University of California, San Diego

TEAM TLAR XII

Design/Build/FLY 2012

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1.0 Executive Summary

The following report details the design, fabrication, testing and performance of the UC San Diego TLAR XII Design/Build/Fly Team's 2011-2012 competition aircraft. The Team designed the aircraft to successfully complete 3 missions: an unloaded speed flight, a payload endurance flight, and a rapid climb to altitude flight. Aside from completing the 3 missions, the Team's overarching goal was to minimize structural weight without sacrificing performance.

1.1 Design Process

When designing the aircraft, the Team used Figures of Merit and Decision Matrices to identify the best choices for aircraft design elements. By identifying and weighting critical metrics and criteria for the final design, the Team was able to discern the components and design that best accomplished the requirements set forth by the competition organizers, and therefore resulted in the highest score and best chance of winning. Once a general layout of the aircraft was agreed upon, the Team worked to refine the design and agree upon a specific combination of battery, motor and propeller. Additionally, the Team performed a lift, drag and stability analysis to determine the appropriate size, shape and airfoil for the wing and tail. Finally, the Team constructed and tested a prototype aircraft in order to confirm their expected performance values. As necessary, the Team tweaked, refined and tuned their final aircraft in order to achieve the best possible performance.

1.2 Key Mission Requirements

The challenge presented to the Team for the 2011-2012 competition consisted of 3 different missions. Mission 1 is an un-weighted speed flight where the number of laps completed determines the Team's score. Mission 2 is a payload endurance flight where the Team needs to complete 3 laps while carry 4 pounds of aluminum bars. Finally, Mission 3 is a rapid climb to altitude test, where the Team needs to carry 2 liters of water to 100 meters and then dump the water from the aircraft. From these mission descriptions, the Team identified 4 important design elements that should be optimized to improve the performance and final score of the aircraft.

- Empty Weight: The final scoring formula (detailed in section 3.1) puts an emphasis on minimize the empty weight of the aircraft. The Team decided early on that they should focus on making a lightweight aircraft.
- Fuselage Design: Since the rules have specific requirements about how the payloads (the aluminum bars and the water tank) need to be arranged and secured, the Team focused on optimizing the design of the fuselage to accommodate both payloads without adding unnecessary weight and drag.
- Water Tank Design: The Team anticipated that the design and fabrication of the water tank would be one of the most challenging and critical parts of the aircraft. In order to allow for additional design time for unforeseen problems, the Team started work on the tank early.
- Stability in Flight: The Team noticed that the rapid release of water, as well as the potential sloshing of water, during Mission 3 could jeopardize the stability and integrity of the aircraft during

flight. In an effort to prepare for this challenge, the Team set out to design a highly stable and balanced aircraft that could compensate for any disturbance caused during release. Even if that sacrificed some high speed performance during Mission 1, the Team felt it was most important to design an aircraft that could readily and successfully complete each mission.

1.3 Capabilities of the System

The final performance capabilities and specifications of the aircraft are summarized below. The aircraft can be seen in flight in Figure 1.1.

- Empty weight of 4 lbs.
- 1.1: 1 ratio of payload to empty aircraft weight
- Ability to complete 5-7 laps at high speed
- Ability to fly 3-4 minutes fully loaded
- Ability to climb to 100 meters in 10 seconds
- Tested and proven rapid water release system
- Proven performance after several flight tests and subsystem testing

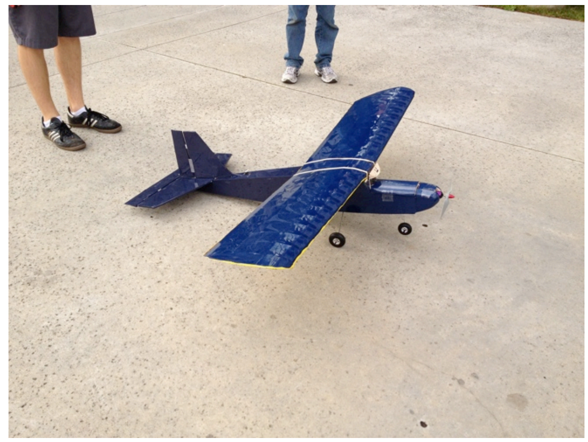


Figure 1.1: Prototype Aircraft

To sum it up, the final design can be described as a single motor, conventional aircraft with a carefully designed fuselage and payload stability system. The aircraft minimizes weight, maximized stability and meets all design requirements for payload stability and release. The TLAR XII Team believes that the design of this aircraft is optimized for the requirements of the mission and will allow the Team to achieve a high score.

2.0 Management Summary

2.1 Project Management

The TLAR XII team was organized into 5 groups that each handle different aspects of the aircraft: Structures, Propulsion, Aerodynamics, Controls, and Fabrication. Group Leads managed specific activities within their own group, and the Project Manager oversaw the workings of the entire project. The management flow chart is shown below. Several team members worked in more than one group in order to allow for better time management as well as better usage of human resources.

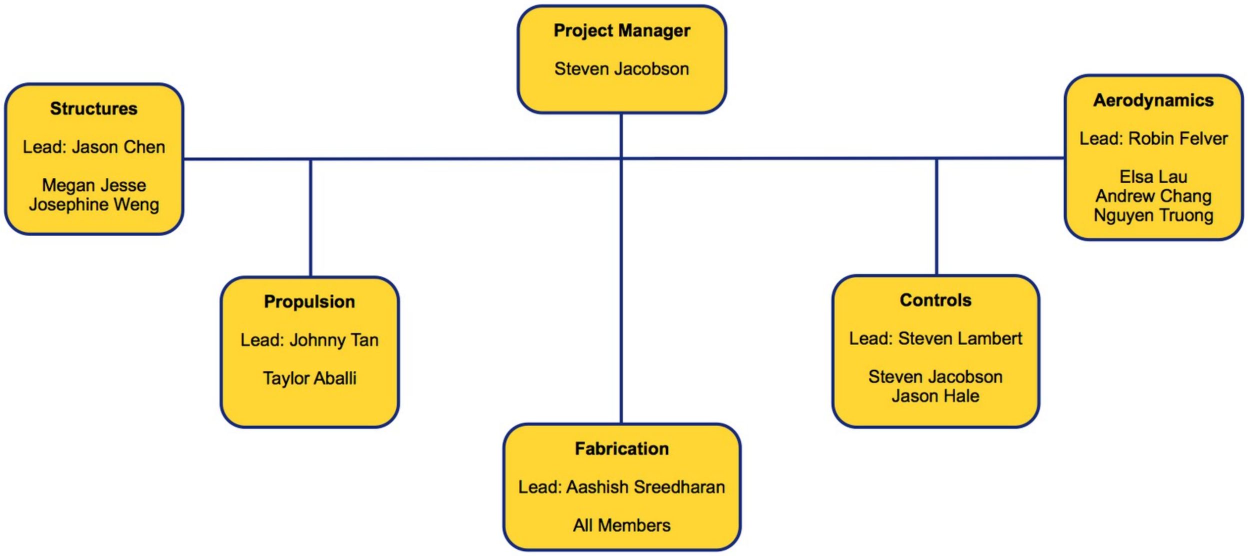


Figure 2.1: Management Flow Chart

The Structures Team was responsible for designing the fuselage, selecting the materials for the airplane, determining the center of gravity of the plane for stable flight, and producing the 3D CAD model. The Propulsion Team was in charge of selecting the motor, the propeller, and the battery pack. The Team used testing and data analysis to determine which motor/propeller/battery combination would yield the best results. The Aerodynamics Team was responsible for determining the airfoil shape, the wing dimensions, and the tail design. The Team used a computer modeling software to create lift and drag comparisons of different airfoils and to analyze lift distribution in order to aid in design decisions. The Controls Team was in charge of deciding on the control systems for the airplane, including the servos and the dimensions of the control surfaces (elevators, ailerons, rudder). The Fabrication Team was responsible for using the designs and specifications of the airplane to create a complete, working competition airplane. They were also tasked with the repair and maintenance of the airplane.

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 Team broke the schedule down into 3 main areas: Design, Construction and Testing. Within these main areas, the team set specific deadlines, time periods, and milestones. The Figure below shows the Team's planned schedule with a comparison to the actual completion dates.

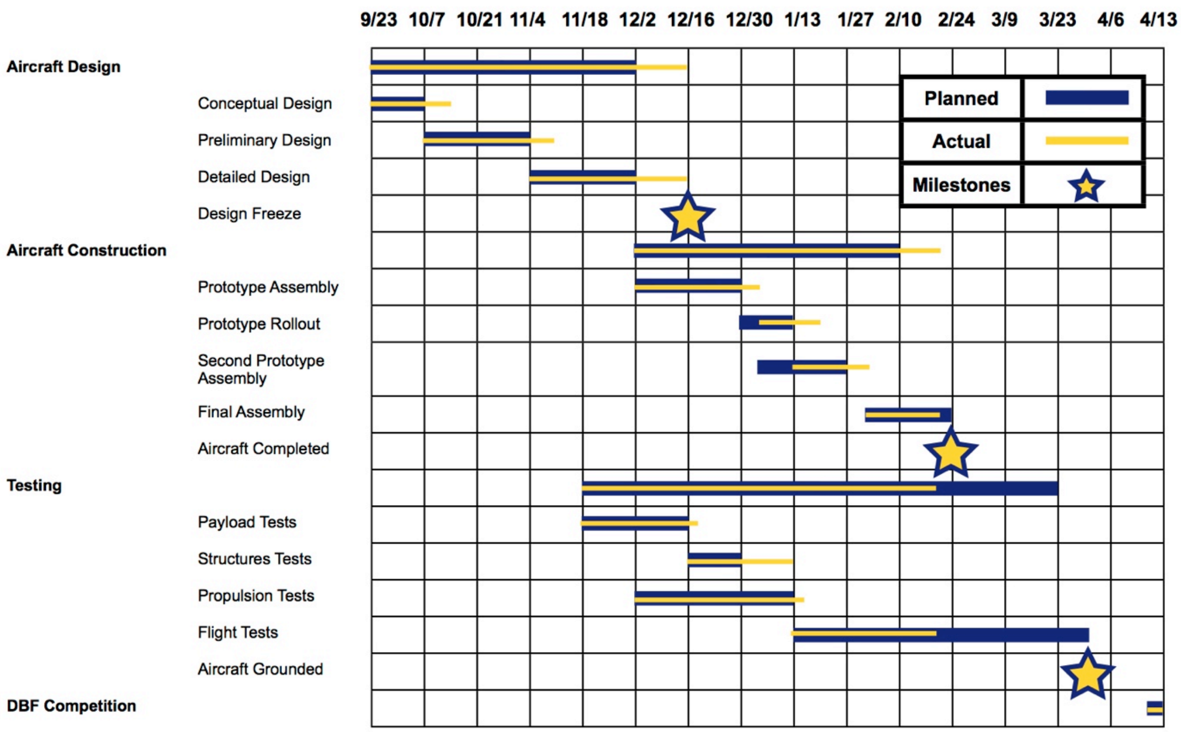


Figure 2.2: Milestone Chart

3.0 Conceptual Design

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

3.1 Mission Requirements

The AIAA Design/Build/Fly 2012 competition total score takes into account the written score report and performance on three flying missions. The report is scored out of 100 points. An interesting part of the overall score is the contribution of Mission 3, which is based off the performance of other teams in the competition. This makes it difficult to predict the maximum possible score for that mission. However, the Team estimates that the maximum score for Mission 1 is 2; for Mission 2, 2; and for Mission 3, 3. There will be more discussion on how the Team arrived at these estimates in the following sections.

The equation for the final score is:

$$\text{Final Score} = [\text{Design Report} * (M1 + M2 + M3)] / \sqrt{(RAC)}$$

RAC is the maximum empty flight weight of the competition aircraft, as measured at the end of each successful flight. This quantity is a critically important factor in the final score as it is directly divided into it. The scoring equation of each mission was analyzed and a sensitivity analysis was performed so as to emphasize the particular missions that the Team found most important towards scoring as high as possible.

3.1.1 - General Requirements, Limitations, and Concerns

- The battery pack for the propulsion system cannot weight more than 1.5 pounds
- The payload must be loaded in under 5 minutes
- The payload must be secured in flight
- All payloads must be carried internally
- Aircraft must land successfully for scoring to take place
- Minimum altitude is determined at the discretion of the Flight Line Judge
- The aircraft must perform a ground rolling take off within 100 feet

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 will be hand launched from the starting line (as shown is the figure) and will begin to climb for the first 500 foot straight-away. At the end of the 500 feet the airplane will encounter its first 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 m before completing the 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.

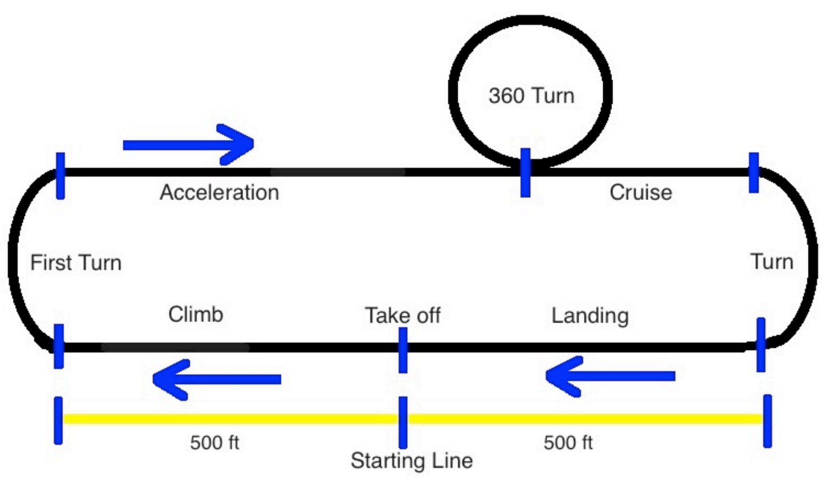


Figure 3.1: Competition Flight Course

3.1.2 - Ground Crew and Assembly Crew

The aircraft can enter the assembly area fully assembled, but the payload must be uninstalled. A single ground crew member must then load the payload and verify that the aircraft is ready for flight. No work can be done on the aircraft after the 5 minute period.

- Mission 1 requires no work in the assembly area.

- Mission 2 requires the ground crew member to weigh and load the aluminum bars.
- Mission 3 requires the ground crew member to fill and load the water tank into the aircraft. The servo-controlled valve must be plugged into the receiver and the altimeter armed.

3.1.3 - Mission 1: Ferry Mission

Mission 1 is a timed, 4 minute speed test. The score for the mission is determined by the equation: M1 = 1 + N_Laps/6, where N_Laps is the number of laps the aircraft completes in 4 minutes. The mission starts when the throttle is advanced for takeoff and ends when the 4 minutes is up. Only fully completed laps will be counted.

3.1.4 - Mission 2: Passenger Flight

Mission 2 is a 3 lap payload mission. The Team will load 8 aluminum bars (with dimensions 1 in. X 1 in. X 5 in) vertically. The bars must weigh a minimum of 3.75 lbs. The loading of these bars must be completed in 5 minutes. After the bars are loaded, the aircraft will takeoff from the runway, complete 3 laps, and land on the runway. The score for the mission is determined by the equation: M2 = 1.5 + 3.75/Flight_Weight, where Flight_Weight is the total weight of the aircraft, including the Aluminum bars. The total weight of the aircraft is measured after the successful completion of Mission 2.

3.1.5 - Mission 3: Time to Climb

Mission 3 involves a rapid ascent to 100 meters. Competition officials will load the tank with 2 liters of water from a standard, 2 liter soda bottle. The team will then load the tank into the fuselage and prepare the aircraft for takeoff. The airplane will takeoff and ascend to 100 meters as fast as possible. Once the aircraft reaches 100 meters, an on-board altimeter will trigger a servo-controlled valve to release the water in the tank. The mission will be completed when the Flight Line Judge sees the water plume. The score for this mission will be computed from the equation: M3 = 2 + $\sqrt{}$(T_avg/T_Team), where T_avg is the average time for all the aircraft in the competition to reach 100 meters and T_Team is the time for the Team's aircraft to reach 100 meters. The clock is started when the throttle is advanced for takeoff and is stopped when the Flight Line Judge sees the plume of water.

3.1.6 - RAC

RAC is the maximum empty weight, which is measured after each successful flight.

3.2 Design Requirements

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

- Mission 1**:** A light weight, fast and highly controllable aircraft capable of completing the competition course at high speeds without any loss of control or stability.
- Mission 2: An aerodynamic, high lift plane with enough power and endurance to complete 3 laps with almost 4 pounds of payload. Also, the fuselage must be the right dimensions to hold the bars vertically.
- Mission 3: Similar to Mission 2, Mission 3 requires an aircraft with plenty of lift, power and endurance to carry 4.4 pounds of water to 100 meters of elevation. Also, the water tank must

quickly release a large volume of water in a manner that does not destabilize the plane in flight.

- Interchangeable Payload and Aircraft Design: The water tank and aluminum bar stability system must fit within the confines of the fuselage and must attach in a way that properly stabilizes the payload for flight. Also, the Team must align the valve on the tank with an opening on the bottom of the fuselage.
- RAC: An aircraft that weights approximately 4 pounds (about ½ of the total weight of the aircraft when fully loaded with payload) should provide the team with a stable and aerodynamic vehicle while only minimally reducing the Team's overall score.

3.2.1 Sensitivity Analysis

The overall scoring formula for this year's contest is given by the equation:

Score = (Report_Score/sqrt(RAC))((1+N_Laps/6)+(1.5+3.75/M2_Flight_Weight)+(2+sqrt(T_avg/T_team)))*

From this equation, it is clear that one of the most significant aspects to stress in order to achieve a high total score is to have the lowest RAC possible. This factors directly into each Mission's score because the sum of the Mission scores is divided by sqrt(RAC), and the weight of the aircraft is also directly related to the score earned for Mission 2. Minimizing the RAC, therefore, is fundamental to a successful design for both Mission 2 and the overall score as a whole.

There are other components of the score that can be emphasized, however, to also maximize its value, particularly when it comes to Missions 1 and 3. Mission 1 inherently requires a high speed, high agility aircraft while Mission 3 requires high speed, thrust and payload carrying capacity. In order to discover if one of these missions should be emphasized in the design of the aircraft, and if so, which one, the Team performed a mathematical analysis of the scoring equation using MATLAB. This was done to understand which of the two missions have the more significant effect on the total score.

Firstly, the MATLAB analysis takes advantage of several important assumptions that must be introduced. Based on early calculations done using MotoCalc, it is estimated that the aircraft completes no less than three laps in Mission 1, and no more than nine laps, with an actual estimation of six laps. These bounds were used to calculate total score values, assuming the Team performed averagely on Missions 2 and 3, for which the individual scores of those Missions were held fixed. Score values were calculated for each increasing number of laps, and this data can be seen in Figure 3.2 below.

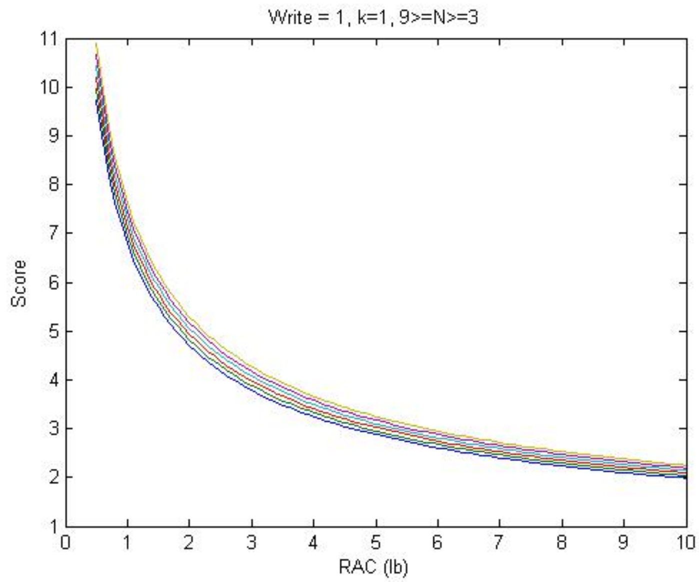


Figure 3.2: Score Vs. RAC for Varying Number of Laps Completed

From the data, it is clear that the total score decreases exponentially with increasing RAC. Furthermore, the lower the RAC, the greater the difference in total score value between completing nine laps versus completing only three laps. This statistic can be seen in Figure 3.3 below:

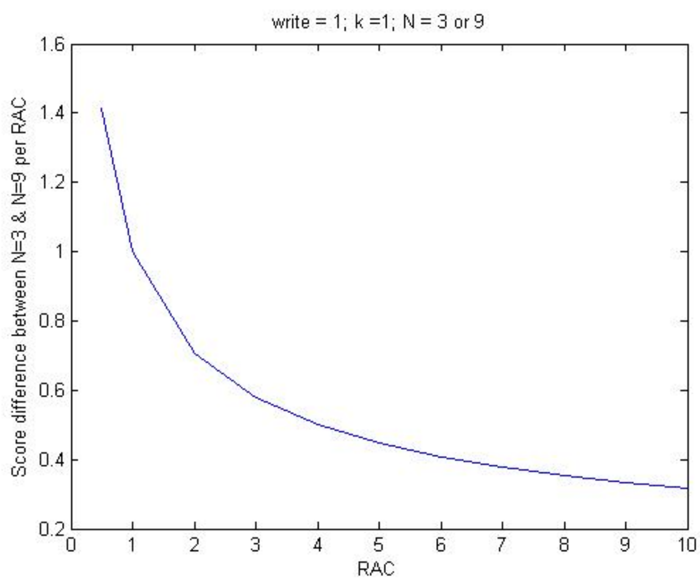


Figure 3.3: Changes in Score for 9 Laps - 3 Laps Completed Vs. RAC

Not only does decreasing the RAC of the plane increase the Team's total overall score, it makes each lap completed worth more, as well.

The next aspects of the score the Team took into consideration were the effects of having a high rate of climb compared to the RAC of the plane. To do this, it is assumed that the aircraft will perform averagely on Missions 1 and 2, and that the value of k =[T_avg/T_team] is between 0.6 and 1.4. This assumption is based on the fact that the general design of the aircraft is relatively conventional, and, therefore, that the Team will perform roughly average on this mission—no worse than roughly two thirds more than the average time, and no better than roughly two thirds under the average time. A wide array of values were considered, with the step size in between these two boundary values being 0.05, so as to view the largest possible number of potential scores.

The results of that data are plot in Figure 3.4 below:

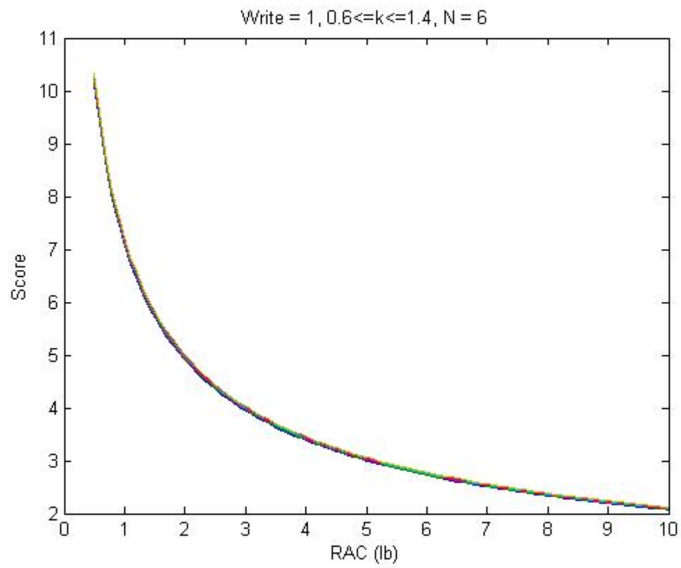


Figure 3.4: Score Vs. RAC for Varying Values of k [=T_avg/T_team]

These results again reveal, as in Figure 3.4 above, that the overall score decreases exponentially with increasing RAC. The difference in the total score for k=1.4 versus k=0.6 is plotted below.

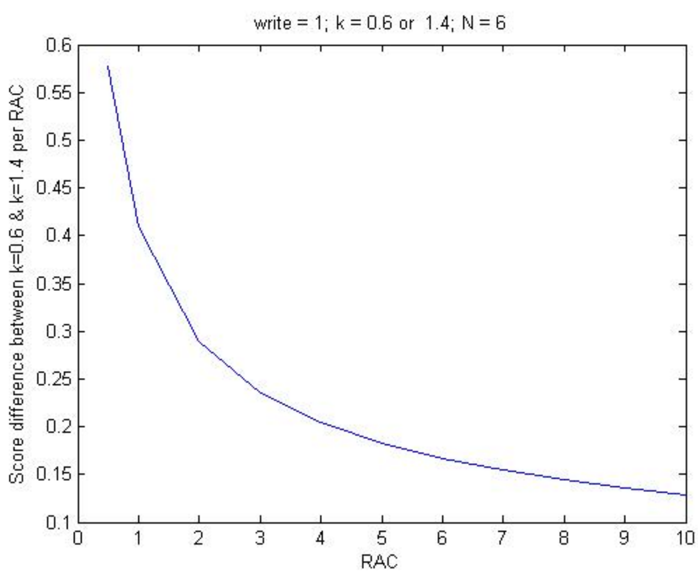


Figure 3.5: Changes in Score for k=1.4 - k=0.6 Vs. RAC

Again, the lower the RAC, the greater the difference between the total score values. Interestingly, however, it can be seen that the difference in the total overall score when having k=1.4 versus k=0.6 is much smaller per unit RAC than the difference between completing nine laps versus completing three laps. For example, for an RAC value of 2, completing nine laps produces an increase in total score of approximately 0.7 while the difference between having k=1.4 versus k=0.6 produces only an increase in total score of about 0.28. Each lap completed, therefore, contributes more to the total overall score than each incremental increase of k.

From this analysis, it can be concluded that the most critical aspect to achieving a high total score is having a low RAC. Furthermore, it can be concluded that having a faster aircraft that completes more laps contributes more to the total score than having one with a high climb rate, and, therefore, high speed should be emphasized in the design. This design is still effective for all three missions, however, as having a high speed design is also important in having a high rate of climb. The final design, therefore, should be as lightweight and high speed as possible.

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 seven major design elements: the fuselage, the wing, the propulsion system, the configuration, the tail, the landing gear, and the water tank. The Team then weighted 5 Figures of Merit and developed a system to score the 3 possible solutions.

Figures of Merit

After the Team translated the mission requirements into design requirements, the Team selected 5 metrics to use to select aircraft design elements. These metrics were then weighted on a scale of 1 to 9, with 9 being the most important and 1 being the least important. The table below shows the relative importance of the 5 metrics.

Metric	1	2	3	4	5	6	7	8	9
Weight									9
Speed			3						
Payload Containment					5				
Ground Handling							7		
Ease of Fabrication	1								

Figure 3.6: Figures of Merit for Design

Alternatives Weighting System

For each design element, three possible solutions were selected. Then, the selections were rated on a scale of 1 to 5, with 5 being the best solution and 1 being the worst. A value of 3 was assigned when the solution was neither positive nor negative.

3.3 Solutions, Configurations and Results

3.3.1 - The Fuselage

Number of Fuselages

The number of fuselages was driven by the need for payload containment and low weight. Two choices were considered: Single fuselage - one fuselage, mounted mid-span, and Dual fuselage - two fuselages, mounted symmetrically in the wingspan.

FOM	Weight	Single Fuselage	Dual Fuselage
Weight	9	3	1
Speed	3	3	1
Payload Containment	5	3	5
Ground Handling	7	3	3
Ease of Fabrication	1	3	3
Total	25	75	61

Figure 3.7: Number of Fuselages Decision Matrix

When considering the number of fuselages, the Team realized that while the dual fuselage configuration would allow for more flexibility when carrying payloads, it would dramatically increase the weight and the drag of the aircraft. This would reduce the score in two ways, first with the RAC component and again with the slower flying speeds (which would reduce the score for Mission 1). Because of these shortcomings, a single fuselage proved to be best choice.

Shape of the Fuselage:

The shape of the payload drove the shape of the fuselage. Three shapes were considered: Circle, Triangle, and Rectangle.

FOM	Weight	Circle	Triangle	Rectangle
Weight	9	3	3	3
Speed	3	3	3	3
Payload Containment	5	1	1	5
Ground Handling	7	3	3	3
Ease of Fabrication	1	1	1	3
Total	25	63	63	85

Figure 3.8: Fuselage Shape Decision Matrix

When considering possible shapes for the fuselage, the Team focused on three main criteria: weight, payload stability and drag. In terms of weight, all three choices had approximately the same score because of their consistent size. When considering drag (and its effect on maximum speed), the Team noted that while a circle is a more aerodynamic shape, all three shapes would have a nose cone to decrease the drag. So again, all 3 choices were equally good. In the end, the rectangular fuselage allowed the greatest payload stability because of the requirement that the bars be 1” x 1” x 5”. A rectangular fuselage could be shaped to encase the smallest volume required to hold the bars. That way, it would reduce weight and drag because of its smaller footprint.

3.3.2 - The Wing

The shape of the wing was driven by competition constraints and performance requirements. Three possible wing shapes were considered:

- Elliptical - wing resembles a symmetrical, stretched circle
- Tapered - chord decreases from the center to the wingtips
- Swept - constant chord with the wingtips behind the center of gravity
- Rectangular - constant chord and symmetrical in both directions

FOM	Weight	Elliptical	Tapered	Swept	Rectangular
Weight	9	3	5	3	1
Speed	3	5	3	3	3
Payload Stability	5	3	5	3	3
Ground Handling	7	3	3	3	3
Ease of Fabrication	1	1	3	1	5
Total	25	79	109	73	59

Figure 3.9: Wing Shape Decision Matrix

When selecting the shape for the wing, the main concern of the Team was the stability of the aircraft in flight and the ability of the airplane to carry the necessary payload. To meet these requirements, the Team realized that some speed would need to be sacrificed. While the elliptical wing provided the best efficiency, the payload would need to be centered perfectly mid-chord to provide the necessary stability. The same can be said for the rectangular wing. The swept wing, while ideal for high-speed flight, provided no benefit on the payload missions. The tapered wing proved to be the best choice because the asymmetry of the wing allowed the center of gravity to move backwards without effecting stability. This is because the balance point of the wing is actually behind the quarter chord. The Team thought that this could be helpful on Mission 3 when the water in the tank could slosh and shift the CG during flight, especially with the plane inclined during ascent.

3.3.3 - Propulsion System

The configuration of the propulsion system was driven by the need for a lightweight aircraft that provided ample thrust for both high speed/low weight flights and low speed/high weight flights. Three possible propulsion configurations were considered.

- Single Tractor - single motor mounted at the front of the fuselage
- Dual tractor - two motors, mounted in nacelle housings in 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	9	3	1	3	1
Speed	3	3	5	1	5
Payload Stability	5	3	5	3	3
Ground Handling	7	3	3	3	3
Ease of Fabrication	1	3	1	3	1
Total	25	75	71	69	71

Figure 3.10: Propulsion System Decision Matrix

In considering potential propulsion systems and configurations, the team determined that a single tractor motor configuration would most effectively satisfy the design requirements. This configuration is lighter than any consisting of two motors, and still provides satisfactory speed, payload stability, and ground handling. The ease of fabrication is also significantly better using only one motor system. Considering the heavy significance given to the overall weight of the aircraft, the team determined that the single tractor motor system was the most appropriate configuration to best accomplish the missions, despite the losses in speed and stability that would come from other configurations.

3.3.4 - Aircraft/Wing Configuration

The configuration of the aircraft and wing was driven by the need for stability and high lift. Three possible configurations were selected.

- Flying Wing - a single, continuous, blended body aircraft
- Conventional - a single wing, attached to the fuselage with a tail attached to the rear of the plane
- Biplane - two wings, stacked vertically with a central fuselage and a rear mounted tail

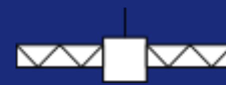
FOM	Weight	 Flying Wing	 Conventional	 Biplane
Weight	9	3	3	1
Speed	3	3	3	1
Payload Stability	5	1	5	3
Ground Handling	7	1	5	3
Ease of Fabrication	1	1	5	3
Total	25	59	101	51

Figure 3.11: Aircraft Configuration Decision Matrix

When selecting the best configuration for the aircraft, the Team took three main ideas into account: stability in flight, weight and payload capacity. While the flying wing would be the lightest of the three alternatives considered, it was also the least stable and had the lowest payload capacity. The biplane, on the other hand, had good payload capacity but the two wings weighed too much for it to be a viable option. Therefore, the conventional design proved to be the best choice because of its low weight, good stability in flight, and large fuselage.

3.3.5 - Landing Gear

The configuration and type of landing gear was driven by competition constraints. Three types of wheel landing gears were considered:

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

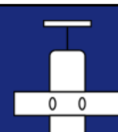
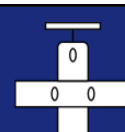
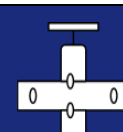
FOM	Weight	 Tail Dragger	 Tricycle	 Bicycle
Weight	9	3	3	3
Speed	3	1	3	1
Payload Stability	5	3	5	3
Ground Handling	7	1	5	3
Ease of Fabrication	1	3	3	3
Total	25	55	99	69

Figure 3.12: Landing Gear Decision Matrix

When deciding on the best landing gear configuration, the Team focused on three areas: stability, drag and ground control. The tail-dragger design prevents the solution with the least drag, the lack of stability it presented made it an unfavorable design, considering the windy conditions in Wichita. The bicycle design presents problems because it distributes weight to the wingtips during landing. Due to the heavy loads, the Team thought this could potentially result in structural failure upon landing. The tricycle design proved to be the best design because it kept the weight centered on the fuselage and allowed for good ground control and stability during takeoff and landing.

3.3.6 - Tail and Stability

The design of the tail was driven by the need for lightweight tail that provided good control and stability for the aircraft. Three different configurations were considered:

- Conventional: Single, large vertical stabilizer (with a rudder) and a horizontal stabilizer (with elevators) mounted below.
- T-Tail: Single, large vertical stabilizer (with a rudder) and a horizontal stabilizer (with elevators) mounted above.
- V-Tail: Two stabilizers, roughly 45 degrees apart, with rudder/elevator mixing.

FOM	Weight	Conventional Tail	T-Tail	V-Tail
Weight	9	3	3	3
Speed	3	3	3	5
Payload Containment	5	3	3	3
Ground Handling	7	5	3	1
Ease of Fabrication	1	3	3	5
Total	25	89	75	69

Figure 3.13: Tail Configuration Decision Matrix

When ranking each of the choices, the Team felt that although the V-tail had only 2 surfaces, the necessary size increase would offset the weight saved, and therefore the weight of the 3 choices would be about the same for all 3 choices. In terms of speed, the Team expected the V-Tail to be slightly faster due to the reduced drag on the surfaces. Finally, for ground handing, the Team decided that the conventional tail, with a rudder and a low mounted horizontal stabilizer would provide superior ground handling and takeoff performance as compared to the other two options. In the end the conventional tail proved to be the overall superior choice for the Team's aircraft.

3.3.7- Water Tank

The Team decided that a water tank and release system that is a self contained and removable package would be the best design. This would reduce the weight of the payload on the missions that do not require the water tank and reduce the time needed to install the tank during assembly for Mission 3.

Shape

When considering possible water tank shapes, the Team designed a tank that would minimize water sloshing (and therefore CG shifting), increase the rate of water release, and minimize the weight of the tank. To this end, the Team considered 3 possible tank shapes.

- Cylindrical - as seen in Figure 3.14, the tank would be approximately the size and shape of a 2 liter bottle with a valve at the bottom rear.
- Rectangular - as seen in Figure 3.15, the tank would be only slightly smaller than the dimensions of the fuselage with the valve mounted on the bottom towards the rear.
- Parallelogram - as seen in Figure 3.16, the tank would be a 3D parallelogram, with the sides inclined at the angle of inclination that the aircraft would fly at during Mission 3. This would center the CG of the water in the tank during flight. The valve would be mounted on the bottom towards the rear.

Figure 3.14: Cylindrical Tank

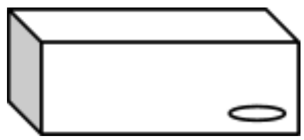


Figure 3.15 Rectangular Tank

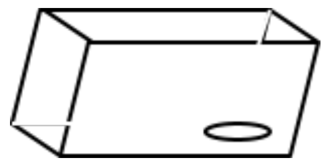


Figure 3.16: Parallelogram

In the end, it was decided that a rectangular tank, made of molded plastic, that was the minimum 2 liters would be the best design. The Team arrived at this conclusion because the rectangular tank would fit well in the fuselage, the molded plastic would be light-weight but rigid, and the exact-volume would minimize slosh and CG movement.

Release Mechanism

When designing the release mechanism for the water, the Team tried to design the most simple, lightweight and reliable water release mechanism. After much discussion and sketching, the Team arrived at a hatch valve that would be held in place by a pin. The servo would pull the pin once the aircraft reaches 100 meters. The Team thought that this would be the best choice because hatch valves are a reliable design and the pin system would minimize the torque needed by the servo to release the valve.

A rendering of the basic design of the tank can be seen below in Figure 3.17.

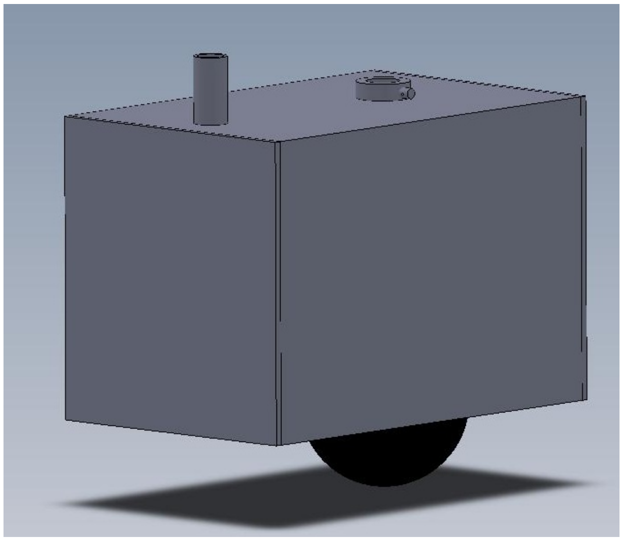


Figure 3.17: Water Tank Rendering

3.4 Final Conceptual Design

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

- Conventional aircraft configuration and wing layout
- Single, rectangular, center mounted fuselage
- Single, front mounted motor
- Tapered wing
- Conventional tail
- Tricycle landing gear
- Plastic, rectangular water tank with a hatch valve release system

The design was selected because it gave the Team the best change of winning the competition. A rendering of the aircraft configuration can be seen below in Figure 3.18.

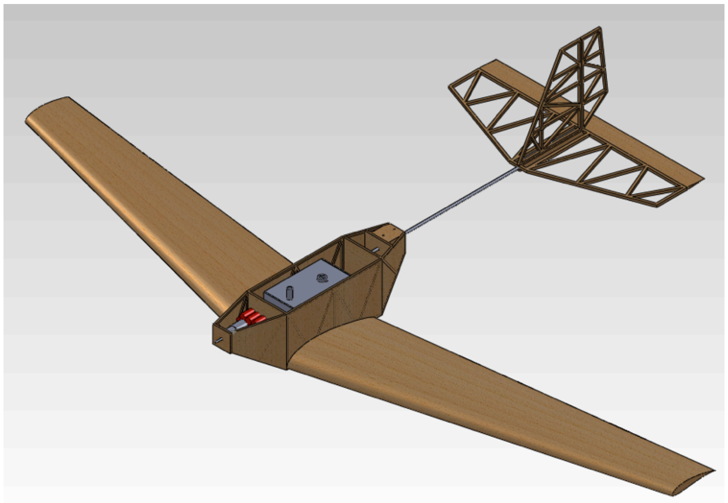


Figure 3.18: Final Aircraft Configuration

4.0 Preliminary Design

The preliminary design phase allowed the Team to perform a basic analysis for each of the 3 main areas: structures, aerodynamics and propulsion. 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

<u>4.1.1 Aerodynamics</u>

There are two important aerodynamic parameters that the Team considered:

Airfoil Selection

Generally speaking, there are two main types of airfoils: airfoils that generate a lot of lift but also have a lot of drag (and therefore a slower top speed), and airfoils that have less lift but allow for a higher top speed. High lift airfoils are good for missions where the payload is heavy, but they are not beneficial when time and speed are a design constraint. On the other hand, high speed airfoils are good for missions where there is little to no payload, but they are not good for mission in which a heavy payload is a requirement.

Wing Size

When sizing a wing, there are a few different parameters that the team needs to consider. First, the team has to calculate the necessary wing area in order to provide enough lift for the required missions and payloads. Next, the team needs to decide on a wing shape (rectangular, elliptical, tapered, swept, etc). From here, the span and the chord can be determined.

<u>4.1.2 Propulsion</u>

In a general sense, the Team used the following flow chart (Figure 4.1) to help choose the final motor and battery combination.

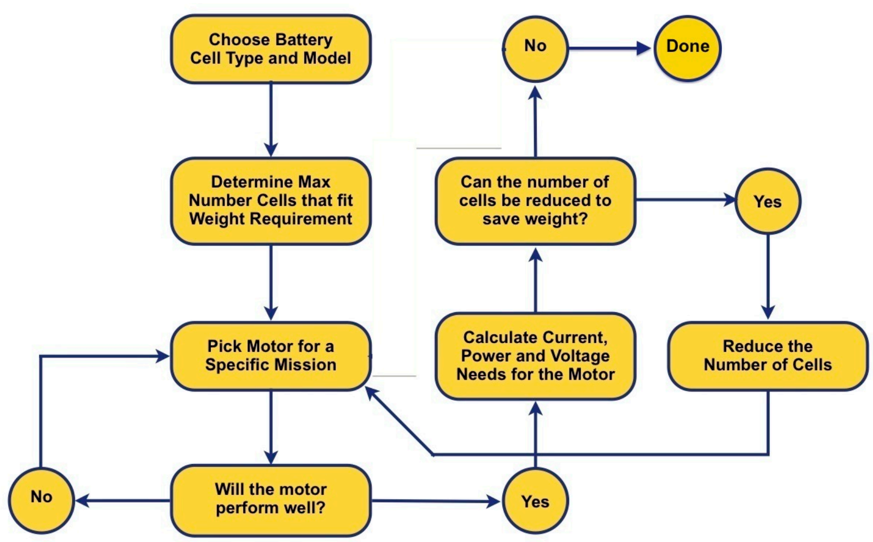


Figure 4.1: Motor and Battery Selection Flow Chart

However, there were three important propulsion parameters that the Team chose to consider in detail. Listed below are those three parameters and the important aspects of each:

Battery Selection

A battery pack using high capacity batteries would require less cells, but each cell would weigh more. A battery pack made of lower capacity cells would require more cells, but each cell would weigh less. Also important to consider is the chemistry used in the cells and their voltages. An optimal battery pack would optimize the weight, capacity and voltage for the selected motor and missions.

Motor Selection

A heavier motor can provide more power and thrust, which can positively effect the mission 1 score. But, the increased weight reduces the overall score because of the RAC component. An optimal motor will be a good balance of power and weight.

Propeller Selection

A smaller propeller would increase the aerodynamics and speed of the aircraft, but decrease the thrust. A bigger propeller would reduce the maximum speed of the aircraft, but would increase the thrust, making it ideal for payload missions. An optimal propeller would find a balance between speed and thrust. Additionally, the team could elect to use two propellers, one for Mission 1 when speed is the primary concern and one for Missions 2 and 3 when weight is the primary concern.

4.1.3 Structures

There are three important structural elements that the Team considered:

External Fuselage Size

A large fuselage provides plenty of room for payload and payload stabilization, but the increased footprint increases the drag and weight of the aircraft. An optimal fuselage should be as small as possible while still meeting all the minimum payload requirements.

Internal Grid Design

While a grid that covers the full vertical length of the bars would be ideal for stability, this violates the rules of the competition and adds unnecessary weight to the aircraft. An optimal grid design should cover the top and bottom of the bars while minimizing weight and structural bulk.

Water Tank

When designing the water tank, the Team took a few factors into account. Firstly, a water tank that is larger than necessary would allow the water to slosh around during flight, thereby changing the center of gravity. Secondly, a water tank with the dump valve located as far rear as possible would allow the water to dump faster due to the angle of inclination of the plane. Finally, the tank should have a water valve that is as large as possible in order to increase the size of the plume and the speed of the dump.

4.2 Mission Modeling and Optimization Analysis

4.2.1 Aerodynamics Mission Optimization

The Aerodynamics Team considered different configurations and airfoils for the plane with the 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 takeoff distance of 100 ft. The flight course is shown in Figure 4.2.

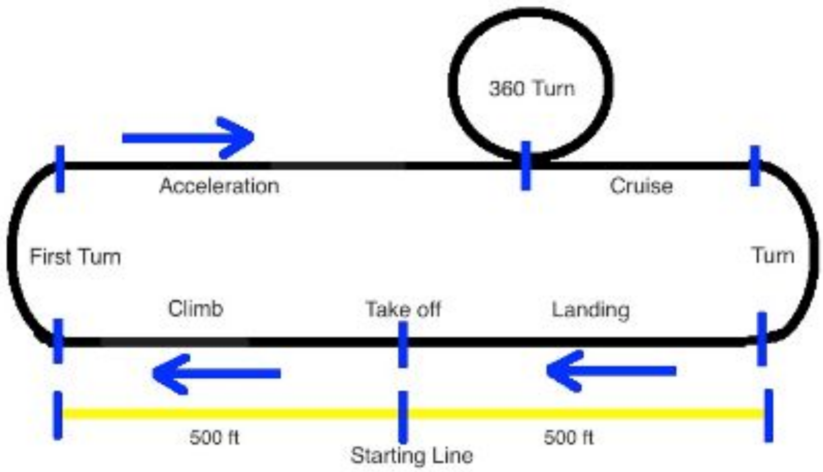


Figure 4.2: The Flight Course

With this data, the Aerodynamics Team decided that a wing configuration that allows for maximum volume in the fuselage for the missions would be best. The Aerodynamics Team was also able to select several airfoils for further analysis that would provide the necessary balance between lift and speed required by the flight course and missions.

4.2.2 Propulsion Optimization

Battery Selection

Battery Description	**Capacity** [mAH]	**Weight** [Ounces]	**Size** [Inches]	**Chemistry**
Elite 1500 2/3A	1500	0.81	1.13 x 0.66 x 0.66	NiMH
Elite 2100 4/5A	2000	1.15	1.7 x 0.7 x 0.7	NiMH
Eneloop 2000AA	2000	0.91	2.0 x 0.6 x 0.6	NiMH
Sanyo KR1700AU	1700	1.20	1.91 x 0.66 x 0.66	NiCAD
Sanyo KR1500AUL	1500	1.00	1.7 x 0.7 x 0.7	NiCAD

Figure 4.3: Battery Specifications

Choosing a set of batteries had to meet certain criteria such as weight, size, and capacity. In Figure 4.3, a list of batteries was taken into consideration based on the above criteria. From the choices, the Team found that nickel-cadmium batteries weigh more and are a larger average size compared to nickel-metal hydride batteries. Even more important was the capacity, which were all within a similar range.

Motor Selection

Motor Description	Kv [*RPM/V*]	No Load Current [*Amps*]	Max Voltage [*Amps*]	Continuous Power [*Watts*]	Weight [*Ounces*]
NeuMotors 1107/2Y	3300	0.9	12	200	3.17
NeuMotors 1107/6D	2100	0.45	28.5	200	3.17
NeuMotors 1105/3Y	3500	0.65	18	200	2.3
Hacker A20 20L	1022	0.85	11.1	210	2.01

Figure 4.4: Motor Specifications

A number of motors were looked at but the selected ones in Figure 4.4 were the most viable for the missions. All four motors are brushless motors that provide the Team with higher torque compared to brushed motors. In addition, the Team took into consideration each motor's performance for every mission because we need a motor that can perform well in all three missions. Thus, the Team looked at the different combinations of electrical components that were preselected and used the program MotoCalc to get predicted performance data. Even more importantly was the weight of the motor which factors into the overall no-load weight value of the aircraft. The Team wanted to optimize the plane performance using as little weight as possible from the electrical components, while still completing each mission.

Propeller Selection

Propeller Size	Propeller Load Factor
9x6	4374
10x6	6000
11x6	7986
11x7	9317

Figure 4.5: Propeller Size vs. Propeller Load Factor

Propeller selection was challenging because there was a wide variety of propellers, and the Missions had very different requirements. In the end, the Team decided use 2 different propellers, one for the Dash Mission and one for the Payload Missions. The Team knew that propeller load factor was inversely proportional to the RPM of the propeller. Furthermore, the Team had already established that higher RPM's leads to high speeds. With this concept in mind, a table was made of possible propeller sizes and their corresponding propeller load factors.

4.3 Aerodynamics Trade-offs

4.3.1 Main Wing Trade-offs

Airfoil

After examining several airfoils, the team narrowed down the options to three airfoils based on the mission requirements. The airfoils are: E591, E210, and SD7037. E210 has a thickness of 13.6% and camber of 4.0%. SD7037 has a thickness of 9.2% and camber of 3.0%. E591 has a thickness of 15.7%, camber of 6.5%. All three airfoils are low Reynolds number airfoils, with the E210 and E591 airfoils having relatively the same thickness.

The team used XFLR5, and airfoil analysis program, in order to choose the optimum airfoil. The graphs below show the results comparing the three airfoils' glide ratio, coefficient of lift, and angle of attack. For both graphs, a type 1 analysis was used (fixed speed) with Reynolds number constant at 120000 and mach 0.00. The dark blue line represents E591, the light blue line represents SD7037, and the yellow represents E210 (as denoted by the key to the right).

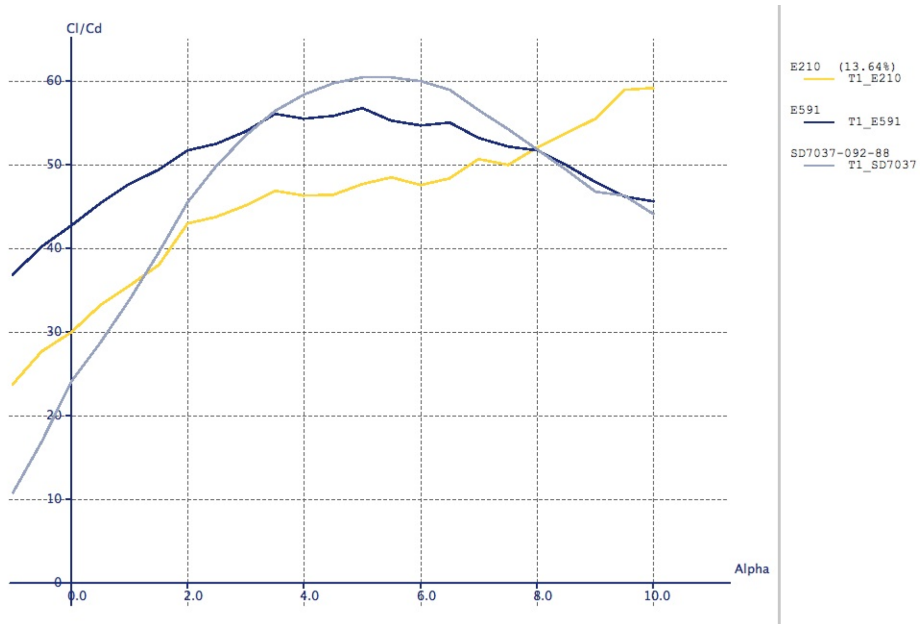


Figure 4.6 : E210, E591, SD7037 Glide Ratio v. Angle of Attack

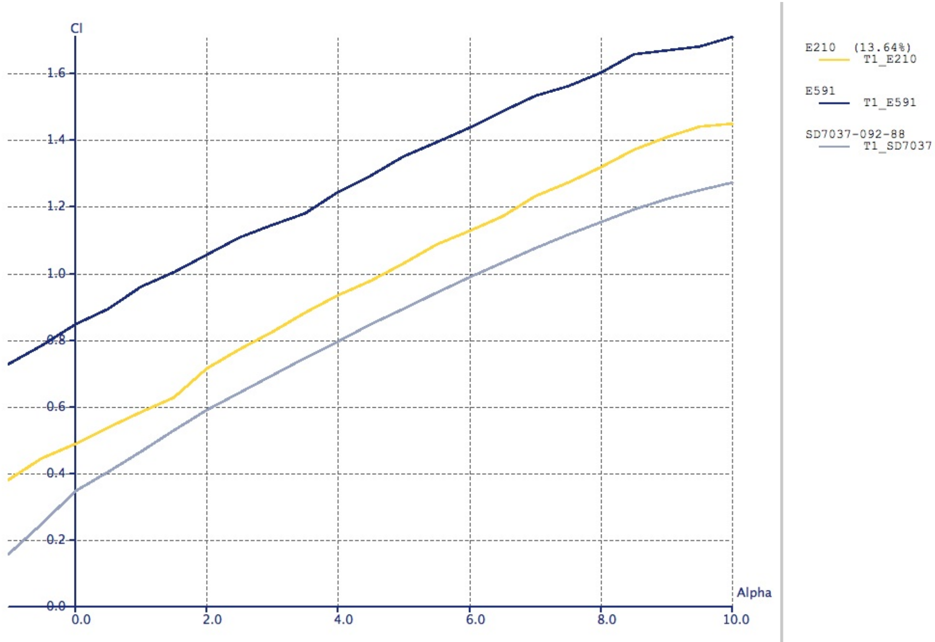


Figure 4.7: E210, E591, SD7037 Coefficient of Lift v. Angle of Attack

From the analysis, the team determined that the E591 airfoil has the highest coefficient of lift relative to the angle of attack. Also at low angles of attack, the E591 airfoil has the best glide ratio relative to angle of attack. For these reasons the team chose the E591 airfoil over the other two options. The E591 airfoil's added thickness compared to the other two airfoils also allows for structural stability. Below is a cross section of the E591 airfoil.

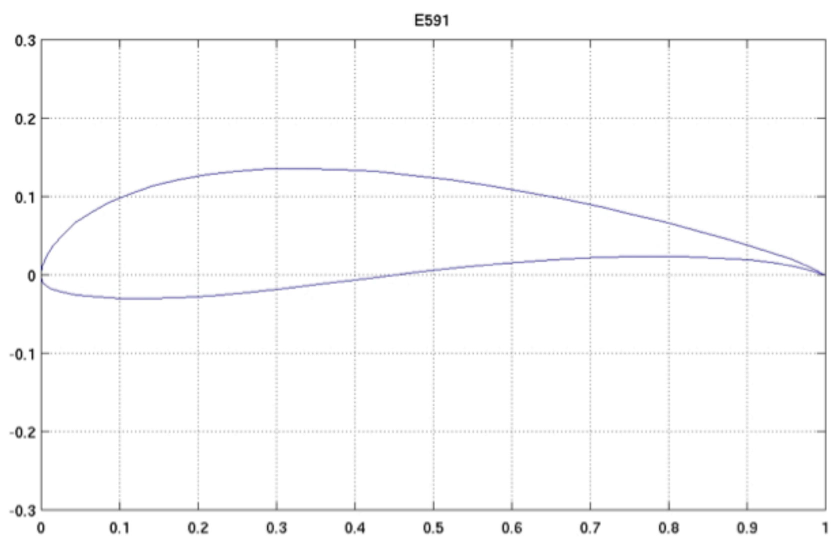


Figure 4.8: The E591 Airfoil

Wing Size

The wing sizing was determined based on our estimation that the completed empty aircraft would weigh approximately 4lbs, while needing to be able to carry a load of approximately 4.5lbs (the weight of

1 litre of water). We decided to account for a somewhat large factor of safety for the lift required.

F.S. = 1.5

Load*F.S. = (4+ 4.5)lbm * 2.5 = 21.25 lbm

Using the equation for lift,

L = (1/2) rho*v^2 *A*C_L

where L is the lift, rho is the density of air 0.0023769 slugs/cubic foot (at sea level on standard day), v is velocity, and C_L is the lift coefficient of E591 airfoil = 2.158. Solving for A, and approximating the speed as 35 mph = 51.333 ft/s:

A = 2L/rho*v^2 *C_L

= 2(21.25 lbm)(1 slug / 32.174 ft/s^2) / (0.0023769 slug/ft^3) (51.333 ft/s)^2 (2.158)

The team made the design decision to build a larger wing in order to allow for more lift on the race to climb altitude mission.

4.3.2 Tail Trade-offs

Airfoil

When choosing an airfoil for the tail, the Team considered 2 approaches. Firstly, the Team considered using an airfoil similar to the wing. This would give the aircraft some additional lift for the payload missions and allow the Team to achieve the greatest aerodynamic performance. Conversely, the Team considered using a flat plate design for the tail because it would reduce the time and resources needed for manufacturing. The Team also considered the fact, that with a relatively small tail compared to the wing, the reduced lift generated by the tail would be negligible. In the end, the Team decided that the benefits of using an airfoil would not outweigh the increased difficulty of fabrication. For simplicity, the Team decided to use a flat plate for the shape of the tail.

Tail Size

When sizing the tail, the Team was concerned with balancing the need for a large tail to increase the maneuverability of the aircraft with also trying to reduce the size, cross-section and drag of the tail. To this end, the Team used the formula $A_{HS} = (C_{HT}*S*c)/L_{Tw}$, where A_{HS} is the area of the horizontal stabilizer, C_{HT} is the design factor, S is the wingspan, c is the wing chord and L_{Tw} is the distance from the wing to the horizontal stabilizer. After solving the equation using the appropriate values, the Team found that the horizontal stabilizer should have an area of 136 in^2. The Team also decided to make the tail a simple rectangle because this would make fabrication easier. In the end, the Team ended up with the horizontal stabilizer seen in Figure 4.9.

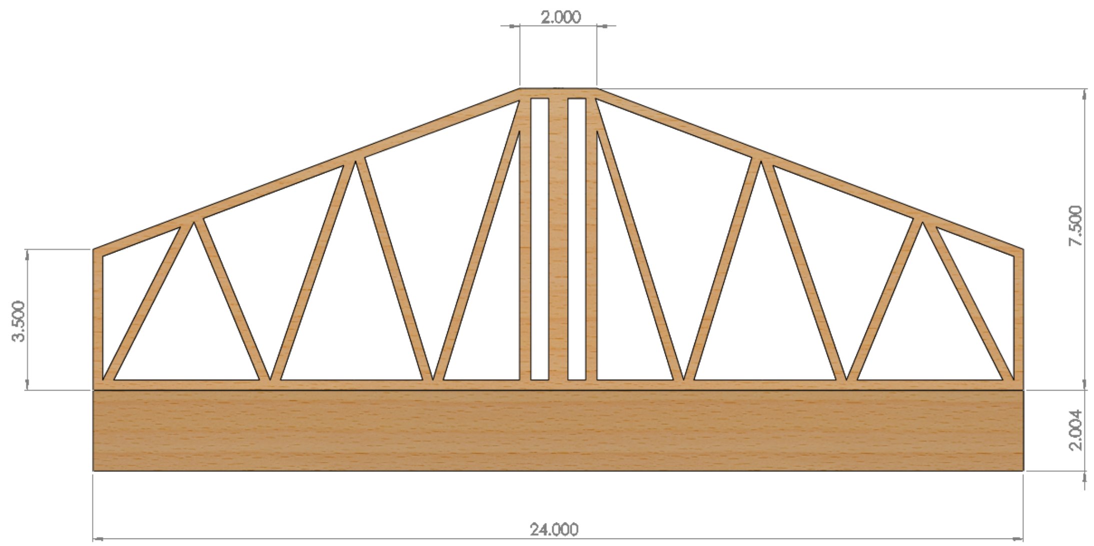


Figure 4.9: The Horizontal Stabilizer

When sizing the vertical stabilizer, the Team decided to use a similar method as they did for the horizontal stabilizer. This resulted in a vertical stabilizer with an area of 64 in^2. A sketch of the vertical stabilizer can be seen below.

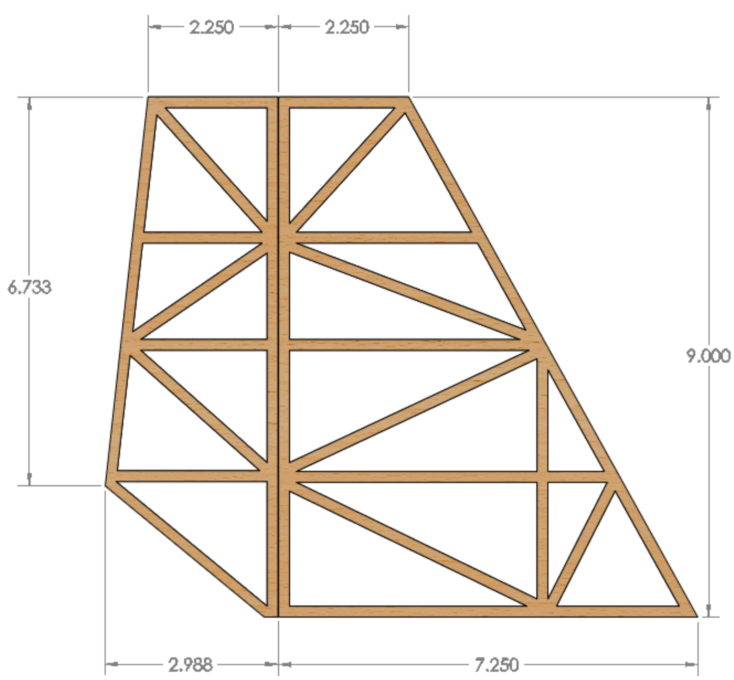


Figure 4.10: The Vertical Stabilizer

4.4 Propulsion Trade-offs

4.4.1 Battery Selection

One of the most significant components in the overall score of the competition is the total weight of the aircraft. Weight being the most significant design limitation, the team decided to minimize the size and weight of the battery needed for required operation. With this, the team chose to use the Elite 1500 with 8 cells, providing a total voltage of 9.6 V and 1500 mAh. This battery selection provided a lightweight solution that supplied the necessary performance to effectively perform each of the three required missions.

4.4.2 Motor Selection

The Team decided to use the NeuMotors 1105/3Y based on the theoretical data collected from using MotoCalc. This motor was found to provide the best theoretical performance out of many tested options, and is lightweight, making it a sound choice given the scoring parameters and design goals. Below are graphs of this specific motor's performance. The red line corresponds to the left Y-axis and the blue line corresponds to the right Y-axis.

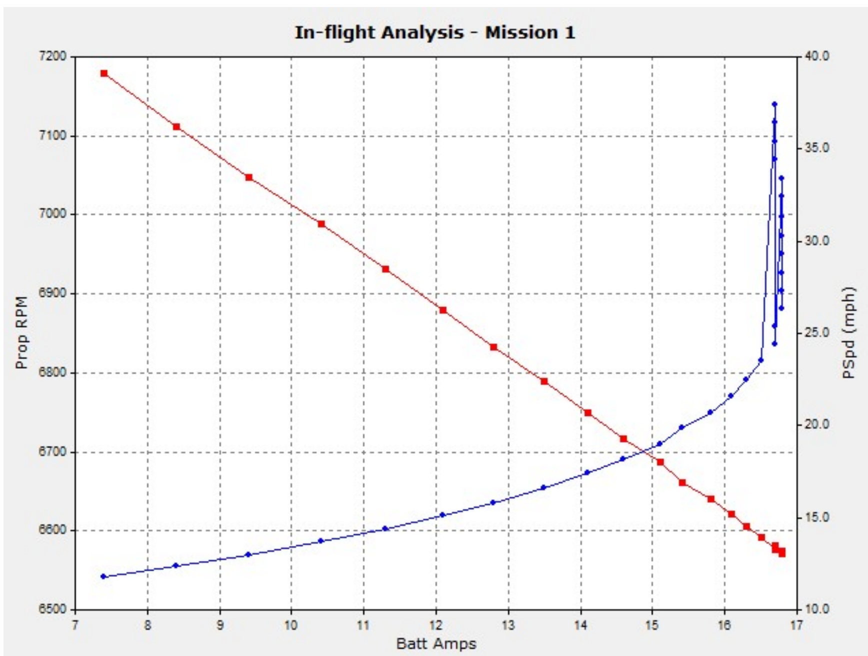


Figure 4.11 Mission 1: Battery amps vs Prop RPM and Plane Speed (NeuMotors 1105/3Y)

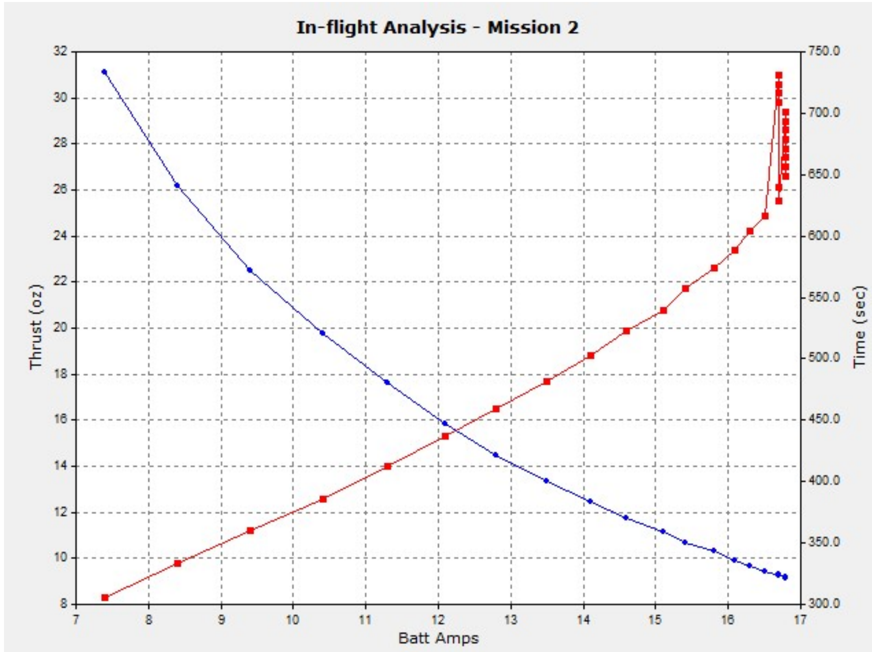


Figure 4.12 Mission 2: Battery amps vs Thrust and Time (NeuMotors 1105/3Y)

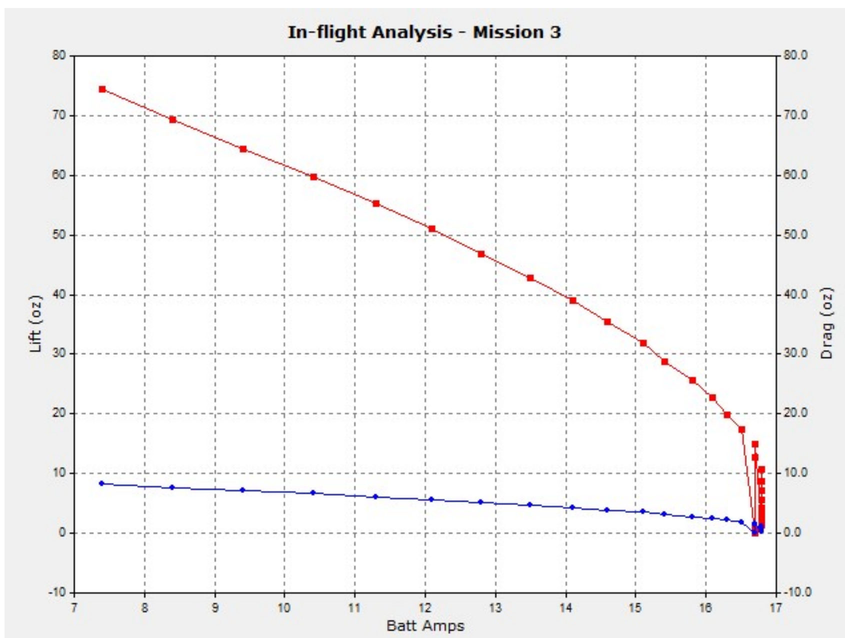


Figure 4.13 Mission 3: Battery amps vs Lift and Drag (NeuMotors 1105/3Y)

With a maximum plane speed of 37 mph, the propeller rpm reaches 6600 rpm at 16.5 amps. This gives a theoretical plane speed the team can work with to analyze the aerodynamic loading on the plane. At the same battery amps, the motor can produce a thrust of 31 oz that can last for about 6 minutes. This provides a large enough force to move the plane with the payload while flying for about 360 seconds. Lastly, the maximum lift that is produced is about 75 oz with a drag of 9 oz. This can be seen from the induced drag that is a result from lift. The greater the lift that is produced, the greater the overall drag is as a result. These numbers all lie within the parameters that are needed to complete the missions.

4.4.3 Propeller Selection

Data obtained using MotoCalc led the Team to decide to use a 9x6 propeller for the speed dash mission and an 11x6 propeller configuration for the passenger and payload missions. The 9x6 propeller provides less thrust, but more speed, making it ideal for the dash mission. The 11x6 propeller causes the plane to fly slower, but with provides more thrust, making it more appropriate for the latter two missions. These propellers, configured with the chosen battery and motor selections, provided effective designs to satisfy and compete in each of the three scored missions.

4.5 Structural Trade-offs

4.5.1 Fuselage Sizing

The fuselage needed to be sized in such a way as to hold all the Aluminum bars as well as the 2 liters of water, while not weighing too much. It was decided that the 8 bars would be placed in two rows of four bars, for an approximate dimension of 2.5” X 5.5”, and each bar was 5” tall as well. The water has a volume of 122.05 in^3, and would need to have the same center of gravity as that of the bars. The fuselage was designed with all these requirements in mind.

4.5.2 Internal Elements/Structure

Instead of a traditional semi-monocoque structure, with bulkheads and longerons, like those in commercial jumbo-jet airplanes, a truss structure will be used. This simplifies the building process, and also makes it easier for the team to swap in and out the payloads for the second and third missions. A divider will section off the electronics (electronic speed controller, battery pack) from the motor and gearbox. Another divider will separate the electronics from the payload. The rear electronics compartment, which will contain servos for the rudder and elevator, will also be separated from the payload with a divider. Figure 4.14 shows the internal structure of the fuselage.

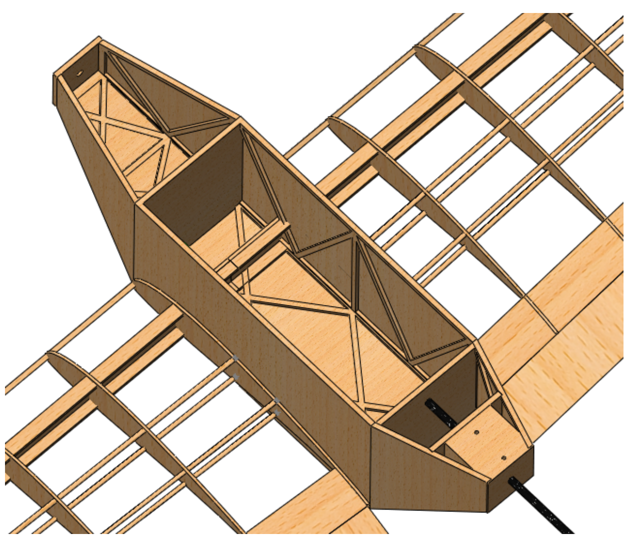


Figure 4.14: Fuselage Internal Structure

4.6 Lift, Drag and Stability Analysis

The coefficient of lift, coefficient of drag, and the angle of attack were examined for our chosen airfoil E591. The team used an aerodynamic analysis program, XFLR5, in order to analyze the properties of the E591 airfoil for several Reynolds numbers.

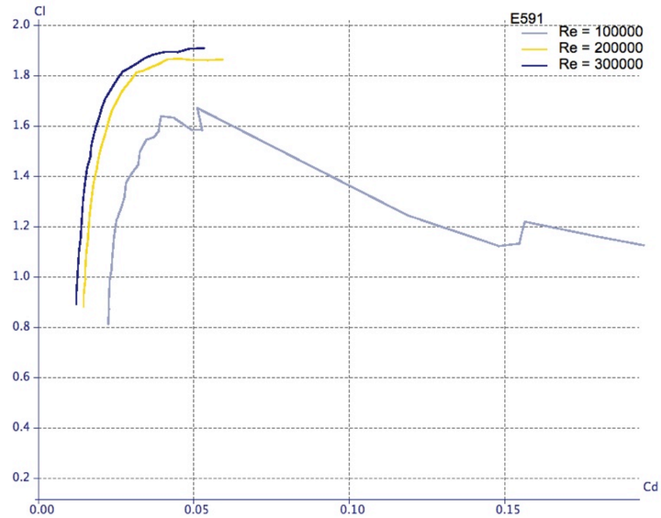


Figure 4.15: Coefficient Lift vs. Coefficient Drag (E591 Airfoil)

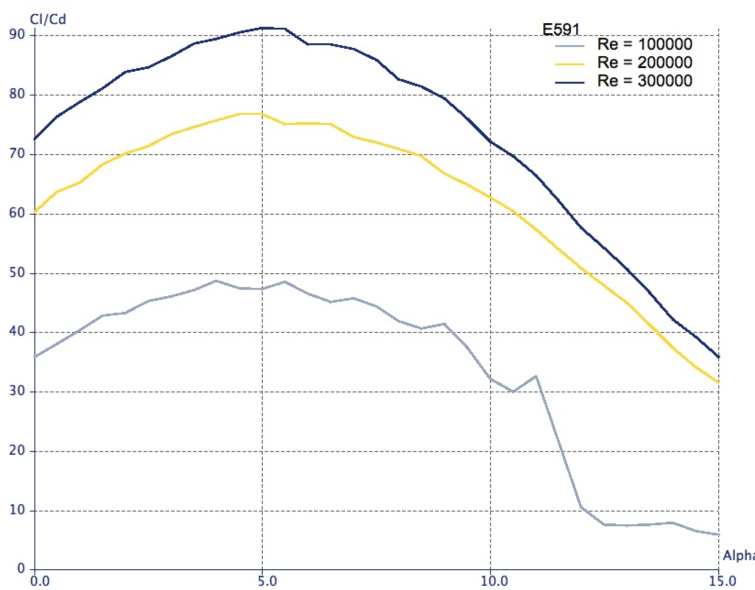


Figure 4.16: Glide Ratio vs. Angle of Attack (E591 Airfoil)

The two graphs above show the results of a type 1 analysis, which assumes fixed speed, for three different Reynolds numbers. For both graphs: the dark blue curves correspond to Reynolds number of 300,000; the yellow to Reynolds number of 200,000; and the light blue to Reynolds number of 100,000. Different Reynolds numbers were graphed in order to ensure that the E591 airfoil is able to perform under a variety of flight conditions.

4.6.1 Drag

Drag Calculation Estimates

In order to calculate the effect of drag on the aircraft, parasite drag (also known as the zero-lift drag coefficient) was approximated using the equivalent skin friction method. Relevant surface areas were obtained from the CAD model of the aircraft in order to estimate the total parasite drag coefficient. The wing surface area was selected as the reference area in the calculation. As shown in Figure 4.16, the wing is the greatest contributor to the parasitic drag due to the large wing length.

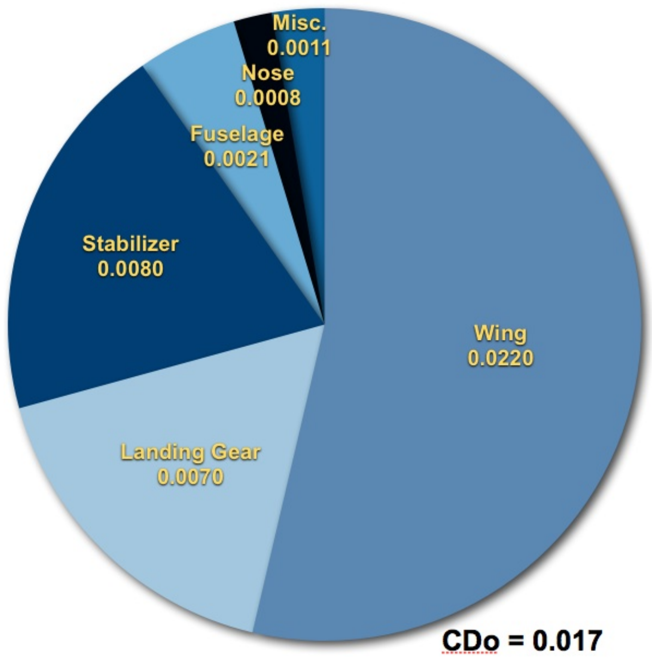


Figure 4.17: Parasitic Drag Approximations

4.6.2 Stability

Predicted aircraft pitching performance was calculated for the 3 different missions, using calculated CL values and cg values. In order to adjust the aircraft trim for all three missions, the tail orientation angle can be manually adjusted on the ground to suit flight profile. The aircraft has a static margin of 33% for mission 1, 37% for mission 2, and 31% for mission 3. Furthermore, the static margin can be adjusted on the fly by ±3% in either direction by repositioning the tail length.

4.7 Aircraft Mission Performance

Using simple analysis of the mission courses and objectives, the Team was able to calculate basic performance estimates for each of the missions. This analysis allowed the Team to estimate which components of the aircraft design to improve in order to improve the total overall score received. The following figures contain the details of this analysis.

Mission 1	**Mission Sequence**	**Distance (ft.)**	**Speed (ft/s)**	**Time (s)**
Lap 1	Take-off & Climb	100	26	3.8
	Cruise	400	54	7.4
	180 Degree Turn	100	47	2.1
	Cruise	500	54	9.3
	360 Degree Turn	175	42	4.2
	Cruise	500	54	9.3
	180 Degree Turn	100	47	2.1
	Cruise	500	54	9.3
Total:		**2375**		**47.4**
Laps 2-N	Cruise	500	54	9.3
	180 Degree Turn	100	47	2.1
	Cruise	500	54	9.3
	360 Degree Turn	175	42	4.2
	Cruise	500	54	9.3
	180 Degree Turn	100	47	2.1
	Cruise	500	54	9.3
Total:		**2375**		**45.5**
Total Time:	***240***	***Seconds***		
Total Possible Laps:	***6.3***	***Laps***		

Figure 4.18: Mission 1

Mission 2	**Mission Sequence**	**Plane Weight (oz)**	**Speed (ft/s)**	**Plane Lift Generated (oz)**	**Distance (ft)**	**Time (s)**
Lap 1	Take-off & Climb	130	35	130	100	2.8
	Cruise	130	51	189	400	7.8
	180 Degree Turn	130	46	170	120	2.6
	Cruise	130	51	189	500	9.8

	360 Degree Turn	130	42	156	160	3.8
	Cruise	130	51	189	500	9.8
	180 Degree Turn	130	46	170	120	2.6
	Cruise	130	51	189	500	9.8
Laps 2-4	Cruise	130	51	189	500	9.8
	180 Degree Turn	130	46	170	120	2.6
	Cruise	130	51	189	500	9.8
	360 Degree Turn	130	42	156	160	3.8
	Cruise	130	51	189	500	9.8
	180 Degree Turn	130	46	170	120	2.6
	Cruise	130	51	189	500	9.8
Total Time						***194 (s)***

Figure 4.19: Mission 2

Mission 3			
Mission Sequence	**Speed (ft/s)**	**Distance (ft)**	**Time (s)**
Take-off	35	60	1.7
Ascent	42	328	7.8
Water Release			1.0
Total Time (s):			***10.5***

Figure 4.20: Mission 3

From the above analysis, the Team estimates that the plane can complete approximately 6 full laps in Mission 1, will have plenty of propulsion power and battery life to complete the four laps in Mission 2, and will climb the 100 m to complete Mission 3 in approximately 10.5 seconds.

5.0 Detail Design

In the last stages of preliminary 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 Figure 5.1 below.

Motor	
Type	Neu 1105/3Y
Weight	5.5 oz
Kv	3300
I_o	.65 A
R	.039 Ohm
Pm	500 W
Thrust	4.5 lbs
I_{batt}	20 A
Propeller	9x6 & 11x7

Horizontal Stabilizer	
Span	24 in
Root Chord	9.5 in
Tip Chord	5.5 in
Wing Area	132 in^2
Airfoil	E591

Batteries	
Type	Elite 1500
Capacity	1500 mAh
R	1.8 Ohm
V	1.2 V
I_{max}	.67 A
Number of Cells	8
Pack Capacity	1500 mAh
R_{pack}	1.8 Ohm
V_{pack}	9.6V
$I_{max\ pack}$	5.4 A

Fuselage	
Length	18 in
Width	6 in
Height	5 in
GTOW (est)	.75 lb

Vertical Stabilizer	
Span	9 in
Root Chord	10.25 in
Tip Chord	4.5 in
Wing Area	64 in^2
Aspect Ratio	1.27
Airfoil	Flat Plate

Wing	
Span	68 in
Root Chord	11 in
Tip Chord	9 in
Aspect Ratio	6.8
Wing Area	680 in^2
Airfoil	E591

Figure 5.1: Finalized Design Parameters

5.2 Structural Characteristics and Capabilities

Each of the three missions introduces unique structural limitations and challenges. The Team's decision to design two separate, removable inner fuselage compartments for Missions 2 and 3 required detailed analyses of the structural requirements placed on the aircraft. The removable compartment design of the aircraft lends itself to tailoring the plane to each mission.

Emphasis is placed primarily on aircraft speed for Mission 1, Ferry Flight. It was crucial for the Team to design an aircraft with as much speed as possible without sacrificing control and stability. This is achieved by reducing the overall weight of the aircraft. The team also anticipated high winds in Kansas in the spring. To compensate for this, the majority of the plane's structures are fabricated from balsa wood, chosen for its lightweight and high strength to weight ratio. For this mission, the cabin of the aircraft will be empty in order to reduce weight and increase speed. An empty fuselage also lends itself to weight modifications later in the fabrication and testing phases, if necessary.

The second mission, Passenger Flight, emphasizes safely carrying eight “passengers,” or aluminum bars. In order to optimize space constraints and avoid carrying any unnecessary weight, the team has chosen to construct a removable fuselage compartment specifically for this mission. To ensure stability of the bars in flight, a fuselage will be crafted with a sturdy but lightweight balsa grid that is tailored to hold the bars in place during flight. This grid will ensure that the bars do not shift and that the center of gravity of the plane remains constant while adding minimal weight to the aircraft.

The third mission, Time to Climb, emphasizes a rapid ascent coupled with the visible release of two liters of water. The team designed a custom molded plastic tank in order to avoid carrying any unnecessary weight. The tank is rigid and almost exactly two liters to minimize slosh and CG movement. It is fitted with a servo-operated hatch valve at the base of the tank (near the tail of the aircraft) to ensure rapid, reliable, and visible release of the water.

The variable payload weights for the multiple missions required a wing that demanded less center of gravity precision. For this the team chose a tapered wing. This design allows for a shifting center of gravity without sacrificing stability, ultimately leading to success in the third mission. The conventional configuration of the aircraft also lends itself to greater stability and effective multi-payload transportation.

Much like the wing and fuselage configuration, the tail is also a conventional shape. This tail design provides superior ground handling, as well as stability both on the ground and in flight. This design will also prove successful and reliable during takeoff and landing sequences, in which the aircraft might be subjected to high winds.

The best design for the landing gear was a tricycle configuration. Since the competition does not include special landing or takeoff components, the tricycle provides the most stability and maneuverability for the competition. The added stability will be especially important for runway maneuvers in which wind is a factor on the Kansas runway. Furthermore, the tricycle design prevents loading of the wings during landing, which would otherwise lead to structural failure.

Careful analysis of each mission, as well as much design and research on aircraft structures has yielded the above characteristics and capabilities of the team’s aircraft. An interchangeable fuselage compartment system coupled with a traditional wing and tail yield superior stability and minimum weight, increasing the aircraft’s speed, effectiveness, and overall score.

5.3 System Designs, Component Selection and Integration

5.3.1 Bar Stability System

The Team understood and emphasized the importance of securing the bars with a lightweight yet stable material. Because balsa is lightweight and easy to work with, it was the chosen material for the bar stability system. Slots of the dimensions of the length and width of the bars were cut into a balsa sheet sized to match the dimensions of the fuselage. This system would restrict the standing bars from any shifting or other unwanted movement while the plane was in flight. Additionally, it was possible to design and space the bars evenly to tweak and optimize both the fuselage and airplane’s center of gravity.

Because the team opted to use multiple, removable fuselages for this competition, this bar stability system was implemented in only the fuselage for Mission 2.

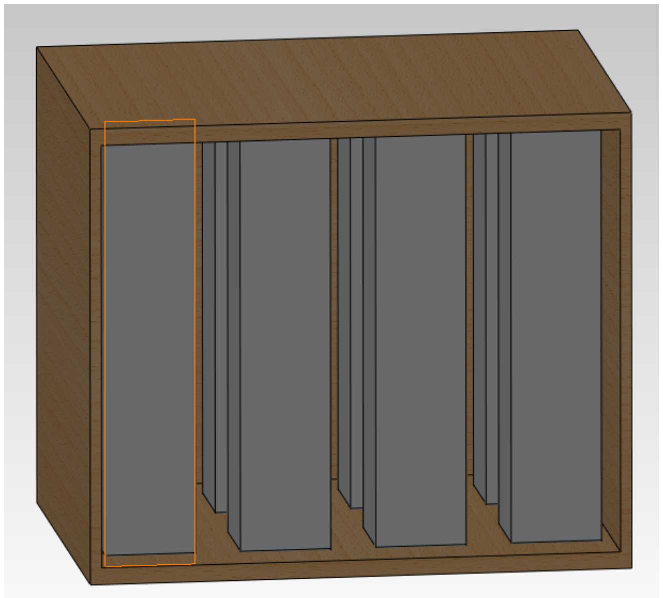


Figure 5.2: Bar Stability System

5.3.2 Water Tank System

The removable, plastic water tank is unique to Mission Three, Time to Climb. The tank is custom built from molded plastic, and will remain rigid under stresses from the water and the flight. The bar stability system will be removed from the aircraft and the water tank will be placed and secured in the fuselage prior to the start of the third mission. In order to minimize slosh and CG shift, the tank is two liters in volume, holding only the required amount of water. The rectangular shape fits snugly in the fuselage and is easily removable for the other two missions. It is fitted with a quick-release hatch valve operated by a small servo (Figure 5.3). At 100 meters in altitude (measured with the altimeter), the servo pulls a pin, opening the hatch valve. The design and placement of the release mechanism prevents the servo from having to pull against the water pressure on the valve, drastically increasing its reliability. Additionally, this low-torque design allows implementation of a smaller, lighter motor that draws less power.

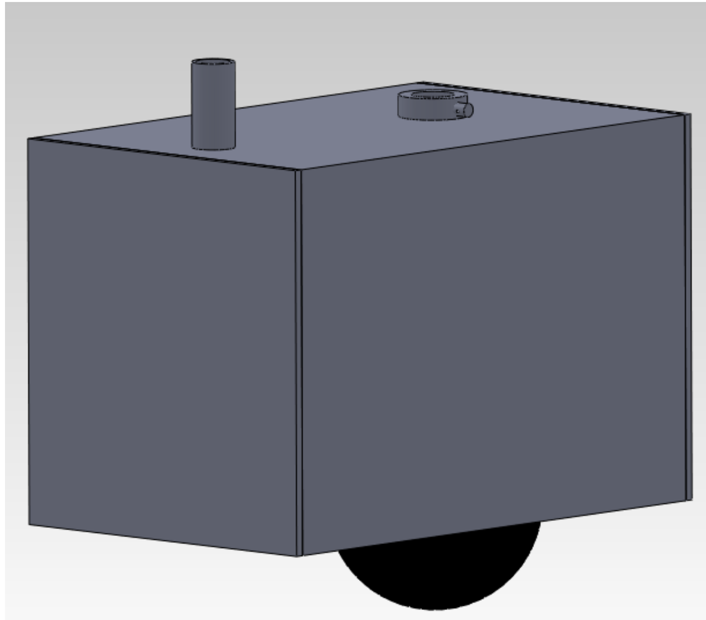


Figure 5.3: Water Tank System

5.3.3 Wing Attachment System

Due to a lack of sizing restrictions and for ease of assembly, the Team opted for a built-in, non-removable wing. The wing will be placed near the bottom of the fuselage, making it easier to load the bars and water tank in missions two and three, respectively. Furthermore, the ground effect will help create additional lift, which is crucial for Mission 3, where it is crucial to minimize time of the 100-meter ascent. To attach the wing to the fuselage, four nylon screws will be used. Two nylon screws go through the main spar and into the fuselage. Another two screws go through the rear spar and into the fuselage. These screws must be strong enough to transfer the lifting force of the wings to the rest of the plane.

5.3.4 Tail

For this year's competition the Team decided to go with a conventional tail configuration, as seen in Figure 5.4. From the size of the wing the Team calculated a horizontal stabilizer area to be 136 in^2, which is approximately 30% of the wing area. The rudder area is 20% of the main wing. This will provide the necessary stability and control during flight.

The Team realized the importance of analyzing the pitching moment caused by moving the elevators on the tail. If the moment was too large, the aircraft would pitch out of control during flight. Alternately, if the moment was too small, the aircraft would not climb fast enough to perform well in Mission 3. In order to mitigate these potential problems, a pitching moment analysis was performed to determine optimal distance from the leading edge of the main wing to the leading edge of the tail. These calculations led to team to place the tail approximately three feet behind the main wing.

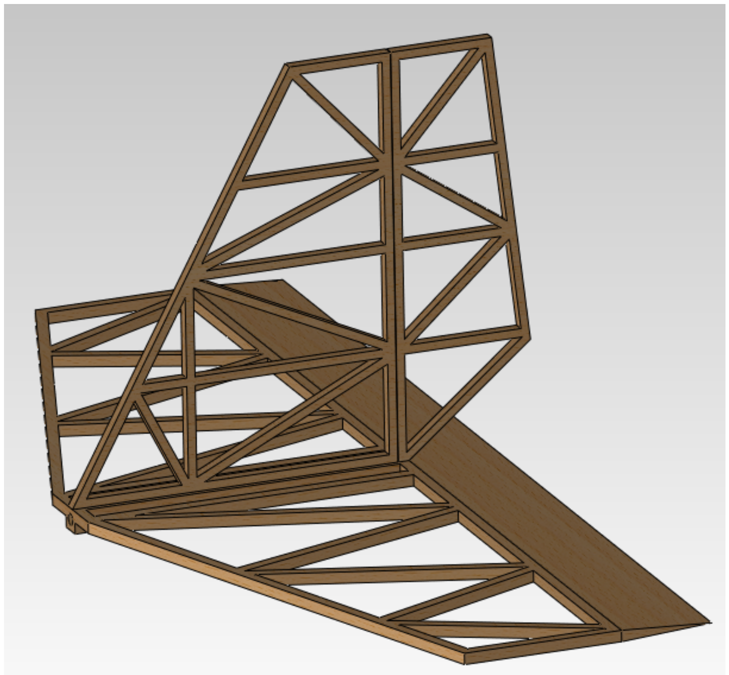


Figure 5.4: Tail Design

5.3.5 Landing Gear

The most important aspect of the landing gear is the stability that it provides the aircraft while it is on the ground, as well as during the landing sequence. As discussed in Section 3.3.5, the triangular landing gear configuration provides the most stability while remaining as lightweight and easy to fabricate as possible (Figure 5.5). The main landing gear is a bent wire, optimizing it to be both strong and lightweight, with only a small sacrifice in ease of manufacturing. The tendency for high, gusting winds in Kansas in the spring required a strong and stable design for the nose landing gear. To prevent instabilities such as bump steer, the strut of the nose wheel is aligned with the center line of the wheel. The bent wire was used for the nose wheel, as with the main landing gear. In order to increase stability at the nose, a spring was incorporated into the design to absorb shock loads on landing. The nose landing gear is equipped with a servo motor control system to help steer while taxiing prior to takeoff and post-landing.

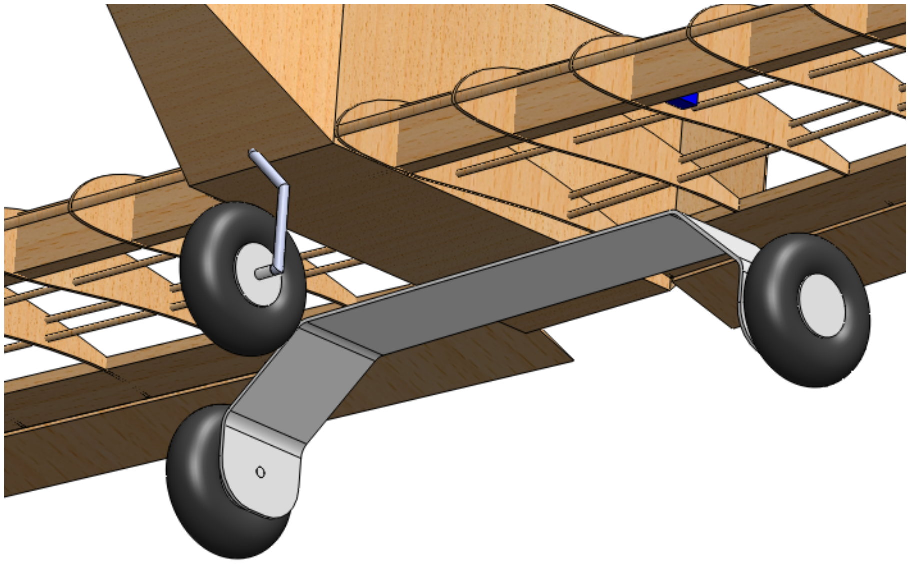


Figure 5.5: Conventional Tricycle Landing Gear

5.4 Weight and Balance

Weight was one of the main concerns in the design of the aircraft. To minimize the weight, the team decided to use lightweight aircraft grade balsa wood for the majority of the structural components of the plane. With a majority of the structure being made with lightweight balsa, most of the weight of the aircraft comes from the electronic components such as the motor and the battery packs. We positioned these heavier components carefully such that the weight of the front cancels out the weight of the tail. This allows the center of gravity to be located along the quarter chord of the wing. The CG distances are relative to the desired quarter chord distance.

Mission 1	Weight (lbs)	CG location		
		X location (inches)	Y location	Z location
Airframe	0.77	0.78	0.03	-5.77
Motor	0.13	0.04	3.72	17.04
Propeller	0.04	-0.34	1.98	10.78
Servos	0.17	-0.07	0.85	-11.98
ESC	0.04	0.54	0.455	0.08
Receiver	0.08	-0.53	-2.10	4.58
Battery Pack	0.41	0	1.89	6.48
Landing Gear	0.50	-0.35	-4.57	0.24
Total	2.19	0.20	-0.64	0.88

Figure 5.6: Mission 1 CG Table

Mission 2	Weight (lbs)	CG location		
		X location (inches)	Y location	Z location
Battery Pack	0.41	0	1.89	6.48
Aluminum Bars	0	0	0	0
Total	6.03	-0.15	-0.12	1.58

Figure 5.7: Mission 2 CG Table

Mission 3	Weight (lbs)	CG location		
		X location (inches)	Y location	Z location
Battery Pack	0.41	0	1.89	6.48
Water Tank	4.41	0	0	0
Total	6.60	0.37	-0.15	1.61

Figure 5.8: Mission 3 CG Table

5.5 Flight Performance Parameters

After finalization of the all of the structural components of the aircraft, it was possible to calculate flight parameters. These can be seen in Figure 5.6. These parameters provide a more detailed understanding of the aircraft's operation and projected performance.

Flight Parameters					
Aircraft Parameters		Mission Parameters	Mission 1	Mission 2	Mission 3
C_{L0}	0.85	Climb Rate (ft/s)	60	50	60
C_{LMAX}	1.62	Stall Speed (ft/s)	44	44	44
e	0.82	Cruise Speed (ft/s)	80	60	60
C_{DO}	0.0315	Maximum Speed (ft/s)	90	70	70
		Max G-Loads	4	4	6
		Turn Rate (degs/s)	105	45	20

Figure 5.6: Flight Performance Parameters

5.6 Mission Performance

<u>5.6.1 Pre-Mission Assembly and Payload Integration</u>

Unlike previous years, the aircraft can enter the staging area fully assembled; this will save the Team time during the assembly process. However, the payload must be external to the aircraft and loaded during the five minute time period. The Team expects that before Mission 2, the bars can be loaded in 1 minute, which is well under the 5 minutes allowed. For Mission 3, the Team expects that filling the tank with water and loading the tank into the aircraft should take no more than 3 minutes, also well under the 5 minutes allowed.

5.6.2 Mission 1 - Ferry Flight

The focus of this mission is to complete the most laps possible in 4 minutes. Since there is no payload, the aircraft will be fitted with the high speed propeller, and is expected to take off in approximately 50 feet. Once airborne, the aircraft will quickly reach its cruising altitude and maximum velocity of 90 feet per second. According to these calculations, the aircraft will complete approximately 8 laps, resulting in a score of 2.3 for Mission 1.

5.6.3 Mission 2 - Passenger Flight

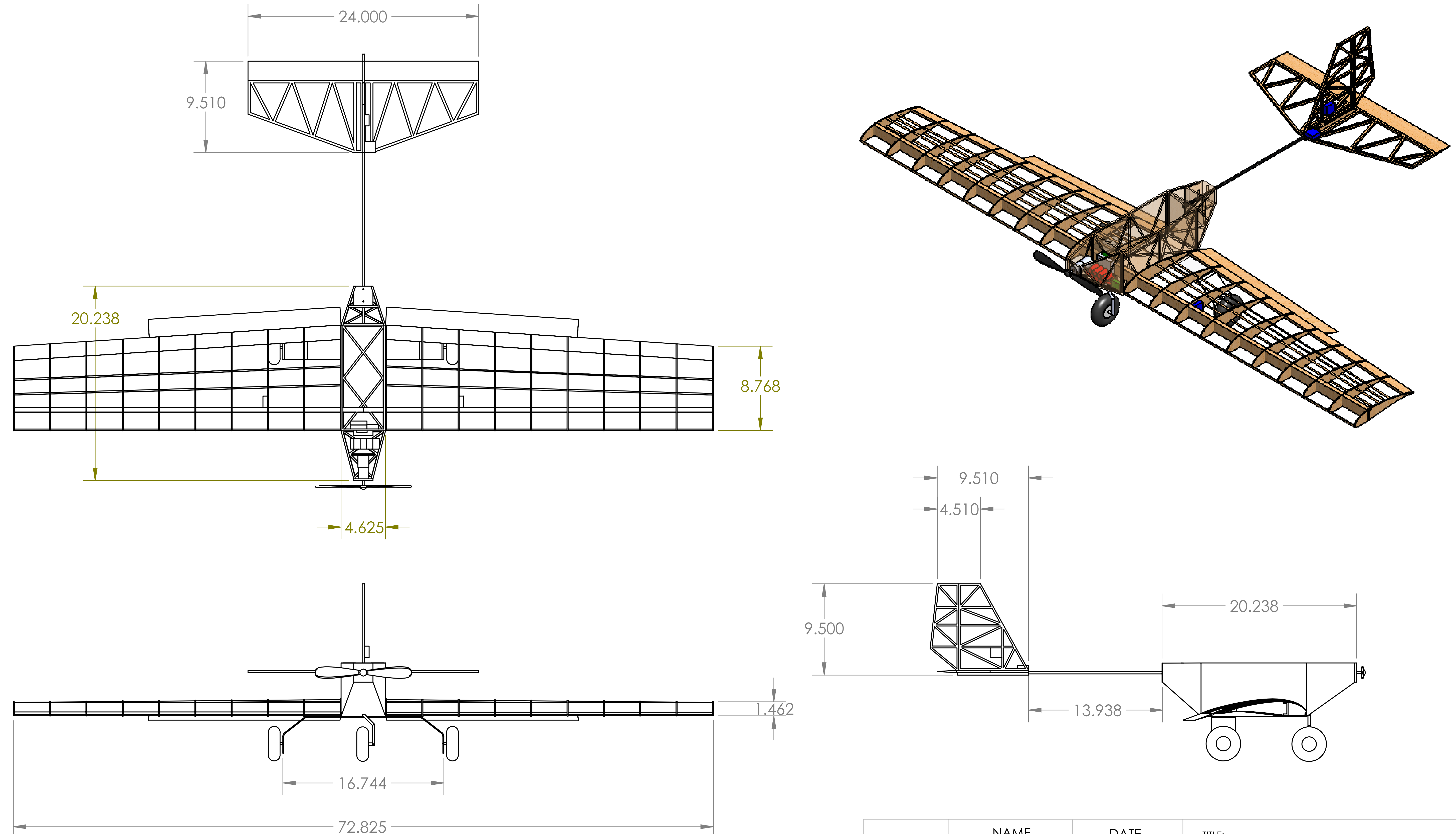
The ultimate goal of this mission is to complete three laps with the aluminum bar payload. The aircraft will be carrying four pounds of payload and will be fitted with the high thrust propeller. As a result, the Team expects the aircraft will take off within 60 feet. Once airborne, the aircraft will climb to its cruising altitude and complete the three laps with the throttle at 75% of its maximum. While this will result in a slower flying speed, the aircraft will fly more efficiently, thereby insuring that the batteries will last for the duration of all three laps. With the complete aircraft weighing 7.75 pounds, the score for Mission 2 is projected to be 2.

5.6.4 Mission 3 - Time to Climb

The focus of this mission is to ascend to 100 meters as rapidly as possible, and visibly release two liters of water from the aircraft. The craft will be flying with 4.4 pounds of water and the high thrust propeller, and it is expected it will take off within 70 feet. Once airborne, the aircraft will pitch upwards, flying with an angle of attack of 35 degrees. With a climb speed of 40 feet per second, adding the appropriate time for takeoff and payload release, the Team expects to reach 100 meters (300 feet) in 20 seconds. The score for Mission 3 is based on the average of other teams' scores, so it is challenging to estimate the score for Mission 3. However, since the Team expects the plane to perform above average, the projected score is 3.2.

5.7 Drawing Package

(See Attached)



SolidWorks Student Edition.
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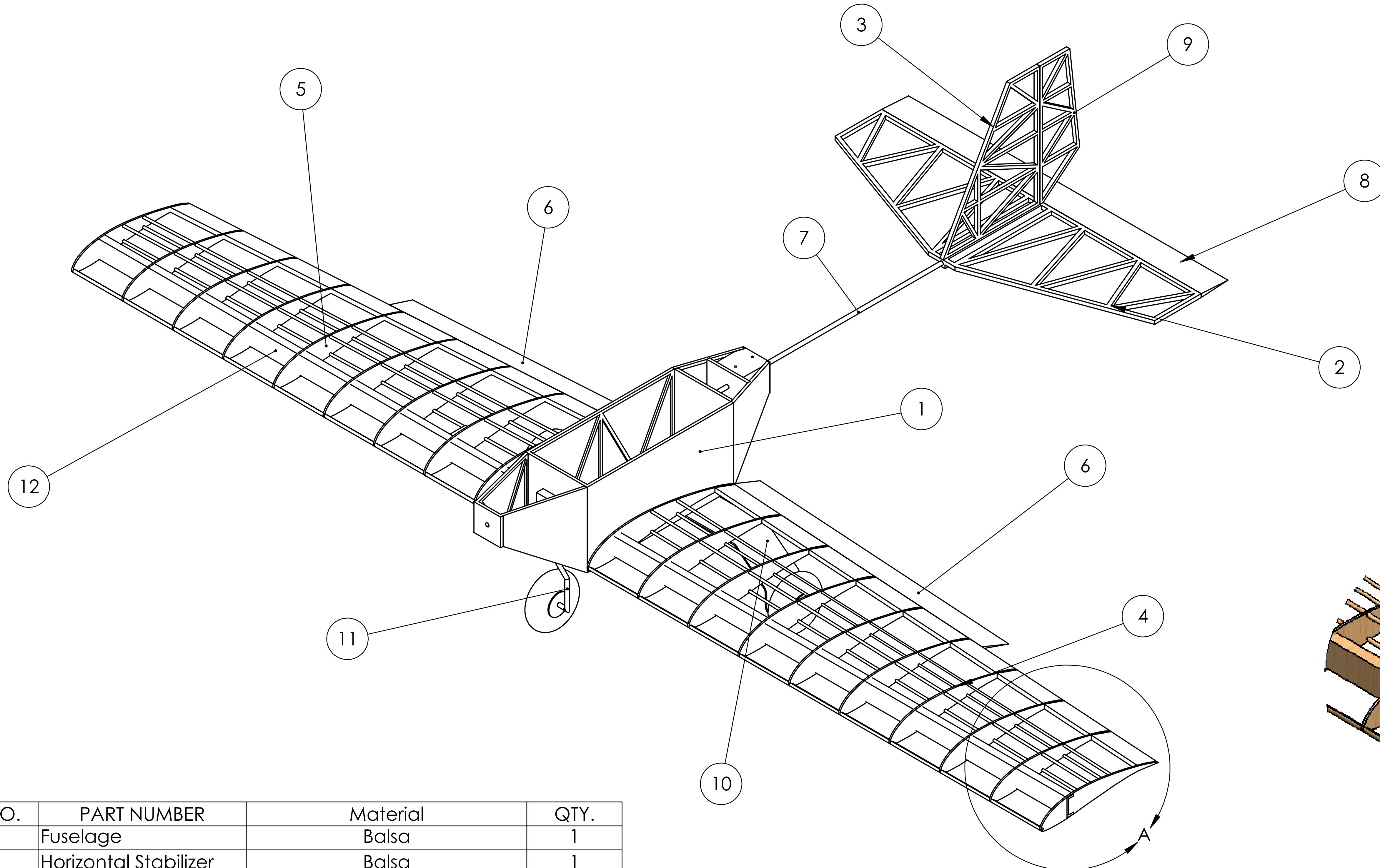
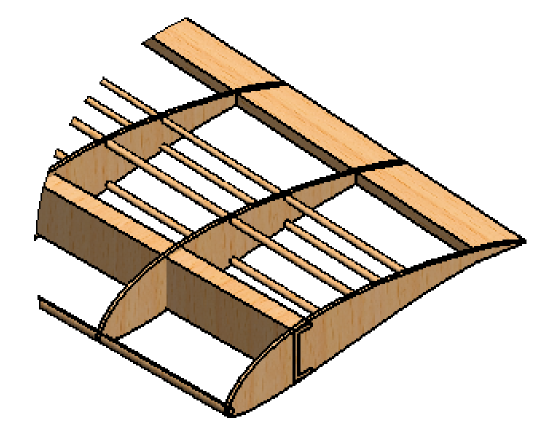
	NAME	DATE
DRAWN	J. Chen	02/15/12
CHECKED	M. ANDERSON	02/17/12
COMMENTS:	UNLESS OTHERWISE SPECIFIED: ALL DIMENSIONS ARE GIVEN IN INCHES	

TITLE:

Aircraft Three-View

SIZE		REV
B	Report Section **DRAWING PACKAGE**	A
SCALE: 1:10		SHEET 1 OF 5





DETAIL A
SCALE 1 : 4

ITEM NO.	PART NUMBER	Material	QTY.
1	Fuselage	Balsa	1
2	Horizontal Stabilizer	Balsa	1
3	Vertical Stabilizer	Balsa	1
4	Port Wing	Balsa	1
5	Starboard Wing	Balsa	1
6	Aileron	Balsa	2
7	Tail Rod	Carbon Fiber	1
8	Elevator	Balsa	1
9	Rudder	Balsa	1
10	Main Landing Gear	Carbon Fiber	1
11	Nose Landing Gear	Carbon Fiber	1
12	Spar	Balsa, Basswood	1

	NAME	DATE
DRAWN	J. Chen	02/15/12
CHECKED	M. ANDERSON	02/17/12

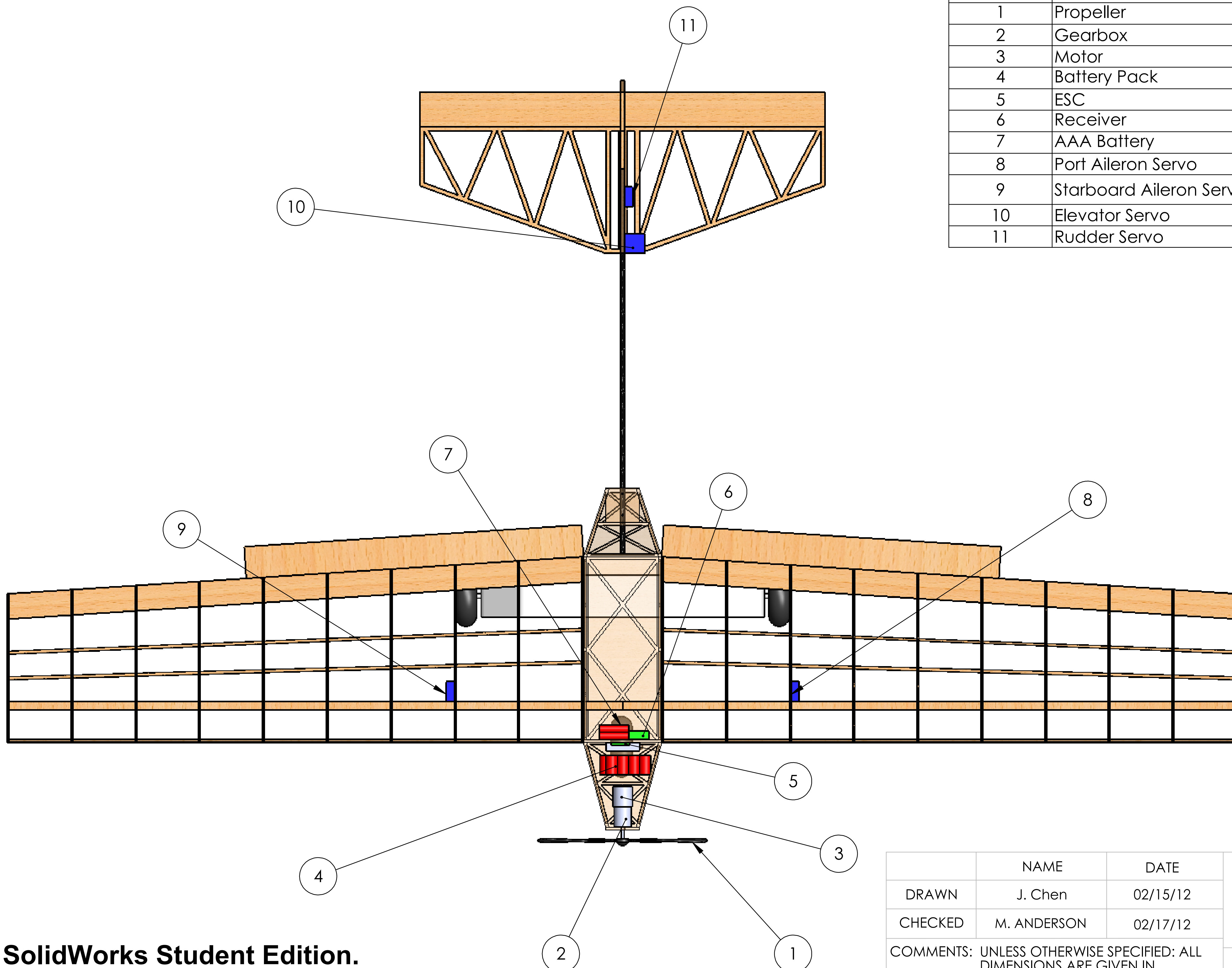
COMMENTS: UNLESS OTHERWISE SPECIFIED: ALL DIMENSIONS ARE GIVEN IN INCHES

TITLE: Structural Arrangement

SIZE B | Report Section DRAWING PACKAGE | REV A

SCALE: 1:10 | SHEET 2 OF 5

ITEM NO.	PART	MODEL
1	Propeller	APC 9x6 / APC 11x6
2	Gearbox	Maxon 4.4:1 Gearbox
3	Motor	Newmotors 1105
4	Battery Pack	8 Elite 1500 Cells
5	ESC	Phoenix-25
6	Receiver	Spektrum AR600
7	AAA Battery	4 Sanyo Eneloop AAA Batteries
8	Port Aileron Servo	Hitech HS-82MG
9	Starboard Aileron Servo	Hitech HS-82MG
10	Elevator Servo	Hitech HS-82MG
11	Rudder Servo	Hitech HS-82MG



	NAME	DATE
DRAWN	J. Chen	02/15/12
CHECKED	M. ANDERSON	02/17/12

COMMENTS: UNLESS OTHERWISE SPECIFIED: ALL DIMENSIONS ARE GIVEN IN INCHES

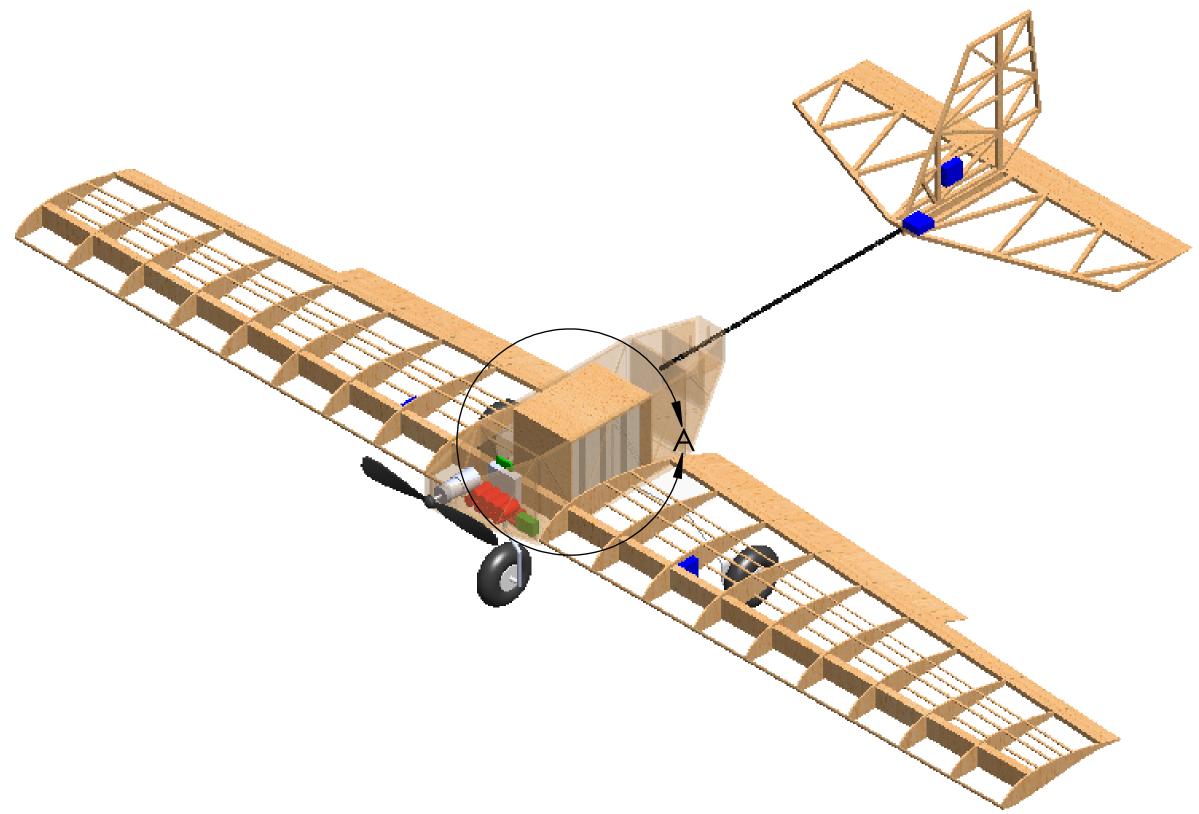
TITLE:

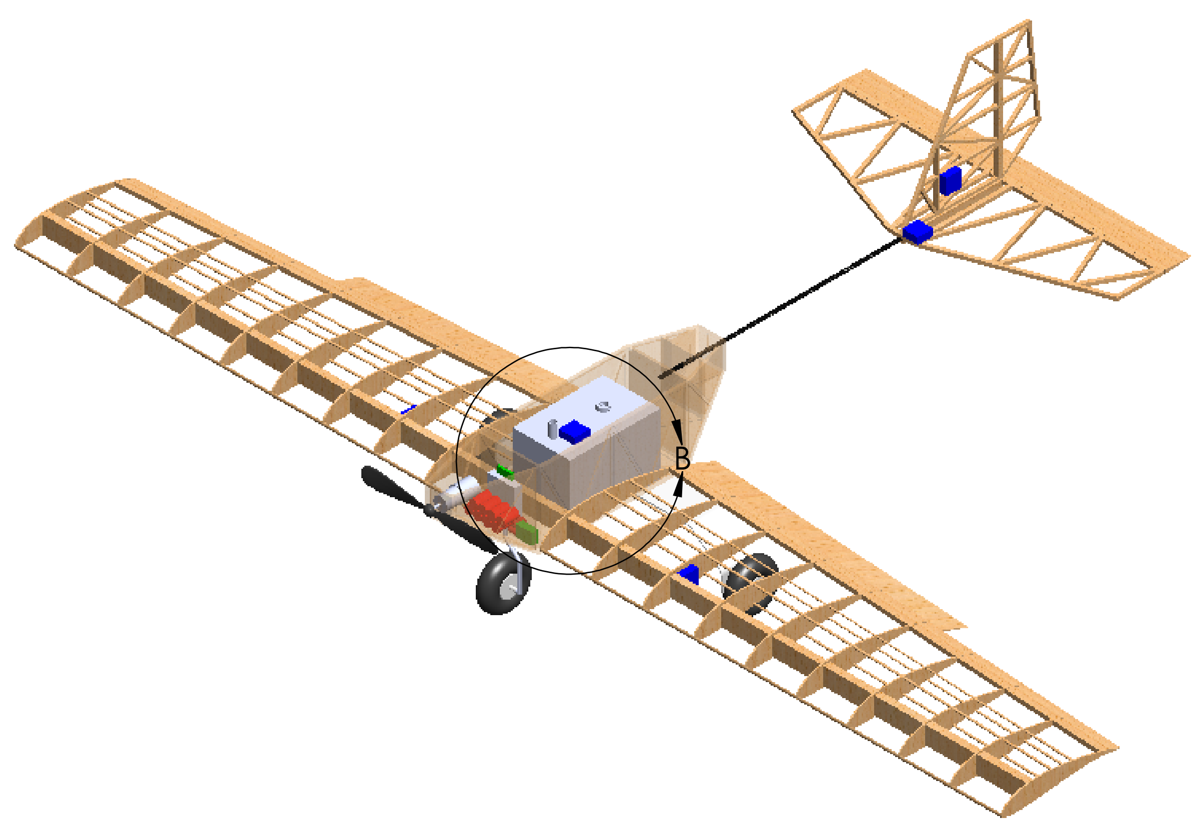
Systems Layout

SIZE	Report Section	REV
B	DRAWING PACKAGE	A

SCALE: 1: 6

SHEET 3 OF 5





DETAIL A
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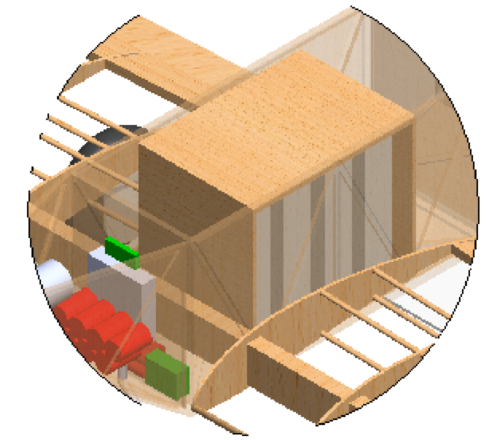

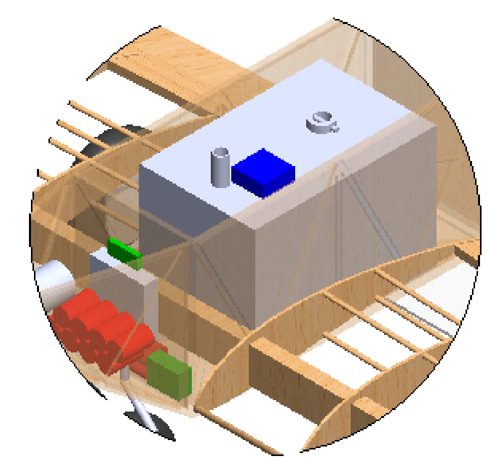

DETAIL B
SCALE 1 : 5

	NAME	DATE	TITLE: Payload Accommodation	
DRAWN	J. Chen	02/15/12		
CHECKED	M. ANDERSON	02/17/12		
COMMENTS:	UNLESS OTHERWISE SPECIFIED: ALL DIMENSIONS ARE GIVEN IN INCHES		SIZE **B**	Report Section **DRAWING PACKAGE** — REV **A**
			SCALE: 1:10	SHEET 5 OF 5

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. The Team considered 5 different Figures of Merit: Weight, Ease of Manufacture, Ease of Repair, Cost, and Strength. Figure 6.1 (below) shows the new Figures of Merit and their weighting.

Metric	1	2	3	4	5	6	7	8	9
Weight									**9**
Ease of Fabrication					**5**				
Ease of Repair							**7**		
Cost	**1**								
Strength			**3**						

Figure 6.1: Figures of Merit for Manufacturing

Additionally, the Team realized that individual components have unique requirements and functions. Because of this, the Team decided that the entire plane did not have to be constructed with a single method, but instead that 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

6.2.1 The Fuselage

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

• **Balsa:** A frame is constructed of balsa wood beams and then the frame is covered in a skin of balsa wood. The whole body is then covered using Mylar.

• **Lost Foam Core:** A block of foam is cut out in the shape of the fuselage. Then the center is removed to create room for the payload and electronic systems.

• **Mold:** A foam model is created and then covered in gypsum. This allows the Team to create a mold from which a fiberglass shell can be made.

The team then put these possible construction techniques into a decision matrix. After careful analysis, the balsa method was selected for the fuselage due to its low weight and easy assembly.

FOM	Weight	Balsa	Lost Foam Core	Mold
Weight	9	27	9	27
Ease of Fabrication	5	25	15	5
Ease of Repair	7	21	7	7
Cost	1	5	3	1
Strength	3	3	9	15
Total	25	82	43	55

Figure 6.2: Fuselage Materials Decision Matrix

6.2.2 The Wing and Tail

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

- **Balsa:** Airfoils for the wing and horizontal stabilizer are constructed out of balsa wood plies and are connected using ribs 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.
- **Lost Foam Core:** A block of foam is cut out in the shape of the wing and tail.
- **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 then put these possible construction techniques into a decision matrix. After an analysis, the balsa method was selected for the wing and tail due to its low weight and easy assembly.

FOM	Weight	Balsa	Lost Foam Core	Mold
Weight	9	27	9	27
Ease of Fabrication	5	15	5	5
Ease of Repair	7	14	7	7
Cost	1	3	3	1
Strength	3	3	6	9
Total	25	62	30	49

Figure 6.3: Wing and Tail Materials Decision Matrix

6.2.3 The Landing Gear

When selecting materials for the landing gear, the Team identified 2 important properties that the material needed to possess: flexibility and strength. The flexibility would allow the landing gear to compress upon landing, thereby acting as a shock absorber and dissipating the load through the fuselage. The strength would allow the landing gear to absorb the force of landing without cracking or deformation. The Team considered a few different choices, including: pre-made landing gear, using heavy gauge control wire, and balsa wood. In the end, the Team realized that the pre-made gear, while strong, had very little flexibility and was very heavy. The balsa wood was very light, but lacked the necessary strength and flexibility. The Team settled on bending the control wire because it was light, flexible and relatively strong.

The Team elected to use off the shelf plastic-foam wheels because of their durability, low cost and wide range of sizes.

6.2.4 The Water Tank

When considering possible materials and fabrication methods for the water tank, the Team focused on 2 main design requirements: watertight and lightweight. The Team considered 2 different approaches: purchase a vessel from the store and modify it, or fabricate a tank from scratch. For self-fabrication, the Team considered 3 different materials: plastic, fiberglass composite, and epoxy-sealed balsa wood. The plastic, though thin, light and waterproof, would be hard to fabricate, because it required a mold/extrusion system. The fiberglass would be easy to layer and make, but the Team thought that a completely watertight container would be unnecessarily heavy and difficult to construct. Finally, epoxy-sealed balsa was rejected due to challenges with sealing and concerns over strength.

Although actual testing was done using epoxy-sealed balsa wood, the Team decided that modifying a commercially available vessel would be the best choice because of its low weight, exceptional durability and ease of modification. To construct the valve, the Team planned on using a lightweight rubber and plastic to seal the water in, and fishing line to hold the valve tight in tension.

6.3 Manufacturing Plan

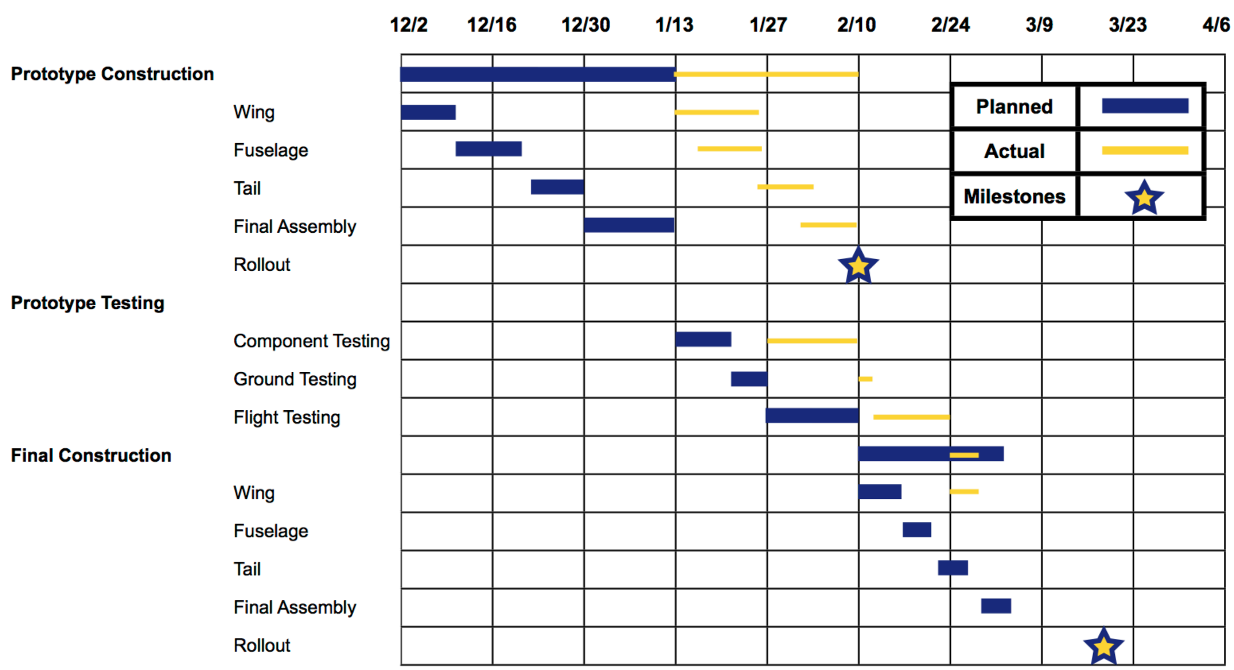

Figure 6.4: Manufacturing Schedule

7.0 Testing Plan

The Team conducted a variety of tests throughout the design and fabrication process in order to ensure that individual components and final assemblies performed as projected. These tests also allowed for correction and optimization of any components that were under-performing.

7.1 Objectives

A comprehensive testing plan was created and executed to gather data. The data was later used to improve the design of the aircraft.

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 of the plane, primarily the wing and the fuselage. The team placed weights along the wing to test wing loading stresses and structural integrity of the wing. In order to test the integrity of the fuselage, it was loaded with its maximum payload and rotated. This test allowed the team to verify that the payload would remain in the fuselage even if the aircraft were to become destabilized in flight.

Aerodynamics

The aerodynamics of the aircraft were tested and optimized with a combination of computer modeling and wind tunnel testing. The Team initially tested the selected wing and airfoil in XFLR5. This also allowed the Team to gather the appropriate performance values. Next, a small section of the wing was tested in the UCSD Wind Tunnel in order to verify performance.

Landing Gear

Due to the heavy payloads for Missions 2 and 3, the Team was concerned about the landing gear failing during a rough landing. In order to prevent this failure, the landing gear was subjected to drop tests to ensure that it would support the weight of a fully loaded aircraft during a rough landing.

7.1.2 Propulsion Testing

Battery Testing

The batteries were tested both individually to certify that they charged and discharged as expected, as well as in an assembled pack to verify that the battery pack produced enough power for the motor.

Propeller and Motor Testing

The Team used a propeller-balancing stand to make sure that the propeller was appropriately balanced before flight. Small changes were made to the wing tips as well in order to balance the propeller. Once balanced, the propeller was attached to the motor, which was mounted on a test stand. The test stand measured the force produced by the motor, which the Team then compared to the estimates produced in MotorCalc. This ensured that the aircraft would have enough speed to take off and allowed the Team to produce estimates for Missions 1 and 3, where speed is critical.

Complete System Testing

The complete system, including the speed controller and fuse, was attached to the testing stand

and subjected to simulated versions of the missions. This allowed the system to be tested full throttle before the aircraft was airborne, ensuring that the batteries had enough capacity to complete the missions and that the fuse wouldn't fail at peak loading.

7.1.3 Payload Testing

Mission 2 Grid

A prototype of the Mission 2 Grid was constructed using the materials outlined in Section 6.2 and subjected to several tests to verify its strength. The Grid was subjected to stress, strain, and a rotational moment to ensure that it wouldn't crack when the bars shifted during a banked turn. Also, the Grid was fitted into a prototype fuselage and loaded with the aluminum bars to ensure that it properly restrained the bars during flight. Also, a check of the center of gravity was performed to certify that that aircraft would remain stable during flight.

Water Tank Testing

The Team tested the water tank to verify its performance in a number of key areas, including water containment, valve operation, water plume size, and performance while loaded in the fuselage. In order to test the water loading and containment, the Team simply filled the tank with water and checked for leaks and structural problems. In order to avoid a possible failure in flight, the valve system was tested at ground level using the servo and receiver before being loaded into the aircraft. Additionally, the Team used a test stand to verify that the speed and size of the water plume would be sufficiently large for the judges to see at 100 meters. Finally, the Team loaded the water tank in the fuselage and verified its in-flight performance.

7.1.4 Flight Testing

After completion of subsystem testing, the Team moved to flight-testing. The goal of flight-testing was to verify the capabilities and performance of the aircraft as a whole. After each test flight, the Team analyzed the performance data and identified areas to improve upon. These areas of improvements were then translated into design changes, which were implemented before the next test flight.

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 and GPS location. Additionally, the Team's pilot gave a report after the flight detailing the stability and handling of the aircraft.

7.2 Master Test Schedule

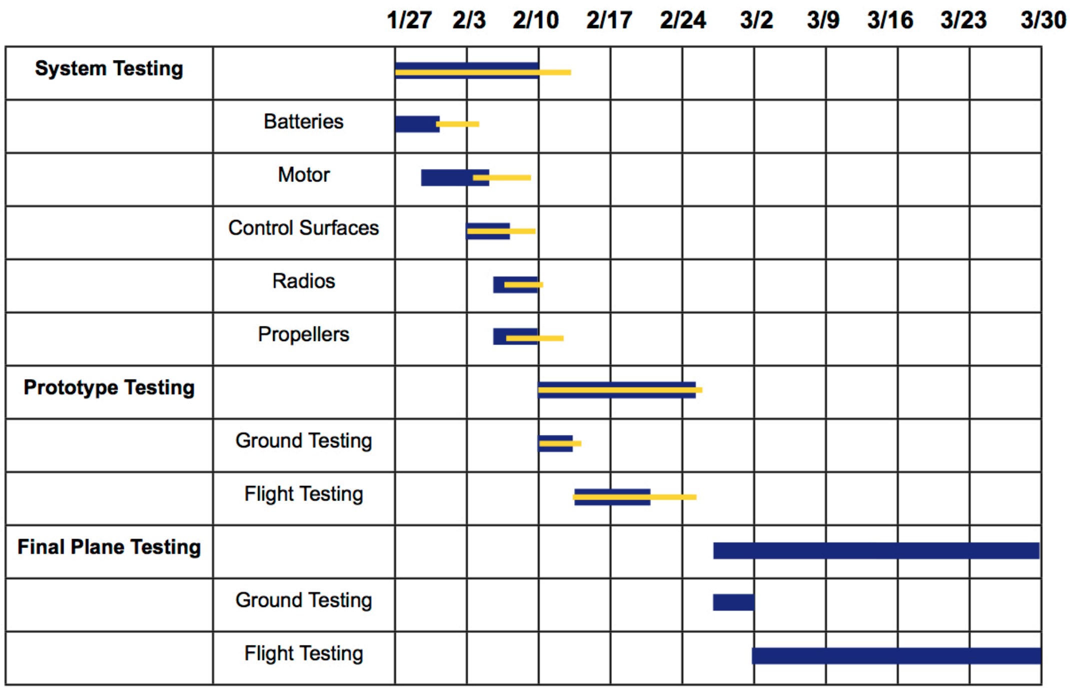

Figure 7.1: Master Test Schedule

7.3 Flight Test Schedule

Flight	Flight Designation	Payload	Description
1	Maiden Flight	None	Ground Takeoff, Fly steady & level for 500 feet
2	Ferry Flight #1	None	Fly 1 Lap at 50% throttle
3	Ferry Flight #2	None	Fly for 4 Minutes at 50% throttle
4	Passenger Flight #1	4 Bars	Complete 1 Lap with 4 Bars
5	Passenger Flight #2	8 Bars	Complete 1 Lap with 8 Bars
6	Time to Climb #1	Empty Tank	Steep Climb to 100 meters
7	Time to Climb #2	1L Water	Steep Climb to 100 meters, Drop Water
8	Full Speed Ferry	None	Complete Maximum Laps Possible in 4 Minutes
9	Full Speed Passenger	8 bars	Complete 3 Laps
10	Full Speed Climb	2L Water	Steep Climb to 100 meters, Drop Water

Figure 7.2: Flight Test Manifest

7.4 Flight Testing Check Lists

Pre-Flight Checklist (These checks are completed immediately before takeoff.)

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 7.3: Pre-Flight Checklist

Final Checklist (These checks are completed immediately before takeoff.)

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

Figure 7.4: Final Checklist

8.0 Performance Results

8.1 Component and Subsystem Performance

8.1.1 Propulsion

Batteries

The Team did a number of real world tests to ensure that the batteries and propulsion system would perform adequately for all missions. Firstly, the batteries were fully charged and then discharged while the throttle was set to 100%. Over 10 tests, the motor ran for an average time of 4 minutes and 40 seconds, which is sufficient to complete any of the missions.

Additionally, the Team connected the propulsion system to a 20 amp fuse, as specified in the contest rules, and ran the motor at maximum RPM until the batteries died. These conditions simulated the maximum current draw possible during any flight. Given that the fuse did not burn out, the Team was confident that they were running below the 20 amp limit.

Motor Thrust

The Team used a motor test stand to measure the force generated by the motor. The Team expected that the motor would produce a maximum of 1.9 lbf of thrust. According to the force meter mounted on the test stand, the motor produced 1.3 lbf of thrust. While this is slightly below the expected value, the Team was confident that the aircraft had enough thrust to overcome the expected drag. A picture of the motor mounted on the test stand can be seen below in Figure 8.1:

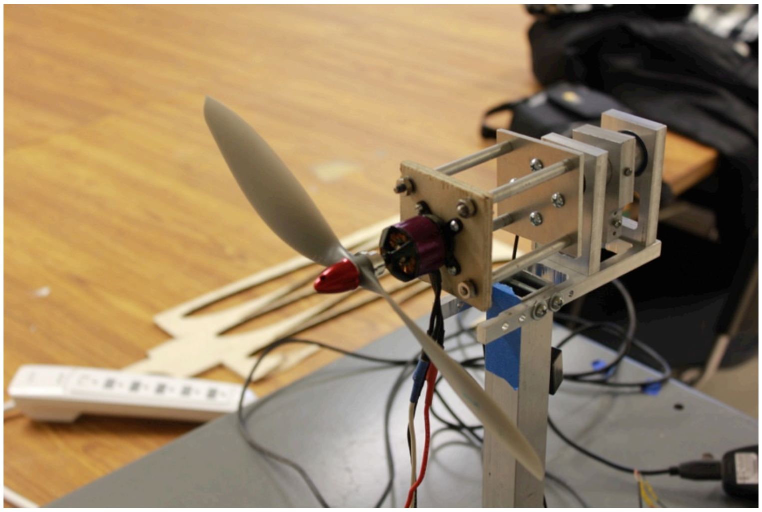

Figure 8.1: Motor on Test Stand

8.1.2 Structures

Wing Strength

To test the wing, the Team performed a wing loading test. The Team estimated that the maximum weight of the aircraft would be 8.5 pounds. To ensure that the wing would be able to survive almost any loading situation, the Team hung 3 pounds of weight from each wing tip and supported the wing at the center. (See below in Figure 8.2.) Since there was no deflection of the wing, the Team is confident that the wing is strong enough to survive the maximum loading during flight.

Figure 8.2: Wing Load Test

Figure 8.3: Wing Spar Load Test

To test the strength of the wing spar (see figure 8.3), the team constructed an I-beam made of balsa and basswood. The team then loaded the wood beam (modeling the wing spar) with 12 pounds without damage and with only ¼ inch deflection toward the tip of the wing. With the assumption that each wing distributes the load of the plane equally, each wing should be loaded with approximately 4lb. The test load of 12 pounds is therefore approximately 3 G's. Since there was only minimal deflection on the wing spar, the test conclusion was that the wing spar design is rigorous enough to withstand flight stresses.

Landing Gear

The Team performed two tests to ensure that the landing gear was strong enough to withstand a rough landing. First, the landing gear was subjected to a number of drop tests from different heights. The Team started small, with an initial drop from 6 inches, and worked their way up to a maximum height of 3 feet. From this height, the aircraft has a downward velocity of 10 ft/s and the landing gear was subjected to a force of 100 lbf. From this height, the landing gear spread an additional 3 inches to the sides, causing the propeller to hit the ground.

Next, the landing gear was subjected to a crush test. The Team loaded increasing increments of weight into the fuselage and measured the deflection of the landing gear. Starting at 1 pound, the Team worked their way up to 12 pounds, almost twice the maximum weight of the aircraft during Mission 2 landing. Given that the landing gear deflection was 1.5 inches, the Team was again concerned about the flexing of the landing gear during a rough landing. The loaded aircraft and flexing landing gear can be seen in Figure 8.4.

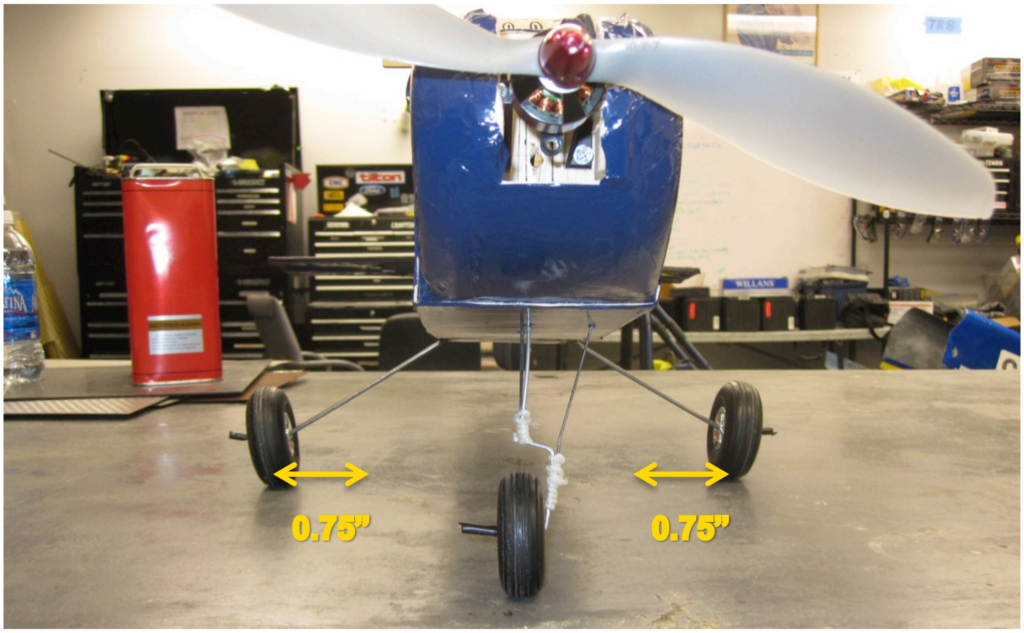

Figure 8.4: Loaded Landing Gear

8.1.3 Payload

Water Tank

The Team constructed a test water tank that was 0.25 times of the size of the final 2L tank (to save time and materials). From there, the Team tested the tank's water retention abilities, the servo release system, and the flow rate. From the testing data, the Team estimated that the flow rate was 0.079 liters per second, and the water plume was 0.5 inches across measured 0.5 feet below the drop point. Given these tests, the projected size of the water plume will be 4 times larger. Additionally, the speed of the aircraft through the air will increase the size of the plume further. Therefore, the Team expects the water plume to be sufficiently large for the judges to see it.

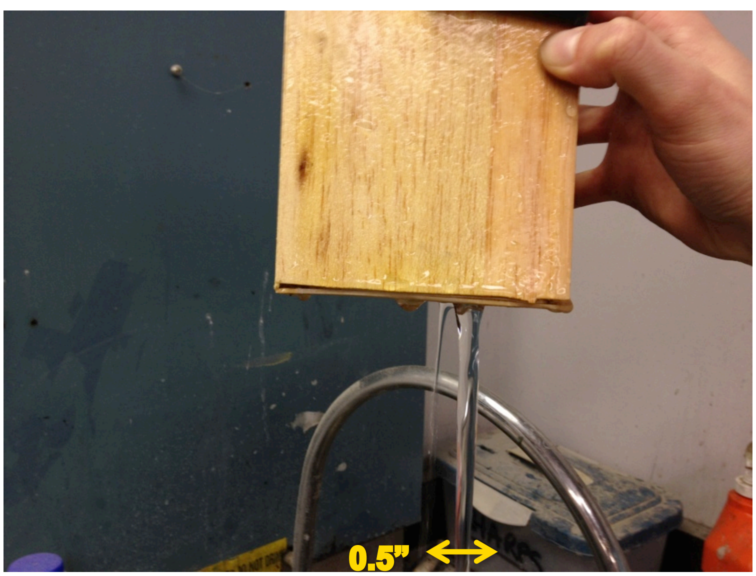

Figure 8.5: Prototype Water Tank and Water Plume

8.2 Complete Aircraft Performance

8.2.1 GPS Unit Testing

The Team purchased a GPS telemetry unit and eLogger V4 flight recorder from Eagle Tree Systems in order to aid their flight-testing. The GPS unit allowed the Team to map their flight path and calculate velocity, turning speed, takeoff distance, and takeoff speed. A plot of the GPS data, from a test, can be seen below in Figure 8.6. The path is red and superimposed over a Google Earth map of the course.

Figure 8.6: GPS Test Course

8.2.2 Electronics Systems

Although the Team tested the motor on the thrust test stand, the Team felt that it was necessary to test the electronics system as a complete package installed in the aircraft. Using the aforementioned Eagle Tree eLogger V4, the Team measured the voltage and amperage of the battery pack with the motor throttled and the servos moving, simulating actual flight. This test showed the team that the electronics did not pull more than 8 amps at 60% throttle. Extrapolating up to 100% throttle, the Team was confident that the electronics system would stay under the 20 amp limit even with the servos drawing power. The graph of voltage/amperage vs. time can be seen below in Figure 8.7.

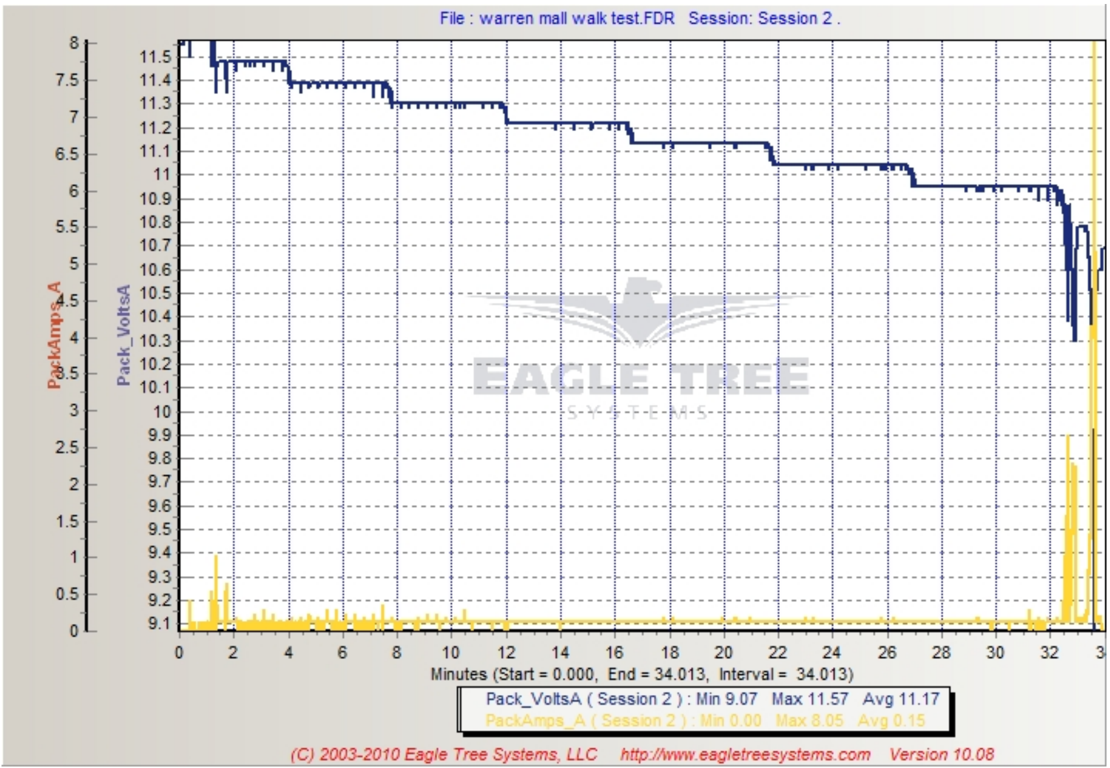

Figure 8.7: Voltage/Amperage vs. Time

8.2.3 Flight Testing

The Team successfully completed a couple of flight tests the produced insightful test results. The first test was a ground taxi and acceleration test during which the Team verified the ground control of the aircraft. From these tests, the Team discovered that the front landing gear was not rigid enough, which caused the aircraft to veer left during takeoff acceleration. After making the necessary modifications, the Team proceeded with a second round of flight test to verify takeoff distance and takeoff speed. After completing 3 takeoff tests, the average takeoff distance was 35 feet with a speed of 25 MPH. When compared to the Team expectations (seen in section 4.7), these values compare favorably. However, the Team was concerned that the loaded plane would struggle to takeoff within the 100-foot limit. Because of this, the Team looked into changes to the motor to generate more thrust. Additionally, the prototype aircraft used a wing mounted on the top of the aircraft. This led to instability in the pitching moment of aircraft as well as more drag. Because of these problems, the Team elected to switch to a low mounted wing, as seen in the CAD models. The prototype aircraft can be seen just after takeoff in Figure 8.8.

Figure 8.8: Prototype Aircraft in Flight

8.2.4 Modifications

After gathering the testing data, the Team looked at ways to fix some of the problems revealed by the testing. One of the biggest problems was the landing gear the flexing problem. To fix this, a cross-member was added to the rear landing gear to create a strong triangle, forming a truss-section. Additionally, the nose gear was converted to a rotating landing gear to give the aircraft better ground control.

In order to improve the stability of the aircraft, a number of changes were made. As noted previously, the wing was moved from the top of the fuselage to the bottom, thereby reducing the tendency of the aircraft to pitch widely during flight. Also, the Team used stiffer control wire with tighter connections so that the control surfaces were less likely to deflect during high G-force moments, such as takeoff.

The Team hopes that these changes will positively increase the performance of the final aircraft. Testing is ongoing and the Team hopes to further improve the performance and control before the competition.