A Thesis Presented to

The Faculty of Alfred University

2017-2018 Design, Build, Fly: A Regional and Business Aircraft

by

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Table of Contents

List of Figures

List of Tables

Introduction:

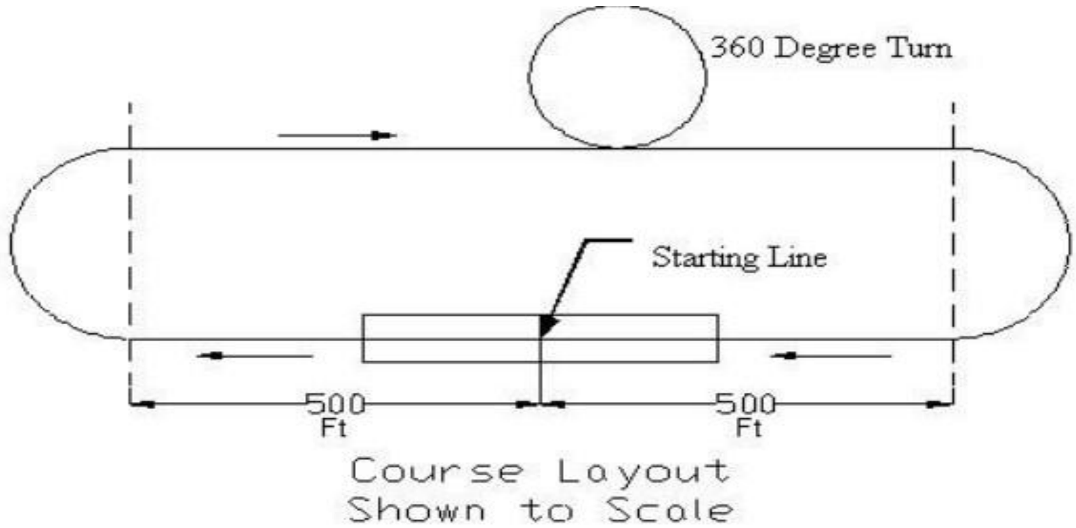
The Design, Build, Fly competition is a yearly contest hosted by the AIAA, American Institute of Aeronautics and Astronautics, that aims to provide engineering university students real-world aircraft design experience by giving them opportunities to validate their analytic studies. These student teams will design, fabricate, and demonstrate the flight capability of an unmanned, electric powered, radio controlled aircraft that can best meet the mission statement. The goal is to build an aircraft with a balanced design, sufficient demonstrated flight handling qualities, and practical and affordable manufacturing requirements while also providing high vehicle performance. To maintain fresh design challenges and encourage innovation, the design requirements and objective changes every contest year. For this contest year, Fall 2017 to Spring 2018, the objective is to design and build a dual purpose regional and business aircraft. At Alfred University, Design, Build, Fly is considered a capstone project. A capstone project is a multifaceted assignment that serves as a culminating academic and intellectual experience for students. This is typically done during that student's senior year of an academic program. These have a variety of forms, but most are long term investigative projects that culminate in a final project. These capstone projects are designed to encourage students to think critically, solve challenging problems and develop various skills that will be helpful throughout their careers. Capstone projects like Design, Build, Fly are considered a form of Senior Design Project which is a requirement for Mechanical Engineering students at Alfred University. This particular project was chosen because it seemed very interesting and challenging to build a remote controlled aircraft that would serve a specific task. The competition was handled differently this year. Instead of participating in the actual competition, the Design, Build, Fly team at Alfred University was split into two groups, Purple Team and Gold Team. These two groups will compete against each other in manufacturing their own aircraft to accomplish the mission task. All guidelines and requirements set forth by the AIAA's contest were still followed. This honors thesis covers the design and construction of the aircraft built by Gold Team for the competition. As stated already, the mission task for this contest year is to design and build a dual purpose regional and business aircraft. This aircraft must complete three separate flight missions. The first flight mission is for the aircraft to fly the predetermined flight course with no payloads or passengers. The second flight mission is that the aircraft must fly through the same flight course but with passengers secured within the aircraft. The third and final flight mission is for the aircraft to fly around the same flight course yet again but with both passengers and payload blocks secured within the aircraft. The number of passengers and payload blocks to be carried is up to the teams to decide. The flight course itself consists of a 500 ft straightaway from the starting line. Then a 180° right hand turn into a 1000 ft straightaway. During this 1000 ft straightaway, the aircraft must perform a 360° left hand turn before completing the 1000 ft straightaway. Afterwards, the aircraft must make another 180° right hand turn and fly 500 ft straight before landing at the original starting line. The winner of the contest will be determined by whoever gets the highest score, which is a function of the score gained in each mission, the written report score, and the aircrafts weight and wing span. The passengers to be carried by the aircraft are represented by bouncy balls which will be provided at the flight starting line. These bouncy balls consist of 5 different weights and sizes. Ranging from a 27 mm diameter and .40 ounces to a 49 mm diameter and 2.39 ounces. The first step taken by Gold Team was decide on the number of passengers that was desired to be carried. It was decided that the wanted to build around carrying 40 passengers. Multiple fuselage types were considered but, in the end, a fuselage similar to cargo planes was found to be best suited for the missions at hand. The body team first designed the passenger compartment around holding the desired number of passengers of 40. That meant it needed to be around 12 inches wide to account for the limit of 4 passengers in a single row along with all the spacing requirements. This also meant that the passenger compartment had to be 25 inches long to hold 40 passengers in it. The width of the aircraft was assumed to be slightly larger to account for the width of the fuselage, 13 inches in this case. The length of the total aircraft was assumed to be about 53 inches to give room for the nose cone and tail connection. Because the aircraft is so large, an internal frame was required to support the aircraft. This internal frame was made from 4 parts, the body frame pieces, the wing support pieces, the integrated passenger compartment, and the 7 carbon fiber rod that hold the frame together. This frame when assembled will simply slide into the fuselage of the aircraft. The entire aircraft was estimated to be about 11 lbs by tallying up the weights of all the passengers, payloads, electronics, and other required parts. Because of the low thrust generated by the aircraft, a deep camber airfoil would be required to generate the lift required for takeoff. With the weight of the aircraft calculated, the wing team could start designing the wing of the aircraft. With an assumed wing span of 6ft and the use of various calculations, the wing loading of the aircraft was found to be 1.2 lb/ft^2. This value may seem low but because of how large the aircraft is and the low amount of thrust it will generate, this value is not only expected but desired. These wings were also designed with two motor mounts for the propeller's motors. Which would be located 15 inches inside the tip of the wing on both sides. Now that the wing was designed, the tail team could design the tail of the aircraft. It was found that the type of tail that would provide the most stability would be a T-tail. The tail elevator for the T-tail needs to be about 20% of the wing span, which for a wing span of 6 feet means the elevator needs to be 15 inches long. The rudder should ideally be about half of the elevator, but due to design constraints, a value of 6.74 inches was chosen. A height of 8 inches was sufficient for the tail to be out of the airflow of the wings and fuselage. Now that that all the parts of the aircraft were designed, it was desired that they all be analyzed to see whether they will be able to handle the forces encountered during flight. First though, the weight and balance of the aircraft was checked by looking at each parts location and the center of gravity of each. It was found that the center of gravity of the aircraft was found to be directly under the front end of the wing. This is important because the center of gravity location ensures that the aircraft will have enough stability, performance, and control to fly. If the center of gravity is too far forward, the elevator will not have enough power to control the plane during pitch but if it is too far backwards, then the plane will not be stable during flight. For maximum stability, the center of gravity of an aircraft should be located at the quarter chord or right below the front end of the wing which for our aircraft it is. The internal frame was analyzed in ANSYS to see whether 5, 7, or 9 carbon fiber rods were required for minimum deformation and stress. It was found that the internal frame assembly with the lowest deformation and stress was the assembly with only 7 carbon fiber rods. In this case, the maximum stress was 4 MPa with a deformation of around 0.013 mm. The wings were also analyzed in ANSYS to see whether the 3/8 inch carbon fiber rods would be strong enough to withstand the lift generated by the aircraft and the weight of the aircraft. It was found that the wings experience a stress of 17137 psi with deformation at the wing tips of 0.7 inches. Finally, the tail was analyzed with ANSYS to find out whether the control surfaces can withstand the forces associated with the rudder and elevator positions at 15° or 40°. It was found that the 15° location was ideal with a deformation of 0.17 mm for the elevator and 2.21 mm for the rudder. The stresses at the 15° location for the elevator and rudder were 0.6 MPa and 4.3 MPa respectively. In all the ANSYS analyses, the parts showed no signs of fracturing or permanent bending over the forces and loads that would be encountered during flight. With the design and analysis of the aircraft done, Gold Team was ready to start constructing the aircraft itself. The fuselage of the aircraft was created by carving a mold of it out of high density foam boards. This mold was then covered in layers of epoxy, fiberglass sheets, and balsa wood boards to create the fuselage itself. The nose cone was created similarly to the fuselage, but instead of balsa wood boards, an extra layer of fiberglass sheets was used. The interior frame pieces were laser cut from 1/4 inch balsa wood boards and then assembled together with the carbon fiber rods and inserted into the finished fuselage. The parts of the tail were also laser cut from the balsa wood boards and then assembled together. The assembled tail had its servos installed and was then installed onto the fuselage itself via a 3D-printed connecter piece. The wing airfoil were also laser cut from balsa wood boards and then assembled with the carbon fiber rods. The motor mounts were added on to the wings with small pieces of balsa wood and then reinforced with carbon fiber sheets. Finally, after the electronics were installed for the motors, the wing was wrapped and installed onto the fuselage. The servos and motors of the plane were then connected to the rest of the electronic system. Though the aircraft was completed for the competition, the aircraft crashed during the missions and the tail was destroyed beyond repair. This meant the team received a score of zero for the competition. However, Purple Team also received a score of zero because their plane also crashed beyond repair. This meant the final scoring would have to be based on the quality of the written report. Regardless of this, Gold Team learned much about the manufacturing process during this project, with what we learned, many of us hope to repair the aircraft in our spare time and make it truly fly.

Mission Requirements

The Flight Course:

The aircraft must be able to accomplish the 3 missions while flying through a predetermined flight course. This flight course is identical for all 3 missions. The direction of the flight course will be adjusted based on the winds at the time of testing and will be set to achieve the optimal degree of safety for everyone involved. The flight course consists of a 500 ft straightaway from the starting line. Then a 180° right hand turn into a 1000 ft straightaway. During this 1000 ft straightaway, the aircraft must perform a 360° left hand turn before completing the 1000 ft straightaway. Afterwards, the aircraft must make another 180° right hand turn and fly 500 ft straight before landing at the original starting line. The course layout can be seen in Figure 1.

Figure 1: Flight Course Layout



Flight Missions:

Mission 1: Aircraft Mission Staging

- No payload for this flight
- Must takeoff within 150 ft of starting line
- Aircraft must complete 3 laps of the flight course within a 5 minute flight window
- A lap is complete when the aircraft passes over the start/finish line in the air
- Landing is not part of the 5 minute flight window
- Time starts when the aircraft throttle is advanced for the first take off
- Time stops when the aircraft passes over the start/finish line at the end of the third lap
- A successful landing is required to get a score

Mission 2: Short Haul of Max Passengers

- The payload for this mission are the passengers, the number of passengers flown cannot exceed the maximum number of passengers declared before flight
- The passengers must be internally carried
- Must takeoff with 150ft of the starting line
- Aircraft must complete 3 laps of the flight course within a 10 minute flight window
- A lap is complete when the aircraft passes over the start/finish line in the air
- Landing is not part of the 10 minute flight window
- Time starts when the aircraft throttle is advanced for the first take off
- Time stops when the aircraft passes over the start/finish line at the end of the third lap
- A successful landing is required to get a score

Mission 3: Long Haul of Passengers and Payload

- The payload for this mission are the passengers and payload blocks
- At least 50% of the passengers from Mission 2 must be carried
- At least 1 payload block must be carried but the number of payload blocks carried cannot exceed the number declared before flight
- The passengers and payload must be internally carried
- There is no limit to the number of laps taken during the flight window
- A lap is complete when the aircraft passes over the start/finish line in the air
- Landing is not part of the 10 minute flight window
- Time starts when the aircraft throttle is advanced for the first take off
- There is a 10 minute flight window
- A successful landing is required to get a score

Payloads:

There are two types of payloads being carried in the aircraft. The passengers themselves and the payload blocks. All passengers and payload blocks will be secured sufficiently to assure safe flight without much variation in the center of gravity of the aircraft outside of design limits during flight.

The passengers of the aircraft will be represented by bouncy balls which will be provided at the flight starting line. These bouncy balls consist of 5 different weights and sizes. Ranging from a 27 mm diameter and .40 ounces to a 49 mm diameter and 2.39 ounces. All potential bouncy ball sizes can be seen in table 1. The number of passengers to be carried is up to the team to decide but the size of the passengers will be picked randomly.

Table 1: Passenger Sizes and Weight

Diameter	Weight (ozs)
27 mm	0.40
32 mm	0.67
38 mm	1.12
45 mm	1.85
49 mm	2.39

The number and shape of the payload blocks are up to the team to decide, but they must be of the same rectangular cuboid shape. The dimensions of the payload blocks must adhere to the formula shown in Eq. 1

$$Length(in) + Width(in) + Height(in) \geq 9\ in \qquad \text{Eq. 1}$$

Where no side is less than 2 inches and no blocks are more than 8 ounces.

Design Requirements:

Payload Compartments:

For the passengers, they each must have their own individual seat with their own restraint system. All seats must be on the same single planar surface. There must be a minimum longitudinal spacing of .25 inches between each seat. No more than two seats can be adjacent to each other and no more than four can be in the same row. The aisle in-between each row of seats must have a minimum width and height of 2.5 inches and must be running the length of the entire passenger compartment.

The payload bay(s) for the payload blocks must be a separate compartment from the passenger compartments and they must be behind and/or below the passenger compartment.

Aircraft Constraints:

For this year's competition, there is no weight limit for the battery's, however there must be a separate battery pack for the power propulsion system and servos. The aircraft must pass the wing tip load test before flight with the largest payload intended to fly with. This maximum load cannot be changed after the start of the missions. The design of the aircraft may be of any configuration besides rotary wing or lighter-then-air. No components may be dropped during the aircraft's flight. The aircraft must take off via the energy coming from the onboard propulsion battery pack(s), no externally assisted take-off is allowed. The propeller/blades of the aircraft and the propeller hub/pitch mechanism must be commercially produced. The propeller may be modified only clipping the tips to change the diameter or by painting them to balance them.

Scoring Summary:

The score for each team is computed by the scores of their written report, each mission score, and the rated aircraft cost. The formula is given by Eq. 2

$$Total\ Score = Written\ Report\ Score * \frac{Total\ Mission\ Score}{Rated\ Aircraft\ Cost} \qquad \text{Eq. 2}$$

The Written Report Score is based on the quality of the design report written prior to the competition. The Total Mission Score is the sum of the individual Mission Scores of each mission and is shown in Eq.3

$$Total\ Mission\ Score = Mission\ 1\ Score + Mission\ 2\ Score + Mission\ 3\ Score \qquad \text{Eq. 3}$$

The Rated Aircraft Cost is a function of the aircraft weight without any payload and the maximum wing span, it is given by Eq. 4

$$Rated\ Aircraft\ Cost = EW_{max} * WS \qquad \text{Eq. 4}$$

Where EW_{max} is the maximum weight of the aircraft without any payloads measured in pounds and the WS is the longest distance between the wing tips, measured perpendicular to the axis of the fuselage in inches.

Conceptual Design:

Body Concept:

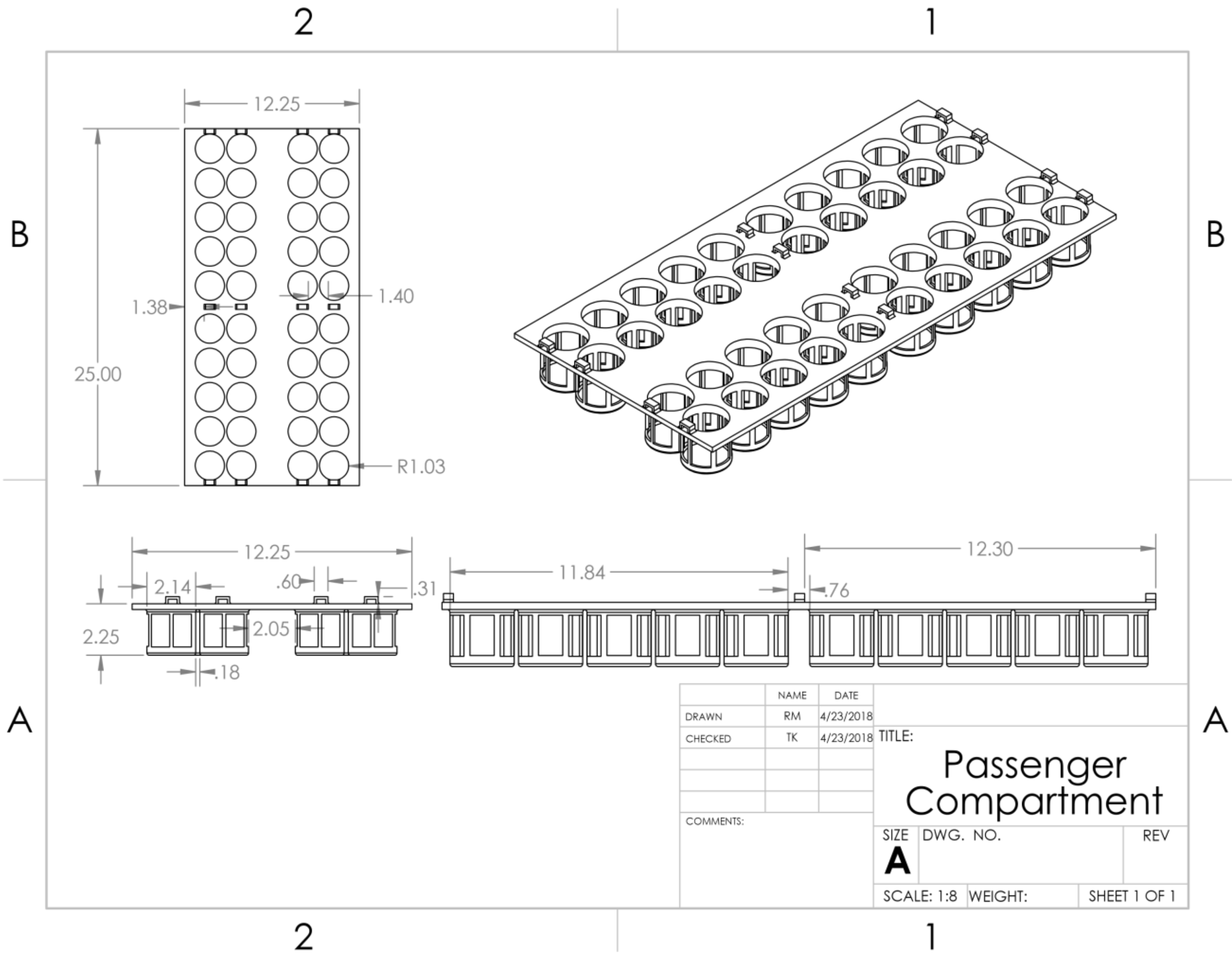
One of the most important parts of the aircraft is its body, not only does it carry the payloads, it also carries the electronics and is responsible for bearing the structural loads encountered during landing and takeoff. For this year, the team collectively decided that we wanted maximize scoring by carrying large amounts of passengers. To do this, three possible configurations of the body were considered. The first configuration was a small compact body, while this would not have carried many passengers it was kept as an option to compare to the others. This smaller plane would also be more easily affected by wind and other atmospheric effects during flight. The second option was a more medium sized body that would be able to hold a decent number of passengers but doing so would leave little room for anything else. This design would also force the use of a tail latch that would make loading and unloading difficult. The final design was one based on military cargo planes, this plane would be large but would be able to hold a large number of passengers and be less susceptible to being tossed around by gusts of wind. This large design would involve the payloads being loaded into the aircraft in the front by lifting the nose cone. This front-loading design would also allow easy access to the inside of the aircraft. These options for the body were compared together based on three criteria, the number of passengers it can hold, how structurally sound the body would be, and how stable it should be in flight. The weighted scoring of each of these configurations can be seen in the table 2.

Table 2: Weighted Scoring of Body Configurations

Body Configuration	Maximize Passengers	Structurally Sound	Stability in Flight	Totals
Small, Compact Body Design	1	4	3	8
Medium Size with a Tail Latch Design	3	3	4	10
Large Front-Loading Cargo Plane Design	5	4	4	13

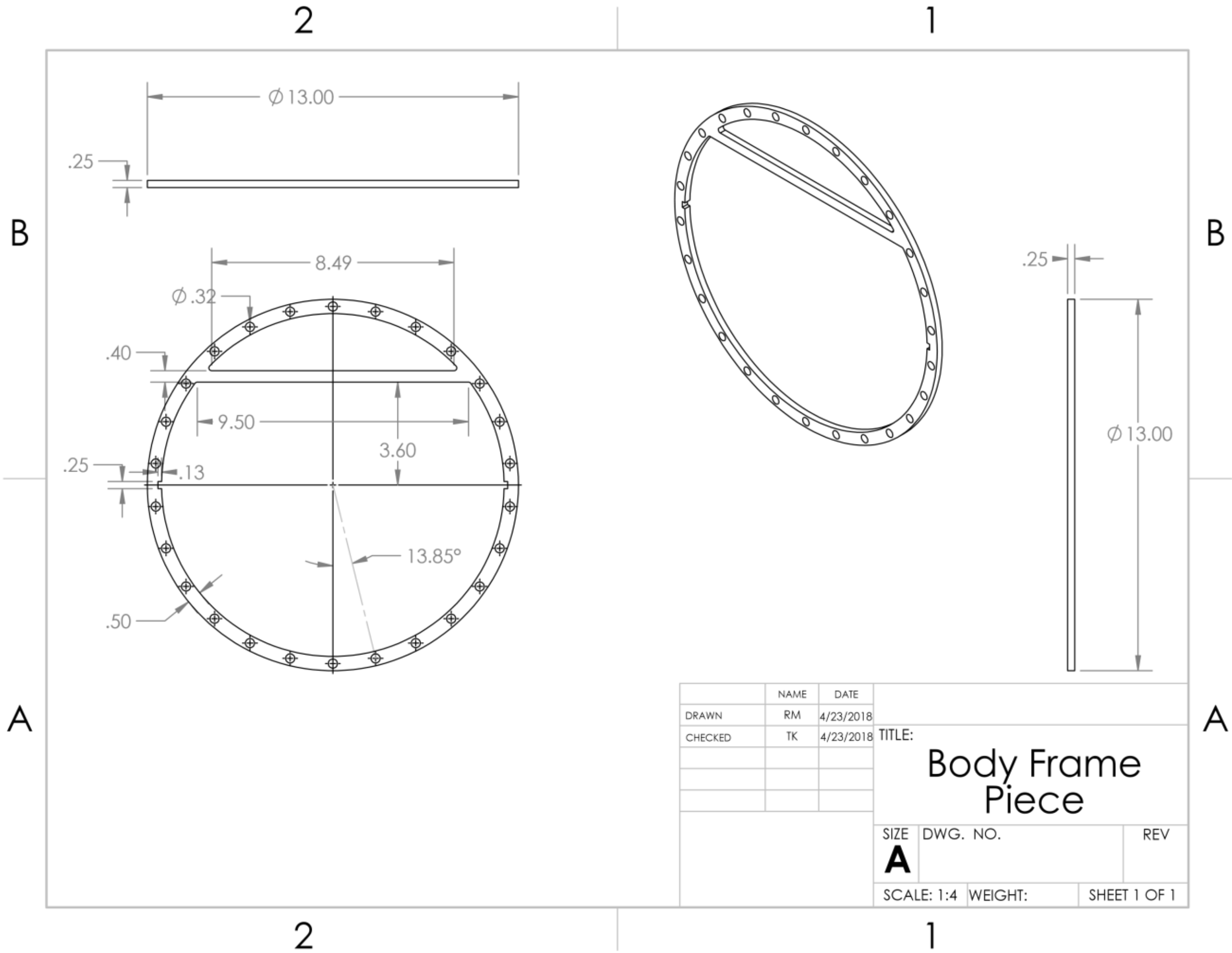
Based on the weighted scoring, the body configuration we should choose is the third option, the Front-Loading Cargo Plane Design. With the type of body configuration chosen, the team moved on to designing the body of the aircraft. To start off with, the team looked at the passenger's compartment and its requirements. The size of the passenger compartment is the limiting factor for the size of our aircraft. With the choice of a large body configuration, the maximum of four passengers could be placed in a row. With this and the design requirements for the passenger holder in mind, the minimum distance across would be 12 inches. Another .25 inches was added to the distance in the design to add some leeway to the design, this lead to the final longitudinal distance of the passenger compartment to be 12.25 inches. Next, the length of the compartment had to be decided. The team wanted to hold a maximum of 40 passengers, so the passenger compartment must be at least 25 inches long. The passengers themselves will be held in their seats by a retainer rod that will slide over each column of passengers. The dimensions of the passenger compartment can be seen in Figure 2.

Figure 2: Passenger Compartment Concept



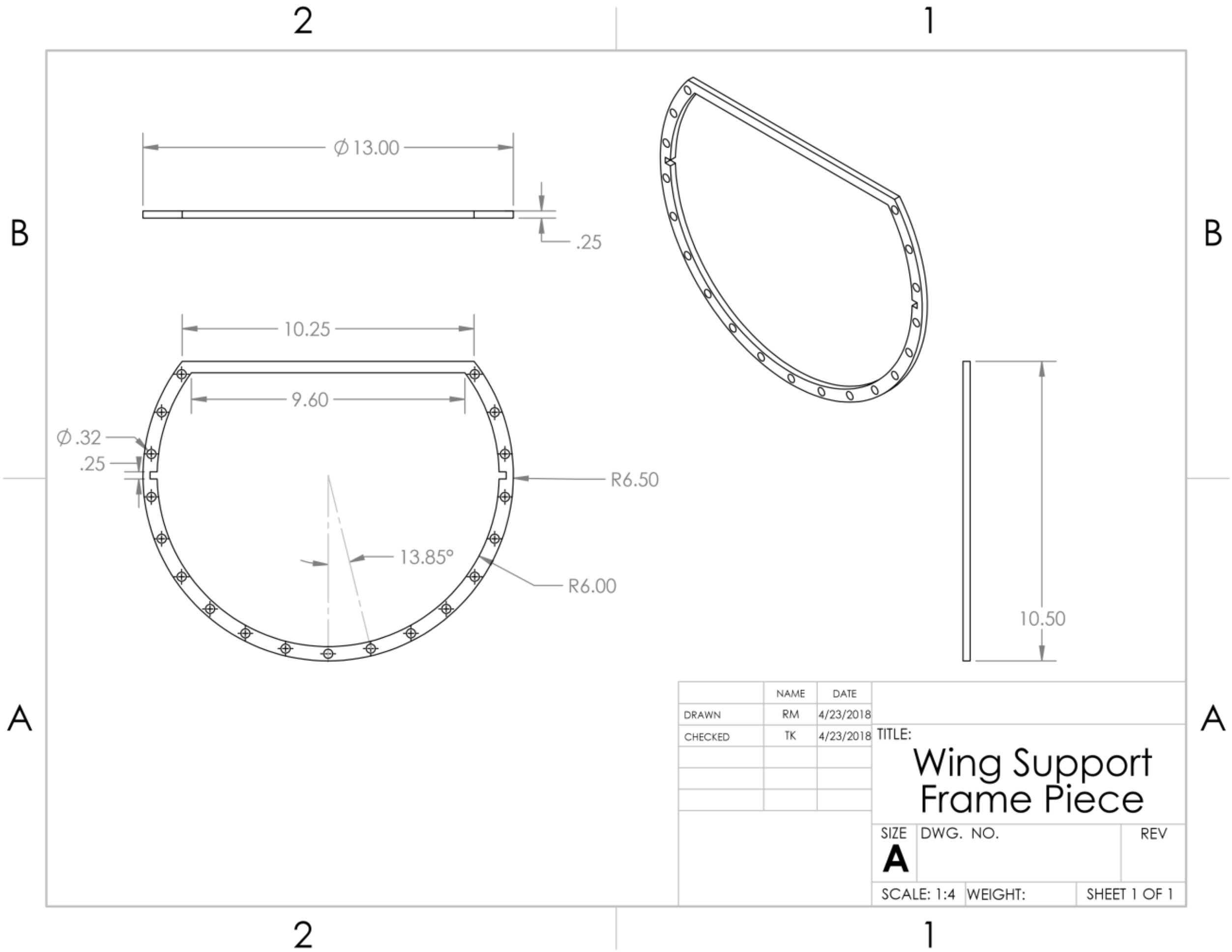
With the passenger compartment designed, the body team moved on to the body itself. To account for the fuselage of the aircraft, an extra ¾ of an inch was added to the longitudinal distance of the passenger holder to get distance of 13 inches across. This extra distance would allow the team to incorporate the passenger compartment directly in the internal frame. To hold the entire passenger compartment, the body would have to be at least 25 inches long. However, the body would also need a nose cone to make the front aerodynamic and the body would need a way to connect to the tail. To remedy this, the length was extended to 53 inches, giving the team plenty of room for a nose cone and a tapered connection to the tail. Because the aircraft is so large, an internal frame is needed to support it as well as the passenger compartment. The internal frame will be made from 4 parts, the first part is the four body frame pieces. These pieces are the main supports for the fuselage of the aircraft and they can be seen in Figure 3.

Figure 3: Body Frame Pieces Concept



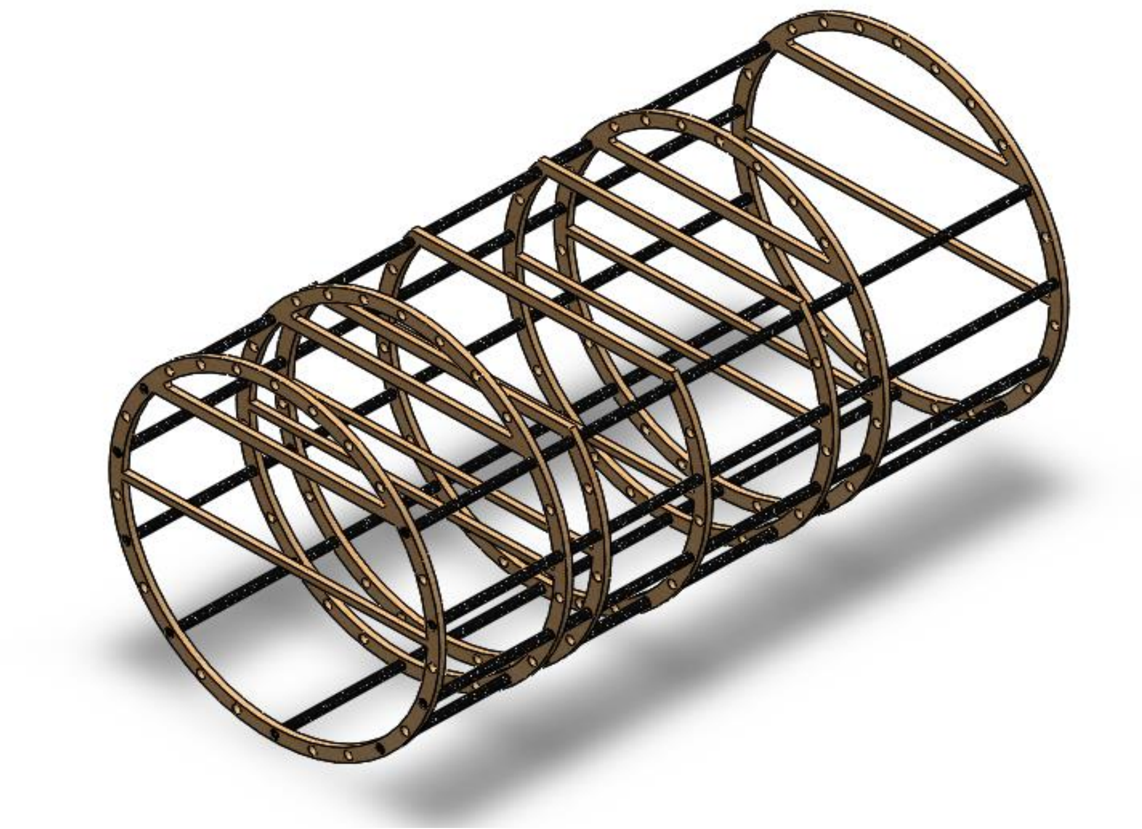
The second part of the internal frame are the frame pieces that are supporting the wing. For our design, the wing of the aircraft will be sitting directly on these frame pieces in a cut slot in the fuselage and can be seen in Figure 4.

Figure 4: Wing Support Frame Pieces Concept



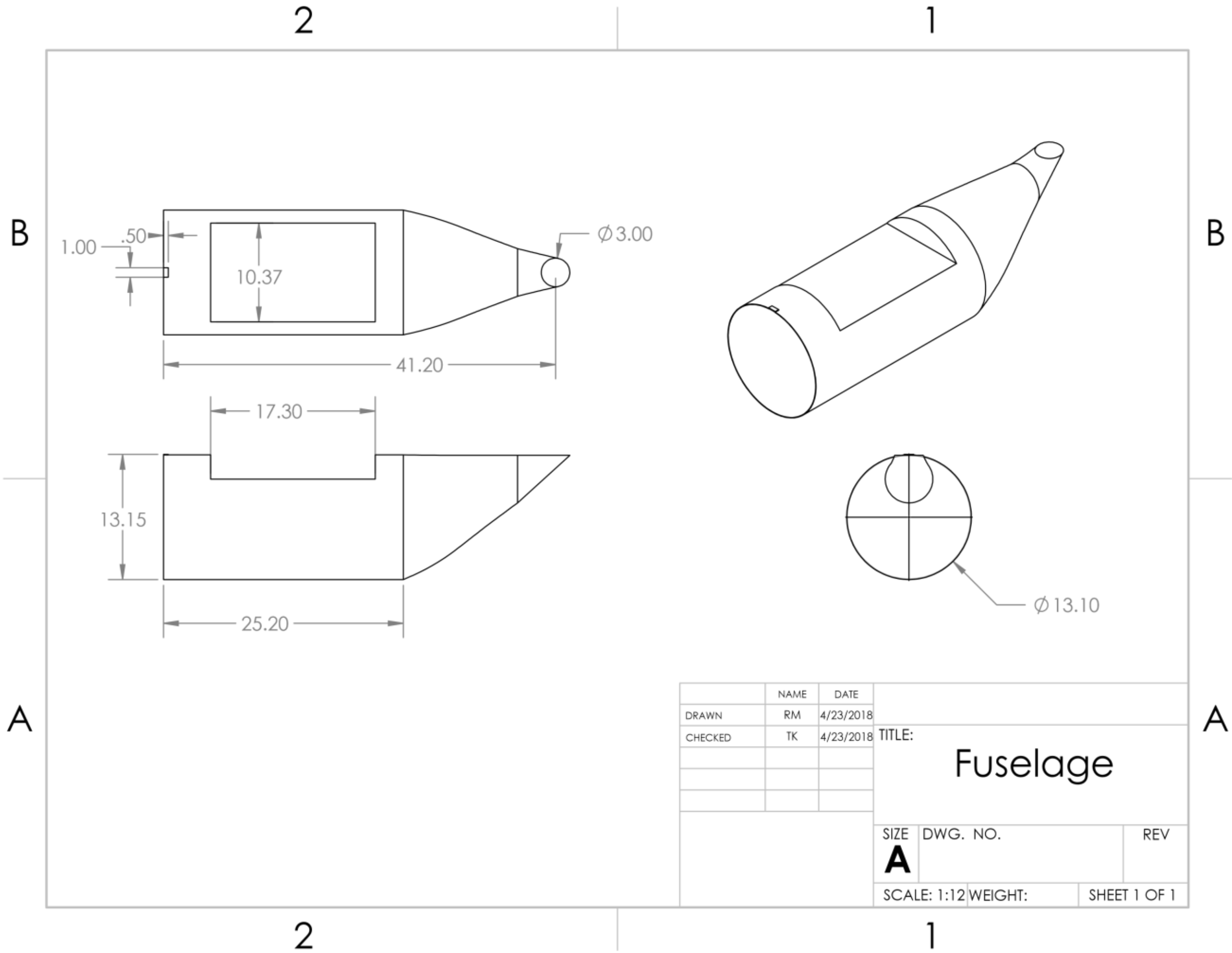
The third part of the internal frame the carbon fiber rods. Within each frame piece are holes cut in the same position. These holes are spread throughout the entire rim of the frame pieces, 13.85° from each other. These rods allow keep the frame together while also minimizing weight. The final part of the internal frame is the passenger compartment seen above in Figure 1, in each frame piece is a slot on both sides of the horizontal diameter. When the frame pieces are put together with carbon fiber rods, the passenger compartment will easily slide in allowing for easy loading and unloading of passengers. An assembly of the internal frame can be seen in Figure 5.

Figure 5: Internal Frame Assembly Concept



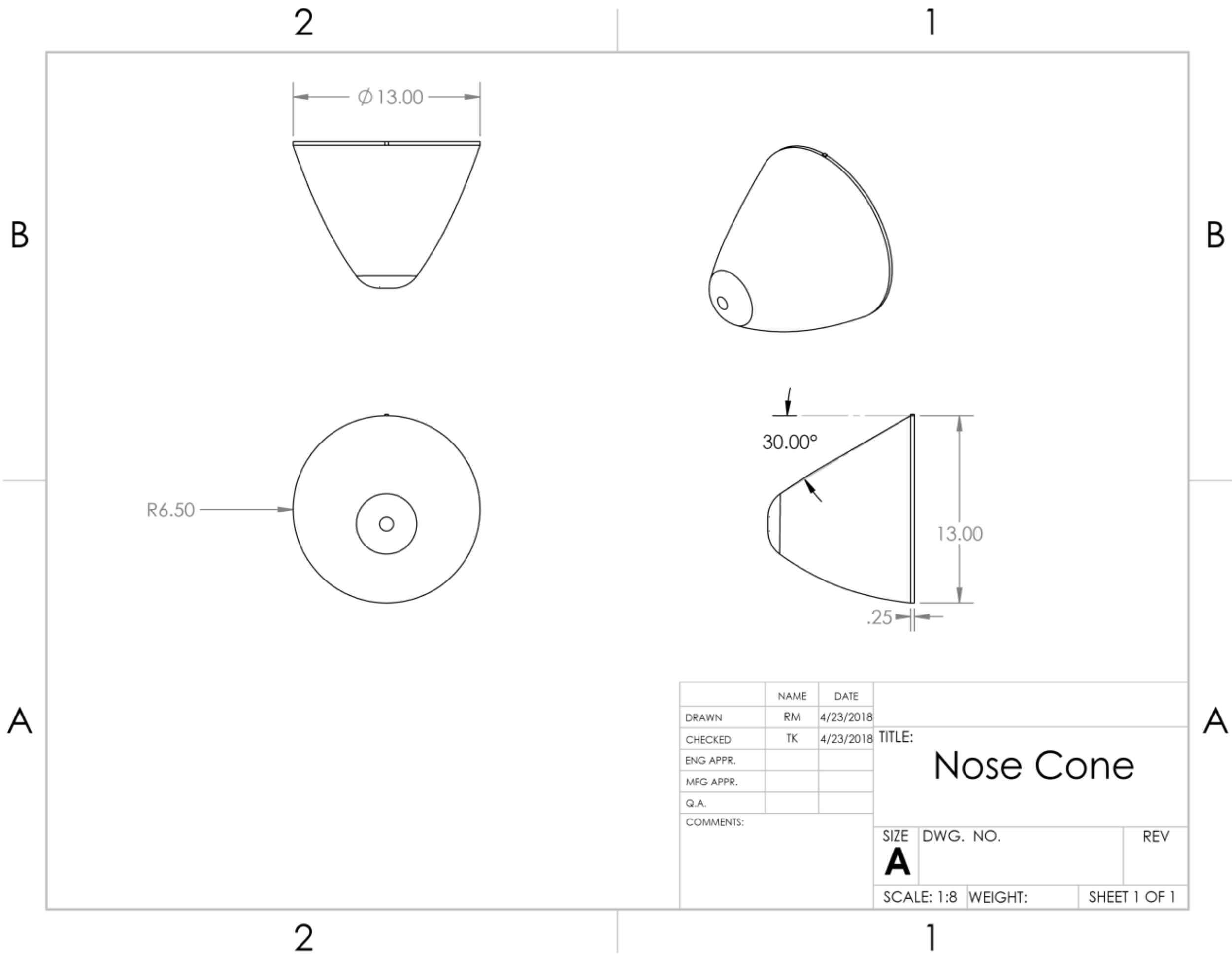
Once the frame is assembled, it will be easily inserted into the fuselage of the aircraft. The fuselage itself will be molded out of foam and made from layers of fiberglass, balsa wood, and epoxy but this process will be covered in the construction section. The fuselage concept can be seen in Figure 6.

Figure 6: Aircraft Fuselage Concept



Finally, a nose cone is required to keep everything within the fuselage as well as ensure minimal drag at the front of the aircraft. Much like the fuselage, the nose cone will be molded out of foam and made from layers of fiberglass, balsawood, and epoxy. This nose cone can be seen in figure 7.

Figure 7: Aircraft Nose Cone Concept



Wing Concept

At first, a symmetrical design airfoil design with 1/4 inch width carbon fiber rods were considered. However, to be sure this was ideal, the wing team investigated what the projected weight of the aircraft would be. To this this, the weights of all potential objects that would be carried within the aircraft at a worst-case scenario, which is when the aircraft would be carrying max passengers as well as payloads during mission 3, were tallied up. This is shown in Table 3, which shows the projected weight of the aircraft to be about 11 lbs. For the calculation of the aircrafts weight, as well as any other calculations done, the number of passengers being carried was assumed to be 20. This will give us some room in case one of the parts turns out heavier than expected. It will be possible to hold up to 40 passengers, though the exact number will only be able to be determined after the aircraft is constructed and its actual weight is found.

Table 3: Projected Aircraft Weight

Item	Weight		Lbs	Quantity	Total (lbs)
Motors	9.50	oz	0.59	2.00	1.1875
Motor Mount	2.30	oz	0.14	2.00	0.2875
Propeller	1.20	oz	0.08	2.00	0.15
ESC	3.10	oz	0.19	2.00	0.3875
Battery	13.50	oz	0.84	1.00	0.84375
Landing Gear Front	5.00	oz	0.31	1.00	0.3125
Landing Gear Back	3.00	oz	0.19	1.00	0.1875
Wheels	3.20	oz	0.20	3.00	0.6
Wiring		oz			0
Signal Reciever		oz			0
Cross Section Large		oz	0.03	5.00	0.15
Cross Section Small		oz	0.02	3.00	0.06
Dowels		oz	0.13	8.00	1.04
Passenger Platform		oz	0.25	1.00	0.25
Passenger Cups		oz	0.05	20.00	0.9
Passengers	1.29	oz	0.08	20.00	1.6125
Tail		oz	0.00		
Wings	46.4	oz	2.9	1.00	2.9
				Grand Total	10.86875

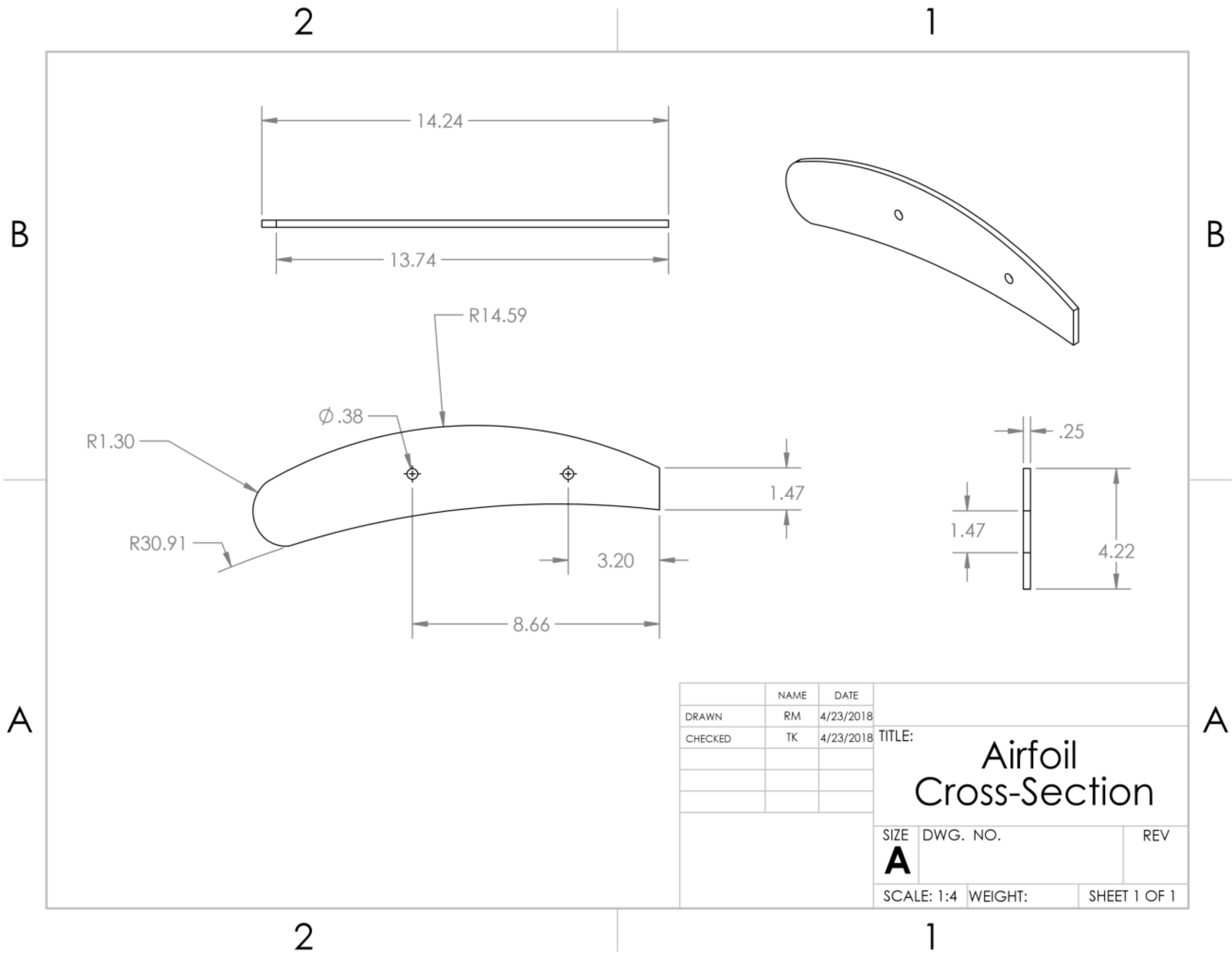
At this point, the wing team saw that the aircraft would have to lift a relatively large amount of weight. They proposed another variation to the airfoil design which involved a deep camber style with 3/8 inch width carbon fiber rods. This variation would allow for a higher amount of lift which may be needed to lift the plane off the ground. These two variations were compared to each other based on rating of potential lift, how structurally sound the wings would be, and stability given during flight. This weighted scoring is seen in Table 4 below.

Table 4: Airfoil Weighted Scoring

Airfoil Design	Potential Lift	Structurally Sound	Stability in Flight	Totals
Symmetric Airfoil with 1/4 in Rods	3	3	4	10
Deep Camber Airfoil with 3/8 in Rods	5	4	4	13

From this, the Deep Camber variation of the airfoil should be chosen. The dimensions of this airfoil can be seen in Figure 8. The holes located in the airfoil is for the carbon fiber rods to slide through and connect all the airfoils together.

Figure 8: Deep Camber Airfoil Design



From the projected weight of the aircraft, 11 lbs, and the length of the fuselage, 53 inches, it was calculated that the aircraft would need a wing span of 6 ft. A chord length of 16.5 inches was found for the airfoil. The wing span and chord length was used in Eq. 5 to find the aspect ratio,

$$Aspect\ Ratio = \frac{Wing\ Span}{Chord\ Length} \quad \text{Eq. 5}$$

The aspect ratio was determined to be 4.29. The aspect ratio was then used to determine the surface area of the wing that would contribute to the lifting force with Eq. 6.

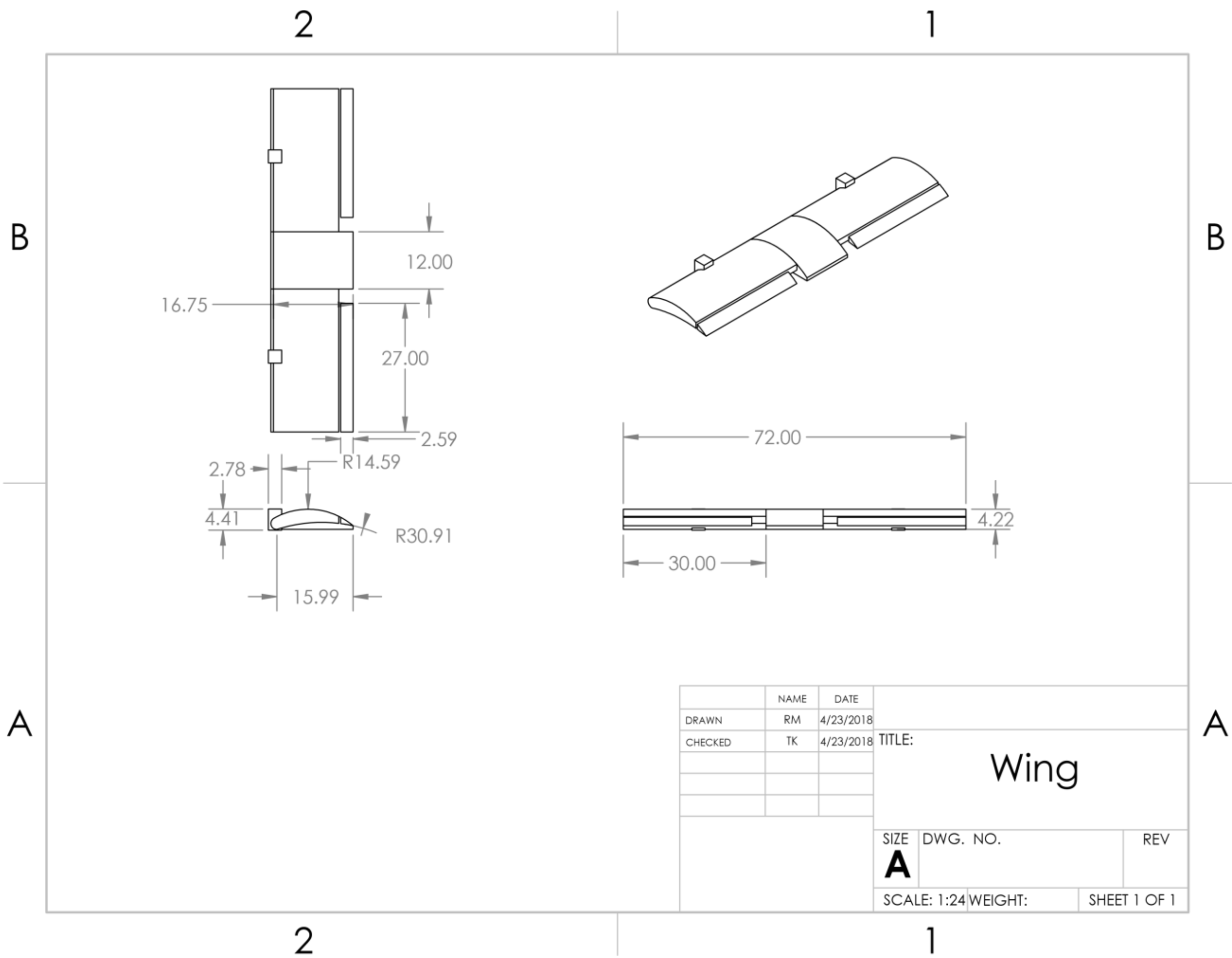
$$Contributing\ Surface\ Area = \frac{Wingspan^2}{Aspect\ Ratio} \quad \text{Eq. 6}$$

With a 6-foot wingspan and an aspect ratio of 4.29, the contributing surface area was calculated to be 8.4 square feet. Finally, the surface area and the weight of the aircraft was used to calculate the wing loading with Eq. 7.

$$Wing\ Loading = \frac{Weight}{Surface\ Area} \quad \text{Eq. 7}$$

This formula gave a wing loading of 1.2 lb/ft^2. Because the aircraft is large, it will generate a low amount of thrust. This means the low wing loading of 1.2 lb/ft^2 is not only expected but desired. The motor mounts are located 15 inches inside the tip of the wing on both sides. Finally, a 12 inch by 16 inch plate will be attached to center of wing to allow it to attach to the fuselage. Finally, there is a flap on each half of the wing that allows changes in the pitch of the aircraft. The conceptual design of the wing can be seen in Figure 9.

Figure 9: Wing Conceptual Design



Tail Concept:

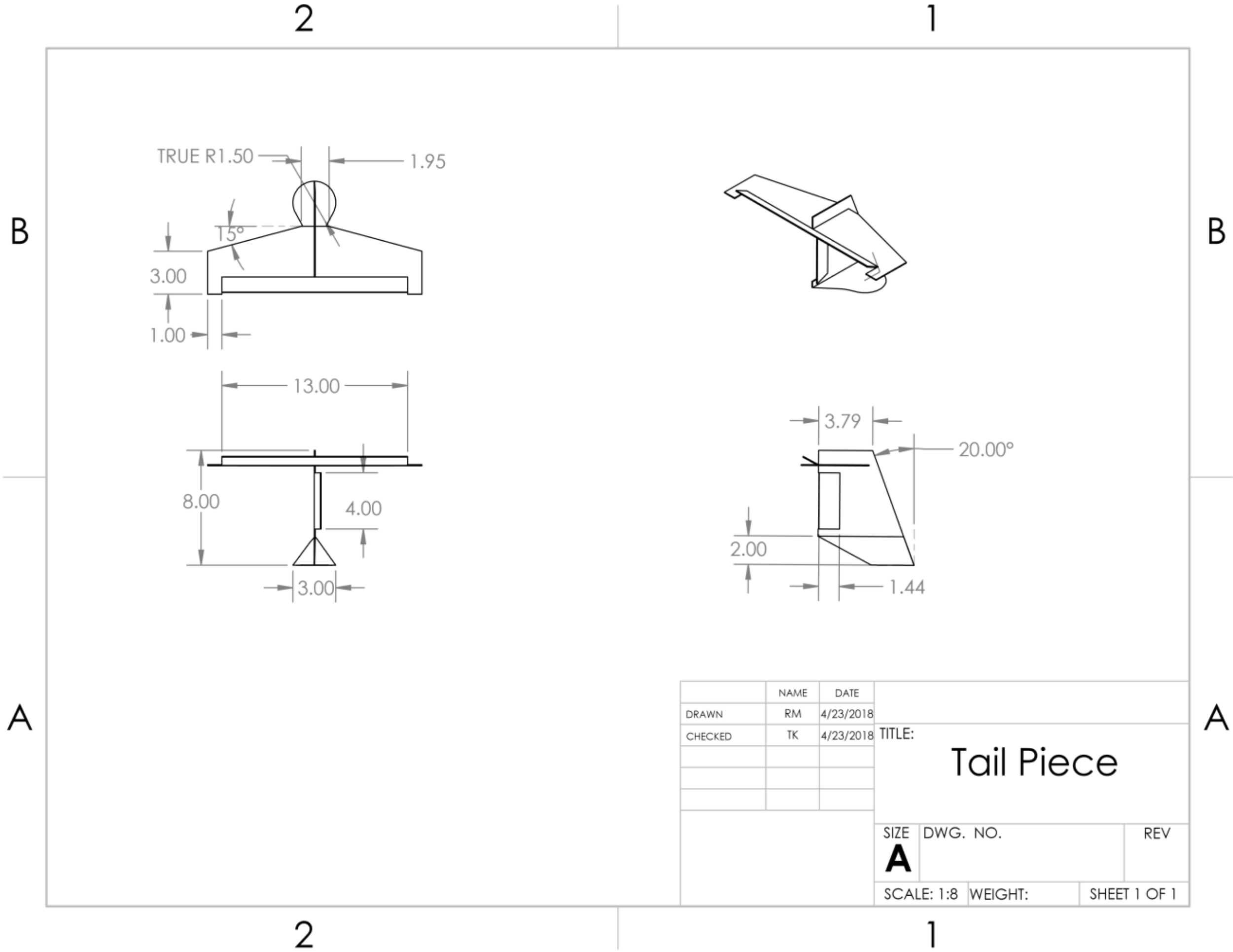
The tail of the airplane is designed to provide stability and control of the aircraft in pitch and yaw. Two types of tails were considered for the aircraft, a conventional tail design and a T-tail design. The conventional tail design involves a sing vertical stabilizer being placed at the tapered end of the fuselage and one horizontal stabilizer divided into two halves on each side of the vertical stabilizer. This design provides adequate control and stability for most aircraft designs, it is also the most common design on airplanes. The T-tail design involves the horizontal stabilizer being positioned at the top of the vertical stabilizer. Because the horizontal stabilizer ends up being above the propeller flow and wing wake, its stability improves, and the tail becomes more aerodynamically efficient. Due to the higher efficiency, the tail's size can be reduced, saving weight and material cost. However, a negative of the T-tail is that its layout imposes a bending and twisting load on the vertical stabilizer, requiring a stronger structure. In Table 5, both designs were compared to each on the criteria of performance, stability, and ease of manufacturing

Table 5: Tail Weighted Scoring

Tail Design	Performance	Stability	Ease of Manufacturing	Totals
Conventional Tail	4	3	3	10
T-tail	5	4	5	14

From the weighted scoring, the T-tail is the design that would be of best use to the team. The dimensions of the tail are entirely based on the parameters of the wing and fuselage. The tail elevator needs to be about 20% of the wing span which for a wing span of 6 feet means the elevator needs to be 15 inches. The rudder should ideally be about half of the elevator, but due to design constraints, a value of 6.74 inches was chosen. A height of 8 inches is sufficient for the tail to be out of the airflow of the wings and fuselage. The final conceptual design of the tail can be seen in figure 10.

Figure 10: Tail Conceptual Design



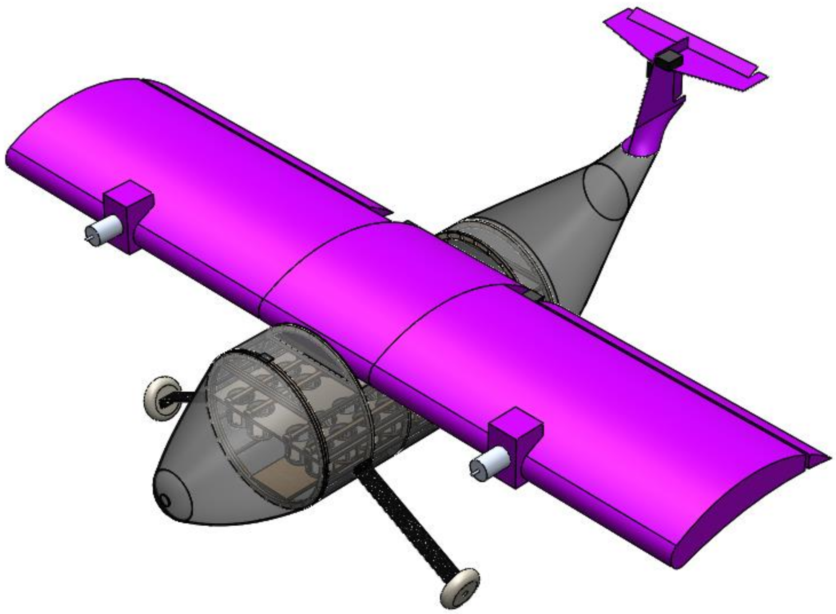
Propulsion:

It was decided that because of the large aircraft design, two motors would be required to provide enough power for the plane. Because the plane weighs 11 lbs, each motor would have to provide enough power for a 6 pound plane each. After research into various motors, it was decided that two Rimfire .55 brushless motors would be used. Each Rimfire .55 motor provides enough power for a 6 pound plane, so two of them will be enough for our 11 lbs aircraft. A brushless motor was chosen because they provide much more torque then a brushed motor. They provide enough torque such that a gearbox will not be needed, which reduces the overall weight of the plane. Attached to each motor is a APC 15x7.5 Thin Composite propeller. These propellers have a 15 inch diameter and a pitch of 7.5 degrees. These large propellers, in combination with the high torque motors, will provide more than enough power for the aircraft to fly.

Full Final Concept:

With the conceptual designs for each part of the aircraft figured out, it was time to put them together to get the full final concept of the aircraft. This can be seen in Figure 11 along with the aircrafts major dimensions.

Figure 11: Full Final Conceptual Design



Aircraft Design Analysis:

Weight and Balance:

Just because you figure out a design to build, does not mean you just immediately start building. One of the most important parts of manufacturing is when you analyze your designs to ensure that they will be sufficient to meet your goals. One of the first analyses done on the final conceptual design was to evaluate the weight and balance of the aircraft. This is important because they ensure that the aircraft will have enough stability, performance, and control to fly. This was done by looking at what each component's position within the aircraft affected its center of gravity. If the center of gravity is too far forward, the elevator will not have enough power to control the plane during pitch but if it is too far backwards, then the plane will not be stable during flight. For maximum stability, the center of gravity of an aircraft should be located at the quarter chord or right below the front end of the wing. For the missions involved in this competition, knowing where your center of gravity is of upmost importance because as you add passengers and payloads to the aircraft, the center of gravity will change accordingly. Table 6 shows the weight and balance of the aircraft during all three missions.

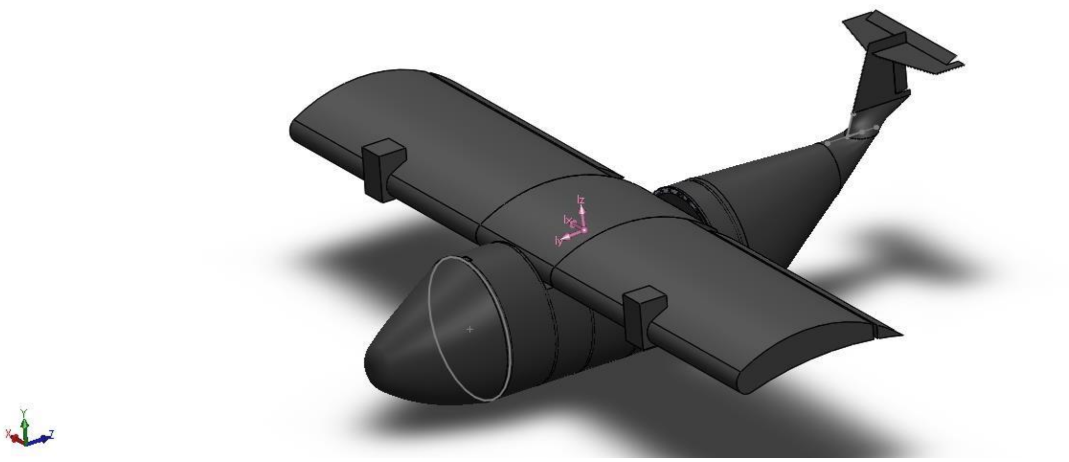
Table 6: Weight and Balance

Mission 1						
Components	Quantity	Weight (lbs)	Total (lbs)	C.G. Loc. (In, xaxis)	C.G. Loc. (in, yaxis)	C.G. Loc. (in, zaxis)
Large Cross Section	5	0.03	0.15	1.75	7.37	-3.27
Small Cross Section	3	0.02	0.06			
Carbon Fiber Rods	8	0.13	1.04	1.75	5.43	-2.28
Passenger Compartment	1	0.25	0.25	1.75	6.29	-2.3
Passenger Cups	20	0.05	1	1.75	6.29	-2.3
Total Fuselage	1		2.5	1.75	6.2	-2.58
ESC	2	0.19	0.38			
Battery	1	0.84	0.84			
Landing Gear Front	1	0.31	0.31			
Landing Gear Back	1	0.19	0.19			
Wheels	3	0.2	0.6			
Motors	2	0.59	1.18	1.82	13.47	-2.59
Motor Mount	2	0.14	0.28	1.82	13.47	-2.59
Wiring						
Signal Receiver						
Propeller	2	0.08	0.16	1.75	6.86	-19.34
Tail	1			1.77	16.6	28.57
Wing	1	2.9	2.9	1.82	13.35	-2.33
Aircraft Totals			9.34	1.79	10.02	-2.02
Mission 2						
Passengers	20	0.08	1.6	1.75	5.93	-8.76
Aircraft Totals			10.94	1.78	9.12	-3.51
Mission 3						
Passengers	10	0.08	0.8	1.55	5.97	-10.78
Cargo	1	0.15	0.15	1.75	3.96	-10.96
Aircraft Totals			10.29	1.75	9.36	-3.33

From Table 6, it shows that the estimated location of the aircraft's center of gravity is at (1.75, 9.36, -3.33). This location when found on the aircraft is located right under the front of the wing, Figure 12. This shows that our aircraft is currently balanced sufficient for flight.

It is important to note that within table 6, there are a few blanks spots for the C.G. location for some items. This is because that the actual location of these items has not been set yet and will depend how the construction of the aircraft turns out. Once construction has finished, those items will be placed so that the center of gravity does not change unfavorably.

Figure 12: Center of Gravity Location



Body Analysis:

There were some initial concerns that because the internal frame was going to be made from balsa wood, the frame pieces wouldn't be able to handle the forces encountered during flight and would fracture. To quell these concerns, the frame pieces were tested in ANSYS for any form of deformation or critical stress. For the wing support frame pieces, a bar was added to the horizontal diameter to represent the passenger compartment during the analysis and a load of 12 lbs was applied to represent the largest possible load the aircraft could experience while in flight. In Figure 13 and Figure 14, it is shown that the body frame pieces would experience a maximum deformation of 0.6 mm and a stress of 6 MPa across the passenger compartment beam. Because the stress experienced is less than the maximum stress of balsa wood, the frame pieces would not fracture.

Figure 13: Wing Support Frame Piece Deformation Analysis

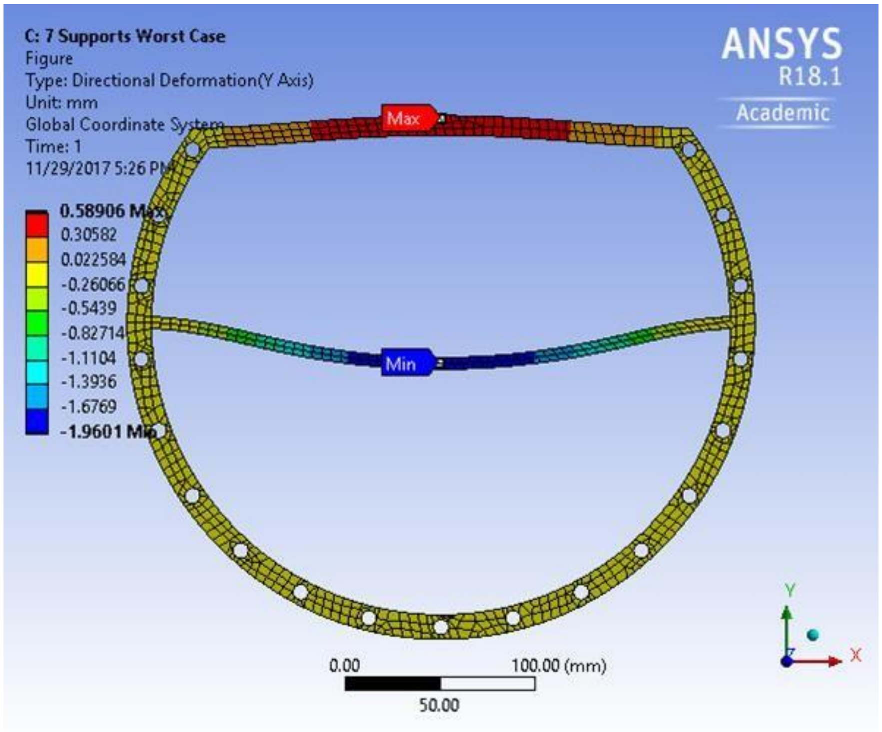
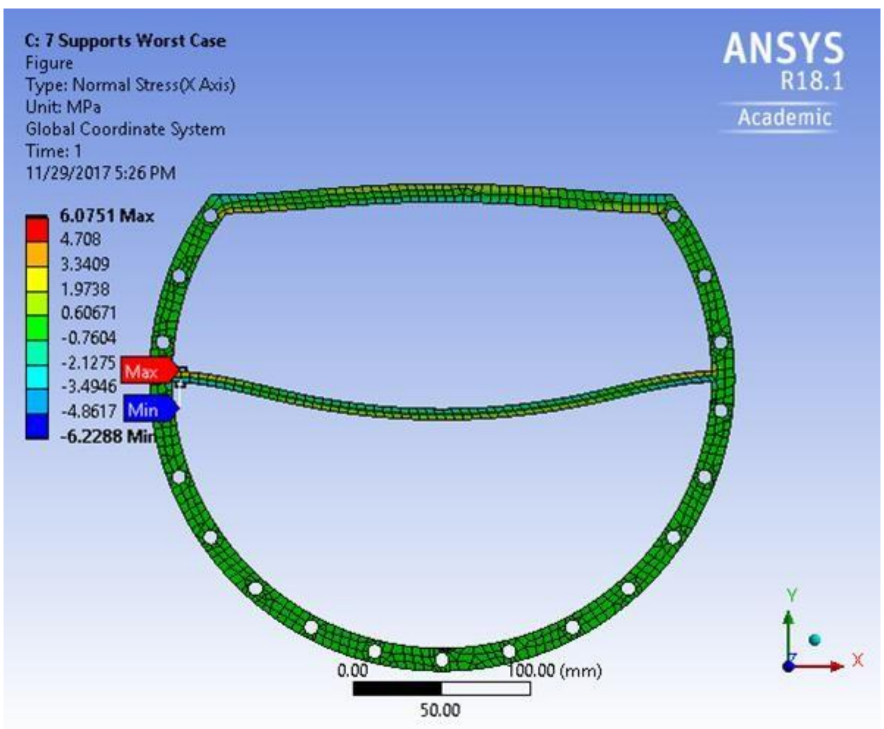


Figure 14: Wing Support Frame Piece Stress Analysis



Similarly, the entire internal frame assembly was analyzed in ANSYS. But this time, the team wanted to find what number of carbon fibers rods would be needed to minimize the maximum stress and deformation. Internal frame assemblies with 5, 7, and 9 evenly spaced out carbon fiber rods were analyzed. It was found that the internal frame assembly with the lowest deformation and stress was the assembly with only 7 carbon fiber rods. In this case, the maximum stress was 4 MPa with a deformation of around 0.013 mm, Figure 15 and Figure 16.

Figure 15: 7 Rod Internal Frame Stress Analysis

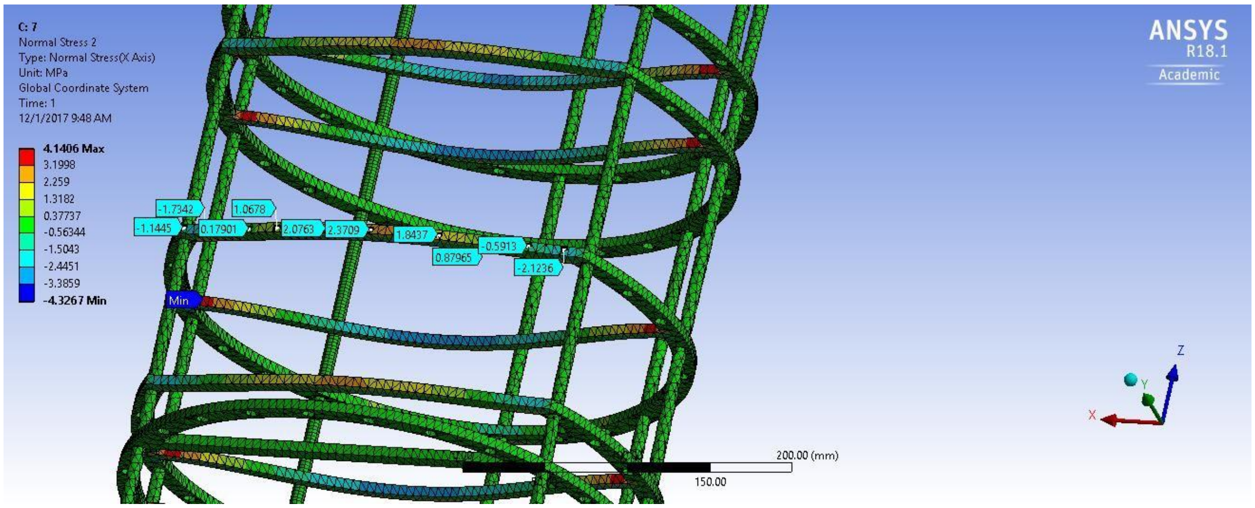
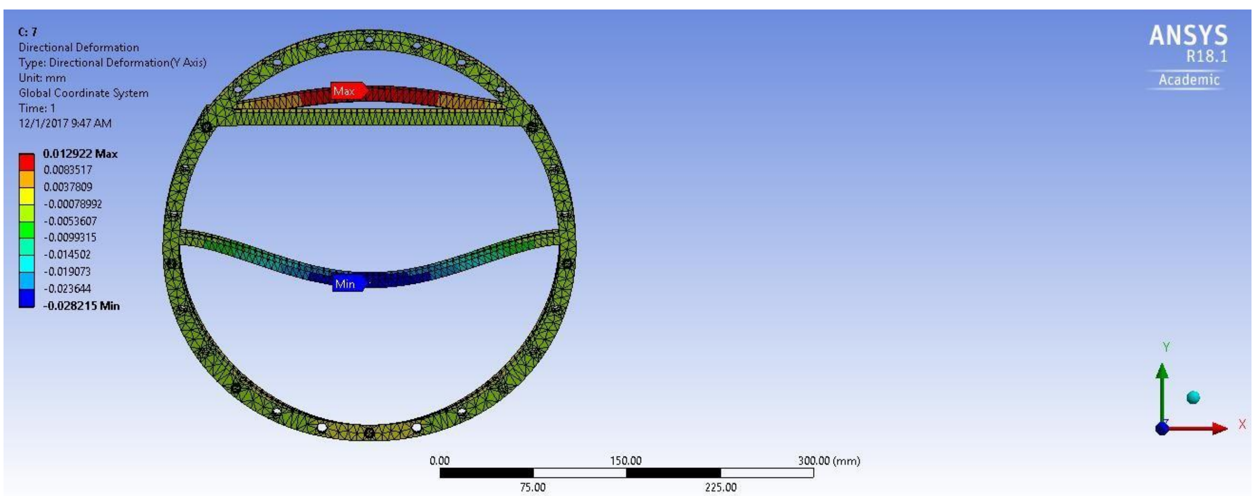


Figure 16: 7 Rod Internal Frame Deformation Analysis



Again, the stresses experienced by the internal frame are far below the maximum stress of balsa wood, so it will not fracture. The deformation experienced is also not significant enough to cause any damage.

Wing Analysis:

ANSYS was used to analyze whether the 3/8 inch carbon fiber rods would be strong enough to withstand the lift generated by the aircraft and the weight of the aircraft. From the analysis, the wings were shown to experience a stress of 17137 psi, Figure 17, and deformation at the wing tip of 0.7 inches, Figure 18. Both of which are within acceptable ranges which means the 3/8 inch carbon fiber rods are sufficient.

Figure 17: Wing Deformation Analysis

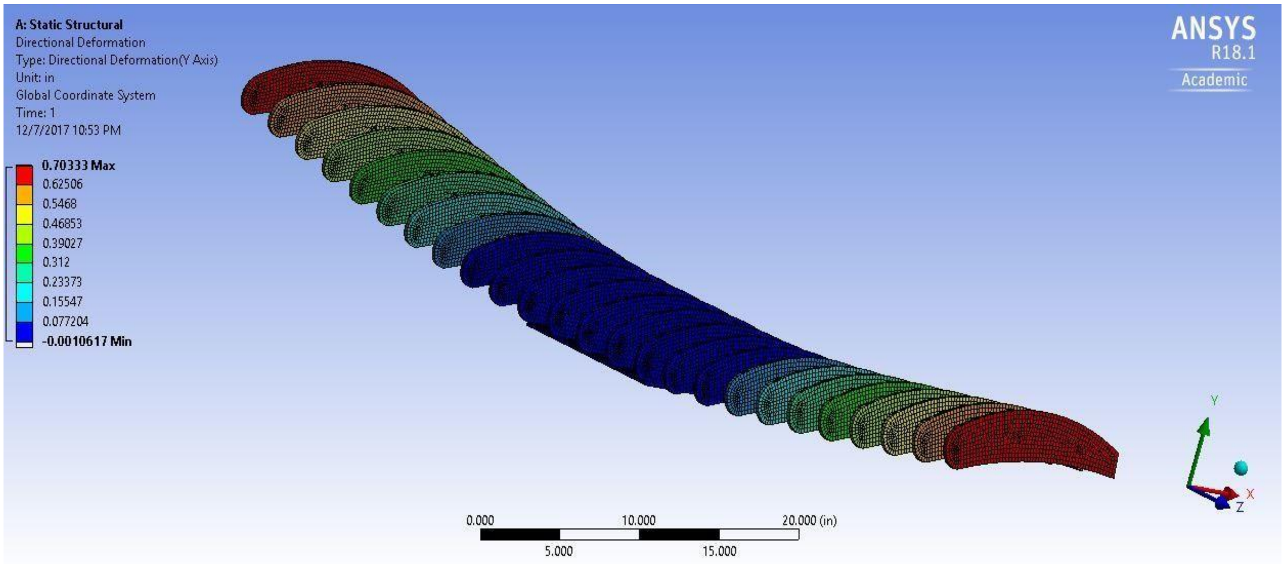
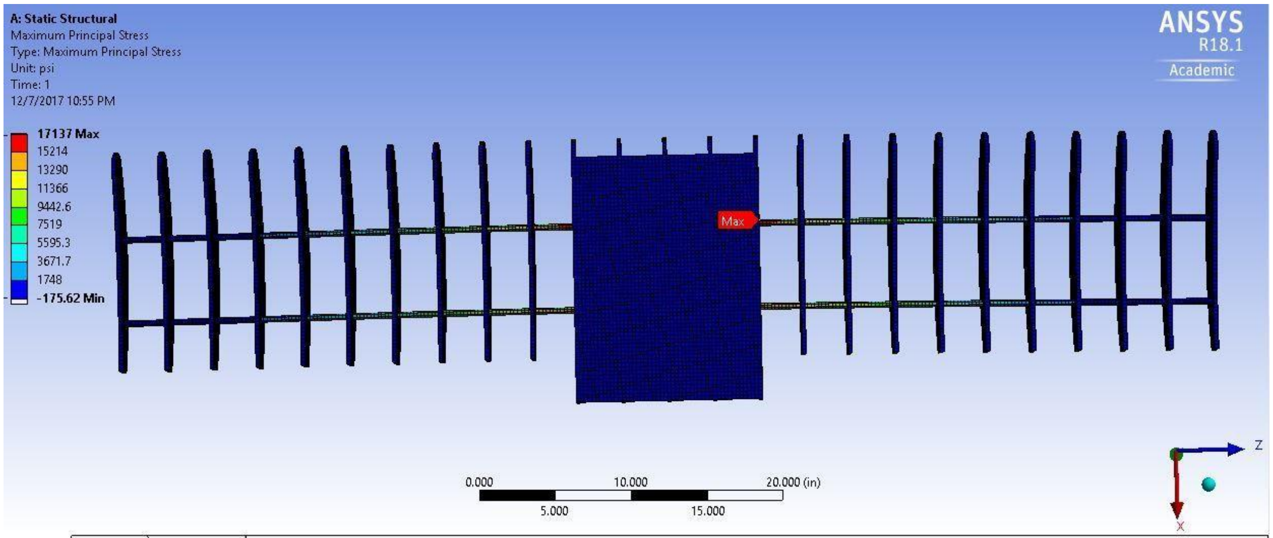


Figure 18: Wing Stress Analysis



Tail Analysis:

The first part in analyzing the tail is to calculate the lift force generated by the tail. This is found with Eq. 8 below.

$$L = \frac{C_L \rho V^2 A}{2} \quad \text{Eq. 8}$$

Where C_L is the lift coefficient, ρ is air density, V is velocity, and A is the area. Two cases are looked at, when the rudder is at a 15° location and at a 40° location. For 15°, the C_L = .5 while for 40°, C_L = 1. The lift forces for the 15° and 40° cases for the elevator are 1.41 N and 2.82 N, respectively, While the lift forces for the rudder are 0.625 N and 1.25 N. The tail can now be analyzed with ANSYS to find out whether the control surfaces can withstand the forces associated with the rudder and elevator positions. At the 15° location, the deformation was found to 0.17 mm for the elevator and 2.21 mm for the rudder. For the 40° case, the deformation was found to be 3.6 mm and 10.92 mm, respectively. The 15° location results in a much smaller deformation so that is the location that will used. The stresses at the 15° location for the elevator and rudder were 0.6 MPa and 4.3 MPa. The stresses of the 15° location for the elevator and rudder are seen in Figure 19 and Figure 20.

Figure 19: 15° Elevator Position Stress Analysis

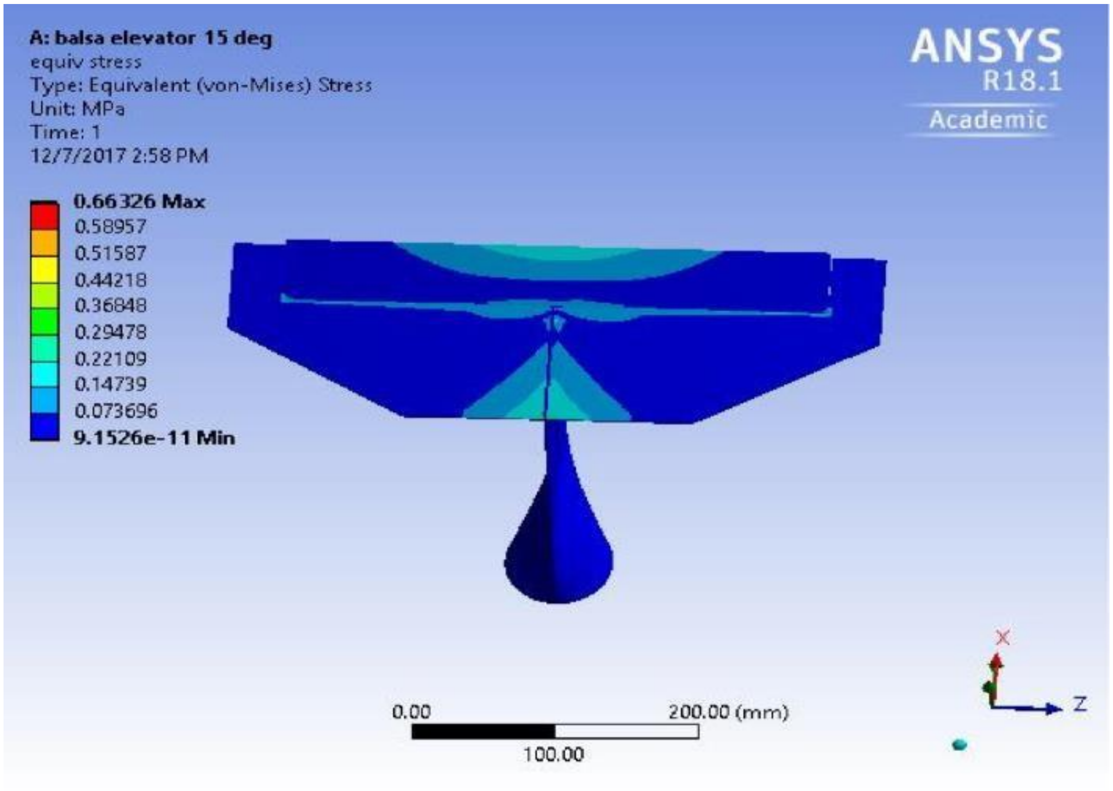
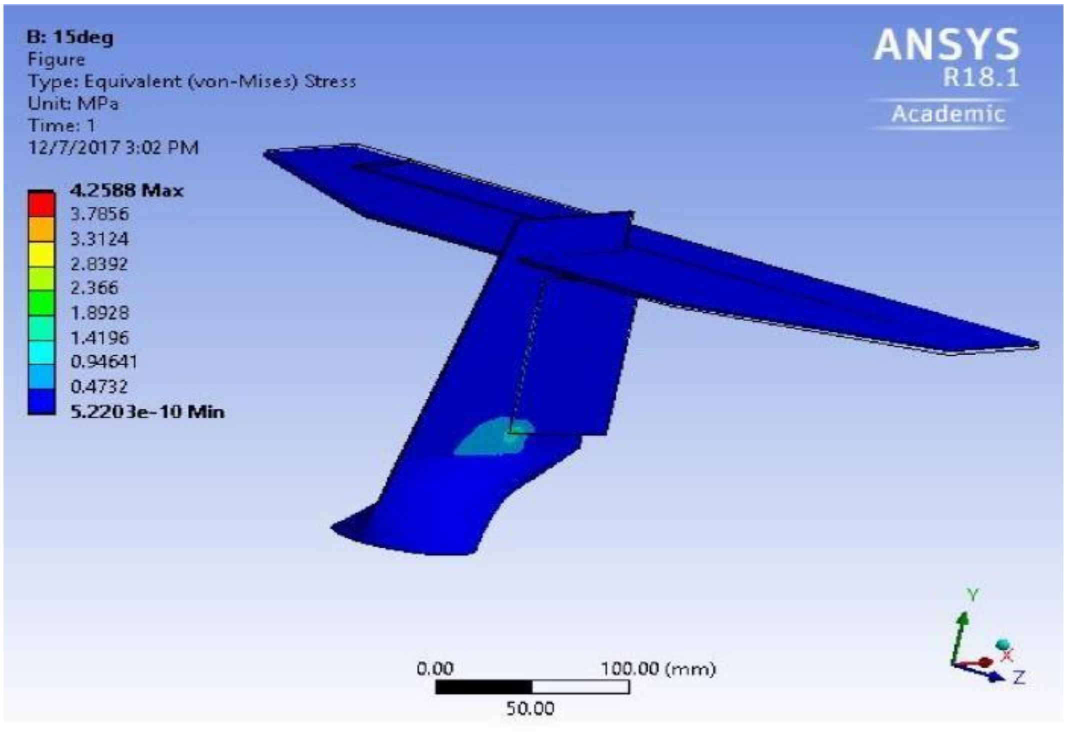


Figure 20: 15° Elevator Rudder Stress Analysis

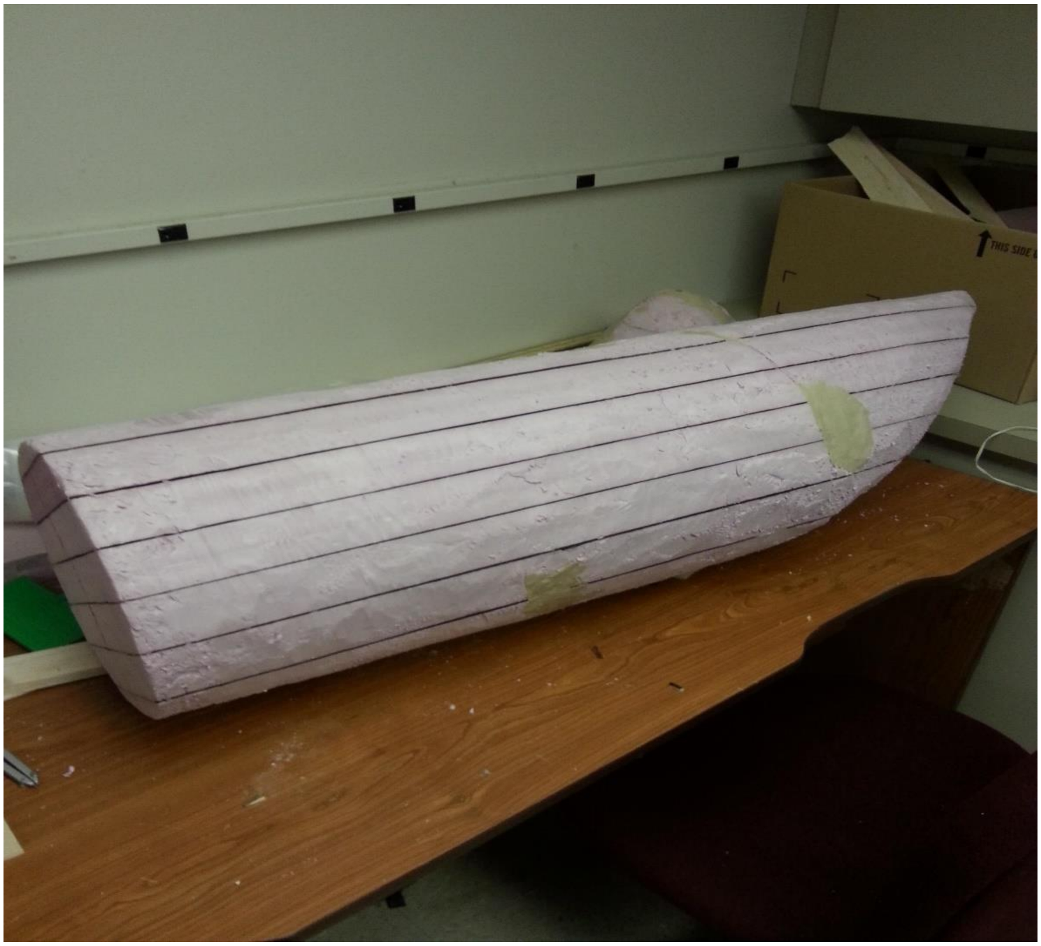


Aircraft Manufacturing:

Body Construction:

The first step in constructing the body was to create a mold of the aircraft's fuselage. This mold will be used to create the fuselage of the aircraft. To get a diameter of 13 inches and length of 53 inches, seven 2x14x60 inch high density foam boards were stacked and then attached together. These boards were then cut into a cylinder of about 13 inches wide and 60 inches long. After this, the end of the cylinder that would be attached to the tail was cut upwards, converging to where the tail would be attached, this is seen in Figure 21.

Figure 21: Fuselage Mold



Now that the mold was complete, the body team moved on to making the fuselage. First, balsa wood boards were soaked in a water bath. After about 5 minutes the balsa wood became soaked enough to easily bend without breaking. Then the soaked balsa wood was wrapped around the fuselage until the entire body was wrapped with no overlap of the balsa wood. The balsa wood was left to dry and after a few days the balsa wood was taken off the fuselage. Because the balsa dried while wrapped around the fuselage mold, it kept the shape in which it was placed. Next, the foam mold was wrapped in plastic filament to prevent the epoxy from sticking to the foam itself. First, epoxy was applied to the mold and carbon fiber strips were placed on the location of the wheels, tail connection, and around the front end of the fuselage to provide some extra strength. A layer of fiberglass sheets was wrapped around the mold with epoxy being applied. The shaped balsa wood was then placed around the mold with again more epoxy being used. Finally, a second layer of fiberglass was wrapped around the fuselage mold with more epoxy. A layer of plastic filament was applied to stop the epoxy from sticking to everything else. The fuselage was wrapped in a cotton breather and then inserted into a plastic bag and vacuum sealed overnight.

The next thing that needed to be constructed is the nose cone. To do this another high-density foam mold was created, as seen in Figure 22.

Figure 22: Foam Nose Cone Mold

Like the fuselage, the nose cone was wrapped in plastic filament first. Instead of balsa wood, 3 layers of fiberglass sheets and epoxy were applied to the nose cone mold. A layer of plastic filament was added along with a layer of cotton breather. Finally, it was inserted into a plastic bag and vacuum sealed. Once the fuselage and nose cone were finish being vacuum sealed, they were removed from the plastic bags and the outside plastic filaments and breathers were removed. The high-density foam molds were then removed from the finished fiberglass nose cone and fuselage. The completed nose cone can be seen in Figure 23.

Figure 23: Completed Nose Cone

The next part in the construction of the body was to construct the internal frame pieces. To do this, 1/4 inch wide balsa wood boards were glued together to form 5 balsa wood sheets. The body frame pieces were then laser printed from these balsa wood sheets. The finished frame pieces can be seen in Figure 24 and Figure 25.

Figure 24: Laser Cut Body Frame Piece

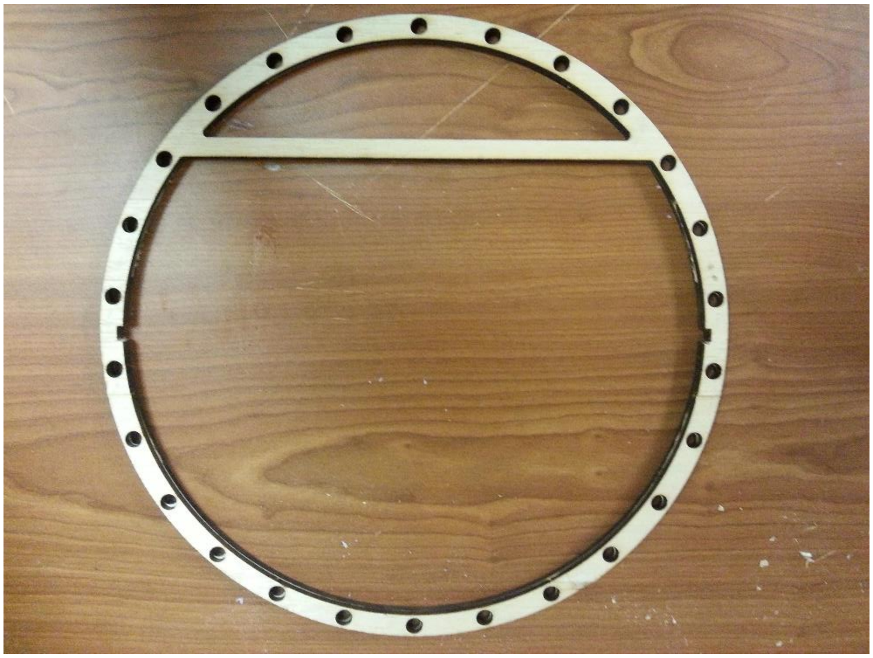
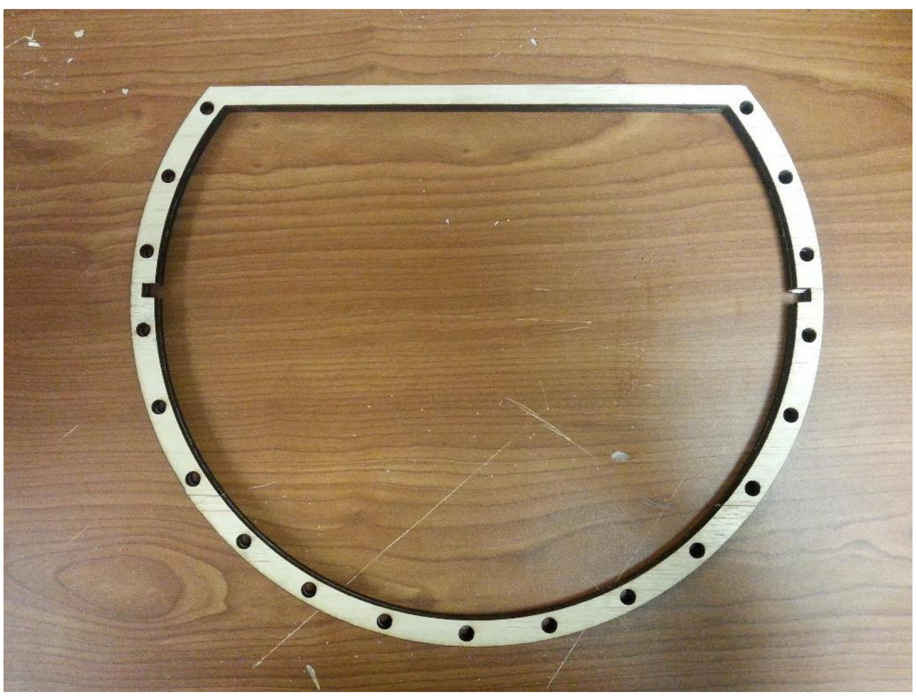
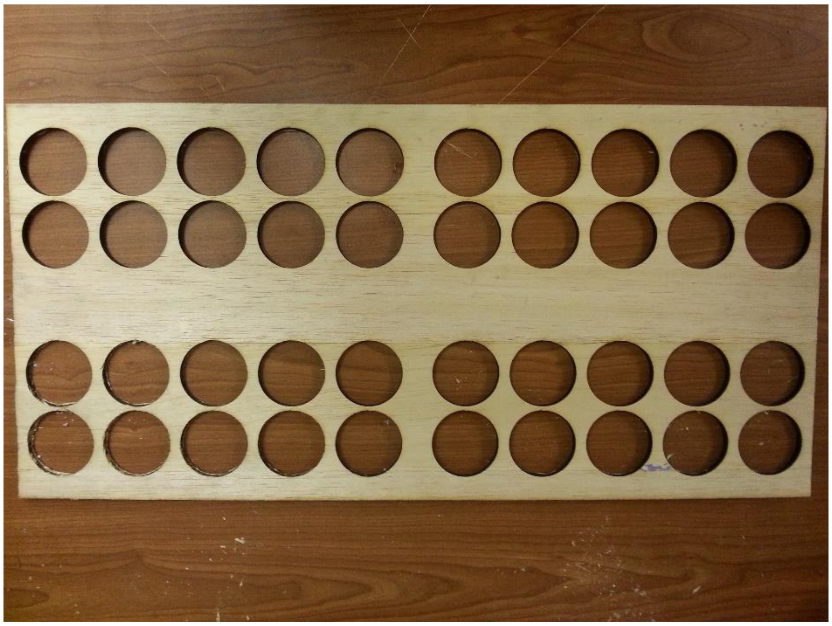


Figure 25: Laser Cut Wing Support Frame Piece



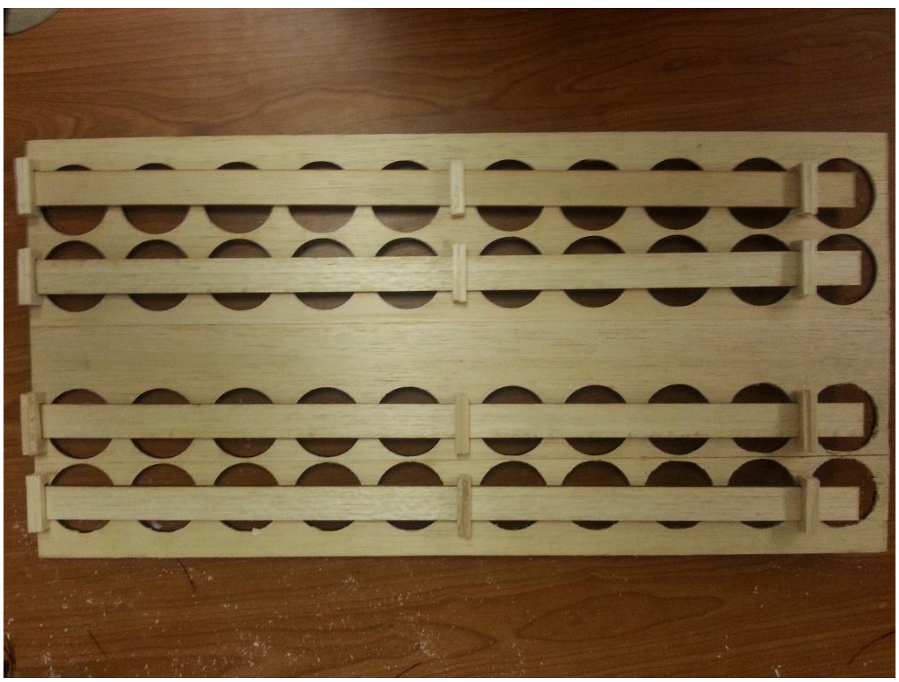
Another sheet of 1/4 inch wide balsa wood boards were glued together, and the passenger compartment was laser cut out of it. This is shown in Figure 26. The cups that will hold the passengers will be made from elastic fabric which will be glued into place over the holes.

Figure 26: Laser Cut Passenger Compartment



Afterwards, the loops for the retainer rods were glued to the passenger compartment, Figure 27 and the retainer rods were inserted. The mesh being used as the holders for the passengers will be attached and the passenger compartment will be fully completed.

Figure 27: Completed Passenger Compartment



Finally, the internal frame was assembled and then inserted into the fuselage. As shown in Figure 28, two balsa wood boards with strips of carbon fiber sheets were placed over the top of the wing support frame pieces to add some extra strength and support.

Figure 28: Assembled Completed Fuselage

Wings Construction:

For the wings, 1/4 inch balsa wood sheets were glued together and 20 copies of the airfoils were laser cut, Figure 29. five flat bottom airfoils were also laser cut to serve as a connector to the fuselage.

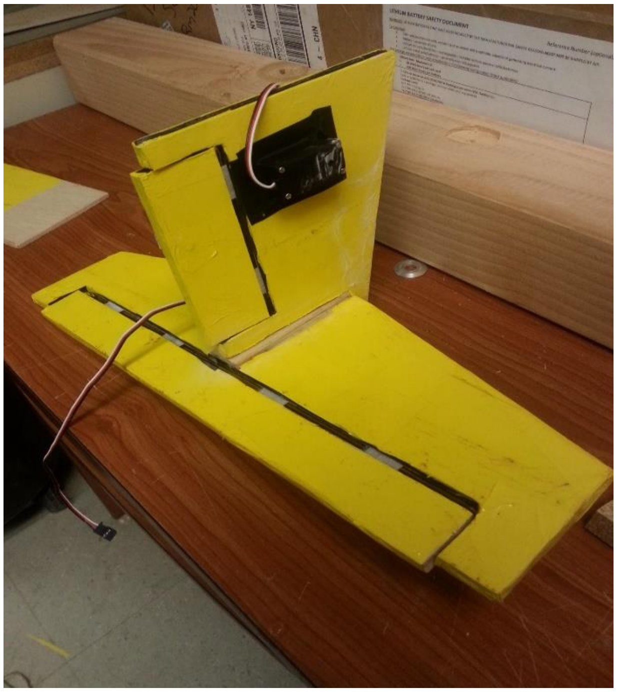
Figure 29: Laser Cut Airfoils

These airfoils were then slid onto the carbon fiber rods and the frame of the wing was constructed. At the position of the motors, mounts were made out balsa wood and reinforced with carbon fiber sheets. The motors for the wing flaps and the propeller blades were installed onto the wings and they were fully wired. Finally, the airfoil skeleton of the wings will be shrink wrapped.

Tail Construction:

For the tail, 1/4 inch balsa wood sheets were created again and from them, the elevator, rudder and other pieces of the tail were laser cut. These pieces were then glued together, and the elevator and rudder were attached to the main tail piece via hinges. Afterword's, the servos for the rudder and elevator were attached. This completed tail can be seen in Figure 30.

Figure 30: The Fully Constructed Tail



The tail will be attached to the fuselage via a 3D printed connecter piece. This connector piece is seen attached to the fuselage in Figure 31.

Figure 31: 3D Printed Tail Connecter Piece

Full Final Aircraft:

Now that all the pieces of the aircraft are completed, it is time to put them together. The tail piece was slid into the tail connecter and glued into place. The flat board on the bottom of the wings was glued onto the wing support frame pieces and the fuselage. Finally, the aircraft's electronic systems will be inserted and connected to the wires in the wing and tail. The center of gravity of the plane was checked by holding the aircraft up by the edges of its wing. When this was done, the tail of the plane started to spin downwards, this meant that the aircraft was unbalanced with too much weight at the tail of the aircraft. This was remedied by moving the batteries and other such components to the front of the aircraft, evening the weight out. The completed aircraft can be seen in Figure 32.

Figure 32: Final Completed Aircraft

Results and Conclusion

The completed aircraft was brought to the competition and attempted to be flown. Unfortunately, after a successful takeoff, the aircraft rose about 25-30 feet into the air and took a nose dive into the ground. The nose dive caused the aircraft to flip as it crashed, crushing the tail of the aircraft. The tail was broken beyond repair and thus resulted in Gold Team receiving zero points for the competition. The good news is that Purple Team's aircraft also crashed during the first mission attempt and was broken beyond repair. This meant that neither teams won the competition and coring would have to be based on the written paper alone. This score would unfortunately be calculated after this thesis is due and as such, the winner won't be known.

This competition provided much insight into the manufacturing process used by engineers, from designing the aircraft to solve a mission statement, to ordering the correct parts and using such parts to construct the aircraft, to finally testing the completed aircraft. Though the mission overall ended in failure, the team learned from the mistakes that were made and already have ideas that could allow the aircraft to fly. The senior design class itself is finished, but many members of the team wish to try and get the plane to fly in their free time. Their ideas include replacing the entire tail of the aircraft, getting rid of the old T-Tail design and adding in a larger H-Tail design. This tail design involves two vertical stabilizer that are placed at the ends of the horizontal stabilizer. This places the vertical stabilizers in the prop wash of the wing mounted propellers which should result in greater directional control. The other idea is to lower the overall weight of the aircraft by cutting off the tail end of the fuselage and connecting the smaller body to the tail by carbon fiber rods. This would reduce the weight by removing much of the carbon fiber strips that were added to the fuselage which were overall unnecessary. With these modifications made, Gold Team is excited to see our aircraft finally fly.

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