University of California, San Diego

Team TLAR XI

Design/Build/Fly 2011

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1.0 Executive Summary

The challenge presented to the team for the Design, Build, Fly Contest for 2010-2011 consisted of 3 missions. Mission 1 is a speed test, where the plane must complete as many laps around the flight course as possible in 4 minutes. The score for Mission 1 will be determined by the number of laps the Team flew divided by the most laps any team flew. Mission 2 is a payload test, where the plane needs to fly 3 laps with a steel bar as the payload. The score for Mission 2 will be determined by calculating payload weight divided by total weight and then multiplying by 3. Finally, Mission 3 will be another payload test where a predetermined number of golf balls were carried for 3 laps. The final score equals 2 times the number of balls carried by the team divided by the maximum number of balls carried by any team. The Team knew that it would be unable to win the competition by focusing on any one mission, so the final plane design balanced the needs and requirements of all three missions.

In addition to the mission scores, the maximum empty weight (Rated Aircraft Cost or RAC) was considered crucial because the final score was divided by the square root of the RAC. In an effort to achieve the highest possible score, the team performed an in depth analysis of the scoring equations, and decided upon a design close to and empty weight of 1lb in order to prevent score reduction.

In an effort to maximize the score for the first mission, the team selected a motor and battery system that would give the best performance and speed without a significant weight increase. In addition, a light weight structure of balsa wood was selected, again to reduce the overall weight of the plane. Finally, a control system, consisting of ailerons on the main wing and elevators on a V-Tail, was selected in order to give the plane efficient maneuverability. The team’s plane can complete 6 laps in 4 minutes.

Success for Mission 2 depends on a good ratio of payload weight to overall weight. The team established a 50-50 ratio as the optimum ratio, and constructed the plane and payload accordingly. Since the goal was to build a plane that weighs about one pound, a payload weight of one pound was planned. Furthermore, securing the payload in flight was a major concern of the team. To this end, a simple grid system that allowed both the retention of the steel bar and the golf balls (for Mission 3) was constructed inside the payload bay.

For Mission 3, the team decided that, since the weight was already maximized on Mission 2, the team would match the weight of the steel bar with an equal weight of golf balls, equating to 9 golf balls. In an effort to increase the stability of the plane in flight, a golf ball retention system was built, consisting of a simple grid pattern to keep the balls in place without adding signifcant weight.

The combined design features of the airplane will allow it to perform well on all three missions. In Mission 1, the plane will fly at high speeds and maneuver well, thereby decreasing lap time and increasing the score for the mission. In Mission 2, the plane will carry half of its weight as payload, thereby guaranteeing the team a score of 1.5. Finally, in Mission 3, the plane will carry the same weight of golf balls as the steel bar. In conclusion, the design of the aircraft gives the team a competitive chance in each of the missions.

2.0 Management Summary

2.1 Project Management

The personnel of the TLAR XI team were organized into 7 groups that handle different aspects of the aircraft: Structures, Propulsion, Aerodynamics, Stability, Fabrication, Flight Performance and Flight Test. Group Leads managed the activities of the groups, and the Project Manager oversaw the workings of the entire project. The management flow chart is shown below. Many people served in more than one group because this allowed the Team to better utilize the available human resources.

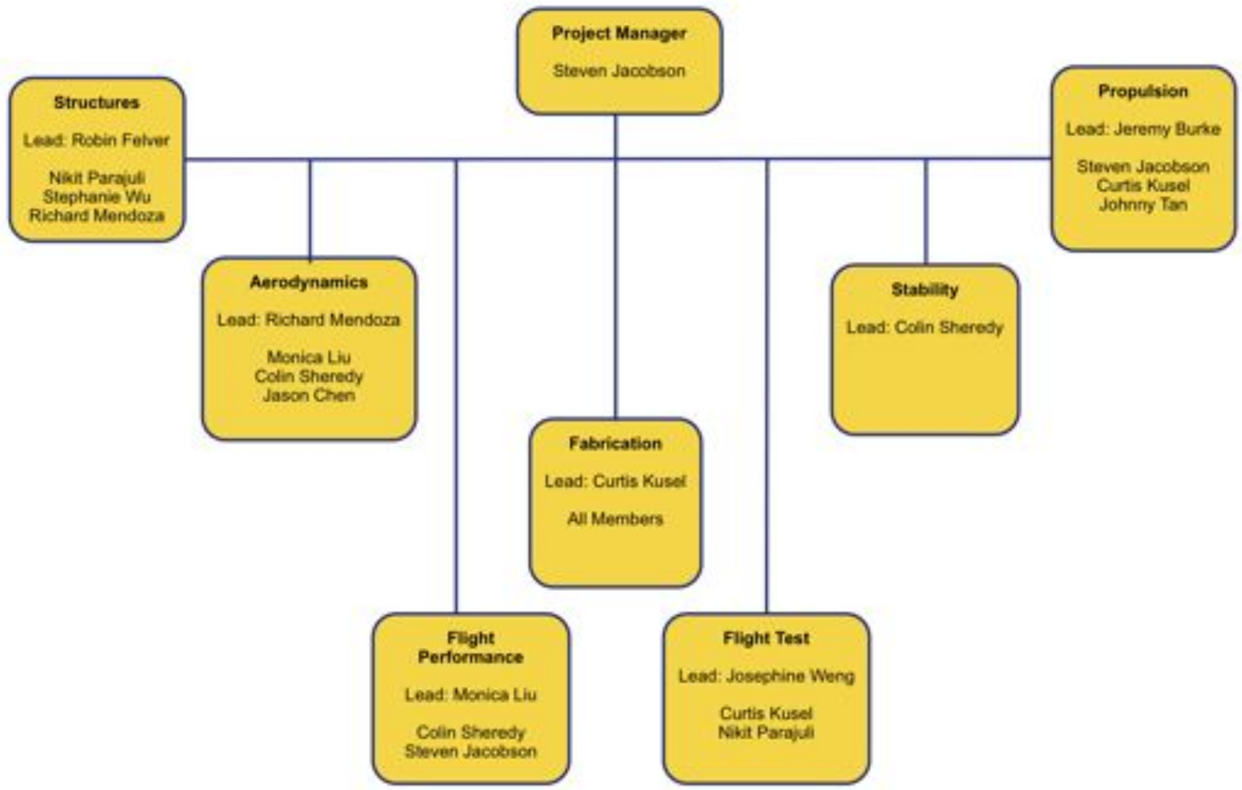


Figure 2.1: Management Flow Chart

The Structures Team was responsible for designing the fuselage and selecting the materials for the airplane. In addition, they determined the center of gravity of the plane so it was balanced in flight. The Propulsion Team was in charge of selecting the motor, propeller and battery pack. They did extensive testing and data analysis to determine which motor/propeller/battery combination would yield the best results. The Aerodynamics Team was tasked with the selection of the airfoil shape, the wing dimensions, and the tail design. They used computer modeling software to create lift charts and flow diagrams in an effort to fully understand the lift distribution. The Stability and Controls team was responsible for 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 taking the designs and specifications of the airplane and creating a complete, working competition airplane. They were also tasked with the repair and maintenance of the airplane. The Flight Test Team was responsible for organizing, planning and executing a variety of flight tests so that the team could prove the airplane's flight readiness, capabilities, and gather valuable, real-world data. It was then the job of the Flight Performance Team to analyze the flight test data and identify areas for improvement.

2.2 Milestone Chart

Planning and keeping to a schedule is a key aspect of project and time management. In an effort to finish the project on time, the Team created a schedule. 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 and how successful the Team was at adhering to it.

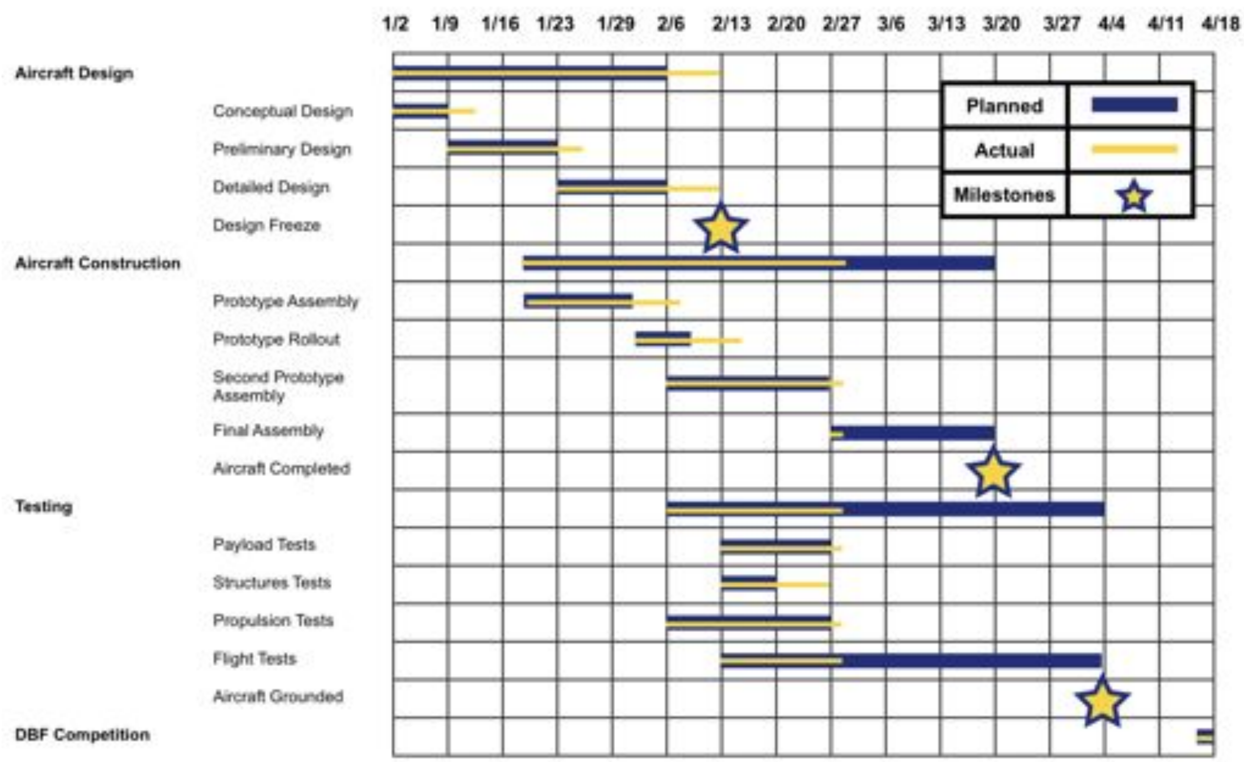


Figure 2.2: Milestone Chart

3.0 Conceptual Design

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 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 were selected.

3.1 Mission Requirements

The AIAA Design, Build, Fly competition for 2011 consisted of three missions and the design report. The report was scored out of 100. Mission 1 had a maximum score of 1. Mission 2 had a theoretical maximum score of 3 (although the real maximum score was around 1.5. More on this idea later) and Mission 3 had a maximum score of 2. The equation for the total team score is:

Final Score = Design Report * (M1 + M2 + M3) / Sqrt(RAC).

RAC is the maximum empty flight weight of the competition aircraft, and ends up being an important component of the final score. The scoring equation of each mission, and the RAC were analyzed and a sensitivity analysis was performed so that the highest scoring aircraft was designed.

3.1.1 - General Requirements, Limitations, and Concerns

- The battery pack for the propulsion system cannot weight more than ¾ of a pound
- The UAV system must fit into a commercially produced carry-on bag
    - The sum of the linear dimensions may not exceed 45 inches
    - No one dimension may exceed 22 inches
- 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 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, shown in Figure 1, 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 the airplane will go under full throttle in order to have enough acceleration to complete the 360 turn. After the airplane successfully completes the 360 turn it will encounter its second turn. The airplane will complete the remaining laps in the same manner and described above. However, at the final lap of each mission the airplane will be reduced to cruise throttle to prepare for landing. Finally, when the airplane has been successfully landed the motor is switched off and the airplane comes to a halt. The layout of the flight course is shown below in Figure 3.1.

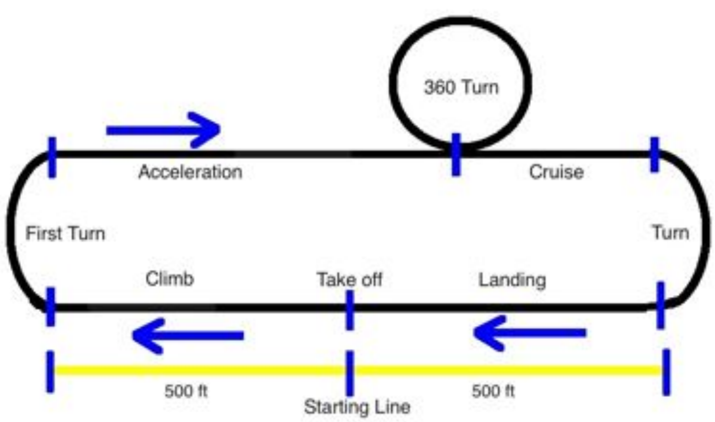


Figure 3.1: Competition Flight Course

3.1.2 - Ground Crew and Assembly Crew

The UAV system must enter the staging area inside the carry-on luggage. A single ground crew member must assemble the aircraft and load the payload in less than 5 minutes. After the 5 minute period, no work can be done on the aircraft.

- Mission 1 simply requires the aircraft to be assembled
- Mission 2 requires the ground crew member to assemble the aircraft and load the steel bar payload.
- Mission 3 requires the ground crew member to assemble the aircraft and then load a preselected number of golf balls into the payload bay. The balls will be provided by competition officials.

3.1.3 - Mission 1: Dash to Critical Target

Mission 1 is a timed, 4 minute speed test. The score for this mission is determined by the equation: M1 = N_laps/N_max where N_laps is the number of laps the aircraft completed in 4 minutes and N_max is the maximum number of laps any team completed in 4 minutes. The mission starts when the aircraft leaves the launchers hand and ends when 4 minutes is up. Only fully completed laps will be counted

3.1.4 - Mission 2: Ammo Re-Supply

Mission 2 is a 3 lap payload mission. After the aircraft is assembled in the staging area, the steel bar (of dimensions 3 in x 4 in x Z in, where Z is determined by the team) is inserted into the fuselage. This assembly, loading, and checkout must occur in the 5 minute assembly window. The aircraft must then complete 3 laps and land successfully. The score for this mission is determined by the equation: M2 = 3 * Payload_Weight/Flight_Weight, where Payload_Weight is the weight of the steel bar and Flight_Weight is the weight of the aircraft with the steel bar. Weights are taken upon the conclusion of a successful flight.

3.1.5 - Mission 3: Medical Supply Mission

Mission 3 is also a 3 lap payload mission. After the aircraft is assembled in the staging area, the ground crew member will load the pre-selected number of golf balls into the payload bay. This assembly, loading, and checkout must occur in the 5 minute assembly window. The aircraft must then complete 3 laps and land successfully. The score for this mission is determined by the equation: M3 = 2* N_balls/N_max, where N_balls is the number of balls the team's aircraft carries and N_max is the maximum number of balls carried by any team. The team receives their score upon completion of 3 successful laps and a successful landing.

3.1.6 - RAC

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: Low weight, good stability to increase speed and handling
- Mission 2: Payload weight roughly equal to, or slightly greater than, empty aircraft weight. Payload must be well secured during flight.

- Mission 3: Need a good way to secure the golf balls. Number of golf balls is determined by their weight (should roughly equal the weight of the steel bar)
- Carry-on Luggage and Aircraft Design: Aircraft needs to split into small pieces that fit into the luggage, but the number of pieces should be kept to a minimum so that assembly is not an issue.
- RAC: Aircraft should weigh about 1 US pound so that the score is not significantly reduced by the sqrt(RAC) term. (RAC is the maximum empty weight after each successful flight.)

3.2.1 Sensitivity Analysis

The team used the mission score equations provided to create graphs and models of possible scores. In some cases, past competition aircraft was analyzed so that a benchmark could be established. Since the total score is divided by the square root of RAC (maximum empty weight). By analyzing previous competition planes, the Team decided that, despite the score increase, it would be infeasible to build a plane at weighed less than a pound. The payload weights were calculated after making the decision to build a 1lb plane. Figure 3.2 shows to what extent the sqrt(RAC) term can damage a team's final score.

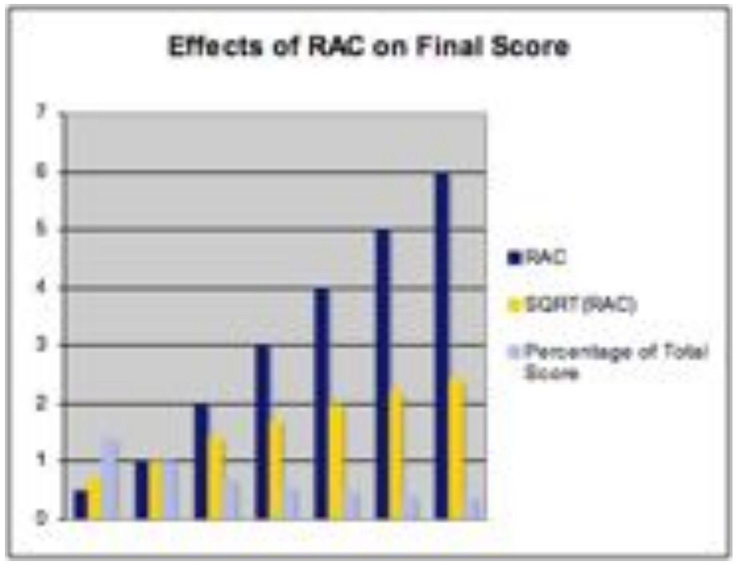


Figure 3.2: Effects of RAC on the Final Score

Figure 3.3: Scoring Analysis for Mission 1

For Mission 1, the team assumed that the maximum number of laps a team could complete in 4 minutes is 8. This assumption was found by calculating the approximate length of the flight course (3400 feet) and then averaging past maximum velocities (about 70 miles per hour). The maximum score for Mission 1 is 1. Figure 3.3 shows the score based on the number of laps flown.

For Mission 2, it was assumed that, in the best case scenario, payload weight would make up 60% of the total flight weight. This meant, that the best possible score for Mission 2 would be 1.8 (M2 = 3 * (0.6)). Figure 3.4 shows the score for Mission 2 based on the weight ratio.

Figure 3.4: Scoring Analysis for Mission 2

For Mission 3, the team assumed that the weight of the golf balls would be roughly equal to the weight of the steel bar in Mission 2. This notion means that it was assumed that weight, not volume, would be the limiting factor for Mission 3. Therefore, since the weight of a golf ball is 1.62 ounces, the maximum number of golf balls for the team's aircraft was assumed to be 10. This result meant that the maximum score for Mission 3 is 2 (M3 = 2 * (10/10)). Figure 3.5 shows how the number of balls affects the score.

Figure 3.5: Scoring Analysis for Mission 3

A final analysis was conducted that compared the weight of the plane to the total flight score. The different plot lines on the graph refer to different numbers of maximum golf balls carried. Figure 3.6 confirms that low empty weight improves the total score.

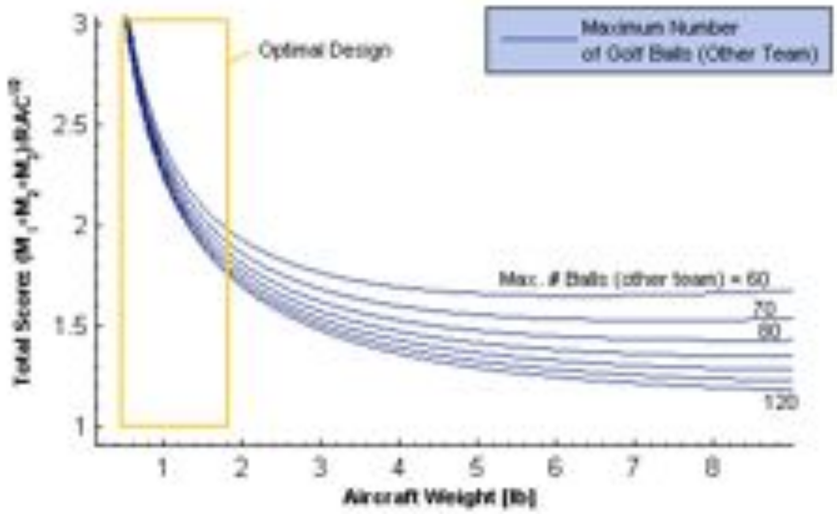


Figure 3.6: Relationship between Aircraft Weight and Total Flight Score

As the above figures show, the best plane would be a light, fast plane that can carry a large payload. But this configuration is just simply not possible because high velocity and the ability to carry a large payload involve two different design directions. So, it became an important part of the scoring analysis to look at how the missions sum together. If the total score of the 3 missions is calculated as the sum of the maximum score for each mission, the total score is 4.8. Then it is possible to represent the percentage of the total score each mission represents.

- Mission 1 = 21%
- Mission 2 = 37%
- Mission 3 = 42%

With this idea in mind, the team came to the conclusion that although it would be relatively easy to build a plane that could achieve a high velocity and therefore win Mission 1, such a plane would have a low payload capacity, and the team's score would suffer because of lower Mission 2 and 3 scores. It was then decided that a slower plane that can complete at least 5 laps would be competitive as long as it is capable of achieving high scores on Missions 2 and 3.

However, the team did recognize that there was the possibility that other teams would design their planes to be stellar in one mission, for example Mission 1, while meeting the minimum requirements for other missions. After much thought, it was decided that a plane that had a balanced design, yet still focused on payload, would yield the highest possible score.

3.3 Solutions, Configurations and Results

3.3.1 - The Fuselage

Several different layouts for the fuselage were considered, and the following decision matrix was created. The triangular fuselage was selected because it best fit the requirements. Figure 3.7 shows this decision matrix used to select the fuselage shape.

	Triangular	Square	Circular
Weight	1	0	0
Strength	0	0	0
Payload Containment	1	0	-1
Ease of Fabrication	0	1	-1
Total	2	1	-2

Figure 3.7: Fuselage Decision Matrix

3.3.2 - The Wing

Several possible wing-detachment schemes were tested to see which one would be the best, based on weight, assembly time, ease of manufacturing and maximum wing size. The top mounted layout was selected because it best fit the requirements. Figure 3.8 depicts the wing attachment decision matrix.

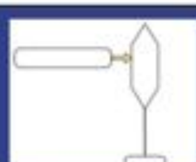
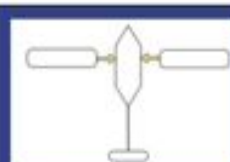
	 Single Side In	 Double Side In	 Top Mount - Single	 Top Mount - Double
System Weight	0	0	0	0
Assembly Time	1	1	3	2
Ease of Manufacture	2	2	2	2
Allowed Wing Length	0	2	0	2
TOTAL	**3**	**5**	**5**	**6**

Figure 3.8 Wing Attachment Decision Matrix

3.3.3 - Propulsion System

Motor Configuration

Several possible motor configurations were evaluated to see which one would be the best for the team's plane. The configurations were then put into a decision matrix where a number of factors were considered. A description of the different motor configurations and the decision matrix are below:

- Single Tractor: one motor and propeller mounted on the front of the plane
- Single Pusher: one motor and propeller mounted on the back of the plane
- Double Tractor: one motor and propeller mounted on the front of a nacelle on each wing
- Tractor and Pusher: one motor and one propeller mounted on the front and back of the plane.

The propulsion team came to the conclusion that the Single Tractor was the best configuration because of its low weight, and simple design. Figure 3.9 shows the why the Single Tractor is the best choice.

	Single Tractor	Single Pusher	Double Tractor	Tractor and Pusher
Weight	0	0	-1	-1
Takeoff Performance	0	-1	1	0
Stability	0	-1	0	-1
Drag	0	0	-1	-1
Complexity	0	0	-1	-1
Total	0	-2	-2	-4

Figure 3.9: Propulsion Configuration Decision Matrix

Battery Layout

The team decided to go with an 8-Cell Battery, which would be smaller and lighter since we didn't need a very long battery life. We fit the battery in the middle of the fuselage, since there is the most space in that compartment as shown in Figure 3.10.

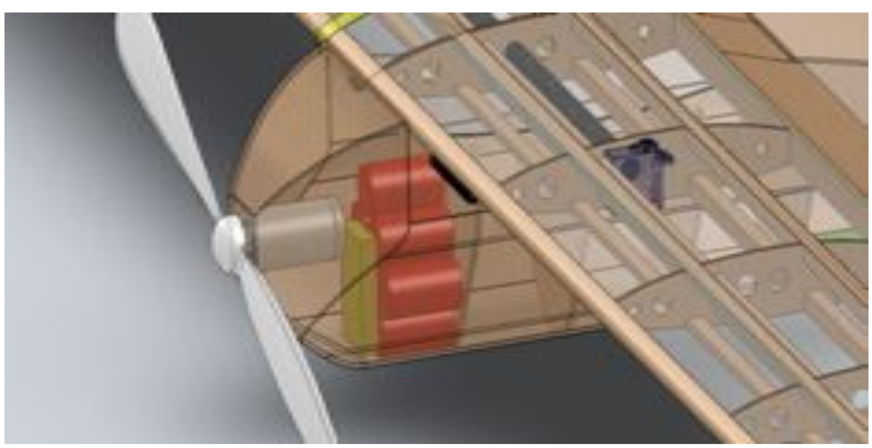


Figure 3.10: Battery Location in Plane

Cooling

From our tests, we've concluded that our team needed some sort of ventilation system in order to maximize our aircraft's efficiency. The battery cell voltage had a high discharge rate due to extremely high temperatures that were a result of build up from the battery itself. Air ventilation routes start from the bottom of the aircraft and exit through the backside of the aircraft (See Figure 3.11).

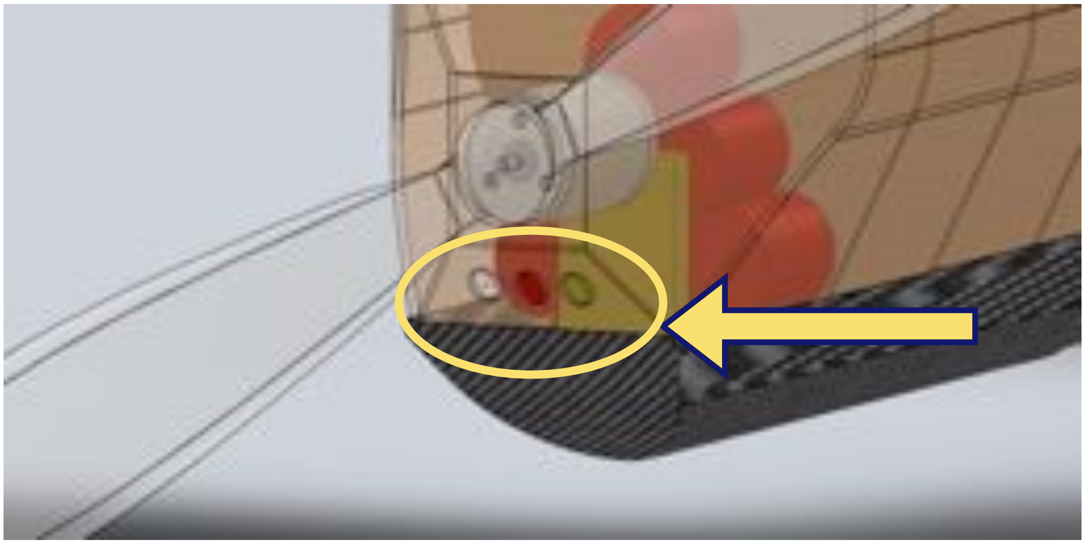


Figure 3.11: Cooling System Intake

Figure 3.12 illustrates the path of air through the internal compartment of the aircraft, which is where the battery is located. The openings are positioned so there is positive pressure on the lower surface where the entrance is and negative pressure on the upper side surfaces. This design facilitates airflow to go through the motor and battery compartments, therefore cooling it down.

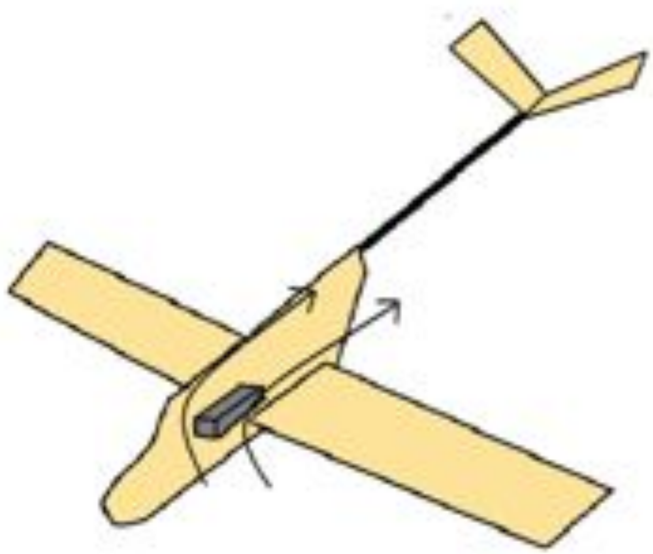


Figure 3.12: Cooling System

3.3.4 - Aircraft Configuration

The configuration of the aircraft was driven by two main concerns: ability of complete the mission and ease of construction. With this idea in mind, the team considered a number of possible configurations, including:

- Conventional Plane with a Two-Piece Wing
- Conventional Plane with a Three-Piece Wing
- Flying Wing
- Bi-Plane

After deciding to look at these four configurations, the team decided to develop a decision matrix with the following parameters:

- Weight
- Assembly Time
- Storage in the Box (suitcase)
- Payload Capacity
- Ground Handling
- Ease of Manufacturing
- Drag

After analyzing the results of the matrix, the team concluded that the conventional configuration with a two-piece wing would be the best option.

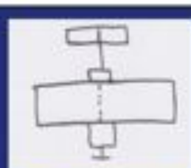
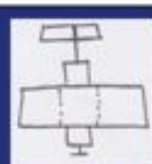
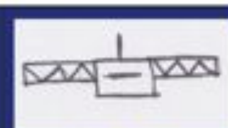
	 Conventional (2 piece wing)	 Conventional (3 piece wing)	 Flying Wing	 Bi-Plane
Weight	0	0	-1	-1
Assembly Time	0	-1	1	0
Storage in Box	0	1	0	0
Payload Capacity	0	0	-1	0
Ground Handling	0	0	0	-1
Ease of Manufacturing	0	-1	-1	-1
Drag	0	0	0	-1
Total	0	-1	-2	-4

Figure 3.13: Aircraft Configuration Decision Matrix

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 center of gravity), one on the tail
- Bicycle - two wheels (front and back of fuselage), two outriggers
- Tricycle - two wheels (side by side at center of gravity), one at front of fuselage

However, since the competition calls for a hand launch, the team made the decision to use a skid on the bottom of the plane rather than a traditional landing gear with wheels. Though wheeled landing gear allows for easier and more stable ground handling, they interfere too much with the hand launch to be advantageous.

As is displayed in the Landing Gear Decision Matrix, a no wheel landing gear configuration was considered and chosen. The Skid is constructed of a sturdy material and attached to the bottom of the fuselage. It was chosen mainly because it allows for ease of hand launching. (See Figure 3.14).

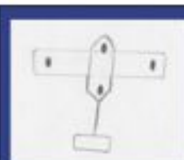
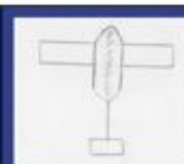
	 Tail Dragger	 Bicycle	 Tricycle	 Skid
System Weight	0	-1	0	1
Ground Handling	2	0	1	0
Drag	1	-1	0	2
Ease of Hand Launch	-2	-2	-1	2
TOTAL	**3**	**-2**	**1**	**5**

Figure 3.14: Landing Gear Decision Matrix

3.3.6 - Tail and Stability

The Team considered many possible tail configurations, which are shown in Figure 3.15.

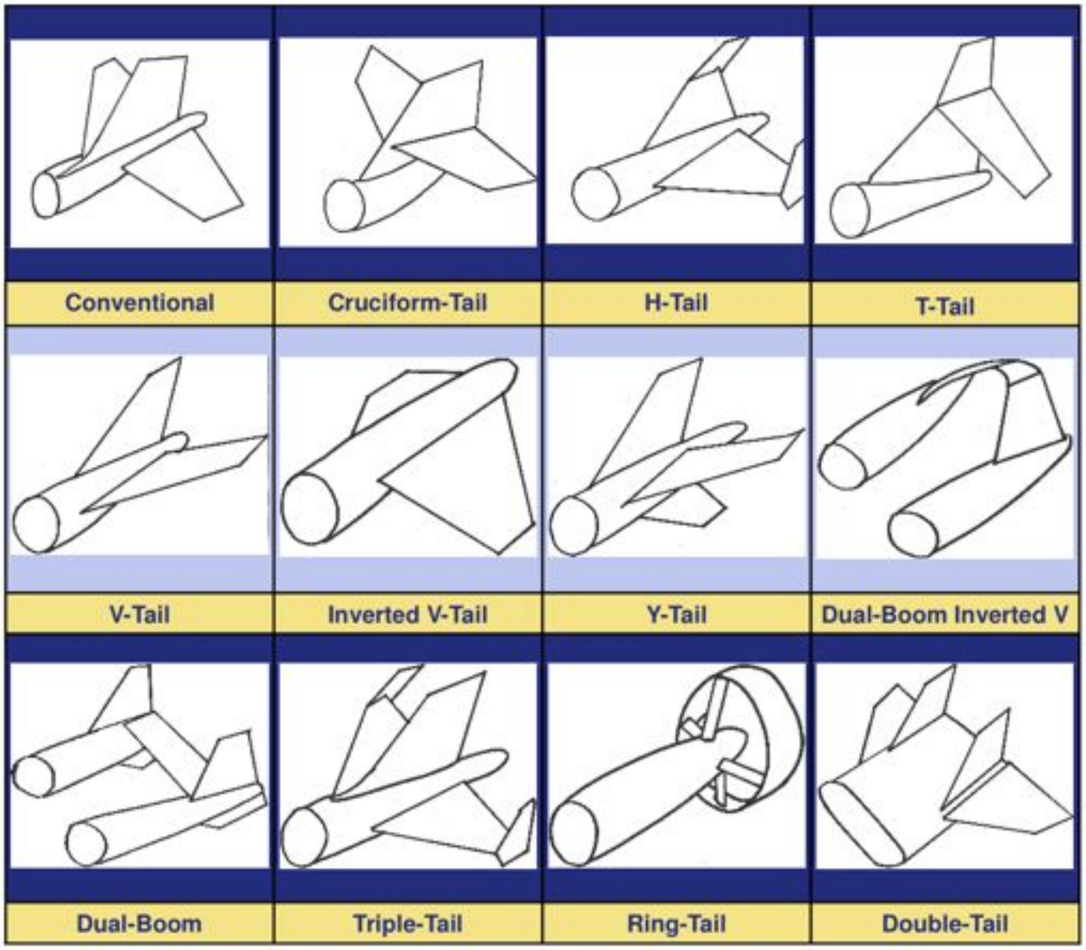


Figure 3.15: Possible Tail Configurations

Several factors came into play as the Team paired this array of configurations down to a select few. Structurally, because the Team planned on using carbon fiber booms for simple tail to fuselage assembly, the Team found a twin boom of any type was more unstable if boom thicknesses were reduced to match the weight of a single larger boom and required more than 25% more weight than a single boom for structural stability. Also considered was the fact that landing gear would not be used so the tail would need to survive landings without catching the ground. Without considerable bracing and added weight the inverted V-tail, inverted Y-tail, and Y-tail would be prone to fail themselves and cause excessive impact on the nose during landing. In the end, the simplest designs with the best aerodynamic features were selected. The Team ended up with the V-tail, conventional and T-tail. These few tail designs were placed in the decision matrix in Figure 3.16 and evaluated.

			
	Conventional	T-Tail	V-tail
Landing Ruggedness	0	1	1
Effectiveness	0	-1	-1
Weight	0	-1	1
Structure	0	1	0
Ease of Storage	0	-1	1
Ease of Fabrication	0	-1	-1
TOTAL	**0**	**-2**	**1**

Figure 3.16: Tail Configuration Decision Matrix

As can be seen in the diagram the T-tail was removed despite the increased horizontal stabilizer efficiency (from the end-plate effect) due to its inherent higher weight from structural re-enforcements needed for the vertical stabilizer to support the horizontal stabilizer. Issues balancing an initial prototype with a conventional tail configuration due to tail weight made us unwilling to choose any but the lightest designs. Finally, the V-tail won out over conventional due to the prospect of lower wetted area, lighter weight, and ease of packing into the luggage. It also proved to be better because the complexity of control mixing was not a concern. There was no concern because the Team decided early on to exclude yaw control to save weight due to the lack of any real need for precise flying. This decision meant the Team could simply use the control surfaces on the V-tail as elevators with no mixing required. Though the V-tail was chosen overall, the Team were uncertain without flight-testing whether the Team would need to over-size it for reasonable stability and pitch control. Thus the Team ultimately built both tail configurations and tested them in flight.

3.3.7- Suitcase

Since many of the dimensions and features of the suitcase were set in the contest rules, the Team did not have many design decisions to make with regards to the suitcase. But a few crucial features were identified early on that helped the team pick a suitcase to buy:

- Single compartment (so that there is maximum space)
- A top-opening suitcase with a large opening (to save time when the plane needs to be removed and assembled)
- Wheels and feet that are incorporated into the main compartment (so that none of the linear dimensions are taken up by unusable space)

Figure 3.17: Sample Suitcase

3.4 Final Conceptual Design

After creating decision matrices as seen before, the team selected an aircraft with the following design elements:

- Triangular fuselage.
- 2 piece wing that mounts on top of the fuselage.
- Single tractor.
- Aircraft will be a conventional design.
- Wing will be detachable and split in the middle.
- Simple skid on the bottom for landing gear
- V-Tail on the end of a boom.
- Standard carry-on suitcase that allowed for the most internal storage. (See Suitcase Aircraft Configuration below)

This design was selected because it gave the team the best chance at achieving a winning score on all the missions.

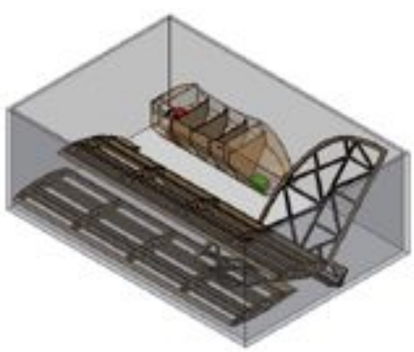


Figure 3.17: Suitcase Aircraft Configuration

Figure 3.18: Design of Plane

4.0 Preliminary Design

Preliminary design covers structures, aerodynamics and propulsion. For each field, the team did analysis work and some testing in order to discern what the best components, configurations and materials would be for the final design.

4.1 Design and Analysis Methodology

Keeping in mind that weight affected the final score the most, each part of the plane was analyzed separately. These methods are described in detail below, and then expanded upon in Section 4.2.

- **Airfoil** - Using a multi-variable analysis, possible airfoils were compared and the best airfoil for the three missions was selected.
- **Tail** - The size of the tail was determined by minimum control requirements. The size was also determined based on the need to fit in the suitcase.
- **Motor** - Motors were compared using data obtained from the manufacturers' website. The lightest motor that gave the required thrust was selected.
- **Propeller** - Propellers were tested to find the size and pitch that yielded the most thrust.
- **Batteries** - Batteries were tested to find the one with the best energy capacity for weight.
- **Payload Bay** - Differing fuselage shapes and grid layouts were tested to see which one would stabilize the load best.
- **Wing Mounting** - The spar system as developed by calculating the required weights and loads and testing possible configurations.
- **Case** - A suitcase was selected that gave the greatest amount of internal space.

4.2 Mission Modeling and Optimization Analysis

This section discusses how the team optimized the performance of the airplane for each mission in terms of aerodynamics and propulsion.

4.2.1 Aerodynamics Mission Optimization

The Aerodynamics Team determined a rough estimate of scores for different configurations. The members of the Aerodynamics Team considered weight, ability of the propulsion system, and general aerodynamic characteristics. Then, this data was considered with the Flight Course in mind. The Flight Course is shown in Figure 4.1.

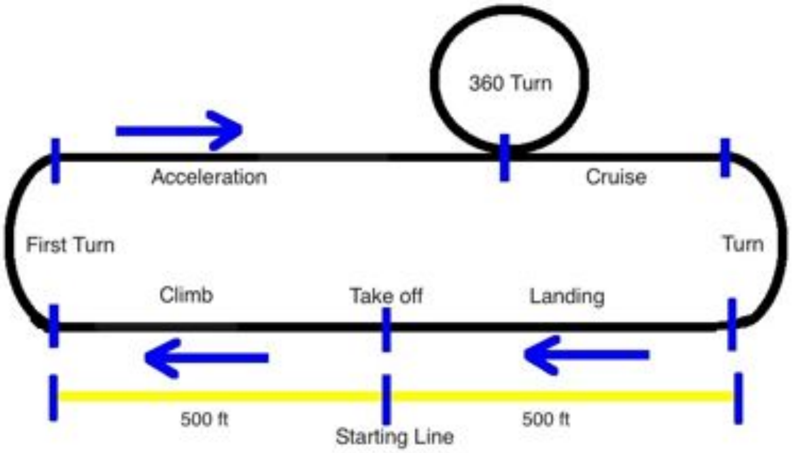


Figure 4.1: The Flight Course

The Aerodynamics Team considered all of the variables, and then selected a few airfoils to further analyze. The Team was also able to estimate the power needs of the airplane from these analyses.

4.2.2 Propulsion Optimization

The challenge that the team faced with propulsion was weight. While a heavier propulsion system meant a faster, stronger plane, it also meant a lower score because the final score was so dependent on a low weight. In an effort to find a good balance between weight and performance, the team created a procedure for determining the best configuration. The flow chart that shows this procedure has been included below.

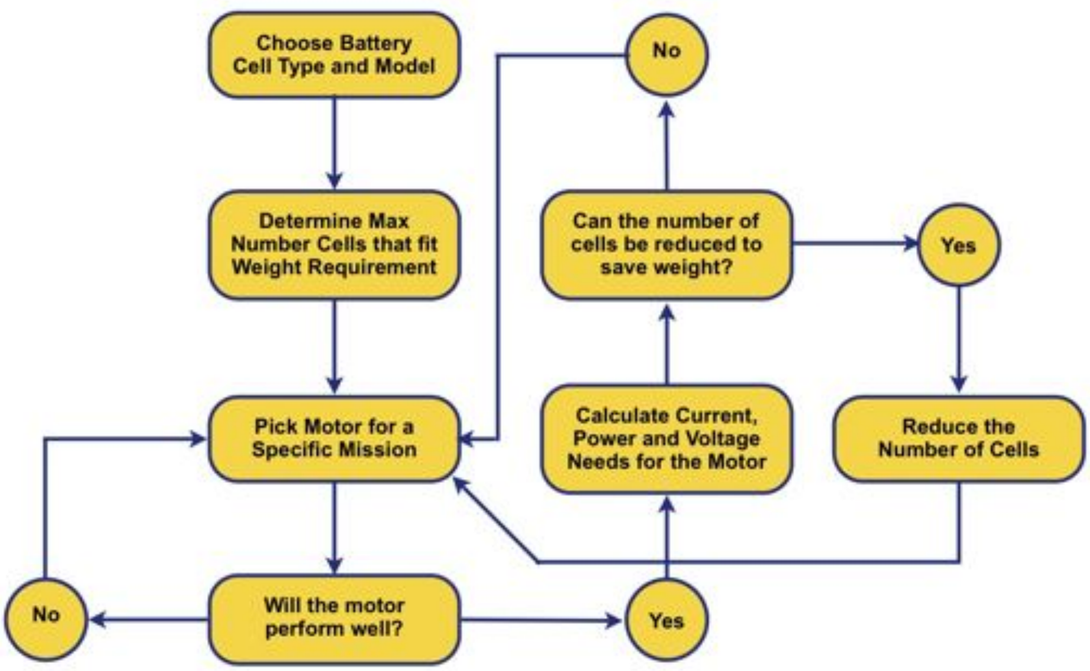


Figure 4.2: Motor and Battery Selection Flow Chart

4.3 Design and Sizing Trade-offs

4.3.1 Aerodynamic Trade-offs

Airfoil

After researching many airfoils, the team narrowed it down to three airfoils: NACA 2412, NACA 66(2)-415, and NASA GA(W)-2. The NACA 2412 has a thickness of 12%, while the NACA GA(W)-2 has a thickness of 12.93%, and the NACA 66(2)-415 has a thickness of 14.99%. These three airfoils are very similar in terms of thickness. The Team used XFLR5, an airfoil analysis program, to find the optimum airfoil. The following figure (Figure 4.3) is a graph of C_L/C_D (lift to drag ratio) vs angle of attack. The Team varied the angle of attack from -2° to 14° and chose a Reynolds number of 400K. Based on this graph, the NASA GA(W)-2 is the best choice out of the three airfoils based on the lift to drag ratio. The Team would like a high lift airfoil for the airplane because the Team focused on carrying golf balls and steel bars, and from the graph, the NASA GA(W)-2 line has the highest C_L/C_D.

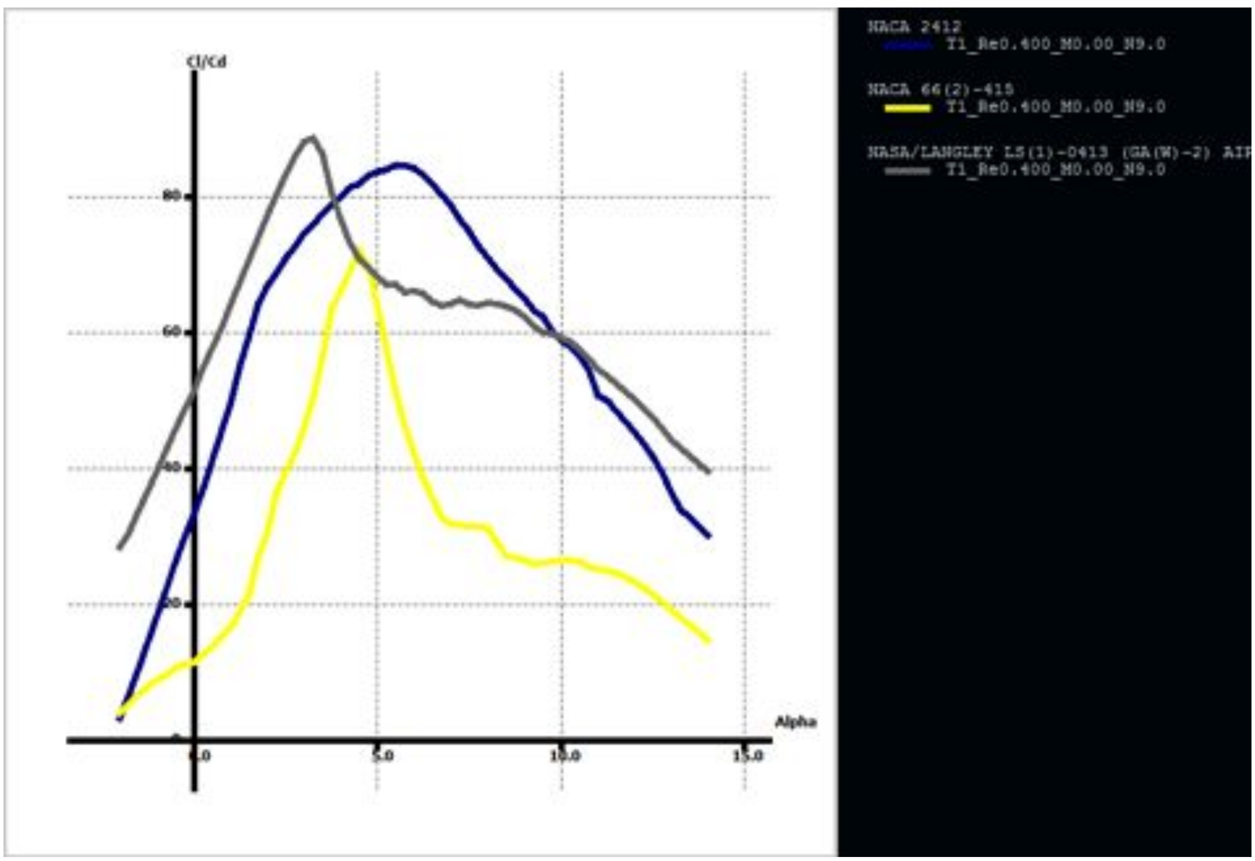


Figure 4.3 : Glide Ratio vs. Angle of Attack

The Team also used XFLR5 to estimate the lift coefficient and angle-of-attack relationship. From following figure (Figure 4.4), one can see that the NASA GA(W)-2 airfoil has the highest coefficient of lift vs angle of attack line. This supports the decision to choose the NASA GA(W)-2 as the airfoil for the plane.

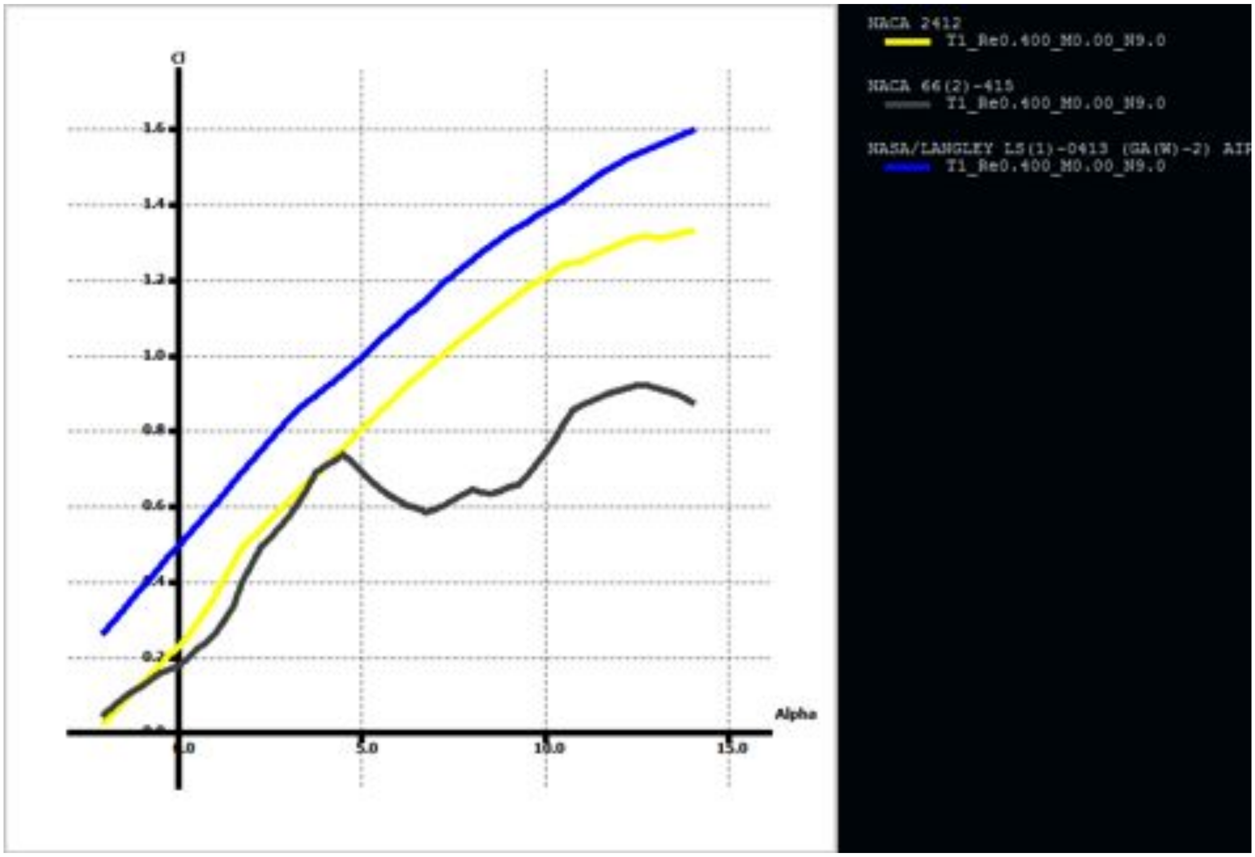


Figure 4.4: Coefficient of Lift vs. Angle of Attack

Figure 4.5 shows the cross section of the NASA GA(W)-2 airfoil.

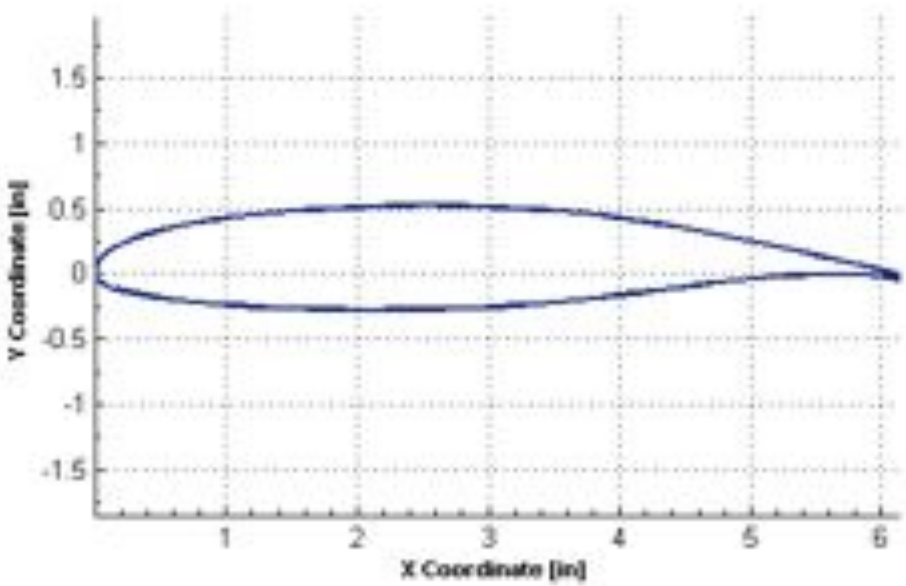


Figure 4.5 The NACA GA(W)-2 airfoil

Wing Size

Because the aircraft must be hand launched, the minimum flight velocity was an important design consideration in the aircraft design. The Team knew that for a successful launch, the plane had to achieve its minimum flight velocity very quickly, or else it would crash shortly after launch. With this in mind, the Team calculated the minimum velocity needed for launch, and then plotted that against wing area. Figure 4.6 was used to determine the required wing area and angle of attack for the wing.

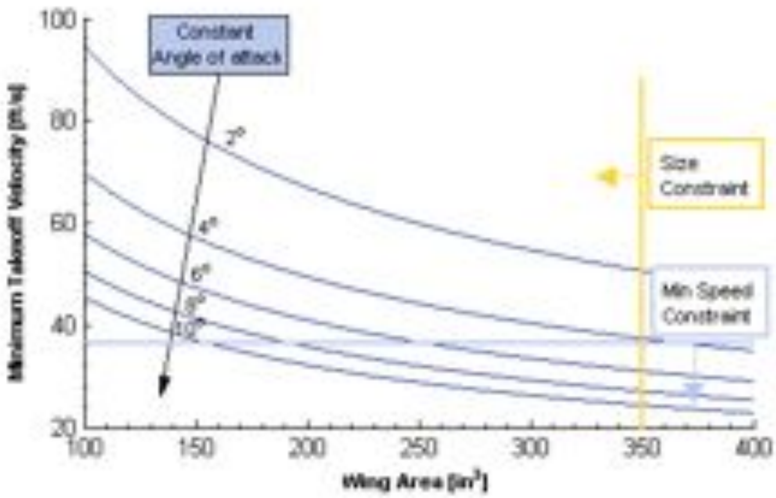


Figure 4.6: Wing Area vs. Minimum Takeoff Velocity

Figure 4.7 was used to optimize the wing span and the chord length. Since the Team wanted to have the lowest weight possible, that was the main factor when making a final decision. As Figure 4.7 shows, a 40 in. wingspan with a chord length between 4 in. and 6.5 in. was considered optimal. With this result in mind, the Team decided on a 40 in. wingspan and a chord length of 6.126 in. Both of these dimensions are within the recommended ranges.

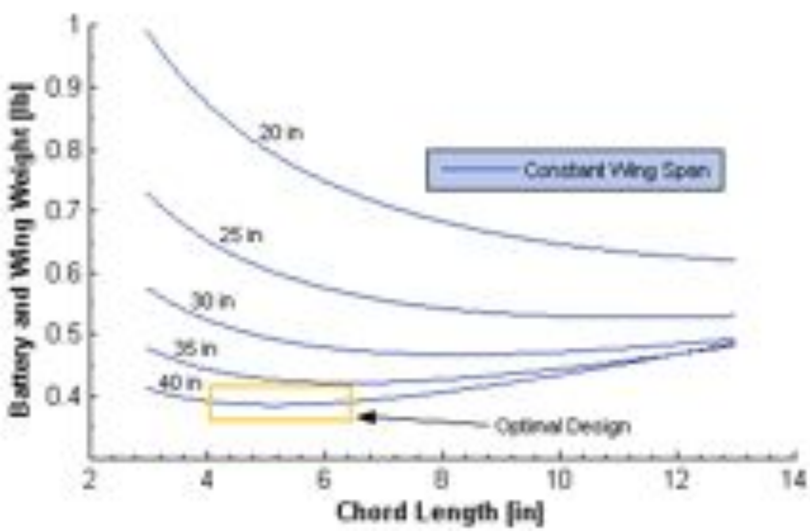


Figure 4.7: Chord Length vs. Battery and Wing Weight

4.3.2 Propulsion System Trade-offs

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
Sanyo KR1500AUL	1500	1.00	1.67 x 0.66 x 0.66	NiCAD
Sanyo KR1700AU	1700	1.20	1.91 x 0.66 x 0.66	NiCAD
Sanyo HR-AAU	1650	0.99	1.97 x 0.56 x 0.56	NiMH
Intellect 1400 2/3A	1400	0.82	1.12 x 0.67 x 0.67	NiMH

Figure 4.8: Battery Specifications

When choosing a set of batteries, the Team had to meet certain criterion such as weight, size, and capacity. In Figure 4.8, a list of batteries was taken into consideration based on the above criterion. 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 the same range. In the end, the Team chose the Elite 1500 because of their high capacity to weight ratio.

Motor Selection

Motor Description	Kv [*RPM/V*]	No Load Current [*Amps*]	Max Current [*Amps*]	Power [*Watts*]	Weight [*Ounces*]
Neo 400-750	750	0.45	20	150	2.12
SuperTiger 400	950	0.6	18	145	1.76
Hacker A20 20L	1022	0.85	19	210	2.01
Hacker A20 30M	980	0.6	14	180	1.48

Figure 4.9: Motor Specifications

A number of motors were investigated but the selected ones in Figure 4.9 were the most viable for the missions. All four motors are brushless outrunner motors that provide the Team with ample torque. Even more important was the weight of the motor which factors into the overall no-load weight value of the aircraft. Other parameters that were taken into consideration were Kv and power output.

Propeller Selection

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.

Propeller Size	Propeller Load Factor
9x4	324
9x6	486
10x4	400
11x5	605

Figure 4.10: Propeller Size vs. Propeller Load Factor

With this data in hand, the team decided that the 9x6 propeller would be good for the Dash mission because it had the potential for the highest speed due to its small diameter and high pitch. Also, it was decided to use the 10x4 propeller for the payload missions because speed was not as much of an issue, and the slower propeller provided more thrust.

4.4 Analysis Methods and Sizing

<u>4.4.1 Tail Sizing</u>

<u>Airfoil Selection</u>

The Team decided to use the same airfoil for the tail as they did for the wing. While this decision may seem odd at first, it offered a lot of advantages. The airfoil was selected based on its low weight, and good aerodynamic capabilities. These same principles still applied to the tail, so the same airfoil was used. Furthermore, this decision made fabrication easier since there was only one, standardized airfoil.

<u>V-Tail Sizing</u>

The size of the V-Tail was especially important. When deciding on sizing for V-Tails, it is important to consider the horizontal projection of the tail. Considering this insures that there will be enough surface to control the plane in flight. The Team performed these analyses, and came to the conclusion that a tail with a span of 14.75 in. and a chord length of 8 in. would be sufficient to properly control the plane.

<u>4.4.2 Fuselage Sizing</u>

<u>External Sizing</u>

Sizing the fuselage was a balancing act. While a larger fuselage allowed more room for payload, it also added weight. The Team had previously decided on a triangular shape for the fuselage. With this in mind, an analysis was performed to see what the optimal fuselage size would be that could also carry the required amount of payload. Since the Team was aiming for an empty weight of 1 lb., the payload weight was also assumed to be 1 lb. Given that the volume of the golf balls was the limiting factor, a fuselage was designed that could hold the required amount of golf balls (9 balls).

<u>Internal Grid</u>

In addition to sizing the external limits of the fuselage, the Team designed a bulkhead system that could contain and stabilize the payload without adding too much weight. The Team decided that, since a triangular fuselage was already stabilizing the payload, a few bulkhead that were spaced 1.6 in. apart would be sufficient. The 1.6 in. corresponds to the diameter of a golf ball.

4.5 Lift, Drag and Stability Analysis

The coefficient of lift, the coefficient of drag and angle of attack were examined for the airfoil NACA GA(W)-2. Figure 4.11 is the graph of C_L vs. C_D .

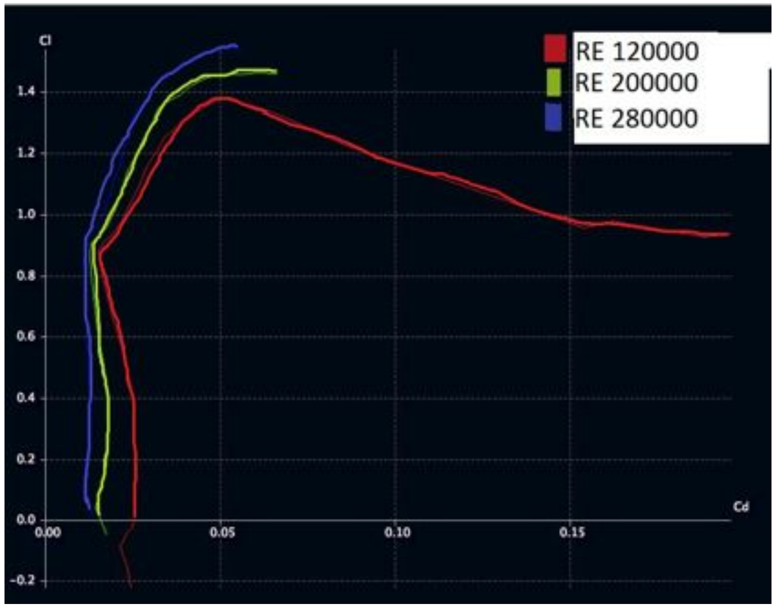


Figure 4.11: Lift vs. Drag for Various Reynolds Numbers for NASA GA(W)-2 Airfoil

Figure 4.12 is the glide ratio vs. angle of attack for varying Reynolds Numbers.

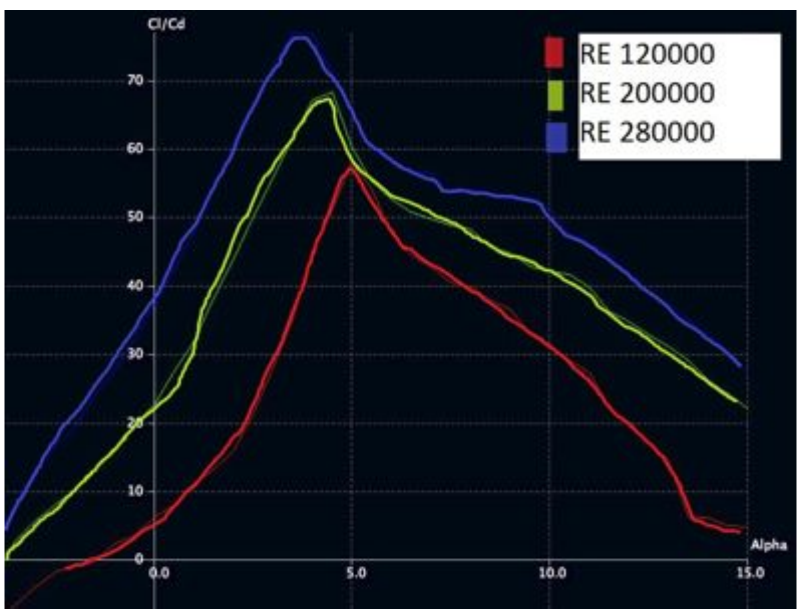


Figure 4.12: Glide Ratio vs. Angle of Attack for NASA GA(W)-2 Airfoil

These two graphs are analyzed with three different Reynolds numbers. The red line represents a Reynolds number of 120,000. The green line represents a Reynolds number of 200,000. Lastly, the blue line represents a Reynolds number of 280,000. Different Reynolds numbers were graphed to ensure that this airfoil will be able to perform under different flight conditions.

In order to accurately 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 4.13, the wing is by far the greatest contributor to the parasitic drag, followed by the stabilizer. This interesting outcome is the result of creating a relatively small fuselage, whose surface area is significantly smaller than the surface area of the wing or vertical stabilizer. Additional components, such as the exposed control cables, had minimal effect on the parasitic drag, and are included in the 'Misc' section of the below figure.

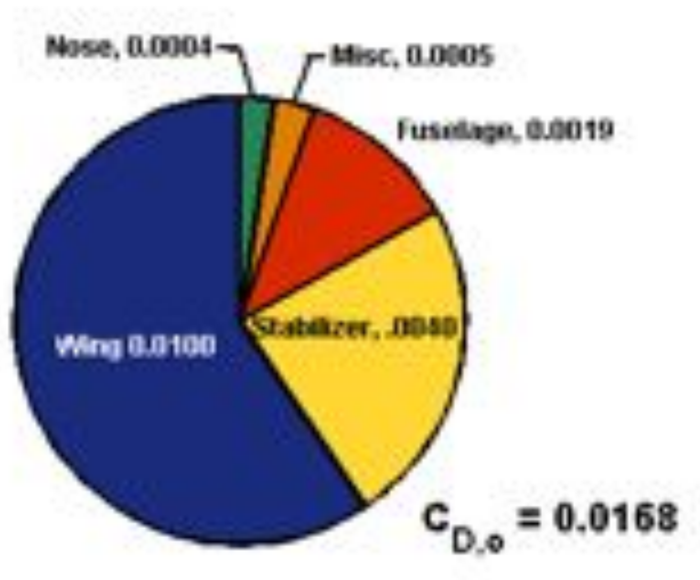


Figure 4.13: Parasitic Drag

4.6 Aircraft Mission Performance

Using analysis software, the Team was able to calculate basic time estimates for each of the missions. This analysis allowed the Team to better see which parts of the aircraft needed to be improved to improve the overall score. The following figures show this analysis.

	Mission Phase	Velocity (ft/s)	Distance (ft)	Time (sec)
Lap 1	"Throw-off"	28-37	50	1.5
	Climb	37	210	5.7
	Cruise	52	304	5.9
	180° Turn 1- (60° bank)	46	129.8	2.8
	Cruise	46	1000	21.7
	360° Turn - (65° bank)	41	160.5	3.9
	180° Turn 2- (60° bank)	46	129.8	2.8
Lap 2	Cruise	52	2000	38.5
	180° Turn - (60° bank) x2	46	259.6	5.6
	360° Turn - (65° bank)	41	160.5	3.9
Lap 3	Cruise	52	2000	38.5
	180° Turn - (60° bank) x2	46	259.6	5.6
	360° Turn - (65° bank)	41	160.5	3.9
Total				140.3

Figure 4.14: Mission 1 Profile

	Mission Phase	Velocity (ft/s)	Distance (ft)	Time (sec)
Lap 1	"Throw-off"	28-37	50	1.5
	Climb	37	210	5.7
	Cruise	48	304	6.3
	180° Turn 1- (60° bank)	48	129.8	2.7
	Cruise	48	1000	20.8
	360° Turn - (65° bank)	42	160.5	3.8
	180° Turn 2- (60° bank)	48	129.8	2.7
Lap 2	Cruise	48	2000	41.7
	180° Turn - (60° bank) x2	48	259.6	5.4
	360° Turn - (65° bank)	42	160.5	3.8
Lap 3	Cruise	48	2000	41.7
	180° Turn - (60° bank) x2	48	259.6	5.4
	360° Turn - (65° bank)	42	160.5	3.8
Total				145.4

Figure 4.15: Mission 2 Profile

	Mission Phase	Velocity (ft/s)	Distance (ft)	Time (sec)
Lap 1	"Throw-off"	28-37	50	1.5
	Climb	37	210	5.7
	Cruise	46	304	6.6
	180° Turn 1- (60° bank)	46	129.8	2.8
	Cruise	46	1000	21.7
	360° Turn - (65° bank)	41	160.5	3.9
	180° Turn 2- (60° bank)	46	129.8	2.8
Lap 2	Cruise	46	2000	43.5
	180° Turn - (60° bank) x2	46	259.6	5.6
	360° Turn - (65° bank)	41	160.5	3.9
Lap 3	Cruise	46	2000	43.5
	180° Turn - (60° bank) x2	46	259.6	5.6
	360° Turn - (65° bank)	41	160.5	3.9
Total				151.2

Figure 4.16: Mission 3 Profile

5.0 Detail Design

In this phase of the design, the Team made final decisions on components and worked on optimizing the aircraft for each mission. Predictions for final flight performance were made based on the final design. The team then turned their energies to construction.

5.1 Dimensional Parameters

Figure 5.1 shows the finalized design parameters for the main systems, including structural, propulsion, and electrical.

Fuselage	
Length	12.5 in
Width	3.5 in
Height	3.7 in
GTOW (est)	.75 lb

Wing	
Span	40 in
Chord	6.126 in
Aspect Ratio	6.53
Wing Area	245 in^2
Airfoil	NASA GA (W)-2

Batteries	
Type	Elite 1500
Capacity	1500 mAh
R	2 Ohm
V	1.4 V
I_{max}	.67 A
Number of Cells	8
Pack Capacity	1500 mAh
R_{pack}	2 Ohm
V_{pack}	11.2V
$I_{max\ pack}$	5.4 A

V-Tail	
Span	14.751 in
Chord	8 in
Aspect Ratio	1.844
Wing Area	118 in^2
Angle of Dihedral	50°
Airfoil	NASA GA (W)-2

Motor	
Type	Hacker A20 20L
Weight	2 oz
Kv	1022
I_o	.85 A
R	.109 Ohm
Pm	120 W
Thrust	1.5 lbs
I_{batt}	20 A
Propeller	14x10

Electrical System	
Speed Controller	Pheonix-25
Radio Receiver	Hitec Fusion-9
Number of Servos	3
Type	HS-82M G Micro

Figure 5.1 Finalized Dimensional Parameters

5.2 Structural Characteristics and Capabilities

These are the overall structural characteristics and capabilities of the aircraft. Further details follow in Section 5.3. Weight of the plane will affect the final score for the missions a great deal, and as a result, the weight of the aircraft was a driving concern in many design decisions.

The contest rules require a hand launch of the aircraft. Because of this rule, conventional landing gear was omitted and replaced with a simple skid. This decision provides benefits in weight, design simplicity, and ease of hand launching.

The tail of the aircraft was designed to be removable. The V-Tail design chosen not only saves space in the suitcase, but it also makes for a simpler design and easier construction. Furthermore, the fact that there are only 2 surfaces, and not 3 as in a conventional tail, saved some weight.

For the internal structure of the aircraft and the payload retention system, the team used a combination of external shape and internal grids in order to stabilize the payload and give the structure rigidity. The triangular shaped fuselage requires the balls to fit in a similar triangular pattern with one golf ball on the bottom and 2 on the top. This configuration was further stabilized by the use of bulkheads so that the balls could not roll around within the fuselage from front to back. The team also included a recessed platform on top of the grid system, so that the bar would fit snugly. For the materials, balsa wood was chosen in order to reduce weight as well as allow for faster and easier construction.

The combination of these design elements resulted in a final airplane optimized to excel in all three missions, thereby giving UCSD the best chance of winning the flight missions.

5.3 System Designs, Component Selection, and Integration

This section highlights some of the finalized systems that the Team selected. These designs were picked because they had the best combination of low weight and high strength, and met the mission requirements.

<u>5.3.1 Payload Stability System</u>

Figures 5.2 and 5.3 illustrate the final payload stability system designed. Figure 5.2 displays the balsa structure used to prevent motion of the bar, and Figure 5.3 shows the grid structure developed in order to secure the golf ball payload. This system was selected because the combination allowed for both payloads to be stabilized while not changing the interior design, which is a requirement of contest rules.

Figure 5.2: Bar Stability System

Figure 5.3: Golf Ball Stability System

5.3.2 Wing Mounting System

A major design decision was the wing mounting system. Because the Team decided to split the wing into 2 pieces so it would fit better in the box, it was crucial that the wing be firmly attached when the plane was assembled for flight. To this end, the Team decided on a friction fit with a composite tube connecting the wings together. This tube will be a carbon fiber composite and it will also serve as a wing spar. The wing will be attached to the top of the fuselage with rubber bands that will connect to two composite pins, as shown in Figure 5.4. These pins will be reinforced with epoxy for structural support.

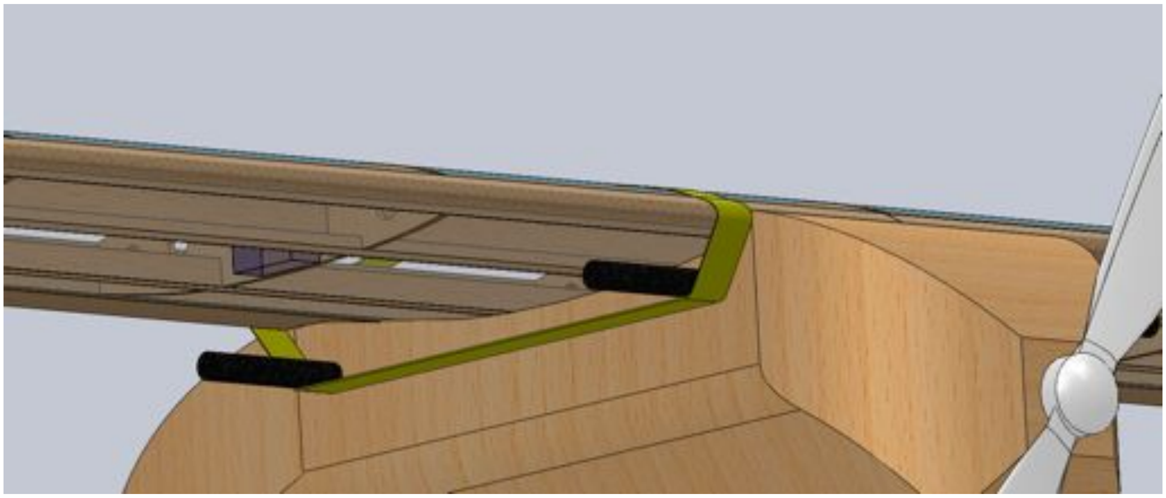


Figure 5.4: Wing Mounting System

5.3.4 Tail

The tail design was of primary importance to the team. The team made 2 important design decisions early on that affected the final design of the tail: one, that it would be detachable for easy storage in the suitcase, and two, that it would be a V-Tail. In the end, these decisions made the final design simpler, because the V-Tail took up less space in the box and there was only 2 control surfaces instead of 3. The final V-Tail design is shown in Figure 5.5.

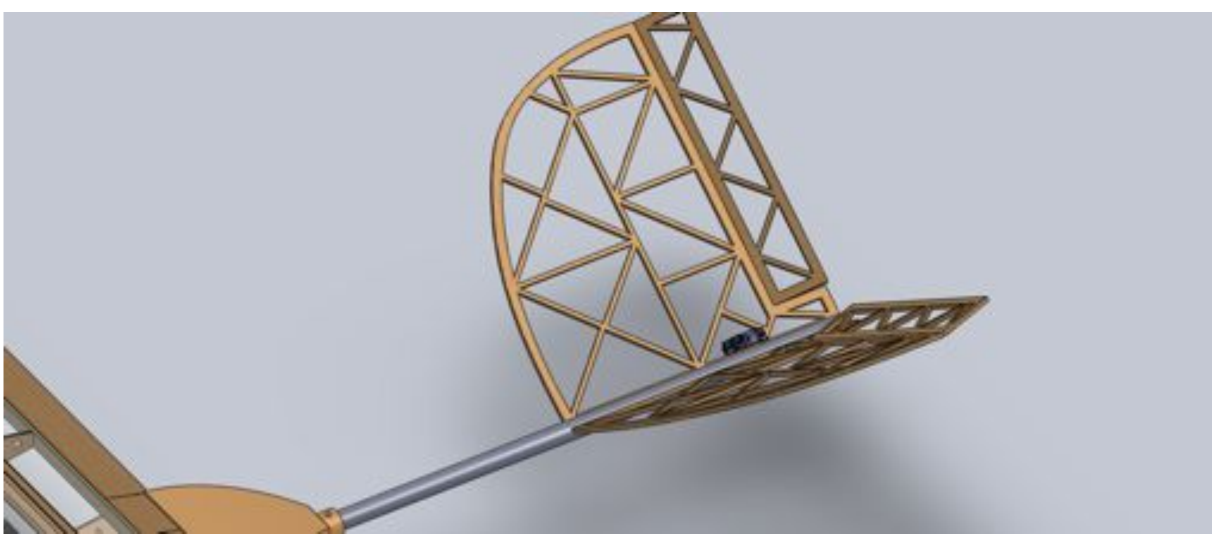


Figure 5.5: the V-Tail

5.3.5 Landing Skid

The landing skid was a critical part of the final design. Normally, a plane would have traditional landing gear so that it can taxi, takeoff and land. The downside to this design is that landing gear adds weight, both in terms of the gear itself, and in terms of the needed structural supports in the fuselage. The additional support is needed because when the plane lands, the weight of the plane is focused on a very small area of the fuselage, which has the potential to break. For this year's contest, the plane was hand-launched, which negated the need for the plane to taxi and takeoff on the ground. The team decided that the landing skid made for a simpler design (in terms of fabrication) and saved weight because no additional structural support was needed, since the weight of the plane was distributed over a larger area of the fuselage compared to traditional landing gear. The landing skid is shown in Figure 5.6.

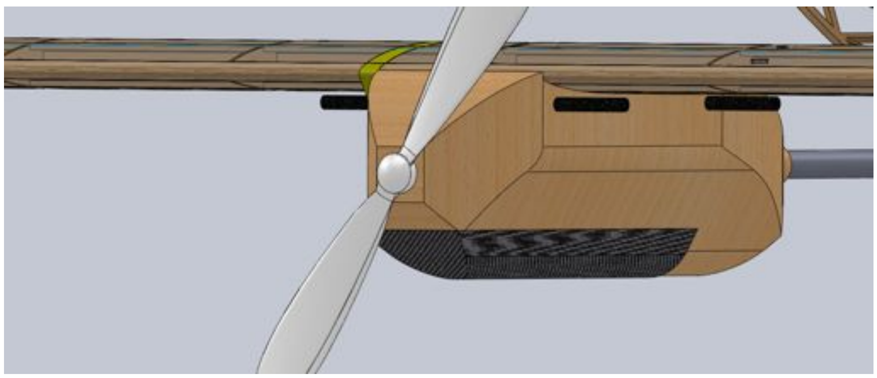


Figure 5.6: The Landing Skid

5.4 Weight and Balance

One of the main concerns in the aircraft design was weight. in order to minimize this, lightweight balsa was used for the majority of the design. With the structural components being so light, a large portion of the weight comes from the motor and the battery pack. This weight up front cancels out the weight of the tail so that the center of gravity will be located at approximately the quarter chord. This idea can be seen in Figure 5.7. Figure 5.8 shows the center of gravity location, aircraft weight, and payload weight for each mission. The center of gravity is measured from the nose of the aircraft.

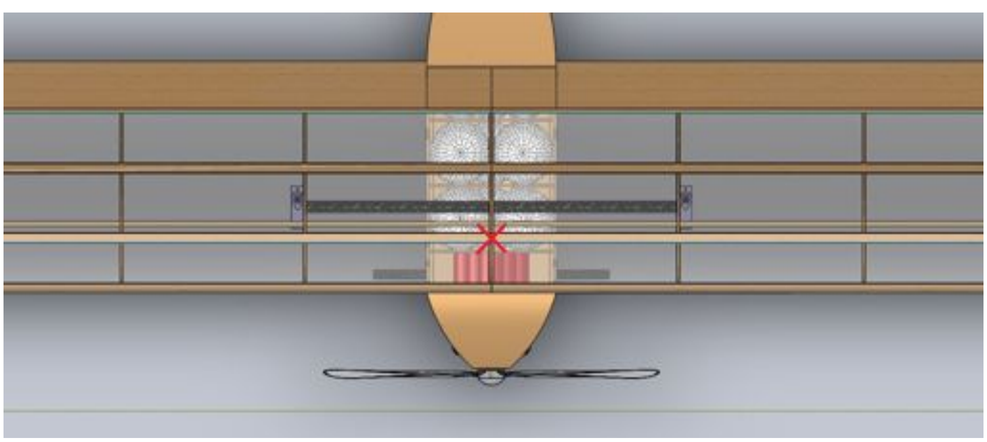


Figure 5.7: Center of Gravity Location

Mission 1	Weight (lbs)	CG Location		
		Fuselage Station (FS)	Buttock Line (BL)	Waterline (WL)
Airframe	0.46	0	1.9	6.5
Motor	0.115	0	1.86	0.88
Propeller	0.037	0	1.86	-0.05
Servos	0.26	-0.14	3.21	7.1
Receiver	0.012	0	0.4	5.5
Battery Pack	0.5	0	1.25	1.3
Total	1.16	0	1.9	4.0
Mission 2	**Weight (lbs)**	**CG Location**		
		FS	**BL**	**WL**
Battery Pack	0.5	0	1.25	1.1
Golf Balls	0.93	0	1.88	3.6
Total	2.09	0	1.8	4.4
Mission 3	**Weight (lbs)**	**CG Location**		
		FS	**BL**	**WL**
Steel Bar	0.95	0	3.3	3.3
Battery Pack	0.5	0	1.25	1.1
Total	2.11	0	2.4	4.2

Figure 5.8: CG Location for Each Mission

5.5 Flight Performance Parameters

Once the design of the plane was finalized, flight parameters were calculated for each mission. Figure 5.9 shows these flight parameters.

Flight Parameters					
Aircraft Parameters		Mission Parameters	Mission 1	Mission 2	Mission 3
C_{L0}	0.5221	Climb Rate (ft/s)	37	37	37
C_{LMAX}	1.423	Stall Speed (ft/s)	30	35	41
e	0.85	Cruise Speed (ft/s)	54	48	46
C_{DO}	0.0344	Maximum Speed (ft/s)	60	60	60
		Max G-Loads	4	2	1
		Turn Rate (degs/s)	115	75	50

Figure 5.9: Flight Parameters

5.6 Mission Performance

5.6.1 Pre-Mission Assembly

The Assembly of the aircraft requires very little time. The wings attach to each other with a carbon fiber rod. They are then attached to the fuselage with rubber bands. The tail and the tail boom will stay attached to each other so that the only assemble required is to attach the boom to the fuselage. Assembly should take no more than 2 minutes, which is 40% of the allowed time.

5.6.2 Mission 1 - Dash to Target

The main focus of this mission is to complete the maximum number of laps in 4 minutes. Since there is no payload and the aircraft is hand launched, there is no reason to worry about takeoff distance and time. The plane will quickly be able to reach its maximum velocity, so the limiting factors for this mission will be the skill of the pilot and the turning radius of the plane. The Team is expecting to complete 6 laps in 4 minutes, and the Team believes this plan will yield a score of around .75, although it is hard to be certain given that this mission is dependent on the scores of other teams.

5.6.3 Mission 2 - Ammo Re-Supply

Loading time for this mission is not of concern, since the steel bar only needs to be placed in the holder at the top of the fuselage. The biggest concerns for this mission are the proportion of the payload weight to the overall weight, and the ability of the plane to fly the three laps with the payload. Since the payload weight is already determined when it comes time to fly, the Team just needs to focus on the flying aspect of the mission.

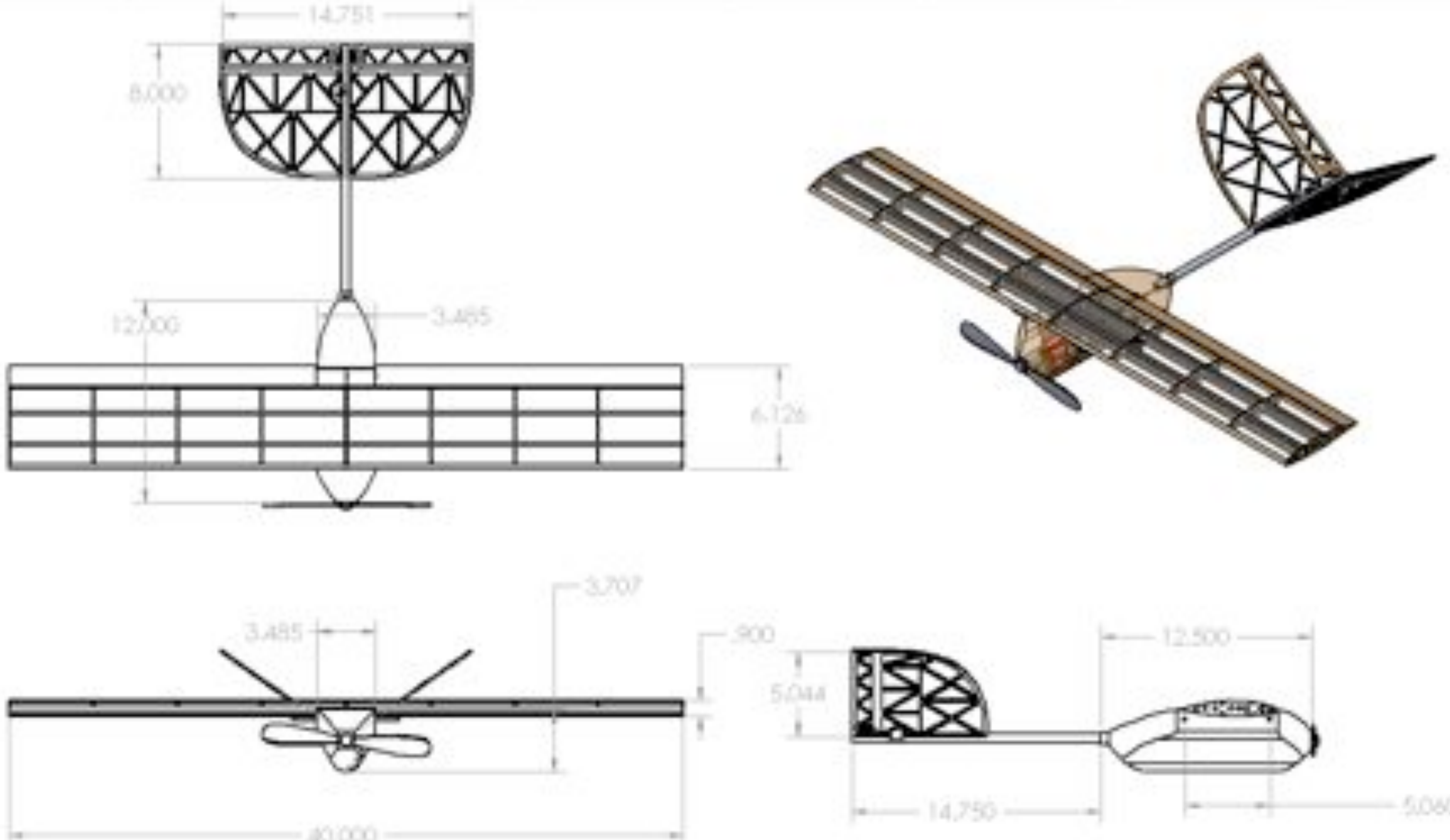
In an effort to save power, the Team plans on flying slightly slower so that the battery is not run down as fast. Given that the steel bar will ½ of the total weight of the plane, the Team hopes to achieve a score of 1.5 for this mission.

5.6.4 Mission 3 - Medical Supply Mission

In order to be competitive in this Mission, the team needs to carry the maximum amount of balls. Since the carrying capacity of the plane will be maximized in Mission 2, the team will carry the same weight of balls as it did steel. In this same thread, since the team will fly at a slower speed to save energy, the same tactic will be employed for Mission 3. It is hard to guess what the Team's score will be for this Mission, but it is conservatively estimated at .5.

5.7 Drawing Package

(see attached pages)



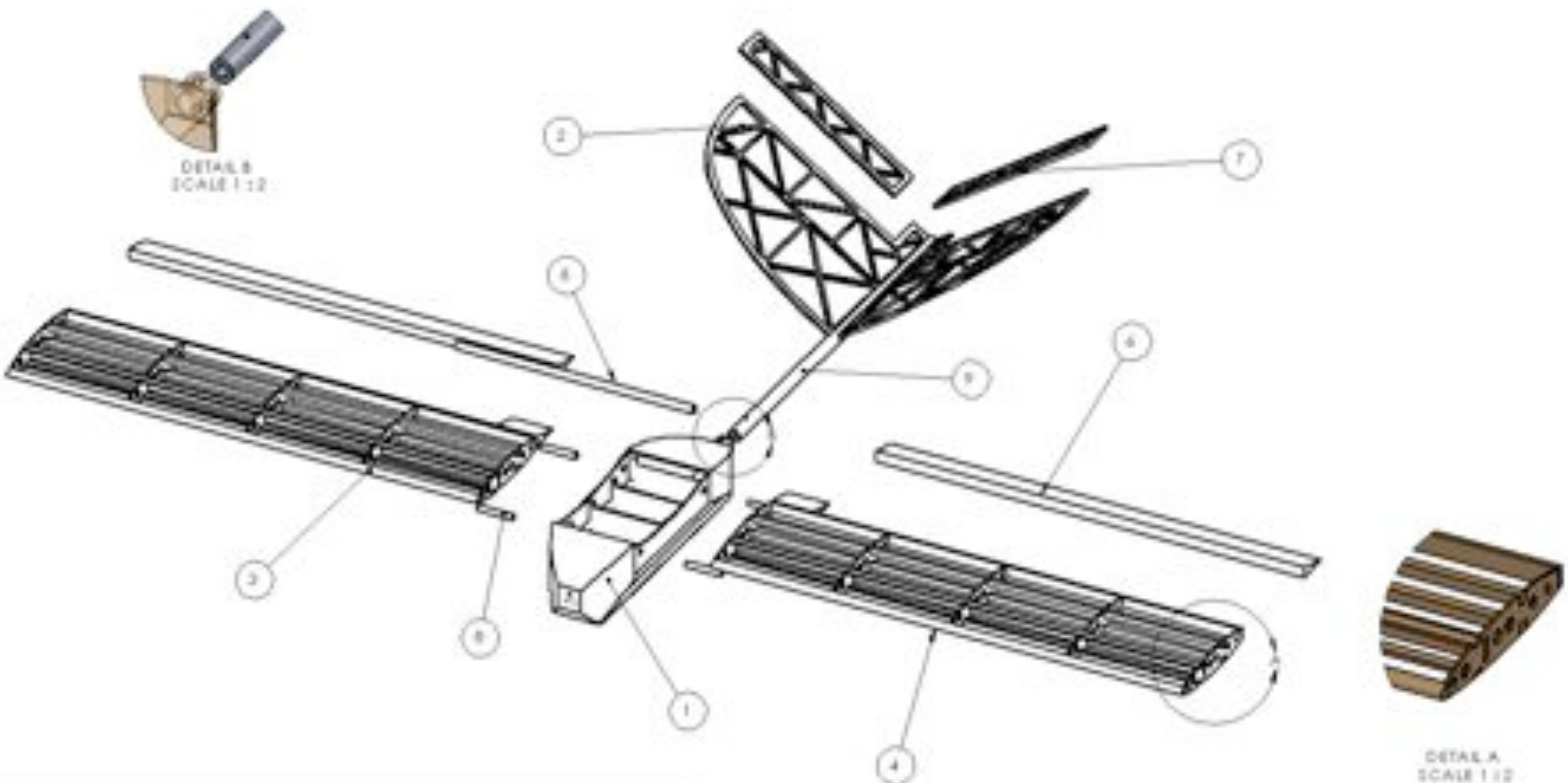
	NAME	DATE
Drawn By	J. BURKE	02/19/2011
Approved By	M. ANDERSON	02/22/2011
Q.A.		

COMMENTS:
ALL DIMENSIONS ARE GIVEN IN INCHESUNLESS SPECIFIED OTHERWISE

TITLE: Aircraft Three-View

SIZE	Report Section	REV
B	**Drawing Package**	A

SCALE: 1:6 SHEET 1 OF 5



ITEM NO.	PART NUMBER	Material	QTY.
1	fuselage	Balsa	1
2	tail	Balsa	1
3	right wing	Balsa	1
4	left wing	Balsa	1
5	Composite Spar	Carbon Fiber	1
6	aileron	Balsa	2
7	elevator	Balsa	2
8	wing hook	Carbon Fiber	4
9	Tail Rod	Carbon Fiber	1

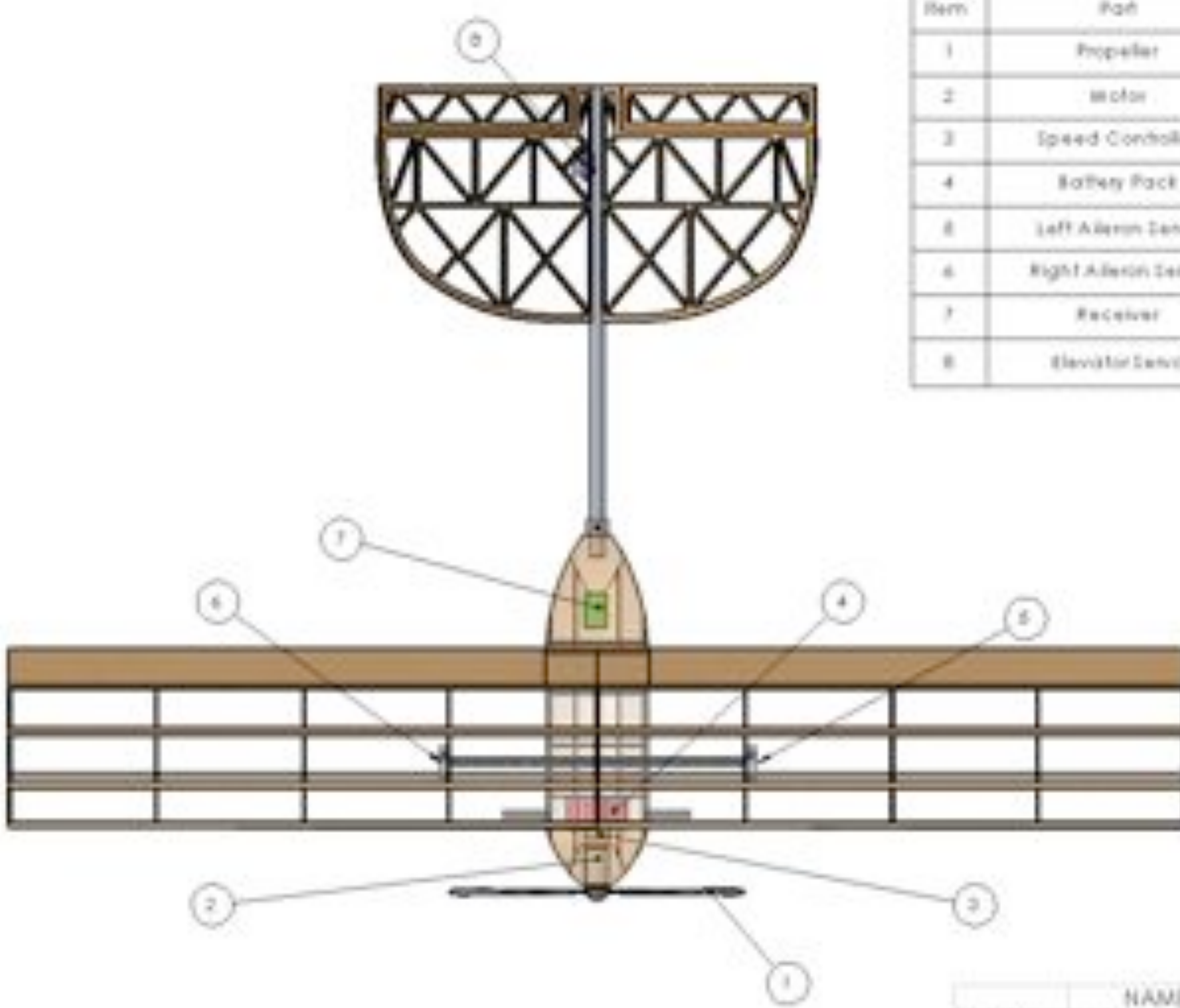
	NAME	DATE
Drawn By	J. BURKE	02/19/2011
Approved By	M. ANDERSON	02/22/2011
Q.A.		

COMMENTS:
ALL DIMENSIONS ARE GIVEN IN INCHESUNLESS SPECIFIED OTHERWISE

TITLE
Structural Arrangement

SIZE B | Report Section: **Drawing Package** | REV A

SCALE: 1:4 | SHEET 2 OF 5



Item	Part	Model
1	Propeller	APC 9x6 / APC 10x4.7
2	Motor	Hacker A20 20L
3	Speed Controller	Castle Phoenix-25
4	Battery Pack	8 Elite 1500 Cells
5	Left Aileron Servo	Futaba S3154
6	Right Aileron Servo	Futaba S3154
7	Receiver	Spectrum AR6100
8	Elevator Servo	Futaba S3154

	NAME	DATE
Drawn By	J. BURKE	02/19/2011
Approved By	M. ANDERSON	02/22/2011
Q.A.		

COMMENTS:
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OTHERWISE

Title: Systems Layout

SIZE	Report Section	REV
B	Drawing Package	A

SCALE: 1:4 SHEET 3 OF 5

DETAIL C
SCALE 1 : 3

DETAIL E
SCALE 1 : 3

	NAME	DATE	TITLE:
Drawn By	J. BURKE	02/19/2011	Payload Acomodations
Approved By	M. ANDERSON	02/22/2011	
Q.A.			

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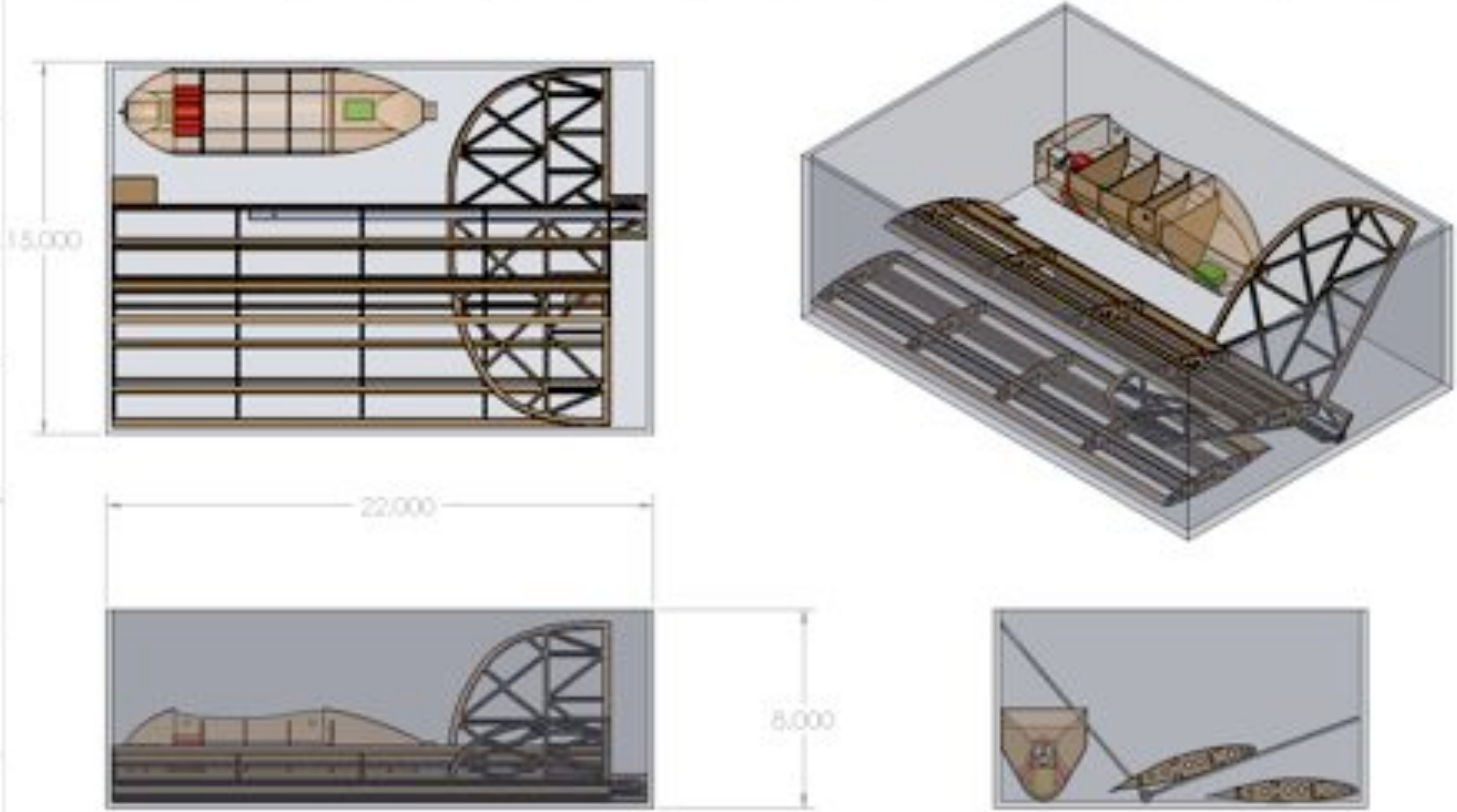

	NAME	DATE
Drawn By	J. BURKE	02/19/2011
Approved By	M. ANDERSON	02/22/2011
Q.A.		

COMMENTS:
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TITLE:

Case Dimensions

SIZE	Report Section	REV
B	Drawing Package	A

SCALE: 1:6 SHEET 5 OF 5

6.0 Manufacturing Plan and Processes

6.1 Investigation and Selection of Major Components and Assemblies

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

6.1.1 The Fuselage

Three different methods were looked 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 due to its low weight and easy assembly.

	Balsa	Lost Foam Core	Mold
Weight	0	-1	0
Assembly Time	1	-1	-1
Durability	-1	1	2
Ease of Repair	0	-1	-1
Cost	1	0	-1
Total	1	-2	-2

Figure 6.1: Fuselage Materials Decision Matrix

6.1.2 The Wing and Tail

Three different methods were looked for construction of the wing and tail. 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.
- **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. The wing is then covered in fiberglass with the foam core intact.
- **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 due to its low weight and easy assembly.

	Covered Balsa	Foam	Mold
Weight	1	-1	0
Assembly Time	1	-1	-1
Durability	-1	1	2
Ease of Repair	1	-1	-1
Cost	0	0	-1
Total	2	-2	-2

Figure 6.2: Wing and Tail Materials Decision Matrix

6.1.3 The Tail Boom

A carbon-fiber tube was selected because it is light weight, very strong, and easy to modify should the team wish to change the distance between end of the fuselage and the tail.

6.1.4 The Landing Gear

Since it was decided that a simple skids would be used for landing gear, it was imperative that the skid be light and durable. A foam mold was created, and the skid was built using layers of fiberglass and resin.

6.2 Manufacturing Plan

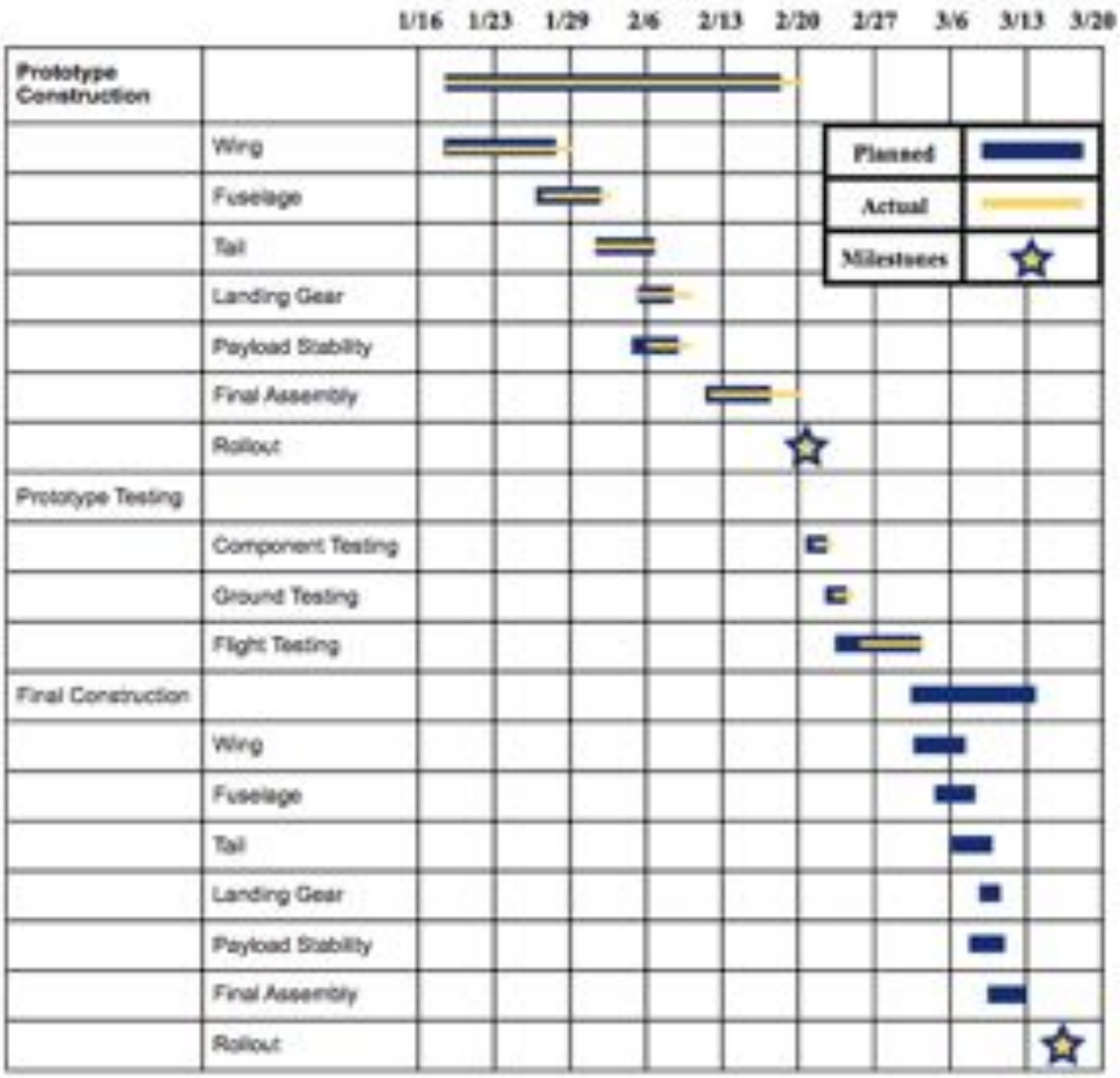

Figure 6.3: The Manufacturing Plan

7.0 Testing Plan

The team conducted various tests throughout the design and fabrication processes in order to ensure the functionality of both individual components and assemblies.

7.1 Objectives

Test plans were drafted and performed on the key components to help optimize our design and improve the aircraft.

7.1.1 Component

Structures

We tested various parts of the fuselage along with the main spar. The spars that are specifically built for testing were loaded to failure in order to ensure the predicted strength. Composite sheets were also be fabricated in order to ensure that the fuselage design will be able to withstand the motor torque and landing loads.

Aerodynamics

To reduce the wing tip vortices, which would increase the speed performance; different wing tip designs were considered. With the recent acquisition of a 3D Printer (1200es Dimension Printer) by the UCSD Mechanical and Aerospace Engineering Department, scaled models of various wing tip designs were made and tested in the UCSD wind tunnel. Drag force for each wing tip configuration were measured and used to decide the final wing tip design.

Landing Gear

Since all flights are required to be hand launched, the team decided to replace the landing gear with a skid plate. The skid plate was be tested to ensure that it can withstand the maximum predicted impact force of the fully loaded aircraft including the payload, the maximum landing velocity, and the roughness of landing surface.

7.1.2 Propulsion Testing

Battery Testing

After determining the desired battery type and size, the team cycled the batteries by fully charging and discharging them multiple times. Then the batteries were tested by completely charging the batteries and then using a CBA (computerized battery analyzer) to test the battery's current output, and voltage. This data can then be used to dispose of bad batteries, and to create an optimized battery pack for competition.

Propeller Testing

A variety of propellers with varying material, size, and pitch were tested in the UCSD wind tunnel with varying wind speeds and keeping the propulsion system constant. Using this data, we found the RPM, thrust, and torque generated. Then efficiency plots were created to find the optimum propeller for the design.

Motor Testing

Static motor testing equipment included the static thrust bench (seen in Figure 7.1), propulsion system, and EagleTree system. The thrust bench had a motor mount attached to a 16 in. vertical lever arm, which was connected to a 14 in. horizontal lever arm. This system translated motor thrust into a proportional force measured by a scale. Readings from the scale were multiplied by a scalar, giving the thrust in terms of ounces. The EagleTree data acquisition system recorded current flow, voltage, power output, and propeller rpms. Data were then analyzed on a computer.

Figure 7.1 Static Motor Bench with Neu 1506/2y and 14x12 APC Propeller

System Testing

After the propulsion system was finalized, the complete system was tested in the UCSD wind tunnel to evaluate power consumption, thrust, battery life, and efficiency at various wind conditions that simulate the conditions at the competition

7.1.3 Flight Testing

In order to test for stability, the team installed an IMU device (Inertial Measurement Unit) in order to monitor the 3-axial motion, 3-axial attitude, and control surface deflections of the aircraft. This unit provided enough data to formulate a dynamic model of the aircraft. With this information the stability of the aircraft can be determined with substantial accuracy. During the test flight of our prototype it was found that the maximum vertical acceleration incurred during flight was 3.74G's.

The team also used the Cooper-Harper rating scale which is a tried and true process used by test pilots since World War II. The scale shown in Figure 7.3 provides a quantitative communication between pilots and engineers to help ensure stability and control of the aircraft.

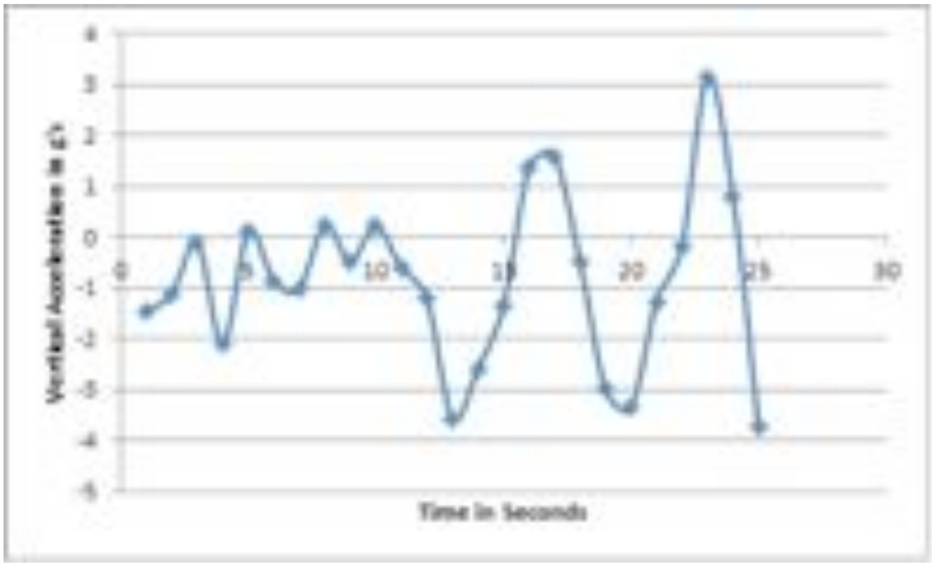

Figure 7.2 Vertical Acceleration Data from IMU

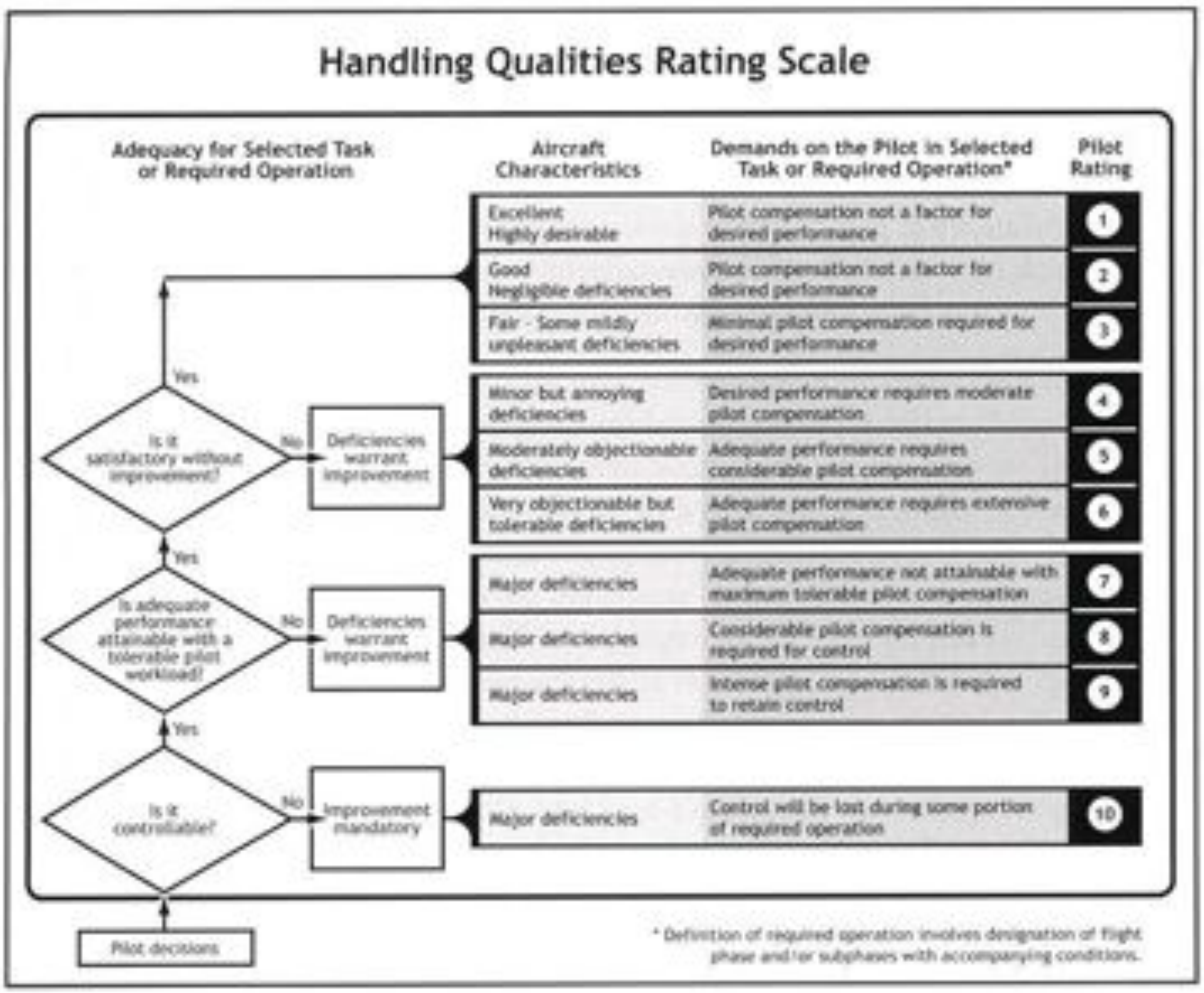

Figure 7.3 Handling Scale found in Raymer

7.1.4 Payload Testing

Ground testing was conducted to test loading configurations, restraint mechanisms, and ease of assembly. In addition, practice flights will be conducted to find the most efficient way for the ground crew to insert and restrain payloads while minimizing time.

7.2 Master Test Schedule

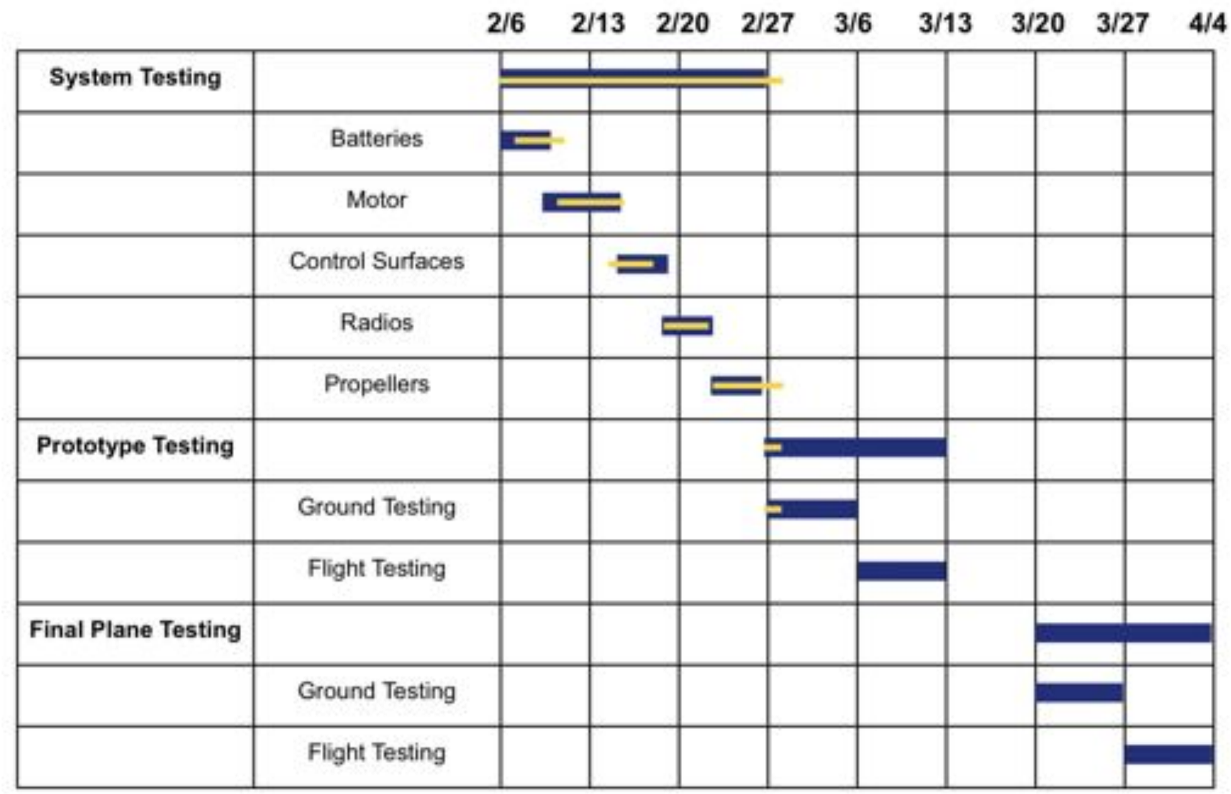

Figure 7.4: Testing Schedule

7.3 Flight Test Schedule

Figure 7.5 shows the Flight Test Schedule, which details the goals and objectives of each flight. Full Speed tests were flown repeatedly until the pilot felt comfortable with each mission and configuration.

Flight Number	Flight Designation	Payload	Objectives
1	Maiden Flight	None	Successful Hand-Launch, Fly Straight and Level for 500'
2	Dash Test #1	None	Fly 1 Lap on the Contest Course at 50% speed
3	Dash Test #2	None	Fly 3 Laps on the Contest Course at 50% speed
4	Ammo Test #1	Steel Bar	Fly 1 Lap on the Contest Course at 50% speed
5	Ammo Test #2	Steel Bar	Fly 3 Laps on the Contest Course at 50% speed
6	Medical Supply Test #1	Golf Balls	Fly 1 Lap on the Contest Course at 50% speed
7	Medical Supply Test #2	Golf Balls	Fly 3 Laps on the Contest Course at 50% speed
8	Stall Test	None	Attempt 4 maximum "G" turns. If the aircraft stalls, adjust elevators and perform test again
9	Full Speed Dash	None	Fly 3 Laps on the Contest Course at 100% Speed
10	Full Speed Ammo	Steel Bar	Fly 3 Laps on the Contest Course at 100% Speed
11	Full Speed Medical	Golf Balls	Fly 3 Laps on the Contest Course at 100% Speed

Figure 7.5: Flight Test Plan

7.4 Flight Test Check List

Pre-Flight Checklist	
Conditions	
Temperature	
Wind Magnitude	
Wind Direction	
Viewing Conditions	
Mission Objective	
Date & Time of Flight	
Structures	
Wing Secured	☐
Horizontal Stabilizer Secured	☐
Vertical Stabilizer Secured	☐
Payload Secured	☐
Control Surfaces Secured	☐
Systems and Controls	
Caibrate/Zero all Servos	☐
Servos all Wired Correctly	☐
Test Servos	☐
Range Check on Receiver	☐
Failsafe Check	☐
Receiver Battery is Charged	☐
Propulsion	
Motors Wired Correctly	☐
Propellor On Securely	☐
Test Motors	☐
Battery is Charged	☐
Record Battery Voltage	☐
Record Battery Temperature	☐
Final	
Final Visual Inspection Check	☐
Ground Crew Ready	☐
Spotter Ready	☐
Pilot Ready	☐
Post-Flight	
Power Off Battery	☐
Power off Transmitter	☐
Record Transmitter Battery Voltage	☐
Record Propulsion Battery Voltage	☐
Record Transmitter Battery Temperature	☐
Record Propulsion Battery Temperature	☐

Figure 7.6: Flight Checklist

8.0 Performance Results

8.1 Sub Systems

<u>8.1.1 Components</u>

Wing

The wing structure was tested with several loading scenarios. This testing was done by clamping the structure in the center and applying a vertical tip load to simulate the loads it will see in flight. It was first tested with a one pound load to simulate steady level flight with no payload. Next a two pound load was tested to simulate both steady level flight with payload and a 60 degree banked turn with no payload. Finally a four pound load was tested, which should be the maximum load seen in the wing, simulating the 60 degree banked turn while loaded. The results were fairly consistent with the predicted results from the finite element analysis performed. The wing structure survived all cases, although in the four pound load case the deflections were high. In the two pound case the deflections were around two inches at the wing tips, while in the four pound case they were more than double at just over 5 inches which was determined to still be acceptable.

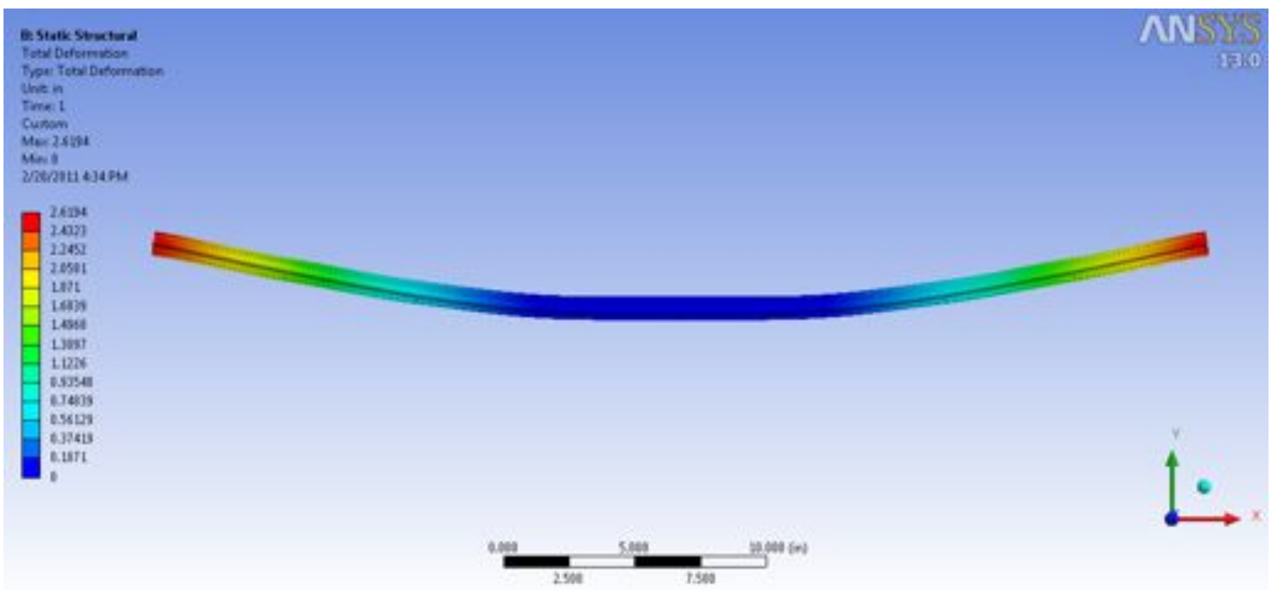

Figure 8.1: Full Wing Two Pound Load Deformation

Figures 8.1 displays the results of the two pound weight deformation test for the full wing. The colors indicate the distribution of the load along the full wing. Even at the wing tips where the loads were applied, the wing was found to still have an acceptable factor of safety (see Figure 8.2).

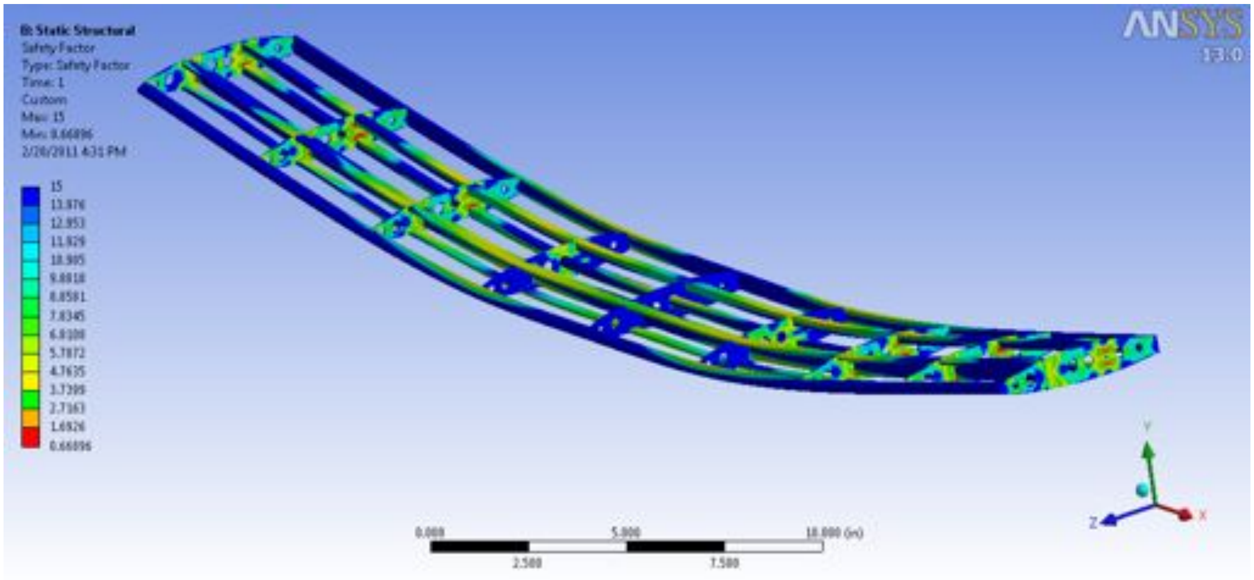

Figure 8.2: Single Wing Factor of Safety Distribution

Figure 8.2 displays the factors of safety along sections of the wing during the two pound wing load simulation. The point of greatest stress is 2.5 inches from the leading edge of the wing at the connection of the carbon spar with the balsa rib where the wings connect. However, this point still has a factor of safety of about 2.4. The carbon rod can withstand a much larger stress than the balsa. Because it is also stiffer than the balsa it takes the majority of the load in this area. The area with the smallest safety factor is where the balsa spars meet with the ribs at the wing tips. Here we see a safety factor of only 0.65 with a two pound load and 0.34 with a four pound load. Although these simulations show the wing withstanding these loads, to be safe the wing ribs in this area will be made thicker. The carbon fiber wing spar helped greatly in reducing the deflection of the wing. If the deflection was greater than desired, this spar could be extended further into the wing, but the sacrifice would be the increased weight.

Landing Gear

The carbon fiber skid was subjected to 2 different kinds of tests. First, the Skid was subjected to a drop test to verify that it can withstand a blunt force. Then, the Skid was put into a vice and compressed to insure that it can withstand a substantial amount of compression force. With these tests, it was determine that the carbon fiber skid was sufficient in protecting the fuselage while landing.

8.1.2 Propulsion

Batteries

To try and estimate the life of the battery pack, battery current was measured over a 10 minute period. Figure 8.3 shows the results from this test in a graph displaying battery current over time.

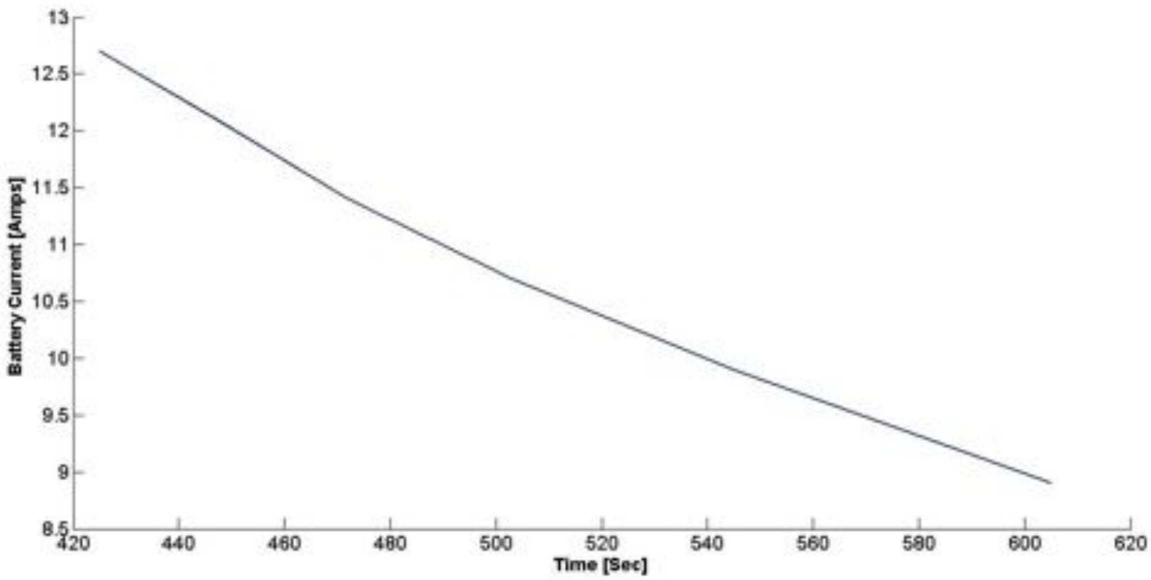

Figure 8.3 Battery Drain Over Time

The important thing to note about the data from Figure 8.3 is that the reduction in current will not significantly affect battery output until 540 seconds into the flight. This time in seconds equates to 9 minutes. Since the longest flight will be 4 minute the Dash to Target mission, the battery pack will be able to provide sufficient current throughout the mission.

Propeller

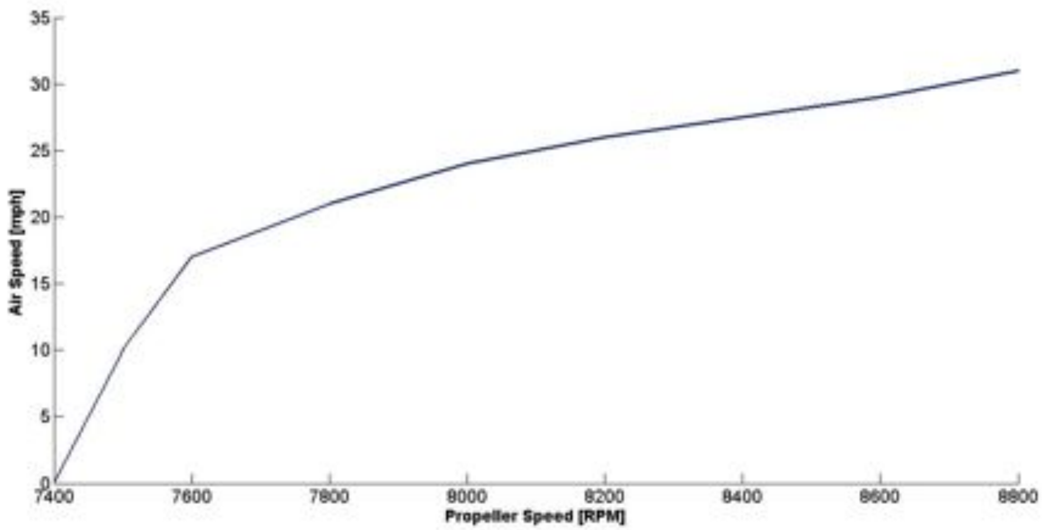

Figure 8.4 Airspeed vs. Propeller Speed

Figure 8.4 shows the graph of Propeller Speed vs Airspeed. As the Team expected, airspeed increasing with increasing RPM's. But one interesting thing to note is that up to 7600 RPM, airspeed is increasing at one rate, and after 7600 RPM, airspeed increases at a different rate. The Team analyzed this data, and came to the conclusion that it justified the throttle being at 100% on hand launch, because it would give the plane the best change at a successful launch.

8.2 Flight Testing

After the components were tested, the complete plane was assembled. The plane was weighed before its first flight. The actual weight was 1.16 lbs, which was very close to the team's planned weight of 1 lb. Using the Flight Test Plan outlined in Figure 7.5, the tests were methodically conducted and the results are listed below.

Mission	Average Laps Completed	Predicted Laps Completed	Percent Difference
Dash to Target	5.8	6	-3.3%
Ammo Resupply	2.8	3	-6.6%
Medical Supply	2.9	3	-3.3%

Figure 8.5: Average Test Results

Mission 1 was the first mission flown because it required no payload. Over the course of many flight tests, the plane flew slightly below the Team's predicted results. The Team attributed this abnormality to a slight miscalculation of the motor output, and to pilot error. The more the pilot flew the plane, the more laps the plane completed.

Mission 2 was the second test mission flown because the steel bar was easier to secure than the golf balls. This decision allowed the Team to test the carrying capacity of the plane before subjecting it to a payload that has the risk of shifting in flight. Except for one test flight where the plane did not complete the 3 laps, the plane was able to complete the 3 laps with the steel bar payload. With regards to the one flight where the plane was unable to complete the laps, the cause was later found to be an insufficiently charged battery pack.

Mission 3 was the last mission to be tested. The team was worried about the golf balls shifting in flight, so some final ground tests of the grid system were tested before the plane was flown with the balls. This mission was by far the riskiest due to the possibility of the balls shifting in flight, but the team was very happy with the flight tests and the airplane performance. There was one mission where the plane was unable to complete the laps because it crashed mid-flight, although this was due to pilot error.

Overall, the Team was quite pleased with the way the plane performed. While more tests are required, and work will continue on the plane, the early results were encouraging and justified many of the difficult design decisions that the Team made during the initial design process. Furthermore, the flight tests were concurrent with the model and analysis results,

Figure 8.6: UCSD TLAR XI Team with Prototypes