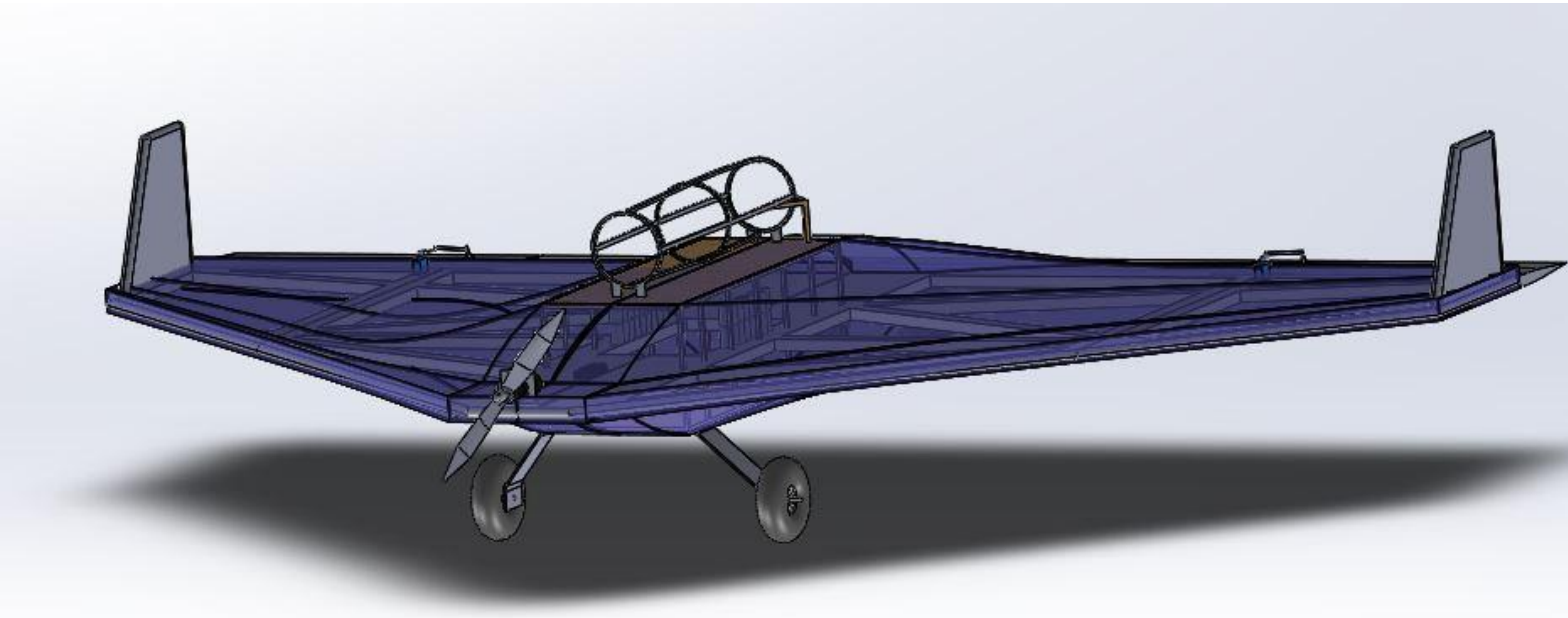
University of California, San Diego

UCSD AIAA Student Chapter
DBF Team How to Train Your Plane



AIAA Design Build Fly 2015

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1.0 Executive Summary

The following report details the design, fabrication, testing, and performance of the UC San Diego Design, Build, Fly Team's 2014-2015 competition aircraft. The Team designed the aircraft to successfully complete 4 missions: an unloaded speed flight, a cargo carrying mission, a payload drop, as well as a ground payload mission. Aside from completing the 4 missions, the Team's overarching goals were to minimize structural weight and the number of servos used, without sacrificing performance.

1.1 Design Process

When designing the aircraft, the Team used a preliminary design review process to determine which design would result in the highest scoring plane for the 2014-2015 competition year. By identifying and weighing critical metrics and criteria, the Team was able to downselect from a list of different possible designs. Similarly, the Team had to choose the appropriate battery, motor, and propeller configuration that best accommodated both the design of the plane and the requirements of the competition. The Team performed lift, drag, and weight analysis as well as considered a configuration optimal for achieving a high score. This gave the Team a preliminary design to build a prototype to be further improved upon by physical and experimental testing. The final selected design was a lightweight foam and carbon fiber delta wing configuration, with two elevons to control the plane, and a streamlined design for minimum drag. As necessary, the Team would tweak, refine, and tune this design in order to achieve the best possible performance.

1.2 Key Mission Requirements

The challenge presented to the Team for the 2014-2015 competition consists of 4 different missions. The first mission is a ground mission that required the quick loading and unloading of cargo. The first flight mission, Mission 1, is an unloaded speed mission where the score is determined by the number of laps completed in four minutes. Mission 2 is a three (3) lap cargo mission with the goal of carrying three wood boards, weighing 5 lbs total, as quickly as possible. Mission 3 is a simulated sensor drop with the goal of dropping a number of Wiffle Balls, with the amount of balls to be determined by the Team. From these mission descriptions, the Team identified three important design elements that should be optimized to improve the performance and final score of the aircraft.

- <u>Empty Weight</u>: The final scoring formula puts an emphasis on minimizing the empty weight of the aircraft. This would have a high impact on our choice of lightweight material, size, and design of the plane.
- <u>Limited Number of Servos While Maintaining Control</u>: The final scoring formula also places a heavy importance on minimizing the number of servos used on the plane. This would have a high impact on the type of design chosen by the Team, and resulted in the decision for the control surfaces to include only two elevons.
- <u>Speed</u>: There are two missions of the three flight missions that emphasize the speed of the

airplane, and this would have a big impact on our choice of motor and airfoil, and also on the emphasis on minimizing drag.

1.3 Final Capabilities

The final performance capabilities and specifications of the aircraft are summarized below:

- Empty weight of 4lbs.
- Maximum payload of 5 lbs.
- Ability to complete 4 laps in 4 minutes unloaded.
- Ability to complete 4 point scoring laps for the ball drop mission.
- Strong, durable aircraft.
- Proven and consistent performance of subsystems, and promising vehicle performance after initial flight tests.

The remainder of this report details the design requirements and process the Team used to arrive at the final design. Final aircraft fabrication is ongoing, as is more detailed subsystem and complete aircraft testing. The Team will use the remaining 7 weeks to finish fabrication and expand the flight envelope of the competition aircraft.

2.0 Management Summary

2.1 Project Management

The members of the UC San Diego DBF team divided into 5 groups to handle the design, testing and fabrication of the aircraft. These 5 groups covered the major aerospace disciplines, consisting of an Aerodynamics, Controls, Propulsion, Structures, and Fabrication group. Group leaders coordinated the efforts of their group members, while the Report Lead Writer oversaw the format and content of the report. The Project Manager coordinated all group members and oversaw the completion of the project.

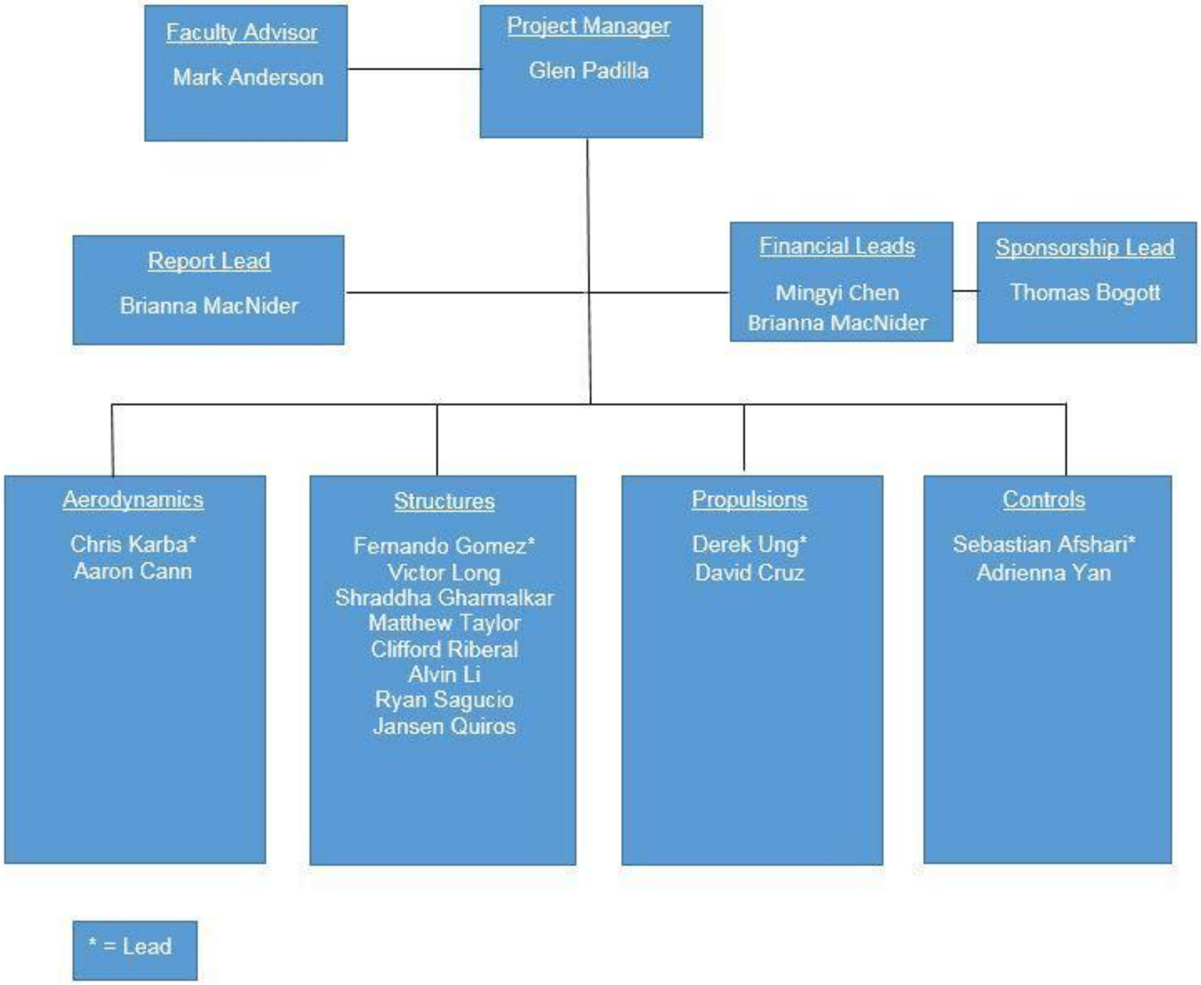
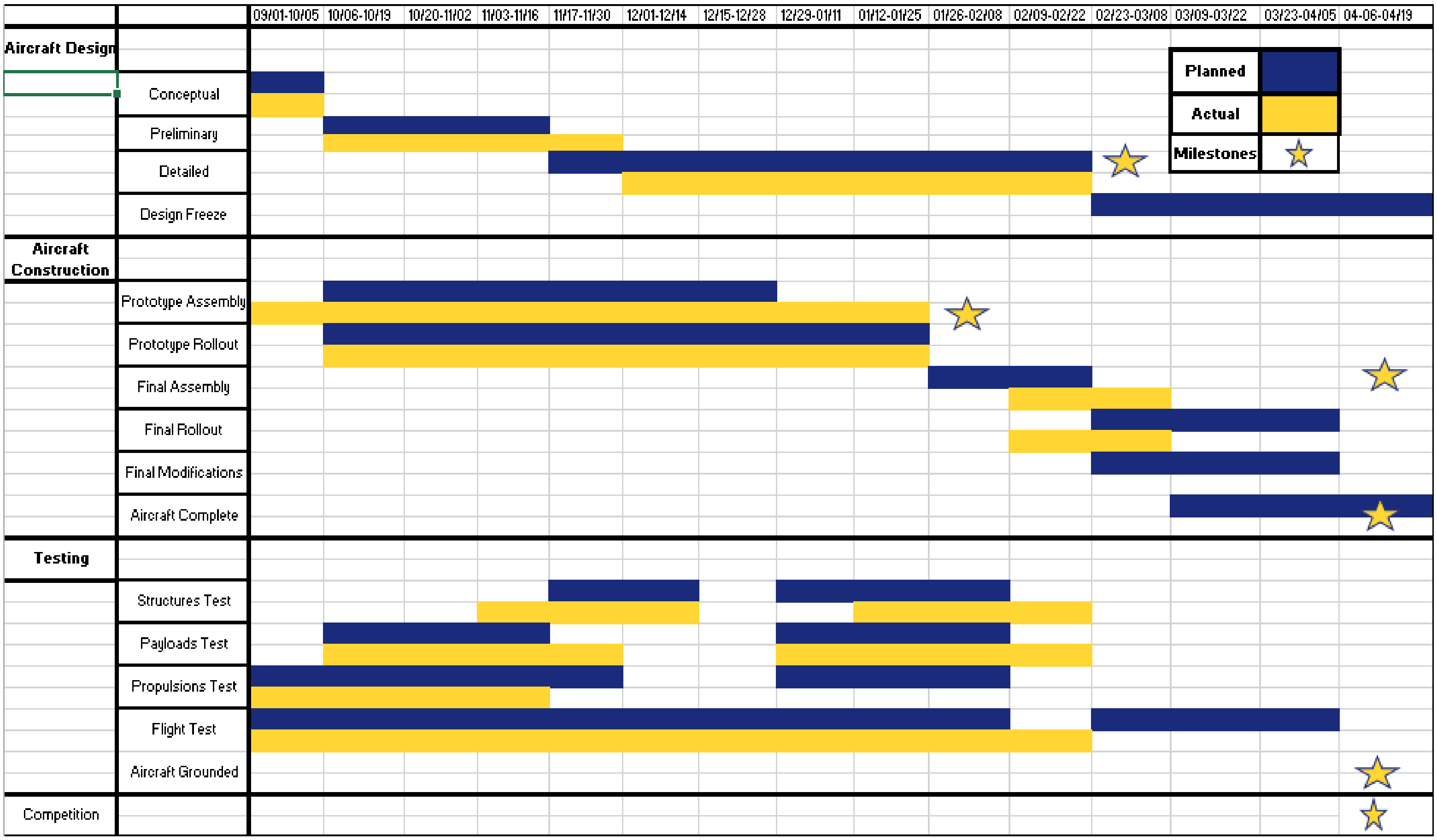


Figure 2.1: Management Flow Chart

2.2 Milestone Chart

Schedule planning and timely completion of milestones is key for effective project completion. A schedule was created in order to better plan out necessary dates of completion for milestones. The figure



below shows the Team's planned schedule with a comparison to the actual completion dates.

Figure 2.2: Master Schedule and Milestone Chart

3.0 Conceptual Design

The Team decided that an important part of conceptual design is breaking down the mission requirements and design constraints to better understand how to achieve the highest possible score. By analyzing each mission's score equations, computing a sensitivity analysis, and considering any design constraints included in the competition rules, the Team selected the design and configuration that provided the highest overall score.

3.1 Mission Requirements

The 2014-2015 AIAA Design/Build/Fly competition total score takes into account the written report score, the total mission score, and the rated aircraft cost (RAC). The total score is computed as:

$$Total\ Score\ =\ Written\ Report\ Score\ *\frac{Total\ Mission\ Score}{RAC}$$

where the written report score is graded out of 100, the RAC is the empty weight of the aircraft time the number of servos, and the total mission score is given by the equations below:

$$Total\ Mission\ Score\ =\ Ground\ Mission\ Score\ *\ Flight\ Score$$

$$Flight\ Score\ =\ \Sigma\ Individual\ Mission\ Scores$$

3.1.1 - General Requirements, Limitations, and Concerns

The following are some general requirements for the competition:

- The battery pack cannot weigh more than 2.0 lbs.
- The aircraft must land safely in order to receive a score for each flight.
- The aircraft must take off within 60 feet on each mission.

The Flight Course was another critical part of the competition that was defined by the competition rules. The Team analyzed the flight course to better understand how the missions would be flown. During the missions the Team's airplane must take off within the 60 foot runway limit and climb for the first 500 feet of straight-away. At the end of the 500 feet the airplane will encounter its first 180 degree turn. After the airplane completes its first turn it will accelerate before completing a 360 degree turn. After this, the plane will encounter its second 180 degree turn. The plane will then accelerate for 500 feet before completing a lap. The airplane will complete the other remaining laps in the same manner as described above. After the maximum amount of time, or laps, has been reached, the airplane will slow down and come to a safe landing, ending the mission. The layout of the flight course is shown below in Figure 3.1.

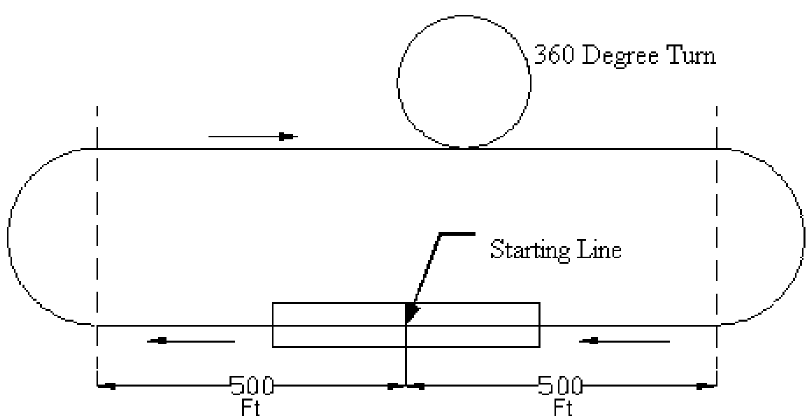


Figure 3.1: Competition Flight Course

3.1.2 - Ground Crew and Assembly Crew

The ground crew and assembly crew for the missions shall consist of three people: the pilot, the spotter and the payload loader. The aircraft can be assembled when it enters the staging area, but the payload must be unloaded. The aircraft must be loaded and cleared for flight within five minutes.

3.1.3 - Ground Mission: Payload Loading Time

The ground mission simulates the fast loading and unloading of payload. The team must load the payload for mission 2 and close all hatches. The plane will then be examined to make sure it is secure. The team will then unload the mission 2 payload and load the mission 3 payload, again securing the plane and closing all hatches. The plane will once again be inspected to insure the payload is secure. The loading and unloading of the payloads must be completed within five minutes for a successful mission score.

$Ground\ Score = \frac{fastest\ time}{time}$ Ground score is .2 if failed.

3.1.4 - Mission 1: Ferry Flight

The ferry flight simulates an unloaded speed test. After taking off from the 60 foot runway, the aircraft must complete as many laps as possible (using course description in Fig. 3.1) in four minutes. At the end of the four minutes, the pilot must execute a successful landing for the flight to be scored. The scoring for Mission 1 is determined using the formula below.

$$Mission\ 1\ Score\ = 2 * \frac{Laps\ Flown}{Most\ Laps\ Flown}$$

3.1.5 - Mission 2: Sensor Package Transport Mission

The sensor package transport mission simulates carrying a large, heavy sensor payload. The payload must be secured internally, and will consist of a stack of three 2” x 6” boards, 10” long. The weight of the payload will be approximately five lbs. After taking off within 60 feet while carrying the payload, the aircraft must complete three laps. At the end of the three laps, the pilot must execute a successful landing for the flight to be scored. The scoring for Mission 2 is determined using the following formula.

$$Mission\ 2\ Score\ = 4 * \frac{Fastest\ Time\ Flown}{Time\ Flown}$$

3.1.6 - Mission 3: Sensor Drop Mission

The sensor drop mission simulates the dropping of an unspecified number of ‘sensor’ payload packages. The payload will be a team chosen number of 12” Champro Plastic Balls, approximately 2.4 ounces each in weight, and must be mounted to the aircraft externally. Externally is defined as fully exposed to air on at least three sides. After taking off from the 60 foot runway, the aircraft must fly a team specified number of laps. During each lap a single ball must be dropped in the 1,000 foot "drop zone," shown in Figure 3.2 below. Each lap will only count if a single ball, no more and no less, is dropped in the drop zone. At the end of the team specified number of laps, the pilot must execute a successful landing for the flight to be scored. The score for mission 3 is determined using the formula below.

$$Mission\ 3\ Score\ =\ 6 * \frac{Laps\ Flown}{Max\ Laps\ Flown}$$

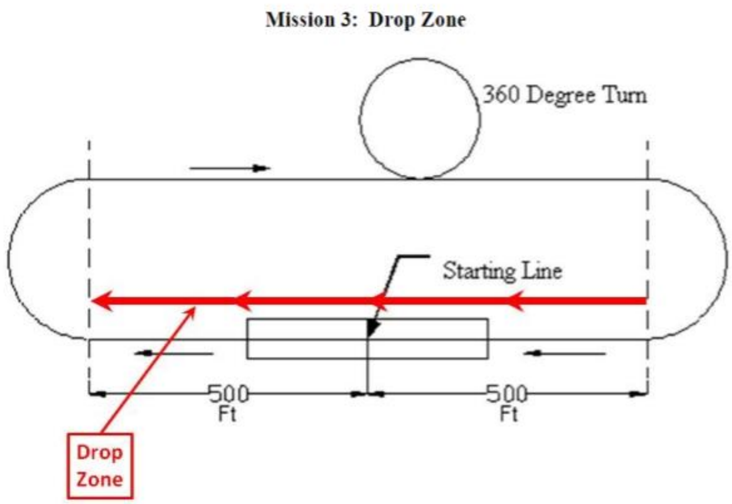


Figure 3.2: Mission 3 Drop Zone

<u>3.1.7 - RAC</u>

The RAC is the empty weight of the aircraft multiplied by the number of servos (N_Servo). After each successful mission, the empty weight of the aircraft will measured. The empty weight (EW) used to calculate the RAC is defined to be the greatest empty weight that was measured.

*RAC Score = EW * N_Servo*

3.2 Design Requirements

The following descriptions of the missions are the design elements the Team found to be necessary to yield the highest score on each mission:

- <u>Ground Mission:</u> The payload structures should be designed to be easy to remove quickly, and easy to load.
- <u>Mission 1</u>**:** The aircraft should be designed to achieve as much speed as possible.
- <u>Mission 2</u>: The aircraft must be able to lift off while carrying a 5 pound payload, and should be designed to fly with as much speed as possible with the payload.
- <u>Mission 3</u>: The aircraft should be maneuverable and the payload deployment system should be able to drop one ball at a time, upon command.
- <u>RAC</u>: The aircraft should be as lightweight as possible and utilize as few servos as possible.

3.2.1 Sensitivity/Optimization Analysis

Given the flight mission requirements, the team decided that it would be best to optimize the motor and battery requirements for the heavy payload mission. As long as the combo was capable of getting the plane off the ground when it was heaviest, the motor and propellor configurations can be optimized for each mission from there. Propellor choices would then simply dictate the rate at which we can complete the speed and ball drop mission. The different options are outlined in the tables below:

Motor/Battery Combinations	Power (Watts)	Weight (lbs)	Mission 1 Laps	Mission 2 Time (Minutes)
Minimal Power	350	1.8	4	9
Medium Power	500	2.2	5	7
Maximum Power	700	2.6	7	6

Table 3.1: Motor/Battery Combinations

3.2.2: Figures of Merit and Design Process

Design Process

In order to make the best design decisions, the Team decided to use a Figure of Merit and Decision Matrix system to analyze possible solutions for each of the major design elements. The aircraft was divided into five major design elements: the fuselage, the wing, the propulsion system, the wing configuration, and the payload containment. The Team then selected Figures of Merit for each of the major design elements, and weighted the Figures of Merit according to their importance in achieving a high score. The completed Decision Matrices were then used to make design choices.

Figures of Merit (FOM)

The Team selected metrics in order to select aircraft design elements after translating the mission requirements into design requirements. These metrics were then weighed on a 100 point scale, with more important metrics given a stronger weight. The metrics were different from decision to decision because each aircraft component had different needs and considerations.

Selection Weighting System

The different possible selections for each design element were rated on a scale of one to five, with five being the best solution and one being the worst. A value of three was assigned when the solution was neither positive nor negative, while two corresponded to slightly worse than average, and four signified slightly better than average.

3.3 Solutions, Configurations and Results

3.3.1 - Fuselage

Shape of the Fuselage

The shape of the fuselage was driven by its aerodynamic capability, weight, and its ability to hold payload. The Team also considered ease of fabrication and ability to interface with the final structure. Three possible shapes were considered:

- Ellipse: A fuselage with elliptical cross-sections.
- Circle: A fuselage with circular cross-sections.
- Rectangle: A fuselage with rectangular cross sections.

FOM	Weight	Ellipse	Rectangle	Circle
Weight	40	3	5	4
Aerodynamics	10	4	3	5
Payload Containment	20	4	4	3
Ease of Integration	10	2	4	2
Ease of Fabrication	20	2	4	2
Total	**100**	**300**	**430**	**330**

Table 3.2: Fuselage Shape Decision Matrix

After considering the options available for fuselage shape, the Team decided to go with a rectangular cross section. This would be the easiest to manufacture and integrate with the wing design the Team had decided upon. It would also hold the rectangular payload easily, and would be very light. The major drawback to this design was its aerodynamic properties, which would be much better on a circular or elliptical design. However, with foam and mylar the rectangular fuselage could be made to be much more aerodynamic, and so its overall benefits outweighed those of the circular and elliptical design options.

3.3.2 - Aircraft/Wing Configuration

Aircraft Configuration

- Flying Wing: Fuselage integrated into wing, high aspect ratio.
- Delta Wing: Single triangular swept back wing with a low aspect ratio
- Conventional: Conventional wing fuselage and tail setup.

FOM	Weight	Flying Wing	Delta Wing	Conventional
Weight	35	4	5	4
Lift Generated	35	4	3	4
Maneuverability	20	2	4	4
Ease of Fabrication	10	4	4	4
Total	**100**	360	400	400
Number of Servos	n	2	2	4
Total/Number of Servos	**100/n**	**180**	**200**	**100**

Table 3.3: Aircraft Configuration Decision Matrix

The main concerns for the aircraft configuration were minimizing the number of servos, since it would factor into our RAC. This made the delta wing and flying wing configurations optimal since they only required two servos with the use of elevons. Other considerations were weight, lift generated, maneuverability, and ease of fabrication. The delta wing configuration was chosen because it is lighter and the low aspect ratio provides greater maneuverability.

Angle of Wing Relative to Fuselage

- Dihedral: Wings angled upward.
- Flat Wing: No angle between the two wings.
- Anhedral: Wings angled downward.

FOM	Weight	Dihedral	Flat Wing	Anhedral
Stability	30	5	4	3
Maneuverability	35	3	4	3
Ease of Fabrication	35	2	5	2
Total	**100**	**325**	**435**	**265**

Table 3.4: Wing Dihedral Decision Matrix

The two most important considerations taken into account when choosing the angle of the wings relative to the fuselage were the maneuverability, which would allow our planes to make tighter, faster turns, and the ease of fabrication, which would streamline the construction process and allow us to do more testing on our plane. Stability was also considered when choosing the angle of the wings. While the dihedral wing is more stable in flight, the flat wing offers greater maneuverability and is easier to fabricate. For these reasons, we chose to do a flat wing.

3.3.3 - Propulsion System

- Single Tractor: Single motor mounted at the front of the fuselage.
- Dual tractor: Two motors mounted in nacelle housings on each wing.
- Single Pusher: Single motor mounted at the rear of the fuselage.
- Tractor/Pusher Combination: One motor mounted at the front of the fuselage and one mounted at the rear of the fuselage.

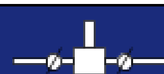
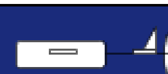
FOM	Weight	 Single Tractor	 Dual Tractor	 Single Pusher	 Combination
Weight	40	4	2	4	2
Speed	35	3	5	2	4
Ease of Fabrication	25	3	2	3	1
Total	**100**	**340**	**305**	**305**	**245**

Table 3.5: Propulsion System Decision Matrix

Each type of propulsion system was scored on weight, speed, and ease of fabrication. The score was weighted, such that weight was worth the most, speed second and ease of fabrication last. The weight score was made the most important because the plane's empty weight directly affects the total score. The speed of the plane was valued over ease of fabrication because the speed indirectly affects the final scores by improving mission times. The single tractor propulsion system was selected because it had the highest score in the decision matrix, due to its high weight score.

3.3.4 - The Wing

Wing Sweep Angle: from perpendicular to chord to leading edge

- Low: Less than 30 degrees, higher Aspect Ratio
- Medium: 30-50 degrees
- High: 50+ degrees of sweep

FOM	Weight	Low	Medium	High
Weight	35	2	4	5
Aerodynamics	30	5	3	2
Stability	20	5	4	2
Ease of Fabrication	15	2	4	2
Total	**100**	**350**	**370**	**305**

Table 3.6: Wing Shape Decision Matrix

When selecting the shape for the wing, the team was most concerned with the weight and aerodynamic performance, because we wanted to maximize our plane's speed and ensure that we are able to take off within the required 60 feet. Other highly weighted concerns included the stability and the ease of fabrication. A moderately swept wing was chosen for its good aerodynamic qualities and the ease of fabrication.

Winglet

- No Winglets: the wing has no winglets.
- Vertical Winglets: the wing has a pair of perpendicular winglets, one on each side.
- Angled Winglets: the wing has a pair of angled winglets, one on each side. This configuration produces extra lift from the horizontal component of the winglets.

FOM	Weight	No Winglets	Vertical Winglets	Angled Winglets
Aerodynamic Efficiency	45	3	4	5
Stability	35	3	5	4
Ease of Fabrication	20	5	4	3
Total	**100**	**340**	**435**	**425**

Table 3.7: Wing Tip Decision Matrix

Another design parameter of the wing is the winglet configuration. When deciding the design of the winglets; the aerodynamic efficiency, stability, ease of fabrication were considered for each configuration. The aerodynamic efficiency was rated the most important because the the team wanted to optimize the aerodynamic performance of the aircraft. The next factor that affected the design decision was stability the winglets would provide. Ease of fabrication was the final deciding factor as winglets are relatively easy to produce. Although the angled winglet has the highest aerodynamic performance, the potential stability issues and fabrications issues made the vertical winglets the more desirable choice.

3.3.5 - Landing Gear

Landing Gear Configuration

- Tail Dragger: Two wheels attached to fuselage (side by side near center of gravity) and one on tail.
- Tricycle: Two wheels (side by side at center of gravity) and one at front of fuselage.
- Bicycle: Two wheels (front and back of fuselage) and two outriggers.

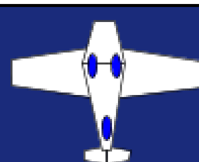
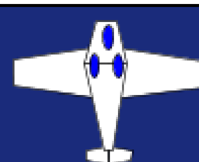
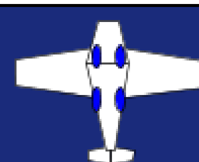
FOM	Weight	 Tail Dragger	 Tricycle	 Car
Weight	20	4	4	3
Increased Lift on Takeoff	30	4	3	3
Stability	40	3	3	5
Ease of Fabrication	10	4	4	4
Total	**100**	**360**	**330**	**390**

Table 3.8: Landing Gear Configuration Decision Matrix

The Team's design of a delta wing aircraft was the deciding factor in going with a car landing gear configuration. The very large wingspan and lack of a tail meant the plane tended to be unstable on the ground, and tipped over easily. The car landing gear was chosen in order to help stabilize the plane during takeoff, and allow for the most stability in the absence of a steering mechanism. The car landing gear would be set up with a lower set on the back than the front to take advantage of the increased lift of a tail dragger.

3.3.6 - Tail and Stability

Tail Configuration

- No Tail: the plane has no tail.
- V- Tail: the plane has 2 tails that join at the base to form a V. It has 2 rudders for control.

- Conventional Tail: the plane has 1 tail with rudder control.

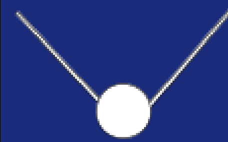
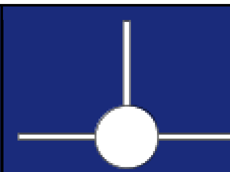
FOM	Weight	 No Tail	 V-Tail	 Conventional
Weight	20	5	2	1
Control	5	0	3	5
Stability	5	0	1	2
Ease of Fabrication	10	5	1	3
Number of Servos	60	5	2	2
Total	**100**	**450**	**190**	**205**

Table 3.9: Tail Configuration Decision Matrix

The main concerns for the team when considering the tail design were stability, control weight, and the number of servos needed. Although a conventional type of tail (mounted on the rear of the aircraft) would provide more stability and control, having one would also require additional servos. The benefit to the overall score by using no servos on a tail would far outweigh the performance lost due to losing the control surfaces. Both pitch and roll could be achieved using other controls on the plane (an elevon configuration), and for this reason there was no reason to include a controllable tail, as yaw control is not essential for success in the missions. The stability could be made up for by adding vertical stabilizing fins on the rear of the plane. Therefore the team decided to go with a design that had no tail as it provided the best benefit to the overall score, and minimal disadvantages.

3.3.7- Amount of Mission 3 Payload

Cargo Payload Sizes

- 1 Ball
- 2 Balls
- 3 Balls
- 4 Balls

FOM	Weight	1 Balls	2 Balls	3 Balls	4 Balls
Mission Score	50	1	2	3	4
Use of Space	5	4	3	2	1
Speed	20	3	3	2	2
Weight	25	5	5	4	4
Total	**100**	**255**	**300**	**300**	**345**

Table 3.10: Number of Internal Payloads Matrix

Gaining the optimal mission score is the most important metric in determining the amount of mission 3 payload, since mission 3 is worth the most in the overall score. Since the payload must be mounted externally, the space it takes up is not too much of an issue. While weight is important, the payload weighs little compared to the rest of the plane, and as the plane is already designed to carry five pounds from mission 2, it is not very detrimental to add more of the relatively light balls. Speed is important, but for mission 3 it only matters in allowing the plane to complete more laps, and drop more balls, while the battery lasts. Therefore, as long as the speed is enough to complete the desired number of laps during the battery life, the drag produced by having more payload is inconsequential.

For these reasons the team chose to go with the maximum payload capability of four balls, which is the number of laps the plane can complete during battery life while carrying the payload. This maximizes the mission 3 score with very little weight cost.

3.4 Final Conceptual Design

After creating the decision matrices seen above, the Team designed an aircraft with the following elements:

- Embedded rectangle-shaped fuselage with payload cargo bay
- A single motor/propeller mounted at the nose of the aircraft
- Flat delta wing with tapered wings
- Clipped wing ends with winglets
- Car configuration landing gear
- 4 ball external cargo bay

This design was selected because it gave the Team the best chance of winning the competition.

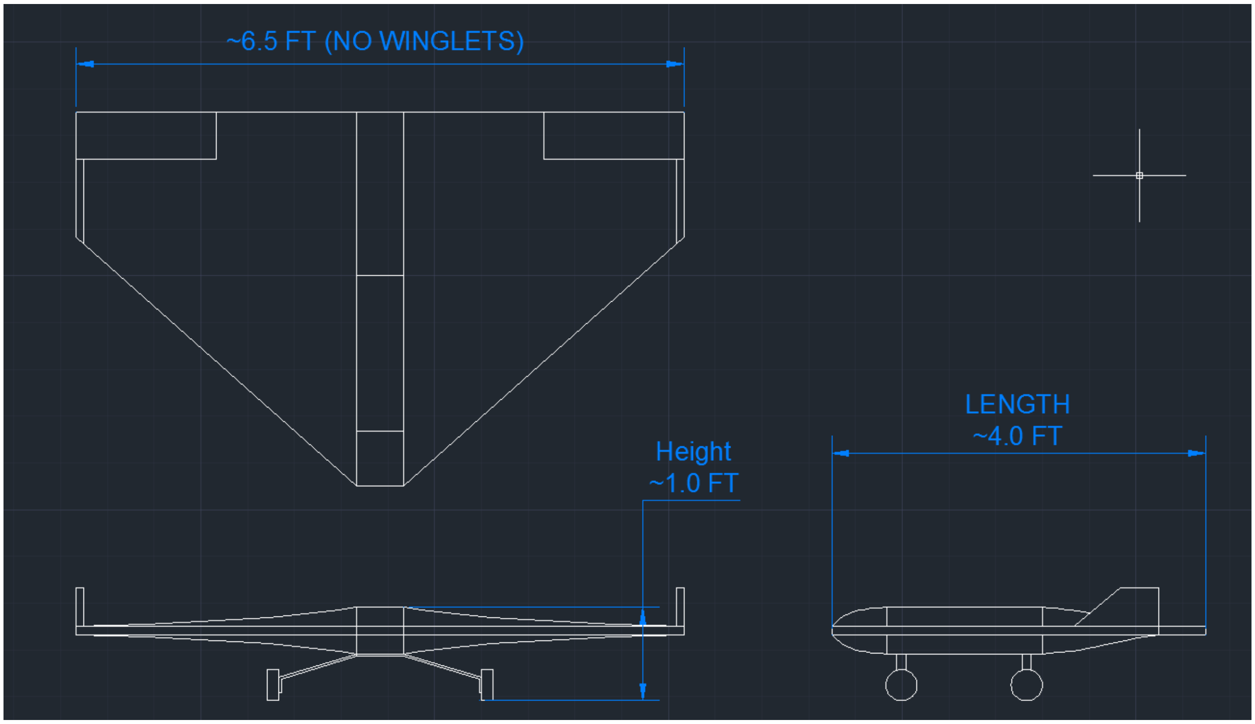


Figure 3.3 Aircraft Conceptual Rendering

4.0 Preliminary Design

The preliminary design phase allowed the Team to perform a basic analysis for each of the 4 main areas: Structures, Aerodynamics, Controls, and Propulsions. From these analyses, the Team selected components and materials, and finalized the configuration and layout of the aircraft. As necessary, the Team performed some basic real-world testing to back up the analysis.

4.1 Design and Analysis Methodology

4.1.1 Aerodynamics

There were two important aerodynamic parameters that the Team considered:

Wing Airfoil Selection

Two types of airfoils were considered: flat symmetrical airfoil and a cambered airfoil. The geometry of cambered airfoils makes it more difficult to fabricate and will increase weight, and the geometry of flat symmetrical airfoils results in lower generated lift and more drag. Flat symmetrical airfoils are beneficial because they are easier to fabricate and do not require any additional weight to be added, but they do not perform as well where a heavy payload and a short takeoff are required. Cambered airfoils are beneficial for missions with a heavy payload and for short takeoff, but are much more difficult to make and require the addition of bulkheads to create the airfoil shape, which will increase the weight.

Wing Size

When sizing the wing, parameters such as necessary area, wingspan, and wing shape were considered. A high aspect ratio was desired for maneuverability and a large planform area was desired for necessary lift, but a large wing added weight to the aircraft. To determine the wing sizing, the Team first calculated the necessary area for the required missions. Then the Team analyzed the benefits of wing configuration (flying wing, delta wing, conventional) and wing shape (rectangular, tapered, swept). From area and shape, the Team determined the necessary chord and span of the wing.

Aerodynamics Mission Optimization

The Aerodynamics Team considered different configurations and airfoils for the aircraft with weight, moment, and aerodynamic characteristics in mind. The members of the Aerodynamics Team also took into account the limitations of the flight course and missions, such as the take-off distance of 60 ft and the loaded and unloaded speed missions. With this data, the Aerodynamics Team decided that a wing configuration that maximized the speed and ease of fabrication.

4.1.2 Propulsion

For preliminary design, the propulsion sub-team was concerned solely with general motor placement and battery restrictions. Details such as pack voltage/capacity, propellor and motor choice will be reserved for detailed design analysis.

Battery Selection

Given the competition's limits on battery chemistry (NiMh or NiCd) and weight (2 lbs max.), the maximum energy density available for the plane is already known, approximately 78 Wh/kg at a nominal voltage of 1.2V for NiMh cells. Specific chemistries aside, for the sake of design, the team will assume max battery weight and scale down our battery weight as more data is collected regarding the aircraft's capability for each mission.

Motor Arrangement

The team explored three different options for motor configurations for the planned characteristics of the plane. Of particular interest was the plane's ability to take off within the required 60 feet runway and ability to consistently manufacturer each iteration.

FOM	Weight	Tractor	Pusher	Dual-Tractor
Mass and overall RAC	30	0	0	-1
Maneuverability	20	0	0	1

Manufacturability	50	1	-1	-1
Total	**100**	**50**	**-50**	**-60**

Table 4.1: FOM for Motor Configuration

Benefit Analysis

A forward mounted propellor setup is by far the easiest to manufacture, as we do not need any special clearance within the fuselage or in relation to the ground. Any clearance needed for the propellor can be designed for much more easily.

Though an aft-mounted pusher would allow cleaner airflow over the craft, we determined the lack of airflow over our control surfaces for low speed maneuvering proved much too disadvantageous. It is clear that a tractor configuration is more inline with our design goals.

A dual tractor setup was considered due to its ability to maneuver as a result of its motor configuration. The plane would be able to take advantage of thrust vectoring to make turns even faster and decrease overall lap times. But the fact that having two motors would count as an additional servo would be too detrimental to the score.

4.1.3 Structures

Payload Containment and Deployment Design

Payload design is driven by the need to fit and secure the 5 lb payload from mission 2, while also leaving space for the ball deployment system to be mounted externally. The design also needs to be as lightweight as possible and as aerodynamic as possible. The best system, then, would integrate well with the design of the plane, be lightweight, and as aerodynamic as possible.

4.2 Mission Modeling and Optimization Analysis

In order to better predict the performance of the aircraft during flight, the Team created a mission model in MATLAB. With this model, the Team could then input the relevant vehicle information (thrust, drag, lift, weight, pilot commands, etc.) and receive an output file detailing the flight path and time, thereby allowing for an accurate prediction of mission performance. Using this program, the Team could iterate through different possible design parameters before deciding on the design that yielded the best flight score. The flight path was divided into the following elements:

- Takeoff (Red): The aircraft starts with velocity equal to zero and accelerates down the runway to a takeoff velocity of 32 ft/s.
- Liftoff (Blue): the aircraft achieves necessary velocity to liftoff from the ground, and begins its climb to flight altitude.
- Straightaway 1 (Gold/Yellow): After achieving altitude, the aircraft flies level until it passes Flag 1 (approx. 500 feet from takeoff start).
- 180-Degree Turn 1 (Green) After passing Flag 1, the aircraft initiates a 180 degree turn to the right.

- Straightaway 2 (Purple): After completing the 180 degree turn, the aircraft flies level for 500 feet.
- 360-Degree Turn (Black): The aircraft completes a 360 degree turn.
- Straightaway 3 (Gray): After completing the 360 degree turn, the aircraft flies level until it passes Flag 2 (approx. 500 feet).
- 180-Degree Turn 2 (Brown): After passing Flag 2, the aircraft completes a 180 degree turn.
- Straightaway 4 (Pink): After completing the 180 degree turn, the aircraft flies level for 500 feet, returning to it's starting point and completing 1 lap.

All subsequent laps start from the "Straightaway 1" section of flight. Figure 4.1 shows the modeled flight path.

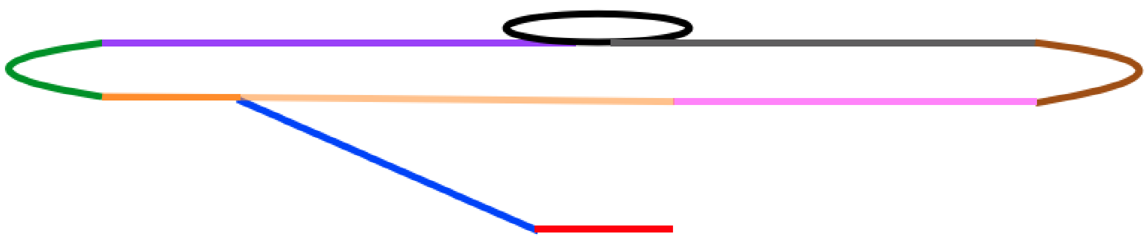


Figure 4.1 Mission Model

4.3 Aerodynamic Design and Sizing Trades

4.3.1 Main Wing Trade-offs

Wing Airfoil

After considering several options for an airfoil shape, the team narrowed it down two main choices:

- Flat Symmetrical airfoil: Flat, symmetrical plate with a rounded leading edge and a tapered trailing edge
- Cambered airfoil: Upper camber with leading edge below the middle of the airfoil

FOM	Weight	Flat Plate	Cambered
Weight	20	5	4
Lift Generated	35	3	4
Drag	25	3	4
Ease of Fabrication	20	5	2
Total	**100**	380	360

Table 4.2: FOM for Airfoil Consideration

The main considerations in choosing an airfoil shape were generated lift and drag, because we wanted to maximize air speed and ensure that our plane took off within the required 60 feet. Additional considerations were weight and ease of fabrication. A flat plate airfoil was chosen because it does not require the addition of any weight and is significantly easier to fabricate, allowing for more real world flight testing. Since much of the lift for highly swept delta wings comes from nonlinear or vortex lift, induced by the formation of leading edge vortices[1], the benefits of a cambered airfoil are rendered insignificant. Especially considering the time and and resources required for manufacturing such an airfoil, opting for simplicity would yield the greatest overall benefit.

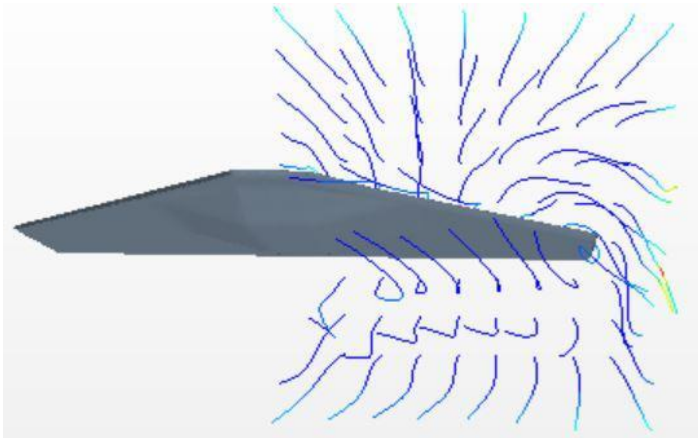


Figure 4.2: StarCCM+ Simulation showing formation of vortices on outside leading edge

Initial Wing Sizing

The team sized the wing based off of the pre-determined structural and payload weight at takeoff. This weight was estimated to be 5 lbs. A factor of safety of F.S. was considered to ensure takeoff ability.

$$W_{calc} = (F.S.)(W_{estimated}) = (1.1)(5\ lb) = 5.5\ lb = 24.465\ N$$

For initial sizing it was assumed that lift (L) and calculated weight (W_{calc}) were directly aligned. A load factor of n=2 was used to account for increased loads during takeoff and turning. The resulting vertical force balance for the aircraft was:

$$L = (n)(W_{calc}) = 11\ lb = 48.93N$$

The team used the general equation for lift with respect to air density (ρ), takeoff velocity (V_{TO}), effective lifting area of the wing (S), and the coefficient of lift (C_L).

$$L = \frac{1}{2}(\rho)(V_{TO})^2(S)(C_L)$$

Setting the two lift equations equal to each other and solving for the needed planform wing area (S):

$$S = \frac{2\ (n)(W_{calc})}{(\rho)(V_{TO})^2(S)(C_L)}$$

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[1] Polhamus, Edward C. *A Concept of the Vortex Lift of Sharp-Edge Delta Wings Based on a Leading-Edge-Suction Analogy*. Rep. no. NASA TN D-3767. Hampton, VA: Langley Research Center, 1966.

The team determined that an effective lifting area of about $2300\ in^2$ is needed to take off at 22 mph at the altitude density of Tucson, AZ using the chosen flat plate airfoil at a 10 degree angle of attack induced by the landing gear. The team chose initial sizing dimensions of an average wing chord of 32 in (including inner control surfaces) and a wingspan of 72 in (not including the width of the fuselage).

Wing Control Surface Sizing

The team used the wing area dimensions to calculate the necessary elevon size of 15% of the wing area. The relationship between the span and the chord were not as critical, so long as the total area met the required value. Initial sizing was done with a ratio of 1:3 to avoid stressing the servo and to act as a base point from which further testing and optimization can be completed.

Final Wing Sizing

Description	Dimensions [inches]
Wing Span (Not including Fuselage)	**72**
Wing Span (Including Fuselage)	**78**
Wing ave chord length	**32**
Elevons/Flap Span (For Each Half of Wing)	**18**
Elevons/Flap Span Chord Length	**6**
Wing Area	**2304 in^2**

Table 4.3:: Final wing sizing

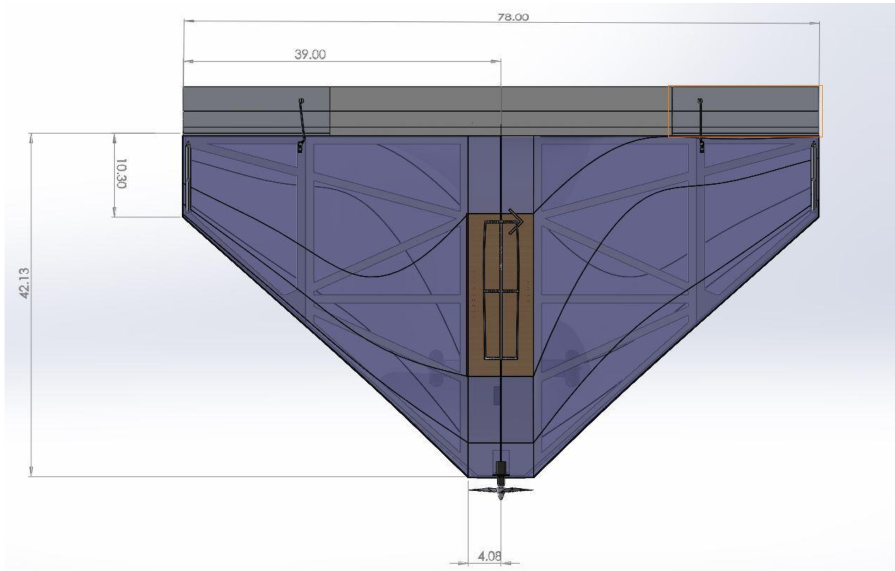


Figure 4.3: Wing Dimensioned Top View

The chosen wing dimensions shown in Figure and Table 4.3 yield an aspect ratio of 2.7.

$$AR = b^2/S = 2.7$$

Where b is the span of the wing and S is the area of the wing. This is within the desired aspect ratio of 2 < AR < 3.

4.3.2 Tail Trade-off

Since the plane doesn't have a tail, analysis needs to be conducted into what is lost in terms of performance. The largest trade-off is having no yaw control, which will make flying in crosswinds difficult as well as remove some pilot control during turns. Both of these effects will slow the plane down, thereby negatively impacting our score in the speed missions. However including a yaw control, and therefore another servo, would have an even more drastic impact on overall score. Based on this, the Team decided that the loss of yaw control is an acceptable trade off. There is no loss of stability, as a delta wing configuration does not require a horizontal stabilizer, and the vertical stabilizer that would ordinarily be part of a tail was instead broken up as vertical fins and winglets.

4.4 Propulsion Design and Sizing Trades

4.4.1 Motor Selection

Motor Description	Kv [*RPM/V*]	No Load Current [*Amps*]	Max Voltage [*Volts*]	Continuous Power [*Watts*]	Weight [*Grams*]
Hacker A30-16M V3	1060	1.6	17	350	104

Eflite Power 52	**590**	**2.3**	**22**	**1100**	**346**
NeuMotors 1110-2.5y	**1814**	**0.7**	**30**	**500**	**114**
NeuMotors 1110/6D	**1400**	**0.3**	**38**	**500**	**114**

Table 4.4: Motor Specifications

The aircraft was estimated to require about 450 watts of power using a simple rule-of-thumb of 50 watts per pound, a rough estimate derived from previous experience. It was preferable to size up and necessary to fully test the chosen motor, but this was a sufficient means to base initial decisions off of. From this power requirement, the team then narrowed choices down based on weight and efficiency. Ultimately, Neu Motor's 1110/6D best matched the criteria. With the lowest no load current and the ability to add a gearbox, the 1110 proved most efficient for its size and current draw. The inrunner design allowed for a higher voltage battery pack, thereby lowering heat generation through amp draw. Preliminary analysis was done using MotoCalc, a common R/C enthusiast program used to gauge propellor performance.

4.4.2 Battery Selection

Battery Description	Capacity [mAH]	Weight [Ounces]	Size [Inches]	Chemistry
Elite 1500 2/3A	**1500**	**0.81**	**1.1 x 0.7 x 0.7**	**NiMh**
Elite 2100 4/5A	**2100**	**1.15**	**1.7 x 0.7 x 0.7**	**NiMh**
Tenergy 2200 SC	**2200**	**2.00**	**1.7 x 0.9 x 0.9**	**NiCd**
Sanyo KR1700AU	**1700**	**1.20**	**1.91 x 0.66 x 0.66**	**NiCd**
Sanyo KR1500AUL	**1500**	**1.00**	**1.7 x 0.7 x 0.7**	**NiCd**

Table 4.5: Battery Specifications

In the process of choosing the power source, characteristics such as weight, size, and capacity were optimized for the required running time. Based on the matrix above, it was clear that the NiCd chemistry could not compete with NiMh; the difference in energy density made the NiCd chemistry much too heavy to be considered.Amongst the available NiMh packs, the team opted for the Elite 1500 series.

This allowed for a higher pack voltage, enabling better use of the motor chosen with the gearbox option. A pack composed of 28 cells for a nominal voltage of 33.6V was chosen. However, the team noted from previous years that these cells in particular sag to about 30V under load. Testing will be done to affirm that this year's cells have similar characteristics. But for the sake of initial propeller selection, it was decided that any propeller software calculations would be done with this 30V value in mind.

4.4.3 Propeller Selection

Initial propeller selection was done via eCalc, a propellor calculator recommended by Neu, the manufacturer of the chosen motor. The team ran various prop sizes and pitches through the calculator to get a general idea of where to start trialing propellers on an actual test stand.

Propeller Size (inches)	Static Thrust (oz)	Pitch Speed (mph)	Current (A)	Power (W)
16x8	101.5	43	15.64	456.4
16x10	123.6	53	18.82	545.8
16x12	144.6	63	21.82	629.5
17x8	118.3	43	19.12	554.3

Table 4.6: Propeller Size Specifications

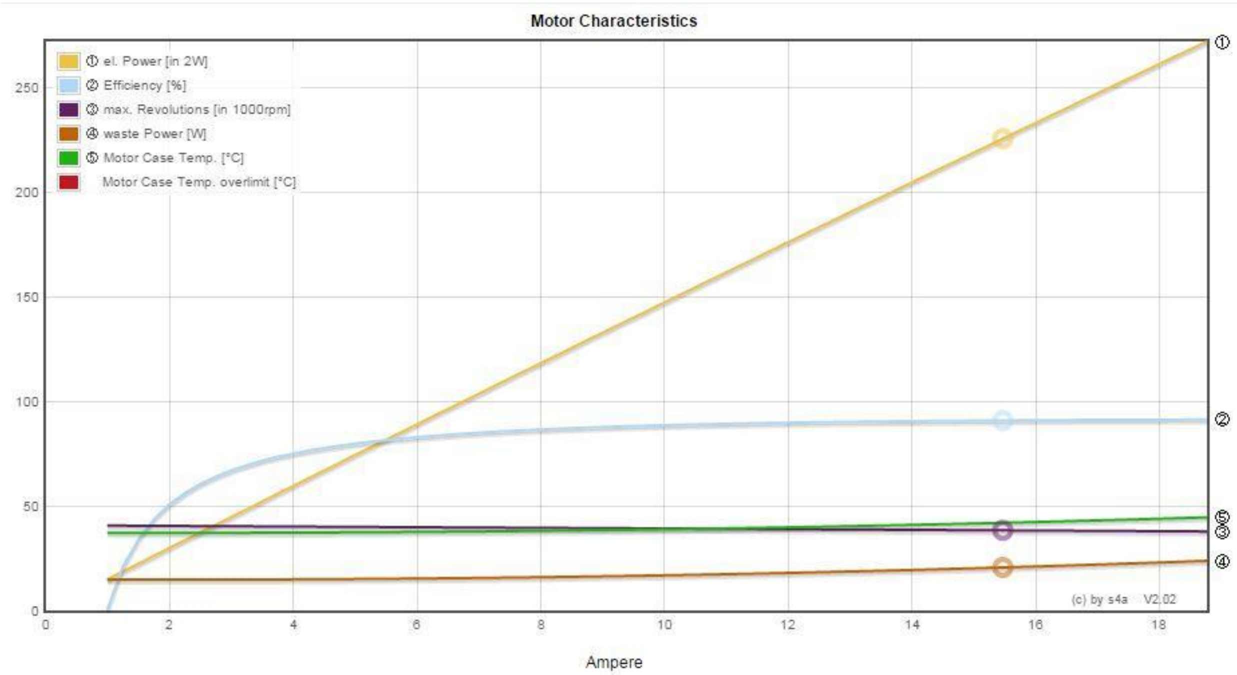


Figure 4.4: 16x8 Propeller Power and Amperage Graph

Based off of the eCalc software predictions, the team will start off by trialing a 16x8 propellor. This prop appeared to be a good starting platform with a theoretical pitch speed of 43 mph, enough leeway for in -flight thrust.

4.5 Structural Design and Sizing Trades

4.5.1 Fuselage Sizing

The Team designed the fuselage based on the dimensions of the payload carried in mission 2. The long edge of the payload is 10 inches, and a ball diameter diameter of 4 inches.With the ball drop casing mounted externally and a the plane being capable of flying for four laps, the payload containment bay must be 6 x 10 inches, and the fuselage frame must have a dimension of 6 x 16 inches.

4.5.2. Internal Elements/Structure

In a break from previous years' designs, which used a truss structure for the entire plane, the Team decided to use a wood truss structure only for the fuselage compartment, which would house the batteries, payload, and internal electronics. Since the plane is a delta wing, the wing makes up the rest of the structural elements of the design. In order to keep this structure light, with a large wing area, and keep it strong enough to bear flight loads, the Team built the internal wing structure out of foam spars coated with carbon fiber. This allowed the wing to bear the loads required to fly with the 5 lb payload from mission 2.

4.6 Lift, Drag and Stability Analysis

4.6.1 Lift

The team examined the coefficient of lift, coefficient of drag, and the angle of attack of the plane.The Team used the aerodynamic analysis programs XFLR5 and StarCCM+ in order to analyze the properties of the airfoils for different Reynolds numbers. A type 1 analysis (assuming a fixed speed) was used with a varied angle of attack from 0 to 15 degrees, and fixed Mach numbers and Reynold's numbers,respectively, of 0.03 and 560,000 (for takeoff), 0.04 and 730,000 (for climb), and 0.05 1,000,000 (for cruising). The Mach number was calculated for airspeeds of approximately 22 mph for takeoff, 30 mph for climb, and 40 mph for cruising. The Reynolds numbers were calculated using the Airfoil Tools Reynolds Number Calculator, which uses the following equation:

$$Re = \frac{VL}{\nu}$$

where the free stream velocity are the airspeeds used above, the characteristic length is the chord length L = 32 in, and the kinematic viscosity of air is given in the Airfoil Tools Calculator. This calculator yielded Reynolds number of approximately 560,000 for takeoff, 730,00 for climb, and 1,000,000 for max speed cruise based on the characteristic length of 32 in.

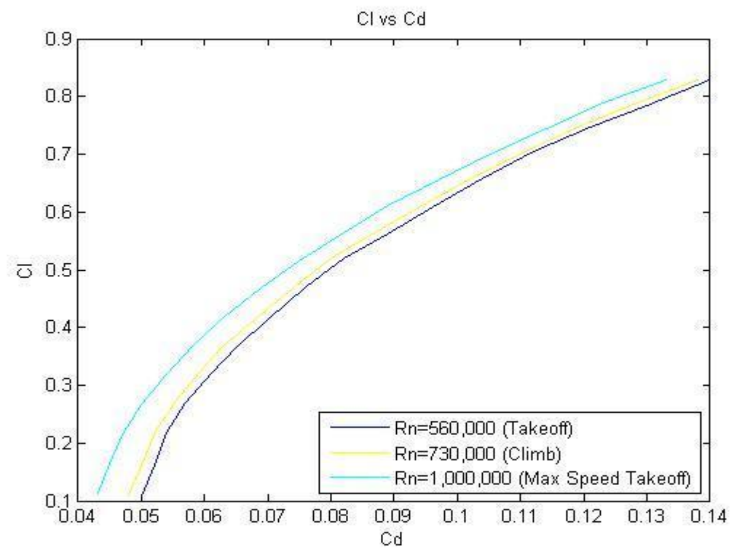


Figure 4.5: Coefficient Lift vs. Coefficient Drag (Flat Plate Airfoil)

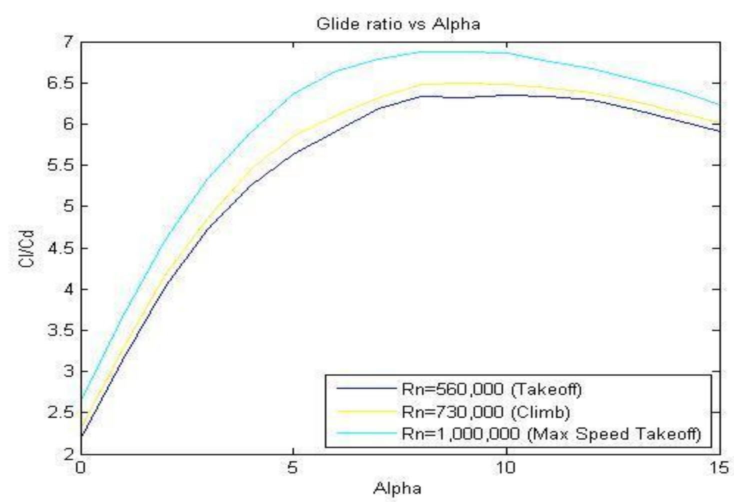


Figure 4.6: Glide Ratio vs. Angle of Attack (Flat Plate Airfoil)

4.6.2 Drag

Drag on an aircraft comes from two main sources: parasitic drag, which is due to the shape of the aircraft structure and the "wet" surface area (i.e., the amount of surface area exposed to airflow) of those parts, and induced drag, which is due to the aircraft moving through the air. When analyzing the drag characteristics of the aircraft, the Team focused on the parasitic drag because it is a function of aircraft structural and aerodynamic design. Induced drag, on the other hand, is a function of wing size ratios and flight conditions. The Team estimated the zero-lift parasitic drag coefficient, C_{D0}, using the equivalent skin friction method and StarCCM+. The results of this are shown below in Figure 4.7. Overall, the Team estimated the C_{D0} to be 0.048. As expected, wing had the greatest contribution to total drag, due to its large large planform area.

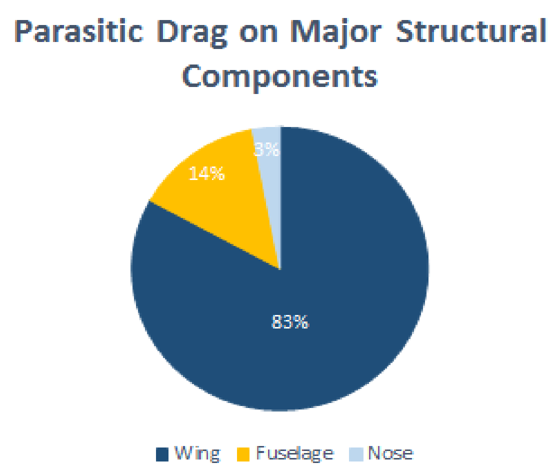


Figure 4.7: Breakdown of Parasitic Drag

4.6.3 Stability

To be longitudinally balanced, the aircraft requires the total pitching moment coefficient at zero lift to be positive and for the center of gravity to be ahead of the neutral point. To be statically stable, the slope of the total pitching moment coefficient vs alpha should also be negative when the total pitching moment coefficient is zero. Longitudinal stability analysis was done using XFLR5 given the structural dimensions of the aircraft.

Table 4.7 below shows the modified analysis with the aircraft passing all requirements for longitudinal stability for all three Missions.

The analysis estimated the neutral point to be 14.72 in from the nose. The static margin was then calculated for the 3 Mission Profiles as shown in Figure 4.8 according to its C.G. location with respect to in the x-axis using the following equation:

$$S.M. = \frac{N.P. - Xcg}{MAC}$$

where S.M. is the static margin, N.P. is the neutral point of the aircraft, X_{cg} is the center of gravity location with respect to the x-axis for the Mission, and MAC is the mean aerodynamic chord of the wing.

	Mission 1	Mission 2	Mission 3
Static Margin	**-21.0%**	**-20.1%**	**-20.8%**

Table 4.7: Static Margin of Aircraft

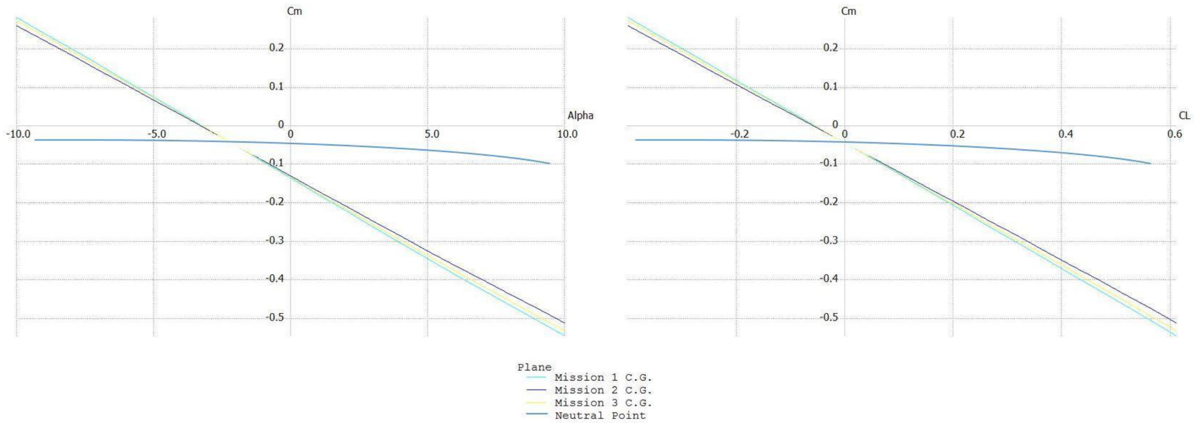


Figure 4.8: Total Pitching Moment Coefficient (Cm) vs Angle of Attack (Alpha) and Total Pitching Moment Coefficient (Cm) vs Lift Coefficient (Cl)

4.7 Estimated Aircraft Mission Performance

With the preliminary design of the aircraft in place, the Team was able to estimate mission performance, and comparing that to expected competition performance, estimate mission scores. The estimated mission scores can be seen in Table 4.8.

Mission 1		Mission 2		Mission 3	
Laps Completed	6	3 Lap Time (min)	4	Balls Dropped	4
Max Laps Completed	6	Best 3 Lap time (min)	3.5	Max Balls Dropped	6
Mission 1 Score	2	Mission 2 Score	3.5	Mission 3 Score	4

Table 4.8: Estimated Mission Performance

5.0 Detail Design

In the final stages of design, the Team finalized component decisions and worked on optimizing the aircraft for each mission. This analysis included flight performance predictions for each mission.

5.1 Final Design Parameters

The finalized design parameters, including electrical, structural, and mechanical components, are outlined in Table 5.1 below.

Overall Dimensions		Fuselage	
Max Length	48 in	**Length**	17 in
Max Width	78 in	**Width**	6 in
Max Height	12.5 in	**Height**	6 in
Wing		**Vertical Stabilizers**	
Span	78 in	**Span**	8.5 in
Ave. Chord	32 in	**Ave. Chord**	7 in
Area	2496 in^2	**Area**	59.5 in^2
Aspect Ratio	2.4	**Aspect Ratio**	1.03
AoA	20 deg		
Motor/Battery		**Elevons**	
Motor	Neu 1110/6D	**Span**	
ECS	Phoenix ICE - 40 HV	**Percent Chord**	15%
Battery Cell	Elite 1500	**Max. Deflection**	$\pm$45 deg
Number of Cells	28	**Control System**	
Volts	33.6 V	**Servos**	Hitec HS-225BB
Max. Amps	15 A	**Torque**	67 oz-in
Max. Power	504 W		

Table 5.1: Finalized Design Parameters

5.2 Structural Characteristics and Capabilities

When designing the aircraft structure, the Team started by considering where the loads would be applied and how the loads would be distributed throughout the structure. With this in mind, the Team first created sketches detailing the places where external loads would be applied. The sketches can be seen below in Figure 5.1.

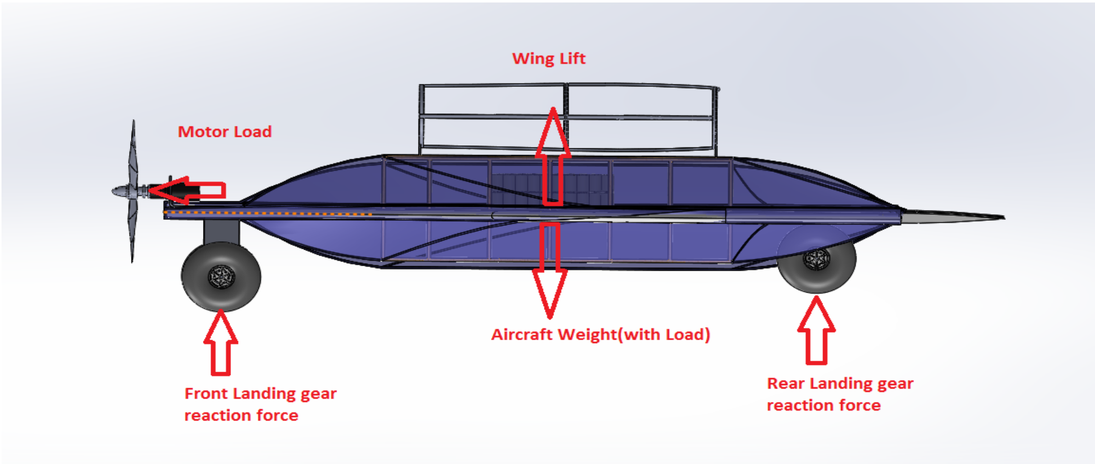


Figure 5.1 External Loads

The goal of an aircraft structure, in addition to giving the aircraft shape, is to distribute applied loads around the structure so that there are no load concentrations. With this in mind, and knowing where the loads were applied, the Team then drew load-paths, showing how external loads would enter and move throughout the structure. A sketch of these load paths can be seen in Figure 5.

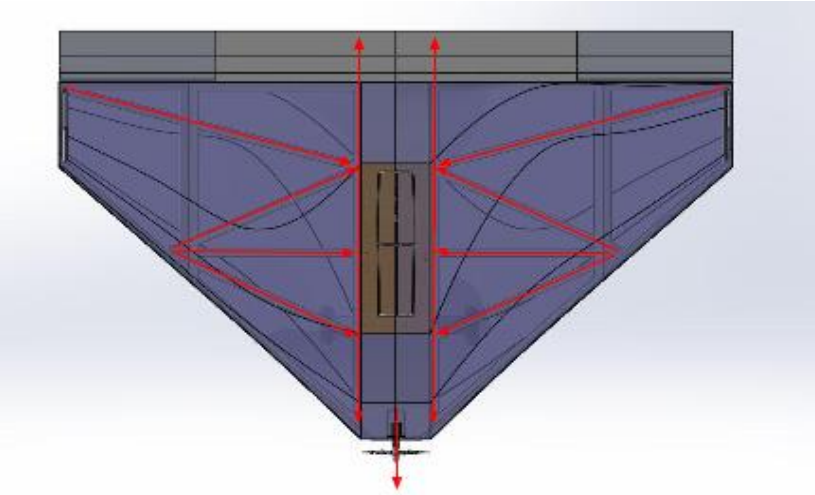


Figure 5.2 Load Paths

Understanding where the load enters the structure and how the load moves through the structure, the Team was able to identify critical load locations, and design the structural elements at those locations accordingly. These structural elements and the required design requirements are listed in Table 5.2. This information and functional requirements decided where the carbon fiber supports would be laid on top of the foam. Additional carbon was then added to other observed weaknesses in the plane, such as along the leading and trailing edge. This allows for a minimalistic structure that satisfies all requirements while achieving the lowest possible weight.

Structural Element	Applied Load	Description of Design
Bottom Firewall	Front Landing Gear Impact	Should be a large plate to distribute and absorb the landing impact.
Rear Firewall	Rear Landing Gear Impact	Large plate to distribute loading along rear portion
Leading Edge	Loading From Lift	Entire length of leading edge coated with carbon fiber
Wing Structural Spars	Tension and Compression From Aerodynamic Loads	Foam center coated in carbon fiber on top and bottom
Motor Mount	Torque and Tension from motor	Sufficient area to distribute torque and handle force of motor pulling forward

Table 5.2: Critical Structural Elements

5.3 System Designs, Component Selection and Integration

5.3.1 Fuselage Structural Design

The fuselage structure is designed for two purposes. The first is to hold the mission 2 payload and batteries. The second is to provide a surface for the mylar to attach to, to produce a contoured, streamlined shape for the plane. The Team found it important for the fuselage to be lightweight but strong enough to hold the loads that would be applied to it, and thus decided to go with a frame made of basswood. The shape and sizing of the fuselage was determined by the need to fit the mission 2 payload and the batteries. A plate was added to the bottom front of the fuselage to attach the front landing gear to.

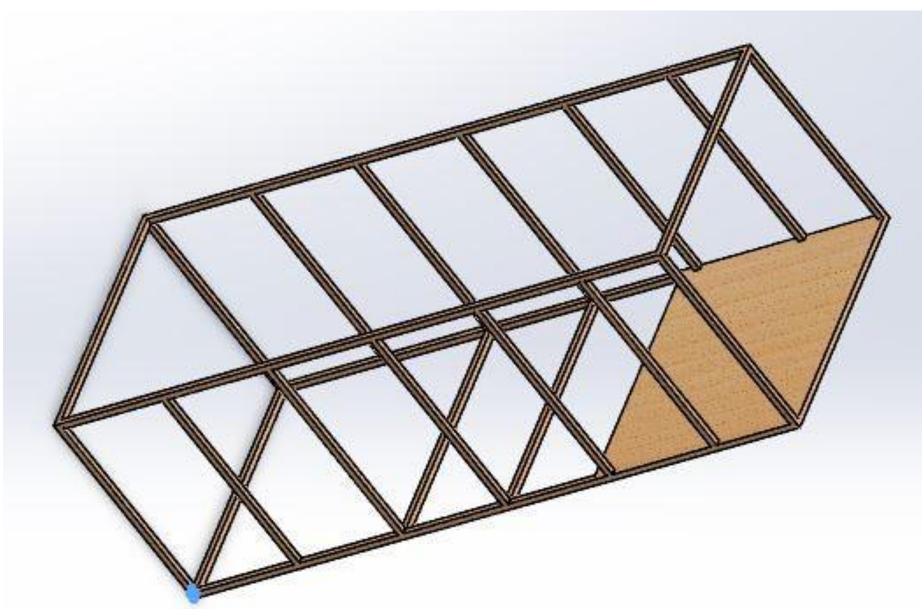


Figure 5.3: Fuselage Structural Design

5.3.2 Landing Gear

Given the payload weight from mission 2, a strong landing gear that could withstand heavy landings was a critical requirement. As mentioned in Section 3, the team elected to go with a car landing gear configuration for reasons of stability. Both the rear and nose landing gear are split gears (port and starboard sections) that mount to the bottom of the plane. The nose landing gear is attached to the bottom of the fuselage by being bolted to a wooden plate on the bottom of the fuselage. The rear landing gear is attached to the bottom of the back end of the plane via being bolted to a carbon fiber plate. This design ensures that the gear is constrained in all directions and is not able to turn, since it has no servo devoted to it for control. Both landing gears can be seen in Figure 5.4.

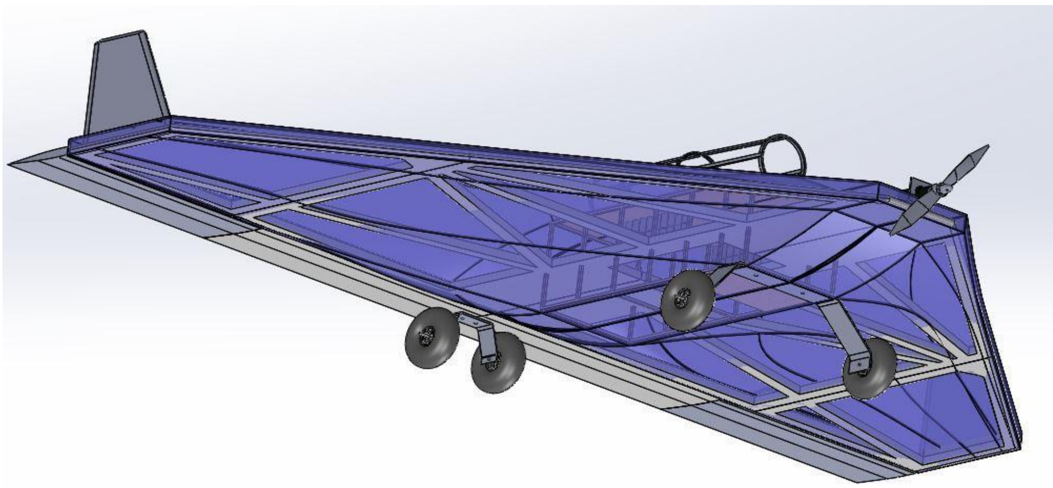


Figure 5.4: Landing Gear Design

5.3.3 Payload Securement and Deployment System

The payload securement system is built around a simple rectangular space in the fuselage for the mission 2 payload to rest. The blocks are held in with hook-and-loop fasteners. The lightweight fuselage is built from basswood sticks glued together to create the final assembly. The deployment system is a 3-D printed nylon structure that forms a 'cage', which holds the balls. They are left open to the air on three sides. A rotating 'door' piece is mounted at the back of the cage, with a rod attaching it to the servo for the left elevon. The mission 3 deployment system is mounted on top of the fuselage that holds the mission 2 payload, and is secured through a wood clip mechanism. At full retraction of this left elevon servo, due to this design, a single ball can be dropped at a time without adding an extra servo to the plane's overall servo count.

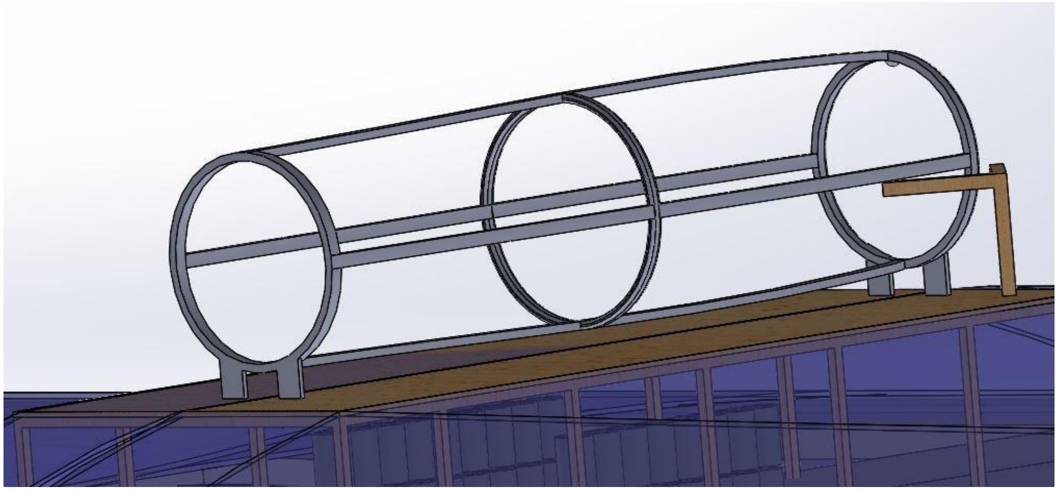


Figure 5.5: Mission 3 Payload Deployment System

5.3.4 Wing/Fuselage Attachment System

The fuselage sits midway through the airframe. The sticks of the fuselage are attached to the foam airframe by being pushed through holes cut in the foam to hold the fuselage. Additionally, glue is used to keep everything secured, and mylar serves to further hold the system together as well as improve the aerodynamics.

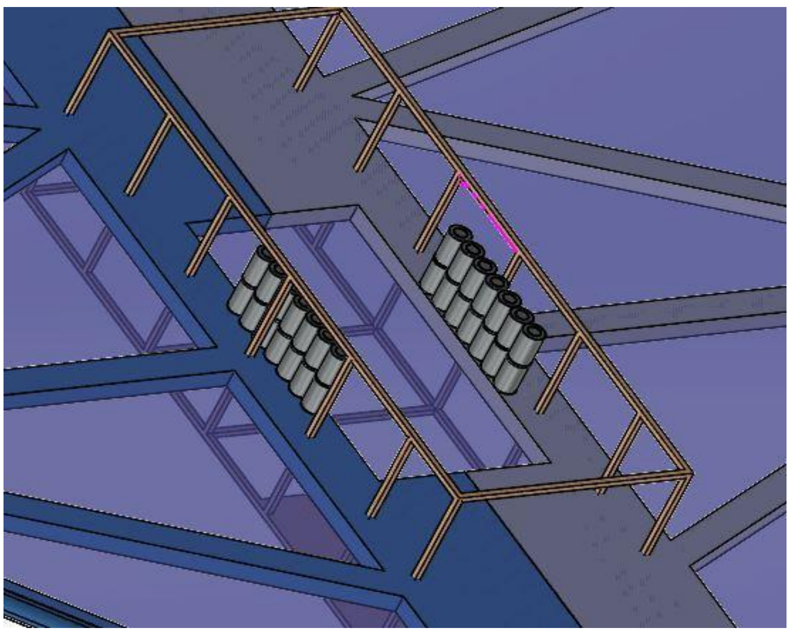


Figure 5.6: Wing/Fuselage Attachment System

5.3.5 Wing Structural Design

Knowing that the wings would make up the bulk of the aircraft, the Team decided upon a lightweight and strong structure as the top priority. The wing was constructed from foam spars coated with carbon fiber. The spars were designed to direct the loads expected upon the plane to keep weaker areas, such as the fuselage, from breaking.

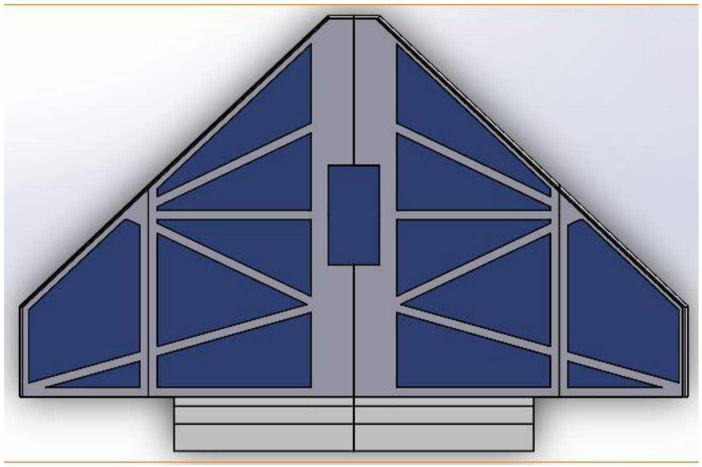


Figure 5.7: Wing Structural Design

5.3.7 Electronic Control System

The Controls Team selected the Spektrum DX6i transmitter/receiver combination for competition use. This radio package provided a wealth of configuration options as well as the necessary failsafe mode. The Team then paired this system with Hitec HS-225BB servos for the flight control surfaces. The Hitec servos were a relatively lightweight option that still provided enough torque to move the control surfaces during flight and prevent aeroelastic forces from moving the control surfaces during high-g maneuvers. Since only two servos are needed, the team elected for slightly heavier and higher torque metal geared servos to ensure operation well within the abilities of the servos to reduce the possibility of failure and ensure smooth control of the large elevons.

5.3.8 Propulsion System

As discussed in Section 4, the selected motor is a Neu 1110/6D, which draws a maximum of 500 watts of power while weighing just .25 lbs. To regulate the motor, a Castle Creations Phoenix ICE-40HV electronic speed controller was used. This speed controller is a capable of 50V operation, which is imperative given the nominal 33.6V battery pack. The battery back consists of 28 Elite 1500 cells, split into 2 packs of 14 cells, all wired together in series. The split pack allows for manipulation of the pack weight to be distributed in the center as much as possible. Though the anticipated current draw is an average of 15A continuous, to ensure operation when the craft exceeds this value for five or ten seconds at a time, the team opted for an 18A fuse. This headroom will allow normal operation of the electronics during flight while still protecting the system in an extreme current draw situation such as a ground prop strike or nose first crash.

5.4 Weight and Balance

Below are the weight and balance tables for the aircraft. The coordinate system origin is at the nose of the aircraft. Positive x-axis runs from the nose down the length of the fuselage, positive y-axis is in the direction of the starboard wing, and positive z-axis is upwards. A figure detailing the coordinate system can be seen below.

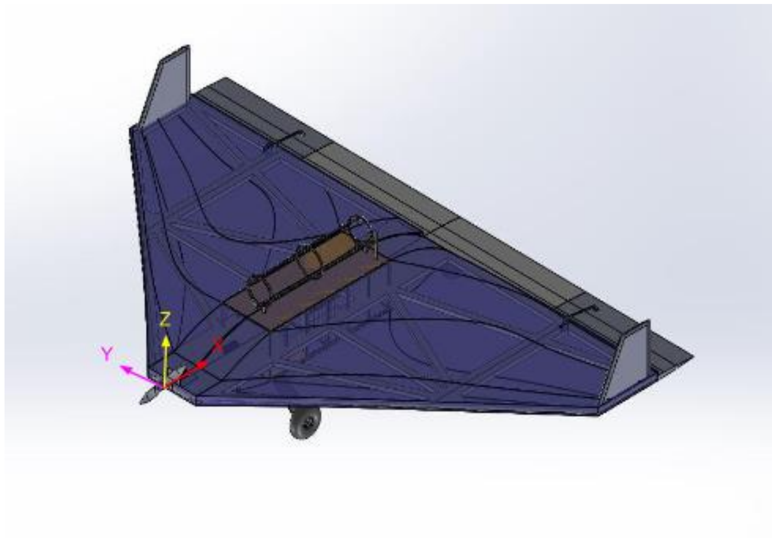


Figure 5.8: Aircraft Axes and Location of Origin

The quarter chord of the wing is at location (x,y,z) inches from the nose. The goal is to have the x-axis center of gravity be at or near the quarter chord of the wing. For the y-axis center of gravity, the goal is to have it at the centerline of the aircraft. The location of the z-axis center of gravity is less important, but in terms of ground stability, a lower CG is more desirable.

	Weight [lb]	X Distance from Origin [in]	Y Distance from Origin [in]	Z Distance from Origin [in]
Fuselage	0.025	22	0	0
Motor	0.25	0	0	0
Batteries	1.4	22	5	0.5
Payload Deployment	0.125	30	0	2.75
Wing	3	0	0	0.5
Wing Tips	0.025	31	39	6.5
Total	4.825	105	44	10.25

Table 5.3: Mission 1 Weight and Balance Table

	Weight [lb]	X Distance from Origin [in]	Y Distance from Origin [in]	Z Distance from Origin [in]
Fuselage	0.025	22	0	0
Motor	0.25	0	0	0
Batteries	1.4	22	5	0.5
Payload Deployment	0.125	30	0	2.75
Mission 2 Payload	5	22	0	0
Wing	3	0	0	0.5
Wing Tips	0.025	31	39	6.5
Total	9.825	127	44	8.9

Table 5.4: Mission 2 Weight and Balance Table

	Weight [lb]	X Distance from Origin [in]	Y Distance from Origin [in]	Z Distance from Origin [in]
Fuselage	0.025	22	0	0
Motor	0.25	0	0	0
Batteries	1.4	22	5	0.5
Payload Deployment	0.125	30	0	2.75
Mission 3 Payload	5	22	0	0
Wing	3	0	0	0.5
Wing Tips	0.025	31	39	6.5
Total	9.825	127	39	8.9

Table 5.5: Mission 3 Weight and Balance Tables

5.5 Flight Performance Parameters

Using the aerodynamic data from XFLR5 and the mission model created in MATLAB, the Team was able to identify and list relevant flight performance parameters for all missions. The flight performance parameters can be seen in Table 5.6.

Parameter	Mission 1	Mission 2	Mission 3
$C_{L\text{-}max}$	0.8	0.8	0.8
$C_{L\text{-}cruise}$	0.13	0.13	0.13

$C_{L\text{-takeoff}}$	0.6	0.6	0.6
C_{D0}	0.48	0.48	0.48
Takeoff Speed [ft/s]	30	30	30
Takeoff Distance [ft]	40	55	50
Climb Angle [deg]	7	7	10
Turn Rate [deg/s]	45	45	45
Wing Loading [oz/in^2]	5	10	10
Flight Time [s]	240	240	240
Gross Takeoff Weight [lb]	4.85	9.85	5.1

Table 5.6: Flight Performance Parameters

5.6 Aircraft Mission Performance

Using aircraft parameters and mission analysis software, the Team was able to calculate performance for each of the missions. This analysis allowed the Team to identify the critical stages of flight, and see if the aircraft design was deficient in any of these areas. The following tables contain the detailed results of this analysis.

Mission 1	**Mission Stage**	**Total Distance [ft]**	**Final Speed [ft/s]**	**Time [s]**
	Takeoff	35	33	2.5
	Climb	80	38	3
	Cruise	385	50	8
	180 Degree Turn	180	55	3.5
	Cruise	500	50	10
	360 Degree Turn	360	60	7
	Cruise	500	48	11
	180 Degree Turn	180	55	3.5
	Cruise	500	50	10
Total:		**2720**		**58.5**

Table 5.7: Mission 1 Mission Performance

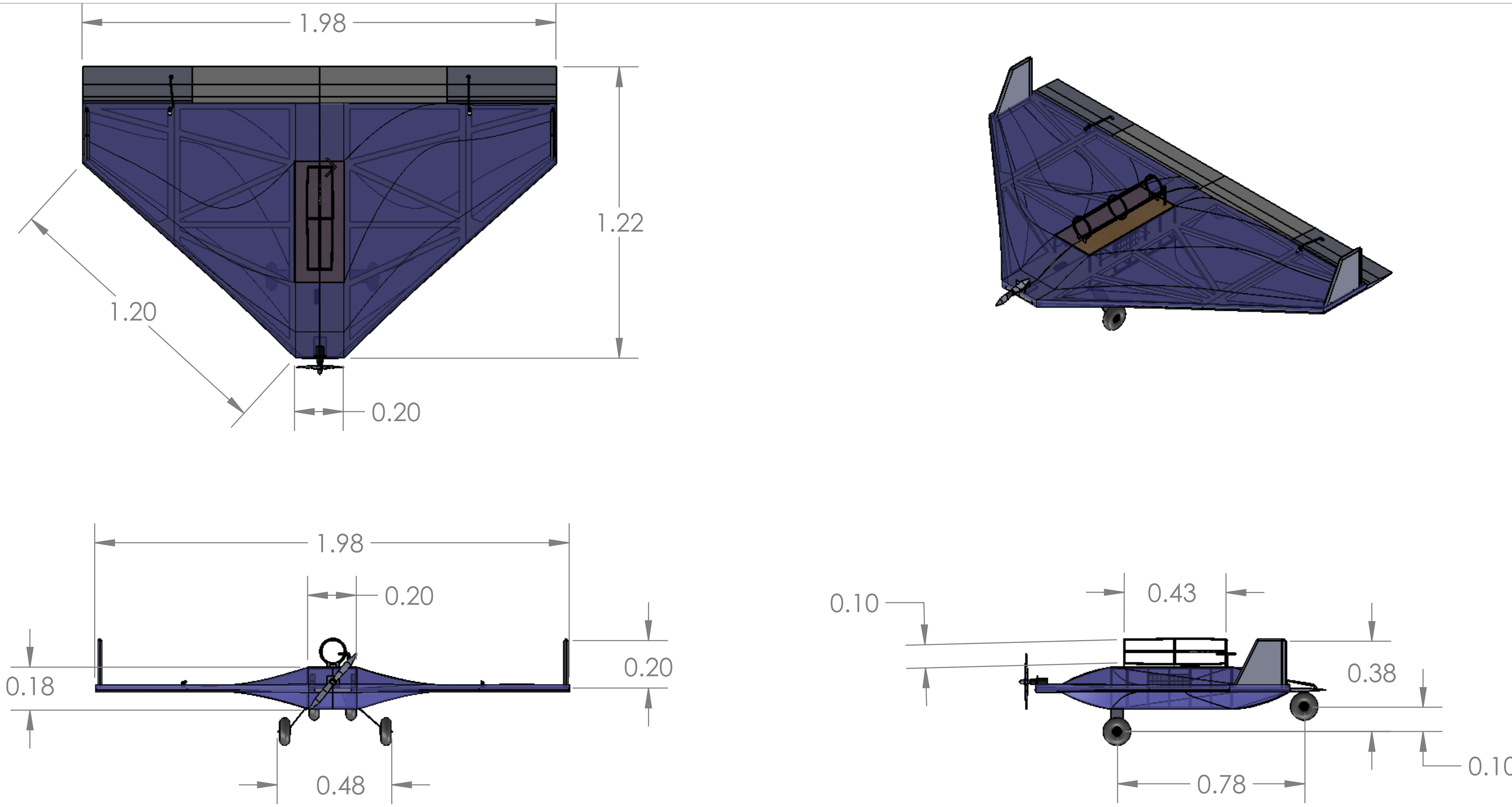
Mission 2	Mission Stage	Total Distance [ft]	Final Speed [ft/s]	Time [s]
	Takeoff	40	33	2.75
	Climb	80	38	5
	Cruise	380	50	9
	180 Degree Turn	180	55	4
	Cruise	500	50	12
	360 Degree Turn	360	60	6
	Cruise	500	46	11
	180 Degree Turn	180	55	4
	Cruise	500	50	10
Total:		**2720**		**62.75**

Table 5.8: Mission 2 Mission Performance

Mission 3	Mission Stage	Total Distance [ft]	Final Speed [ft/s]	Time [s]
	Takeoff	58	35	4
	Climb	120	38	7
	Cruise	322	42	9
	180 Degree Turn	180	46	4
	Cruise	500	42	14
	360 Degree Turn	360	48	8
	Cruise	500	42	14
	180 Degree Turn	180	46	4
	Cruise	500	42	14
Total:		**2720**		**78**

Table 5.9: Mission 3 Mission Performance

5.7 Drawing Package (see following pages)



	NAME	DATE
DRAWN	B. MACNIDER	2/20/15
CHECKED	G. PADILLA	2/20/15
ENG APPR.		
MFG APPR.		

UNLESS OTHERWISE SPECIFIED
ALL UNITS ARE IN INCHES

TITLE:

Aircraft Three View

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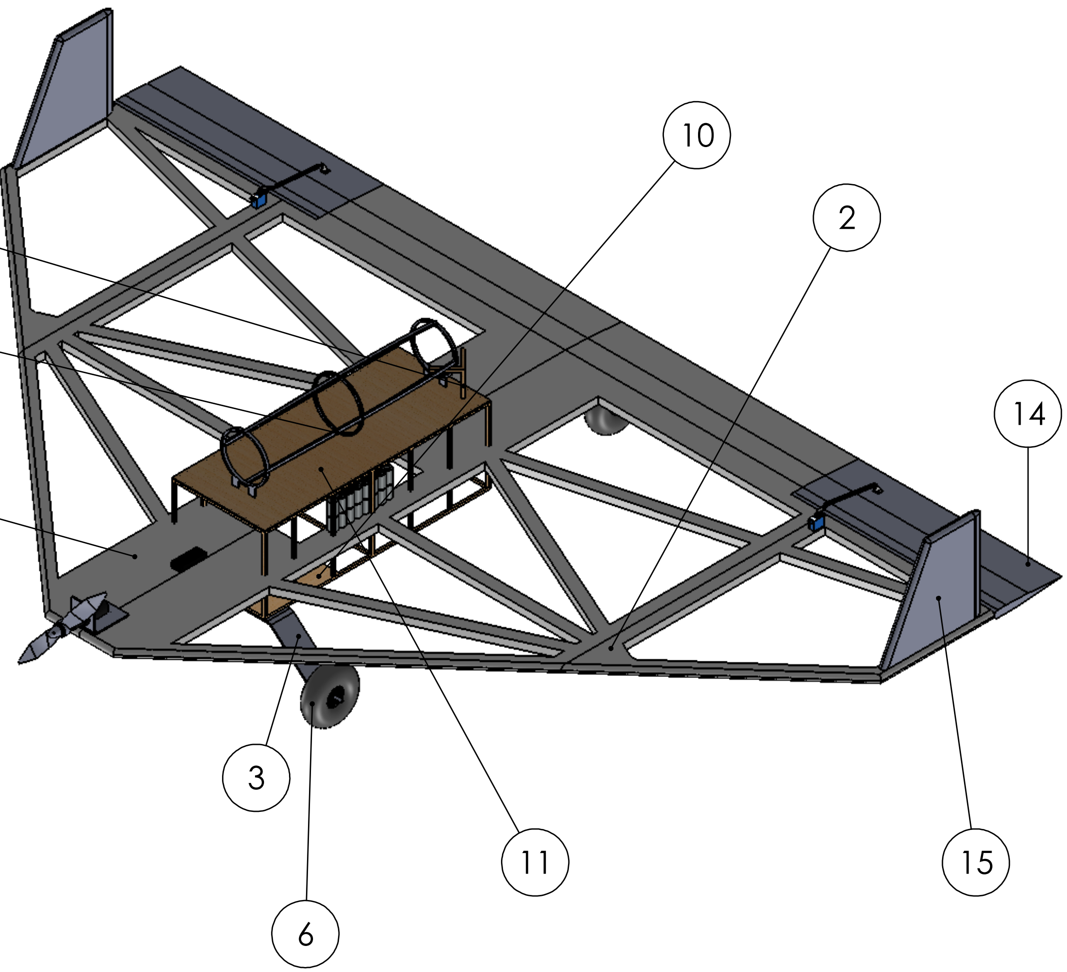
A	Drawing Package	
SCALE: 1:25	WEIGHT:	SHEET 1 OF 4

5 4 3 2 1



ITEM NO.	PART NUMBER	QTY.
1	Wing Half	2
2	Wing Tip	2
3	Front Landing Gear	1
4	Back Landing Gear	1
5	ball drop	1
6	wheel	4
8	Motor Mount	1
9	Motor	1
10	fuselage	1
11	Fuselage Plate	1
12	EliteBatteryPack	4
13	propeller	1
14	Elevon	2
15	Vertical Stabilizer	2
16	thicker finalmylar	2
17	control_horn_assem	2
18	ServoBox	2
19	ServoArm	2
20	Controlrod6inch	2
21	reciever	1
22	rotating door piece	1

	NAME	DATE
DRAWN	B. MACNIDER	2/20/15
CHECKED	G. PADILLA	2/20/15
ENG APPR.		
MFG APPR.		
Q.A.		

UNLESS OTHERWISE SPECIFIED
ALL UNITS ARE IN INCHES

TITLE:

STRUCTURAL ARRANGEMENT

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A	DRAWING PACKAGE	

SCALE:12 SHEET 2 OF 4

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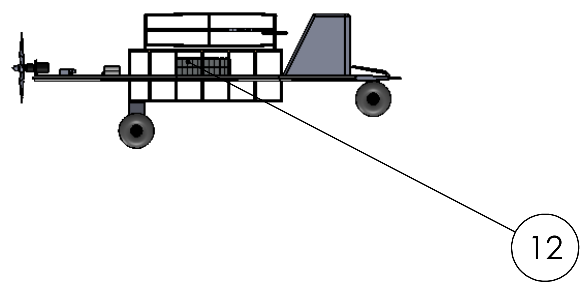
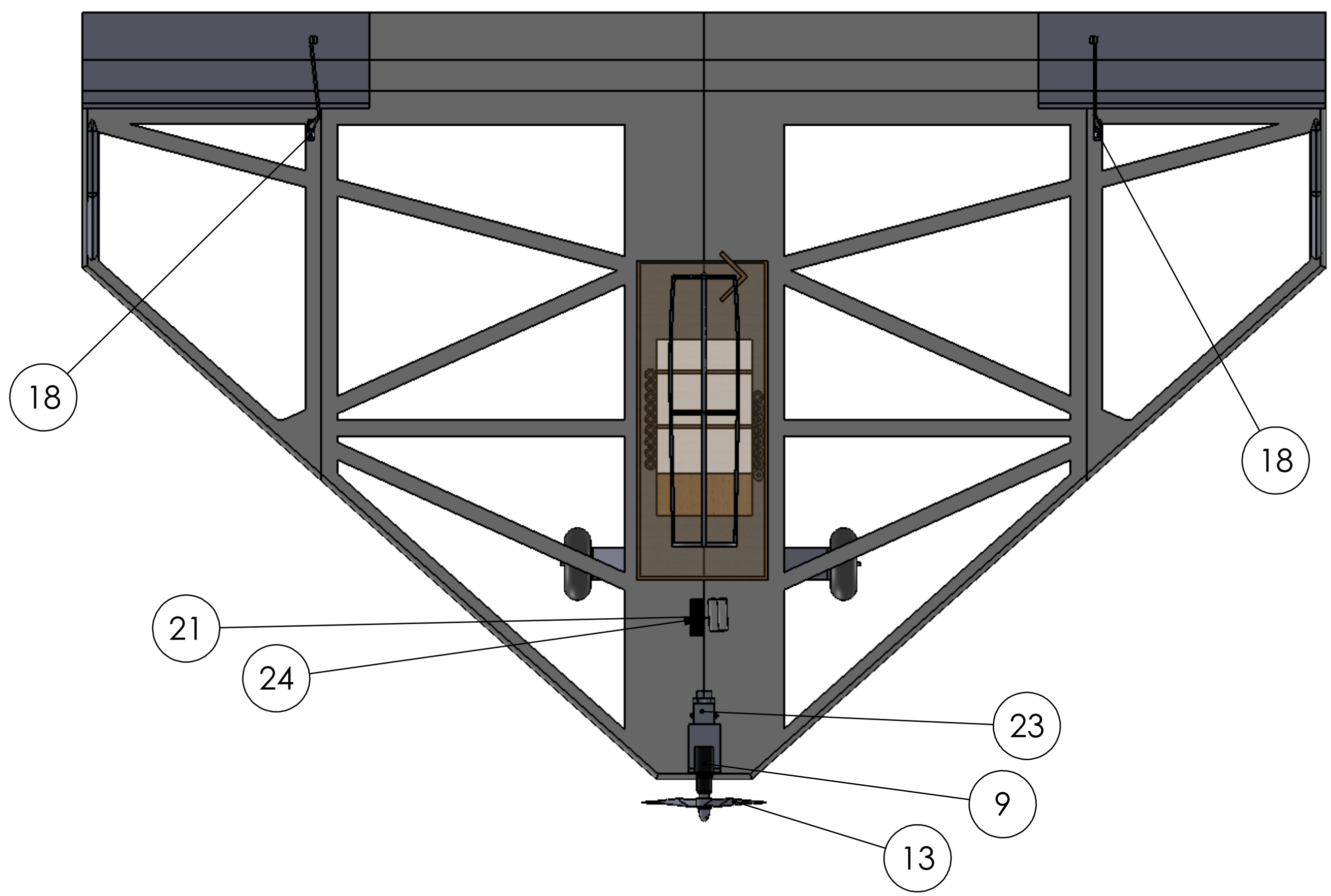


ITEM NO.	PART NUMBER	QTY.
1	Wing Half	2
2	Wing Tip	2
3	Front Landing Gear	1
4	Back Landing Gear	1
5	ball drop	1
6	Wheel	4
8	Motor Mount	1
9	Motor	1
10	Fuselage	1
11	Fuselage Plate	1
12	EliteBatteryPack	4
13	propeller	1
14	Elevon	2
15	Vertical Stabilizer	2
16	thicker finalmylar	2
17	control_horn_assem	2
18	ServoBox	2
19	ServoArm	2
20	Controlrod6inch	2
21	reciever	1
22	rotating door piece	1
23	Phoenix ICE2 HV 40	1
24	Receiver Battery Assembly	1



	NAME	DATE
DRAWN	B. MACNIDER	2/20/15
CHECKED	G. PADILLA	2/20/15
ENG APPR.		
MFG APPR.		
Q.A.		

UNLESS OTHERWISE SPECIFIED ALL UNITSARE IN INCHES

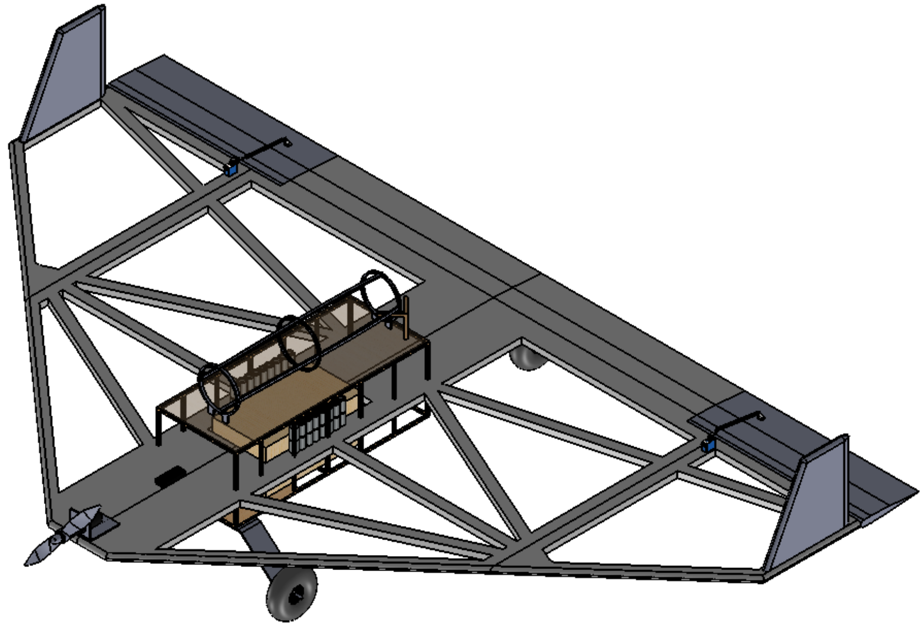
TITLE:

SYSTEMS LAYOUT

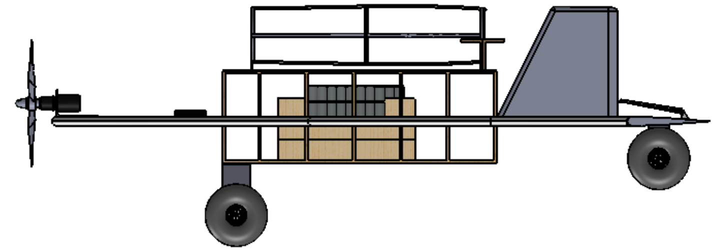
SIZE	DWG. NO.	REV
A	DRAWING PACKAGE	

SCALE1:12 | SHEET 3 OF 4

5 4 3 2 1



MISSION 2 PAYLOAD



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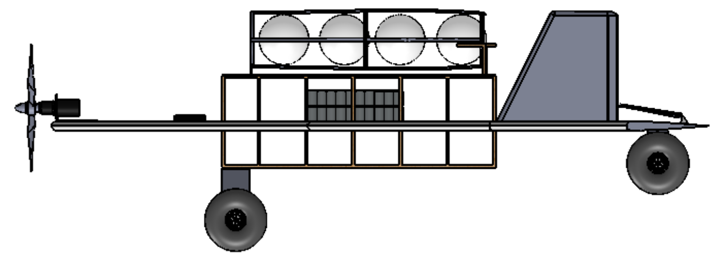
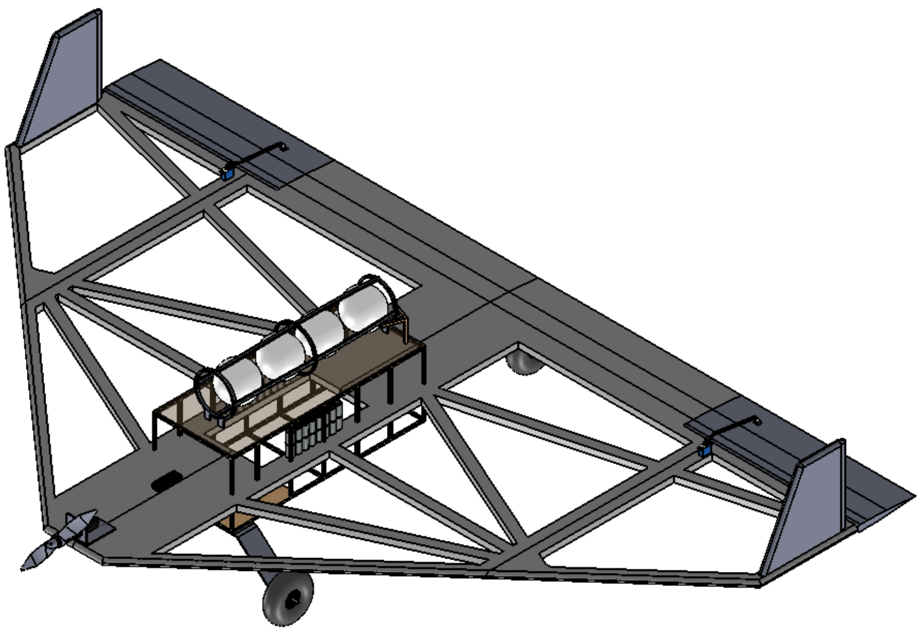


MISSION 3 PAYLOAD



MISSION 3 PAYLOAD

	NAME	DATE
DRAWN	B. MACNIDER	2/20/15
CHECKED	G. PADILLA	2/2015
ENG APPR.		
MFG APPR.		
Q.A.		

UNLESS OTHERWISE SPECIFIED ALL UNITS ARE IN INCHES

TITLE:

PAYLOAD ACCOMODATIONS

SIZE	DWG. NO.	REV
A	DRAWING PACKAGE	

SCALE: 1:25

SHEET 4 OF 4

5 4 3 2 1

6.0 Manufacturing Plan and Processes

6.1 Selection Methodology

The team looked into several different methods of construction and different materials for each one of the major components of the plane. When choosing construction techniques and materials, the team selected the method/material that would best fit the requirements of the missions.

When considering possible options for manufacturing, the Team used different criteria than when designing the plane. 5 different Figures of Merit were considered: Weight, Ease of Manufacture, Ease of Repair, Cost, and Strength. Table 6.1 (below) shows the new Figures of Merit and their weighting.

Metric	0	5	10	15	20	25	30	35	40
Weight									**40**
Ease of Fabrication				**15**					
Ease of Repair			**10**						
Cost			**10**						
Strength						**25**			

Table 6.1: Figures of Merit for Manufacturing

Additionally, the Team realized that individual components have unique requirements and functions. As a result, the entire plane would not be constructed with any single method. Instead, each component could be constructed individually and with a different method if needed. In order to allow for this possibility, a decision matrix was created for each major component.

6.2 Investigation and Selection of Major Components and Assembly Methods

<u>6.2.1 The Fuselage</u>

Four different methods were considered for construction of the fuselage. They are detailed below.

- **Balsa Truss:** A frame is constructed of balsa wood beams and then covered in a skin of Mylar.
- **Balsa Semi-Monocoque:** Fuselage bulkheads (ribs) are cut out on the LaserCamm, and then assembled together using longerons. Structure is then covered in Mylar skin.
- **Lost-Foam Core:** A block of foam is cut out in the shape of the fuselage negative. A shell positive is then formed from this mold. Once cured, the foam is removed to create room for the payload and electronic systems.
- **Mold:** A foam model is created and then covered in gypsum. This creates a positive mold that can be reused to form wings and shells from materials like fiberglass.

The team then put these possible construction techniques into a decision matrix. After careful analysis, the balsa truss method was selected for the fuselage due to its low weight, ease of fabrication and repair, and easy integration with the designs the Team had already decided upon.

FOM	Weight	Balsa Truss	Balsa Semi-Monocoque	Lost Foam Core	Mold
Weight	40	5	2	1	3
Ease of Fabrication	15	5	3	3	1
Ease of Repair	10	5	3	1	1
Cost	10	4	3	3	1
Strength	25	2	2	3	3
Total		**415**	**235**	**200**	**235**

Table 6.2: Fuselage Fabrication Decision Matrix

6.2.2 The Wing

Three different methods were examined for construction of the wing. They are detailed below.

- **Balsa:** Airfoils for the wing and horizontal stabilizer are laser-cut out of balsa sheets and are connected using spars and stringers made from thin balsa wood rods. The vertical stabilizer is constructed from balsa wood beams. The whole wing and tail is then covered using Mylar.
- **Foam Core:** A foam frame is built and carbon fiber strips applied to the top and bottom, creating a stiff structure. Foam wedges are used to create an aerodynamic shape which then has mylar applied to it.
- **Mold:** A foam model is created and then covered in gypsum. This allows the Team to create a mold from which a fiberglass wing and tail can be made.

The team put these possible construction techniques into a decision matrix. After analysis, the foam core method was selected for the wing due to its low weight, high strength, and ease of integration with the fuselage.

FOM	Weight	Balsa	Foam Core	Mold
Weight	40	2	4	3
Ease of Fabrication	15	3	2	1
Ease of Repair	10	3	2	1
Cost	10	3	3	1
Strength	25	1	5	3
Total	**100**	**210**	**365**	**230**

Table 6.3: Wing Fabrication Decision Matrix

6.2.3 The Landing Gear

When fabricating the landing gear, the Team's main decision was between a store-bought solution, which required little assembly but was not customizable, or a custom-fabricated landing gear, which would need to be designed, analyzed and fabricated in-house. The Team started by searching for commercially available landing gear that would meet the design requirements (stability with large wingspan and being able to withstand a landing with the 5 lb payload). The landing gear was broken down into two categories, rear landing gear (RLG) and nose landing gear (NLG).

The main problem in choosing the landing gear was that the width of the plane tended to make it unstable on the ground. For this reason the Team chose to use a two wheel configuration for both the rear and nose landing gears, as pictured below. Additionally, the landing gear needed to be strong enough not to break upon landing with the mission 2 payload while still being as light as possible. For this reason, fabricating a carbon fiber piece for both landing gears yielded a lightweight, yet strong landing gear that could withstand the naturally harsher landings with the mission 2 payload.

Figure 6.1: Custom Manufactured Landing Gear

6.2.4 Ball Deployment System

In designing the ball deployment system, the Team's main concerns were the weight of the system, that it be easy to remove and load for the ground mission, and that it be open to the air on three sides without compromising the reliability of the drop system. A rail based system was designed to act as a cage to contain the balls while still remaining open to the air. In order to make the system light and easy to remove, a 3-D printing manufacturing process was employed from a third-party company. Their laser-sintering process allowed for precise construction of lightweight rails.

6.3 Manufacturing Plan

In order to coordinate building times, the Team constructed a manufacturing plan, which can be seen below.

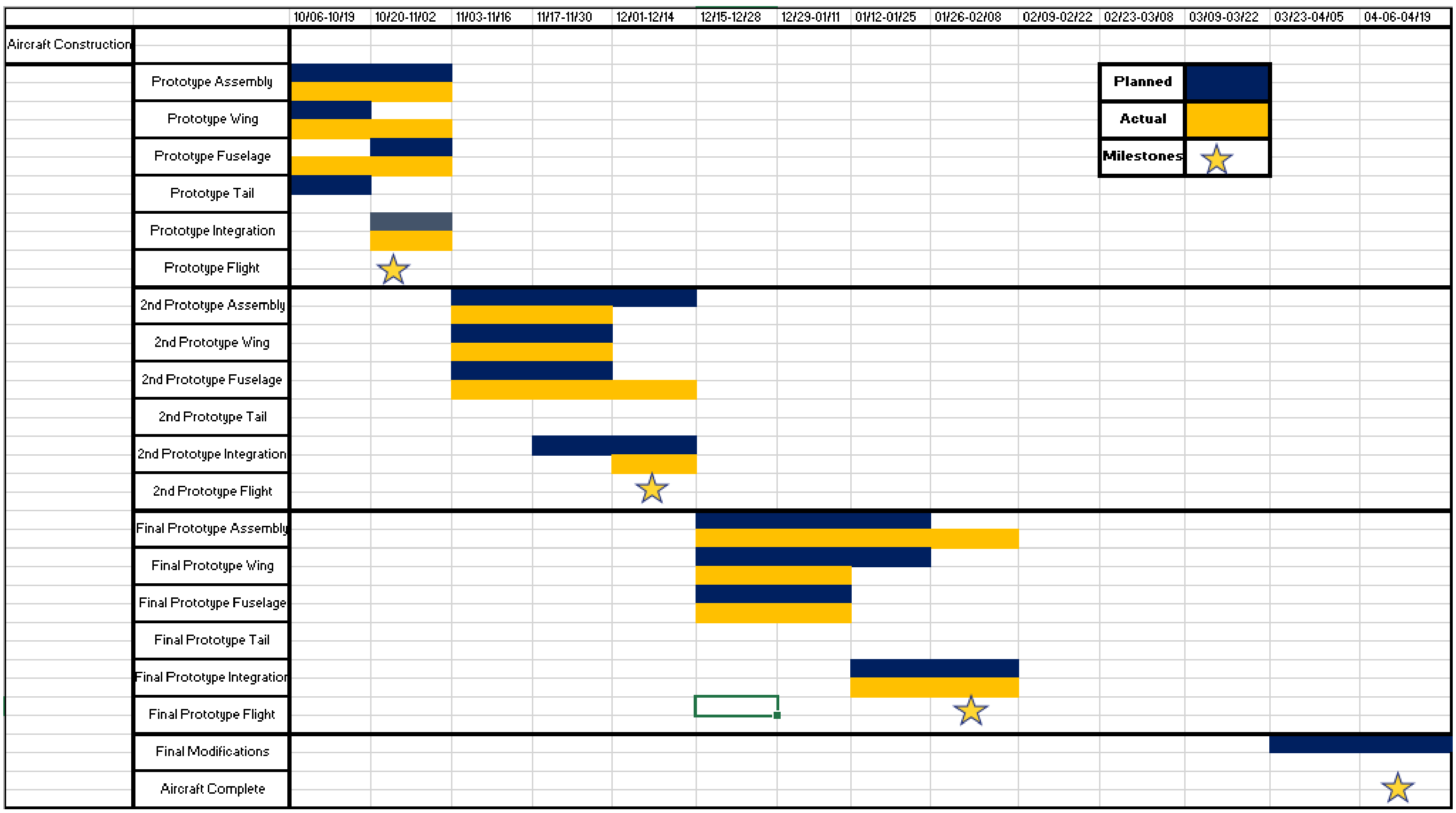


Figure 6.2: Manufacturing Schedule

7.0 Testing Plan

7.1 Objectives

The Team created and executed a comprehensive testing plan to gather data that was later used to improve and optimize the design of the aircraft. The results of the testing are detailed in Section 8.

7.1.1 Components

Structures

In order to verify the structural integrity of the aircraft, the Team performed a number of tests on structural elements, namely the wing and the fuselage. To test the stresses and structural integrity of the wing, weights were placed along the wing in order to simulate maximum wing loading. In order to test the integrity of the fuselage, a tip test was performed. Then, to test the integrity for mission 2, it was loaded with the 5 lb payload and another tip test was performed upon the plane. These tests allowed the Team to verify that the aircraft could withstand the flight loads.

Figure 7.1 Prototype Tip Test Unloaded

Figure 7.2 Prototype Tip Test Loaded

Aerodynamics

To test the aerodynamic merits of the design the Team ran a series of flight tests, beginning with a flat plate and rectangular fuselage. Once each phase of testing was complete, an aerodynamic improvement was made and the flight results were noted. The Team settled on a design that included a mid-plane fuselage with formed covering out to the wings. Additional aerodynamic improvements were made from the result of flight tests. The evolution of aerodynamic changes is shown from Figure 7.3 to Figure 7.5.

Figure 7.3 1st Prototype (Bing)

Figure 7.4 2nd Prototype (Bang)

Figure 7.5 3rd and Final Prototype (Boom)

Landing Gear

Due to the heavy payload for mission 2, the Team was concerned about the landing gear failing during a rough landing. To test for these various conditions, deflection tests were performed on the plane with the landing gear attached to determine the structural integrity of the landing gear. Numerous flight tests were also performed on several landing gear designs to determine if they would be able to withstand a mission 2 landing. The final configuration is shown in Figure 7.5 and 7.6.

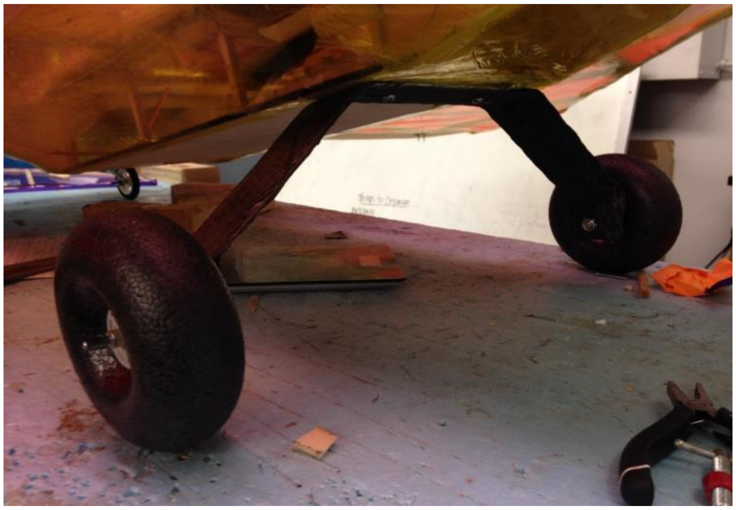


Figure 7.6 Front Landing Gear

Figure 7.7 Rear Landing Gear

7.1.2 Propulsion Testing

Battery Testing

To test the true capacity of the battery, the team purchased an advanced charger capable of measuring the mAh in as it is charging. Cycling between charge and discharge not only conditions the battery,but also lets us average the amount of Ah put in. After numerous cycles, the capacity of the batteries was confirmed to be within 5% of the rated 1500mAh

In order to test the C-rating of the batteries, loads will be placed on the battery to determine their steady-state draw voltage.

Propeller and Motor Testing

Propeller and motor combinations will be iterated on a test stand using an analog load cell and an Arduino Uno. As the propeller produces thrust, it will push against this load cell, allowing measurement of static thrust. This will be used in tandem with the e-logger that measures amp draw, voltage, and airspeed of the propeller while the stand measured static thrust. Testing was done with battery packs with variances in source voltage as the pack wears down, any conclusions drawn had this caveat in mind.

Propellor (inches)	16x8	16x10	16x12	17x8
Airspeed (mph)	44	50	55	43
Pack Voltage (V)	27.5	26.7	25.4	27.5
Amp Draw (A)	13	16.9	18	15.6
Wattage (W)	356	451	457.2	429
Thrust (lbf)	5.6	5.6	4.9	6.8

Table 7.1 Motor Testing

The 17x8 produced the highest power without exceeding the amp draw imposed by the batteries. The airspeed of the plane will unload the propeller to ensure that amp draw is below the rated 10C of the batteries. Especially for the payload mission, the plane will need as much thrust as possible. But actual testing will begin with the 16x8 to get baseline sense of actual draw during flight.

Complete System Testing

Once the motor was decided upon several flight tests were run with varying propellor sizes. A data recorder allowed time plots of current and voltage draw, as well as airspeed measurements. This information was coupled with other flight information such as climb rate, takeoff distance and flight time for analysis.

7.1.3 Payload Testing

The Team was mainly concerned with the ability of the plane to fly safe and stable with the 5 lb payload from mission 2, and also with the ability of the ball deployment system to reliably deploy a single ball upon command. For this reason it was verified that the plane could take off and fly with the 5 lb payload, first through load tests on the ground and then through flight tests. The ball drop system was verified first on the ground, with static test runs, and then through numerous test flights that allowed the Team to fine tune and perfect the system.

7.1.4 Flight Testing

For flight testing, the Team constructed 3 complete aircraft. The first aircraft, dubbed Bing, was a flat plate model, but equipped with the selected motor/battery combination. This aircraft was used to verify the basic configuration of the aircraft. Once the Team was satisfied with the performance of Bing, the second prototype, Bang V1 was built. Bang V1 was a full scale version of the aircraft detailed in Sections 1-5. Bang-V1 was used to verify the ground handling, takeoff abilities, speed and payload carrying capacity needed for the competition. Once the Team was satisfied with the performance of the Bang prototypes, the final competition aircraft, Boom, was built. Boom’s main improvement was increased wing area and lighter construction. Final flight tests with Boom included all of the required missions and allowed time for the pilot to become comfortable with the aircraft.

During flight testing, the Team used a flight recorder to measure a number of values that would help gauge performance, including speed, g-forces, altitude, power draw, RPM and GPS location. After each test flight, the Team analyzed the performance data and identified areas that needed improvement. These areas of improvements were then translated into design changes, which were implemented before the next test flight. Additionally, the Team’s pilot gave an empirical report after each flight detailing the stability and handling of the aircraft while in flight.

7.1.5 Ground Mission Testing

For ground mission testing the team practiced loading the plane, in order to find the fastest method and what needed to be optimized for the fastest loading and unloading of payload.

7.2 Master Test Schedule

The team's schedule for testing of the aircraft and its components is outlined below.

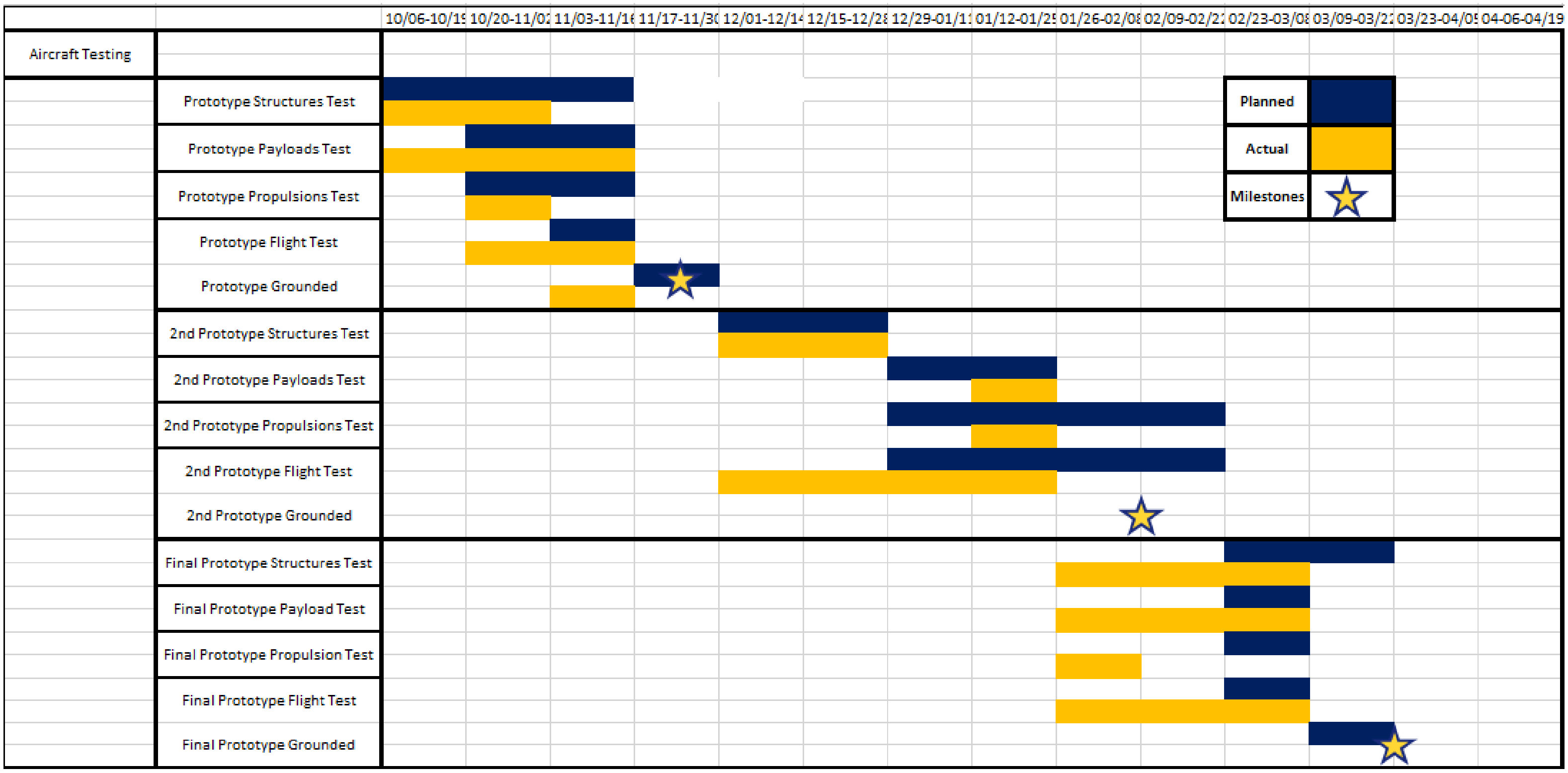


Figure 7.8 Master Test Schedule

7.3 Flight Test Schedule

The team understood the importance of flight tests that did not require full mission performance at the very outset. In order to find and correct instabilities and other unforeseen problems, the test plan below details the gradual increase in demand on the aircraft. This allowed the Team to foresee and correct problems that might otherwise negatively impact other components. The flight tests are named such that the first 2 letters indicated the aircraft (P1 is Prototype 1, F is final aircraft), while the second 2 letters indicate the flight designation (MF for Maiden Flight, M1 for mission one, BD for ball drop, PL for payload, S for simple test)..

Flight Number	Flight Designation	Payload	Description
1	P1-MF	None	First Flight with Bing, testing airworthiness, and delta wing design

2	**P1-S**	**none**	**Testing mission 1 with Bing, determine a baseline for future tests**
3	**P1-S**	**None**	**Test Bing with aerodynamics modifications**
4	**P2.1-MF**	**None**	**Test Bang V1 for airworthiness. First flight**
5	**P2.1-M1**	**None**	**Using Bang V1, fly Mission 1 and test speed and maneuverability.**
6	**P2.1-BD**	**4 balls**	**Using Bang V1, test ability to perform ball drop mission.**
7	**P2.1-PL**	**5lb blocks**	**Using Bang V1, test ability to takeoff with and carry 5lb payload**
8	**P2.2-MF**	**None**	**First flight with Bang V2 (airfoil and structure upgrade), test flight characteristics**
9	**P2.2-PL**	**5lb block**	**Use Bang V2, test ability to takeoff and fly with 5lb block**
10	**F-MF**	**None**	**Using Boom (Competition plane), test airworthiness of design**
11	**F-M1**	**None**	**Using Boom, fly Mission 1**
12	**F-PL**	**5lb block**	**Using Boom, fly Mission 2**
13	**F-BD**	**4 balls**	**Using Boom, fly Mission 3**

Table 7.2: Flight Test Manifest

7.4 Flight Testing Checklists

Insuring the aircraft is ready to fly immediately before takeoff increases the Team's chances of repeated success. The tasks outlined below are performed by the team prior to each flight in order to prevent unintended damage to components or structures while testing.

Pre-Flight Checklist

The following checks are performed five minutes prior to flight.

Pre-Flight Checklist			
Propulsion		**Payload**	
Right Propeller?	☐	Weight Verified?	☐
Propeller Secured?	☐	Payload Secured?	☐
Batteries Charged?	☐	**Aircraft**	
Batteries Hot?	☐	CG Verified?	☐
Receiver Pack Charged?	☐	Wing Securely Attached?	☐
Receiver On?	☐	Landing Gear Solid?	☐
Connection Secured?	☐	Top Lid Secured Shut?	☐

Figure 7.9 Pre-Flight Checklist

Final Checklist

The following checks are performed immediately before the aircraft's takeoff.

Final Checklist			
Propulsion		**Signatures**	
Receiver Connection?	☐	Pilot	______________
Control Surfaces Responsive?	☐	Faculty Advisor	______________
Telemetry Software On?	☐	Project Manger	______________
Visual Inspection	☐	Date	______________

Figure 7.10 Final Checklist

8.0 Performance Results

8.1 Component and Subsystem Performance

8.1.1 Propulsion

Batteries

Once the battery pack was received from the supplier, the team attempted to condition the batteries by discharging and charging at a rate of 0.1C for 10 cycles. This helps balance each cell in the pack to avoid over-discharging any one cell. In the process, the team noted the amount of mAh taken away and put back into the cells through the charger's software. The values were in line with the expected capacity value of 1500mAh.

However, problems arose when testing the C-rating of the pack. Although the cells are supposedly rated for 10C use and should be able to deliver the nominal 33.6V at this draw, the team saw the pack voltage drop as low as 27V under a 15A load. This significant drop in voltage was noted at various amp draws, meaning a higher amp draw was necessary to approach a useful wattage.

All iterations of motor and propeller combos were thought up with this voltage sag in mind. The system would now be limited to a continuous operating input power of about 405 watts.

Motor Performance in Air

For flight, the team tried the 16x8 propeller to see how the propeller would perform with freshly charged batteries. Analysis of the data from the elogger showed that the propeller actually pulled the 15A during flight. The discrepancy between test stand and flight tests is due to the difference in battery discharge state and condition.

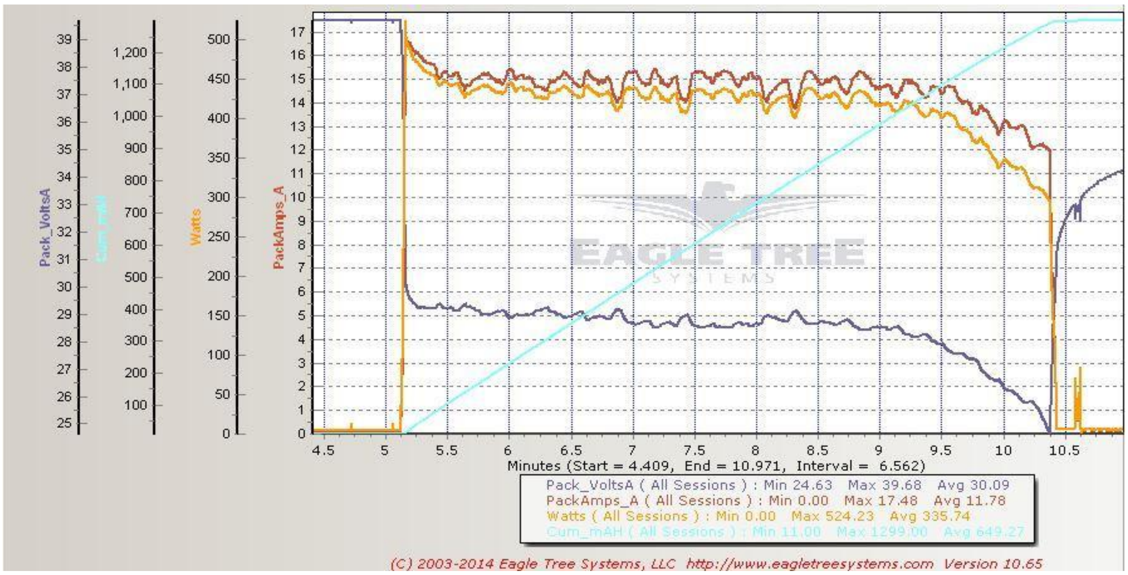


Figure 8.1 In Air Motor Performance for 16x8

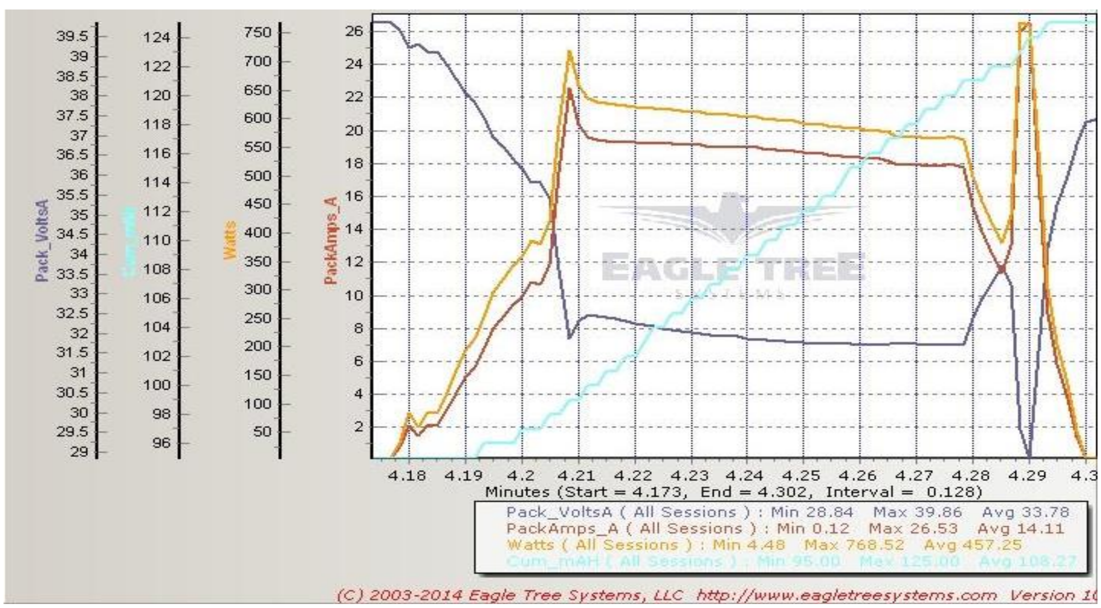


Figure 8.2: In Air Motor Performance for 17x8

From Figure 8.2, it was clear that although the 17x8 seemed to hold promise in theory, in real life, the amp draw was too high. The new batteries held onto their voltage relatively well under load, only dropping to 32V. And that combined with an amp draw of more than 18A drew too much power from the system. Given freshly charged batteries in new condition, the 16x8 propeller is the most appropriate for this electrical power system.

8.1.2 Structures

Fuselage and Wing

The fuselage is able to contain a 5 lb payload in addition to the batteries. The entire structure of the aircraft weighs 1.5 lbs, and during a tip test has 3 inches of wingtip deflection with the 5 lb payload and 1 inch deflection without the payload. Flight tests confirmed that prototypes were capable of carrying the 5 lb payload during flight without breaking.

Landing Gear

Tests show that the landing gear itself can withstand any landing within the scope of our parameters, and that mounts only fail in extreme crash conditions.

8.2 Complete Aircraft Performance

Takeoff Distance

The competition plane takes off in 40ft with no payload, and 55 feet with payload.

Mission 1 Results

Climb Rate	Turn Rate	Top Speed	1 Lap Time	Battery Pack Endurance
30 ft/s	50 deg/s	37 mph	55 s	4.5 min

Table 8.1: Flight Performance Data Mission 1

Mission 2 Results

Climb Rate	Turn Rate	Top Speed	1 Lap Time	Battery Pack Endurance
14 ft/s	45 deg/s	30 mph	65 s	4.5 min

Table 8.2: Flight Performance Data Mission 2

Mission 3 Results

Climb Rate	Turn Rate	Top Speed	1 Lap Time	Battery Pack Endurance
18 ft/s	45 deg/s	30 mph	75 s	5 min

Table 8.3: Flight Performance Data Mission 3

Figure 8.3: Prototype in Flight

Pilot-Rated Performance

Climb Rate	Responsiveness	Turn Rate	High Speed Handling	Low Speed Handling
Good	Good	Acceptable	Acceptable	Good

Table 8.4: Pilot Review

Pilot reports say that the aircraft is acceptable or good in every category that is important. Climb rate and responsiveness are both good, the plane is controllable in all flight envelopes, and easy to fly. The aircraft's low speed handling characteristics are good with a low stall speed and high stall angle, allowing for easy landings. The areas that are acceptable but not optimal are turn rate and high speed handling characteristics. The aircraft requires wide turns to avoid losing altitude and is unstable at high speeds, however, both of these issues can be fixed by manual inputs and controls programming to assist the pilot.

8.3 Future Work

Work on the aircraft continues until the competition in April. The Team is currently testing a new motor mount configuration and is experimenting with different densities of foam. The Team will continue flight testing and will make minor changes to the plane, when necessary. The Team is confident that such a plan will lead to a highly competitive aircraft at the flyoff.