Design Report

Send It Industries

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AE 171B Aircraft Design

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1.0 Executive Summary

For Aircraft Design I & II, our team is submitting our design report on the Send It Aircraft. The objective of this two-semester length endeavor was to design, build and ultimately successfully fly an RC aircraft. Our team established mission parameters that were to be priority number one throughout the process. Configuration requirements that we had were: a high thrust to weight ratio, low drag, design suited for EDF and RC planes built for speed. We designed and built an aircraft that will have high cruise speed and swift aerodynamic performance. The goal for this aircraft was to fly at 70mph at cruising altitude. Incorporating aspects such as low drag for maximum efficiency and high power to weight ratio was taken into account for the design. This aircraft would be hand thrown, thus no landing gear was designed or attached. This reduced costs for us and also reduced complications when designing the aircraft. Our aircraft was designed around its motor. We opted to use a 70mm EDF (electric ducted fan). Although this is not the most efficient motor for radio control aircrafts, it is a lot more compact and can be fit anywhere needed. This specific EDF produces around 5.5 pounds of thrust based on the spec sheet provided from the manufacturer. With this, the power to weight ratio of greater than 1:1 would be achievable. The thin, yet structurally sound design is capable of accomplishing the speed requirements that we set for ourselves. We wanted to make the aircraft as cost-efficient as possible and used materials that would be everlasting such as carbon fiber. The weight of the electronics in the fuselage are the majority of the items contributing to the weight. The wings, tail, and fuselage body do not weigh more than 2 lbs. This gave a huge advantage, allowing our center of mass to be easily changed to match our mission profile needs, and it allowed us to keep our power to weight ratio to be high giving us high thrust values.

2.0 Management Summary

2.1 Team Layout

At the beginning of Fall 2019 semester, our team was made up of 8 individuals. Each person was put into a subteam based on their expertise and choice. People were responsible for areas of design and fabrication. Many roles overlapped between team members so that accuracy and precision could be crossed checked. Figure 1 shows the hierarchy of our division.

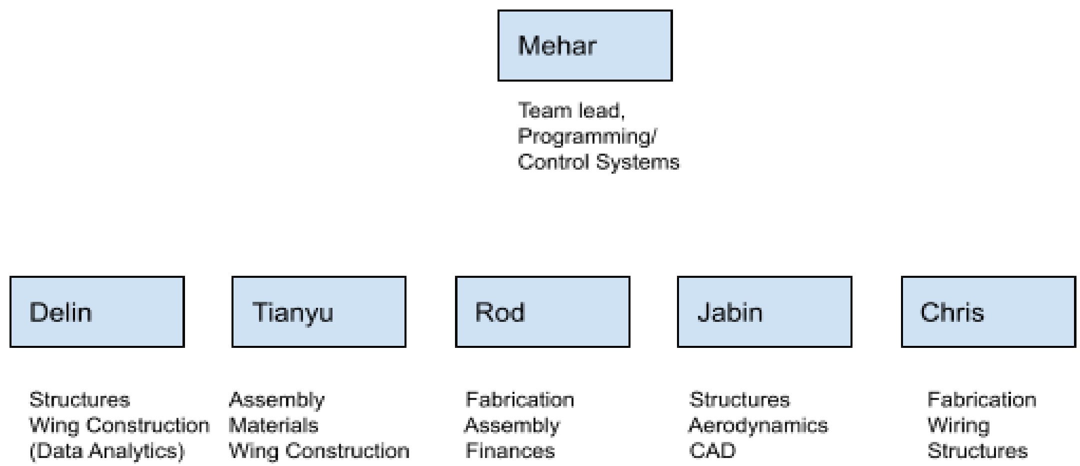


Fig 1. Hierarchy of team members and their roles.

2.1.1 Organizational Roles

At the top of the pyramid is the team lead, Mehar Jaiswal, whose job it is to make sure everything runs smoothly and everyone is able to carry out their tasks. The lead's main goal is the quality and accuracy of deliverable throughout the semesters. Next comes the roles of Delin Huang. His job is to make sure the aircraft is structurally sound as well as assisting in the testing and data analysis portion of the project. Tianyu Gao's role is the assembly of the wings and also aid in the further testing of the aircraft. Testing includes bench testing the electronics, and stress testing the materials used for the construction. Rodmehr Ahmadi and Christopher Van's roles dealt with the majority of the fabrication and assembly of the aircraft as well as knowing what materials were needed and how to attain them. Jabin Benjamin's role was the main CAD work and SolidWorks items needed to visualize and properly design the aircraft.

2.2 Schedule

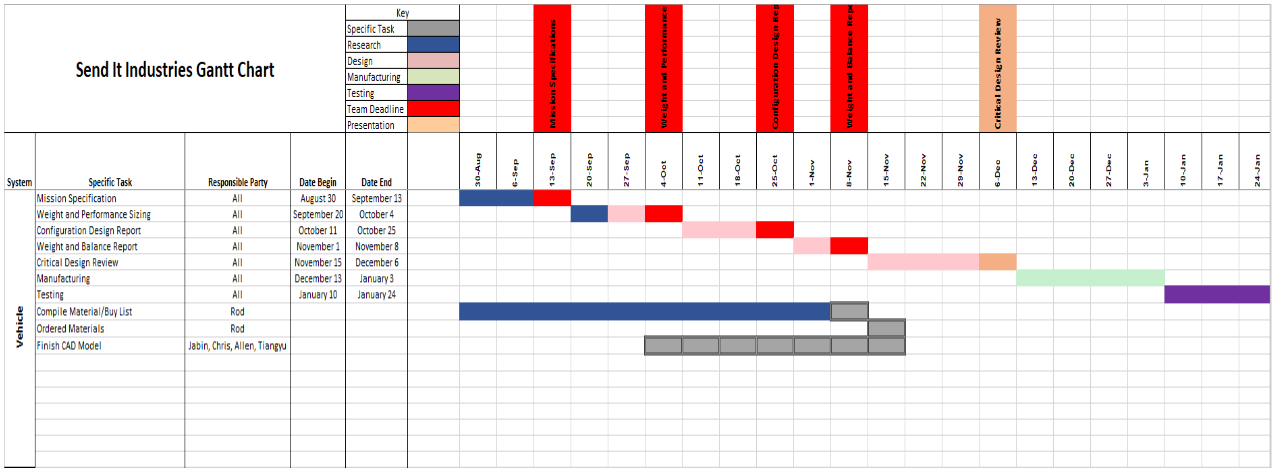


Fig 2. Gantt Chart displaying the order of events and completion milestones

3.0 Conceptual design

3.1 Mission Requirements

The modern aerospace industry has been highly developed, many airplanes can reach sonic speed easily without afterburning. According to that, the Sendit team considers the secret of high speed is hidden in the aerodynamics. How can we make the airplane fly faster? What design of the airplane will achieve better aerodynamics? The major mission for the Sendit Aircraft is to achieve a high rate of speed in a short period of time, and the minimum speed that we wish to achieve at cruising altitudes is 70 mph.

This mission requires the airplane to have a high thrust engine, lightweight fuselage, and high lift-drag ratio wing design. For high-speed aircraft, the engine is the main component that decides the thrust that an aircraft can produce and also decides the amount of weight you can put on for takeoff. The bigger engine provides more thrust, but it expends the scale of the aircraft. Therefore, a moderate engine is needed. The lighter fuselage is the keystone of increasing power to weight ratio, thus, the materials for the parts of the airplane should be light, the fuselage's structure should be simple but strong, and the weight balance should be reasonable. The majority of the lift comes from the wings: the shape of the airfoils determines how much lift the aircraft has. In this mission, the aircraft needs to contain low wing load and low aspect ratio. The low aspect ratio requires a high wingspan and low area. The weight should be 5lbs or less, since the amount of thrust generated by the motor will be 5.5lbs. Our aircraft should also be 3x3 ft so that it is easy to throw and carry.

3.2 Design Requirements

To reach the concept requirements, the Sendit team opted for an engine that can provide around 5 lb of thrust, as a result, the total weight of the airplane will be under 5 lb. In order to achieve a W/P of better than 1:1, we had to design a lightweight aircraft. For the airfoil, the Sendit team decided to take NACA 2408 as the main model. The reason is the shape of NACA 2408 has a great cl/cd ratio and we believed it would be easy to manufacture.

Weight is the most important part of this design. Originally, the Sendit team considers the airplane's total weight to be 5 lbs, which is based on the data of mass for individual components. This was configured from weight sizing and material input from the Solidworks designs. For example, the battery is 1.3lb and the motor .44lb.Because our motor produces 5 lbs of thrust, having a total weight of 5 lbs as our goal would allow us to have a T/W ratio of 1:1. To reduce the total weight, the Sendit team decided to choose light materials for the fuselage and the airfoils. After the summation of the weight of all components added, our aircraft should have been 5lbs at a maximum.This was estimated after weight sizing for our thrust values of 5.5lbs of thrust. After the changing of some materials, it came out to be 3.5lbs. The aircraft was to be 3x3 ft. This was so that it would be easy to handle while throwing and for moving from one location to another. Since our plane was going to be hand thrown, having it too big would make it hard to throw with enough force and at the right angle of attack.

3.2.1 Scoring Analysis

	100%	90%	80%	70%	60%	Pass	Fail
Can take launch and continue flight	….	….	….	….	….	Able to continue flight after launch.	Falls to ground.
Able to maintain flight via FPV camera + Record Top	...	….	….	….	….	Plane is able to maintain steady flight.	Unable to maintain steady flight.

Speed							
Weight Limit (5lbs)	….	….	….	….	….	Plane is within 5lbs.	Plane exceeds the weight limit.
Size limit (3ft by 3ft)	….	….	….	….	….	Fits within the limit	Exceeds the limit.
Plane Stability	Plane is able to withstand small environmental disturbances	Minor issues but still usable			Unable to fly steadily	….	Unable to fly.
Remote Controlled flight	Plane is radio controlled.	Plane follows the flight path with few issues.			Unable to follow flight path	….	Unable to fly.
Flight time of 5 minutes	Flies for 5+ minutes with consistent performance.				Flies for 3 minutes.	….	Unable to fly.
Fly at 70mph at cruising	Speed is met.	Speed of less than 70mph	Speed is below 50mph.	Speed is below 40mph	Speed is below 30mph	Able to fly at 70mph at	The plane never

altitudes		but greater than 50mph is met				cruising speeds	reaches cruising speeds.

Fig.3 Scoring analysis chart

3.2.2 Performance Requirements

To meet basic performance requirements our aircraft must be able to fly at cruise altitude of 200 ft after takeoff range, fly at 70 mph, cruise for about 30 seconds and then attempt to land in the general takeoff path. The takeoff part of the mission will require the aircraft to reach 200ft altitude and reach velocity of 70mph. The cruise in a visible area at 70mph for a readable amount of time (30secs.). SendIt does not have a landing gear attached, which makes landing safely a concern for our design teams. After cruising at 70mph, our aircraft should be able to slow down significantly when getting ready to land. Our radio controller will aid us for this part of the mission. Since our battery life is 4 minutes at full throttle, we made our flight time to be maximum 3.5 minutes long so that the battery would not fully discharge while our plane was still in the air.

3.3 Configuration Study

In order to design a RC plane built for highspeeds, configuration for performance parameters were researched and studied. Having a very light aircraft was at the core of the configuration. Lightweight meant that our aircraft would easily gain lift when thrust was applied. While researching, we came across other aircraft that used EDFs that were the same size. These aircrafts were easily flying at speeds above 70mph which made us optimistic for our plane's mission specification.

3.4 Configuration Details

3.4.1 Wing sweep

Even though a swept wing is harder to manufacture at our level, as a team we decided to go with a different version one because of its aerodynamic properties. Our wing is a trapezoidal wing configuration. We designed our aircraft off of fighter jets which have swept wings and fly at a very high rate of speed. Even though with our wing configuration, it would make less lift at slower speeds, we believed that the amount of thrust available would overcome this deficiency.

3.4.2 Drag Reduction Features

To reduce drag, we configured our aircraft to have a smooth cone at the front of the fuselage, with curved braces on the sides. We also wrapped our aircraft all over in the same material to avoid clashing edges of different materials underneath. The main aspect of our aircraft that reduces drag is our wings. Although not fully swept, the aircraft wings have sharp and seamless edges that allow flow to be laminar over the leading edge.

3.4.3 Fuselage

Our fuselage is the main body that holds all our electronics including the receiver, and the battery packs, two of the heaviest items on the aircraft.The fuselage has no landing gear attached to it and so the belly is smooth allowing for more aerodynamic properties. For future configurations, depending on the performance of the aircraft, we would like to design the landing gear so that it could sustain landing conditions without the risk of crashing into the ground upon descent.

3.4.4 Propulsion Integration

The decision to integrate an EDF (electric ducted fan) came as a group consensus. Upon research, we concluded that an EDF would be the best type of motor for our design. It is tightly packaged, easily mountable, and makes a lot of thrust. The ducted fan came with tabs on either end which made mounting in between the C-channels easy. A drawback is that it's not as efficient as a regular propeller on longer flights. This was not an issue to use because of our short flight time. The only complications we would face would come when manufacturing. Building our design around the ducted fan came with issues such as proper scaling, streamlining the fuselage with the fan, and using sufficient material around it so that the fan wouldn't be obstructed by loose ends.

3.4.5 Empennage Configuration

Our empennage or tail assembly was 12.75 inches in length parallel to the length of the wings. It was designed to be a two part fixture, where the horizontal elevator would slide up and down the main structure of the tail. The main tail structure would be made as one peice so that we could ensure structural integrity. The elevator was made of the same materials as the rest of the tail.

4.0 Preliminary Design

4.1 Design Optimization Methodology

Our initial calculations of the aircraft were for a maximum weight of 5lbs. After having manufactured it using lighter materials such as carbon fiber, the final weight of the aircraft turned out to be much lighter than expected, almost 3lbs less. This means that we had to recalculate the power to weight ratio. This turned out to be in our favor because it allowed our motor to be able to generate the same amount of power at the same time creating more lift than we had anticipated earlier.

To calculate the wing load and the power load, we stimulated our aircraft model in Solidworks, and achieved the data below.

Velocity Max	C_Lmax	C_Do	C_di	Efficiency	Weight	Thrust
70.007mph	0.133	0.06	0.062	0.85	3 lbs	5 lbs
Wing Span	Wing Area	Engine Max Power	Actual W/S	Actual W/P		
2.69 Ft	1.8 ft^2	1638 W	1.67	9.82		

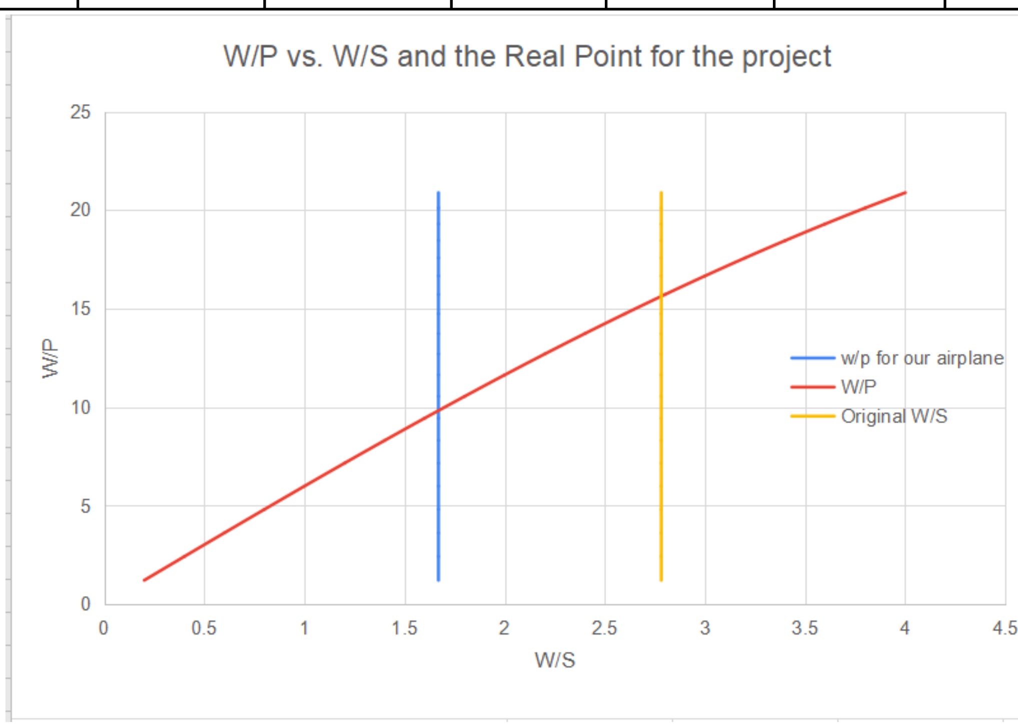


Figure 4. Wing Load vs. Power Load with the Actual Selection

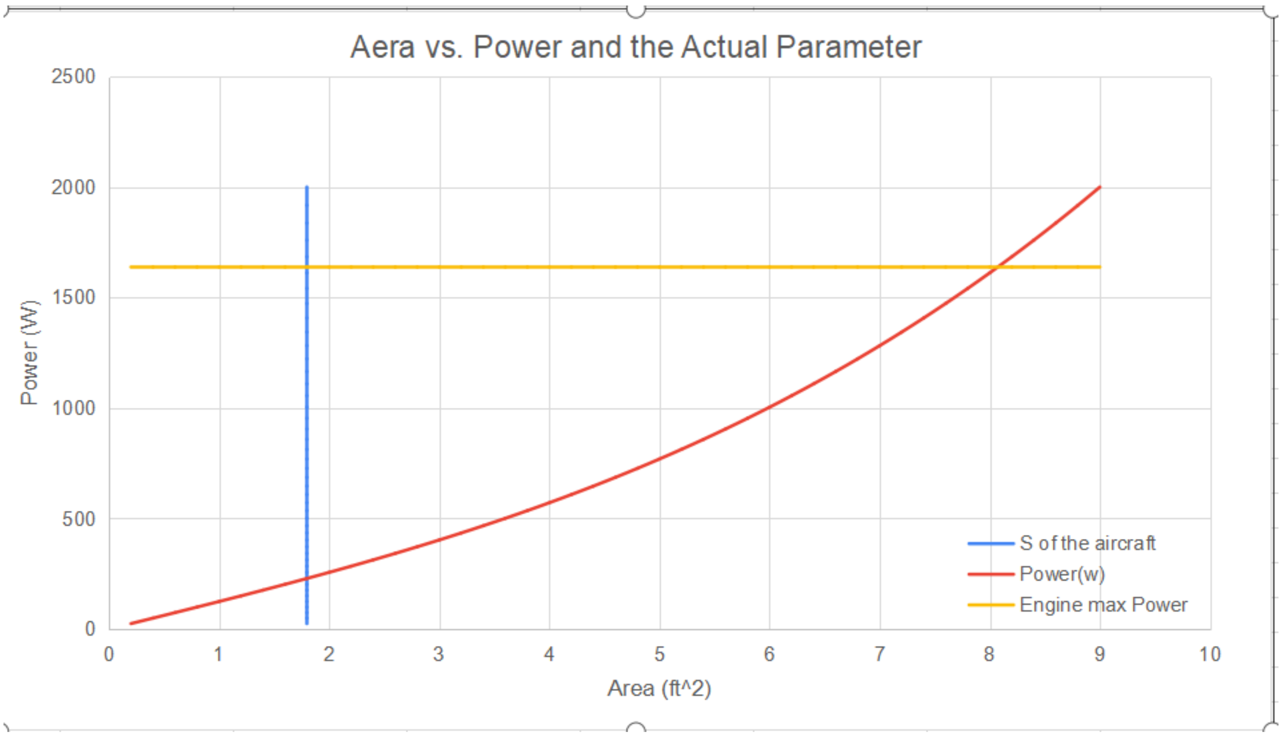


Figure 5. Wing Area vs. Power with the Actual Selection

In the first graph, we have the theoretical, or the original wing load around 2.8, and the power load is around 16 base on the maximum allowed weight and the actual wing area. However, after the assembly, the actual weight is around 3.5 lbs, so we took the actual W/P from the W/S vs. W/P graph with the actual W/S, which is under the maximum wing load. We used the actual weight-to-power ratio and found the actual power needed from the graph of Wing Area vs. Power. We compared the actual power needed with the maximum power that the engine could provide, and concluded that the power provided by the engine is more than enough for the airplane needs.

4.2 Design Tradeoffs

A swept wing would have given us the ability to easily maneuver the aircraft through the controller, however we voted against this idea for the sole purpose of easy manufacturing. As students it would have been hard for us to accurately make a swept wing without jeopardizing the rest of structural aspects of the fuselage. If not made correctly the wing would break off in the air. The cost of replacing the wing exceeded our demands and therefore we went with a dihedral wing with no sweep. The wing area and span are very small because at the beginning, we were trying to reduce the wing area and span in order to reduce the total weight of the airplane and drag. We assumed that the engine would generate enough thrust and velocity for the airplane. As a result, the power load and wing load is slightly higher than we expect. We also opted for no landing gear to make the aircraft as light and aerodynamically sleek as possible, this however would make landing very difficult for the pilot. Because of where the motor is mounted, we had to incorporate a high tail configuration with two separate vertical stabilizers.

4.3 Mission Model

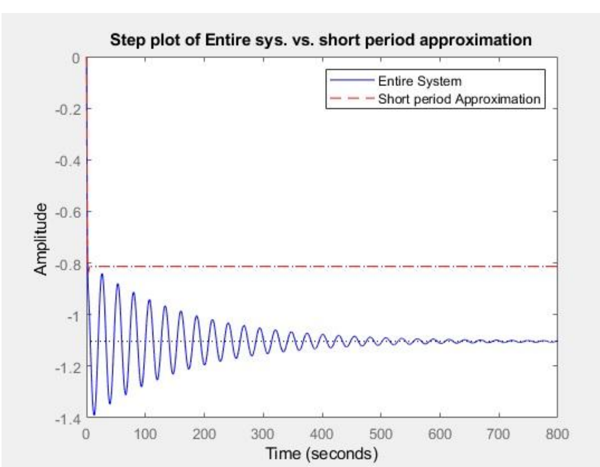
Our aircraft is designed to be able to fly 70pmh at cruising speed. We hoped that we would be able to carry this out during the flight test. The objective for our entire mission is to be able to fly to up 200ft altitude during takeoff while maintaining stability. Then, the aircraft should fly at 70mph uninterrupted at that same altitude for 30 seconds and then prepare for descent. It should then land on its belly at about 10mph over grassy terrain. We have estimated that it will consume all of the battery power at full throttle after flying for about 4 minutes. Therefore the entire mission profile has a time duration of less than that.

4.4 Stability and control

To analyze the stability of our aircraft, we used the standard longitudinal and lateral equations of motion for aircraft. This allowed us to create a state-space matrix. We used equations found in Roskam's *Airplane Design* [5] and the vehicle dynamics course reader [4] to solve for each variable in the matrices.We pulled measurements and data from our Solidworks model [Fig. 11 and 12] and used them in our equations. After fully making our state space matrices we created our transfer functions to then use in testing static and dynamic stability. Studying these graphs helped us to understand the stability of our aircraft.

4.4.1 Longitudinal Approximations

In order to study the longitudinal static stability of our aircraft we use the short period and phugoid approximations.



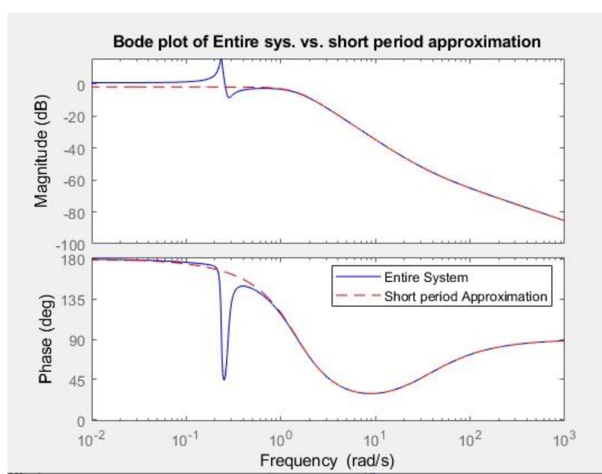


Fig. 6 Short period app. (high speeds)

In the figure above, the first graph shows the step response of the system over a period of time. The system seems to be unstable over 800 seconds. However since this is only a step response, the time it takes to stabilize the aircraft will be quicker than the response. The second graph is the frequency response of the system compared with the short period approximation, the short period tracks the gain and phase margins very well in the bode plot. For the step input for the system, the aircraft oscillates a lot and damps out after about 800 seconds. Since it is able to damp out, the system is stable.

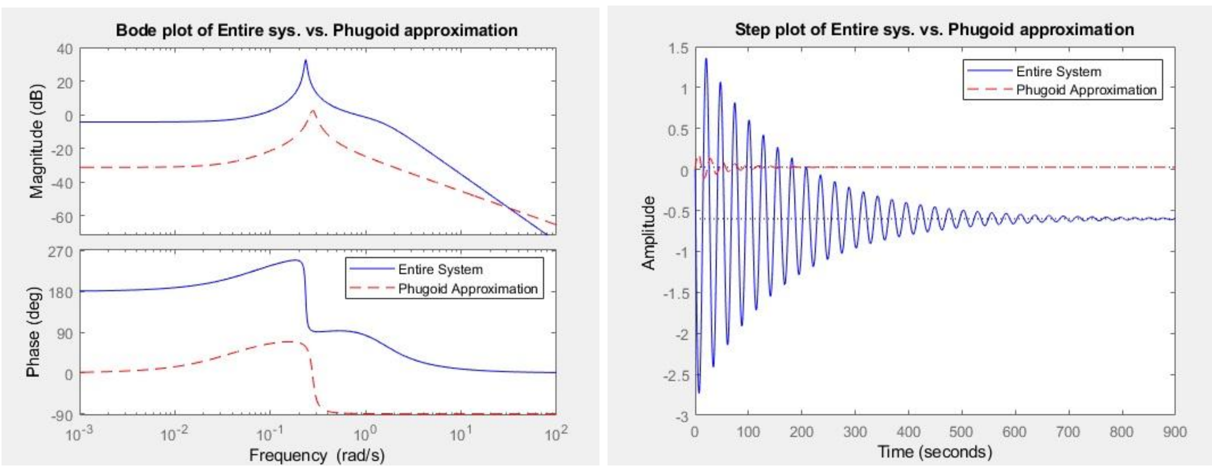


Fig. 7 Phugoid app. (high speeds)

For the frequency response compared with the phugoid approximation, the system takes 900 seconds to damp out. This shows that after 900 seconds is when the system is fully stable. However, the time interval between each oscillation is quite long. This displays a very slow response to stabilize, as expected from a phugoid approximation. The time between each peak is about 30 seconds, which is a long time for the pilot to action and stabilize the aircraft.

5.0 Detailed Design

5.1 Dimensional Parameters

Part	Quantity	Measured Weight	Dimensions
Turnigy 4000mAh 6S 30C LiPo Battery	1	1.34 pounds	7in x 2 in x 1.5in
Receiver	1	.059 pounds	1.5in x 0.9in x 0.5in
Hobbywing Skywalker 80A	1	.180 pounds	57x31x12mm

ESC			
70mm 12 Blade Electric Ducted Fan (EDF) 2300KV Motor (6S/22.2V)	1	.441 pounds	70mm fan (2.75 in) 73mm inner diameter (2.87 in) 83mm outer edge diameter (3.27 in) 89 mm max length (3.5 in)
Aileron Servo	2	.048 pounds	1.3in x 1.2in x 0.4 in
Horizontal Stabilizer Servo	1	.048 pounds	1.3in x 1.2in x 0.4 in
GPS Module	1	.055 pounds	1.8in x 0.4in x 1.7in
On Screen Display (OSD) Module	1	.010 pounds	1.3in x 0.2in x 0.8in
FPV Camera Assembly	1	.011 pounds	0.79in x 1.33in x 0.4in
Fuselage + Horizontal Stabilizer	1	1.06 pounds	----
Wing Assembly	1	.189 pounds	---
Total		3.441 lbs	
Constraints		5pounds (2268 grams)	

Fig. 8 List of items and their respective weights and dimensions

5.2 Structure

To maximize the thrust, we had to keep the weight as low as possible. So we made the fuselage out of carbon fiber. This gave us a huge advantage and we were able to keep the weight below 5lbs overall. The tail, elevators, and ailerons were 3-D printed. The wings were laser cut from balsa wood and had carbon fiber rods as spars which had the added effect tying into the fuselage, giving it additional structural support. We made the L - brackets out of carbon fiber as well which acted as the frame structure/chassis for the fuselage. The wings were then wrapped with a monokote wrapping.

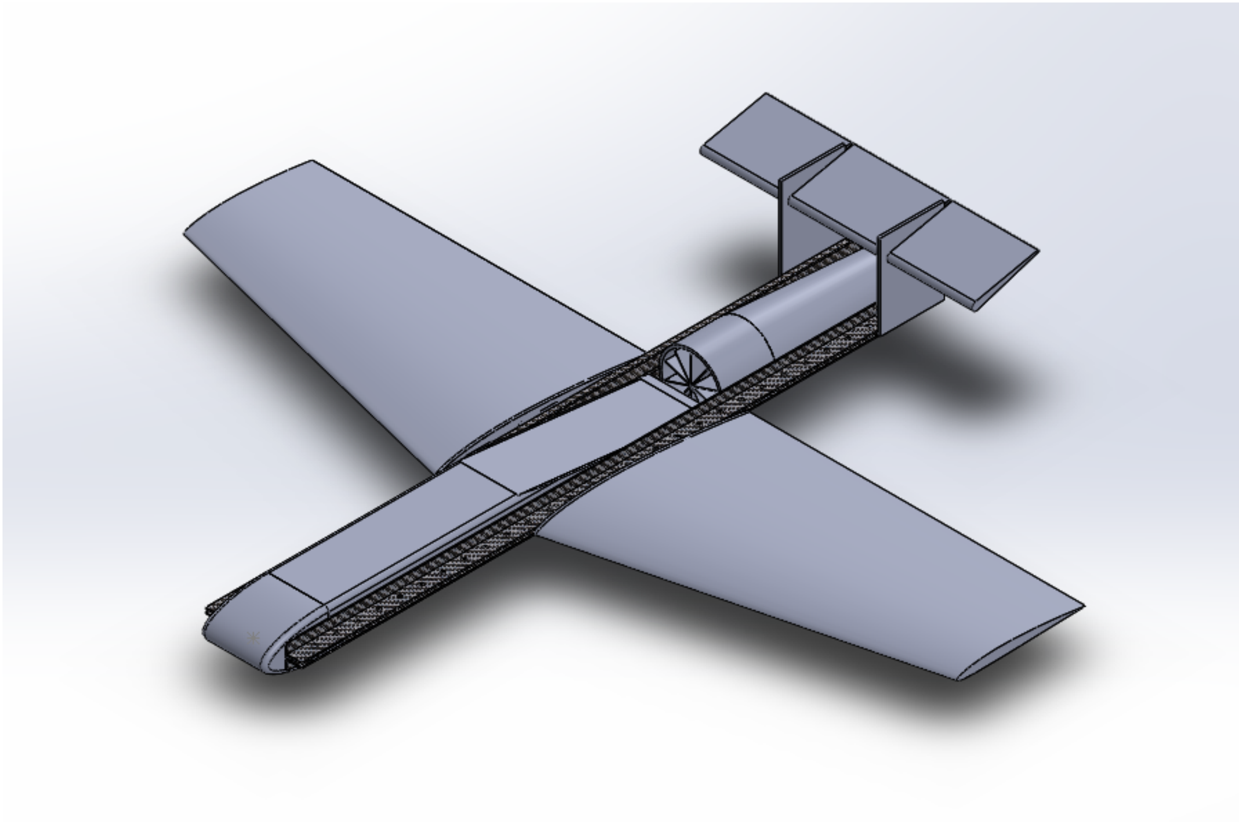


Fig. 9 3-D model

5.3 Subsystem Design

5.3.1 Fuselage layout

The purpose of the fuselage is to hold the battery and electronics. We designed our fuselage so that it would be suitable for high speed flights and would also integrate an EDF motor in the back. The fuselage was shaped aerodynamically in a way that would introduce a stream of air straight to the EDF. The thrust tube for the motor and the fan can be removed for easy installation if something breaks or if the motor burns out.

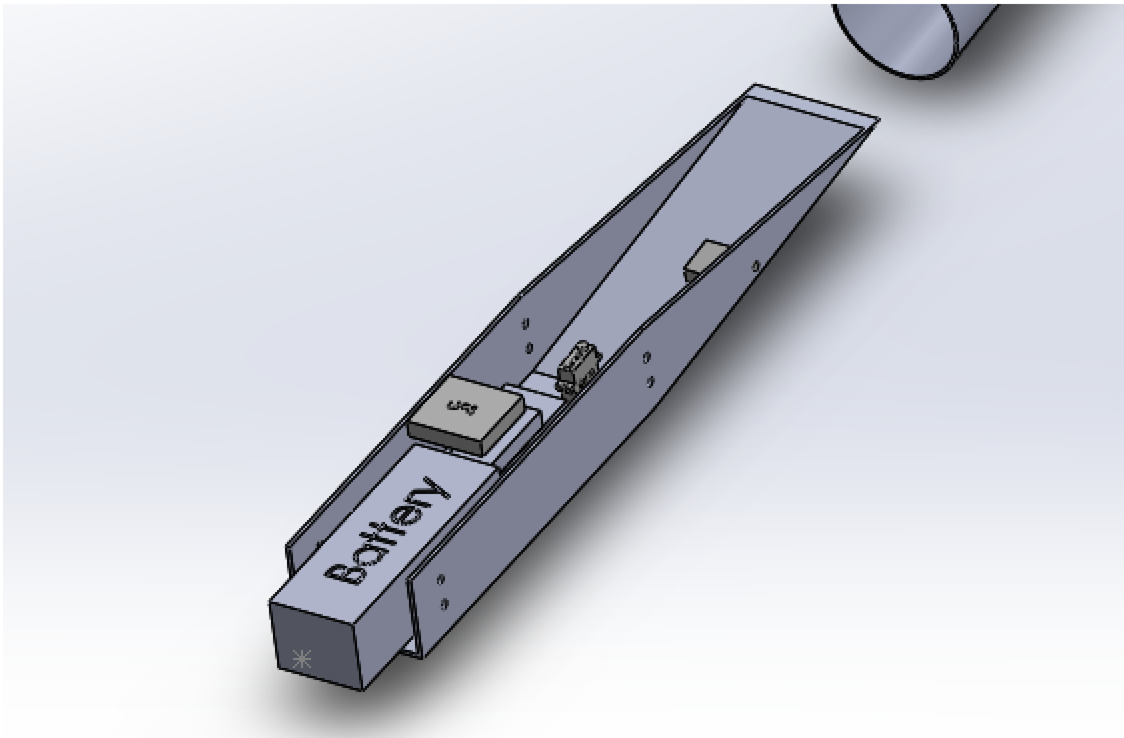


Fig. 10 Fuselage model

5.3.2 Electronics

The electronics package consisted of a 70mm 12 Blade Electric Ducted Fan powered by a 6S 25V 4000 mAH LiPo Battery with an 80A capable electric speed controller (ESC). For control surfaces we had one servo controlling our elevator, and the initial plan was to have a single servo controlling a linkage for the ailerons in the interest of saving weight. However upon assembly for the initial test article delivery, we found that the aileron linkage had too much stiction and slop and did not exhibit enough resolution and control.

We did not feel safe proceeding with the linkage so we decided to utilize two servos to control each aileron. Servo mounts were made to move the servos to the wings, which completely fixed our control issues.

The GPS module wired up to an on-screen display (OSD) module was installed on the plane so that we can track the speed of our plane and have it display on a screen. In addition we were planning to use a camera to assist in tracking/flying our plane but we did not end up installing it for the initial test article due to time constraints.

5.3.3 Engine Arrangement and Tail Design

Our airplane has the T-tail design because of the engine arrangement. Compared to the regular T-tail, our aircraft has two supporting beams supporting the elevator, and the engine is placed under the elevator. Our engine is one of the heaviest components on the airplane, so we have to balance the weight and arrange it behind the fuselage. Making sure the engine will get enough flow, we attach the engine with the L-brackets half inch behind the fuselage, so that the engine will generate high speed flow on the fuselage surface. There is a limit for this design, the engine will not receive as much flow as we expect. There is a closing cone-nozzle at the outlet of the engine, and the reason is to generate higher speed flow when flow exits the nozzle.

The elevator is arranged above the nozzle, so that the flow from the engine and wings will not impact the elevator. The elevator consists of three airfoils, the large area elevator can generate considerable lift that makes the airplane pitch up and down easily. There is a limit for this design, we have to make an external control linkage to the elevator.

5.4 Weight and Balance

Calculations done for center of mass and moment of inertia were obtained from our Solidworks model of the airplane [Fig. 12]. First we modeled the airplane fuselage, wing and tail assembly. Then we modeled all of the components listed in [Fig. 8] accurate to their dimension and weight and then placed it within the fuselage. The configuration seen in [Fig. 11] is how we ended up constraining the electronics within the model, which was also how we configured it for our initial test article during final assembly. It is also worth noting that following the layout made in the model helped us during assembly because fitment inside the fuselage was tight and the parts would only fit where they were constrained in our Solidworks model.

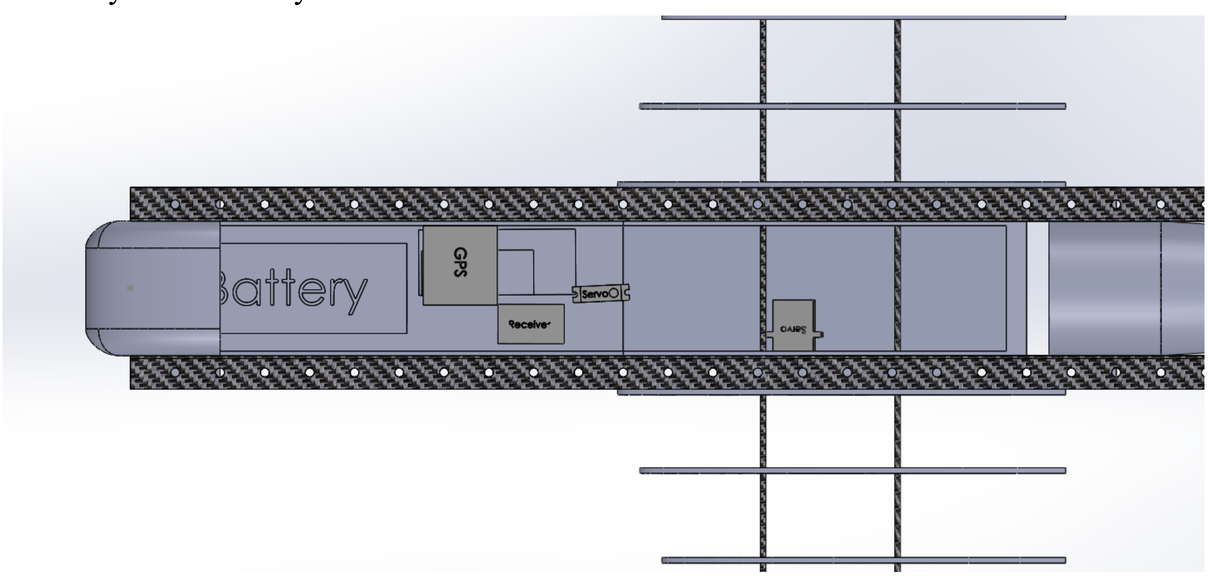


Fig. 11 Components Modeled and Constrained in Solidworks

Center of mass: (inches)
X = -13.00
Y = 0.00
Z = -0.09

Principal axes of inertia and principal moments of inertia: (pounds * square inches)
Taken at the center of mass.

Ix = (1.00, 0.00, 0.03)	Px = 22.60
Iy = (0.00, -1.00, 0.00)	Py = 292.02
Iz = (0.03, 0.00, -1.00)	Pz = 310.63

Moments of inertia: (pounds * square inches)
Taken at the center of mass and aligned with the output coordinate system.

Lxx = 22.86	Lxy = -0.06	Lxz = 8.52
Lyx = -0.06	Lyy = 292.02	Lyz = 0.01
Lzx = 8.52	Lzy = 0.01	Lzz = 310.37

Fig. 12 Calculated Center of Mass and Moments of Inertia of the Aircraft

5.5 Mission Performance

The SendIt aircraft is not designed for stable takeoff and landing. It's sole purpose is to be able to fly at 70mph at cruising altitudes. If we are able to accomplish this, the main part of our mission will be completed. Getting the aircraft to land is quite difficult as well, so being able to decrease speed is important when close to the landing phase of the mission.

5.6 Drawing Package

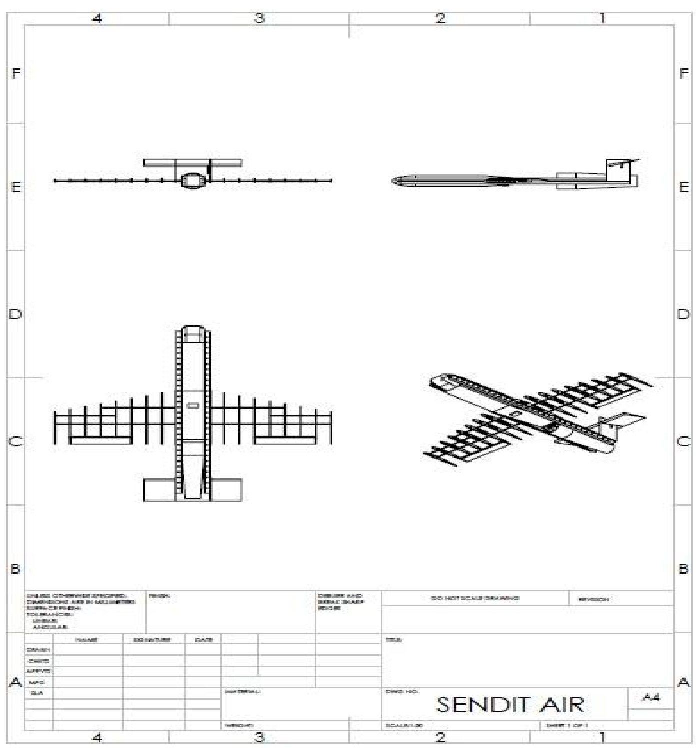


Fig. 13 Drawing Package

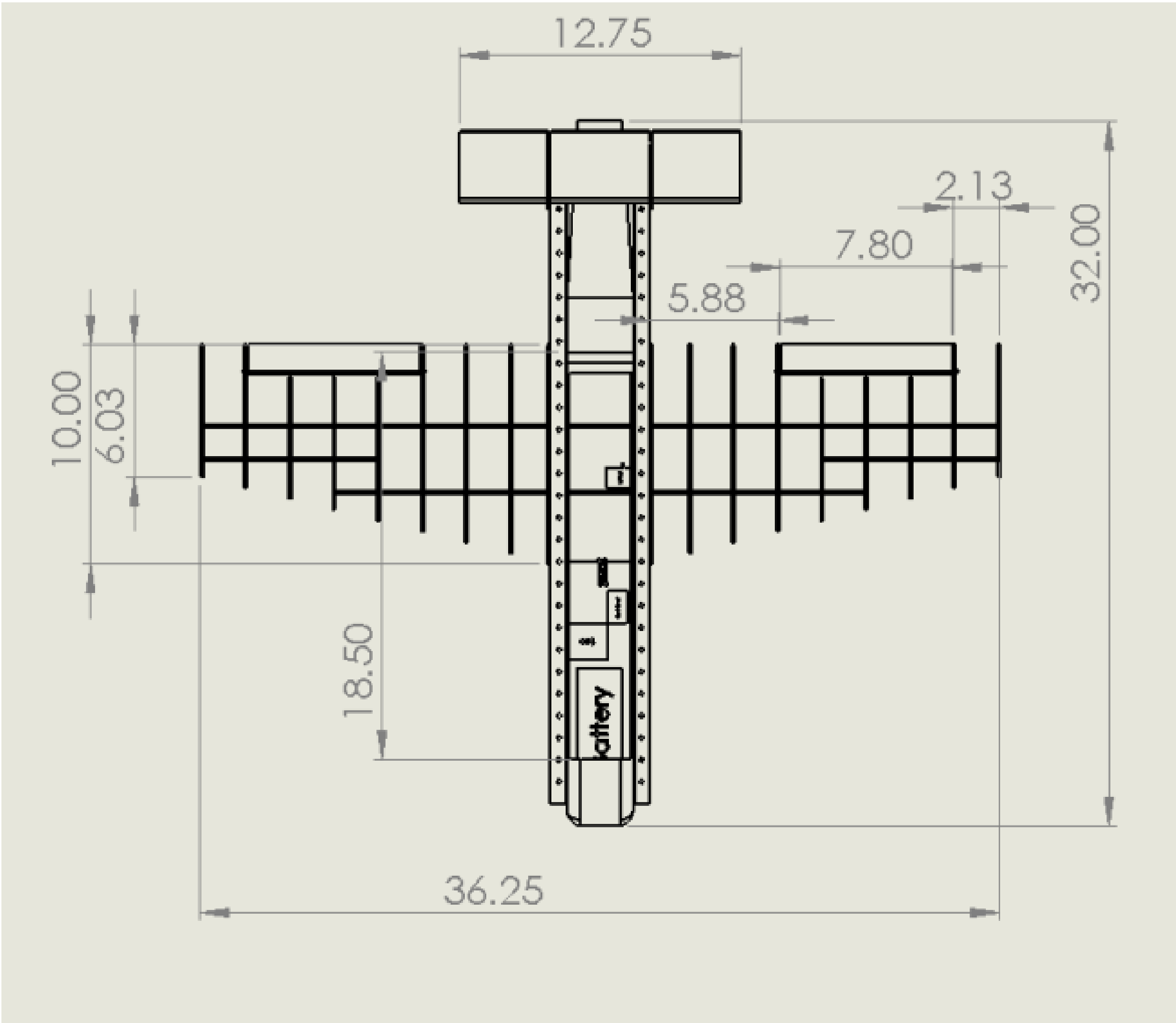


Fig. 14 Top View with Dimensions

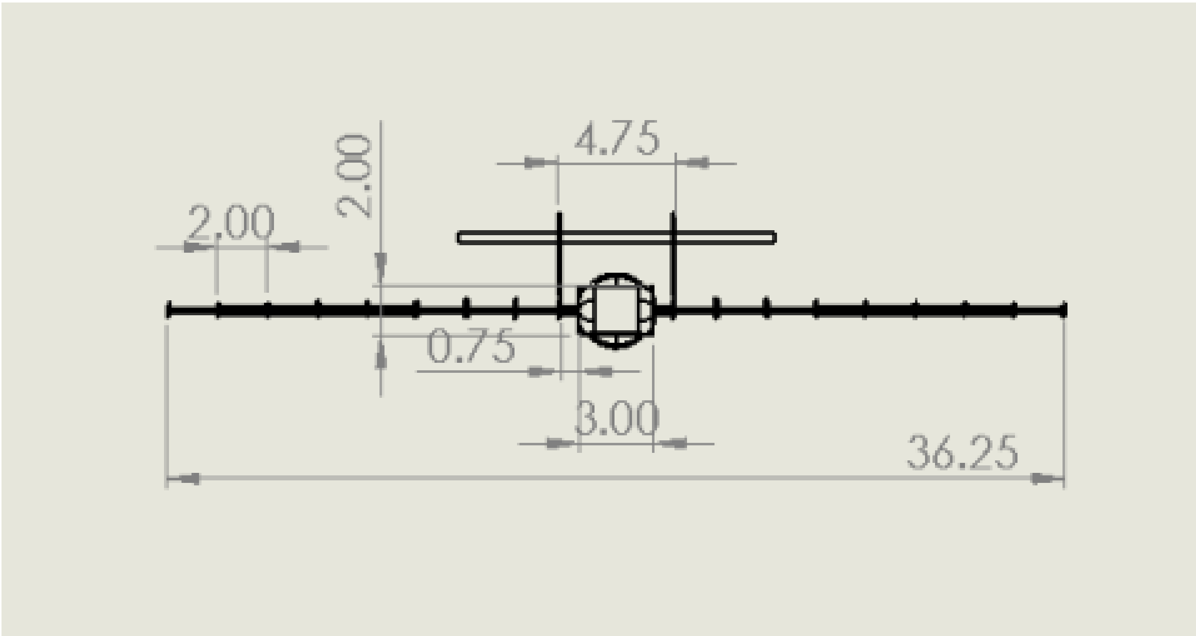


Fig. 15 Front View with Dimensions

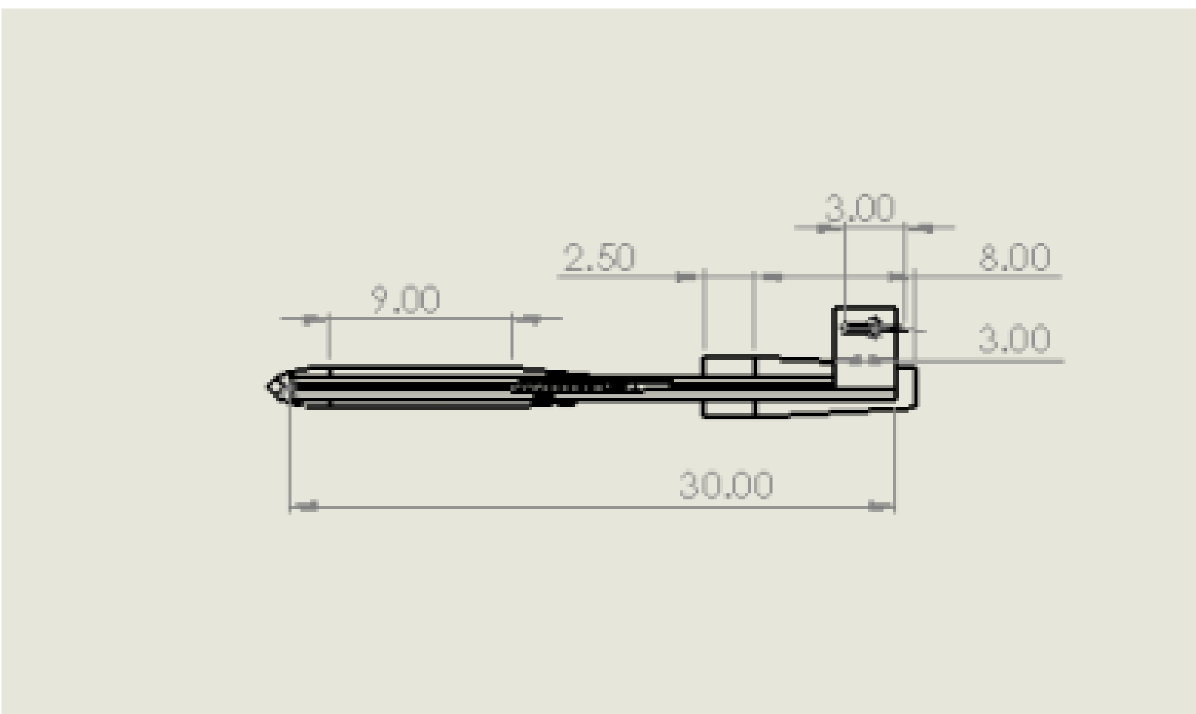


Fig. 16 Side View with Dimensions

6.0 Manufacturing Plan

6.1 Materials Selection

Initially, the plan was to use wood, fiberglass, and 3D printed objects to build the plane. Once the materials were being purchased, we realized that it was still within our budget to manufacture with more exotic materials. This allowed us to use carbon fiber for a lot of the aircraft. The fuselage, wing spars, and fuselage chassis are all made of carbon fiber now. This dropped the projected weight of the aircraft by almost two pounds. Using the more rigid carbon fiber also allowed us to use lighter and thinner balsa wood for the ribs of the wings.The wings were also wrapped in monokot so that all spars and edges could be cleaned up and have a smooth finish. The empennage was selected to be made out of ABS or PLA. Since PLA warps under heat, we went with 3D printing in ABS.

6.2 Manufacturing Methods

6.2.1 Methods Reviewed

The fuselage was debated on the most. Making it out of plexiglass would have been easy, but it would make the aircraft very heavy. It would also risk the electronics on the inside if it were to crash. Using carbon fiber seemed like the best option. It would be difficult to lay the carbon properly and we would have to make molds of everything we wanted to be made of carbon fiber. Fiberglass wing spars were also considered however, we decided against them and opted for the more expensive carbon fiber to save weight and add rigidity. The formation of the wing was to be made from each spar ranging in size and then joined through rods in between. We thought about making the wings out of other types of wood, but decided that balsa wood would be the lightest.

6.2.2 Methods Selected

The decision to use carbon fiber brought about many new challenges, but was worth it due to the various benefits of using such a light, yet stiff, composite. The process our team used to mold and cure carbon fiber was the wet layup process. The mold was generally made of fiberglass or wood wrapped in mylar. Most of the work of laying carbon is the prepwork. This work includes making an airtight bag, cutting all the various layers to size, and finally mixing the resin and hardener. The ratio of resin to hardener is very important and is usually written on both chemicals since they are usually a matching set. Once the chemicals are mixed, there is a strict time limit to work in before it starts hardening. The layup order is fairly straightforward. The epoxy hardener mixture is directly applied to the mold followed by the layers of carbon. Each layer of carbon also gets coated in the mixture. After the carbon, there is a layer of either mylar

or peel-ply depending on what texture prefered. Then there is a perforated release film and then the breather. Now this assembly is sealed inside the bag. The bag is then vacuum sealed and checked for leaks. After about 12 hours or leaving it overnight, the carbon fiber part can be extracted from the mold and various layers.
The ribs on the wings were laser cut using a 2d sketch of each rib based on our Solidworks model. We laser cut each rib onto the balsa wood and then glued them together on the carbon fiber rods that went through the fuselage to maintain a high rigidity on the wings.
The empennage was 3D printed out of ABS plastic. We first made them out of Polylactic Acid (PLA) but PLA does not resist high temperatures well, and being printed in black we had concerns of PLA warping in the sunlight. We chose ABS because it is much more resistant to heat and has a higher melting point. ABS also has better impact resistance than PLA which was another reason why we considered it. Seeing as it is a control surface, we did not want it to warp so we picked a more resilient plastic.

6.3 Manufacturing Schedule

Fig. 17

7.0 Testing Plan

7.1 Test Objectives

On the morning of February 21th, we conducted our flight test at Coyote Creek. This was our first test flight after the aircraft had been assembled. After the initial conception, design, aircraft analysis, and completion of assembly, we were finally able to test the results of the hard work done in the past six months. The main goal of this flight is to see if our plane can take off successfully, and fly steadily and land safely. Here is the schedule that we had anticipated for this semester (unfortunately most of this did not pan out):

In this test flight, our test and checklists are as follows.

- Weigh the airplane to under 5 pounds.
- Check if the size of the aircraft meets the requirements
- Test if it can take off successfully
- Test if it can maintain a stable flight attitude
- Test if it can land safely
- Test the highest speed and see whether it can reach 70 mph.
- Test how long a single battery can fly
- The remote control can successfully control the aircraft.

7.2 Structural Testing

To test the structure, we will hold the airplane at it's wingtips and move it up and down. This will show that the wings are strong structurally to withstand the most extreme wing loading situations. This should not be an issue because of the carbon fiber wing spars we used. It will allow for some bending but will not break. To test the fuselage, we will twist it enough to simulate the torque of the EDF as it revs up and down.

7.3 Avionics Testing

Testing the avionics consisted of a couple of steps. First, we connected the fully charged battery to the aircraft. Then we check our battery alarm which tells us how many volts are available in each cell of the battery. Anything under 3.3 volts would start beeping and warn us that we are running low on power. After this, we check the range of motion of the servos as well the actual control surfaces.

Further testing of the electronics would involve using an ammeter to determine the amperage draw of the motor under load to calculate and verify the power output given by the manufacturer. Doing this test would also allow us to verify the battery life and theoretical flight time based on our battery capacity.

7.4 Flight Plans

The flight plan is very basic. One of the team members would launch the aircraft by hand. This was supposed to be achievable because of the high power to weight ratio of the aircraft. Then the aircraft would make a pass for the pilot to initially feel it out and then a final pass to achieve the mission of the aircraft which is to fly at 70mph.

7.5 Testing Schedule

2020/1/24 - 2020/2/14	Finished assembling work

2020/2/15	First flight test
2020/2/15 - 2020/3/6	Improving design and control system
2020/3/8	Second flight test
2020/3/9-4/15	Make final optimizations and improvements to the aircraft.
2020/4/21	Final flight test
2020/5/1	Final design review

Fig. 18 Testing Schedule

7.6 Checklists

- Full battery
- Ailerons move within their range of motion
- Elevator moves within range of motion
- EDF runs up and down the rev range with ease
- All fasteners torqued down
- Servos set in place
- No play in motor mounts
- No play in vertical stabilizer mounts

7.7 Thrust Testing

Our plane crashed on our initial test flight raising concerns about insufficient amounts of thrust. As mentioned earlier the EDF produces about 5 lbs of static thrust based off of the specs given to us by the manufacturer. It was then decided that we should design a test stand to verify the static thrust figures given by the manufacturers, while also being able to verify the thrust tube design. The proposed design was to use a newton meter, which is what we had available to us.

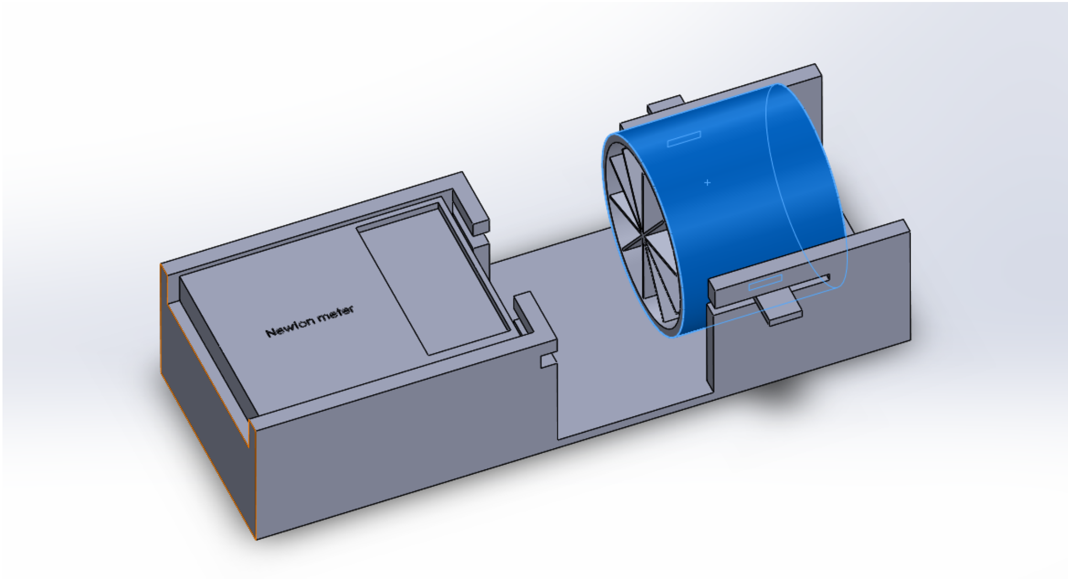


Fig 19. Proposed Static Thrust Test Stand

It would also be a good idea to test the installed thrust to verify that the fuselage is not obstructing the EDF too much and that the aerodynamic design of the fuselage is actually working. The installed thrust test could be done by attaching the newton meter to the back of our plane while it is resting on a table or flat surface.

8.0 Performance Results

8.1 Subsystem Performance

Our plane will be thrown out by hand to take off. After taking off, the plane will climb to an altitude of 200ft. After reaching the predetermined altitude, the aircraft will start accelerating, flying up to 70mph. Cruise tests will then be performed at various speeds. After completing the speed and stability tests, the aircraft will fly around a certain area and return to the starting point. Because our aircraft has no landing gear for the time being, taking off and landing will be a challenge. We need a strong team member to take off by throwing the aircraft, and it is not yet known whether the initial speed of the throw can successfully make the aircraft reach the minimum take-off speed. At the same time, we need to try to land safely without landing gear. If it is difficult to take off and land during this test, we will start designing the landing gear and launch system next week after the test. Because we use a lot of composite materials, the weight of the aircraft should be lighter than expected. Lighter aircraft will help us to push the top speed to 70mph and make the aircraft more maneuverable. Our previous simulations show that our aircraft is more stable at high speeds than at low speeds. So we will be very concerned about the status of the aircraft at low speeds. Because our aircraft has not yet officially tested, so many problems will be revealed after the test flight.

8.1.1 Structure and Fuselage

The carbon fiber fuselage and L bracket frame system performed well enough in terms of structural integrity, it survived the crash with a couple chips in the fuselage that are repairable and no damage whatsoever to the L bracket frame.

8.1.2 3D Printed Parts

The 3D printed parts consisted of the nose cone, thrust tube, ailerons, and the horizontal stabilizer (empennage). As mentioned earlier we printed them out of ABS because of our concerns of warpage in sunlight, and they proved to hold their shape even after being exposed to the sun for long periods of time. Initial testing of PLA left in sunlight showed that it warped within a matter of minutes. However, although we had chosen ABS for its impact resistance, it still shattered in testing when we crashed. The main benefit of 3D printing though is that we can simply print new parts and have multitudes of spares while also allowing for rapid prototyping.

8.1.3 Electronics

For the most part the electronics performed the way they were supposed to in our initial testing. We had some trouble with our ailerons in the single servo linkage configuration introducing a lot of stiction and slop so we decided to switch to a dual servo setup which alleviated our control issues. The servos and control linkages still functioned as intended after the crash.

As mentioned earlier, after our initial test and crash, there was concern that the reason could be insufficient installed thrust. Given more time we would have done testing to verify if our installed thrust was sufficient.

8.1.4 Wing

Most of the wing structure survived the crash with only a couple of broken ribs. The carbon fiber spars were undamaged and we were able to determine that they will be reusable in the case that we rebuild the wings. The 3D printed ailerons also survived the crash, and they were the only 3D printed components that did not break in the impact.

8.2 Planned Optimization

We have a lot of ideas on how to optimize our version two of this aircraft. First, the being the molds for the carbon fiber. The one for the fuselage was not ideal. It was made out of a four by four piece of wood. This time we will 3D print one and lay the carbon around that. Also the carbon fiber angle brackets will need to be shaped and cut better once out of the molds. We also will include the GPS module as well as the FPV camera. These were not included with this iteration of the design because of the wiring complexity given how close we were to the first flight deadline. The next aircraft will also have a second battery that operates the control surfaces separately so that the maximum battery life can be set aside only for propulsion.

Because our plane crashed the next step would definitely be to conduct static and installed thrust tests to verify that we had enough thrust for our design. In addition we could also resize the wings to allow for more lift while also moving them forward towards the nose to change the center of mass. Doing so may also require us to resize our elevator and ailerons.

Fig. 20 Final Assembly of Airplane Before Crash

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