University of California, San Diego

UCSD AIAA Student Chapter
DBF Team Sharknado

AIAA Design Build Fly 2014

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1. Executive Summary

The following report details the design, fabrication, testing, and performance of the UC San Diego Design/Build/Fly Team's 2013-2014 competition aircraft. The Team designed the aircraft to successfully complete 4 missions, including 3 flight missions: an unloaded speed flight, a cargo carrying mission, a passenger carrying mission, as well as one additional ground taxi mission. Aside from completing 4 total 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 a preliminary design review/critical design review process to determine which design would result in the highest scoring plane for the competition year 2013- 2014. By identifying and weighing critical metrics and criteria for the final design, the Team was able to downselect individual components of the plane from a list of possible designs. Similarly, the team had to choose the appropriate battery configuration, motor and propeller that best accommodated both the design of the plane and the requirements of the competition. With a lift, drag and stability analysis, the Team was able to determine an airfoil appropriate for the wing and tail. This gave the Team a preliminary design to build a prototype to be further improved by physical and experimental testing. As necessary, the Team would tweak, refine and tune the final aircraft in order to achieve the best possible performance.

1.2. Key Mission Requirements

The challenge presented to the Team for the 2013-2014 competition consists of 4 different missions. The first mission is a ground taxi mission which simulates the environment of an uneven takeoff area. The goal is to avoid the provided obstacles within five minutes with the plane undamaged. The first flight mission, Mission 1 is an unloaded speed mission where the score is determined by the number of laps completed in four minutes. Mission 2 is a 3 lap cargo mission with the goal of carrying a number of ballasted blocks, and the score is determined by the number of blocks carried by the plane. Mission 3 is a simulated emergency medical mission in which two passengers and two nurses must be carried for 3 laps, and the score is dependent on how fast the plane completes the mission. From these mission descriptions, the Team identified 3 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 minimizing the empty weight of the aircraft. This would have a high impact on our choice of material and size of the plane.
- Ground Control and Clearance: The total mission score of the final score is also highly dependent on the plane's ability to complete the ground taxi mission. This would impact our choice of wheels and wing configuration for our plane.
- Speed: There are two missions of the three flight missions that emphasize the speed of the airplane, and this would have a big impact on our choice of motor and airfoil.

1.3. Capabilities

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

- Empty weight of 4 lbs.
- Maximum payload weight of 2 lbs.
- Ability to complete taxi mission without damage to the plane within the 5 minute time limit.
- Ability to complete 4 laps in 4 minutes unloaded.
- Ability to carry 2 cargo payloads internally.
- Ability to carry 2 passengers and 2 nurses.
- Strong, durable aircraft.
- Proven and consistent performance of subsystems, and promising vehicle performance after initial flight test.

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

2. Management Summary

2.1. Project Management

The members of the UC San Diego DBF Team divided into 5 groups to handle the design, testing and fabrication of the aircraft. These 5 groups covered the major aerospace disciplines, consisting of aerodynamics, controls, propulsion and structures, as well as the fabrication group. Group leaders coordinated the efforts of their group members, while the lead report writer oversaw the format and content of the report. The Project manager coordinated all group members and oversaw the completion of the project.

Figure 2.1: Management Flow Chart

The structures team designed and tested the frame of the aircraft, including the fuselage, wing truss structure and payload bay. Additionally, the structures team assembled the CAD drawing package of the report and verified that the center of mass aligned with the aerodynamic center of the wing. The aerodynamics team selected the airfoil for the main wing and tail, and also handled wing sizing and placement on the fuselage. The controls team was responsible for sizing the control surfaces (ailerons, tail, elevator, rudder and flaps) and selecting servos, as well as monitoring and verifying the overall stability of the aircraft for all 3 missions and all possible payload configurations. Additionally, the controls team handled the radio control system used to control the aircraft in flight. The propulsions team selected and tested the power system for the aircraft, which consisted of the batteries, motor, and speed controller.

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.

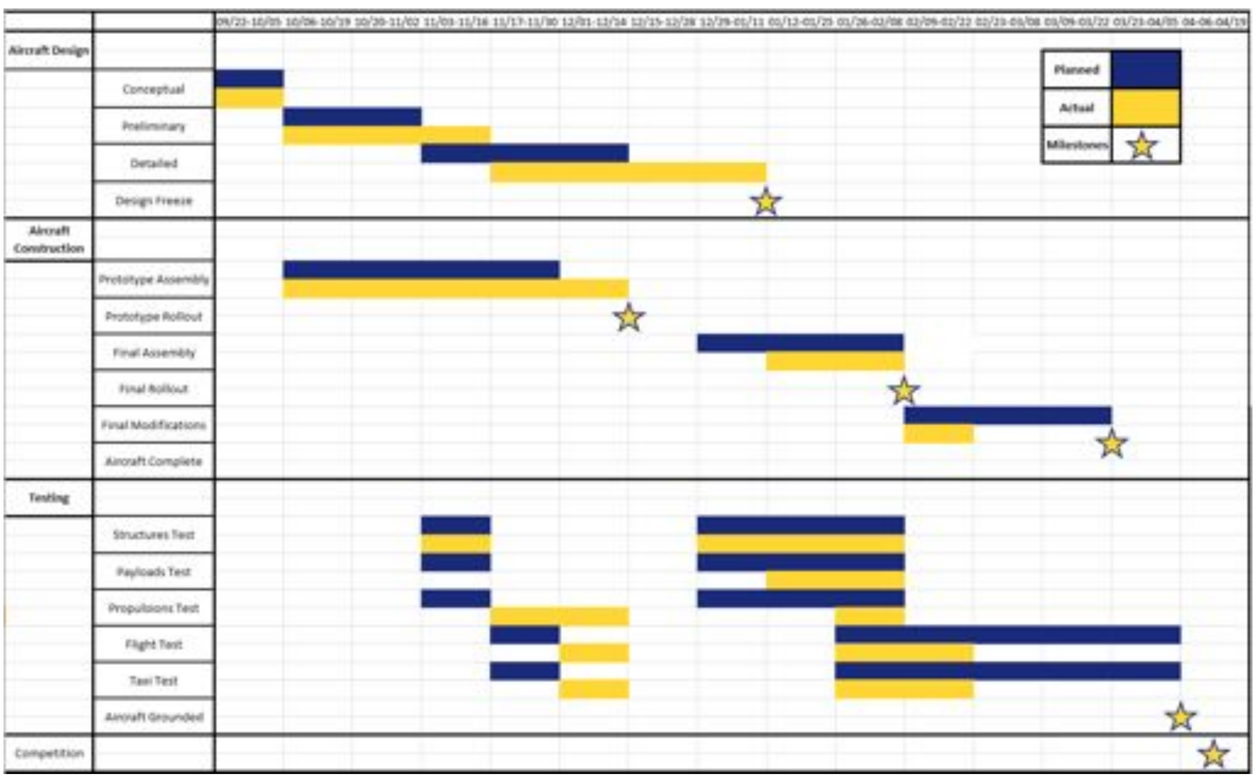


Figure 2.2: Master Schedule and Milestone Chart

3. Conceptual Design

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

3.1. Mission Requirements

The 2013-2014 AIAA Design/Build/Fly competition total score takes into account the written report score, the total mission score, and the rated aircraft cost (RAC). The total score is computed as:

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

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

$$\text{Total Mission Score} = \text{Taxi Score} * \text{Flight Score}$$

$$\text{Flight Score} = \Sigma\ \text{Individual Mission Scores}$$

3.1.1. General Requirements, Limitations, and Concerns

The following are some general requirements for the competition:

- The battery pack cannot weigh more than 1.5 lbs. Power system fuse-limited to 15 amps.
- The aircraft wings must have sufficient ground clearance to pass over a standard 2x4 (3.5" vertical distance). This clearance will be measured with the payload from flight mission 3.
- The aircraft must land safely in order to receive a mission score for the flight.
- Aircraft must takeoff within 40 feet on each mission.

The Flight Course was another critical part of the competition that was defined by the competition rules. The layout of the flight course is shown below in Figure 3.1. A more detailed model of the flight course is discussed in Section 4.2.

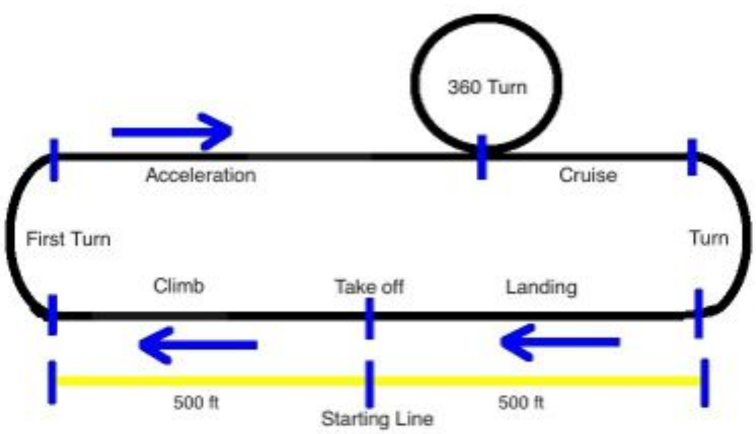


Figure 3.1: Competition Flight Course

3.1.2. Ground Crew and Assembly Crew

The ground crew and assembly crew for the missions shall consist of 3 people: the pilot, the spotter and the payload loader. The aircraft can be assembled when it enters the staging area, but the payload must be unloaded. The aircraft must be loaded and cleared for flight within 5 minutes.

3.1.3. Ground Taxi Mission: Rough Field Taxi

The ground taxi mission simulates taxiing over rough terrain on a remote airfield. For this mission, the aircraft must taxi over 40 feet of corrugated plastic roofing while carrying the payload for Mission 3. Approximately 13 feet from either end of the course, there are wooden 2x4's that the aircraft must taxi around. During the completion of this mission, the aircraft may never leave the ground, and must complete the mission in 5 minutes. A schematic of the course can be seen in the figure below.

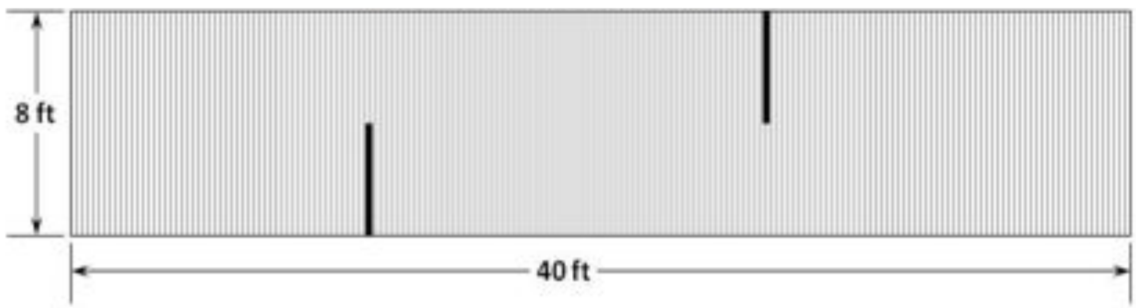


Figure 3.2: Taxi Mission Course Schematic

A successful taxi mission has a Taxi Score of 1. If the Team is unable to successfully complete the taxi mission, the Taxi Score becomes 0.2.

3.1.4. Mission 1: Ferry Flight

The ferry flight simulates an unloaded speed test. After taking off from the 40 foot runway, the aircraft must complete as many laps as possible in 4 minutes. At the end of the 4 minutes, the pilot must execute a successful landing for the flight to be scored. The scoring for Mission 1 is determined using the formula below.

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

3.1.5. Mission 2: Maximum Load Mission

The maximum load mission simulates carrying a large cargo out of a remote area. After taking off from the 40 foot runway with a pre-defined number of blocks (ballasted to 1 lbs each), the aircraft must complete 3 laps. At the end of the 3 laps, the pilot must execute a successful landing for the flight to be scored. The scoring for Mission 2 is determined using the following formula.

$$\text{Mission 2 Score } = 4 * \frac{\text{Blocks Flown}}{\text{Most Blocks Flown}}$$

3.1.6. Mission 3: Emergency Medical Mission

The emergency medical mission simulates the evacuation of 2 patients and 2 attendants from a short runway. Patients and attendants weigh .5 lbs each, for a total payload of 2 lbs. After taking off from the 40 foot runway, the aircraft must complete 3 laps as fast as possible. At the end of the 3 laps, the pilot must execute a successful landing for the flight to be scored. The score for mission 3 is determined using the formula below.

$$\text{Mission 3 Score} = 6 * \frac{\text{Fastest Time Flown}}{\text{Time Flown}}$$

3.1.7. RAC

The RAC is the empty weight of the aircraft. Empty weight will be measured after each successful scoring flight and the RAC will be the maximum weight recorded of the three recorded weights of the plane as shown in the following formula.

$$\text{RAC} = \text{Max}(\text{EW1}, \text{EW2}, \text{EW3})$$

3.2. Design Requirements

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

- Taxi Mission: The aircraft must be ground stable and highly maneuverable.
- Mission 1**:** The aircraft must fly as many laps as possible carrying no weight. Speed and maneuverability are critical.
- Mission 2: The aircraft must be able to carry as much payload as possible. A short takeoff while loaded is critical.
- Mission 3: The aircraft must fly as fast as possible while carrying 2 lbs. of payload. A short takeoff and speed are critical.
- RAC: The aircraft should be as lightweight as possible.

3.2.1. Sensitivity/Optimization Analysis

Using the score equations given, the Team performed a sensitivity analysis to identify which elements of the design were most critical in achieving a high score. The first thing the Team noticed was how critical the taxi mission was to overall score. With this in mind, the Team placed a high priority on the completion of the taxi mission.

When considering the flight missions, the Team tried to break down the aircraft into possible configurations. To do this, the Team identified 3 possible motor/battery options and 3 possible Mission 2 payload sizes. It was assumed that the motor/battery combination was the driving factor in the Mission 1 and 3 scores, while in Mission 2 payload quantity was the driving factor behind the score and the empty weight of the aircraft. The different options are outlined in the tables below:

Motor/Battery Combinations	Power	Combination Weight	Mission 1 Laps	Mission 3 Time
Low Weight	400 Watts	.65 lbs	3 laps	4 mins
Medium Weight	600 Watts	1.2 lbs	5 laps	3 mins
High Weight	1000 Watts	1.75 lbs	7 laps	2 mins

Table 3.1: Motor/Battery Combinations

Mission 2 Payload Sizes	Payload Weight	Empty Weight
1 Block	1 lbs	4 lbs
2 Blocks	2 lbs	4 lbs
3 Blocks	3 lbs	5 lbs

Table 3.2: Mission 2 Cargo Payload Sizes

These motor/battery and payload options were then combined into 5 possible aircraft configurations, and these configurations were analyzed to identify which yielded the highest score. The 5 configurations are outlined below.

Configuration	Motor/Battery Combination	Mission 2 Payload Size
1	Low Weight	1 block
2	Medium Weight	2 blocks
3	High Weight	3 blocks
4	High Weight	2 blocks
5	Medium Weight	3 blocks

Table 3.3: Configurations Considered For Sensitivity Analysis

Using the scoring equations and the parameters defined by the configurations, the Team was able to calculate the mission scores and the total scores resulting from the different configurations. The results are plotted in Figure 3.3.

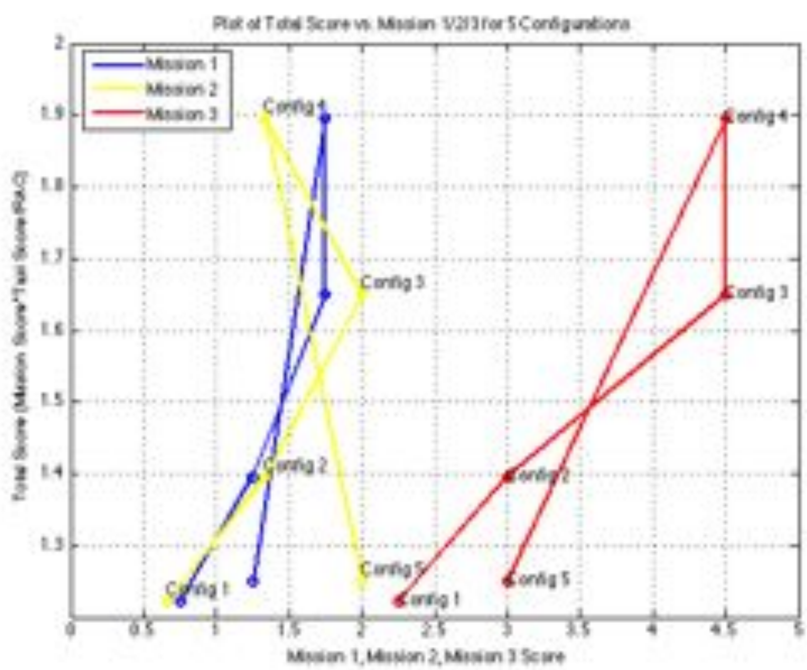


Figure 3.3: Total Mission Score vs. Individual Mission Scores for Various Configurations

Using the information from the graph, the Team could see that while configuration 2 yielded the highest score on Mission 2, and equal scores on Missions 1 and 3 with configuration 4, configuration 4 was the best overall score because its lower weight lowered the RAC and therefore raised the total score. Therefore, the Team decided that an aircraft with a powerful/heavy motor and battery that carried 2 blocks would yield the highest score.

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 eight major design elements: the fuselage, the wing, the propulsion system, the wing configuration, the tail, the landing gear, and the payload containment. The Team then selected Figures of Merit for each of the major design elements, and weighted the Figures of Merit according to their importance in achieving a high score. The completed Decision Matrices were then used to make design choices.

Figures of Merit

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

Selection Weighting System

The different possible selections for each design element were rated on a scale of 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, while 2 corresponded to slightly worse than average, and 4 signified slightly better than average.

3.3. Solutions, Configurations and Results

3.3.1. The Fuselage

Shape of the Fuselage

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

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

FOM	Weight	Ellipse	Rectangle	Circle
Weight	25	3	2	4
Aerodynamics	25	4	2	5
Payload Containment	30	4	4	2
Ease of Integration	10	3	4	3
Ease of Fabrication	10	3	4	3
Total	100	355	300	345

Table 3.4: Fuselage Shape Decision Matrix

When considering the options for fuselage shape, the Team decided on an elliptical shaped cross section. Although the circular shaped cross section was close in score in the decision matrix, the Team decided that the ellipse was the superior choice because the wider shape allowed for better payload containment as well as more stable ground handling without sacrificing aerodynamic performance.

3.3.2. The Wing

Shape of the Wing

Four possible wing shapes were considered for the planform shape of the wing:

- Elliptical: Wing shape resembles an ellipse.
- Tapered: Chord decreases from the center to the wingtips.
- Swept: Constant chord with the wing tips behind the center of gravity.
- Rectangular: Constant chord and symmetrical in both directions.

FOM	Weight	Elliptical	Rectangular	Swept	Tapered
Weight	15	4	3	3	4
Aerodynamics	25	3	3	2	4
Stability	25	3	4	3	3
Ground Handling	15	3	4	2	3
Ease of Fabrication	20	3	5	2	3
Total	100	315	380	240	340

Table 3.5 Wing Shape Decision Matrix

When selecting the shape for the wing, the Team was most concerned with the aerodynamic performance and flight stability. Other highly weighted concerns included the ground handling, and the ease of fabrication. The Team also considered the weight of the wing structure. A rectangular wing was chosen for its good aerodynamic qualities, good ground handling, and the ease of fabrication.

Wing Tips

The Team considered four different types of possible wing tips:

- Cut Off: No additional wing tip after last rib.
- Hoerner: Continuation of airfoil on top and lower surface cut 30 degrees.
- Rounded: Curved angle from both top and bottom.
- Sharp edge: Ends in a sharp edge angled from top and bottom.

FOM	Weight	Cut Off	Sharp	Rounded	Hoerner
Weight	35	5	2	2	2
Aerodynamics	35	2	3	3	4
Ease of Fabrication	30	5	4	3	2
Total	**100**	**395**	**295**	**265**	**270**

Table 3.6 Wing Tip Decision Matrix

Important considerations for the Team were the aerodynamic advantages of the wing tip and the weight of construction. The Team also considered ease of fabrication of the wing tips. The cut off wing tip does not add any additional weight and is easier to build. Therefore, the Team chose cut off wing tips.

3.3.3. Propulsion System

The arrangement of the aircraft's propulsion system was determined by considering the need for a lightweight airframe that provided sufficient thrust for both high speed/low weight flights and low speed/high weight flights. Four possible propulsion configurations were examined:

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

FOM	Weight	Single Tractor	Dual Tractor	Single Pusher	Combination
Weight	30	3	1	3	1
Speed	15	3	5	1	5
Payload Stability	20	3	5	3	3
Ground Handling	25	3	3	3	3
Ease of Fabrication	10	3	1	3	1
Total	**100**	**300**	**290**	**270**	**250**

Table 3.7 Propulsion System Decision Matrix

After considering the potential propulsion systems and configurations, the Team determined that a single tractor motor configuration would most effectively satisfy the design requirements. This configuration is significantly lighter than any configurations consisting of two motors, and provides more speed, payload stability, and ground handling than the single pusher arrangement. Using only one motor also greatly increases the ease of fabrication, while decreasing the likelihood of technical complications.

3.3.4. Aircraft/Wing Configuration

Aircraft 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.
- Biplane: Two wings, stacked vertically with a central fuselage and a rear mounted tail.
- Conventional: A single wing, attached to the fuselage with a tail attached to the rear of the plane.

FOM	Weight	 Flying Wing	 Biplane	 Conventional
Weight	15	3	3	4
Stability	20	2	4	4
Drag Generated	15	3	3	4
Lift Generated	30	3	5	3
Ease of Fabrication	20	2	4	5
Total	**100**	**260**	**400**	**390**

Table 3.8 Aircraft Configuration Decision Matrix

When selecting the best configuration for the aircraft, the Team's main considerations were the aircraft's weight, the stability in flight, the drag and lift of the configuration, and the ease of fabrication. Since the required takeoff distance for the competition is relatively short, the Team weighted lift generated as the most important consideration.

Wing Location Relative to Fuselage

When selecting the location of the wing, three configurations were considered:

- Low Wing: Wings mounted below the fuselage.
- High Wing: Wings mounted above the fuselage.
- Mid Wing: Wings connected to the midsection of the fuselage.

FOM	Weight	Low Wing	Mid Wing	High Wing
Weight	15	3	3	3
Structural Integration	15	3	5	3
Stability	30	2	3	4
Payload Access	30	3	3	3
Ease of Fabrication	10	3	4	3
Total	**100**	**270**	**340**	**330**

Table 3.9 Wing Location Decision Matrix

The Team considered weight, structural integration, stability, ability to access payload, and ease of fabrication when choosing location of the wing. A mid wing was chosen primarily for the ability to structurally integrate the wing with the plane, as well as for the ease of fabrication.

Angle of Wing Relative to Fuselage

When selecting whether or not to use dihedral for the wing, the main concerns of the Team were stability, maneuverability, and ease of fabrication. Three possible configurations were considered:

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

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

Table 3.10 Wing Dihedral Decision Matrix

While the dihedral wing is more stable in flight, the flat wing allows for more maneuverability and ease of fabrication. For these reasons, the Team chose a flat wing configuration.

3.3.5. Landing Gear

Landing Gear Configuration

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

FOM	Weight	 Tail Dragger	 Tricycle	 Bicycle
Weight	30	5	5	3
Increased Lift on Takeoff	10	5	3	1
Payload Stability	10	5	5	3
Ground Handling	35	3	5	1
Ease of Fabrication	15	3	3	3
Total	**100**	**400**	**450**	**210**

Table 3.11: Landing Gear Configuration Decision Matrix

When considering possible landing gear configurations, the driving design elements were gear weight and ground handling. With these elements in mind, a tricycle was a clear choice because it provided the most ground control without adding unnecessary weight.

Landing Gear Wheel Size

The configuration and type of landing gear was driven by competition constraints. Three sizes of landing gear wheels were considered:

- Small
- Medium
- Large

FOM	Weight	Small	Medium	Large
Weight	20	5	3	1
Stability	30	1	3	5
Ground Handling	30	1	3	5
Ease of Assembly	20	3	3	3
Total	**100**	**220**	**300**	**380**

Table 3.12: Landing Gear Wheel Size Decision Matrix

When considering possible landing gear wheel sizes, the important elements were the weight, stability, and ground handling. While a small wheel was the lightest-weight option, it didn't provide enough traction on the taxi mission. Therefore, the Team elected to go with a large landing gear wheel (diameter of roughly 4.5 inches).

3.3.6. Tail and Stability

Tail Shape

The design of the tail was driven by the need for an easily maneuverable and stable tail that provided good control and lift for the aircraft. Three different configurations were considered:

- Conventional: Single, large vertical stabilizer (with a rudder) and a horizontal stabilizer (with elevator) 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	15	3	3	3
Lift	25	5	3	4
Stability	30	5	2	4
Ease of Fabrication	30	4	1	2
Total	**100**	**440**	**210**	**325**

Table 3.13: Tail Configuration Decision Matrix

When considering tail configurations, weight was the first factor discussed. The Team concluded that although the V-tail had only two surfaces, the necessary size increase would offset the weight saved; therefore, the weight for all three configurations would be the same. For ground handling, the Team decided that the conventional tail with a rudder and low mounted horizontal stabilizer would provide superior ground handling and takeoff performance as compared to the other two options. The conventional tail would also be the easiest of the three to build. In the end, the conventional tail was chosen for the final design.

Tail Airfoil

The airfoil of the tail was driven by the need for to provide extra lift for the aircraft while trying to minimize the drag produced. Three different configurations were considered:

- Flat Plate
- Cambered Airfoil
- Symmetrical Airfoil

FOM	Weight	Flat Plate	Cambered Airfoil	Symmetrical Airfoil
Weight	15	3	3	3
Ease of Fabrication	25	4	2	2
Drag	35	2	3	4
Lift	25	3	1	4
Total	**100**	**290**	**225**	**335**

Table 3.14 Tail Airfoil Decision Matrix

After analyzing the characteristics of the different types of tails, the Team decided that the weights of the three designs were nearly identical. For a cambered airfoil, it was decided that the extra lift provided would be a hindrance to cancel out the pitching moment of the wing and fuselage. When comparing a flat plate to a symmetric airfoil, it was decided that the small increase in fabrication time did not outweigh the benefit of the reduction of drag from a symmetric airfoil. A symmetric airfoil tail would provide the aircraft with additional lift for the payload missions while receiving the greatest aerodynamic performance. The Team settled on a symmetric airfoil for the tail as it had the least drag.

3.3.7. Amount of Mission 2 Payload

Cargo Payload Sizes

The selection for the number of Mission 2 cargo blocks chosen were restrained by the given battery weight and propulsion system current limitations. An estimation of at least 80 watts of propulsion power per 1 pound of aircraft was used. With battery limit of 1.5 lbs leading to no more than 33.6 volts, and a current limit of 15 amps, the resulting max power output is 504 Watts. Assuming a best-case design is 50/50 empty/loaded aircraft weight ratio, the max payload is 3.3 lbs, or 3 blocks. With this knowledge the following cargo payload numbers were considered.

- 1 Block
- 2 Blocks
- 3 Blocks

FOM	Weight	1 Block	2 Blocks	3 Blocks
Mission Score	40	1	3	5
Use of Internal Space	10	1	3	5
Speed	10	5	3	1
Weight	40	5	3	1
Total	**100**	**300**	**300**	**300**

Table 3.15 Number of Internal Payloads Matrix

The Team created the following decision matrix using the optimization in Section 3.2 to find the optimum Mission 2 payload size. When ranking the choices using the chosen metrics, the Team found that no one choice was clearly superior. However, when discussing the possible choices, the Team decided that 2 blocks made the most sense because it weighed the same as the required Mission 3 payload and eliminated the need for more structure to support the 3rd block, thereby reducing the RAC.

3.3.8. Mission 2 and 3 Payload Containment

When considering possible ways to secure the payload for Missions 2 and 3, the Team looked to previous teams for inspiration. Three different containment systems were considered:

- Velcro on Floor
- Reversible Tray
- Restraining Tabs

FOM	Weight	Velcro on Floor	Reversible Tray	Restraining Tabs
Speed	10	3	3	3
Payload Stability	40	3	5	3
Weight	30	5	3	3
Viability	20	1	5	5
Total	**100**	**320**	**420**	**340**

Table 3.16 Number of Internal Payloads Matrix

Using the above matrix, the Team decided that while Velcro was the lightest-weight solution, the fact that the blocks were provided by the judges precluded this from working since there would be no matching Velcro strip. Furthermore, while the restraining tabs added the least amount of weight, they did not guarantee enough payload stability to prevent movement during flight. Therefore, the reversible tray was the best solution. A more detailed description of this system can be seen in Section 5.

3.4. Final Conceptual Design

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

- Ellipse-shaped fuselage cross section
- A single motor/propeller mounted at the nose of the aircraft.
- Rectangular shaped bi-wing, mounted mid-fuselage.
- Conventional tail.
- Tricycle landing gear with large wheels.
- Ability to carry 2 blocks and 2 nurse/patient packages, restrained in a reversible tray.

This design was selected because it gave the Team the best chance of winning the competition. A rendering of the aircraft configuration can be seen below in Figure 3.4.

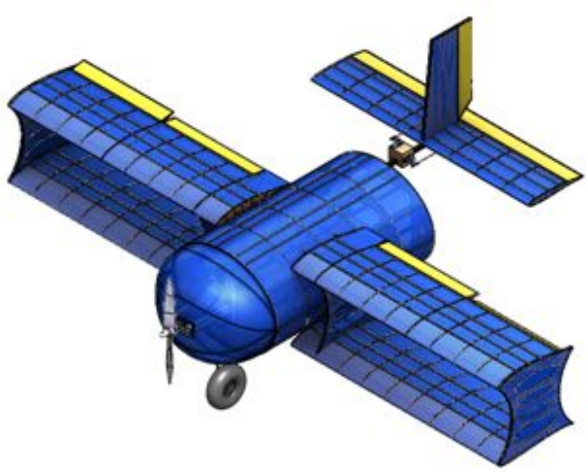


Figure 3.4: Aircraft Conceptual Rendering

4. Preliminary Design

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

4.1. Design and Analysis Methodology

4.1.1. Aerodynamics

There were two important aerodynamic parameters that the Team considered:

Wing Airfoil Selection

Two types of airfoils were considered: high lift and high speed airfoils. The geometry of high lift airfoils results in a slower top speed, and the geometry of high speed airfoils results in lower generated lift. High lift airfoils are beneficial for missions with a heavy payload and for short takeoff, but they do not perform as well where time and speed are a constraint. High speed airfoils are beneficial for timed missions, but high speed airfoils do not perform well for missions with a heavy payload or short takeoff distances.

Wing Size

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

Aerodynamics Mission Optimization

The Aerodynamics Team considered different configurations and airfoils for the aircraft with weight, moment, and aerodynamic characteristics in mind. The members of the Aerodynamics Team also took into account the limitations of the flight course and missions, such as the takeoff distance of 40 ft.

With this data, the Aerodynamics Team decided that a wing configuration that maximized the lift for short distance takeoff would be best. The Aerodynamics Team also selected several airfoils for further analysis that would provide the necessary balance between lift and speed required by the flight course and missions.

4.1.2. Propulsion

Battery Selection

A battery pack using high capacity batteries would require less cells, but each cell would weigh more. A battery pack consisting of lower capacity batteries would require more cells, but each cell would weigh less. It is also important to consider the chemistry used in the cells and their voltages. Therefore, a favorable battery pack optimizes the weight, capacity, and voltage for the selected motor and missions.

Motor Selection

A heavier motor can provide more power and thrust, which can lead to better results for Mission 1. However, the increased weight reduces the overall score due to the RAC component. Therefore, a lighter motor with a higher Kv would provide higher rpm but lower torque. An optimal motor would include a good balance of power and weight.

Propeller Selection

A smaller propeller would increase speed of the aircraft but would decrease the thrust. A bigger propeller would reduce the maximum speed of the aircraft while increasing the thrust, making it ideal for payload missions. Therefore, the best propeller choice would find a balance between speed and thrust.

4.1.3. Structures

External Fuselage Size

The size of the fuselage was driven by three main elements: the ability to secure the required payload, the ability to interface with the necessary aircraft components (wing, tail, propulsion system) and the effect of the fuselage on performance. The preliminary sizing was driven by the size of the payload. Once the Team had a fuselage large enough to hold the payload, the next step was insuring that there was room to mount electronics and attach the wing and tail. As a final step, the Team then tried to downsize the final design as much as possible, thereby saving valuable weight and drag.

Payload Containment Design

Payload containment is driven by two factors: the need for a lightweight system, and the need to secure the payload during flight. Unfortunately, these factors are often mutually exclusive, with a more stable, robust system often weighing more than a lighter-weight, less stable system. Therefore, the design process involves studying a variety of designs, analyzing the tradeoffs, and eventually converging to an acceptable design.

4.2. Mission Modeling and Optimization Analysis

In order to better predict the performance of the aircraft during flight, the Team created a mission model in MATLAB. With this model, the Team could then input the relevant vehicle information (thrust, drag, lift, weight, pilot commands, etc.) and receive an output file detailing the flight path and time, thereby allowing for an accurate prediction of mission performance. Using this program, the Team could iterate through different possible design parameters before deciding on the design that yielded the best flight score. The flight path was divided into the following elements (color in Figure 4.1 in parentheses):

- Takeoff (red): The aircraft starts with velocity equal to zero and accelerates down the runway to takeoff velocity.
- Liftoff (blue): the aircraft achieves necessary velocity to liftoff from the ground, and begins its climb to flight altitude.
- Straightaway 1 (orange): After achieving altitude, the aircraft flies level until it passes Flag 1 (approx. 500 feet from takeoff start).
- 180-Degree Turn 1 (green): After passing Flag 1, the aircraft initiates a 180 degree right turn.

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

All subsequent laps start from the "Straightaway 1" section of flight. Figure 4.1 shows the modeled flight path. The different colors indicate the different stages of flight.

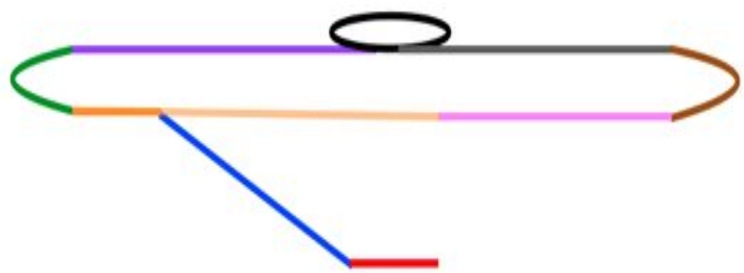


Figure 4.1 Mission Model

4.3. Aerodynamic Design and Sizing Trades

4.3.1. Main Wing Trade-offs

Wing Airfoil

After examining the aerodynamic characteristics of several airfoils, the Team narrowed down the options to seven different airfoils based on the mission requirements. The Team performed further analysis to select from the following airfoils: E210 with 13.4% max thickness and 4% camber, E214 with 11.1% max thickness and 4% camber, E216 with 10.4% max thickness and 5.2% camber, S1210 with 12% max thickness and 7.2% camber, S4320 with 9.4% max thickness and 4.5% camber, SD7032 with 10% max thickness and 3.7% camber, and SD7034 with 10.5% max thickness and 3.9% camber.

The Team used the airfoil analysis program XFLR5 to select the optimum airfoils (one airfoil for each wing). A type 1 analysis (assuming a fixed speed) was used with a constant Reynolds number of 250,000, fixed Mach number of 0.04, and varied angle of attack from 0 to 15 degrees. The Mach number was calculated for an airspeed of approximately 30 mph, and the Reynolds number was calculated using the Airfoil Tools Reynolds Number Calculator, which uses the following equation:

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

where the free stream velocity is approximately V = 30 mph, the characteristic length is the chord length L = 9.5 in, and the kinematic viscosity of air (ν) is given in the Airfoil Tools Calculator.

The graphs below show the results of the XFLR5 analysis comparing the airfoils' glide ratio, coefficient of lift, and angle of attack.

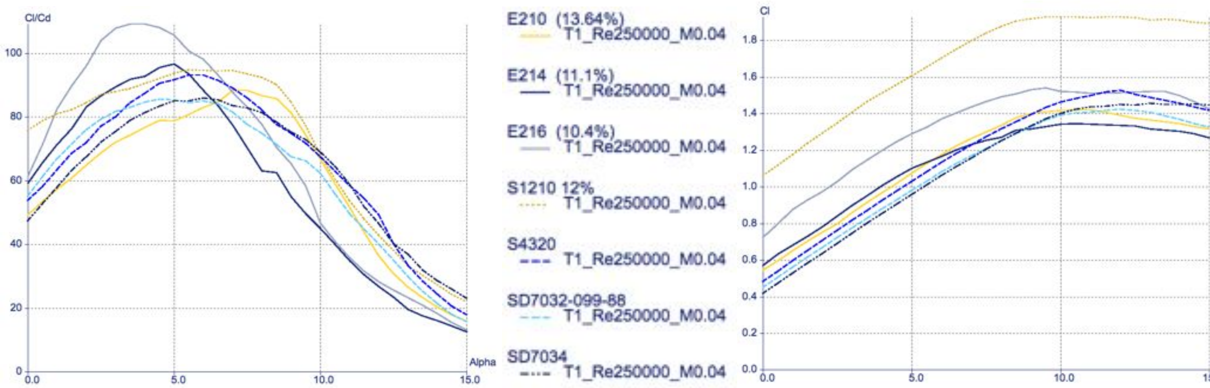


Figure 4.2: Comparison of Airfoil L/D vs. AoA and Comparison of Airfoil Cl vs. AoA

From the analysis, the Team determined that the E216 airfoil has a good coefficient of lift at low speed, which is necessary for a short distance takeoff. Additionally, the E216 airfoil has the highest glide ratio at low angles of attack, making it an efficient airfoil for steady level flight. The SD7034 airfoil has moderate coefficient of lift and glide ratios compared to the other airfoils, but it stalls at a later angle allowing for a steep climb and also allowing for additional stability for maneuvers. Finally, the moderate thicknesses (10.4% for E216 and 10.5% for SD7034) are sufficient for structural stability of the wing, while still remaining thin enough to reduce drag. For these reasons the Team chose the E216 airfoil for the bottom wing and the SD7034 airfoil for the top wing. The cross section of each airfoil is shown below.

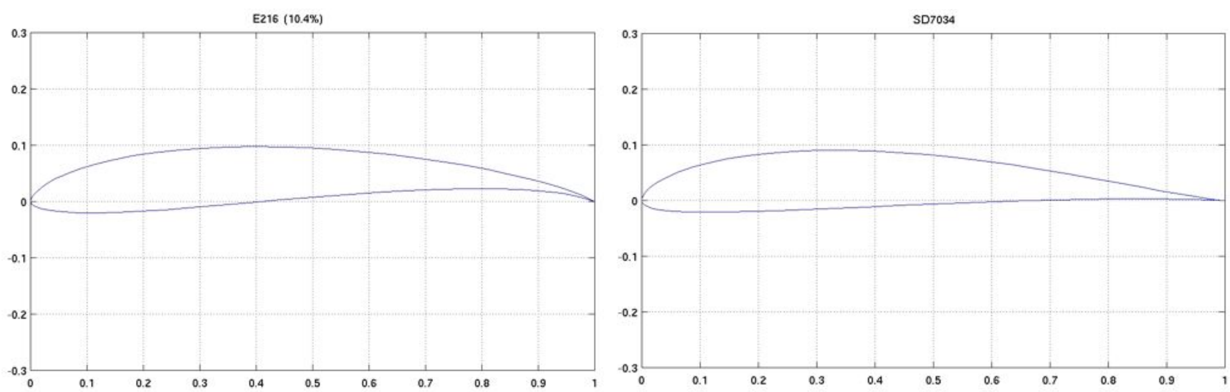


Figure 4.3: E216 Airfoil (Left) and SD7034 Airfoil (Right)

Initial Wing Sizing

The Team sized the wing based off of the pre-determined structural and payload weight at takeoff. This weight was estimated to be 6 lbs. A factor of safety of F.S. = 1.1 was used during the calculations.

$$\mathrm{W_{calc}} = (\mathrm{F.S.})(\mathrm{W_{estimated}}) = (1.1)(6\ \mathrm{lb}) = 6.6\ \mathrm{lb} = 29.358\ \mathrm{N}$$

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

$$\mathrm{L} = (\mathrm{n})(\mathrm{W_{calc}})$$

The Team used the general equation for lift with respect to air density (ρ), takeoff velocity ($\mathrm{V_{TO}}$), effective lifting area of the wing (S), and the total wing coefficient of lift ($C_{L\,(Total)}$).

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

Due to the disruption of airflow between the wings, the top wing of a bi-wing configuration only produces approximately 20% of the amount of lift it would produce as a single wing. Therefore, the total coefficient of lift of the bi-wing was calculated as:

$$C_{L\,(Total)} = C_{L\,(Bottom)} + 0.2\,C_{L\,(Top)}$$

where $C_{L\,(Bottom)}$ is the coefficient of lift of the E216 airfoil used for the bottom wing, and $C_{L\,(Top)}$ is the coefficient of lift of the SD7034 airfoil used for the top wing. The Team set the two lift equations equal to each other, then solved for the needed planform wing area (S):

$$S = \frac{2\,(n)(W_{calc})}{(\rho)(V_{TO})^2(S)(C_{L\,(Total)})}$$

The Team determined that an effective lifting area of $459.540\ in^2$ is needed to take off at 30 mph at the altitude density of Wichita, KS using the chosen airfoils SD7034 and E216. The Team chose initial sizing dimensions of wing chord of 7.9 in (not including inset control surfaces) and wingspan of 54 in (not including width of the fuselage).

Wing Control Surface Sizing

The Team used the chord and wingspan dimensions to calculate the necessary size of ailerons and flaps for the wing. The span of the aileron was calculated as 40% of the span of the wing, and the chord of the aileron was calculated as 20% of the chord of the wing. The Team sized the flaps and ailerons such that the flaps and ailerons would be the same size. Therefore the minimum necessary control surface dimensions for half a wing were calculated as:

$$b_{aileron} = b_{flap} = 0.4\,b_{wing} = 10.8\ in$$

$$c_{aileron} = c_{flap} = 0.2\,c_{wing} = 1.58\ in$$

Final Wing Sizing

The Team decided to use inset control surfaces, such that the total chord of the wing airfoils include the chord of the control surfaces. The control surfaces will be attached to the top wing. The final chord length of each wing will be the sum of the wing chord length from initial sizing and the chord length of the aileron. Both the top and bottom wing will have the same final chord length. The Team decided to increase the span of the ailerons so that the ailerons would fit between the chosen wing rib spacing of 3 inches. The Team decided to have the spacing between the top and bottom wings to be approximately equal the chosen wing chord length ($\pm$10% to allow for integration with the fuselage). This yields final wing dimensions of:

Description	Dimension [Inches]
Wing Span (Not Including Fuselage)	54
Wing Span (Including Fuselage)	64.17
Wing Chord (Including Control Surfaces)	9.5
Distance Between Wings	8.5
Aileron/Flap Span (For Each Half of Wing)	11.71
Aileron/Flap Chord Length	1.58

Table 4.1: Final Wing Sizing

The figures below also show these dimensions in the model of the wing.

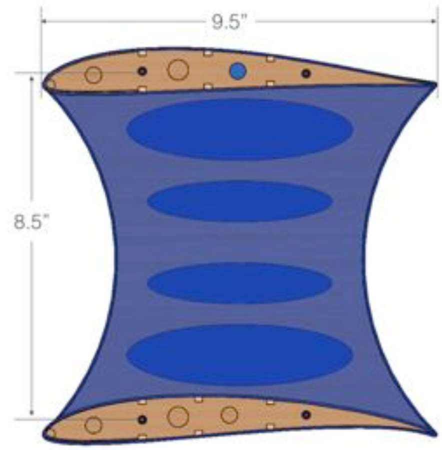


Figure 4.4: Wing Dimensions Side View

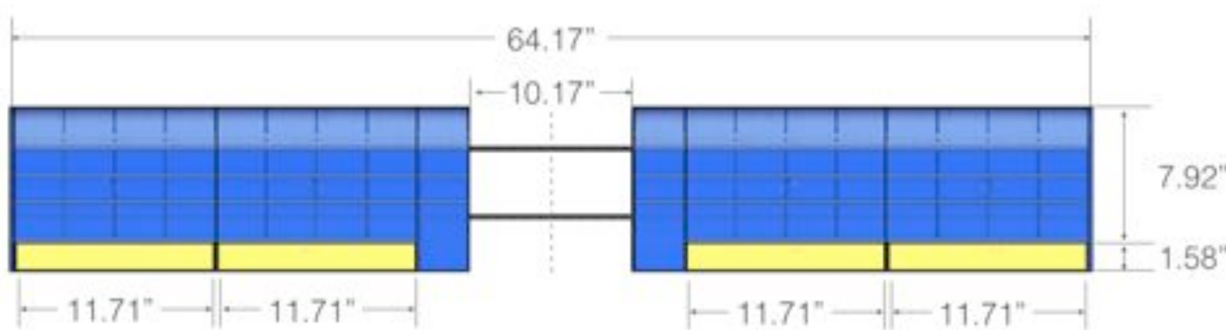


Figure 4.5: Wing Dimensions Top View

The chosen wing dimensions shown in Table 4.1 and Figures 4.4 and 4.5 yield an aspect ratio of 5.67.

$$\mathrm{AR} = \frac{b^2}{b * c} = 5.67$$

where b is the span of the wing and c is the wing chord length dimension from Figure 4.6. This is within the desired aspect ratio of $5 < \mathrm{AR} < 7$.

4.3.2 Tail Trade-off

Tail Sizing

The Team calculated the stabilizer areas using the Tail Volume Coefficients (TVC) equations which relates the area of the tail surfaces (S_{ht} and S_{vt}), the chord of the wing (c), and the wing lift area (S_L), and the distance from wing to tail L_{ht} and L_{vt}, both designed to be 20 inches. The values for the TVC were taken from lecture notes of Airplane Design Projects of previous years at UCSD with the horizontal TVC as 0.67 and the vertical TVC as 0.032. The horizontal and vertical tail volume equation is as follows:

$$S_{ht} = \frac{c * C_{ht} * S_L}{L_{ht}} = 141.55\ \text{in}^2$$

$$S_{vt} = \frac{c * C_{vt} * S_L}{L_{vt}} = 44.23\ \text{in}^2$$

Once the areas for the stabilizers were calculated, the chord and wingspan for the stabilizers were calculated. The horizontal stabilizer was designed to have a chord of 7 in, and the vertical stabilizer was designed with a root chord of 6.25 in. and a tip chord of 5 in. The Team chose to design the wingspans (b_{ht} and b_{vt} for the horizontal and vertical wingspan respectively) using the following equation which related the Control surface's area and chord:

$$b_{ht} = S_{ht-tot} * c_{ht} = 28.309\ \text{in.}$$

$$b_{vt} = \frac{2 * S_{vt-tot}}{c_{vtr} + c_{vtt}} = 11.008\ \text{in.}$$

The elevator and rudder of the plane were calculated to require an area of 40% of the horizontal and vertical stabilizer respectively. Using this percentage, the area of the elevator was calculated to be 56.628 in^2 while the rudder has an area of 17.692 in^2. The figures below show the layout of the horizontal and vertical tail structure.

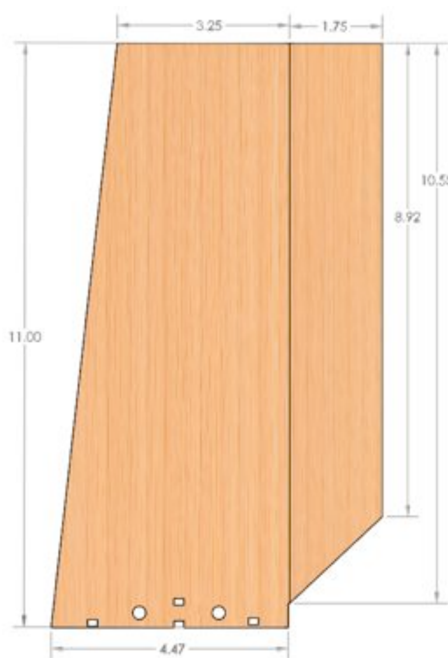


Figure 4.6: Vertical Tail and Rudder Sizing

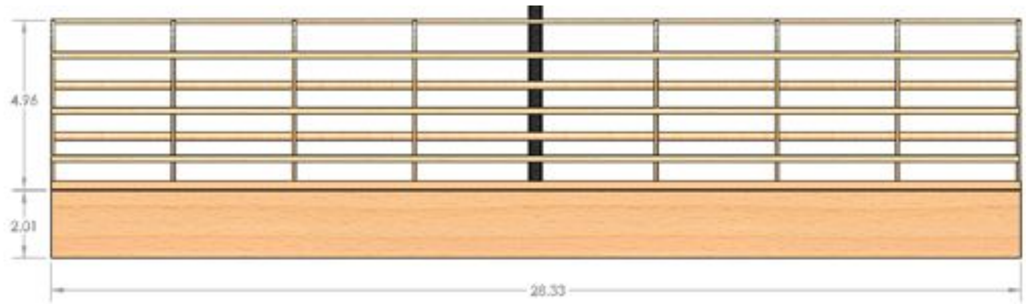


Figure 4.7: Horizontal Tail and Elevator Sizing

4.4. Propulsion Design and Sizing Trades

4.4.1. 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	NiCAD
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

Table 4.2: Battery Specifications

The Team considered a number of different batteries when deciding which would be ideal for the mission requirements. When searching for the optimal battery, the Team looked at specific characteristics, such as weight, size, and capacity. The Team used the table above to compare these characteristics, and found that nickel-cadmium batteries weighed more and had a larger average size compared to nickel-metal hydride batteries. Additionally, all the batteries considered had similar capacities.

Given the battery weight limit, the Elite 1500 batteries were ultimately chosen with 28 cells. This configuration provides a total voltage of 33.6 V and 1500 mAh. The lighter weight allowed for more batteries to be used, which maximized the voltage of the pack.

4.4.2. Motor Selection

Motor Description	Kv [*RPM/V*]	No Load Current [*Amps*]	Max Voltage [*Volts*]	Continuous Power [*Watts*]	Weight [*Grams*]
Hacker A30-16M V3	1060	1.6	17	350	104
Eflite Power 52	590	2.3	22	1100	346
NeuMotors 1110-2.5y	1814	0.7	30	500	114
NeuMotors 1110/6D	1400	0.3	38	500	114

Table 4.3: Motor Specifications

The Team considered a set of criteria for the plane to narrow the motor selection. A lightweight motor was preferable, and only brushless motors were considered because they had higher torque when compared to brushed motors. For the given limitation on current from the rules and the voltage from the battery selection, the Power of the aircraft was estimated to be 504 Watts. A motor that matched this power was sought out that also was able to handle the 33.6 Volts provided for the battery selection. Ultimately, the NeuMotors 1110/6D best matched the criteria, and its performance was analyzed using Motocalc, a propulsion system optimization program, to test its performance given the preliminary design specifications.

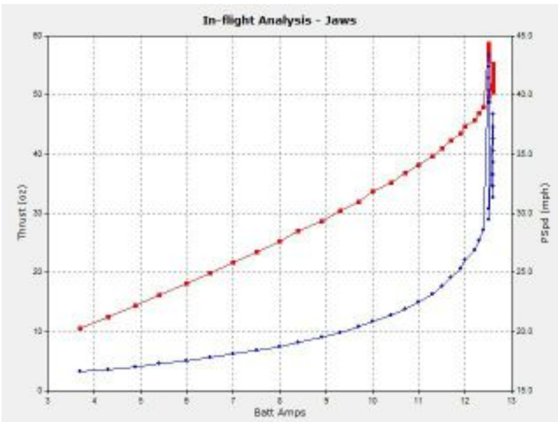


Figure 4.8: Thrust and Plane Speed vs. Battery Amps

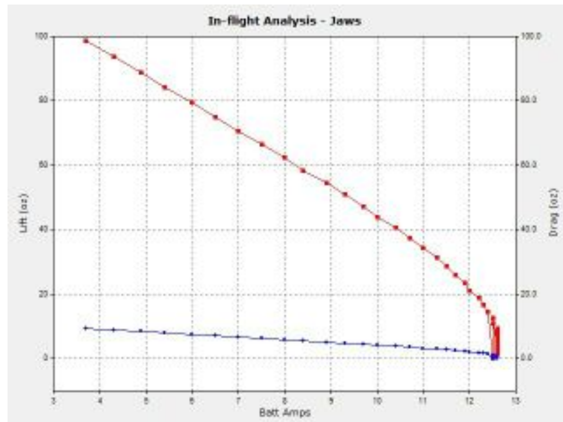


Figure 4.9: Lift and Drag vs. Battery Amps

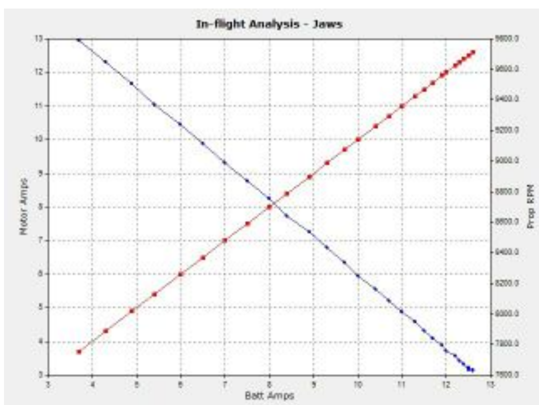


Figure 4.10: Motor Amps and Propeller RPM vs. Battery Amps

The information in the above graphs corresponds to a 12x6 propeller. With a plane speed of 30 mph, the propeller rpm reaches 7600 rpm at about 12.5 amps. At roughly 3.5 amps, there are roughly 100 ounces of lift that is produced coupled with about 12 oz. of drag. This lift is ample enough to complete the required short takeoff given the preliminary design. The thrust produced is about 56 ounces during steady level flight. During turning flight, the aircraft may not receive all the amperage as the servos draw from the same power source that the motor does. Because of this, the aircraft may lose some thrust. The values obtained by the Team all lie within the parameters necessary to complete the mission profile.

4.4.3 Propeller Selection

When selecting a propeller, the propeller load factor was taken into consideration. Propeller load factor is inversely proportional to the maximum achievable RPM of the propeller. Furthermore, the Team had already established that higher RPM's lead to high speeds. With this concept in mind, the values in Table 4.4 show chosen possible propeller sizes and their corresponding load factors. These propellers were then run through Motocalc to check its efficiency when ran with the chosen battery and motor configuration. The 12x6 propeller was shown to provide the best RPM and thrust without sacrificing the necessary lift.

Propeller Size	Propeller Load Factor
10x4	4000
11x4	5324
11x6	7986
12x6	10368

Table 4.4: Propeller Size vs. Propeller Load Factor

4.5. Structural Design and Sizing Trades

4.5.1. Fuselage Sizing

The Team designed the fuselage around the Mission 3 payload since its longest dimension (9 inches) would drive the size of the fuselage. The Team considered two possible ways to arrange the nurse/patient combinations: longitudinally, which would yield a longer, narrower fuselage or laterally, which would yield a shorter, wider fuselage. The Team elected to go with a longer, narrower fuselage since it would be more aerodynamic and the length would provide good pitch stability. With the patients mounted longitudinally, the payload area of the fuselage would be 18 inches long. After providing room for the propulsion system and tail mount, the Team settled on a length of 24 inches.

Next, the Team turned to the sizing of the elliptical cross section. Given a maximum payload height of 6 inches, and allowing 2 inches on the top and bottom for the bi-wing mounting system, the Team settled on a maximum fuselage height of 10 inches. Finally, given a maximum payload width of 6 inches and the need for battery space, the Team settled on a width of 14 inches and a height of 10 inches.

4.5.2. Internal Elements/Structure

In a break from previous years designs, which used a truss structure and therefore a squared shaped fuselage, the Team elected to use a semi-monocoque design. This allowed for the creation of a circular shaped fuselage. The fuselage was made up of bulkheads and stringers, covered by a lightweight skin. In the center of the bulkheads, and main trench was cut, providing a place for the payload to sit. Reinforced segments on the top and bottom of the fuselage, as well as the back end, provided places for the wings and tail to mount.

4.6. Lift, Drag and Stability Analysis

4.6.1. Lift

The Team examined the coefficient of lift, coefficient of drag, and the angle of attack for the chosen airfoils SD7034 and E216. The Team used the aerodynamic analysis program XFLR5 in order to analyze the properties of the airfoils for different Reynolds numbers. The Reynolds numbers examined were determined with the same Airfoil Tools Reynolds Number Calculator described in section 4.3.1. This calculator yielded Reynolds number of 170,000 for takeoff, 250,00 for climb, and 300,000 for max speed cruise based on the characteristic length of 9.5 in.

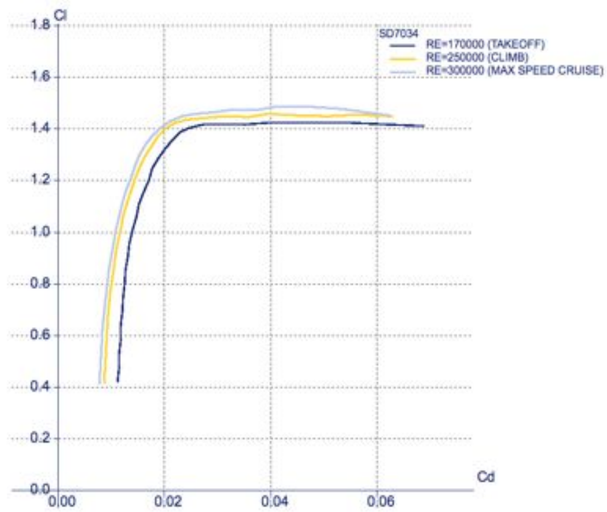


Figure 4.11: CL vs. CD (SD7034)

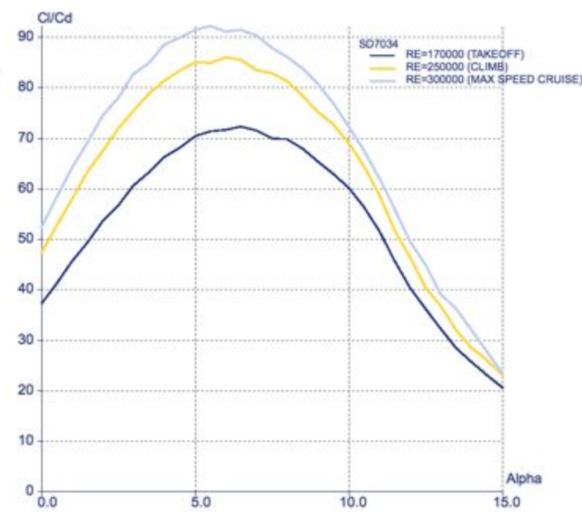


Figure 4.12: Glide Ratio vs. AoA (SD7034)

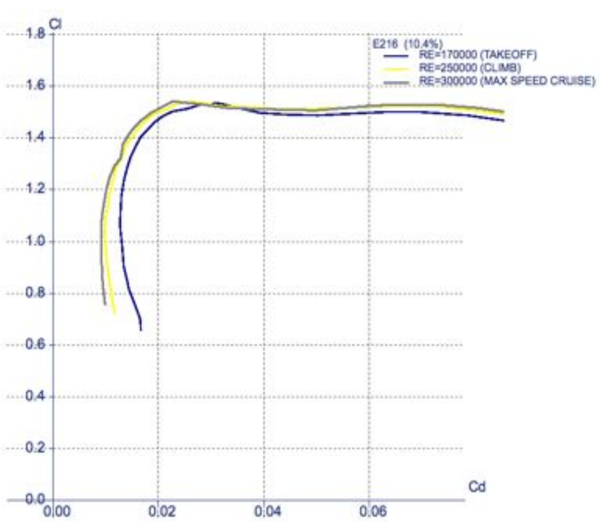


Figure 4.13: CL vs. CD (E216)

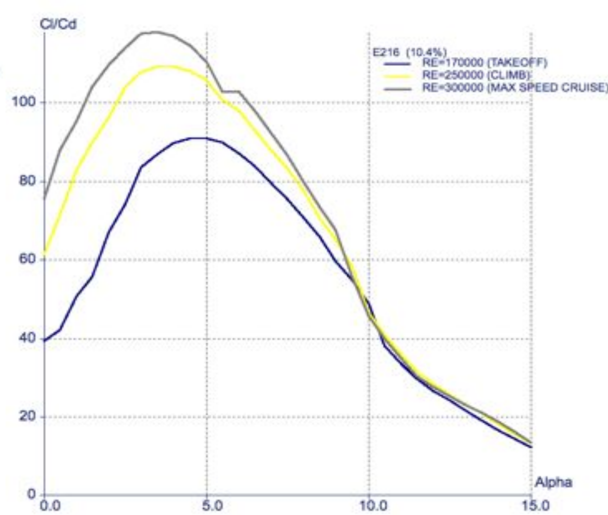


Figure 4.14: Glide Ratio vs. AoA (E216)

4.6.2. Drag

Drag on an aircraft comes from two main sources: parasitic drag, which is due to the shape of the aircraft structure and the “wet” surface area (i.e., the amount of surface area exposed to airflow) of those parts, and induced drag, which is due to the aircraft moving through the air. When analyzing the drag characteristics of the aircraft, the Team focused on the parasitic drag because it is a function of aircraft structural and aerodynamic design. Induced drag, on the other hand, is a function of wing size ratios and flight conditions. The Team estimated the zero-lift parasitic drag coefficient, C_{D0}, using the equivalent skin friction method. The results of this are shown below in Figure 4.15. Overall, the Team estimated the C_{D0} to be 0.028. As expected, the nose and wing had the greatest contributions to total drag, due to its large frontal area and large planform area, respectively.

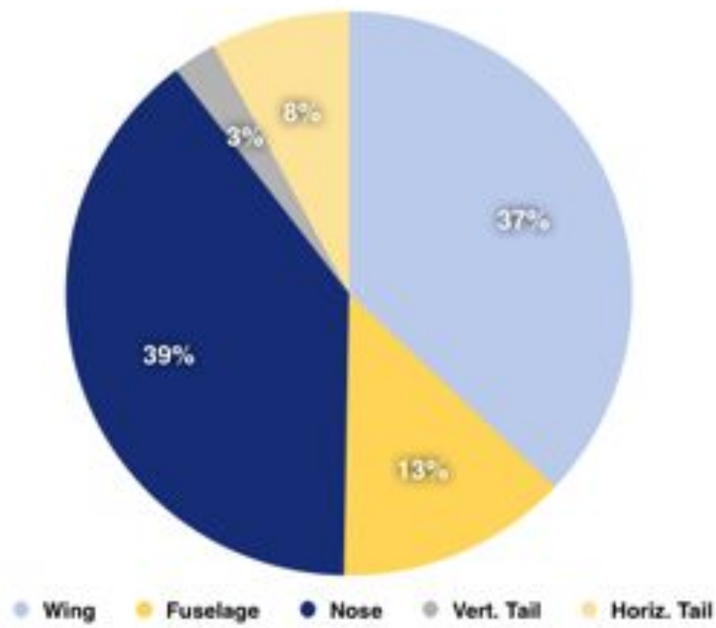


Figure 4.15: Breakdown of Parasitic Drag

4.6.3. Stability

To be longitudinally balanced, the aircraft requires the total pitching moment coefficient at zero lift to be positive and for the center of gravity to be ahead of the neutral point. To be statically stable, the slope of the total pitching moment coefficient vs. alpha should also be negative when the total pitching moment coefficient is zero. Longitudinal stability analysis was done using XFLR5 given the structural dimensions of the aircraft. Initial analysis showed that an elevator trim is necessary to maintain stability, so an elevator tilt of -7° was added into the analysis. Figure 4.16 below shows the modified analysis with the aircraft passing all requirements for longitudinal stability for all three Missions.

The analysis estimated the neutral point to be 3.4 inches from the leading edge of the main wing. The static margin was then calculated for the 3 Mission Profiles as shown in Table 4.5 according to its C.G. location with respect to in the x-axis using the following equation:

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

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

	Mission 1	Mission 2	Mission 3
Static Margin	**21.3%**	**22.5%**	**19.4%**

Table 4.5: Static Margin of Aircraft with Elevator Tilt of -7°

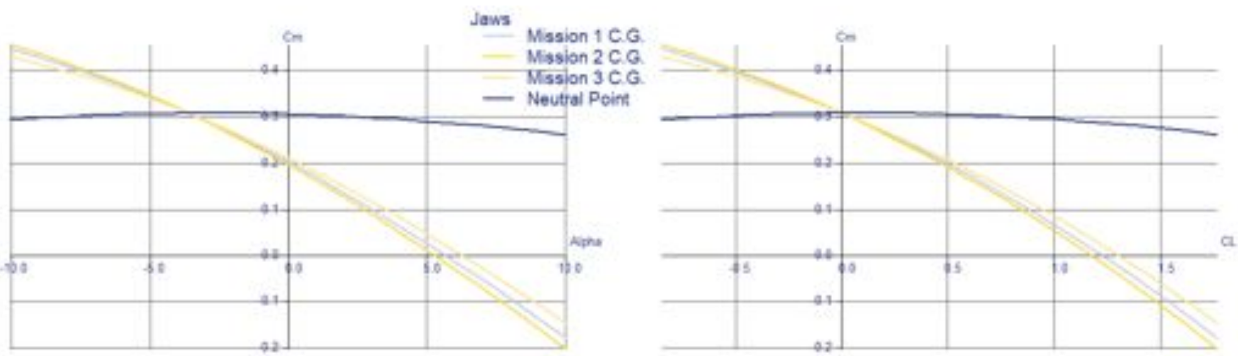


Figure 4.16: Tot. Pitching Mom. Coeff. (Cm) vs AoA and Tot. Pitching Mom. Coeff. (Cm) vs Cl

4.7. Estimated Aircraft Mission Performance

With the preliminary design of the aircraft in place, the Team was able to estimate mission performance, and comparing that to expected competition performance, estimate mission scores. The estimated mission scores can be seen in Table 4.6.

Mission 1		Mission 2		Mission 3	
Laps Completed	5	**Weight Carried**	2	**Time Flown**	180
Max Laps Completed	8	**Max Weight Carried**	4	**Best Laps Completed**	120
Mission 1 Score	1.25	**Mission 2 Score**	2	**Mission 2 Score**	4

Table 4.6 Estimated Mission Performance

5. Detail Design

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

5.1. Final Design Parameters

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

Overall Dimensions		Fuselage		Ailerons	
Max Length	41.02 in	Length	26 in	Span	10.8
Max Width	64.14 in	Width	13.5 in	Percent Chord	17%
Max Height	27.21 in	Height	10.5 in	Max. Deflection	±20 deg
Wing		Horiz. Tail		Flaps	
Span	54 in	Span	28.3 in	Span	10.8
Chord	9.5 in	Avg. Chord	7 in	Percent Chord	17%
Area	512 in^2	Area	141.5 in^2	Max. Deflection	-30 deg
Aspect Ratio	5.70	Aspect Ratio	4.04	Elevator	
Top Airfoil Bottom Airfoil	SD7034 E216	Airfoil	NACA 0008	Span	28.3 in
AoA	0 deg	AoA	0 deg	Percent Chord	29%
Motor/Battery		Vertical Tail		Max. Deflection	±45 deg
Motor	Neu 1110/6D	Span	11 in	Rudder	
ESC	Phoenix ICE-40 HV	Avg. Chord	5.625 in	Span	11 in
Battery Cell	Elite 1500	Area	44.2 in^2	Percent Chord	29%
Number of Cells	28	Aspect Ratio	1.96	Max. Deflection	±30 deg
Volts	33.6 V	Airfoil	Flat Plate	Control System	
Max. Amps	15 A	AoA	0	Servos	Hitec HS-55
Max. Power	504 W			Torque	15.27 oz-in

Table 5.1: Finalized Design Parameters

5.2. Structural Characteristics and Capabilities

The complete airframe was designed to withstand loading up to 2.5 g's. This load factor provides the design limit loads for the airframe. Furthermore, the industry standard safety factors (limit load 125% of design load and ultimate load 150% of design load) were used to ensure the structural integrity of the airframe even in worse than expected load cases.

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

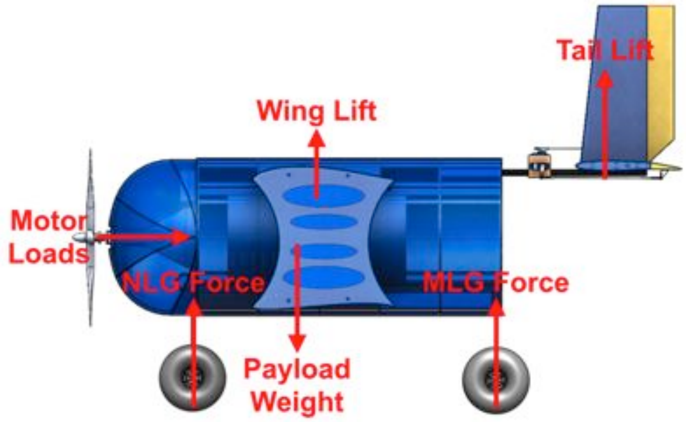


Figure 5.1 External Loads

The goal of an aircraft structure, in addition to giving the aircraft shape, is to distribute applied loads around the structure so that there are no load concentrations. With this in mind, and knowing where the loads were applied, the Team then drew load-paths, showing how external loads would enter and move throughout the structure. A sketch of these load paths can be seen in Figure 5.2.

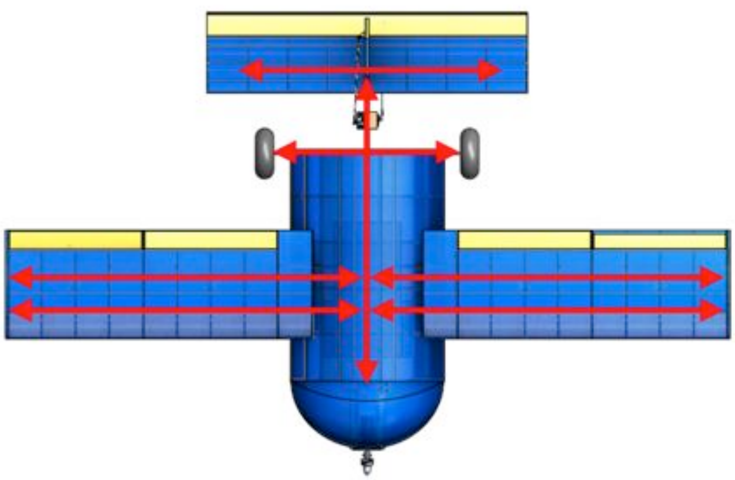


Figure 5.2 Load Paths

Understanding where the load enters the structure and how the load moves through the structure, the Team was able to identify critical load locations, and design the structural elements at those locations accordingly. These structural elements and the required design requirements are listed in Table 5.2.

Structural Element	Applied Load	Description of Design
Front Firewall	Motor torque/vibration Nose landing gear impact	Should be a large plate to absorb the landing impact and motor vibrations, with multiple connections to the fuselage to allow for load transfer.
Rear Firewall	Main landing gear impact	Should be a large plate to absorb the landing impact and motor vibrations, with multiple connections to the fuselage to allow for load transfer.
Wing Mounts	Wing shear/bending/torsion	Should be rigid and provide multiple contact points with rest of fuselage to allow for adequate load distribution.
Tail Mount	Tail shear/bending/torsion	Should provide enough contact points with tail boom to fully constrain tail movement. Given the length of boom, y-axis bending is the biggest concern.
Fuselage Longerons	Load distribution	Should be made of rigid material, and provide a continuous, unbroken connect from front to back. Better to have multiple smaller elements to provide multiple load paths, as compared to one large element.

Table 5.2 Critical Structural Elements

5.3. System Designs, Component Selection and Integration

5.3.1. Fuselage Structural Design

The fuselage structure is designed around an elliptical cross section with an open trench cut through the middle. This trench provides room for the payload and batteries to mount to the aircraft. The fuselage is constructed using a semi-monocoque structural design. Fuselage bulkheads provide the shape of the cross section, while longerons give the structure its length and longitudinal strength. The top and bottom of the fuselage provide the bulk of the structural support, and leave room to attach the wings, tail and landing gear.

The motor mounts to the front firewall using an homemade, but commercially-derived motor mount. Around this, a mylar-balsa cowling provides an aerodynamic surface that diverts the incoming air around the fuselage with as little drag as possible. The complete fuselage can be seen in Figure 5.3.

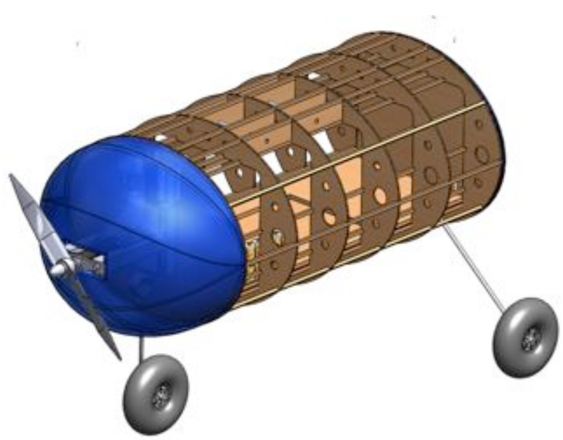


Figure 5.3: Fuselage Structural Design

5.3.2. Landing Gear

Given the mission requirements, a strong, stable, steerable landing gear was a critical requirement for the aircraft to be successful in its mission scores. As mentioned in Section 3, the Team elected to go with a tricycle landing gear. The nose landing gear is a single, steerable gear that mounts to the front firewall with two nylon gear blocks. The main landing gear is a split gear (port and starboard sections) that mounts to the rear firewall. The main gear is attached by first creating a sandwich (wooden blocks surround the metal rods), and then gluing and bolting the sandwiched pieces to the firewall. This design ensures that the gear is constrained in all directions (backwards rotation and vertical shear). Furthermore, the design requirements state that the aircraft must have at least 4 inches of clearance between the ground and the wing at half-span. The landing gear was therefore designed to provide more than the required clearance, with a final 6.5 inches of clearance at the wing half-span. The nose landing gear and main landing gear can be seen in Figure 5.4.

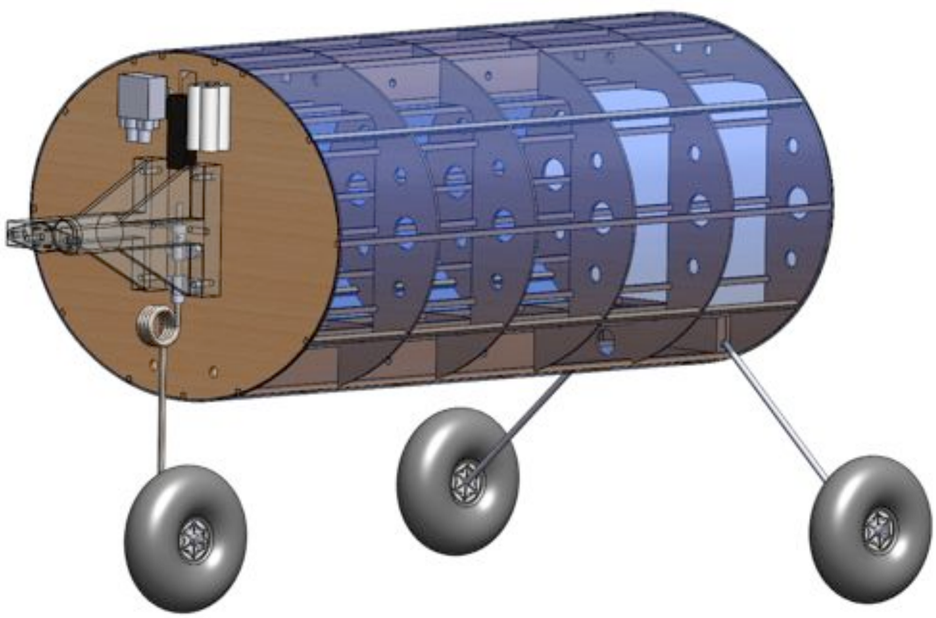


Figure 5.4 Landing Gear Design

5.3.3. Payload Securement System

The payload securement system is built around a reversible tray. On one side of the tray, there are cut outs to fit the Mission 2 blocks. On the other side of the tray, there are cut outs for the Mission 3 nurse/patient combinations. The blocks are held into the tray using securing straps. The tray is then secured to the floor of the aircraft using Velcro. The tray is a permanent part of the aircraft in that it flies on all three missions, but provides the flexibility required for the dramatically different payload shapes in Missions 2 and 3. The light weight tray is lasercut from two sheets of balsa wood, and then glued together to create the final assembly. The tray also provides a place to secure the battery packs. The assembled and loaded payload trays can be seen in Figures 5.5 and 5.6.

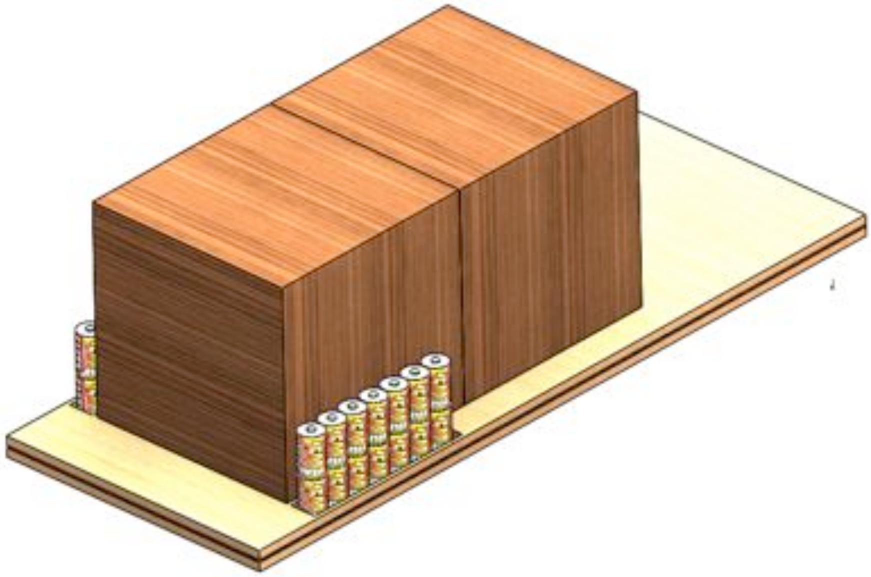


Figure 5.5: Mission 2 Payload Securement System

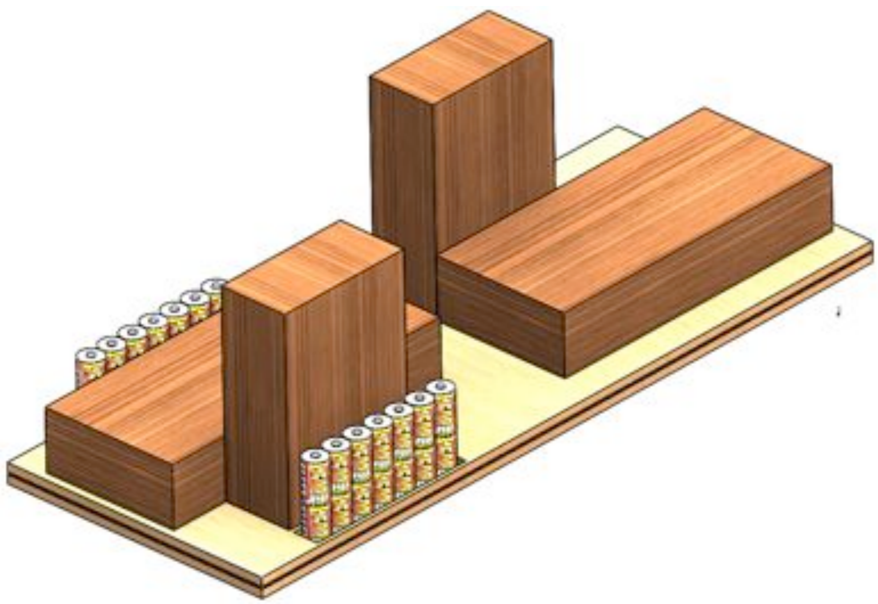


Figure 5.6: Mission 3 Payload Securement System

5.3.4. Wing Attachment System

The wing attaches to the fuselage through mounts located at the top and bottom of the fuselage. The mounts are made of hollow aluminum tubes, anchored by solid blocks on either end. Wing spars enter at each side of the tube, meeting in the middle. The inside diameter of the tubes matches the outside diameter of the wing spars, providing a tight, secure fit. The long contact area between spar and mount allows for uniform load distribution from the wing to the fuselage. Although the wing mounts provide a tight fit for the spars, rubber bands are used top and bottom to pull each wing half towards the middle of the fuselage, ensuring that the wings stay rigidly attached during flight. The wing mounting system is shown in Figure 5.7.

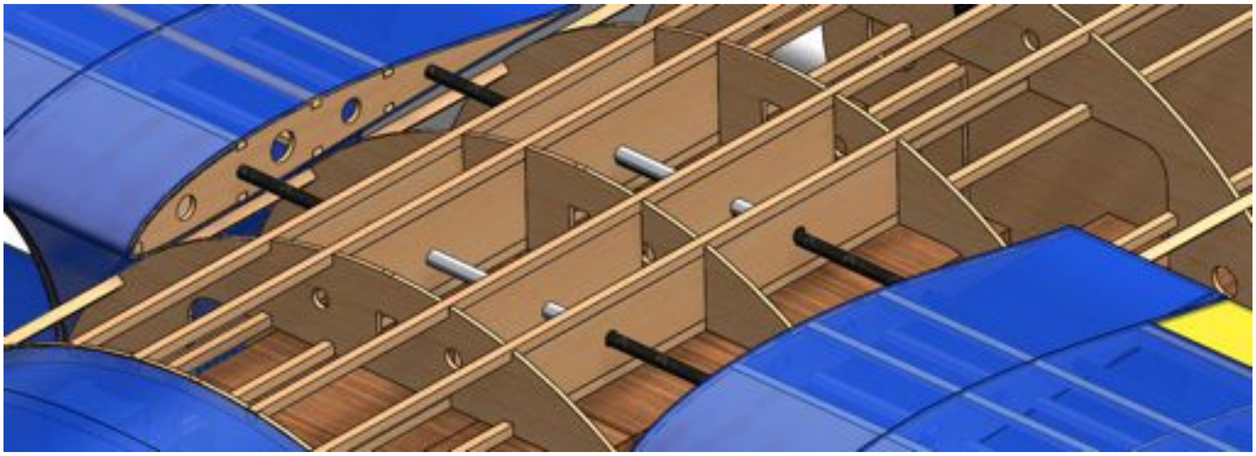


Figure 5.7: Wing Attachment System

5.3.5. Wing Structural Design

The wing is built around 2 carbon fiber rods that act as wing spars. Ribs form the airfoil shape, and stringers provide top and bottom rigidity to the structure. Two ribs in each wing are made of plywood, and are fitted with cutouts through which the aileron and flap servos are mounted. The ailerons and flaps are inset, in the hopes that this will provide more strength and flutter resistance than if they were mounted off the end of the wing. Since the aircraft is a biplane, the top and bottom wings are secured together using two top to bottom supports, one at the wingtip and one at approximately the 33% span location. These 2 supports ensure that the wing performs as one solid structure, and that loads can be passed from the top wing to the bottom wing (and vice-versa). The wing structural design is shown in Figure 5.8.

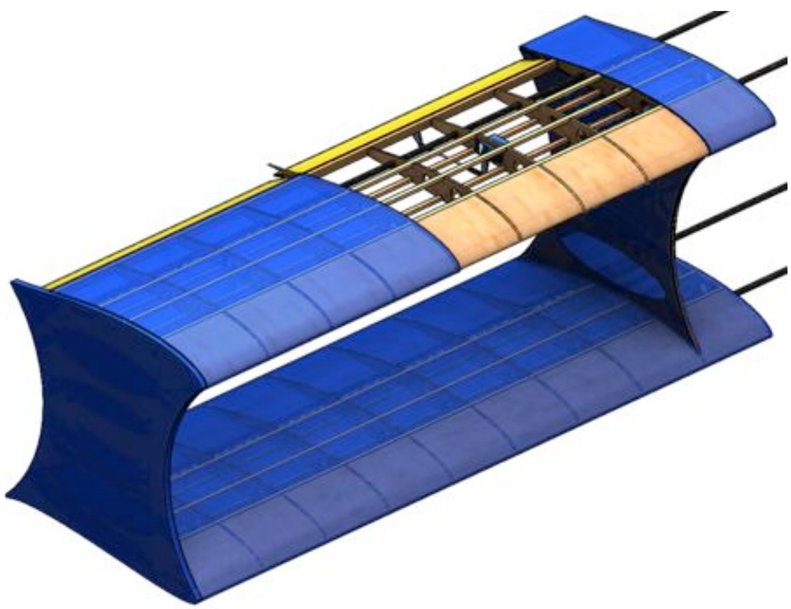


Figure 5.8: Wing Structural Design

5.3.6. Tail Structural Design

The structural design of the tail mirrors that of the wing, using the same materials for the ribs, spars and stringers. The vertical tail is mated to the horizontal tail using a notch in the horizontal tail that allows the vertical tail to be inset. The entire tail assembly is then attached to the tail boom, a square carbon fiber tube. The tail boom also has places for the tail servos to mount, and attaches to the fuselage using two mounts, which are made of solid blocks with a precision-cut hole in the center. Setscrews hold the tail boom in place. The dual-mount design ensures that the tail will not shift during flight. The tail structural design is shown in Figure 5.9.

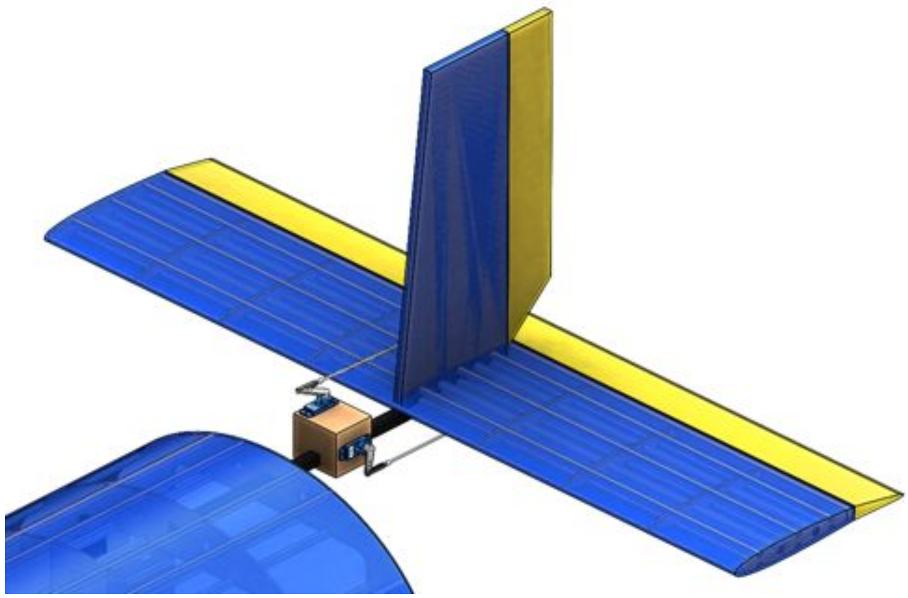


Figure 5.9: Tail Structural Design

5.3.7. Electronic Control System

The Controls Team selected the Hitec Eclipse 7 Pro transmitter/receiver combination for competition use. This radio package provided a wealth of configuration options as well as the necessary failsafe mode. The Team then paired this system with Hitec HS-55 servos for moving the flight control surfaces. The Hitec servos, with gears made of nylon, were a lightweight option that still provided enough torque to move the control surfaces during flight and prevent aeroelastic forces from moving the control surfaces during high-g maneuvers.

5.3.8. Propulsion System

As discussed in Section 4, the selected motor is a Neu 1110/6D, which draws a maximum of 500 watts of power while weighing just .25 lbs. To regulate the motor, a Castle Creations Phoenix ICE-40HV electronic speed controller was used. This speed controller is a high voltage model, which is imperative given the 33.6 volt battery pack. The battery back consists of 28 Elite 1500 cells, split into 2 packs of 14 cells, all wired together in series. The split pack allows for a more balanced placement of the heavy battery packs while not compromising the series wiring of the packs. In between the ESC and the batteries is a 15 amp fuse, which limits the current draw of the motor. At 15 amps and 33.6 volts, the system can produce 504 watts of power, which pushes the motor to its limit.

5.4. Weight and Balance

Below are the weight and balance tables for the aircraft. The coordinate system origin is at the nose of the aircraft. Positive x-axis runs from the nose down the length of the fuselage, positive y-axis is in the direction of the starboard wing, and positive z-axis is upwards. The coordinate system detailing can be seen in Figure 5.10.

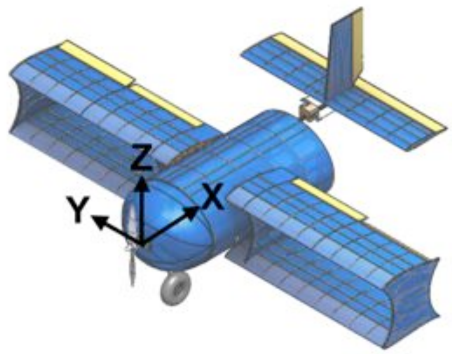


Figure 5.10: Aircraft Axes and Location of Origin

The quarter chord of the wing is at location (x,y,z) inches from the nose. The goal is to have the x-axis center of gravity be at or near the quarter chord of the wing. For the y-axis center of gravity, the goal is to have it at the centerline of the aircraft. The location of the z-axis center of gravity is less important, but in terms of ground stability, a lower CG is more desirable. The target center of gravity is at (x,y,z) = (14.19, 0, -2). In Tables 5.3-5.5, the weights and center of gravity locations of all aircraft components are listed for each mission.

	Weight [lb]	X Distance from Origin [in]	Y Distance from Origin [in]	Z Distance from Origin [in]
Fuselage	1.25	19	0	-5
Motor	0.25	1	0	0
Batteries	1.4	8	0	-3.5
Payload Tray	0.1	17	0	-5
Port Wing	0.75	13	-34	0
Starboard Wing	0.75	13	34	0
Tail Boom	0.25	26	0	5
Tail	0.25	36	0	7
Total	5	14.38	0	-1.73

Table 5.3: Mission 1 Weight and Balance Table

	Weight [lb]	X Distance from Origin [in]	Y Distance from Origin [in]	Z Distance from Origin [in]
Fuselage	1.25	19	0	-5
Motor	0.25	1	0	0
Batteries	1.4	8	0	-3.5
Payload Tray	0.1	17	0	-5
Mission 2 Payload	2	14	0	-2
Port Wing	0.75	13	-34	0
Starboard Wing	0.75	13	34	0
Tail Boom	0.25	26	0	5
Tail	0.25	36	0	7
Total	7	14.27	0	-1.81

Table 5.4: Mission 2 Weight and Balance Table

	Weight [lb]	X Distance from Origin [in]	Y Distance from Origin [in]	Z Distance from Origin [in]
Fuselage	1.25	19	0	-5
Motor	0.25	1	0	0
Batteries	1.4	8	0	-3.5
Payload Tray	0.1	17	0	-5
Mission 3 Payload	2	15	0	-2
Port Wing	0.75	13	-34	0
Starboard Wing	0.75	13	34	0
Tail Boom	0.25	26	0	5
Tail	0.25	36	0	7
Total	7	14.56	0	-1.81

Table 5.5: Mission 3 Weight and Balance Tables

5.5. Flight Performance Parameters

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

Parameter	Mission 1	Mission 2	Mission 3
$C_{L\text{-}max}$	1.5	1.5	1.5
$C_{L\text{-}cruise}$	1.1	1.1	1.1
$C_{L\text{-}takeoff}$	1.3	1.3	1.3
C_{D0}	0.028	0.028	0.028
Takeoff Speed [ft/s]	44	44	44
Takeoff Distance [ft]	30	38	38
Climb Angle [deg]	15	15	15
Turn Rate [deg/s]	52	52	52
Wing Loading [lb/in^2]	1.125	1.688	1.688
Flight Time [s]	240	195	195
Gross Takeoff Weight [lb]	4	6	6

Table 5.6: Flight Performance Parameters

5.6. Aircraft Mission Performance

Using aircraft parameters and mission analysis software, the Team calculated performance for each of the missions. This analysis allowed the Team to identify the critical stages of flight and see if and where aircraft performance was deficient. The following tables contain the results of this analysis.

Mission 1	Mission Stage	Total Distance [ft]	Final Speed [ft/s]	Time [s]
	Takeoff	30	44	5
	Climb	220	59	10
	Cruise	250	65	4
	180 Degree Turn	250	50	5
	Cruise	500	65	8
	360 Degree Turn	350	50	7
	Cruise	500	65	8
	180 Degree Turn	250	50	5
	Cruise	500	65	8
Total:		**2850**		**60**

Table 5.7: Mission 1 Mission Performance

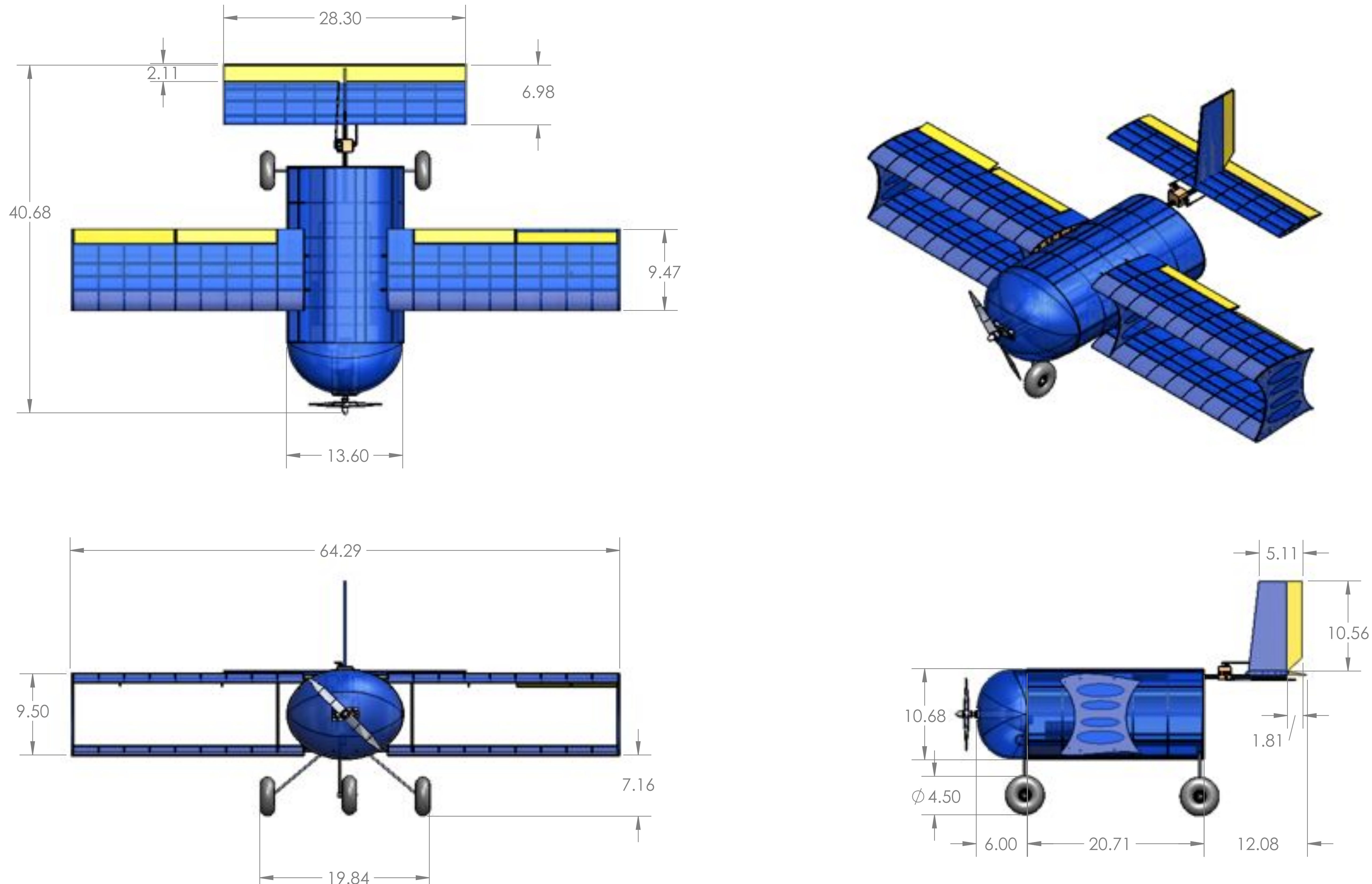
Mission 2	Mission Stage	Total Distance [ft]	Final Speed [ft/s]	Time [s]
	Takeoff	38	44	5
	Climb	220	52	12
	Cruise	250	60	4
	180 Degree Turn	250	50	5
	Cruise	500	60	9
	360 Degree Turn	350	50	7
	Cruise	500	60	9
	180 Degree Turn	250	50	5
	Cruise	500	60	9
Total:		**2850**		**65**

Table 5.8: Mission 2 Mission Performance

Mission 3	Mission Stage	Total Distance [ft]	Final Speed [ft/s]	Time [s]
	Takeoff	38	44	5
	Climb	220	52	12
	Cruise	250	60	4
	180 Degree Turn	250	50	5
	Cruise	500	60	9
	360 Degree Turn	350	50	7
	Cruise	500	60	9
	180 Degree Turn	250	50	5
	Cruise	500	60	9
Total:		**2850**		**65**

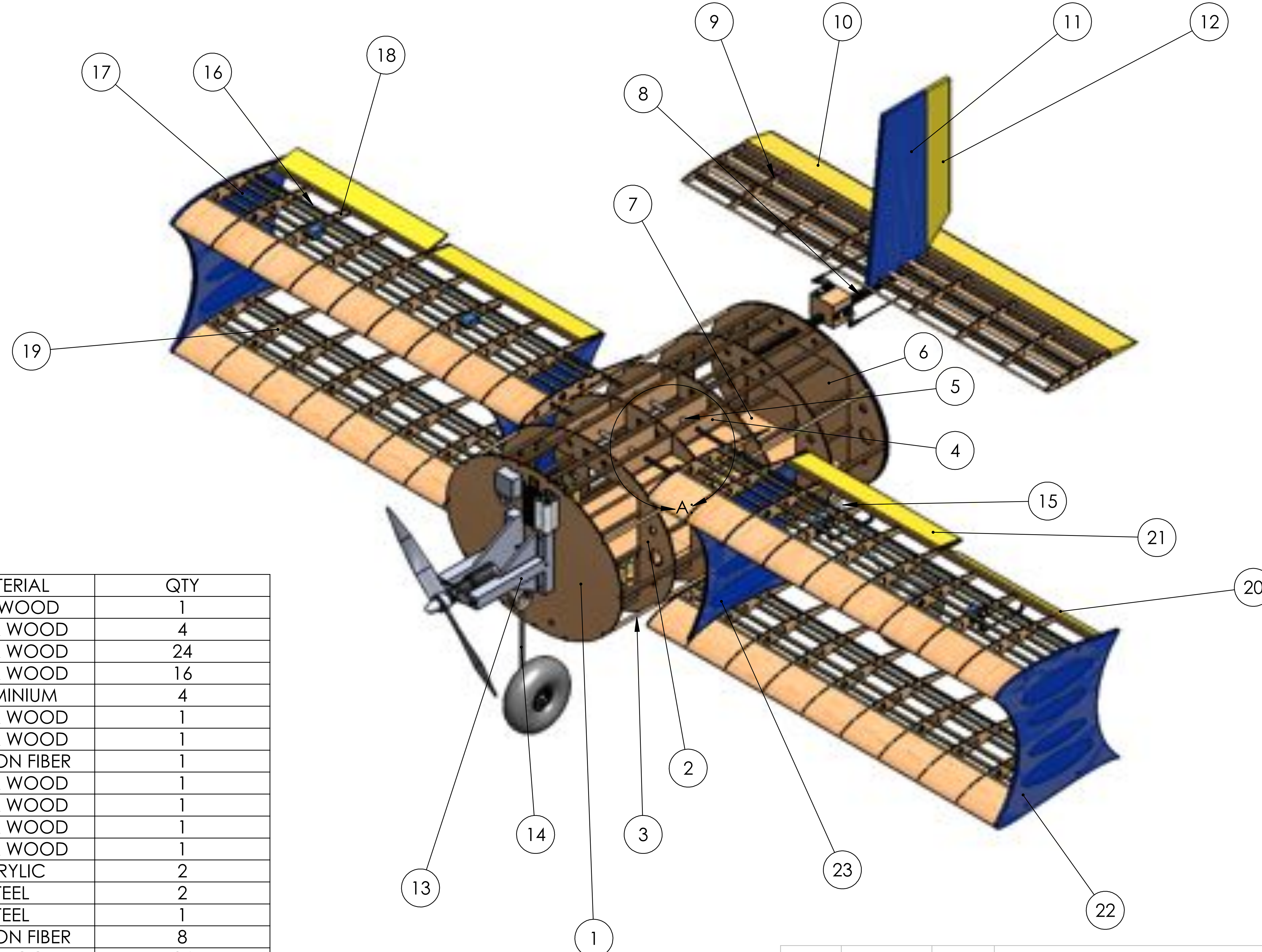
Table 5.9: Mission 3 Mission Performance

5.7. Drawing Package (see following pages)



	NAME	DATE	TITLE: **AIRCRAFT THREE VIEW**
DRAWN	S. JACOBSON	2/20/14	
CHECKED	R. FELVER	2/20/14	
COMMENTS: ALL UNITS IN INCHES UNLESS OTHERWISE SPECIFIED			SIZE **B** — REPORT SECTION: DRAWING PACKAGE — REV **A**
			SCALE: 1:12 — SHEET 1 OF 4

DETAIL A: WING MOUNT
SCALE 1 : 3



ITEM NO.	NAME	MATERIAL	QTY
1	FUSELAGE FRONT RIB	BASSWOOD	1
2	FUSELAGE RIB	BALSA WOOD	4
3	FUSELAGE STRINGER	BALSA WOOD	24
4	WING MOUNT PLATE	BALSA WOOD	16
5	WING MOUNT	ALUMINIUM	4
6	PAYLOAD/BATTERY TRAY	BALSA WOOD	1
7	FUSELAGE BACK COVER	BALSA WOOD	1
8	TAIL BOOM	CARBON FIBER	1
9	HORIZONTAL TAIL	BALSA WOOD	1
10	ELEVATOR	BALSA WOOD	1
11	VERTICAL TAIL	BALSA WOOD	1
12	RUDDER	BALSA WOOD	1
13	MOTOR MOUNT	ACRYLIC	2
14	MAIN LANDING GEAR	STEEL	2
15	NOSE LANDING GEAR	STEEL	1
16	WING SPAR	CARBON FIBER	8
17	WING STRINGER	BASSWOOD	24
18	TOP WING RIB	BALSA WOOD	20
19	BOTTOM WING RIB	BALSA WOOD	20
20	AILERON	BALSA WOOD	2
21	FLAP	BALSA WOOD	2
22	WINGTIP SUPPORT	BALSA WOOD	2
23	MID-WING SUPPORT	BALSA WOOD	2

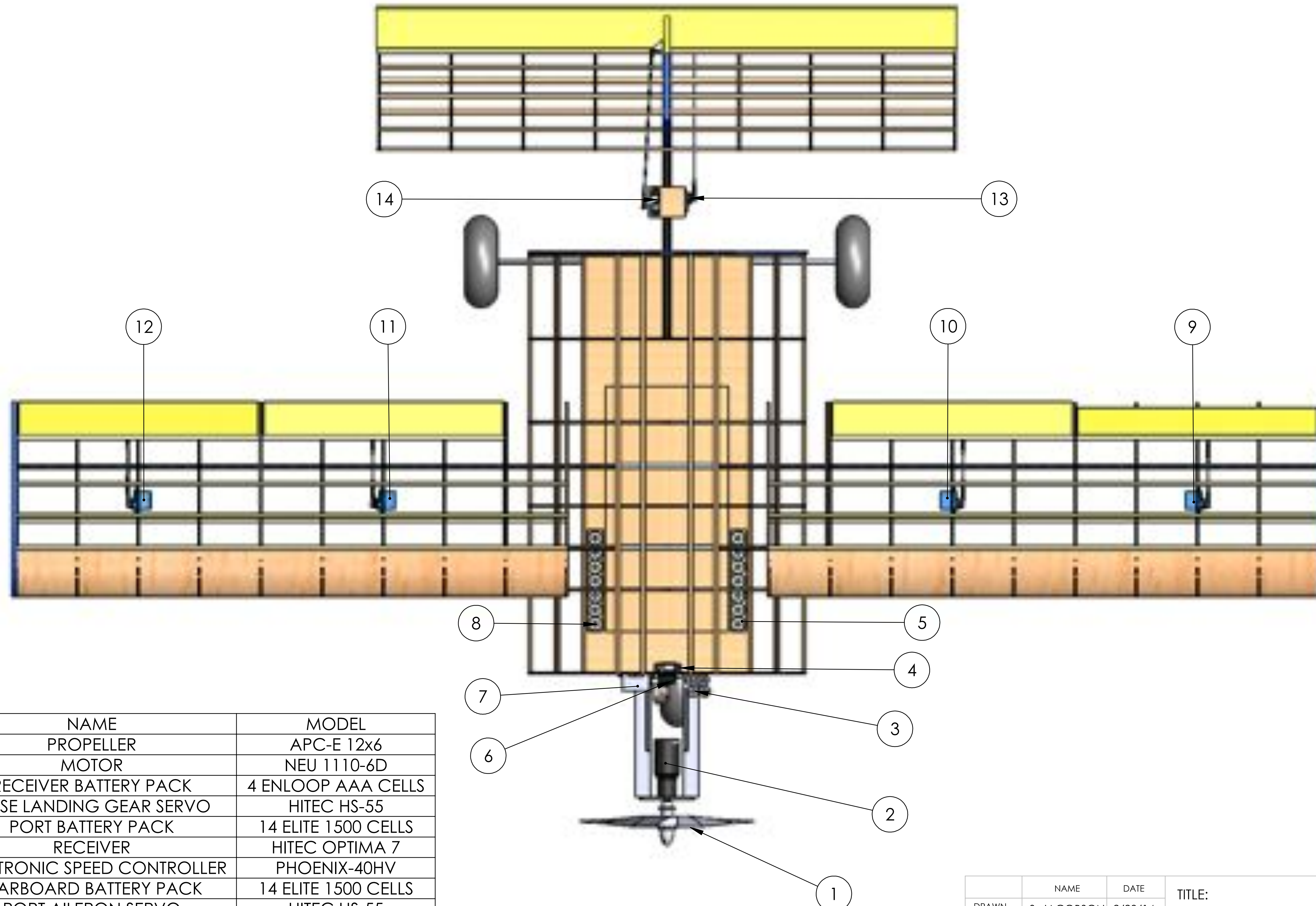
	NAME	DATE
DRAWN	S. JACOBSON	2/20/14
CHECKED	R. FELVER	2/20/14

COMMENTS:
ALL UNITS IN INCHES UNLESS OTHERWISE SPECIFIED

TITLE: **STRUCTURAL ARRANGEMENT**

SIZE **B** | REPORT SECTION: DRAWING PACKAGE | REV **A**

SCALE: 1:6 | SHEET 2 OF 4



ITEM NO.	NAME	MODEL
1	PROPELLER	APC-E 12x6
2	MOTOR	NEU 1110-6D
3	RECEIVER BATTERY PACK	4 ENLOOP AAA CELLS
4	NOSE LANDING GEAR SERVO	HITEC HS-55
5	PORT BATTERY PACK	14 ELITE 1500 CELLS
6	RECEIVER	HITEC OPTIMA 7
7	ELECTRONIC SPEED CONTROLLER	PHOENIX-40HV
8	STARBOARD BATTERY PACK	14 ELITE 1500 CELLS
9	PORT AILERON SERVO	HITEC HS-55
10	PORT FLAP SERVO	HITEC HS-55
11	STARBOARD FLAP SERVO	HITEC HS-55
12	STARBOARD AILERON SERVO	HITEC HS-55
13	ELEVATOR SERVO	HITEC HS-55
14	RUDDER SERVO	HITEC HS-55

	NAME	DATE
DRAWN	S. JACOBSON	2/20/14
CHECKED	R. FELVER	2/20/14

COMMENTS:

ALL UNITS IN INCHES UNLESS OTHERWISE SPECIFIED

TITLE:

SYSTEMS LAYOUT

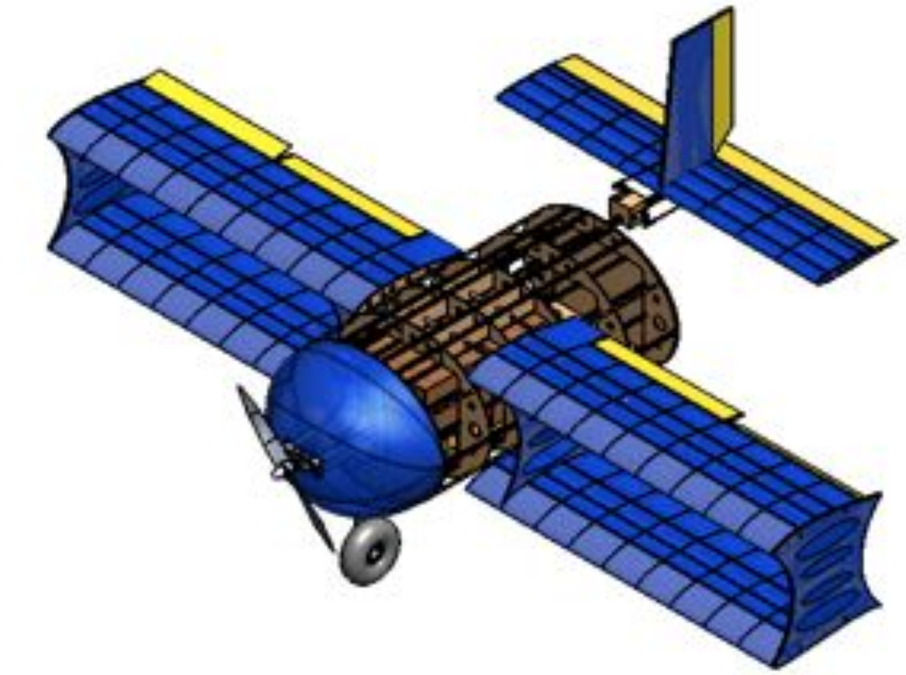
SIZE **B**

REPORT SECTION: DRAWING PACKAGE

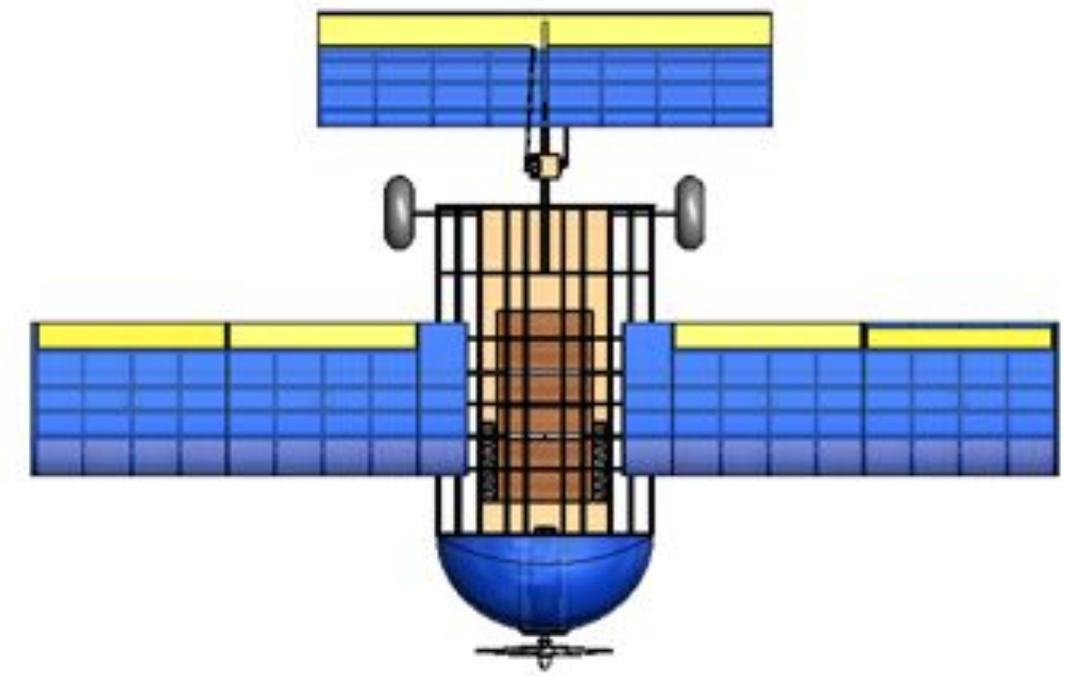
REV **A**

SCALE: 1:5

SHEET 3 OF 4



MISSION 2 PAYLOAD



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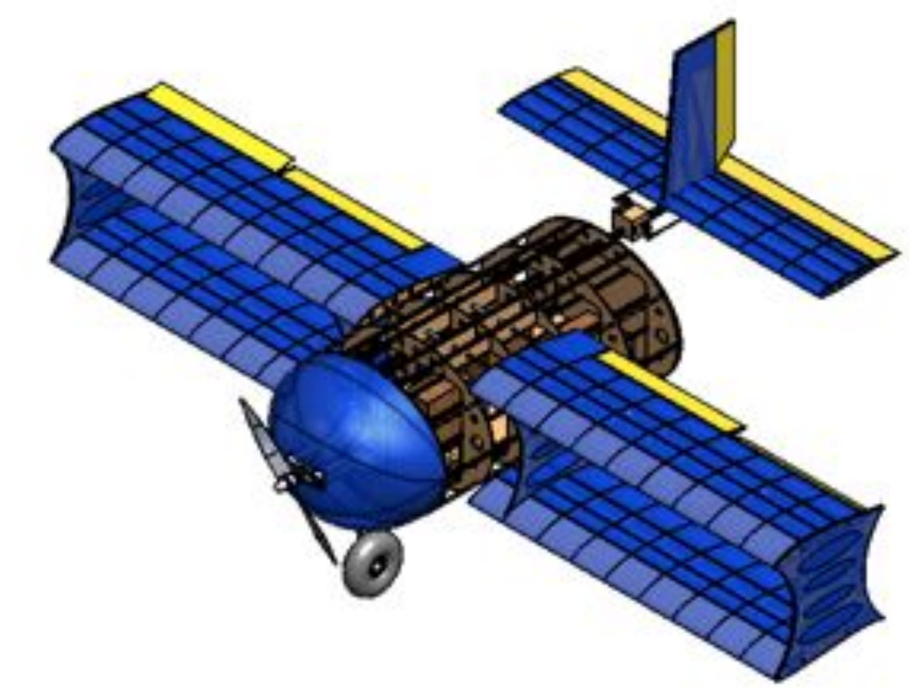

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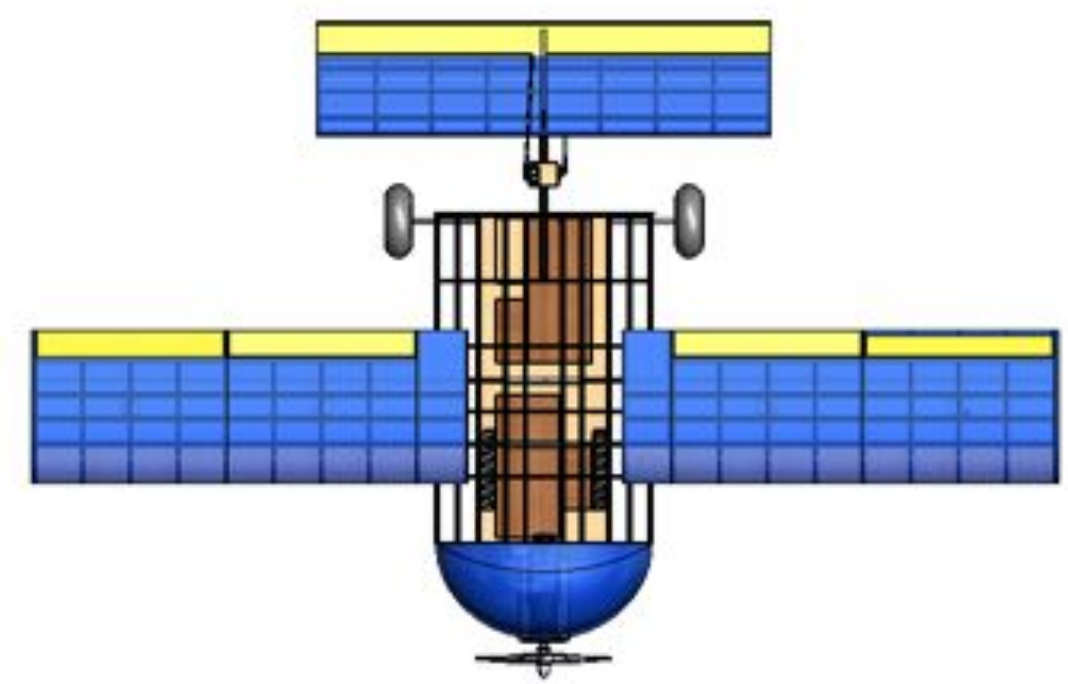

MISSION 3 PAYLOAD

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DRAWN	S. JACOBSON	2/20/14
CHECKED	R. FELVER	2/20/14

COMMENTS:

ALL UNITS IN INCHES UNLESS OTHERWISE SPECIFIED

TITLE: **PAYLOAD ACCOMODATIONS**

SIZE	REPORT SECTION:	REV
B	DRAWING PACKAGE	**A**
SCALE: 1:12		SHEET 4 OF 4

6. 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. These Figures of Merit covered all relevant concerns regarding fabrication.

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. Instead, each component could be constructed individually and with a different method if needed. In order to allow for this possibility, a decision matrix was created for each major component.

6.2. Investigation and Selection of Major Components and Assembly Methods

6.2.1. The Fuselage

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

- **Balsa Truss:** A frame is constructed of balsa wood beams and then covered in a skin of Mylar.
- **Balsa Semi-Monocoque:** Fuselage bulkheads (ribs) are cut out on the LaserCamm, and then assembled together using longerons. Structure is then covered in Mylar skin.
- **Lost Foam Core:** A block of foam is cut out in the shape of the fuselage. Then the center is removed to create room for the payload and electronic systems. Outside is covered in fiberglass.
- **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 semi-monocoque method was selected for the fuselage due to its low weight, high strength, and easy assembly.

FOM	Weight	Balsa Truss	Balsa Semi-Monocoque	Lost Foam Core	Mold
Weight	36	3	5	1	3
Ease of Fabrication	20	5	5	3	1
Ease of Repair	28	3	3	1	1
Cost	4	5	5	3	1
Strength	12	1	3	3	5
Total	**100**	**324**	**420**	**172**	**220**

Table 6.1: Fuselage Fabrication 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 laser-cut out of balsa sheets and are connected using spars and stringers made from thin balsa wood rods. The vertical stabilizer is constructed from balsa wood beams. The whole wing and tail is then covered using Mylar.
- **Foam Core:** A block of foam is cut out in the shape of the wing and tail. The foam is then covered in fiberglass.
- **Mold:** A foam model is created and then covered in gypsum. This allows the Team to create a mold from which a fiberglass wing and tail can be made.

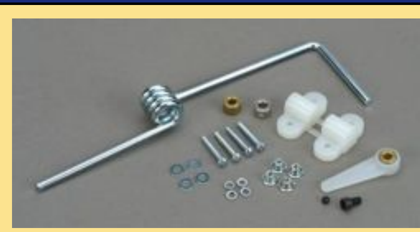
The Team put these possible construction techniques into a decision matrix. After an analysis, the balsa method was selected for the wing and tail due to its low weight and easy assembly.

FOM	Weight	Balsa	Foam Core	Mold
Weight	36	3	1	3
Ease of Fabrication	20	3	1	1
Ease of Repair	28	2	1	1
Cost	4	3	3	1
Strength	12	1	2	3
Total	**100**	**248**	**120**	**196**

Table 6.2: Wing Fabrication Decision Matrix

6.2.3. The Landing Gear

When fabricating the landing gear, the Team's main decision was between a store-bought solution, which required little assembly but was not customizable, or a custom-fabricated landing gear, which would need to be designed, analyzed and fabricated in-house. The Team started by searching for commercially available landing gear that would meet the design requirements (most notably, the need for 4 inches of ground clearance mid-wing). The Team assembled a list of possible options (seen below). The landing gear was broken down into two categories, main landing gear (MLG) and nose landing gear (NLG). The commercial landing gear options are shown in Table 6.3.

Type	Weight	Mount Location	Picture
NLG	.15 lbs	Nose Firewall	

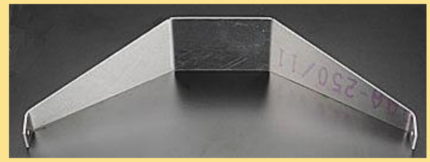
Type	Weight	Mount Location	Picture
MLG	1.08 lbs	Wing	
MLG	.275 lbs	Fuselage	

Table 6.3: Table of Landing Gear Options

After considering these options, the Team decided to go with a commercially available landing gear for the steerable nose wheel, which consisted of only one wheel and did not require as much customization. For the fixed main gear, the Team could not find a commercially available option that met the design requirements, and therefore elected to fabricate one. The Team elected to bend a steel rod (.19" diameter) to the shape designed in Section 5. Once complete, the rod was mounted to the fuselage using nylon blocks and plywood plates. One half of the fabricated main landing gear is shown in Figure 6.1 below.

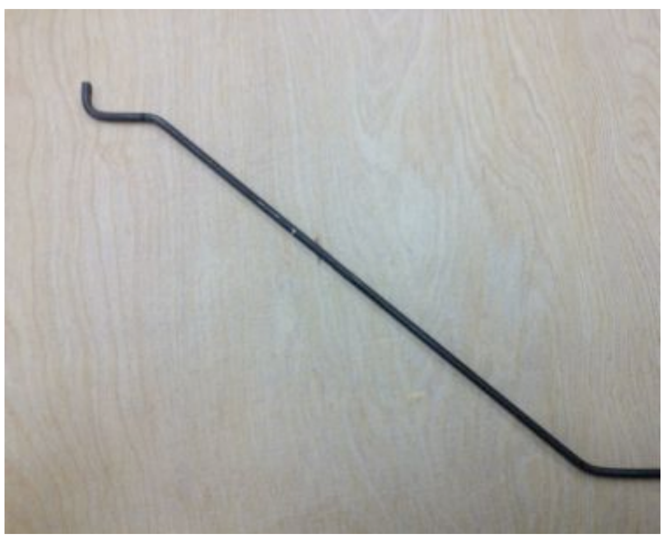


Figure 6.1: Custom Fabricated Main Landing Gear

6.2.4. Payload Tray

In designing the payload tray, the Team had three main concerns: weight of the tray, rigidity of the tray, and precision of the payload cutouts. In order to insure the highest level of precision, the Team decided to cut the tray out on UC San Diego's Lasercamm. After deciding on the lasercut method, this limited the possible materials to either a paper-backed foam or balsa wood. While foam would be a lower-weight solution than balsa, the Team felt that it did not provide the required rigidity to the tray. Therefore, the Team elected to use .25 in thick balsa sheets to create the payload tray.

6.3. Manufacturing Plan

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

Figure 6.2: Manufacturing Schedule

7. Testing Plan

The Team conducted a variety of tests throughout the design and fabrication process to insure that individual components and final assemblies performed as projected. These tests also allowed the Team to correct and optimize any components that were underperforming prior to the competition.

7.1. Objectives

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

<u>7.1.1. Components</u>

Structures

In order to verify the structural integrity of the aircraft, the Team performed a number of tests on structural elements, namely the wing and the fuselage. To test the stresses and structural integrity of the wing, weights were placed along the wing in order to simulate maximum wing loading. In order to test the integrity of the fuselage, it was loaded lengthwise to verify bending stiffness. These tests allowed the Team to verify that the aircraft could withstand the flight loads.

Aerodynamics

The aerodynamics of the aircraft were tested and optimized with a combination of computer modeling and flight testing. The Team initially tested the selected wing and airfoil in XFLR5. This also allowed the Team to gather the appropriate performance values.

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. The Team was also concerned that the landing gear was able to handle the rough surface during the taxi mission. To test for these various conditions, deflection tests were performed on the plane with the landing gear attached to determine the structural integrity of the landing gear.

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. In addition, tests were performed to verify the batteries' capacity.

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 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 MotoCalc. This insured that the aircraft would have enough speed and thrust to take off and allowed the Team to produce estimates for Missions 1, 2, and 3, where take off distance 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, insuring 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

Payload stability in flight was a critical concern for the Team, as a shift mid-flight could destabilize the aircraft and cause it to crash. In an effort to prevent this, the Team completed 2 types of payload testing: static and dynamic. For the static tests, the payload retention tabs were loaded to twice the weight of the payload (simulating a 2-g loading) and then inspected for damage. For the dynamic tests, the fuselage and payload were subjected to a vibration test that insured that the payload remained firmly in place, even during rough flight.

7.1.4. Flight Testing

For flight testing, the Team constructed 3 complete aircraft. The first aircraft, dubbed Narwhal, was a 75% scale model, but equipped with the selected motor/battery combination. This aircraft was used to verify the basic configuration of the aircraft. Once the Team was satisfied with the performance of

Narwhal, the second prototype, Jaws-X1 was built. Jaws-X1 was a full scale version of the aircraft detailed in Sections 1-5. Jaws-X1 was used to verify the ground handling, takeoff abilities, speed and payload carrying capacity needed for the competition. Once the Team was satisfied with the performance of Jaws-X1, the final competition aircraft, Jaws, was built. Final flight tests with Jaws included all of the required missions and allowed time for the pilot to become comfortable with the aircraft.

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

7.1.5. Taxi Testing

For taxi testing, the aircraft was tied to a string and run over the corrugated roofing material to verify the stability of the aircraft when taxiing over unsteady road conditions and its ability to maneuver. Additional design changes were implemented to the landing gear if results were poor and the process was repeated until the Team felt confident in the design. Only then would tests with the aircraft powered by the motor be performed.

7.2. Master Test Schedule

The Team's schedule for testing of the aircraft and its components is outlined in Figure 7.1.

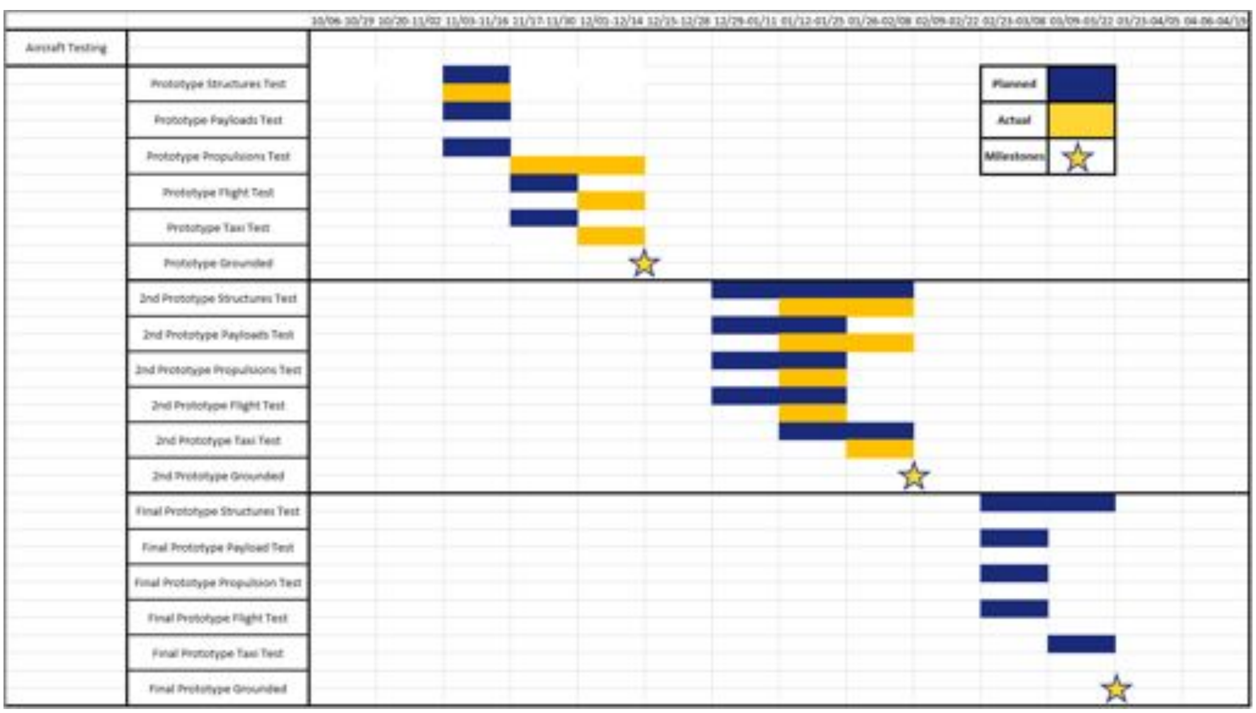


Figure 7.1: Master Test Schedule

7.3. Flight Test Schedule

The Team understood the importance of flight tests that did not require full mission performance at the very outset. In order to find and correct instabilities and other unforeseen problems, the test plan below details the gradual increase in demand on the aircraft. This allowed the Team to foresee and correct problems that might otherwise negatively impact other components. The flight tests are named such that the first 2 letters indicated the aircraft (P1 is Prototype 1, F is final aircraft), while the second 2 letters indicate the flight designation (MF is maiden flight, TX is taxi test, B1 is mission 2 carrying 1 block, etc).

Flight Number	Flight Designation	Payload	Description
1	P1-MF	None	First flight with Narwhal. Test flight worthiness, perform basic maneuvers. Verify basic configuration and sizing.
2	P2-TX	2 Blocks	Using Jaws-X1, test the ground handling of the aircraft on the Taxi Mission course.
3	P2-MF	None	First flight with Jaws-X1. Test flight worthiness, perform basic maneuvers.
4	P2-ST	None	Using Jaws-X1, test short takeoff performance.
5	P2-M1	None	Using Jaws-X1, fly Mission 1 and test speed and maneuverability.
6	P2-B1	1 Block	Using Jaws-X1, test ability to takeoff with and carry 1 block.
7	P2-B2	2 Blocks	Using Jaws-X1, test ability to takeoff with and carry 2 blocks (max weight).
8	F-MF	None	First flight with Jaws (competition aircraft). Trim control surfaces, perform basic maneuvers
9	F-M1	None	Using Jaws, fly Mission 1.
10	F-M2	2 Blocks	Using Jaws, fly Mission 2 with 2 blocks.
11	F-M3	2 Patients/Nurses	Using Jaws, fly Mission 3.

Table 7.1: Flight Test Manifest

7.4. Flight Testing Checklists

Insuring the aircraft is ready to fly immediately before takeoff increases the Team’s chances of repeated success. The flight test crew completes the following tasks prior to each flight in order to prevent unintended damage to components or structures while testing.

Pre-Flight Checklist

The following checks are performed five minutes prior to flight.

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

Table 7.2: Pre-Flight Checklist

Final Checklist

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

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

Table 7.3: Final Checklist

8. Performance Results

8.1. Component and Subsystem Performance

8.1.1. Propulsion

Batteries

The Team did a number of real world tests to insure that the batteries and propulsion system would perform adequately for all missions. First off, the batteries were fully charged and then discharged while the throttle was set to 100%. Over the course of 3 tests, the motor ran for an average time of 5 minutes and 40 seconds, which is sufficient to complete any of the missions.

Additionally, the Team connected the propulsion system to a 15 amp fuse, as specified in the contest rules, and ran the motor at full throttle until the batteries died. These conditions simulated the maximum current draw possible during any flight. Given that the fuse didn't burn out, the Team was confident that they were running within the 15 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 3.75 lbf of thrust based on MotoCalc. According to the force meter mounted on the test stand, the motor produced on average 1.8 lbf of thrust. This was roughly 50% of the expected thrust (probably due to a combination of test stand friction and real-world loses), but still enough thrust to overcome the expected drag of .755 lbf at cruise speed.

Figure 8.1: Motor on Test Stand

8.1.2. Structures

Fuselage

After initial construction of the fuselage prototype, an empty drop test was performed to check its durability, and the initial tests showcased weaknesses in the original design of the frames of the fuselage. The corners of the inner hole of the fuselage frames were filleted to reduce the stress concentration. Drop tests were then performed on the modified design in increments of 6 inches, with a final test drop at 3 ft above the ground without the fuselage breaking.

The payloads for the aircraft and the battery configuration were also put into the plane to verify the internal structural integrity of the aircraft. The fuselage was able to successfully carry the internal payloads without breaking.

Wing

A tip test was performed with no payload both to verify the C.G. of the plane was located at the quarter chord of the wing and to verify that the wings were strong enough to handle the weight of the aircraft. The design turned out successful as the aircraft successfully balanced with one Team member holding the plane at the quarter chord of each wing.

Figure 8.2: CG Tip Test

Further testing was done on wing prototype to determine how much load it could handle without breakage or permanent yielding. A half-wing's carbon rods were attached to a styrofoam box while pieces of clay weighing 0.5 lbs each were distributed along the wingspan. The testing concluded with a half-wing being able to handle 15 lbs of payload on its own without breakage, which equals the 2.5 g limit set for both wings. Although the yielding looked large, permanent yielding did not occur and the half-wing went back to its original shape after testing was done.

Figure 8.3: Wing Flex Test

Landing Gear

Deflection and taxi tests were performed on the landing gear to insure that the plane would be able to land without the gear shearing off, and to complete the critical taxiing mission without damage to the gear. For the deflection test the Team loaded the plane with the different payload possibilities and observed the deflection of the landing gear. Though the gear did deflect slightly, the deflection was not significant enough to affect mission performance, insuring that the landing gear would hold up under payload missions.

A taxiing test was also performed, with the plane being pulled over corrugated roofing material that simulated the taxiing mission the plane would be required to complete in competition. This tested the stability of the aircraft due to the landing gear configuration, and also the aircraft's ability to maneuver during the taxiing mission. This test showed the Team that the moment arm on the front landing gear was unbalanced, resulting in an unstable front wheel. As a result, the Team was able to identify the need to use a longer bar for the front landing gear, stabilizing out the moment arm and providing more stability for the whole aircraft.

Figure 8.4: Landing Gear Deflection Test

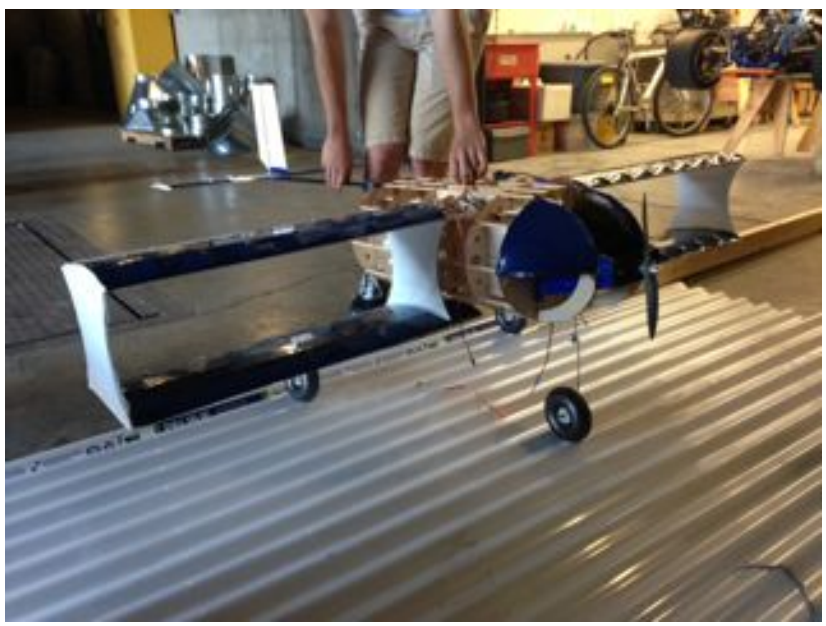


Figure 8.5: Landing Gear Taxi Test

Tail - Fuselage Attachment

The tail-fuselage attachment was tested for its axial and bending strength. The biggest concern was tail-fuselage separation due to axial drag force acting on the tail surfaces. The Team tested this by holding the aircraft at a 90-degree pitch angle and hanging weights from the tail. The tail assembly held 1 lb. without the tail separating from the boom or the boom separating from the aircraft, which proved the attachment system would be strong enough. A picture of the tail-fuselage mate can be seen below in Figure 8.6.

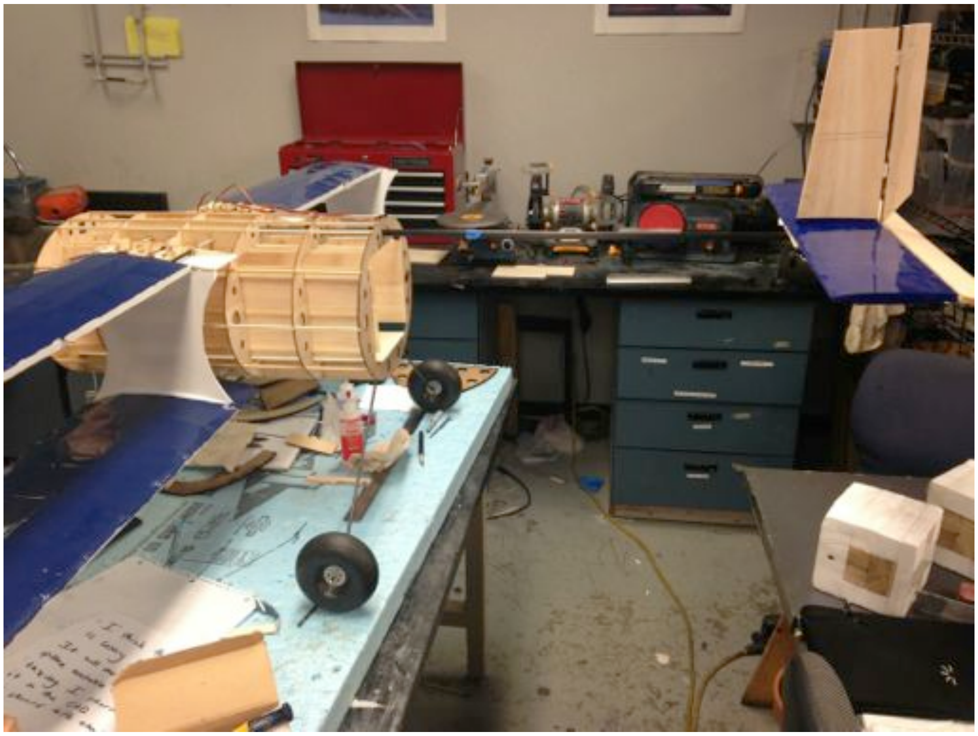


Figure 8.6: Tail - Fuselage Attachment

8.2. Complete Aircraft Performance

The complete aircraft performance was determined during a flight test of the prototype Narwhal.

Takeoff Distance

Using markers on the ground, the Team was able to measure the no-payload takeoff distance of Narwhal at 32 feet. While this is slightly longer than was predicted (prediction was 30 feet), the final design, Jaws, will have a 1.5 ft. longer wing, which should help to reduce takeoff distance.

Mission 1 Results

Overall, the aircraft performed as expected during the Mission 1 test. Turn rate and climb rate were within the expected range. Top speed was slightly lower than expected, however the motor used during the test was smaller and less powerful than the one being used in the final aircraft. 1-lap time was below expected the expected value of 60 seconds, also owing to the smaller motor. Battery pack endurance was slightly below the static test time of 5.67 minutes, most likely due to the motor working harder due to wind. However, 5.33 minutes of endurance exceeds the minimum requirement of 4 minutes. Mission 1 flight performance data is shown in Table 8.1, and a picture of the aircraft in-flight is shown in Figure 8.7.

Climb Rate	Turn Rate	Top Speed	1 Lap Time	Battery Pack Endurance
10 ft/s	50 deg/s	50 ft/s	70 sec	5.33 mins

Table 8.1: Flight Performance Data

Figure 8.7: Prototype in Flight

Pilot-Rated Performance

The pilot thought the aircraft handled well, with no major complaints regarding stability or controllability. Future flight tests will provide more time to trim the aircraft and test the limits of the flight envelope.

8.3. Future Work

Work on the aircraft continues until the competition in April. The Team was working to finish final assembly of Jaws-X1, and then begin flight testing. The Team expects to complete the flight test regime for Jaws-X1 by the 1st week of March, thus providing 5 weeks to build and test the competition aircraft Jaws. Although this is an ambitious schedule for the final month, the Team is confident that such a plan will lead to a highly competitive aircraft at the fly-off.