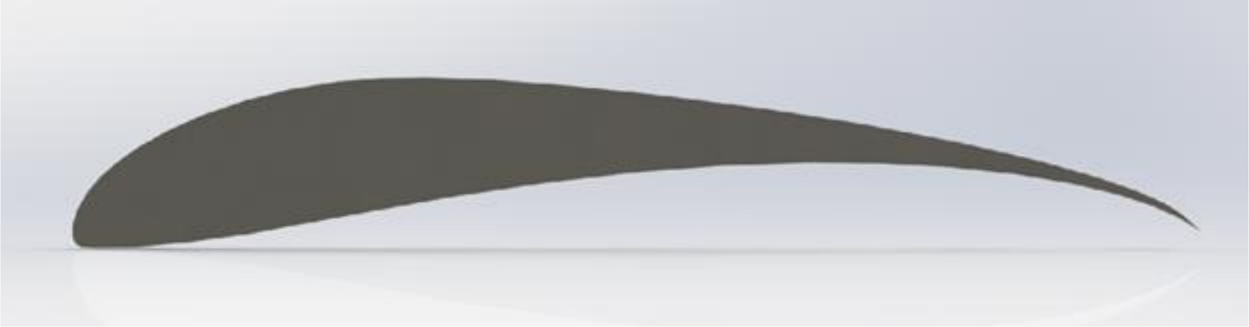


Figure 31: Selig S1223 airfoil

During the fall, initial calculations showed that the lift between the Clark Y and the Selig were minimal. A re-calculation was done and showed that the lift greatly differed at various speeds. Figure 32 shows the lift comparisons at two different Reynolds numbers. The Reynolds number correlates to flow conditions and the two airfoils were analysed at 50,000 and 100,000. For the Clark Y airfoil at 9 m/s, 1.4 lbs. of lift is generated. For the Selig S1223 airfoil at the same speed, 3.6 lbs. of lift is generated. Based on this recalculation, the Selig S1223 airfoil generates about 2 times the lift at the same speed.

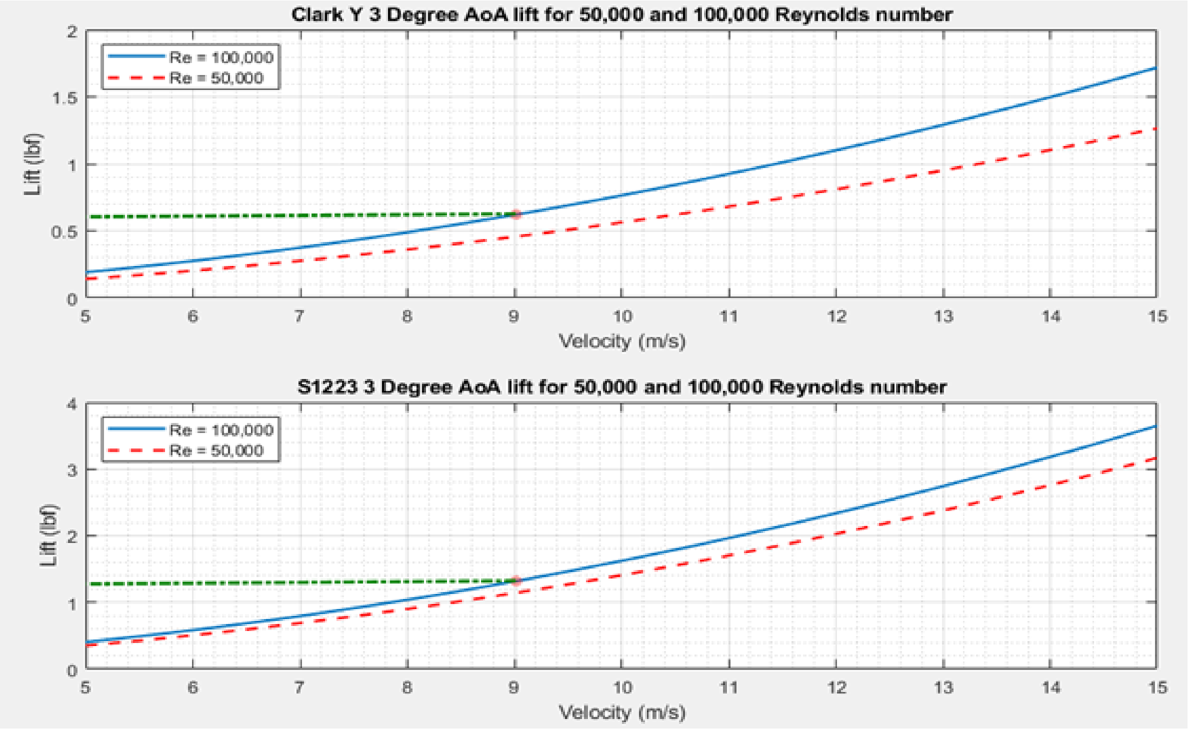


Figure 32: Comparison of lift between the Clark Y airfoil and the S1223 airfoil

Based on the observing other competition aircraft, a 15^{o} dihedral was added to the aircraft. This dihedral increases aircraft stability by allowing the aircraft to roll back towards the center during turns. The dihedral effect is shown in the wing tips of figure 29.

8. TESTING

A ground take-off was performed on March 18th, 2019 and the initial design was able to perform a successful test flight. However, air properties at Van Nuys, CA (sea level) and Flagstaff, AZ (7,000 feet) have a significant impact on flight performance. This results in a roughly 20% decrease in performance at Flagstaff compared to sea level. Based on this, the aircraft should perform better during competition.

During competition in Van Nuys, California, the initial design attempted flight 4 times. Each of these flight attempts resulted in crashes at hand launch. The reason for this was caused by the speed of the aircraft needed for the necessary lift. The aircraft needed to reach about 30 mph during launch, which was unobtainable during hand launch. Since this aircraft was based on competition requirements, this aircraft was rated against the engineering requirements. Table 10 shows the results of the meeting engineering requirements.

Table 10: Shows if the engineering requirements were passed, failed, or uncertain.

Requirement	Passed, Failed, or Uncertain
ER 1	PASSED
ER 2	UNCERTAIN
ER 3	FAILED
ER 4	PASSED
ER 5	PASSED
ER 6	PASSED
ER 7	PASSED
ER 8	PASSED
ER 9	PASSED
ER 10	PASSED
ER 11	FAILED
ER 12	PASSED

The reason why certain ER’s were passed, failed, or uncertain was discussed in section 2.4. Based on the ER’s, the aircraft passed 9 out of the 12 requirements, failed 2 out of the 12, and was uncertain on 1 out of the 12 requirements.

Once returned from competition, the final design was chosen and needed to be constructed before the semester ends. This final design was not graded towards the competition guidelines due to the competition being completed. The final design was discussed in section 7.2. Once the aircraft was completed, a flight was performed and completed in Flagstaff.

9. CONCLUSIONS

The initial design did not perform as expected at competition. During four flight attempts, the aircraft did not gain enough lift to support the entire aircraft. Repairs were made throughout each flight round to try to get the aircraft into flight ready condition. The team did not meet the goal of placing in the top 50th percentile of teams at competition where the placement was 13th out of 21st. A final design was created to create a proof of concept for the next micro team.

9.1 Contributors to Project Success

One of the contributors to project success was going to competition. Competition was a huge learning experience where the team learned what other schools were building, how they were interpreting the rules, and how much payload they were carrying. The final design was heavily based on other designs and helped contribute to the design of the aircraft.

Another contributor to the project success was the learning experiences throughout the first design. The team learned how to build an aircraft, what to do when a problem arose, and how to fix the problem. It took multiple tries to get the manufacturing and assembly of the aircraft done. The laser cutter was used on 3 separate occasions to get each part perfectly cut.

A final contributor to the project success was the work that each teammate put into the project. Many late nights were had to build the aircraft and complete reports. Without the effort that each person put into the report to complete the necessary tasks, multiple planes would have not been built.

9.2 Opportunities/areas for improvement

One of the opportunities for improvement would be fully developing the aerodynamics of the aircraft. Due to time constraints, the final design did not have full aerodynamics done on the wing and body of the aircraft. A fully developed model of the lift and drag generated around the entire aircraft would be beneficial.

Another opportunity for improvement would be developing a method to manufacture the wing on the final design in an effective manner. Using 3” sections would take quite some time to reach a wing span of 44”. Outsourcing the wing to a foam wing manufacturing may be preferred, but the lead time may be a few months.

A final area for improvement would be better scaling of the tail and the boom for the final design. Currently, the boom is a bit long for the size of the tail so properly sizing of each component of the aircraft would be preferred.

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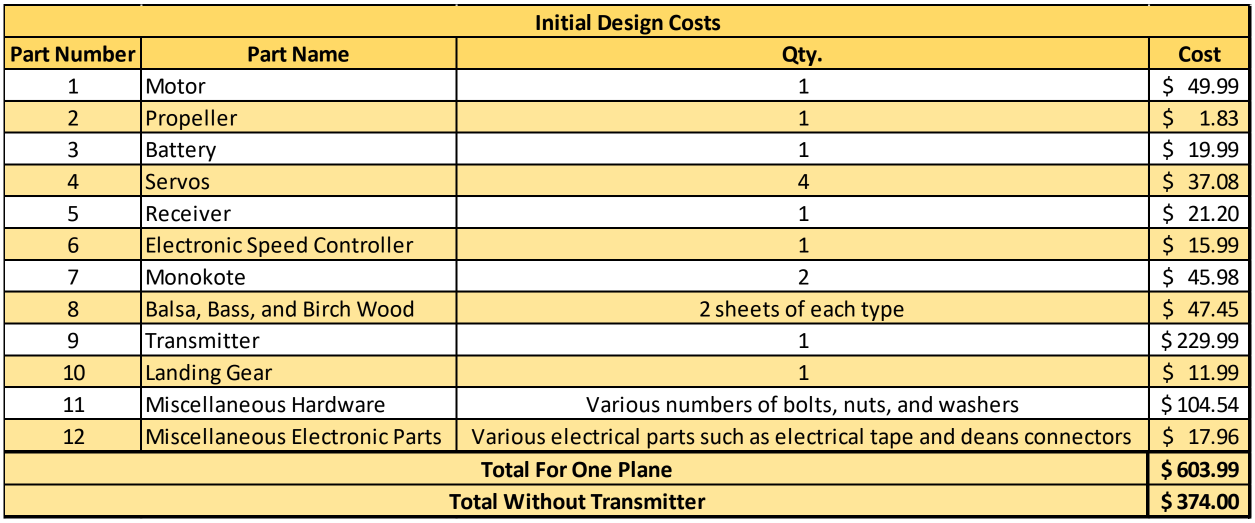
11. APPENDICES

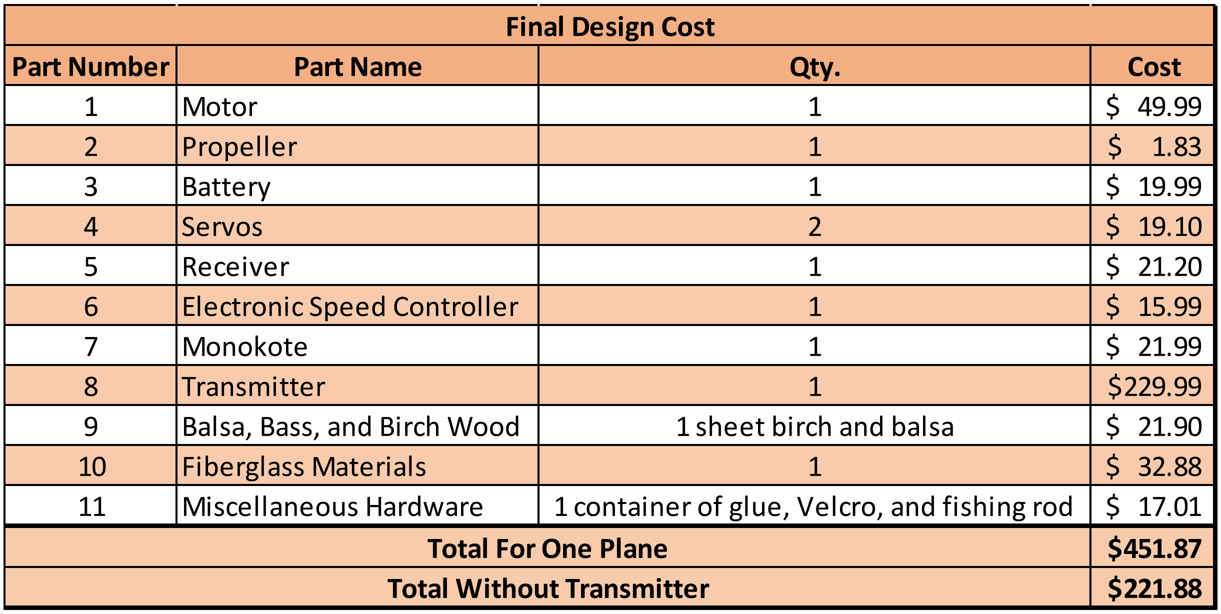
11.1 Appendix A: Bill of Materials

Table 11: Initial design cost



Initial Design Costs			
Part Number	Part Name	Qty.	Cost
1	Motor	1	$ 49.99
2	Propeller	1	$ 1.83
3	Battery	1	$ 19.99
4	Servos	4	$ 37.08
5	Receiver	1	$ 21.20
6	Electronic Speed Controller	1	$ 15.99
7	Monokote	2	$ 45.98
8	Balsa, Bass, and Birch Wood	2 sheets of each type	$ 47.45
9	Transmitter	1	$ 229.99
10	Landing Gear	1	$ 11.99
11	Miscellaneous Hardware	Various numbers of bolts, nuts, and washers	$ 104.54
12	Miscellaneous Electronic Parts	Various electrical parts such as electrical tape and deans connectors	$ 17.96
Total For One Plane			**$ 603.99**
Total Without Transmitter			**$ 374.00**

Table 12: Final design cost



Final Design Cost			
Part Number	Part Name	Qty.	Cost
1	Motor	1	$ 49.99
2	Propeller	1	$ 1.83
3	Battery	1	$ 19.99
4	Servos	2	$ 19.10
5	Receiver	1	$ 21.20
6	Electronic Speed Controller	1	$ 15.99
7	Monokote	1	$ 21.99
8	Transmitter	1	$229.99
9	Balsa, Bass, and Birch Wood	1 sheet birch and balsa	$ 21.90
10	Fiberglass Materials	1	$ 32.88
11	Miscellaneous Hardware	1 container of glue, Velcro, and fishing rod	$ 17.01
Total For One Plane			**$451.87**
Total Without Transmitter			**$221.88**

Table 13: Final design bill of materials

Final Design Bill of Materials			
Main Aircraft Components			
Part Number	**Part Name**	**Description**	**Qty.**
1	Motor	Scorpion SII - 2212 - 1850	1
2	Propeller	UXCELL 8x4 in Nylon Proeller	1
3	Battery	Venom Fly RC 800 mAh	1
4	Servos	Freewing 9g Digital Gear Servo 18" Lead	2
5	Receiver	Lemon Rx 7 Channel	1
6	Electronic Speed Controller	Grayson 50 A with 3 A BEC	1
7	Horizontal Stabilizer (HS)	Laser cut with monokote	1
8	Vertical Stabilizer (VS)	Laser cut with monokote	1
9	Elevator	Control surface attached to the HS	1
10	Rudder	Control surface attached to the VS	1
11	Wing	Wing made from foam and fiberglassed	1
12	Boom	Bought fishing rod	1
13	Tail Connector	3D printed tail-to-boom connector	1
14	Wing Connector	3D printed wing-to-boom connector	1
15	Motor Plate	3D printed motor-to-boom connector	1
Miscellaneous Parts			
1	Monokote	Sapphire Blue TOPQ0226: 6 ft Roll	1
2	Transmitter	DX8e 8-Channel DSMX Transmitter	1
3	Fiberglass	Fiberglass including mesh and resin	1
4	Velcro	Velcro to attach electronics to boom	1
5	Glue	Superglue to attach connectors to boom	1
6	Tape	Packing tape to connect control surfaces	1
7	Control Rods	Control rods that connect servos to control surfaces. Includes hinges	2

Table 14: Total cost for the project

Total Costs	
Total Competition Costs	$ 1,635.00
Intitial Design Plane Without Transmitter	$ 374.00
Final Design Plane Without Transmitter	$ 221.88
Total Project Cost Without Transmitter	**$ 2,230.88**
Total Project Cost Without Registration	**$ 1,180.88**

11.2 Appendix B: System Designs Considered

1. **Single motor, straight tail, no landing gear, no ailerons**

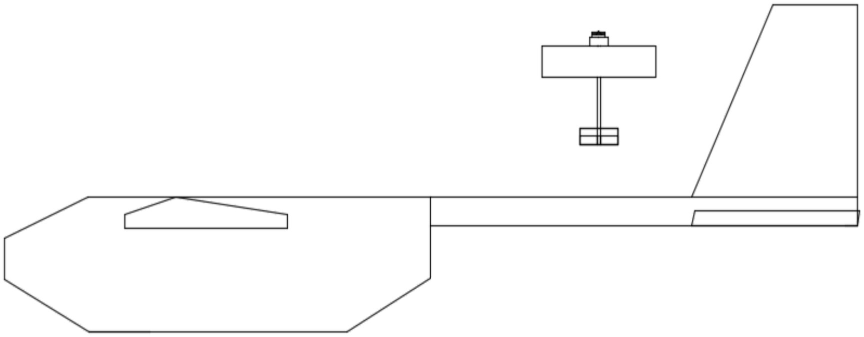


Figure 33: Single motor, straight tail, no landing gear, no ailerons

2. **Single motor, straight tail, front skid, no ailerons**

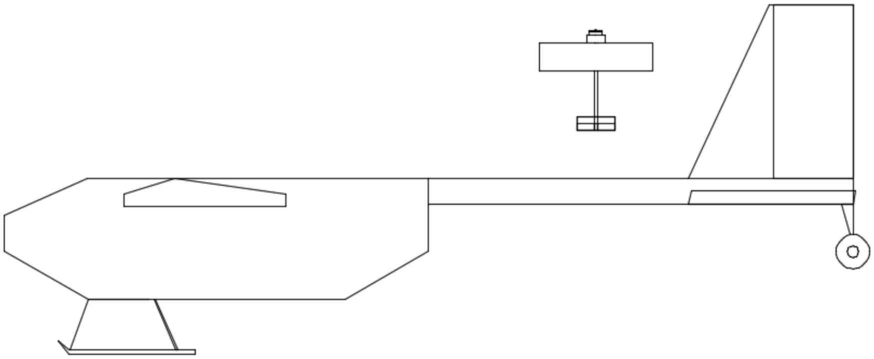


Figure 34: Single motor, straight tail, front skid, no ailerons

3. **Single motor, straight tail, front skid, with ailerons**

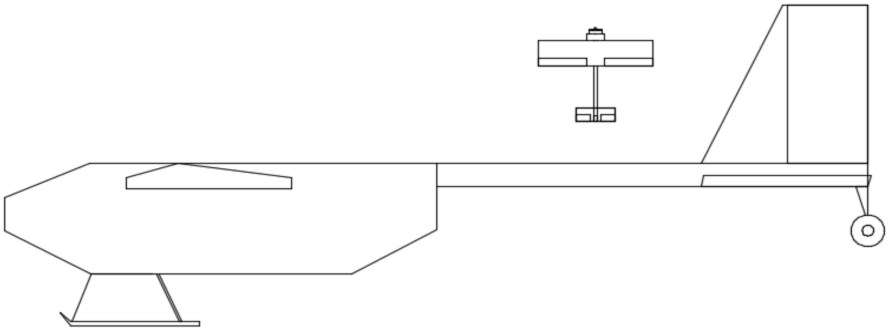


Figure 35: Single motor, straight tail, front skid, with ailerons

4. **Single motor, straight tail, no landing gear, with ailerons**

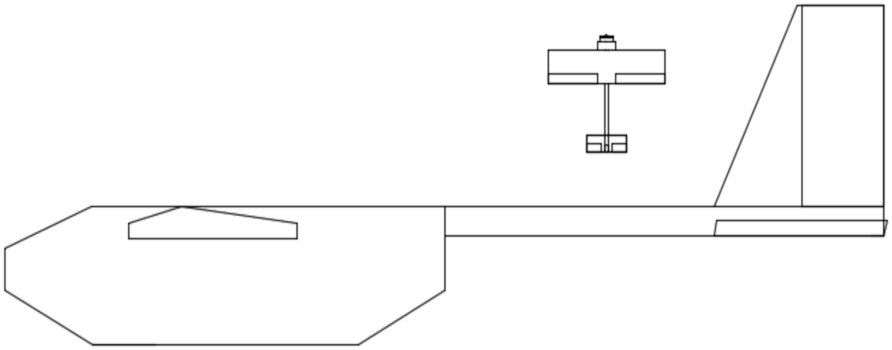


Figure 36: Single motor, straight tail, no landing gear, with ailerons

5. **Two motors, V-Tail, full skid landing gear, with ailerons**

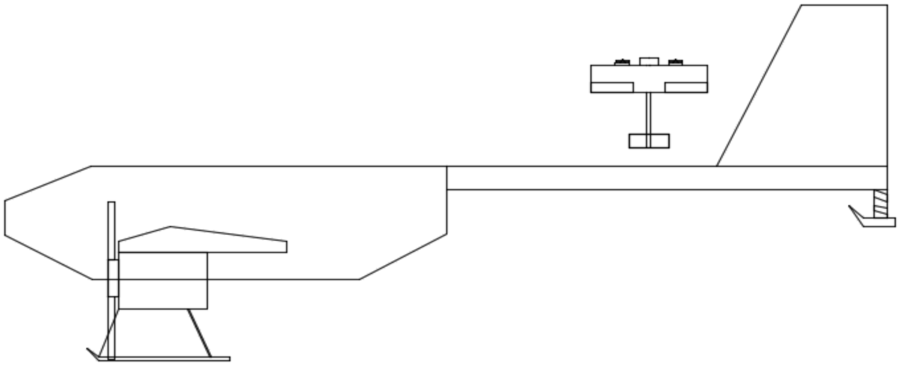


Figure 37: Two motors, V-tail, full skid landing gear, with ailerons

6. **2 motors, straight tail, wheeled landing gear, and conventional controls**

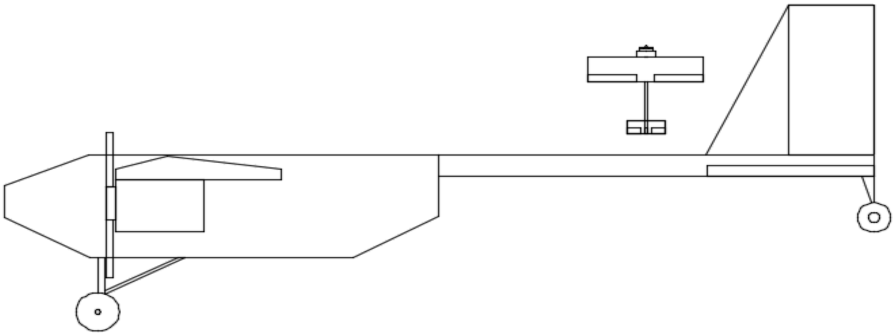


Figure 38: 2 motors, straight tail, wheeled landing gear, and conventional controls