Senior Design II

The Wright Flyers

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Design, Analysis and Fabrication of a RC UAV

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Abstract

The purpose of this project is to design and manufacture a remote controlled aircraft that will house model passengers for this year's AIAA DBF competition. The design was conceptualized last semester and will undergo only minor changes at this point. The analytics certainly provided sufficient parameters to advance to the second step of our project. The goal for this semester is to manufacture the final product to the best of our abilities. The process is very iterative as structural modifications were constantly made to create an ideal product. The materials used for the manufacturing process were selected carefully to yield the most optimal results. However, substitutions had been made due to unforeseen circumstances. A great tool we learned along this semester is the ability to reassess and make adjustments to our product. This ultimately allowed us to finish our working prototype in a timely fashion.

Nomenclature

Symbol	Term
EW	*Empty Weight*
WS	*Wing Span*
RAC	*RAC*
L	*Lift*
ρ	*Density*
C_L	*Coefficient of Lift*
V	*Take Off Velocity*
A	*Wing Surface Area*
AR	*Aspect Ratio*
S	*Wing Span*
C	*Chord Length*
M	*Moment Equation*
S_C	*Span of Chord*
C_m	*Pitching Moment Coefficient*

Introduction

Project Description

The 2017-18 Design Build Fly (DBF) international competition hosted by the American Institute of Aeronautics and Astronautics (AIAA) requires us to build a regional/business RC aircraft with the capacity to carry at least one passenger and one payload block. The RC plane must complete multiple missions and must comply with the design specifications given. New constraints are introduced every year to invoke a greater sense of challenge along with ingenuity and creativity amongst the competitors. As such, the final product differs greatly year to year.

Motivation

A competition like AIAA DBF provides a real world aircraft design experience for students like us by providing the opportunity to validate our analytic studies. The processes of this project taught us valuable skills needed to work in the aerospace field. Furthermore, a project of this magnitude is an appropriate culmination of our 4 year engineering education. By venturing this endeavor, we can full heartedly exercise our engineering knowledge and judgment. As the aerospace/aeronautical field is growing vastly every year, it behooves every mechanical engineering graduate to learn the ins and outs of aeronautical design. We, the Wright Flyers, certainly believe so and pursued this effort to acquire industry specific tools to gain an edge. Besides analytical work, this task provides project management, budgeting, and group work experience that is largely prominent in any engineering profession. Thus, we definitely chose a well balanced project.

Problem Statement and Objectives

As stated in the AIAA Competition Manual, the proposed aircraft must satisfy multiple criteria. Every year the mission changes and so does the specifications for the plane. Student teams will design, fabricate and demonstrate the flight capabilities of an unmanned, electric powered, radio controlled aircraft that can best meet the specified mission profile. The goal of this year's competition is to design a regional/RC aircraft, or simply to create an RC plane that mimics a passenger airplane. The design must possess good demonstrated flight handling qualities and practical and affordable manufacturing requirements while providing a high vehicle performance. These are the base specifications for the aircraft and the mission requirements to fulfill in order to reach a score.

As a disclaimer, the Wright Flyers ultimately did not attend the DBF competition for various reasons. Primarily, our budget has been insufficient throughout this whole project. The Grove School funding was very limited and the AIAA club has historically received less money than other clubs. Likewise, the USG Club funds were heavily decreased. The funding we received was barely enough to purchase the materials to build our prototypes. Travel and hotel costs to attend the DBF competition were out of the question. Besides monetary reasons, we faced challenges with our first two prototypes. Neither of them were able to fly during flight tests thus we could not collect data necessary for the competition report. We did not feel confident advancing to the competition without conducting extensive flight tests. Subsequently, we decided it was best to withhold from the competition this year.

Product Design Specifications

Base Requirements

These requirements describe what should be included when designing the aircraft. This affects all components, such as the propulsion and structures of the plane. This year's competition requires the following:

Passenger Compartment (Cabin)

- Each passenger must have its own individual "seat" with its respective restraint system that accommodates all passenger sizes
- All seats must be on one level and on a single planar surface
- Vertical spacing between the largest passenger size must be a minimum of 0.25 inches
- Side to side spacing must accommodate the largest size passengers without interference
- No more than two adjacent seats and no more than four seats in a single row
- There must be a vertical aisle with a minimum width and height of 2.00 inches running the whole length of the passenger compartment. If there are only one or two adjacent seats per row, the aisle may be on either side of the cabin, but must still meet the minimum size requirement.

Payload Bay(s)

- Payload bay(s) must be a completely separate compartment from the passenger compartment
- It must be behind and/or below the passenger compartment

Other Requirements

- There is no limit on battery weight this year
- Aircraft must demonstrate serviceability by replacing line replacement units (LRUs)

- Aircraft must be propeller driven and electric powered with an unmodified electric motor.
- Aircraft must use an unmodified NICad or NiMH batteries. LiPo batteries are not allowed. Electrical contacts on the battery must be insulated.
- Radio Rx and servos must be connected on a separately battery pack.
- The aircraft must have an externally accessible switch to turn on the radio control system. It cannot be internal or under a panel or hatch

Mission Requirements

The aircraft must be able to perform all the missions.There are 4 missions and out of 4 missions 3 missions will be responsible for the scoring.

Ground Mission

The Ground Mission consists of a removal and replacement of a two (LRUs) chosen at random with rolls of a single 6 sided die. This missions will be conducted in two stages. This mission is done to determine how retractable or replaceable our plane LRUs are.

Mission 1: Aircraft Mission Staging

This mission is to test the aircraft's airworthiness. The aircraft without any payload or passenger will be flown from a takeoff within the required field length. The team must complete 3 laps within the flight window and must complete a successful landing to get a score.

Scoring:

M1 = 1.0 for successful mission

Mission 2:Short Haul of Max Passengers

This mission requires that we carry passengers. The number of passengers is chosen by the team; however, the size of the passengers will be chosen at random by competition judges, from a pool of balls and must be carried internally. The mission score depends on the number of passengers carried, 3 laps and the completion time with a successful landing.

Scoring:

M2 = 2*[N_(#passengers/time)/ Max_(#passengers/time)] , where

Max_(#passengers/time) is the highest #passengers/time score of all teams

Mission 3: Long Haul of passengers and Payload

The plane must carry at least 50% of the passengers from Mission 2. The plane must also carry a selected number of payload blocks with restricted dimensions. The team may select the blocks' weight (must be 8 ounces or less). Mission 3's score will increase with greater payload, passenger count, and lap count. There will be a 10 minute window for this mission and the aircraft must complete a successful landing.

Scoring:

M3 = 4*[N_(#passengers * total payload (oz) * #laps) /Max_(#passengers * total payload (oz) * #laps)] + 2, where Max_(#passengers * total payload (oz) * #laps) is the highest (#passengers * total payload (oz) * #laps score for all team

Scoring Criteria

The mission scores then will go on to the final competition score. Each team's final score will be computed from their Written Report Score, Total Mission Score and Rated Aircraft Cost using the formula:

FINAL SCORE = Written Report Score * Total Mission Score / RAC

The Total Mission Score is the sum of the individual Mission Scores:

Total Mission Score = M1 + M2 + M3

The RAC is a function of aircraft empty weight and maximum wing span:

RAC = EWmax * WS

EWmax = Maximum aircraft empty weight recorded after each successful mission in pounds (lbs); aircraft empty weight does not include the payload but does include any payload supports or restraints and batteries WS = Longest distance between wingtips measured perpendicular to the axis of the fuselage in inches (in).

Sensitivity Analysis

Given so much freedom on the amount of passengers and blocks we can carry, and their internal layout we performed a sensitivity analysis to see how changing any of these affect the completion time in Mission 2, payload and amount of laps the plane could fly in mission 3, the wingspan, and empty weight. We first began by changing a single parameter in the equations given in the previous section to see how it affects the Score. As can be seen in the following figure decreasing the RAC will produce the biggest change in the Final Score giving us an idea that decreasing the empty weight and wingspan would give us a higher chance of placing high in the competition. However, this test only varied a single parameter at a time and to validate this result we conducted another sensitivity study varying multiple parameters at once.

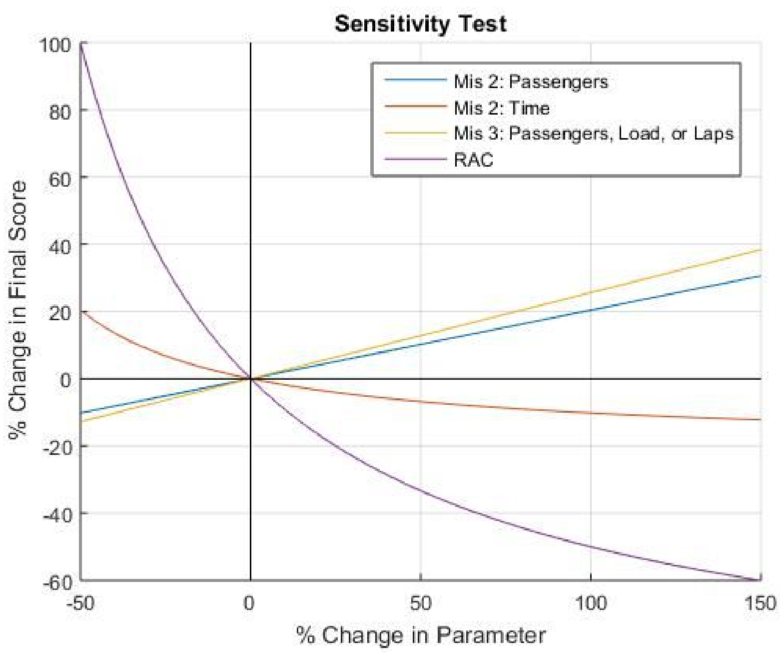


Figure 1: First Sensitivity Study - Single Variable Change

After doing a lot of online research and speaking with RC plane pilots we gathered data correlating different parameters with each other and we were able to finish our second sensitivity study, shown in the two figures below.

The first 3D plot compares the wingspan, amount of passengers in Mission 3, and the final score simultaneously. From the previous equations given we see that for Mission 3 the amount of the passengers, laps completed, and payload carried are all weighed the same and thus the axis labeled “Passengers 3” can represent either of those parameters. As well, in the RAC equation we see that the wing span and empty weight are weighed the same as well and thus the axis labeled “Wingspan” can represent either of those two parameters. Noting that the increasing number of passengers carried, payload, or laps flown will ultimately increase the wing span and empty weight there will always be a trade off between these two sets of parameters. Observing the plot we see that the Final Score rises must faster when decreasing the wingspan than it does when we increase the number of passengers and thus we concluded that for Mission 3 our objective should be to decrease the RAC at the expense of number of passengers carried, validating our first sensitivity study for the case of Missions 3.

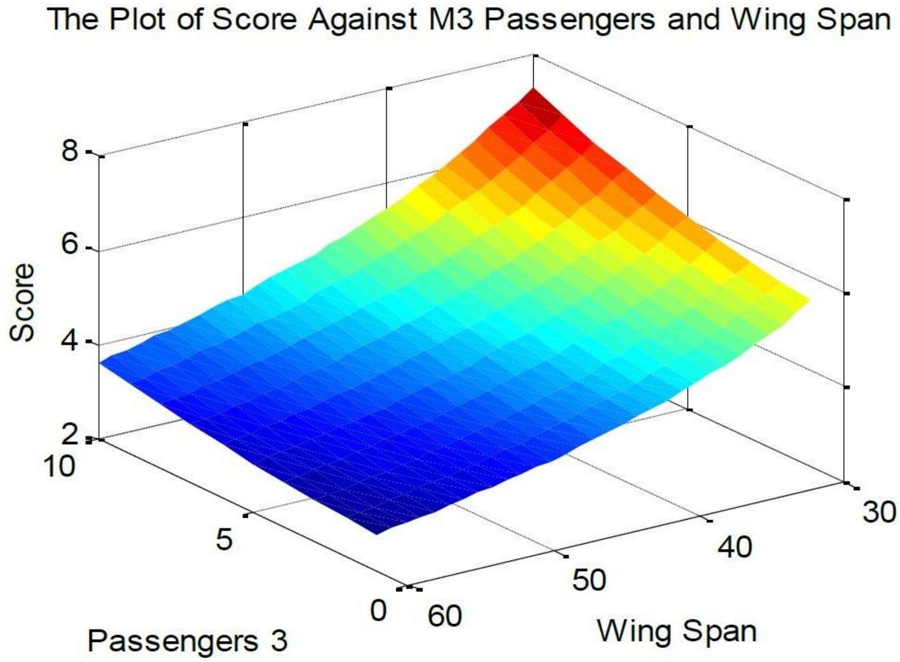


Figure 2: Second Sensitivity Study - Multiple Variable Change for Mission 3

The second part of our second sensitivity study is the same as above but it compares the parameters of Mission 2 to the final score. Again from the Mission 2 equation we see that the amount of passengers and completion time is weighed the same and so the axis labeled " Completion Time" can represents either of those parameters. The axis labeled "Wing Span" again can represent either the wing span or empty weight. Observing the plot below we see that the Final Score again rises must faster when decreasing the wingspan than it does when we decrease the completion time and thus we concluded that for Mission 2 our objective should also be to decrease the RAC at the expense of number of passengers carried and the completion time, validating our first sensitivity study even more for the case of Missions 2.

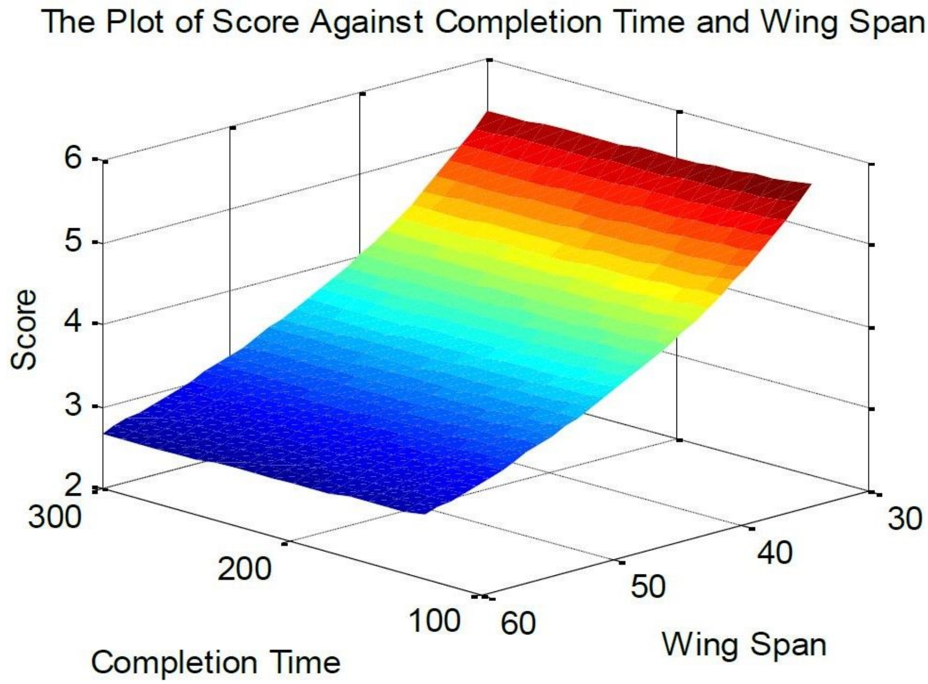


Figure 3: Second Sensitivity Study - Multiple Variable Change for Mission 2

The second sensitivity study summarizes that to score has high as we can the RAC should be lowered as much as possible, even at cost if a lower mission score.

In summary our major constraints will be the minimization of the empty weight and wingspan if the UAV, while manufacturing the plane so that the LRU's are easily replaceable.

Gantt Chart

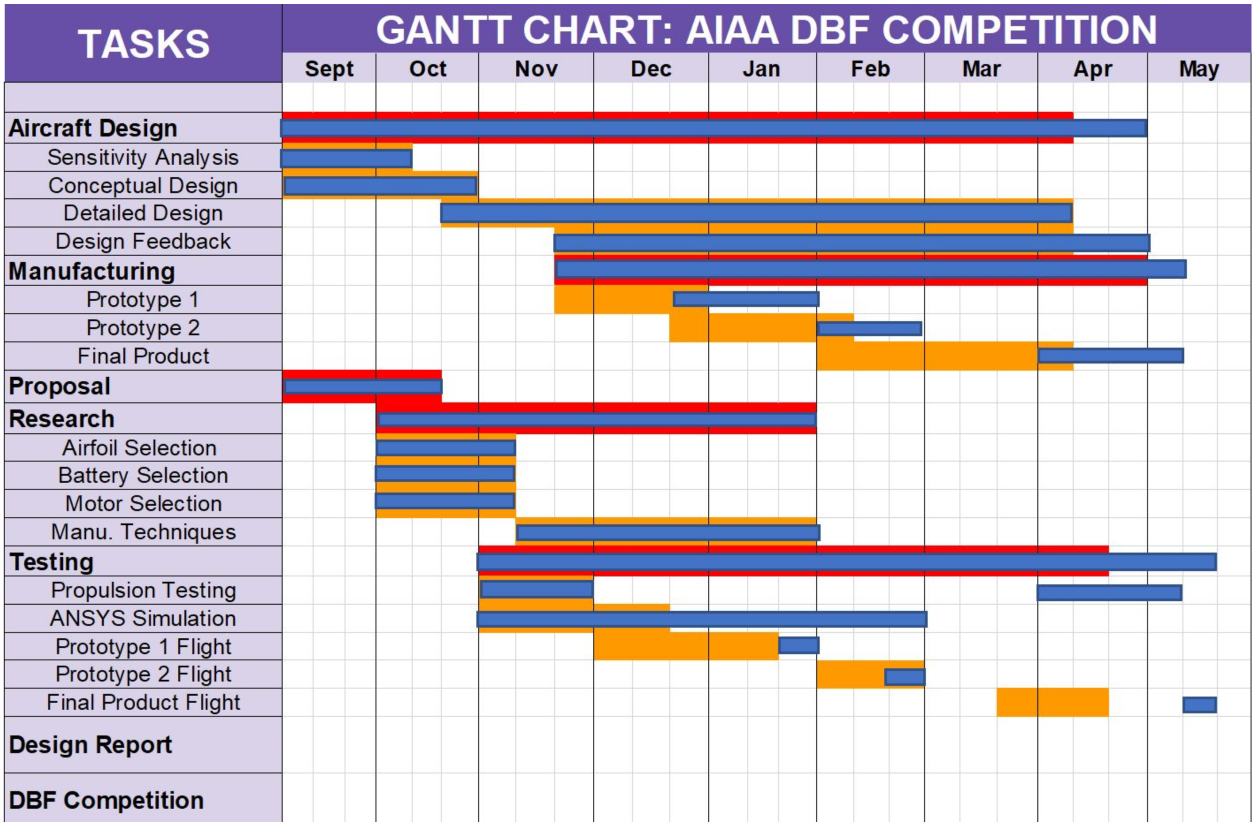


Figure 4: Gantt Chart

Design Concepts

Selection Process

After performing some extensive research regarding various types of design configuration that can be utilized for our plane, we decided to prepare a concept design matrix for each of the major components of the aircraft. We evaluated each component based on various differing factors known as "weights". In general the weight of the component and stability had the most "weights" and were most influential in making the final decision. The decision matrices for this plane are tabulated below where the chosen design/configuration have been highlighted (in green).

	Plane Type			
	Weights	**Monoplane**	**Bi-Plane**	**Canard**
Weight	30%	1	0	1
Manufacturability	20%	1	0	-1
Stability	20%	0	1	0
Drag	20%	0	-1	0
Compactness	10%	1	-1	0
Total	100%	0.6	-0.1	0.1

Table 1: Plane Configuration Decision Matrix

	Wing Configuration			
	Weights	Low Wing	High Wing	Mid Wing
Weight	40%	0	-1	-1
Manufacturability	30%	1	1	-1
Stability	30%	1	1	0
Total	100%	0.6	0.2	-0.7

Table 2: Wing Configuration Decision Matrix

	Tail Configuration			
	Weights	Conventional	V-Tail	T-Tail
Weight	40%	0	0	0
Manufacturability	20%	0	-1	0
Stability	20%	1	-1	0
Drag	20%	0	1	0
Total	100%	0.2	-0.2	0

Table 3: Tail Configuration Decision Matrix

	Propulsion System			
	Weights	**Single Pusher**	**Single Tractor**	**Dual Tractor**
Weight	30%	0	0	-1
Aircraft Efficiency	20%	0	1	0
Stability	30%	-1	0	1
Size	20%	0	0	-1
Total	100%	-0.3	0.2	-0.2

Table 4: Propulsion Configuration Decision Matrix

	Landing Gear Configuration			
	Weights	**Tail Dragger**	**Bicycle**	**Tricycle**
Weight	30%	0	1	0
Strength	20%	1	-1	1
Manufacturability	20%	0	0	0
Takeoff capability	30%	1	0	0
Total	100%	0.5	0.1	0.2

Table 5: Landing Gear Decision Matrix

	Passenger & Payload Configuration			
	Weights	1 passenger 1 payload	2 passenger 2 payload	2 payload 1 passenger
Weight	40%	1	-1	-1
Fuselage Size	40%	1	-1	-1
CG Balancing	20%	-1	1	1
Total	100%	0.6	-0.6	-0.6

Table 6: Fuselage Configuration Decision Matrix

After reviewing the design decision matrices, we concluded on a low wing configuration, conventional tail, single tractor monoplane with a tail dragger landing gear. Furthermore, we will be designing the fuselage based on the 1 passenger and 1 payload configuration. Overall these design decisions gives us an aircraft with the least weight and most stability which are the two most important factors for scoring high in the competition.

Alternative Designs

Tip DIhedral Wing:

Our first design was a low wing with tip dihedral configuration, as the following Figure shows.

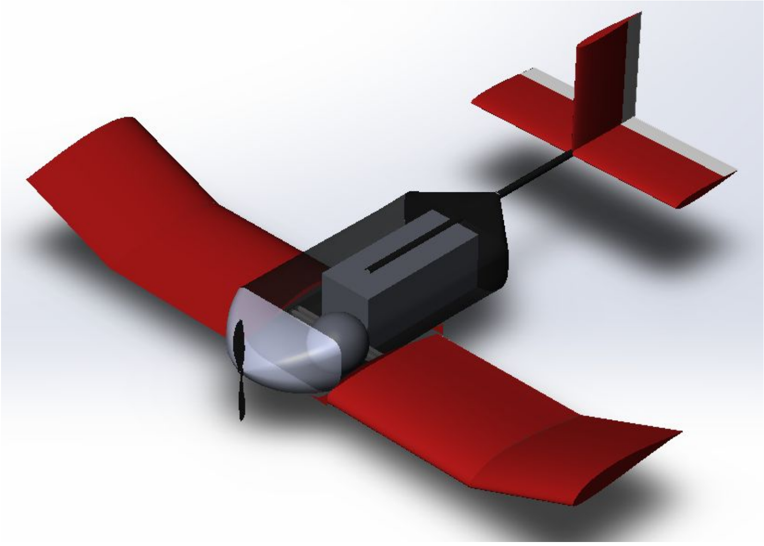


Figure 5: Preliminary Design - No Landing Gear

The idea of the tip dihedral wing was rejected as manufacturing the wing proved to be very difficult and so It was replaced with a flat wing.

Flying Wing:

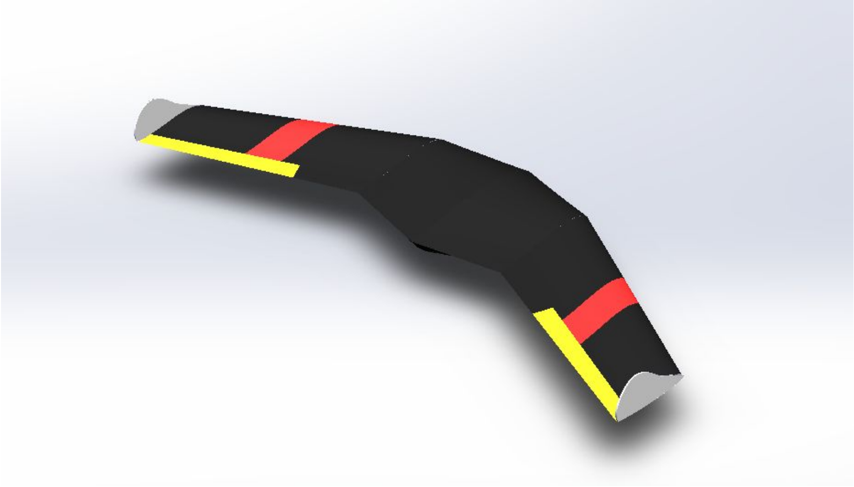


Figure 6: Second Design Solid Model

The flying wing design is a design where the fuselage and wing are essentially one whole part. This design looked quite hopeful due to the fact that the overall weight of this design was fairly low due to it having no tail, but the main catch was that the coefficient of lift it would generate was too low. This particular design requires us to use a certain range of airfoils and all those airfoils exhibited a lift of around 0.8 which is quite low compared to our projected 1.5 coefficient of lift. So, that is why this design was disregarded. But we did learn a lot regarding flying wing designs which are highly used in the military.

Final Design Iterations

Iteration 1:

Most of the design aspects were kept the same from the first design with the exception of the wing which was replaced with a flat wing. Adding the internal layout of the plane and wing structure we created our third design as shown in Figure 7. During our first two designs, we conceptualized a fuselage in a way such that it would be aerodynamically sound and thus making the fuselage curvy was agreed upon. But with the issues such as manufacturing and weight, we compromised the fuselage body with a design which was comparatively easy to manufacture and also less in weight. The curvy fuselage was replaced with the angled edges which now could be attached easily.

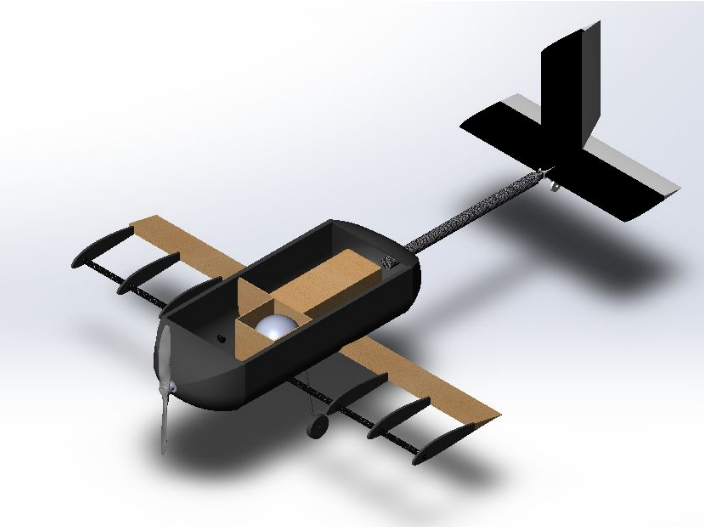


Figure 7: Third Design Solid Model

Iteration 2:

This is the first iteration that we manufactured during the 2018 winter break. In this iteration we cut out holes into the fuselage as well as the tail stabilizers to minimize the weight as much as possible. As well the fuselage was designed with more detail to after learning that these doesn't have to be walls separating the passenger and payload compartments, just that there must be be no overlap between different compartments and electronics. In this iteration we decided to only use flaps and no ailerons as our ANSYS and AVL analysis shows it is stable. Figure 8 shows our second iteration of our final design. Upon testing the plane we found that the landing gear was inadequate as it was uncontrollable going down the strip. The wing did generate lift however it was not enough before the landing gear finally cause the plane to topple over and break.

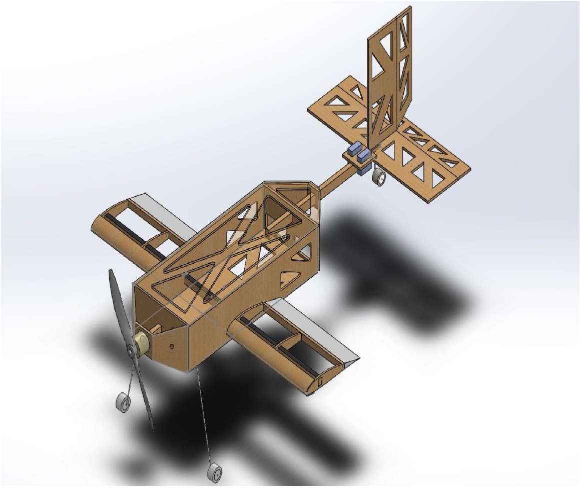


Figure 8: Second Iteration

Iteration 3:

After testing our first manufactured plane (second iteration) and learning from its failures we immediately began working on manufacturing the third iteration. We extended the fuselage in order to fit in all the LRU's for the Ground Mission and used different a wire gauge for the landing gear. Upon testing we discovered that the plane could not controlled with just the flaps and the landing gear could be further improved.

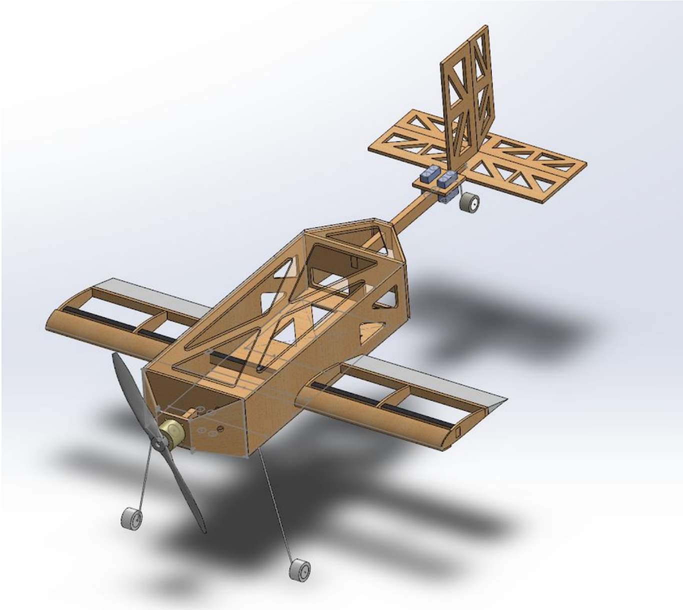


Figure 9: Third Iteration

Final Iteration:

For the final iteration of our plane, we increased the wingspan in order to generate more lift and increased the tail adequately. To make the plane more controllable we decided to use ailerons instead of flaps. As well, we would use a stronger motor. This entailed that we'll need a stronger battery and an additional servo.

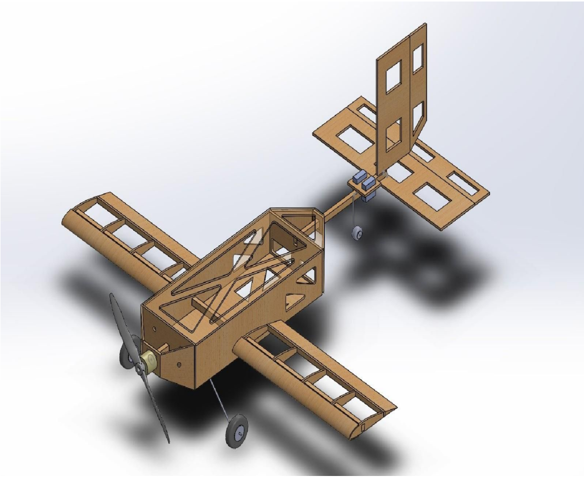


Figure 10: Final Iteration

Final Manufacturing

After manufacturing two prototypes, the final prototype was assembled in a short time. Nonetheless, we did also encounter various difficulties which will be discussed under their respective topics. The plane was mostly built with balsa wood. This includes the structure of the fuselage, nose, wingspan and tail. The landing gear was made with piano strings attached to foam wheels. The balsa wood was cut using the laser cutting equipment in the Zahn Center to get precise dimensions. Due to the limited amount of balsa wood ordered, we had to laser cut limited pieces and thus we really had to be careful about getting the right pieces together. It was difficult setting appointments for the laser cutting, thus our schedule was often pushed back due to issues at the Zahn Center.

Fuselage

The fuselage consisted of a base plate, left and right plate, front and back plate which were laser cutted. They were attached together with wood glue and then reinforced with epoxy at the joint to make the edges stronger. We really had to be careful as the thin balsa wood were prone to breaking if a strong enough force was applied.

Figure 11: assembling of the fuselage.Notice the epoxy at the base in the middle. Two pieces of separate balsa (due to the unavailability of a bigger piece) were joined together and epoxied to make it strong.

Nose

The nose consisted of two side plates angled inward from either edges of the front plate of the fuselage. These two side plates were connected to a plate where the motor was mounted. The side plates were not exactly cut as we wanted from the laser cutting so we had to sand down the corners until they fit flush. A nose spar was introduced to make the pieces more stable since the motor was heavy. Similarly, later, two more spars were epoxied at the top and the bottom to provide more stability.

Figure 12: Assembling of the nose piece where the side pieces are angled inward and joined with a plate which is supported by a nose spar. The front place is where the motor goes. Traces of epoxy can be seen.

Wing

The wing consisted of a long wing spar extending across the sides of the fuselage which was first glued and reinforced with epoxy for extra strength. Extra ribs were laser cut in case mistakes were made. Five ribs were inserted into the wing spar on either sides at 2.27 inch distance from one another. Similarly they were glued on the wing spar and then epoxied. The ends of the ribs were then joined with a strip of balsa wood so as to align the ribs and add extra stability. To give the ribs the shape of an airfoil, very thin balsa woods were bent by immersing into water. After the wood was softened, it was placed over the ribs with a rubber band and after a day it was glued. Some extra pieces of wood were sanded down to give it a more precise look before glueing.

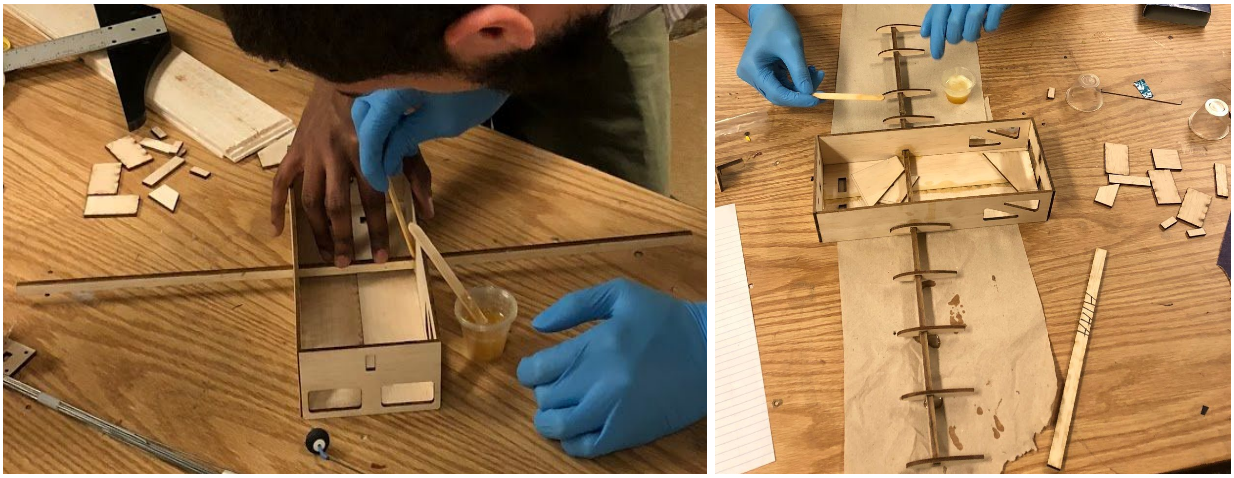


Figure 13: On the left- Inserting and epoxying the wing spar into the fuselage. On the right-Inserting the ribs into the wings spar.

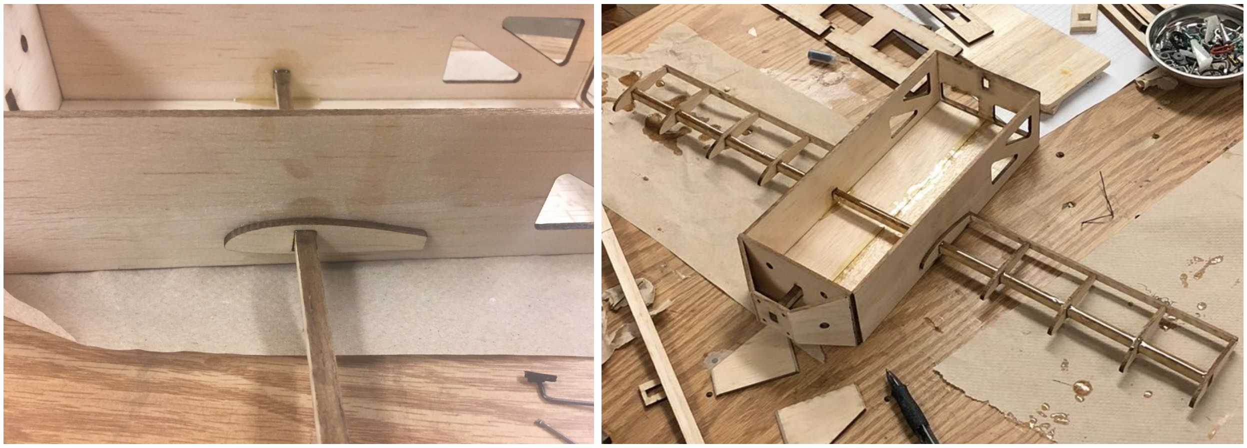


Figure 14: Left-Rib attached to the fuselage. Right-Assembly of the fuselage and the wing.Notice a strap of balsa wood attached to the rear of the ribs for extra support.

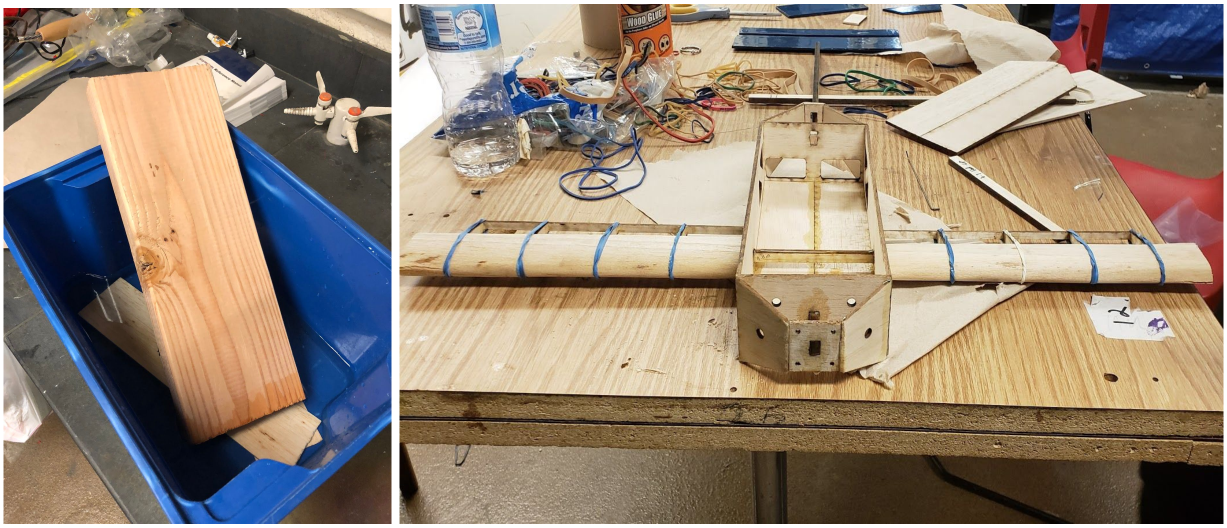


Figure 15: Left-Balsa wood being soaked into the water. Right-Soaked balsa applied over the wings and reinforced with rubber band to get the shape of the airfoil.

Ailerons

The flaps were also laser cut. To give it the shape of the end of an airfoil, we joined two pieces of wood on top of one another. Both were sanded down and glued again to give it the desired look of the airfoil. We finally realized that these flaps provided the aircraft with the necessary lift for take off. In previous iterations of our design, we maintained our “less weight, higher score” theory and scrapped the flaps. As mentioned, the dimensions of the structure were significantly increased for our final prototype. As this increased the weight, we decided to utilize a larger and more powerful motor and battery. Consequently, our plane became very nose heavy. Thus, adding flaps was most definitely needed to provide increased lift during take off. It is worth noting that the aircraft drag had increased as well, but this was counteracted by our feathered propeller.

Figure 16: Monokoted flaps connected to the support by hinges that connects the rib on the left. Right-Monokoted wings and flaps.

Tail

As with the nose spar, the tail spar was also assembled in the same fashion. Two side plates were angled inward from the edge of the back plate of the fuselage. The two side plates were then connected to the rectangular hollow plate. This junction was then glued together. Then one end of the tail spar was inserted into the hollow rectangular plate which extended upto the inner edge of the back plate of the fuselage; and glued and epoxied together. At the other end, the horizontal stabilizer was attached. A notch was made on the end of the spar perpendicular to the horizontal stabilizer, where we could attach the vertical stabilizer.

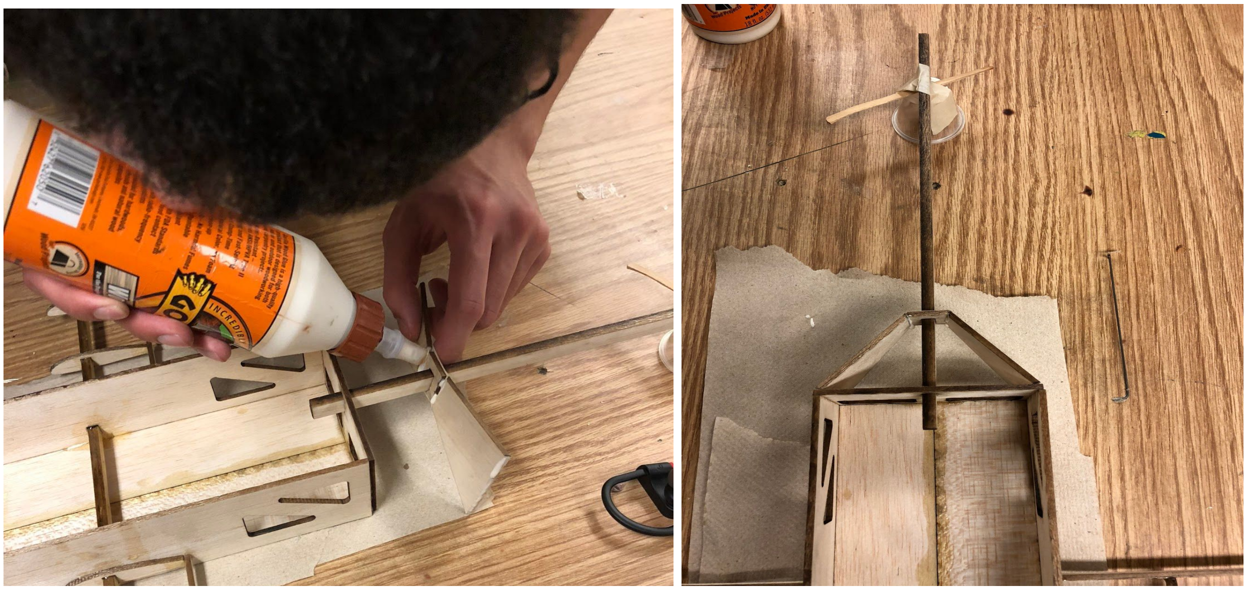


Figure 17: Left-Tail spar for reference inserted into the fuselage through the hollow rectangular plate. RIght-Side plates attached to the small hollow rectangular plate. Note that the tail spar wasn't glued to this junction as at this point the length of the tail spar wasn’t figured out.

Figure 18: Left-Stabilizers connected to the end of the tail spar. The rudder and the elevators were connected by a hinge through a scotch tape. RIght-Detailed view of the connection of the stabilizers. The horizontal stabilizer had a notch laser cutted previously so that it could attach to the tail spar. For the vertical stabilizer, we had to carve a notch on the tail spar carefully so that it could go in. The combination was then reinforced with 5 minute epoxy.

Landing Gear

The first prototype had a small and steep landing gear with a wheel size of 1.5 inches. The second prototype had a wider and a taller gear with very small wheels. But the second prototype consisted of a thin gauge which was not stiff and collapsed under the weight of the plane. So taking into account all of what we learned from previous prototypes, we used the piano wire of the gauge 0.0765” and the wheel diameter of 1.5”. The piano wires were bent using a clam which proved to be very handy compared to the tedious processes used before. The wheels were foam and were held together on the gear using strips of scotch tape.

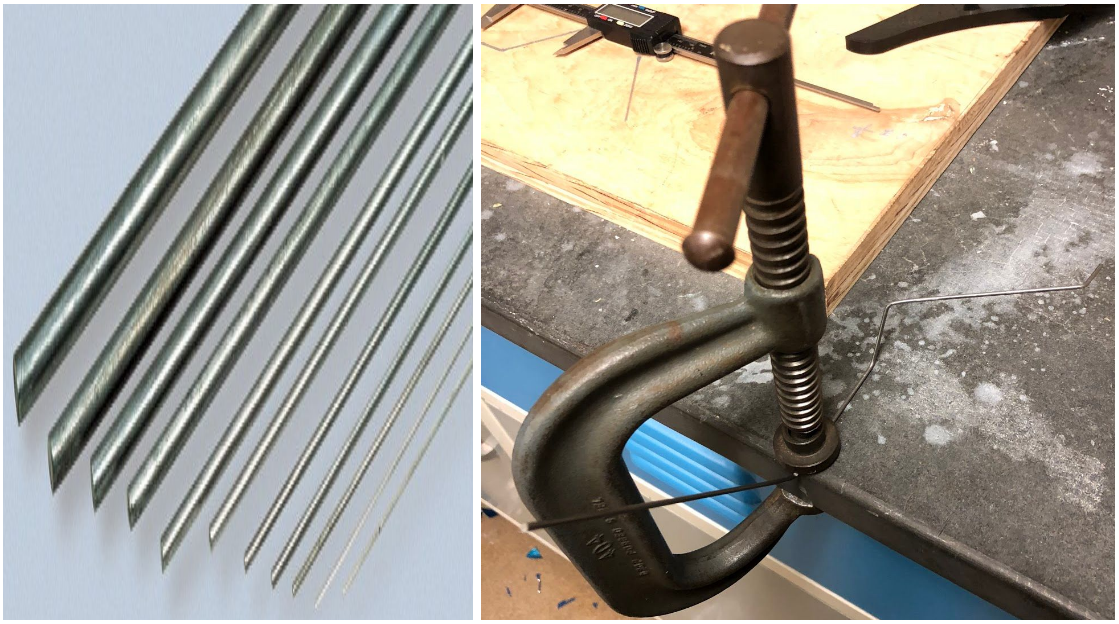


Figure 19: Piano wires on the left with various diameters. Right-Clamp being used to bend the wires.

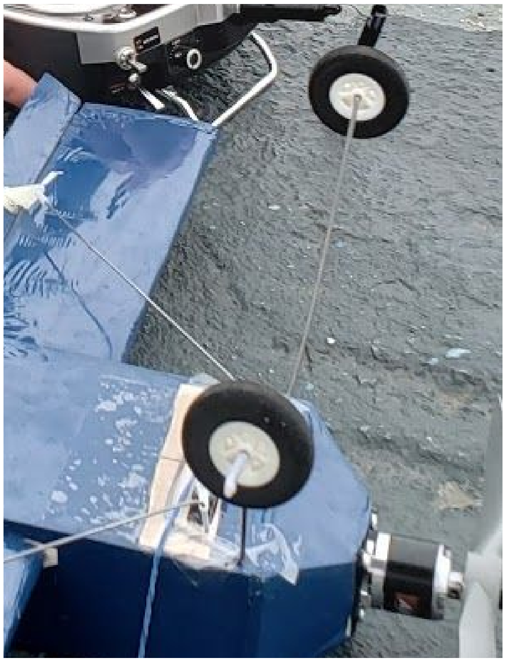


Figure 20: Basic orientation of landing gear. Tape was added to both sides to prevent the translation of the wheels.

After the basic manufacturing processes, we underwent through other processes where we had to tweak several aspects of the design in terms of strength, positioning, stiffness and stability.

Nose was reinforced with extra spars so that it would be strong enough to hold the heavy motor. Tail spar was coated with carbon fiber on the top as it was the main area where on the previous prototype while flight test it broke down. The rear landing gear was attached to a balsa wood and then attached to the bottom of the tail spar. A plate was also attached to the tail spar where servos could go in which served the stabilizers.

Also on the bottom of the fuselage, two servos were placed which controlled the flaps on either side.

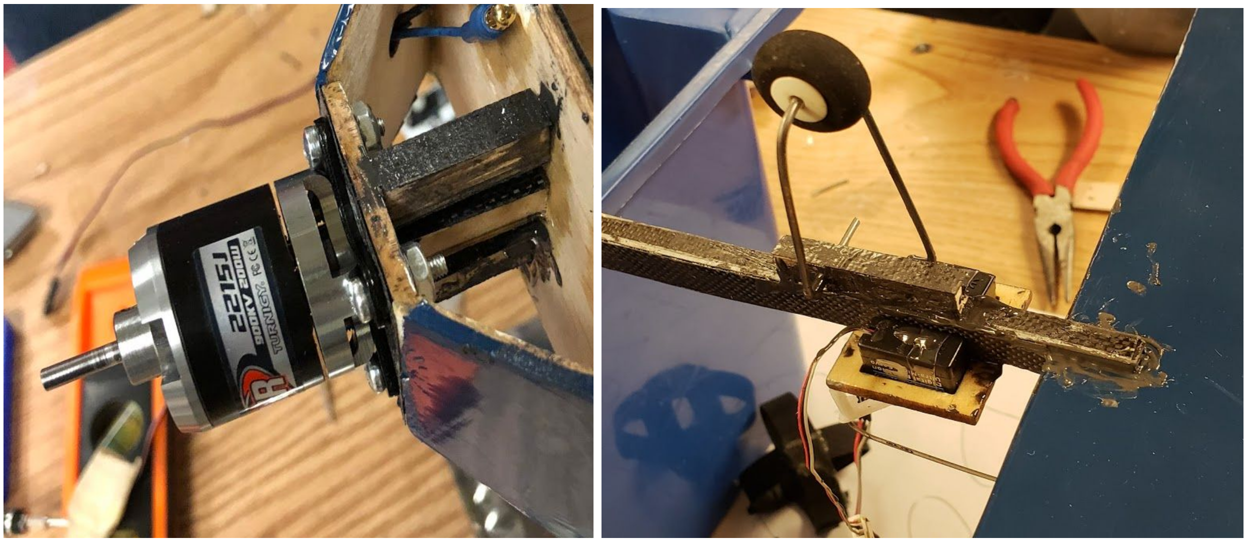


Figure 21: Nose reinforced with extra spars and the tail reinforced with carbon fiber along with the attachment of the rear wheel.

Figure 22: Plate attached to the tail spar and then servos attached to it.

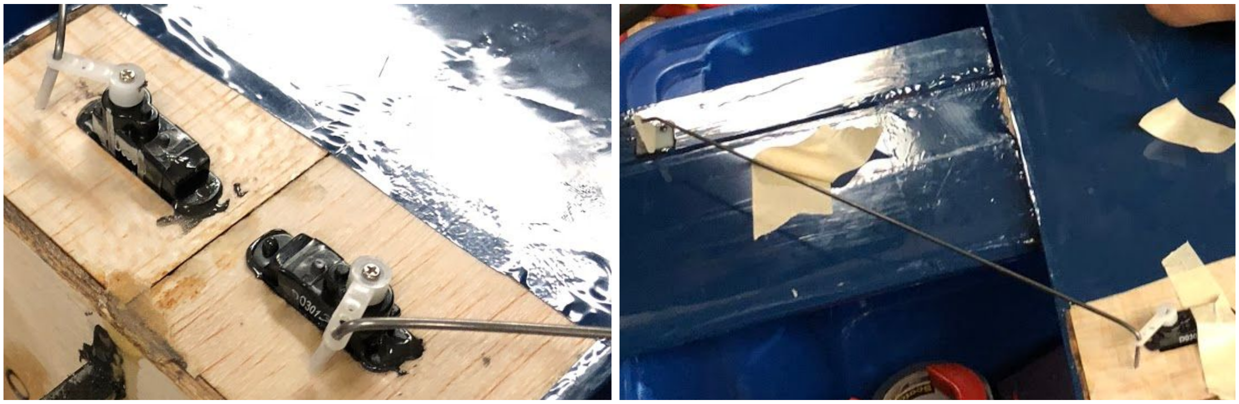


Figure 23: Servos placed on the bottom of the fuselage and then the piano wires being attached to the control horns on the flaps.

Monokote:

To make the whole plane streamlined and to avoid breakage of the connections due to high stress during flight, monokote was applied. Fuselage, wings, flaps and stabilizers were the areas where monokote was applied.

Figure 24: Applying monokote to the stabilizer(left) and to the wing(right). It had to be done carefully as the iron would have damaged the balsa wood as well as safety hazard.

Analysis and Testing

For analyzing the lift generated on the airfoil and the drag generated on fuselage, computational fluid dynamics were performed using ANSYS. Throughout the whole process of testing out prototypes, we never altered the airfoil type we chose. This was mostly due to the fact that we liked the lift that it generated. Furthermore, looking for another airfoil would have been time consuming. The same goes for the basic shape of the fuselage, we kept it the same for all prototypes so there weren't additional ANSYS analysis necessary to calculate its drag coefficient. The main focus for this semester as far as analysis and testing goes were on propulsion and experimental testing. But before we get into that, below is a short summary of our previous ANSYS analysis.

ANSYS

The airfoil chosen for this project was SD 7062. Below are some pictures and simulation results for the SD 7062 are shown below. All tests were performed with a inlet velocity of 11 m/s at different angles of attack.

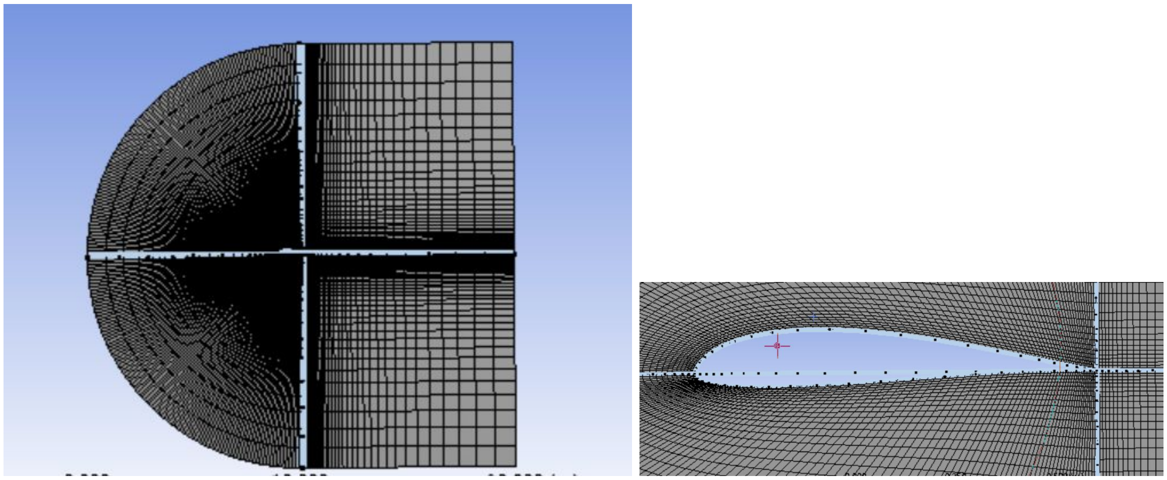


Figure 25: 2D meshing of SD 7062

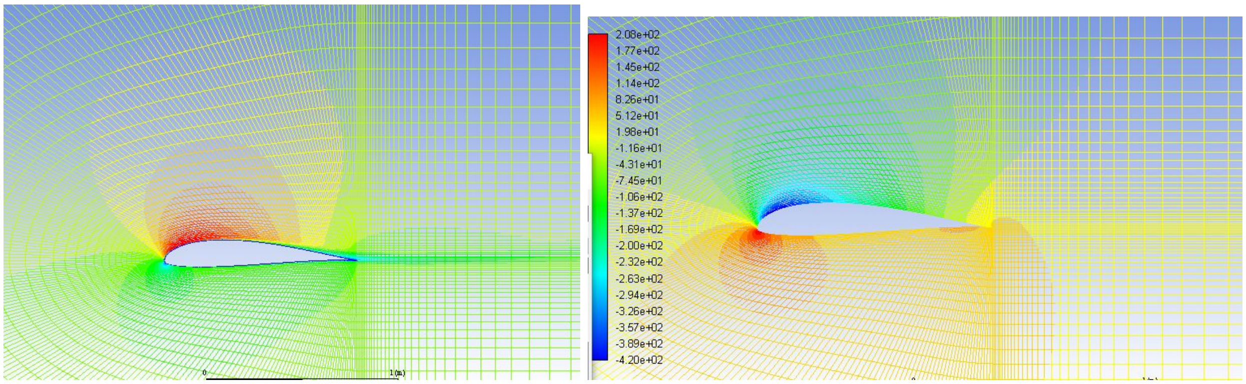


Figure 26: Velocity and Pressure profile of SD 7062

While fluid simulations were performed on the 2D airfoil, a CFD analysis on the fuselage performed to determine how fluid interacts with the body.

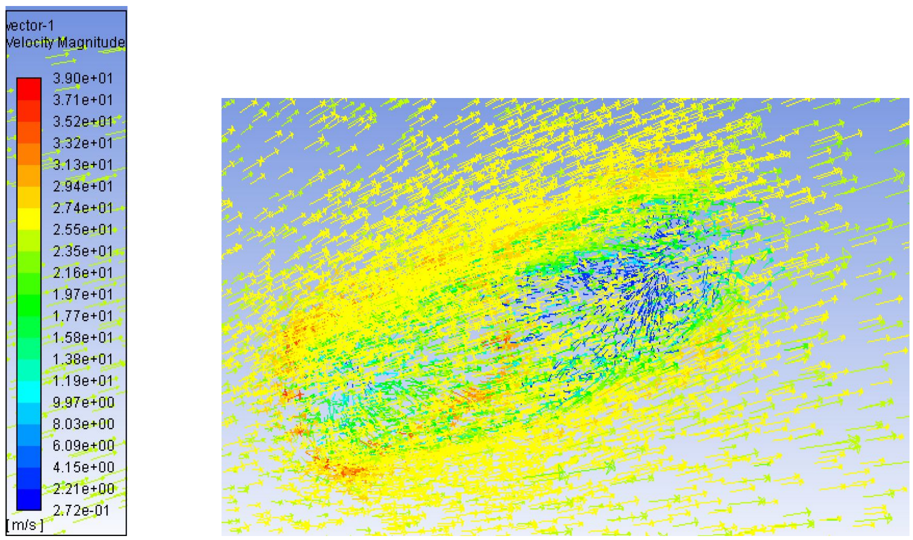


Figure 27: Velocity distribution for the fuselage

After completing the study, we saw that the drag was converge to 0.00136.

In the figure above, the velocity field is clearly visualized. The left shows the back of the fuselage and the wake produced. As expected, the vortices and and large momentum build up is located in the back. The largest velocity experienced is at the front of the fuselage. This affects the turbulences generated and thus the drag created. The turbulence plot behind also shows expected result.

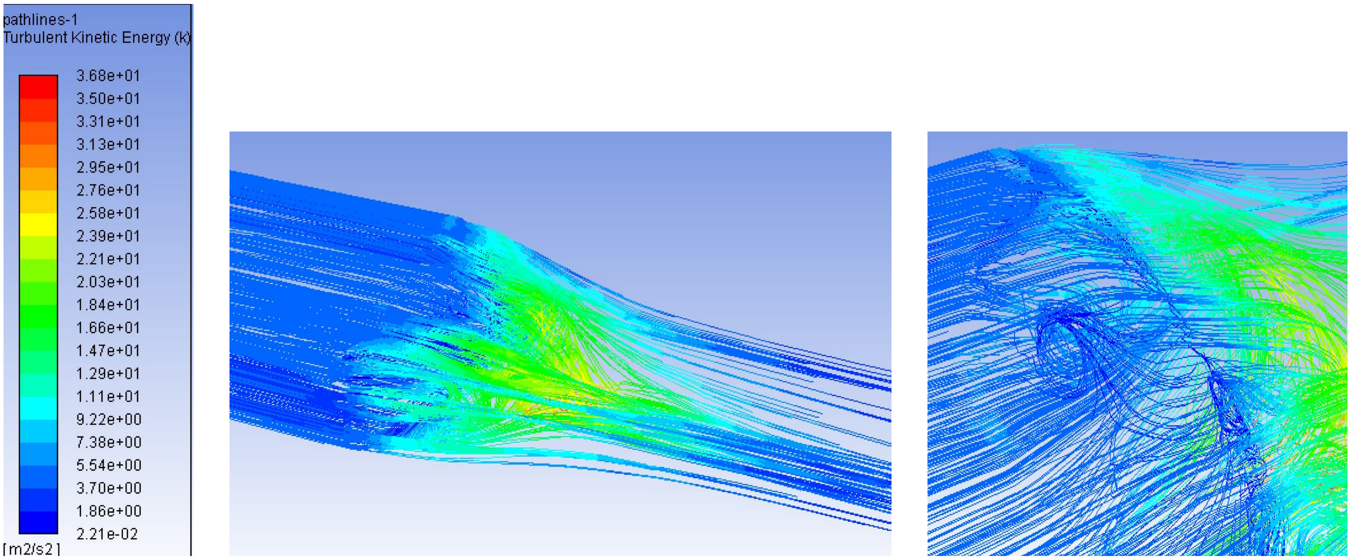


Figure 28: Turbulent Kinetic Energy Streamline

Turbulent kinetic energy streamline

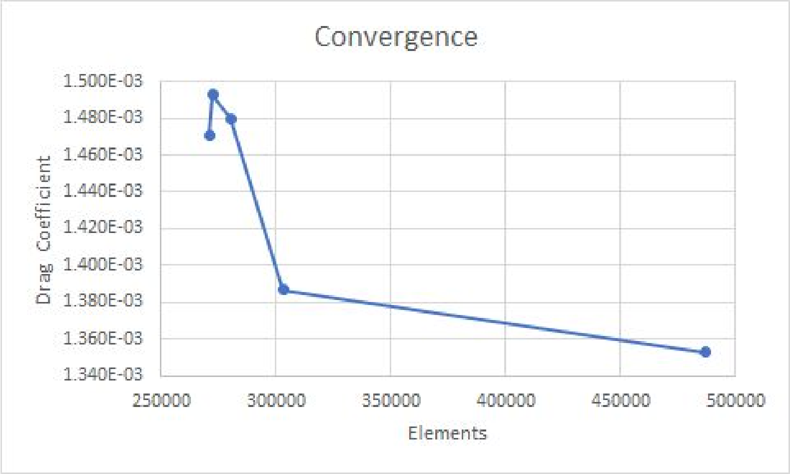


Figure 29: Convergence test for drag coefficient

Experimental Testing

After the failure of the first two prototype, we realized that in order generate more lift we needed a bigger wingspan. While it is true that a bigger wingspan will cause our overall competition score to go down, it was a compromise we were willing to go along with. Apart from stronger wingspan we also needed a stronger tail spar and the supports around it. After some brainstorming we came up with some ideas of how we can make the spars stronger but we needed to test them.

We laser cutted some spars and divided them upto into three different categories. A spar with epoxy, a spar with carbon fiber reinforcement and just the normal spar without any changes. The spar was made out of 1/4th inch balsa wood. So, the spar with epoxy were just coated with epoxy and left overnight, this strengthened the overall stiffness of the spar. The spar with carbon fiber, had thin carbon fiber strips that were vacuum bagged on the top and bottom face for extra strength. After all the spars were ready, we tested their strengths by applying a constant force on it and see how they reacted. The carbon fiber spar was the strongest spar but also was the heaviest. The epoxy coated spar was just a little bit weaker than the carbon fiber one but it was quite light and the stiffness was good enough thus, we ended up using that for our final model. A similar test was done for the tail spar.

Figure 30: Testing different thickness woods with either carbon fiber and epoxy.

We also tested various landing gear designs with various thickness of piano wires. After the first two prototypes, we realized that stiffness of the landing gear was an issue. So, after some testing and comparison, we chose to go with the wire with a gauge of 0.0765"

AVL

Athena Vortex Lattice (AVL) is a stability program created in MIT to determine the state of the plane at different attitudes to stabilize. We use it to test different bank angles and more importantly to see how far the tail must be from the wing so that the elevator won't have to be trimmed and avoid creating more drag. Our plane's geometry is shown below.

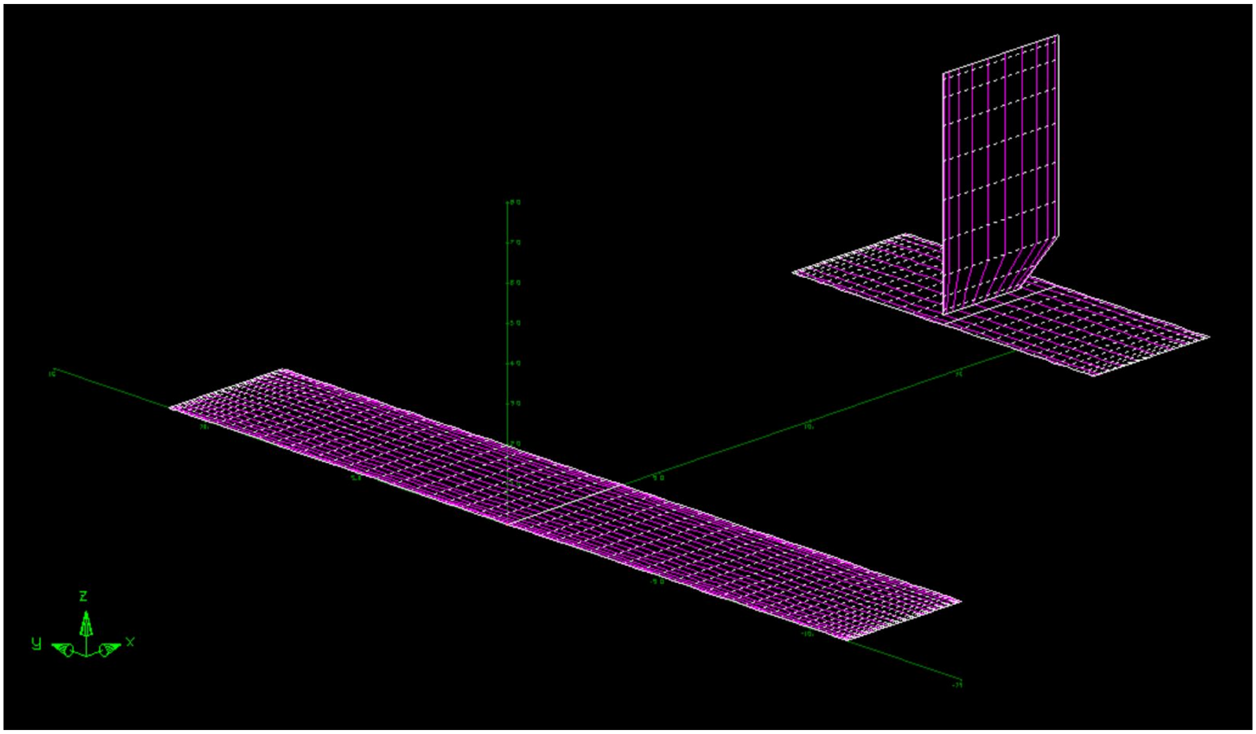


Figure 31: Geometry plot of our plane.

An example of how fast the plane can become stable is shown below, where a gust of wind tilts the plane to the side. Running through the simulation we see that as long as the pilot is capable the plane can return to its cruising position in less than a second.

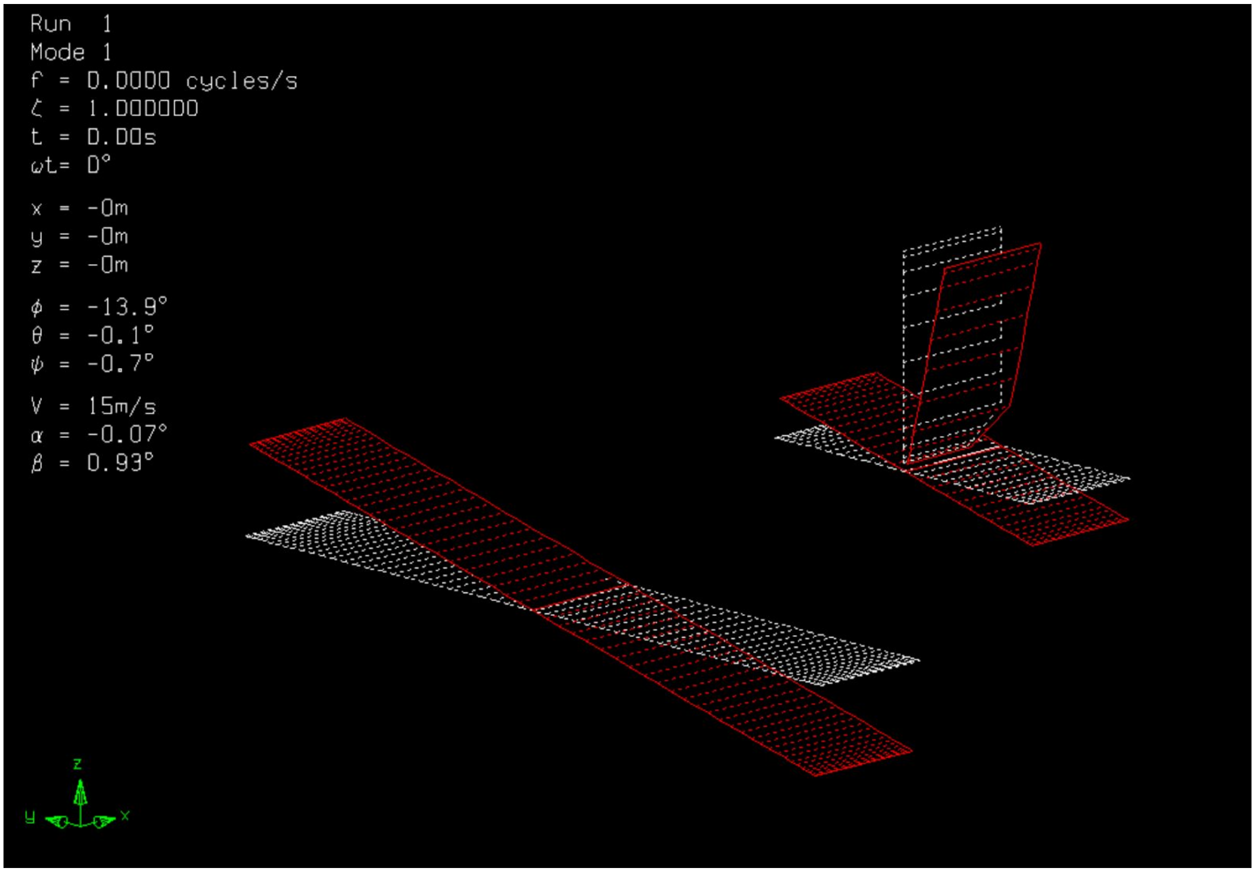


Figure 32: Plane stabilization from rolling.

Our testing shows that a tail spar of 8 inches in length would be optimal.

Ground Mission Testing

To practice for the Ground Mission we timed ourselves in replacing the LRUs. The following table shows the average times it took to replace an LRU.

Stage 1:

LRU	Average Time (s)
Servo	66
Battery	15
Control pushrod	55
Landing Gear Wheel	48
Propeller	71

Stage 2:

LRU	Average Time (s)
ESC	22
Left Aileron	124
Right Aileron	124
Elevator	112
Rudder	118
Receiver	59
Main Landing Gear	61
Motor	140

From our simulations and practice we can finish Stage 1 and 2 in under the 8 allowable minutes for any component.

Final Design Test Flight

The plane was tested on May 13th at Gerritson Beach Model Airplane Field. Sergey, an experienced RC pilot who has assisted AIAA before, would pilot the plane.

Going through all the preflight tests (e.g. checking the range of the control surfaces, setting up the transmitter) the plane was put unto the runway. The location of the center of gravity was checked. It was a bit in front of the ideal location but Serhey insisted it was fine. tHe plane was turned on and it lifted off smoothly. The landing gear provided the best performance thus far and the ailerons allowed the plane to be more maneuverable. However, shortly after, the plane nose dived onto the grass confirming that the center of gravity was too far forward making the plane too nose heavy. The plane was repaired and we're awaiting for Sergey's availability to test it again.

Product Architecture

The electronics and system controls of our UAV enable it to fly and maneuver midair. Direct control is between the pilot and the transmitter, which are the controls. The transmitter communicates with the receiver in the plane via radio frequencies at 2.4 GHz. The signals are collected from the receiver then gets relayed to the corresponding connected components. Below is a schematic of the electronics

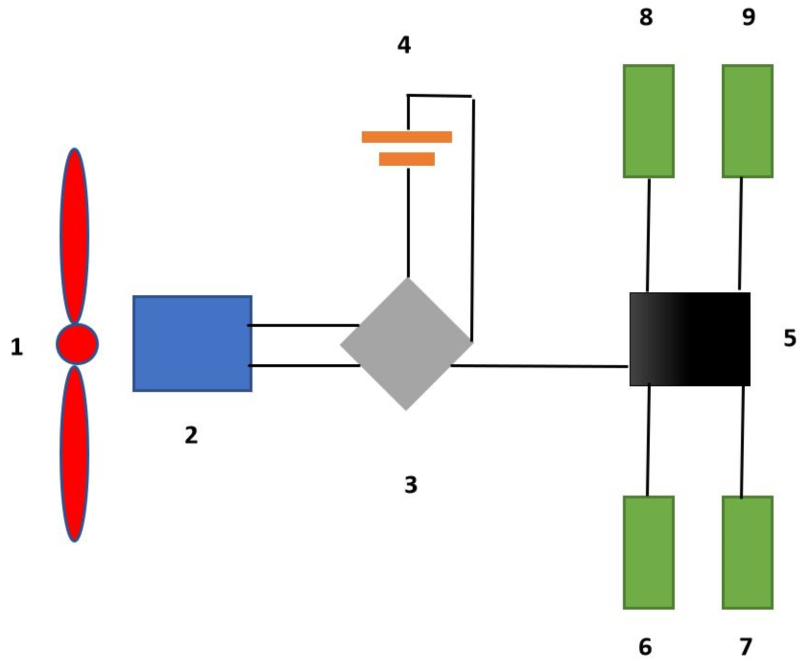


Figure 33: Engineering Drawing of Little Falcon

Components

1. *Propeller*
2. *Electric Motor*
3. *Electric Speed Controller (ESC)*
4. *10.8 V Battery*
5. *Radio Receiver*
6. *Left Aileron*
7. *RIght Aileron*
8. *Rudder*
9. *Elevator*

As displayed in the solid models, the *Little Falcon* possesses attributes of any standard RC plane. A Fuselage, wings, tail, propeller and landing gear. However, there are various subsystems in our product which enable it to function as it should that need to be discussed.

Propulsion System and Testing

Figure 34: Thrust measuring device.

To further determine the probability of flight and its reliability of our UAV, propulsion testing were initiated. The main goals of the testing are to determine the maximum thrust produced by different motors with different propellers, calculate the thrust to weight ratio of the plane, and determine which motor-propeller configuration produces the minimum amount of vibrations. Static thrust testing was the only required method.

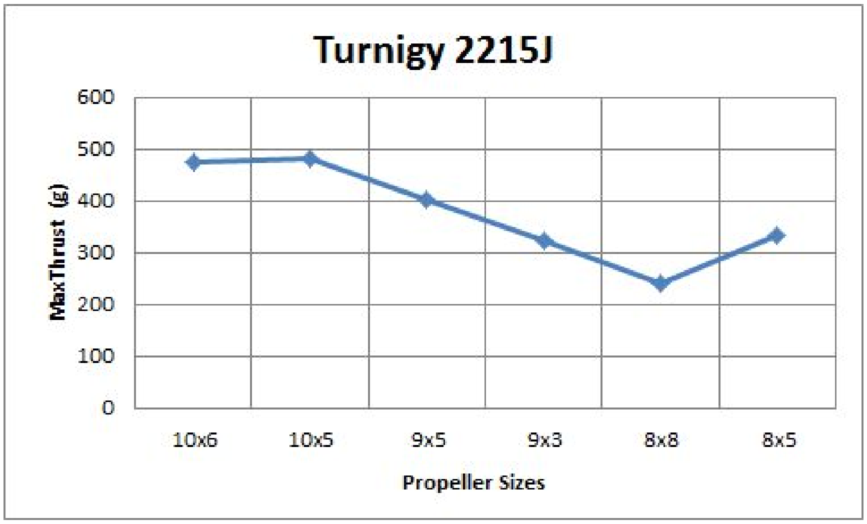
We narrowed down our selection of motors down to two candidates; the Turnigy 2210C and 2215J Motor. We selected these motors due to their high wattage, low KV rating, intrinsic thrust, being lightweight and inexpensive. We then chose the set of propellers to be tested. Since the UAV is carrying passengers and payload, the diameter of propeller needs to be large and the motor should have a low KV. The thrust to weight ratio range is from 0.5 to 1.0. That range guarantees flight for RC planes. After the selection, the static test was prepped and electronic components were connected.

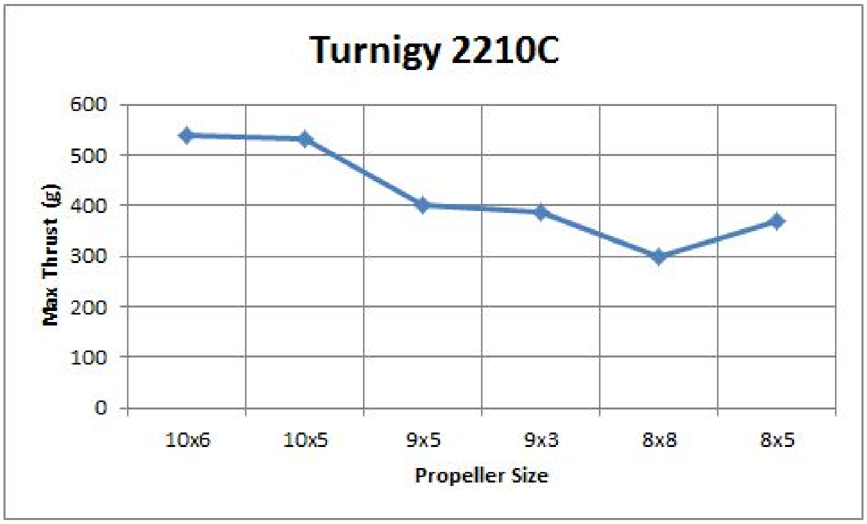
Turnigy 2215J Motor		Plane Mass (g)
Prop Size (Diam x Pitch)	Max Thrust (g)	454
10x6	474	1.04
10x5	482	1.06
9x5	402	0.89
9x3	322	0.71
8x8	240	0.53
8x5	334	0.74

Figure 35: Propulsion test data for Turnigy 2215J Motor

Turnigy 2210C Motor		Plane Mass (g)
Prop Size (Diam x Pitch)	Max Thrust (g)	445
10x6	537	1.21
10x5	531	1.19
9x5	402	0.90
9x3	387	0.87
8x8	300	0.67
8x5	370	0.83

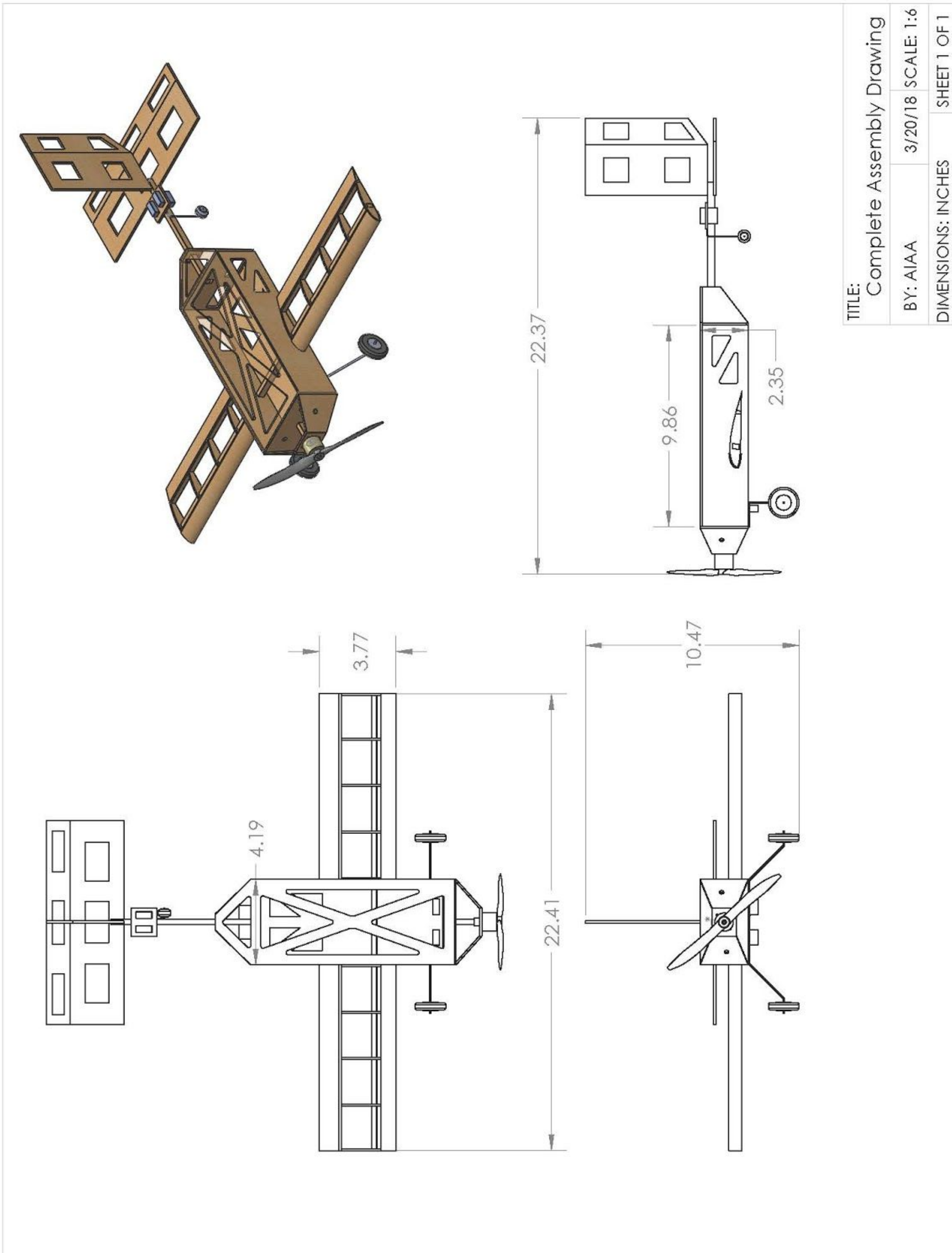
Figure 36: Propulsion test data for Turnigy 2210C Motor





After performing the static test, the following was concluded. The Turnigy 2210C motor provided the highest amount of thrust under all propellers relatively to the 2215J motor. The highest thrust to weight ratio created peaked at 1.21. Though powerful, the 2210C motor caused a noticeable amount of vibrations. The motor and the stand was shaking but not violently. We did not want vibrations to compromise the structural integrity of the nose or the fuselage, so we choose the 2215J motor with the 10x5 propeller. These configuration gave a thrust to weight ratio of 1.05, a little outside the range but by two decimal places.

Configuration and Parametric Design



Issues faced In the final iteration ranged from budgeting, manufacturing, and purchases. One of the greatest issues we faced is the lack of adequate funding. Funding for all ME clubs this year especially took a hard hit. This forced us to pay out of pocket without the assurance that we'll be reimbursed. Another issue faces were when motors were researched that the thrust specs marketed did reflect what was actually measured and so multiple motors had to be purchased, each time it being shipped from overseas. Manufacturing the plane first entailed that we must laser cut the balsa wood first utilizing the Zahn Center. Unfortunately the Zahn Center is very busy, especially during the last few weeks of the semester and availability for us was few and far in between, as well as their service not being free of charge.

A table of our purchases is given below. Please note that this is only the cost for our third manufactured plane.

Part	**Cost**
Balsa Wood	$ 47.84
Motor (x2)	$ 49.52
Servos (x4)	$ 56.76
ESC (x2)	$ 48.80
Batteries (x2)	$ 99.53
Piano Wires	$ 51.45
Wheels	$ 6.82
Monokote	$ 23.79
Zhan Center Laser Cutting	$ 56.00
TOTAL	$ 440.51

Conclusion

Ultimately, our goal throughout this past year was to gain valuable knowledge and necessary skills through a meaningful experience. Over the course of our engineering education, we have been assigned many projects of varying difficulties. None however have been as extensive and demanding as this. The AIAA project challenged us as students and individuals in a very unique. Appropriately so, as this task was meant to exercise all that we had learned over the course of four years. We experienced many ups and downs.

Originally, we set out to qualify for the DBF competition by brainstorming intricate and creative ideas. After studying previous competition winners, we noticed a strong correlation between complicated designs and high ranking. Thus, we became fixated on perfecting complicated designs and lost precious time building something within our means. Our *low weight, high score* attitude became troublesome as many crucial pieces were excluded to fulfil this philosophy. Specifically, our propulsion system was grossly under powered by small motors and small batteries to insure a lower weight, subsequently a higher RAC score. Because of this issue and numerous others created through our original convoluted designs, we failed to demonstrate flight capabilities during our first two flight tests. Consequently, we opted out of the competition even after qualifying. We lost our confidence.

After regrouping and reassessing our strategy, we understood changes needed to be made. Theoretically, our design should score well because of its RAC and passenger/payload configuration. But that does not matter if the plane does not fly. So inevitably, we simplified our design. We focused on what we knew and the capabilities of our material. We decided to significantly increase the dimensions of our plane. Moreover, we amped up our propulsion system to insure a capable flying plane. With lesser weight restrictions, we also included servos attached to flaps, an idea we initially had but scrapped. We felt very good about our final prototype and exercised all the manufacturing skills learned previously to build it as best as possible. Due to inclement weather and odd decisions made by Sergy, the test pilot, our plane only partially flew. This however, was not disheartening to us as the analytics suggested this model to definitely fly. After putting in a lot of work and working as a team, we finally felt successful.

Working as a team certainly made this experience much more valuable and worthwhile for all of us. Overtime, we got to learn more about each other and about ourselves. It was clear to us that sacrificing other aspects of our lives to insure we met the deadlines and produced something of quality was a priority to every member. This experience was not met without failure, as discussed about. Many setbacks had left us dejected but we persevered as a unit. And without the mistakes, we would not have gained half the knowledge we had throughout this project. Although we did not attend the competition, our goal was to simply learn and learn as much as possible. This is something we can carry on with ourselves, throughout our careers. In retrospect, there is very little we would differently. We believe we successfully completed our senior design project.

Acknowledgements

We'd like to give our heartfelt gratitude to the following people for their help and guidance in making our plane a reality.

Professor Charles Watkins

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Aulio Diaz - Zahn Center

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Mazen Alhirsh - AIAA VP

Sergei - Test Pilot

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