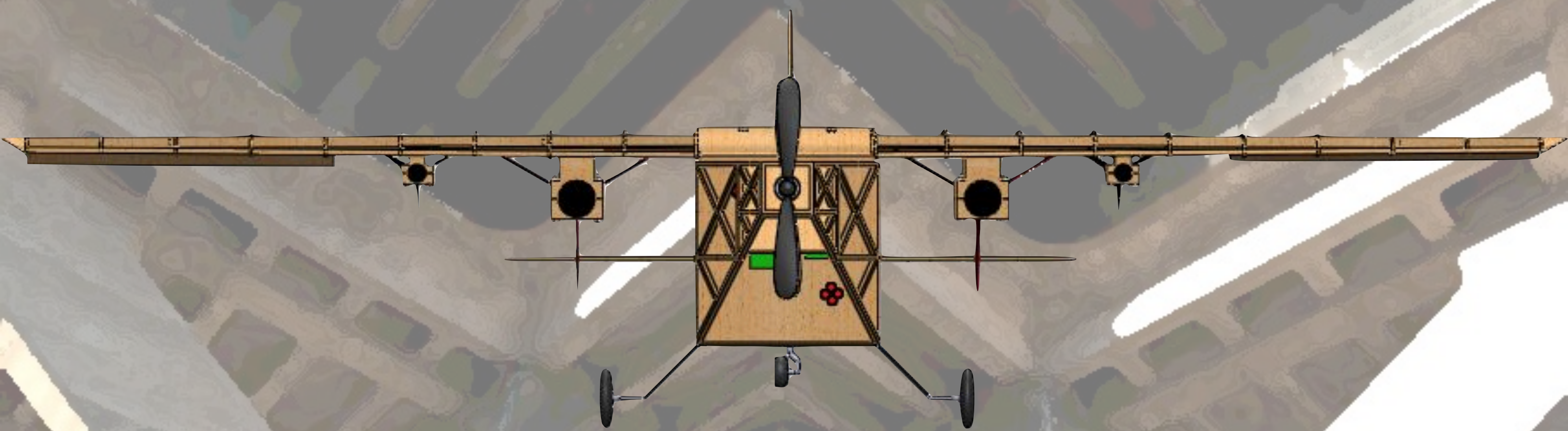
University of California, San Diego

TEAM TOP GUN



Design/Build/Fly 2013

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1.0 Executive Summary

The following report details the design, fabrication, testing and performance of the UC San Diego Design/Build/Fly Team's 2012-2013 competition aircraft. The Team designed the aircraft to successfully complete 3 missions: an unloaded speed flight, a stealth mission, and a strike mission. Aside from completing the 3 missions, the Team's overarching goal was to minimize structural weight without sacrificing performance.

1.1 Design Process

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

1.2 Key Mission Requirements

The challenge presented to the Team for the 2012-2013 competition consisted of 3 different missions. Mission 1 is an unloaded speed flight with short takeoff where the number of laps completed determines the Team's score. Mission 2 is a stealth mission with internal stores, where the number of stores flown determines the Team's score normalized against the maximum number of stores flown. Finally, Mission 3 is a strike mission in which a random assortment of internal and external payloads must be flown for 3 laps. 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. The Team decided early on that they should focus on making a lightweight aircraft.
- Fuselage Design: The final scoring formula also emphasizes minimizing the length of the fuselage. Since the rules have specific requirements about how the internal payloads need to be arranged and secured, the Team focused on optimizing the design of the fuselage to accommodate the internal payload without adding unnecessary weight, drag, and fuselage length.
- Stability in Flight: The Team noticed that the required external payloads during Mission 3 could jeopardize the stability and integrity of the aircraft during flight. In an effort to prepare for this

challenge, the Team set out to design a highly stable and balanced aircraft by calculating the best payload configuration to minimize rolling moments.

1.3 Capabilities

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

- Empty weight of 4 lbs.
- Maximum payload weight of 3 lbs.
- Ability to complete 4 laps in 4 minutes unloaded.
- Ability to carry 8 rockets internally.
- Ability to carry all 6 Mission 3 configurations.
- Strong, durable aircraft.
- Documented performance after several flight tests.

To sum it up, the final design can be described as a single motor, conventional aircraft with a carefully designed fuselage and payload stability system. The aircraft minimized weight, maximized stability and met all design requirements for payload stability and release. The UCSD DBF Team believes that the design of this aircraft was optimized for the requirements of the missions and will allow the Team to achieve a high score.

2.0 Management Summary

2.1 Project Management

The members of the UC San Diego DBF team divided into 5 groups to handle the design, testing and fabrication of the aircraft. These 5 groups covered the major aerospace disciplines, consisting of 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 financial leader oversaw team finances and handled all purchases and travel planning. Finally, the Project manager coordinated all group members and oversaw the completion of the project.

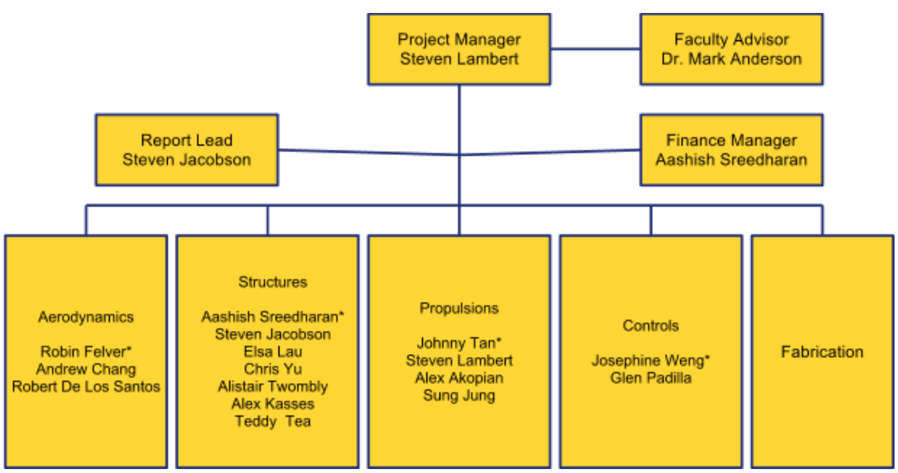


Figure 2.1: Management Flow Chart

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.

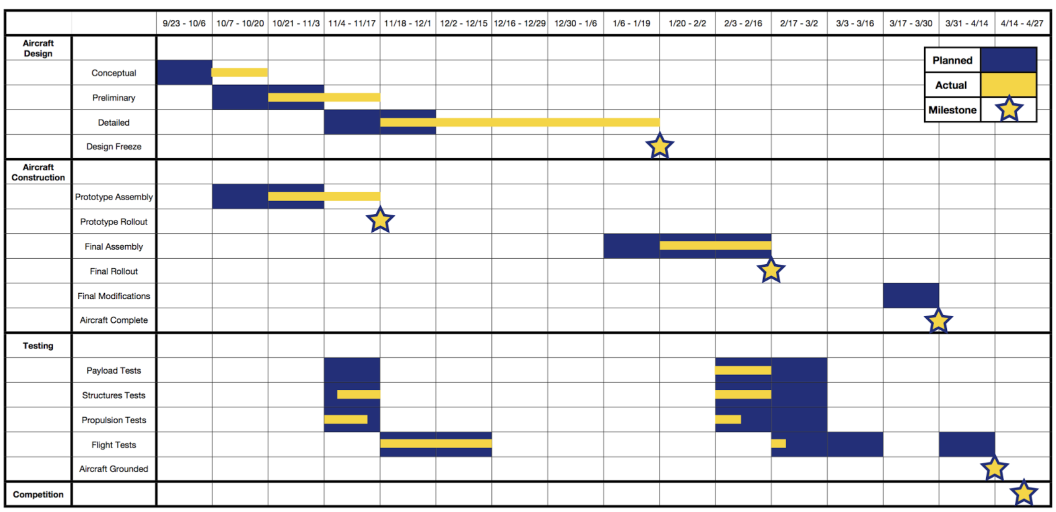


Figure 2.2: Master Schedule and Milestone Chart

3.0 Conceptual Design

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

3.1 Mission Requirements

The AIAA Design/Build/Fly 2013 competition total score takes into account the written report score and performance on three flying missions. The report is scored out of 100 points. An interesting part of the overall score is the contribution of Mission 3, which is based off of the performance of other teams in the competition. This makes it difficult to predict the maximum possible score for that mission. However, the Team estimates that the maximum score for Mission 1 is 2; for Mission 2, 4; and for Mission 3, 6. There will be more discussion on how the Team arrived at these estimates in the following sections.

The equation for the final score is:

Final Score = [Design Report * (M1 + M2 + M3)] / RAC

The RAC, "Rated Aircraft Cost", takes into account the weight and dimensions of the aircraft. This quantity is a critically important factor in the final score as it is inversely proportional to the final score. The scoring equation of each mission was analyzed, and a sensitivity analysis was performed to emphasize the particular missions that the Team found most important towards scoring as high as possible.

3.1.1 - General Requirements, Limitations, and Concerns

- The battery pack cannot weigh more than 1.5 pounds.
- Aircraft must be capable of loading Mission 3 payload configurations 1 to 6.
- Aircraft must land safely for scoring to take place.
- Aircraft must perform a ground rolling take off within 30x30 feett square.

The Flight Course was another critical part of the competition that was defined by the competition rules. The Team analyzed the flight course to better understand how the missions would be flown. During the missions the Team's airplane will take off within the 30x30 feet square and climb for the first 500 feet straight-away. At the end of the 500 feet the airplane will encounter its first turn. After the airplane completes its first turn it will accelerate before completing a 360 degree turn. After this, the plane will encounter its second 180 degree turn. The plane will then accelerate for 500 feet before completing the lap. The airplane will complete the other remaining laps in the same manner as described above. After the maximum amount of time, or laps, has been reached, the airplane will slow down and come to a safe landing, ending the mission. The layout of the flight course is shown below in Figure 3.1.

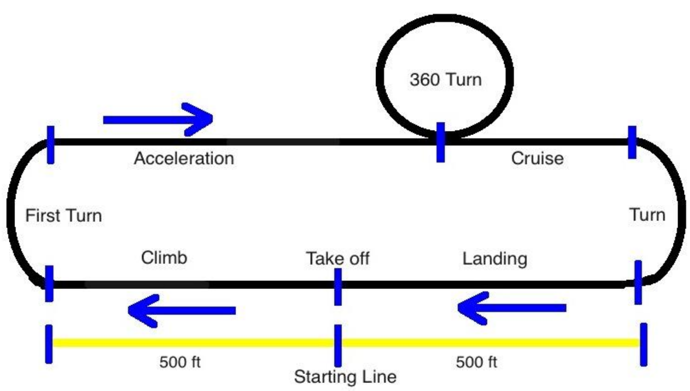


Figure 3.1: Competition Flight Course

3.1.2 - Ground Crew and Assembly Crew

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

- Mission 1 requires no work in the assembly area.
- Mission 2 requires the ground crew member to load the Mini-Maxes.
- Mission 3 requires the ground crew member to roll a die and load the internal- and external-stores onto the plane as specified by the die roll outcome.

3.1.3 - Mission 1: Short Take Off

Mission 1 is a timed, 4 minute speed test. The score for the mission is determined by the equation: M1 = 2*(N_Laps_Flown/Max_N_Laps_Flown), where N_Laps_Flown is the number of laps the Team's aircraft completes in 4 minutes, and Max_N_Laps_Flown is the most number of laps flown by any team. The mission starts when the throttle is advanced for takeoff and ends when the 4 minutes is up. Only fully completed laps will be counted.

3.1.4 - Mission 2: Stealth Mission

Mission 2 is a payload carry test that assesses the aircraft's ability to carry stores internally. The Team identified the following critical requirements for the mission:

- Stores must be accessed through the bottom of the aircraft.
- Mounting structure must be a permanent part of the airframe.
- Stores cannot touch each other or any part of the structure.
- Stores must be mounted so that they could be released downwards.

The score for this mission is determined using the following formula: M2 = 4*(N_Stores_Carried/Max_Stores_Carried), where N_Stores_Carried is the number of rockets the Team's aircraft carried, and Max_Stores_Carried is the most rockets carried by any team. This encourages teams to maximize the number of internal stores carried.

3.1.5 - Mission 3: Strike Mission

Mission 3 is a payload carry test that assesses the aircraft's ability to carry a random allotment of internal and/or external stores and fly 3 laps in the shortest time possible. The Team identified the following critical mission requirements:

- Internal stores have the same requirements as Mission 2.
- External store fins must be below the lower surface of the wing's trailing edge height.
- External stores cannot touch each other or any part of the structure.
- External stores may not overlap or block access to the internal store locations.

The mission starts when the throttle is first advanced for takeoff, and ends when the aircraft passes over the finish line, in the air, in the last lap. The score for this mission is determined by the following formula: M3 = 6*(Fastest_Time_Flown/Team_Time_Flown), where Fastest_Time_Flown is the shortest flight duration by any team, and Team_Time_Flown is the Team's flight duration.

3.1.6 - RAC

For the 2013 competition, the RAC is a combination of the aircraft's empty weight and the aircraft's dimensions, in both the spanwise direction and the chordwise direction. The RAC is calculated using the following formula: RAC = SQRT((Empty_Weight*(X_Max + 2*Y_Max))/10), where X_Max is the longest dimension in the chordwise direction, and Y_max is the longest dimension in the spanwise direction.

3.2 Design Requirements

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

- Mission 1**:** A lightweight, high lift, fast and highly controllable aircraft capable of taking off within a 30x30 feet area and completing the competition course at high speeds without any loss of control or stability.
- Mission 2: An aerodynamic, high lift plane with enough power and endurance to complete 3 laps with the specified payload. Also, the fuselage must be the right dimensions to hold the internal-stores in such a way that they can be released one at a time without coming in contact with the other stores or the sides of the fuselage.
- Mission 3: Similar to Mission 2, Mission 3 requires an aircraft with plenty of lift, power and endurance to carry 3 pounds of internal- and external-stores.
- RAC: The aircraft should be as lightweight as possible, and should have a short wing and fuselage.

3.2.1 Sensitivity Analysis

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

Overall Score = ((Report Score) + 2*(N_Laps_Flown/Max_N_Laps_Flown) + 4*(N_Stores_Carried/Max_Stores_Carried) + 6*(Fastest_Time_Flown/Team_Time_Flown))/RAC

From this equation, a number of observations were made:

- The three missions do not have the same importance in the overall score; Mission 3 is the most valuable (with a maximum score of 6), Mission 2 is the next most valuable (with a maximum score of 4), and Mission 1 is the least valuable (with a maximum score of 2). However, a detailed analysis is needed to see how increasing the speed and/or payload capacity will affect the overall score.
- The RAC is an important part of the score. However, a detailed analysis is needed to see how the dimensions and weight affect the final score.

The Team used MATLAB to build a scoring model for this year's contest. This allowed the Team to iterate over different design parameters to determine which ones yield the highest overall score. To create this model, the following assumptions were made:

- To make a faster aircraft, the power output of the motor and battery pack needs to increase. This leads to an increase in size of these elements, which will increase the overall weight of the aircraft. Correspondingly, the structural weight will also increase to support the heavier power system.
- As the number of Mission 2 stores increases, the weight and dimensions of the aircraft increase proportionally to accommodate the larger payload.
- The scores for Missions 1 and 3 are inherently coupled due to the fact that they are both speed missions. Since Mission 3 is the more challenging of the two missions, it was used in the sensitivity analysis.
- Using results from previous years as reference, the maximum number of laps for Mission 1 is estimated to be 8. Since Missions 1 and 3 are coupled, the maximum number of laps for Mission 3 is estimated to be 4, half of Mission 1. This reduction is due to the increase in weight and drag from the external payload.

The Team started the analysis by looking at how the RAC changes as the dimensions and weight change. To simplify the analysis, the Team correlated size changes with weight changes, meaning that as length and span increase, the weight increases proportionally. As seen in Figure 3.2 below, the larger the aircraft, the more it weights, and the bigger the RAC.

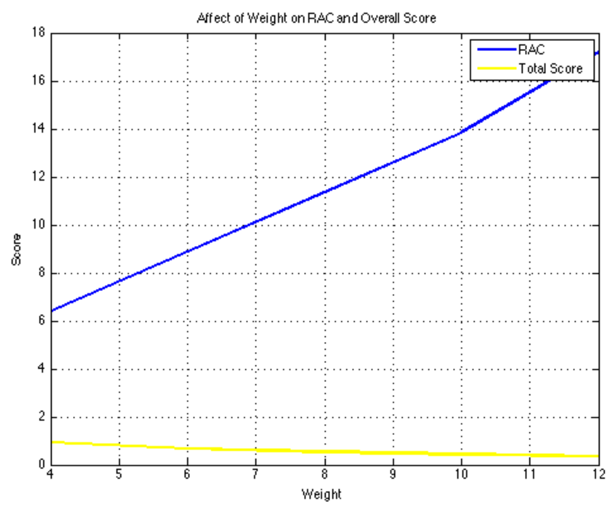


Figure 3.2: Change in RAC due to Size and Weight Increases

Next, the Team looked at how increasing the number of stores would affect the Team's overall score. As mentioned above, the analysis accounts for the idea that more stores lead to a bigger aircraft, and, therefore, a higher RAC. The results of the analysis can be seen below. The blue line is the score for Mission 2, and the yellow line is the overall score. The intersect location indicates the number of internal stores to maximize the overall score. Using the graph, and rounding to the nearest even number, the Team identified 8 rockets as the best option.

Finally, the Team analyzed how speed (and therefore power system weight) affects the final score. The Team realized that, since Mission 1 and Mission 3 are both speed missions, they are inherently coupled, and, therefore, can be analyzed together. The Team elected to study Mission 3, and then scale the results to determine the optimal configuration for Mission 1. The results of the study can be seen below in Figure 3.4. From the results, it is clear that the aircraft should be built to complete two laps in Mission 3.

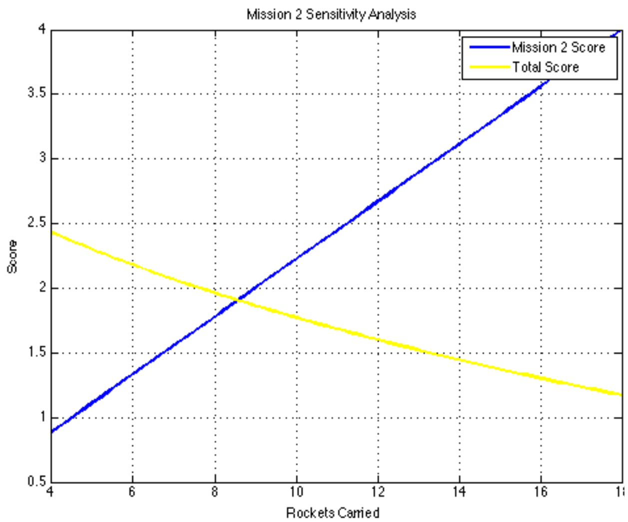


Figure 3.3: Mission 2 Optimization

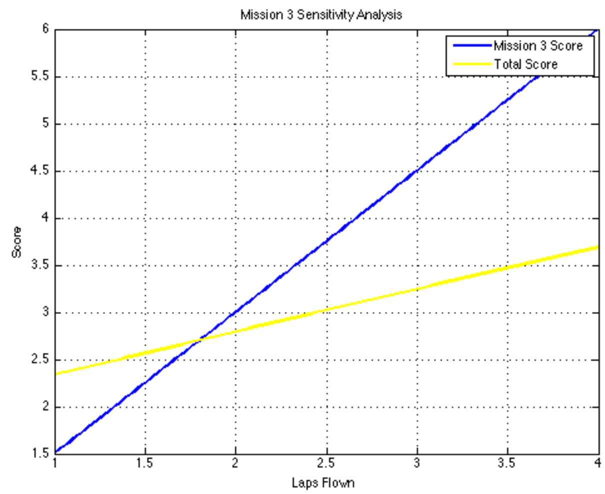


Figure 3.4: Mission 3 Optimization

Using the results from Mission 3 and estimating that the aircraft will weigh 50% less during Mission 1, the Team estimated that the aircraft should strive to complete 4 laps for Mission 1. The Team continued this process to size the power system, thereby giving the Propulsions Group a good starting point for their analysis. Using the results from the Mission 3 analysis, the Team found that the system needed to generate at least 250 watts of power.

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, the internal payload containment, and the external payload containment. The Team then selected Figures of Merit for each major design elements, and weighted the Figures of Merit according to their importance towards achieving a high score. Then the decision matrix was filled out, and a decision was made.

Figures of Merit

The Team selected metrics to use 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.

Alternatives 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 was for slightly worse than average and 4 was for 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 stores. The Team also considered how easy it would be to build and integrate into the final structural design. Two possible shapes were considered:

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

FOM	Weight	Circle	Rectangle
Weight	35	3	3
Aerodynamics	25	5	1
Payload Containment	15	3	5
Ease of integration	15	1	5
Ease of Fabrication	10	1	5
Total	**100**	**300**	**330**

Figure 3.5: Fuselage Shape Decision Matrix

For the final configuration, the team settled on a rectangular shaped fuselage. The aerodynamic qualities of the circular fuselage were counteracted by its difficulty to be built and attached to the wings. The rectangular fuselage allowed for easy building and integration and allowed more room for stores.

3.3.2 - The Wing

Shape of the Wing

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

- Elliptical: Wing resembles a symmetrical, stretched circle.
- Tapered: Chord decreases from the center to the wingtips.
- Swept: Constant chord with the wingtips behind the center of gravity.
- Rectangular: Constant chord and symmetrical in both directions.

FOM	Weight	Elliptical	Tapered	Swept	Rectangular
Weight	30	3	3	1	1
Aerodynamics	20	3	5	1	3
Stability	30	1	3	3	3
Wingspan	10	1	3	5	3
Ease of Fabrication	10	1	3	1	5
Total	**100**	**200**	**340**	**200**	**260**

Figure 3.6 Wing Shape Decision Matrix

When selecting the shape for the wing, the main concerns of the Team were the weight of the aircraft, the aerodynamics of the wing shape, and the stability of the aircraft in flight. The Team also considered ease of fabrication and the size of wingspan, where a shorter wingspan is more desirable due to mission scoring. A tapered wing was chosen for its good aerodynamic qualities as well as the weight saving compared to the rectangular wing.

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: One motor mounted at the front of the fuselage and one mounted at the rear of the fuselage.

FOM	Weight	Single Tractor	Dual Tractor	Single Pusher	Combination
Weight	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**

Figure 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 system also greatly increases the ease of fabrication, while decreasing the likelihood of technical complications. With the total weight of the aircraft bearing heavy significance over the basic design, the Team decided that the single tractor motor system was the most appropriate configuration to successfully accomplish the given missions.

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

FOM	Weight	 Flying Wing	 Conventional	 Biplane
Weight	25	1	1	1
Stability	25	1	5	3
Payload Capacity	25	3	5	1
Ground Handling	10	1	3	3
Ease of Fabrication	15	1	5	1
Total	**100**	**150**	**380**	**170**

Figure 3.8 Aircraft Configuration Decision Matrix

When selecting the best configuration for the aircraft, the Team's main considerations were the weight of the aircraft, the stability in flight, and the payload capacity. The conventional aircraft configuration was chosen for the high payload capacity and stability in flight.

Wing Location Relative to Fuselage

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

- Low Wing: Wing is mounted below the fuselage.
- High Wing: Wing is mounted above the fuselage.
- Mid Wing: Wing is connected to the mid section of the fuselage.

FOM	Weight	Low Wing	High Wing	Mid Wing
Weight	15	3	3	3
Speed	15	1	1	3
Stability	30	3	5	3
Payload Access	30	1	5	3
Ease of Fabrication	10	3	3	3
Total	**100**	**190**	**390**	**300**

Figure 3.9 Wing Location Decision Matrix

When determining the wing location, the Team's main concerns were stability of the aircraft and access to the payload. The competition requires that the payload is able to be dropped from the bottom of the fuselage making a high wing or mid a good choice. A high wing allows for more room for the internal payload for Mission 2 and also gives the rockets mounted on the wing more ground clearance for Mission 3. Though a mid wing provides the lowest drag, which increases speed, a high wing gives the wing an effective dihedral thereby increasing stability. For these reasons a high wing configuration was chosen.

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:

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

FOM	Weight	Flat Wing	Dihedral	Anhedral
Stability	55	3	5	1
Maneuverability	25	3	1	5
Ease of Fabrication	20	3	1	1
Total	**100**	**300**	**320**	**200**

Figure 3.10 Wing Dihedral Decision Matrix

Dihedral would provide extra stability at the cost of lower maneuverability, while anhedral would provide increased maneuverability at the cost of stability. However, both of these cases would be more difficult to fabricate than a flat wing. The Team decided that stability would be preferred in our decision, especially with mission requirements that require multiple rocket configurations. Ultimately, a dihedral wing configuration was chosen because the advantages of improved flight stability and easier piloting outweighed the disadvantages of a slightly harder fabrication. Only a slight dihedral of 1 to 2 degrees would be used since the top mounted wing gives an effective dihedral.

Wing Tips

The Team considered four different types of possible wing tips in order to reduce the drag on the wing:

- 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.

For the wing tips, the considerations were the weight added to the aircraft, the aerodynamic advantages, the added length to the wingspan, and the ease of fabrication.

FOM	Weight	Hoerner	Sharp	Rounded	Cut Off
Weight	20	3	3	3	5
Aerodynamics	40	7	5	3	1
Wingspan	30	3	3	3	5
Ease of Fabrication	10	3	3	3	5
Total	**100**	**460**	**380**	**300**	**340**

Figure 3.11 Wing Tip Decision Matrix

The most important considerations for the Team were the aerodynamic advantages of the wing tip and the added length to the wingspan. The cut off wing tip would not add length to the wingspan, but the cut off wing tip has poor aerodynamic properties. The Hoerner has the best aerodynamic properties and would add about the same length to the wingspan as both the sharp and rounded tips. For these reasons, the team chose the Hoerner wing tips.

3.3.5 - Landing Gear

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

- Tail Dragger: Two wheels attached to fuselage (side by side near center of gravity) and one on the 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.

For the landing gear the important aspects were the weight, the ability to get increased lift during takeoff, and the ground handling.

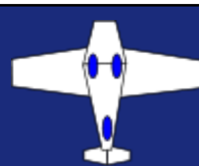
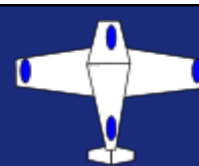
FOM	Weight	 Tail Dragger	 Tricycle	 Bicycle
Weight	45	3	3	3
Increased Lift on Takeoff	20	5	1	1
Payload Stability	10	3	5	3
Ground Handling	15	3	5	3
Ease of Fabrication	10	3	3	3
Total	**100**	**340**	**310**	**260**

Figure 3.12: Landing Gear Decision Matrix

The tail dragger had the ability to give an extra boost in lift during takeoff, which the other two configurations lacked. The tricycle configuration proved to be the most stable and easiest to control. The bicycle design distributes loads to the wing during landing, and for Mission 3 this could be problematic with the heavier external loads present. In the end, the tail dragger design was shown to have a good balance of weight, additional takeoff lift, and ground handling.

3.3.6 - Tail and Stability

The design of the tail was driven by the need for 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 elevators) mounted below.
- T-Tail: Single, large vertical stabilizer (with a rudder) and a horizontal stabilizer (with elevators) mounted above.
- V-Tail: Two stabilizers, roughly 45 degrees apart, with rudder/elevator mixing.

FOM	Weight	 Conventional Tail	 T-Tail	 V-Tail
Weight	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**

Figure 3.13: Tail Configuration Decision Matrix

When ranking each of the choices, the Team decided 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. On the other hand, the V-Tail is expected to increase aircraft speed by reducing the wet tail surface area. 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 shown to be the overall better choice for the Team's aircraft.

3.3.7- Internal Payload Containment

The need for minimal weight, maximum speed and a maximum score for Mission 2 drove the number of rockets carried by the aircraft's internal payload configuration. The Team considered three configurations:

- 4 Rockets
- 6 Rockets
- 8 Rockets

FOM	Weight	4 Rockets	6 Rockets	8 Rockets
Mission 2 Score	50	3	4	5
Use of Internal Space	15	4	2	4
Speed	10	4	3	3
Weight	25	4	3	2
Total	100	350	335	390

Figure 3.14 Number of Internal Rockets Matrix

Using the decision matrix, and the scoring analysis detailed in section 3.2, the Team determined that 8 rockets was the best combination of Mission 2 score and minimizing the RAC. After deciding on the number of rockets to be carried, the Team turned their attention to the configuration of the internal stores.

The configuration of the aircraft's internal payload configuration was driven by the need for a consistent center of gravity with and without the internal payload along with a minimal size. Four possible configurations were selected:

- Square: 2x2x2 square configuration.
- Diamond: 2x2x2 Diamond configuration.
- Vertical: 8 rockets in a vertical line.
- Horizontal: 8 rockets in a horizontal line.

FOM	Weight	Square	Diamond	Vertical	Horizontal
Size	40	5	4	2	2
CG Placement	35	3	2	3	3
Ease of Fabrication	15	4	2	3	3
Total	100	365	260	230	230

Figure 3.15: Internal Rocket Configuration

While considering the internal configuration of the rockets the main concerns of the Team were the size of the fuselage and the center of gravity placement. A vertical or horizontal configuration would make the aircraft fuselage too long in each respective dimension. A square configuration gives the greatest ease of fabrication making it the best choice.

3.3.8- External Payload Containment

The design of the external payload containment was driven by the need for a stable way to hold the external payload for Mission 3 with minimal additional weight and drag. Three possible mechanisms were selected:

- Pin: A male end attached to the wing and a female end attached to the rocket to be pinned together.
- Collar: Rocket is held in between 2 half circles, bolted together, forming a collar.

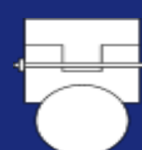
FOM	Weight	 Pin	 Collar
Stability	35	5	3
Weight	15	1	3
Drag	25	3	4
Ease of Fabrication	15	3	5
Design Specifications	10	1	5
Total	**100**	**320**	**375**

Figure 3.16: External Rocket Containment

The Team considered the pin system for its secure containment of payload with very little weight. However, the most secure design of the pin system requires permanent attachment of the pin system to the rocket. In order to meet the design requirements for which no permanent attachment is allowed, the Team considered an alternate design using a collar system. The collar system also has the added advantages of easier fabrication and of lighter weight. For these reasons the Team chose the collar system.

3.4 Final Conceptual Design

Using the design characteristics selected using the decision matrices, the final conceptual design has the following design parameters:

- Conventional aircraft configuration and wing layout
- Single, rectangular, center mounted fuselage
- Single, front mounted motor
- Tapered wing
- Conventional tail
- Tail dragger
- 8 Internal rockets
- Collar external rocket containment

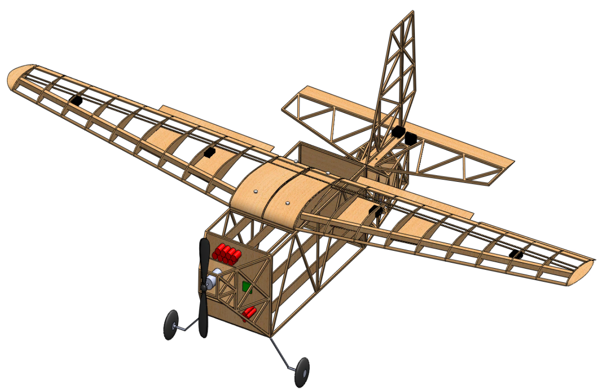


Figure 3.17: Final Conceptual Design

4.0 Preliminary Design

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

4.1 Design and Analysis Methodology

4.1.1 Aerodynamics

There were two important aerodynamic parameters that the Team considered:

Wing Airfoil Selection

Two types of airfoils were considered: a high lift airfoil and a high speed airfoil. 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 high lift airfoils 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.

4.1.2 Propulsion

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

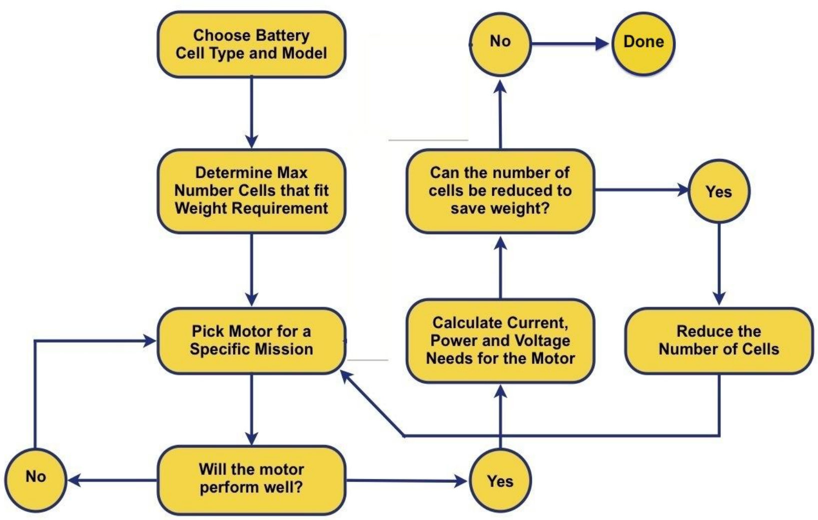


Figure 4.1: Motor and Battery Selection Flow Chart

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

Battery Selection

A battery pack using high capacity batteries would require less cells, but each cell would weigh more. A battery pack 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 their cells and their voltages. Therefore, a favorable battery pack would optimize the weight, capacity, and voltage for the selected motor and missions.

Motor Selection

A heavier motor can provide more power and thrust, which can lead to positive results in Mission 1. However, the increased weight reduces the overall score due to the RAC component. Therefore, an optimal motor included 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. Additionally, the Team decided to use two propellers, one for Mission 1, when speed is critical, and the other for Missions 2 and 3, when weight is the primary concern.

4.1.3 Structures

There were three important structural elements that the Team considered:

External Fuselage Size

The size of the fuselage was driven by the RAC as well as the number of rockets the Team hoped to store internally for mission 2. A larger fuselage would provide more space for internal storage and payload stabilization but would also increase drag and weight. The optimal fuselage size was a combination of small and light, yet big enough to hold the number of rockets found to maximize the score (as determined by the scoring analysis). The Structures Team felt that it would be best to use the z-axis (height) to maximize the internal volume because this dimension does not affect the RAC.

Internal Payload Storage Design

Due to the fact that the internal store containment system is a permanent part of the airframe, the Team worked to minimize the weight of the system. The Team also recognized that, unlike the external stores, the internal stores would not be subject to any forces due to airflow. This meant that the restraining system could be less robust, resulting in a weight reduction.

External Payload Storage Design

The external stores presented more of a challenge than the internal stores for a number of reasons. First and foremost, there are three different rockets and six different configurations, requiring a flexible design. Secondly, the external stores are mounted under the wing, and therefore are subject to the forces of the oncoming airflow. This requires that the stores be firmly attached to both the collar and the wing.

4.2 Mission Modeling and Optimization Analysis

4.2.1 Aerodynamics Mission Optimization

The Aerodynamics Team considered different configurations and airfoils for the aircraft with the weight, moment, and aerodynamic characteristics in mind. The members of the Aerodynamics Team also took into account the limitations of the flight course and missions, such as the take-off distance of 30 ft. The flight course is shown in Figure 4.2.

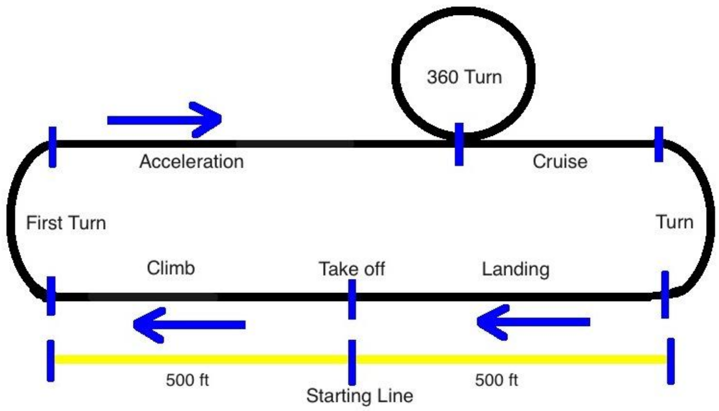


Figure 4.2: The Flight Course

With this data, the Aerodynamics Team decided that a wing configuration that maximized the payload storage volume in the fuselage for the missions 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.

4.2.2 Propulsion Optimization

Battery Selection

Battery Description	Capacity [mAH]	Weight [Ounces]	Size [Inches]	Chemistry
Elite 1500 2/3A	1500	0.81	1.13 x 0.66 x 0.66	NiMH
Elite 2100 4/5A	2000	1.15	1.7 x 0.7 x 0.7	NiMH
Eneloop 2000AA	2000	0.91	2.0 x 0.6 x 0.6	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

Figure 4.3: Battery Specifications

The Team considered many different batteries when deciding which would be optimal 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.

Motor Selection

Motor Description	Kv [*RPM/V*]	No Load Current [*Amps*]	Max Voltage [*Amps*]	Continuous Power [*Watts*]	Weight [*Ounces*]
Hacker A30 16M	1060	1.6	33	330	3.74
Tacon Bigfoot 15	950	1.7	18	425	6.00
Hacker A20 20L	1022	0.85	11.1	210	2.01

Figure 4.4: Motor Specifications

The Team initially considered a wide range of motors, including both brushed and brushless motors. When narrowing the list of motors considered, the Team decided to only consider brushless motors because they had higher torque as compared to brushed motors. The Team elected to study the 3 motors listed in Figure 4.4. When comparing the different motors, the Team used Motocalc, a propulsion system optimization program, to study the performance of the motors. Motocalc allowed the Team to analyze the motors with different combinations of batteries and propellers. This method of analysis insured that the propulsion system chosen would be able to complete the missions.

Propeller Selection

Propeller Size	Propeller Load Factor
9x6	4374
11x7	9317
13x5	10985
13x7	15379

Figure 4.5: Propeller Size vs. Propeller Load Factor

Propeller Selection was challenging because there are a wide variety of propellers, and the mission requirements varied greatly. The Team decided that two different propellers work the best for the varied mission requirements. The Team knew that the load factor was 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 table in Figure 4.5 was made of possible propeller sizes and their corresponding load factors.

4.3 Aerodynamics Trade-offs

<u>4.3.1 Main Wing Trade-offs</u>

Wing Airfoil

After examining several airfoils, the Team narrowed down the options to to four different airfoils based on the mission requirements. The Team performed further analysis to select from these airfoils: E214 has a thickness of 11.1% and camber of 4%, S1210 has a thickness of 12% and camber of 7.2%, SD7062 has a thickness of 14% and camber of 4%, and NACA-4512 has a thickness of 12% and camber of 4%. All four airfoils perform relatively well at low Reynolds numbers each with medium thickness between 11% and 14%.

The Team used the airfoil analysis program XFLR5 to select the optimum airfoil. The graphs below show the results comparing the four airfoils' glide ratio, coefficient of lift, and angle of attack. A type 1 analysis (fixed speed) was used with Reynolds number constant at 125,000 and mach 0.00, and angles of attack from 0degrees to 15degrees. The dashed blue line represents E214, the light blue line represents S1210, the yellow line represents SD7062, and the dark blue line represents NACA-4512 (as denoted by the keys for each graph).

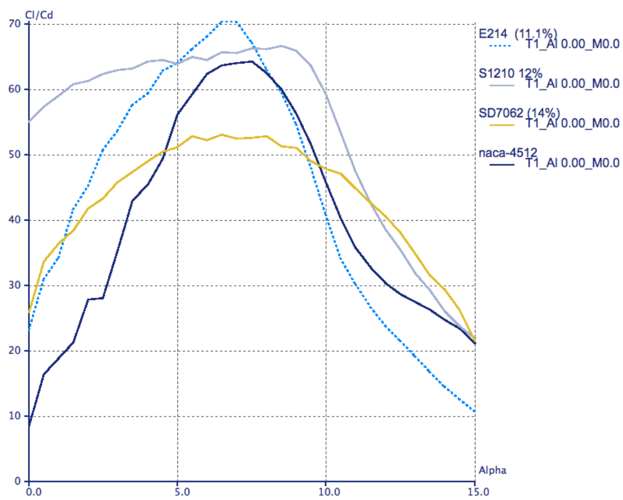


Figure 4.6: E214, S1210, SD7062, NACA-4512 Glide Ratios vs. Angle of Attack

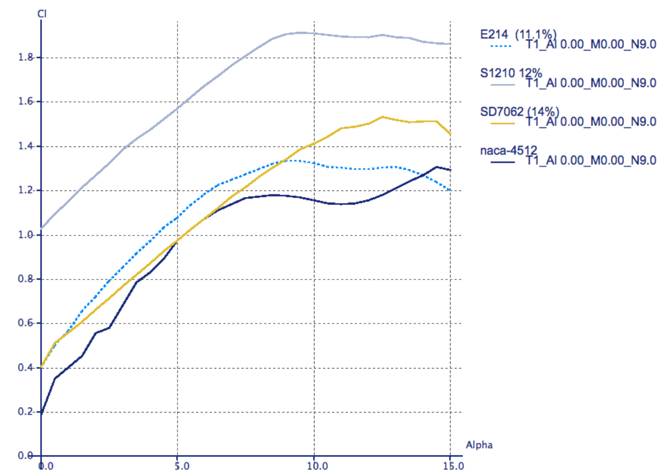


Figure 4.7: E214, S1210, SD7062, NACA-4512 Coefficients of Lift vs. Angle of Attack

From the analysis, the Team determined that the S1210 airfoil has the highest coefficient of lift at a low Reynolds number, which is necessary for a short takeoff. Additionally, the S1210 airfoil has the best glide ratio at low angles of attack, making it an efficient airfoil for steady level flight. Finally, the moderate thickness (12%) of the S1210 allows for structural stability of the wing, while still remaining thin enough to reduce drag. For these reasons the Team chose the S1210 airfoil. The cross section of the S1210 airfoil is shown below.

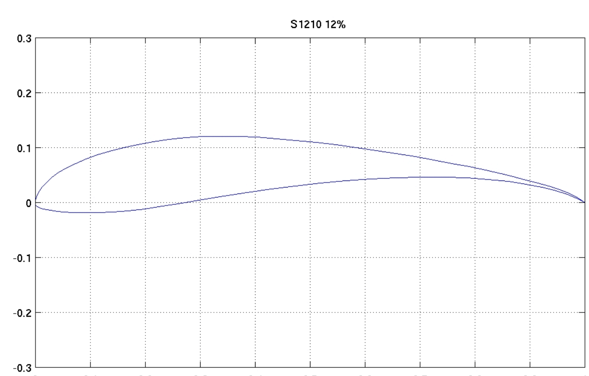


Figure 4.8: S1210 Airfoil

Wing Size

The Team determined the wing sizing based on an earlier estimation that the maximum gross takeoff weight would be 7 lbf. The Team used a safety factor of 1.1, which is standard for unmanned aircraft.

$W = (Load)*(F.S.) = (7\ lbf)*(1.1) = 7.7\ lbf = 34.2513$ Newtons

Using the vertical force balance of the aircraft:

$L = n*W$

where L is lift, n is load factor (the max number of g's pulled in flight), and W is weight. Using the equation for lift, where ρ is density of air, V is takeoff velocity, S is wing area, and C_L is coefficient of lift:

$L = 0.5*\rho*V^2*S\ *C_L$

The two equations for lift were set equal, and minimum area S was solved for.

$S_{min} = (n*W) / (0.5*\rho*V^2*C_L)$

The wing area was solved using a max load factor of n=2, the combined weight of aircraft and payload of 34.2513 N, a takeoff velocity of 15 m/s, the average coefficient of lift of 1.6 for the S1210 airfoil, and the density of air at 80 degrees Fahrenheit. The necessary area is shown below converted to inches.

$S_{min} = [(2)*(34.2513\ N)] / [(0.5)*(1.184\ kg/m^3)*(15\ m/s)^2*(1.6)] = 0.3214\ m^2 = 498.2124\ in^2$

The Team made the decision to have a tapered rectangular wing, using a taper ratio of $\lambda = c_{tip}/c_{root} = 0.5$,where a taper ratio of 0.4 to 0.5 is good for an unswept wing. From this the Team chose root chord $c_{root} = 11$in, tip chord $c_{tip} = 5.5$in, and wingspan (including wing tips) of $b = 63.42in$ resulting in a total effective lift wing area 523.215 in^2. This exceeds the minimum area of 498.2124 in^2, leaving some tolerance for the lift lost at the Hoerner wing tips. The total wingspan used for scoring will also include the additional width of the fuselage of 8 in. This gives a total span $b_{total} = 71.42$ in, which is still a small enough wingspan to score well based on the mission scoring formulas. The chosen wing dimensions also give a relatively good aspect ratio for the effective lift wing area and span:

$AR = b^2/S = (63.42\ in)^2/(523.215\ in^2) = 7.69$

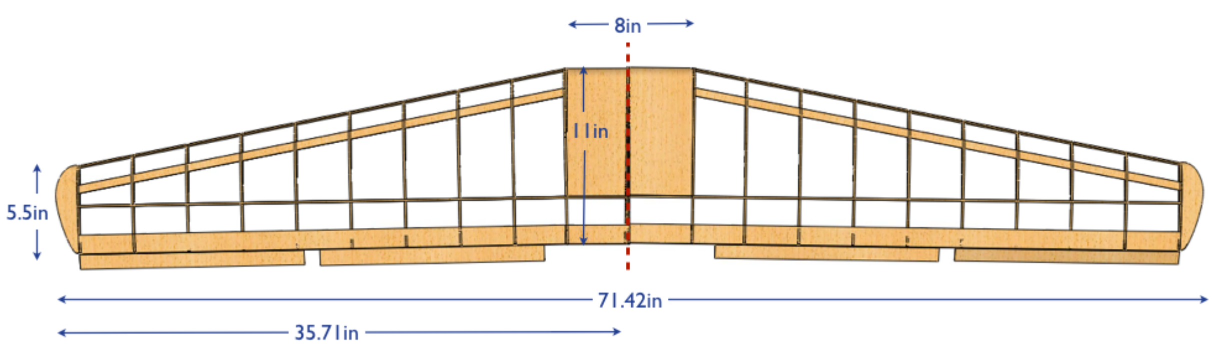


Figure 4.9: Wing Top View

4.3.2 Tail Trade-offs

Tail Airfoil

When choosing an airfoil for the tail, the Team considered two approaches. Firstly, the Team considered using an airfoil similar to the wing. By using an airfoil, this would give the aircraft some additional lift for the payload missions while receiving the greatest aerodynamic performance. Secondly, a flat plate design was considered for the tail because it would reduce the time and resources needed for manufacturing. The Team also considered the fact, that with a relatively small tail compared to the wing, the lift generated by the tail would be negligible. In the end, the Team decided that the ease of manufacturing outweighed the benefits of a tail with an airfoil. To minimize drag, the Team selected a tapered rectangle as the shape of the tail.

Tail Size

When sizing the tail, the Team was concerned with balancing the need for a large tail to account for the short takeoff distance requirement while also trying to reduce the size, cross-section, and drag of the tail. To this end, the Team used the formula $A_{HS} = (C_{HT}*S*c)*L_{Tw}$, where A_{HS} is the area of the horizontal stabilizer, C_{HT} is the design factor, S is the wingspan, c is the wing chord and L_{Tw} is the distance from the wing to the aerodynamic center of the horizontal stabilizer. After solving the equation using the appropriate values, the Team found that the horizontal stabilizer should have an area of 147 in^2. The Team also decided to make the horizontal stabilizer tapered because it would reduce drag. In the end, the Team ended up with the horizontal stabilizer seen in Figure 4.10.

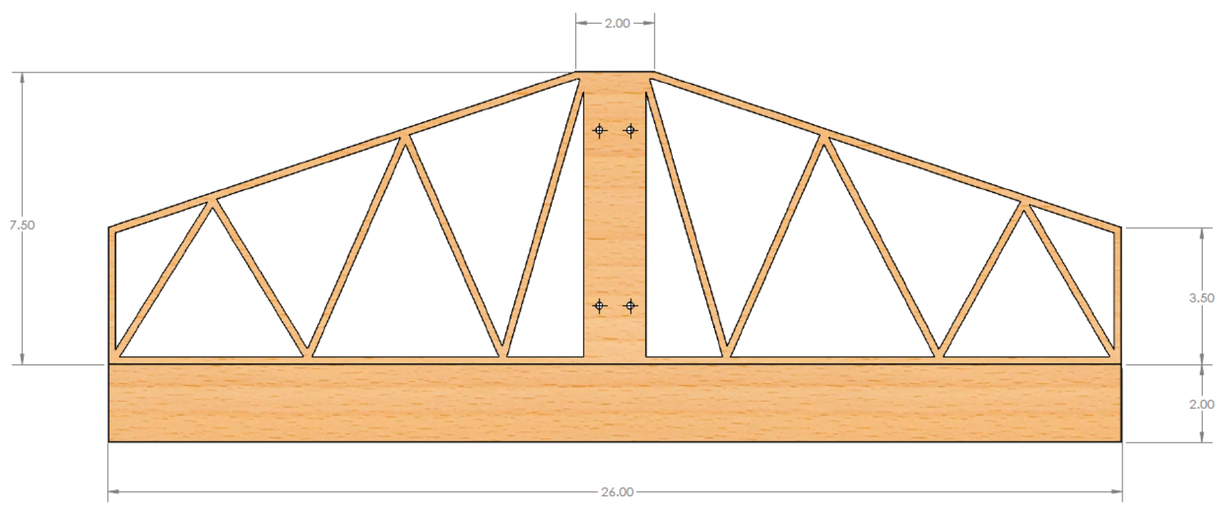


Figure 4.10: The Horizontal Stabilizer

When sizing the vertical stabilizer, the Team decided to use a similar method as done for the horizontal stabilizer. This resulted in a vertical stabilizer with an area of 79 in^2. A sketch of the vertical stabilizer can be seen below.

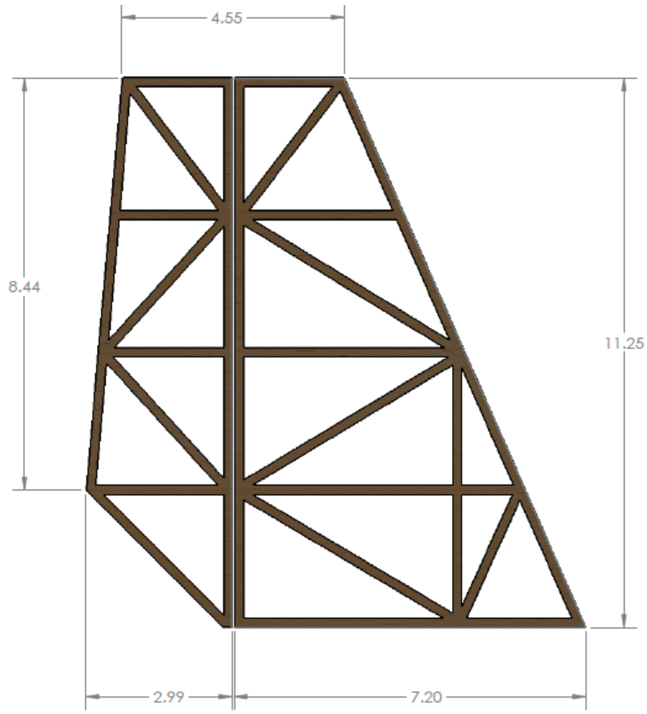


Figure 4.11: The Vertical Stabilizer

4.4 Propulsion Trade-offs

4.4.1 Battery Selection

The total weight of the aircraft was an important factor in the overall score of the competition. With weight being the most significant design limitation, the team decided to minimize the size and weight of the battery needed for required operation. With this in mind, the Team chose to use the Elite 1500 with 12 cells, providing a total voltage of 14.4 V and 1500 mAh. This battery selection provided a lightweight solution that supplied the necessary performance to effectively complete each of the three required missions.

4.4.2 Motor Selection

The Team decided to use the Hacker A30 16M based on the theoretical data from Motocalc. Given the test parameters specified in Section 4.2, this motor was found to provide the best theoretical performance. In addition, the motor is lightweight, which further cements its selection. Below are graphs recorded from Motocalc on this specific motor's performance. The red line corresponds to the left Y-axis and the blue line corresponds to the right Y-axis.

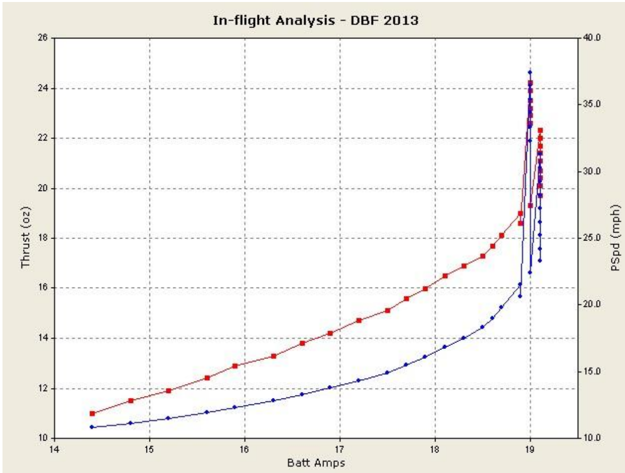


Figure 4.12: Thrust and Plane Speed vs Battery Amps

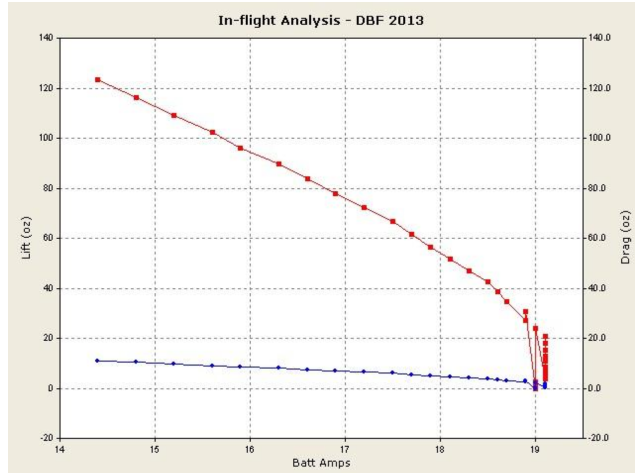


Figure 4.13: Lift and Drag vs Battery Amps

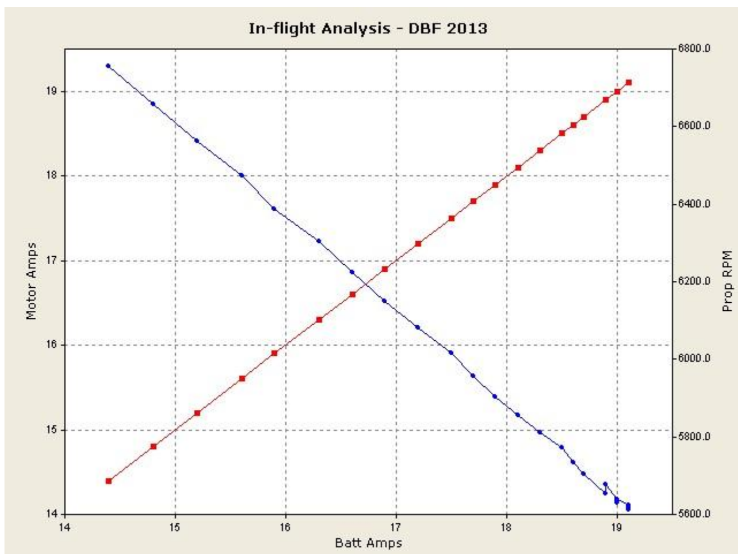


Figure 4.14: Motor Amps and Propeller RPM vs Battery Amps

The information in the above graphs correspond to an 11x7 propeller. With a maximum plane speed of 30 mph, the propeller rpm reaches 5600 rpm at about 19.25 amps. This theoretical speed is substantial enough for the first mission. At 14.5 amps, there is about 120 ounces of lift that is produced coupled with about 10 oz of drag. This lift is ample enough to complete the required short takeoff. The thrust produced is about 24 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 numbers that the Team obtained all lie within the parameters necessary to complete the missions.

4.4.3 Propeller Selection

Using data obtained from MotoCalc, the Team noticed that an 11x7 in propeller size would be efficient for the first mission while a 13x5 in propeller would be efficient for the second and third missions.

These propellers provided a balance between thrust and speed for each mission. These propellers coupled with the the motor and the battery provide enough speed for the timed mission and enough thrust for the payload missions. These are effective design choices chosen and they should perform well in each of the scored missions.

4.5 Structural Trade-offs

4.5.1 Fuselage Sizing

The Team designed the fuselage with the idea that it should be lightweight, with a small cross-sectional area, to reduce drag. However, the fuselage still needed to hold at least 4 Mini-max rockets for Payload Configuration 1 of Mission 3, and preferably more to maximize the score for Mission 2. The Team had to choose between increasing fuselage space to maximize the possible Mission 2 score, or limiting the fuselage size to conserve weight and ultimately increase speed. In the end, the Team elected to increase the fuselage size to maximize the score for Mission 2.

4.5.2 Internal Elements/Structure

To simplify the fabrication process and conserve weight, the Team adopted the truss structure to reinforce the frame of the fuselage. Although a unibody structure would greatly improve sturdiness, it would be disadvantageous to the aircraft's speed for Mission 1 and Mission 3. The internal mounting system was designed to hold the payload in place, without interfering with the motors or the servos.

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 airfoil S1210. The Team used an aerodynamic analysis program, XFLR5, in order to analyze the properties of the S1210 airfoil for different Reynolds numbers.

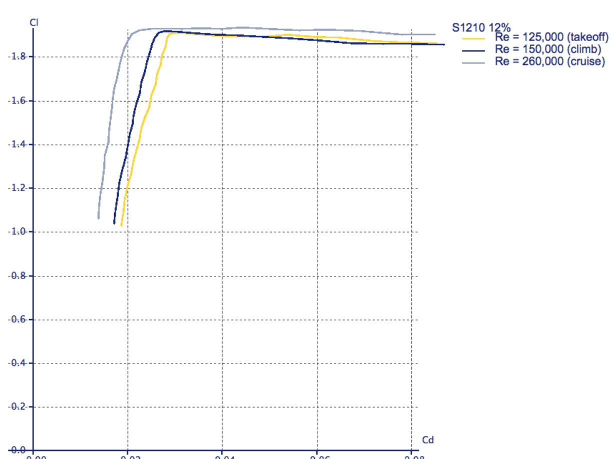


Figure 4.15: Coefficient Lift vs. Coefficient Drag (S1210 Airfoil)

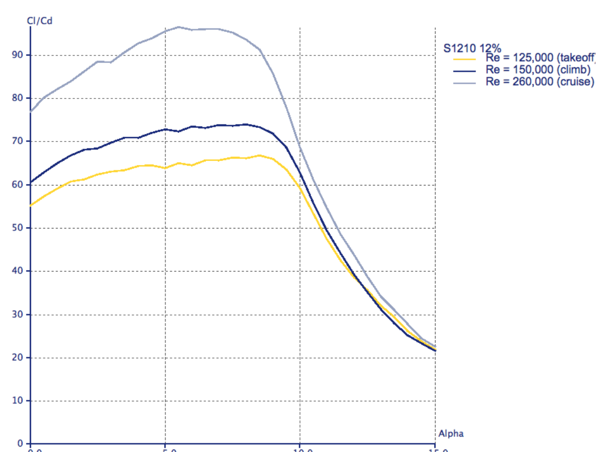


Figure 4.16: Glide Ratio vs. Angle of Attack (S1210 Airfoil)

The two graphs above show the results of a type 1 analysis in XFLR5, where a type 1 analysis assumes a fixed speed for each of the three cases. The analysis was performed for three different Reynolds numbers: 125,000, 150,000, and 260,000. The Reynolds numbers chosen are typical of takeoff, climb, and cruise conditions respectively. For both graphs: the yellow line shows airfoil performance at Re=125,000, the dark blue line shows airfoil performance at Re=150,000, and the light blue line shows airfoil performance at Re=260,000. Results for different Reynolds numbers were graphed in order to ensure that the S1210 airfoil could perform under a variety of flight conditions.

4.6.2 Drag

When the Team analyzed the drag of the aircraft, the main areas of concern were total drag force at cruise speed, and the parasitic drag of each component. Using a commercially available CFD package, coupled with hand calculations, the Team found that the total drag force of the aircraft was 0.625 lbf. This was well under the expected thrust of the aircraft, indicating that the aircraft should have no problem overcoming its own drag. When looking at parasitic drag, the Team generated the chart, seen in Figure 4.?, to better understand what components produced the most drag. As expected, the wing generates the most parasitic drag, due to its length. This data was then used to try and reduce the drag of the aircraft.

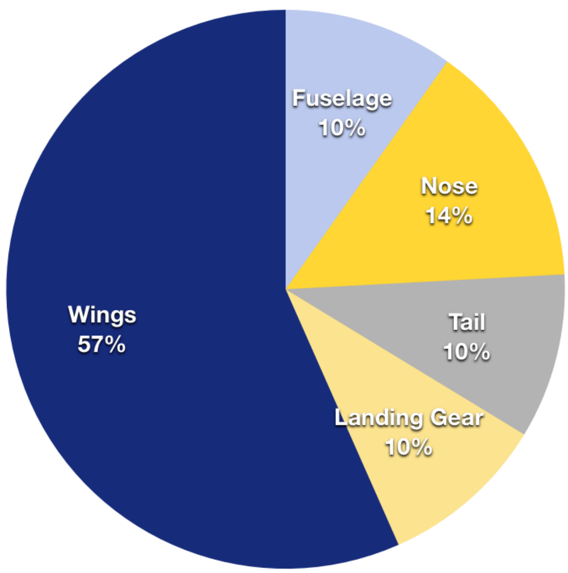


Figure 4.17: Breakdown of Parasitic Drag

4.6.3 Stability

The aircraft needs the ability to maintain longitudinal stability despite the shift in center of gravity (CG). between the three missions. Longitudinal stability analysis was done using XFLR5 given the structural constraints of the aircraft. In the figure below, the light blue line represents the CG at the expected neutral point, the dark blue line the CG at 10% static margin, and the yellow line at 16.4% static margin.

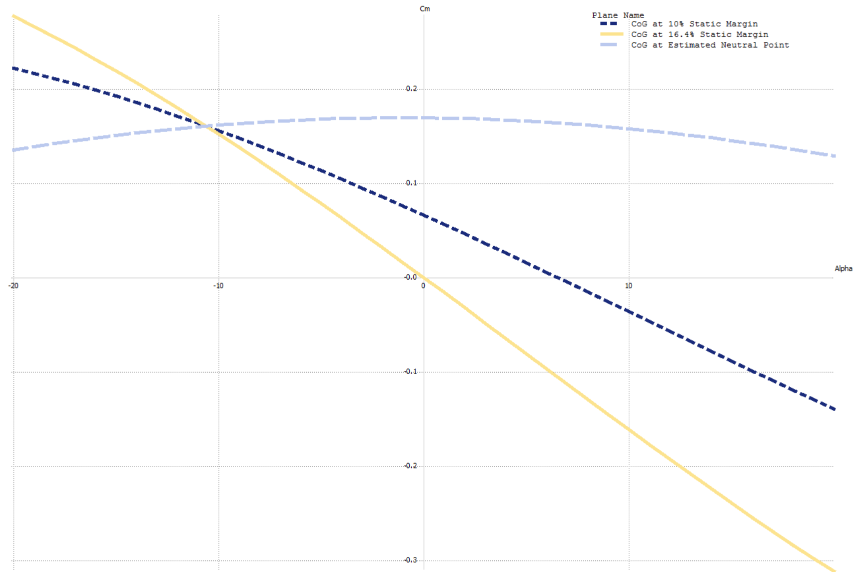


Figure 4.18: Total Pitching Moment Coefficient vs Angle of Attack

To be longitudinally balanced, the aircraft requires the total pitching moment coefficient at zero lift to be positive and that the center of gravity should be ahead of the neutral point. To be statically stable, the slope of the total pitching moment coefficient vs alpha should be negative. Analysis estimated the neutral point for the aircraft to be 8.15 inches from the leading edge of the main wing. To maintain longitudinal stability, the aircraft should have a static margin less than 16.4%, which is 6.745 inches from the leading edge. As long as the C.o.G. is between these two parameters, the plane will maintain longitudinal stability.

4.7 Aircraft Mission Performance

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

Mission 1	**Mission Sequence**	**Distance (ft.)**	**Speed (ft/s)**	**Time (s)**
Lap 1	Takeoff & Climb	30	variable	4
	Climb	300	17	18
	Cruise	170	42.5	4
	180 Degree Turn	100	40	2.5
	Cruise	500	50	10

	360 Degree Turn	175	40	5
	Cruise	500	50	10
	180 Degree Turn	100	40	2.5
	Cruise	500	50	10
Total:		**2400**		**66**
Laps 2-N	Cruise	500	50	10
	180 Degree Turn	100	40	2.5
	Cruise	500	50	10
	360 Degree Turn	200	40	5
	Cruise	500	50	10
	180 Degree Turn	100	40	2.5
	Cruise	500	50	10
Total:				**50**
Total Time:	***240***	***Seconds***		
Max Laps:	***4.48***	***Laps***		

Figure 4.19: Mission 1

Mission 2	**Mission Sequence**	**Distance (ft)**	**Speed (ft/s)**	**Time (s)**
Lap 1	Takeoff	30	30	4
	Climb	470	15	25
	180 Degree Turn	150	35	4.25
	Cruise	500	45	11.1
	360 Degree Turn	300	35	8.5
	Cruise	500	45	11.1
	180 Degree Turn	150	35	4.25
	Cruise	500	45	11.1
Total:		**2400**		**79.3**

Laps 2-3	Cruise	500	45	11.1
	180 Degree Turn	150	35	4.25
	Cruise	500	45	11.1
	360 Degree Turn	300	35	8.5
	Cruise	500	45	11.1
	180 Degree Turn	150	35	4.25
	Cruise	500	45	11.1
Per Lap Total		**2400**		**61.8**
Total Time	***202.9***	***seconds***		

Figure 4.20: Mission 2

Mission 3	**Mission Sequence**	**Distance (ft)**	**Speed (ft/s)**	**Time (s)**
Lap 1	Takeoff	30	30	4
	Climb	470	15	25
	180 Degree Turn	150	35	4.25
	Cruise	500	45	11.1
	360 Degree Turn	300	35	8.5
	Cruise	500	45	11.1
	180 Degree Turn	150	35	4.25
	Cruise	500	45	11.1
Total:		**2400**		**79.3**
Laps 2-N	Cruise	500	45	11.1
	180 Degree Turn	150	35	4.25
	Cruise	500	45	11.1
	360 Degree Turn	300	35	8.5
	Cruise	500	45	11.1

	180 Degree Turn	150	35	4.25
	Cruise	500	45	11.1
Total:		**2400**		**79.3**
Total Time	***202.9***	***seconds***		
Total Laps	***3.6***	***laps***		

Figure 4.21: Mission 3

From the above analysis, the Team estimated that the plane theoretically could complete 4 full laps during Mission 1, 2 full laps for Mission 2 and will have plenty of propulsion power and battery life to complete the three laps in Mission 2.

5.0 Detail Design

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

5.1 Final Design Parameters

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

Motor	
Type	Hacker A30-16M
Weight	3.74 oz
Kv	1060
I_o	1.6 A
R	.039 Ohm
Pm	330 W
Thrust	3 lbs
I_{batt}	20 A
Propeller	11x7

Horizontal Stabilizer	
Span	24 in
Root Chord	9.5 in
Tip Chord	5.5 in
Wing Area	136 in^2
Airfoil	Flat Plate

Batteries	
Type	Elite 1500
Capacity	1500 mAh
R	1.8 Ohm
V	1.2 V
I_{max}	.67 A
Number of Cells	8
Pack Capacity	1500 mAh
R_{pack}	1.8 Ohm
V_{pack}	9.6V
$I_{max\ pack}$	5.4 A
Endurance	270 sec

Fuselage	
Length	42 in
Width	8 in
Height	8 in
GTOW (est)	.75 lbs

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

Wing	
Span	71.42 in
Root Chord	11 in
Tip Chord	5.5 in
Aspect Ratio	7.69
Wing Area	523.215 in^2
Airfoil	S1210

Servos	
Type	Hitec HS-81
Weight	.59 oz
Torque	36 oz/in

Figure 5.1: Finalized Design Parameters

5.2 Structural Characteristics and Capabilities

When designing the structural components of the aircraft, the Team had two overarching goals. First, the Team recognized the need for a strong, lightweight structure that could take and distribute loads. Second, the structure should be functional, meaning that it is designed to support the necessary payload without too much extra structure.

With these overarching goals in mind, the Team designed the fuselage of the aircraft using a truss structure, covered in a lightweight film. The truss structure provided strength while minimizing the amount of material needed. To mount the stores to the inside of the fuselage, the collars were attached directly to the truss structure.

When designing the structure of the wing and tail, the Team decided to use a semi-monocoque structure consisting of ribs, stringers and a strong spar, all covered by a film for skin. Due to the length of the wing, this system allowed much of the wing volume to be empty space, yet use the inherent strength of the structure that resulted from the truss-like design. The wing and tail were attached to the fuselage with nylon screws, thereby creating a strong bond, while also making the components removeable.

Overall, the structure of the aircraft was designed to be lightweight, rigid and strong. Careful analysis of each mission, as well as design and research on aircraft structures has yielded the above characteristics and capabilities of the team's aircraft. This combination of capabilities yields superior stability and minimum weight, increasing the aircraft's speed, effectiveness, and overall score.

5.3 System Designs, Component Selection and Integration

5.3.1 Internal Store Mounting System

As stated in the conceptual design section, the Team decided on a collar system to secure the internal stores (rockets) to the fuselage for Mission 2. The collar was designed as two pieces, with the top half permanently attached to the body of the fuselage and the bottom half free. The Team designed the collars to fit snugly around the cylindrical body of the rocket, with the top half of the collar secured to the bottom half using a nylon screw and nut. Inside the body of the fuselage, the rockets were stacked in a 2x2x2 arrangement. To avoid the top rockets hitting the bottom rockets if they needed to be "dropped" during flight, the collars were staggered slightly, thereby meeting this requirement without affected the stability. To increase stability, The Team elected to use two collars per rocket. The final collar design can be seen in Figure 5.2 and 5.3, and the collar, rocket, fuselage attachment scheme can be seen in Figure 5.4.

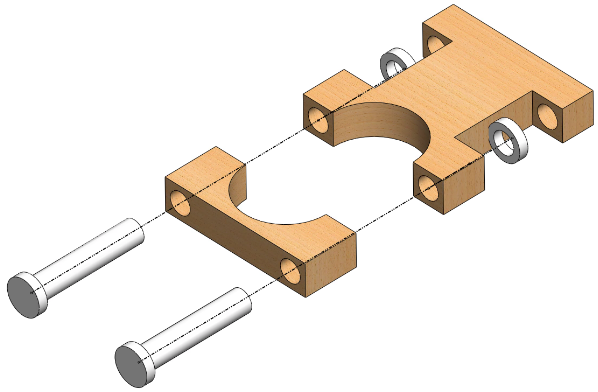


Figure 5.2: Final Collar Design (Exploded)

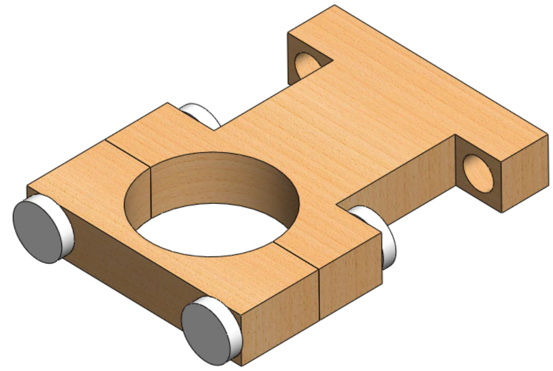


Figure 5.3: Final Collar Design (Assembled)

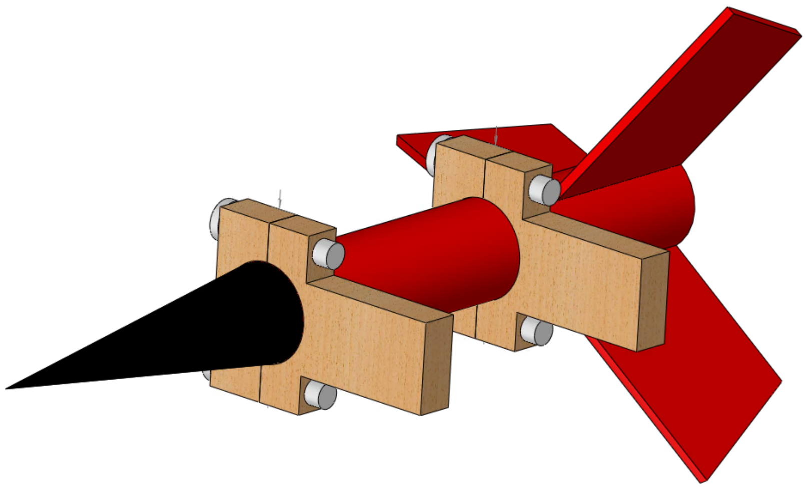


Figure 5.4: Internal Store Attachment System

5.3.2 External Store Mounting System

When designing the external store collars, the Team realized that a system that was as uniform as possible resulted in the simplest design. In order to achieve this goal of simplicity, the external store mounting system was modeled after the internal store system. Specifically for the external store system, the two primary design considerations for the external store containment system were that they were able to hold the three different rockets and that they were removable. To achieve these requirements, the Team made two important design decisions. First, the Team made the collar-wing attachment system standard, with two nylon screws fastening the top half of the collar to the wing. Secondly, the Team made a different collar for each rocket, thereby insuring that the rockets would fit tightly in the collars, ensuring stability during flight. Each rocket is attached to the wing in two places, also increasing the stability. Figure 5.5 shows the Der Red Max mounted beneath the wing. The Mini Honest John and High Flier mount in much the same way, and can be seen in the drawing package.

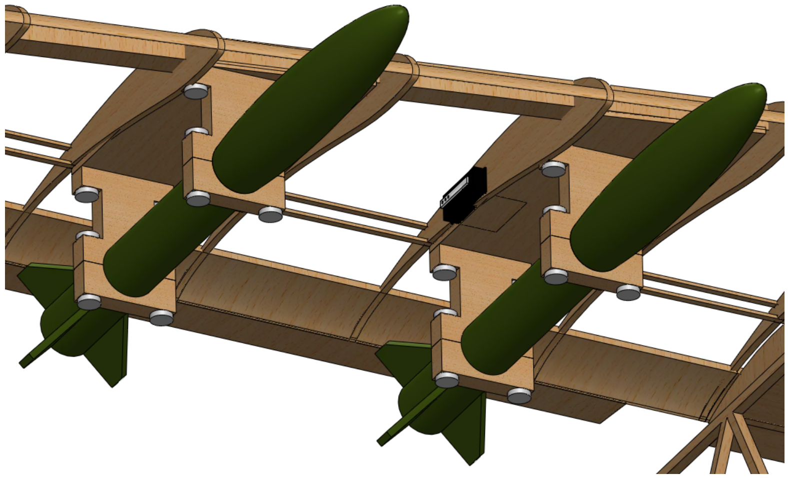


Figure 5.5: External Store Mounted to Wing

5.3.3 Wing Attachment System

When selecting a wing attachment system, the Team's main concern was the ability to transport the aircraft to the competition in a car. Accordingly, the team opted for a detachable wing that is mounted to the fuselage. In order to fit a curved wing on a flat fuselage, the Team attached small pieces of balsa to the bottom of the wing with a curved top and a flat bottom. This will ensure a flush attachment between the fuselage and the wing. The wing is mounted to the topic the fuselage, with the quarter-chord of the wing lining up with the center of gravity of the fuselage. This allows a better balance of aerodynamic forces. The wing is secured to the fuselage with nylon screws, two forward and two aft. The screws bisect the fuselage through a plywood plate, giving the wing a stuff attachment point. The plate and screws were sized so that the the loads from the wing can be transferred to the fuselage without damaging the structure. The wing attachment system can be seen in Figure 5.6.

Figure 5.6: Wing Attachment System

5.3.4 Tail

For this year's competition the Team decided to go with a conventional tail configuration, as seen in Figure 5.7. From the size of the wing the Team calculated a horizontal stabilizer area to be 140 in^2, which is approximately 30% of the wing area. The rudder area is 20% of the main wing. This provided the necessary stability and control during flight.

The Team realized the importance of analyzing the pitching moment cause by moving the elevators on the tail. If the moment was too large, the aircraft would pitch out of control during flight.

Alternately, if the moment was too small, the aircraft would not climb fast enough to perform a short takeoff. In order to mitigate these potential problems, a pitching moment analysis was performed to determine optimal distance from the leading edge of the main wing to the leading edge of the tail. These calculations led to team to place the tail approximately three feet behind the main wing.

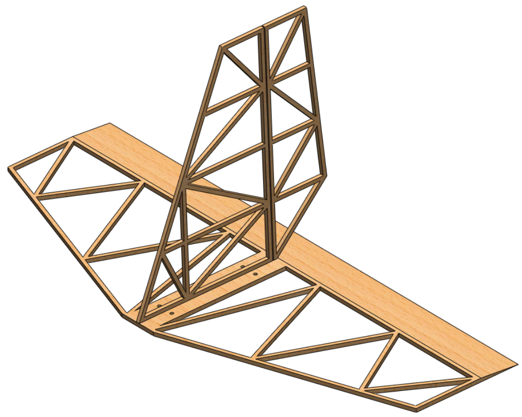


Figure 5.7: Tail Design

5.3.5 Landing Gear

One of the most important aspects of the landing gear was the stability that it provided to the aircraft while it was on the ground, as well as during the landing sequence. Due to the extra boost that was provided, the team decided on a tail dragger, which was designed to be lightweight and easy to fabricate. The main landing gear was constructed of bent wire. This choice optimized strength while still keeping a lightweight design, with only a small sacrifice in ease of manufacturing. Due to the necessity of a quick takeoff, the tail dragger provided a high amount of lift that was optimal for this event. The tail wheel was attached to the rudder to provide steering while taxiing prior to takeoff and post-landing.

Due to the need for the bottom of the fuselage to be open to the ground for payload loading, the Team recognized the need to attach the main landing gear in such a way that it did not impinge on the opening of the payload bay door. To this end, the Team decided to give the landing gear a wide spread, and attach it to the firewall separating the main fuselage from the motor and battery compartment. Figure 5.8 shows the final design.

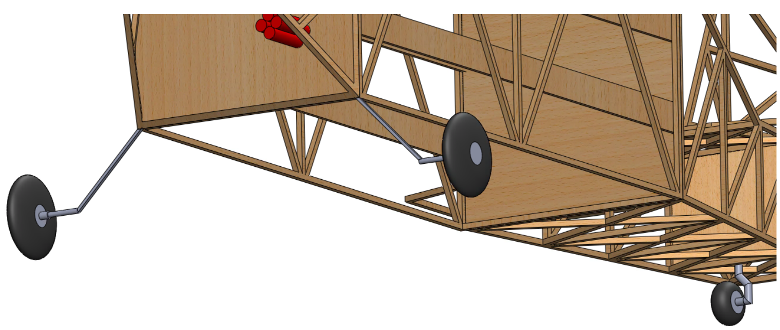


Figure 5.8: Landing Gear Design

5.3.6 Electronic System

The electronics system of the aircraft provided the power and control of the aircraft in flight. As discussed in Section 4, the Team sized the motor and battery based on the thrust needed for takeoff and flight. The Team selected a 20 amp blade fuse, mounted externally to the aircraft, to limit the power system. The other crucial part of the power system was the electronic speed controller, which uses the incoming signal from the transmitter to throttle the motor. The Team selected the Phoenix-25 because of its lightweight design and 25-amp limit (which limited the chance of overdrawing the fuse).

The final components of the electronic system were the servos, which moved the control surfaces and tail wheel. After sizing the control surfaces, the Team calculated the torque required to move the surfaces. From here, the Team selected the Hitec HS-81 because it met the power requirements and was lightweight, due to its resin gears.

5.4 Weight and Balance

The attachment points in the fuselage allowed the Team a lot of flexibility in placing components in the fuselage. The rocket mounts were custom fabricated in order to place the CG of the aircraft right under the wing. Thorough moment calculations were done on the wing and tail to ensure that the plane would remain at the appropriate angle of attack throughout the duration of all flights in all configurations. This flexibility will prove very important in the testing phase of the aircraft. All components will be easily accessible, and lend themselves to position adjustments in order to optimize the aircraft's flights and performance. As mentioned in section 5.3.3, the wing is mated to the fuselage such that the quarter-chord of the wing is over the CG of the fuselage. In Mission 3, the stores will be attached to the wing, with the CG's of the stores aligned with the quarter chord. This simplifies the design because then the CG of the aircraft is constant, regardless of the stores carried. The projected weights and balances for each mission/configuration can be seen in the tables below.

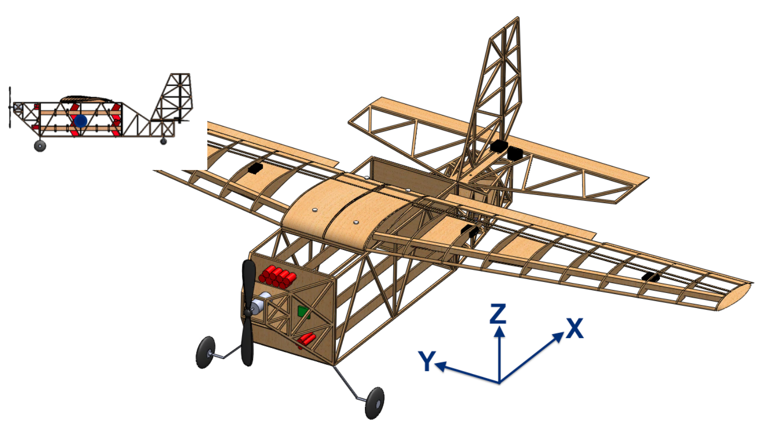


Figure 5.9: Aircraft Axes and Location of Origin

Mission 1	Weight (lbs)	X Location (in)	X Moment (lb*in)	Y Location (in)	Y Moment (lb*in)	Z Location (in)	Z Moment (lb*in)
Motor	0.23	-13.00	-3.04	0.00	0.00	2.00	0.47
Receiver Battery Pack	0.10	-10.00	-1.01	1.00	0.10	-2.00	-0.20
Battery Pack	0.61	-10.00	-6.08	-1.00	-0.61	0.00	0.00
Receiver	0.13	-10.00	-1.25	1.00	0.13	0.00	0.00
ESC	0.06	-10.00	-0.63	-1.00	-0.06	0.00	0.00
Wing Servos	0.15	2.00	0.30	0.00	0.00	4.00	0.59
Tail Servos	0.07	18.00	1.33	0.00	0.00	2.00	0.15
Fuselage	1.00	-5.00	-5.00	0.00	0.00	-1.00	-1.00
Nose Landing Gear	0.45	-10.00	-4.50	0.00	0.00	-4.00	-1.80
Tail Landing Gear	0.19	18.00	3.38	0.00	0.00	-4.00	-0.75
Wing	0.70	5.00	3.50	0.00	0.00	4.00	2.80
Tail	0.30	24.00	7.20	0.00	0.00	2.00	0.60
Total	3.99	-1.46	-5.81	-0.11	-0.44	0.21	0.85

Figure 5.10: Mission 1 Weight and Balance Table

Mission 2	Weight (lbs)	X Location (in)	X Moment (lb*in)	Y Location (in)	Y Moment (lb*in)	Z Location (in)	Z Moment (lb*in)
Empty Aircraft	3.99	-1.46	-5.81	-0.11	-0.44	0.21	0.85
Internal Stores	2.00	0.00	0.00	0.00	0.00	4.00	8.00
Total	5.99	-0.97	-5.81	-0.07	-0.44	1.48	8.85

Figure 5.11: Mission 2 Weight and Balance Table

Mission 3-1	Weight (lbs)	X Location (in)	X Moment (lb*in)	Y Location (in)	Y Moment (lb*in)	Z Location (in)	Z Moment (lb*in)
Empty Aircraft	3.99	-1.46	-5.81	-0.11	-0.44	0.21	0.85
Internal Stores	1.00	0.00	0.00	0.00	0.00	4.00	4.00
External Stores - Right Wing	1.00	0.00	0.00	8.00	8.00	4.00	4.00
External Stores - Left Wing	1.00	0.00	0.00	-8.00	-8.00	4.00	4.00
Total	6.99	-0.83	-5.81	-0.06	-0.44	1.84	12.85

Mission 3-2	Weight (lbs)	X Location (in)	X Moment (lb*in)	Y Location (in)	Y Moment (lb*in)	Z Location (in)	Z Moment (lb*in)
Empty Aircraft	3.99	-1.46	-5.81	-0.11	-0.44	0.21	0.85
Internal Stores	0	0	0	0	0	4	0
External Stores - Right Wing	1.5	0	0	12	18	4	6
External Stores - Left Wing	1.5	0	0	-12	-18	4	6
Total	6.99	-0.83	-5.81	-0.06	-0.44	1.84	12.85

Mission 3-3	Weight (lbs)	X Location (in)	X Moment (lb*in)	Y Location (in)	Y Moment (lb*in)	Z Location (in)	Z Moment (lb*in)
Empty Aircraft	3.99	-1.46	-5.81	-0.11	-0.44	0.21	0.85
Internal Stores	0	0	0	0	0	4	0
External Stores - Right Wing	1.0	0	0	16.5	16.5	4	4
External Stores - Left Wing	1.5	0	0	-10.5	-15.75	4	6
Total	6.49	-0.89	-5.81	0.05	0.31	1.67	10.85

Mission 3-4							
	Weight (lbs)	X Location (in)	X Moment (lb*in)	Y Location (in)	Y Moment (lb*in)	Z Location (in)	Z Moment (lb*in)
Empty Aircraft	3.99	-1.46	-5.81	-0.11	-0.44	0.21	0.85
Internal Stores	0	0	0	0	0	4	0
External Stores - Right Wing	1.5	0	0	10	15	4	6
External Stores - Left Wing	1.5	0	0	-10	-15	4	6
Total	6.99	-0.83	-5.81	-0.06	-0.44	1.84	12.85

Mission 3-5							
	Weight (lbs)	X Location (in)	X Moment (lb*in)	Y Location (in)	Y Moment (lb*in)	Z Location (in)	Z Moment (lb*in)
Empty Aircraft	3.99	-1.46	-5.81	-0.11	-0.44	0.21	0.85
Internal Stores	0	0	0	0	0	4	0
External Stores - Right Wing	1.5	0	0	10	15	4	6
External Stores - Left Wing	1.5	0	0	-10	-15	4	6
Total	6.99	-0.83	-5.81	-0.06	-0.44	1.84	12.85

Mission 3-6							
	Weight (lbs)	X Location (in)	X Moment (lb*in)	Y Location (in)	Y Moment (lb*in)	Z Location (in)	Z Moment (lb*in)
Empty Aircraft	3.99	-1.46	-5.81	-0.11	-0.44	0.21	0.85
Internal Stores	0	0	0	0	0	4	0
External Stores - Right Wing	1.5	0	0	12.5	18.75	4	6
External Stores - Left Wing	1.25	0	0	-14.5	-18.125	4	5
Total	6.74	-0.86	-5.81	0.03	0.18	1.76	11.85

Figure 5.12: Mission 3 Weight and Balance Tables

5.5 Flight Performance Parameters

After finalization of all of the structural components of the aircraft, the Team calculated final parameters. These can be seen in Figure 5.13. These parameters provided a more detailed understanding of the aircraft's operation and projected performance.

Flight Parameters					
Aircraft Parameters		Mission Parameters	Mission 1	Mission 2	Mission 3
C_{L0}	1.05	Climb Rate (ft/s)	25	20	20
C_{LMAX}	1.92	Stall Speed (ft/s)	44	44	44
e	0.81	Cruise Speed (ft/s)	54	40	40
C_{DO}	0.0315	Maximum Speed (ft/s)	54	45	40
		Max G-Loads	4	4	6
		Turn Rate (degs/s)	105	45	45

Figure 5.13: Flight Performance Parameters

5.6 Mission Performance

5.6.1 Pre-Mission Assembly and Payload Integration

For all missions, the aircraft can enter the assembly area fully assembled. For Mission 1, there is no payload; the aircraft will be flight-ready when it enters the assembly area. However, for Missions 2 and 3, the payload must be external to the aircraft and loaded during the five minute period. The team expects mounting the rockets to take no more than 3 minutes, well under the five minute time limit allowed.

5.6.2 Mission 1 - Short Takeoff

There are two main goals of this mission. The first is to achieve takeoff in under thirty feet. The next goal is to complete as many laps as possible within the 4 minute time period. After the short takeoff, estimated to take 20 feet, we expect the aircraft to quickly reach its cruising altitude and maximum velocity of about 24 feet per second. According to our calculations, the aircraft will complete approximately 4 laps. Using past year's results, the team estimates that the maximum number of laps completed will be 7. This would yield a Mission 1 score of 1.14.

5.6.3 Mission 2 - Stealth Mission

There are two goals for this mission: complete the takeoff in 30 feet and fly for 3 laps with the internal payload. After the short takeoff, which the Team estimates will take 26 feet, the aircraft will reach its cruising altitude and complete the 3 required laps. The Team estimates that completion of this mission will take 3 minutes. Trying to estimate the score for Mission 2 is difficult because it is dependent on how many internal stores other teams carry. Using the sensitivity analysis, the Team felt that it was infeasible to carry more than 12 rockets. Based on this assumption, the Team estimates that their Mission 2 score would be 2.67.

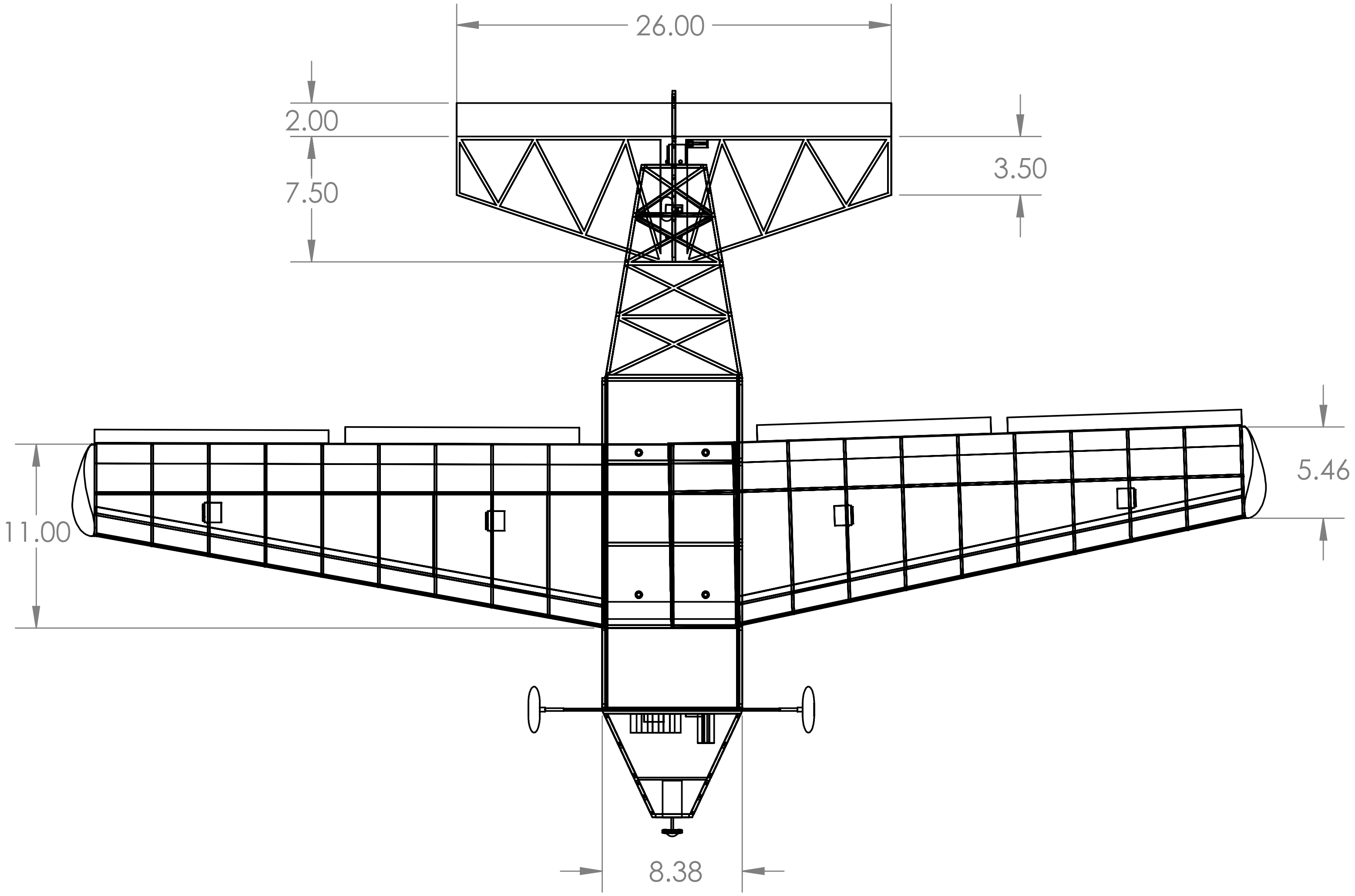
5.6.4 Mission 3 - Strike Mission

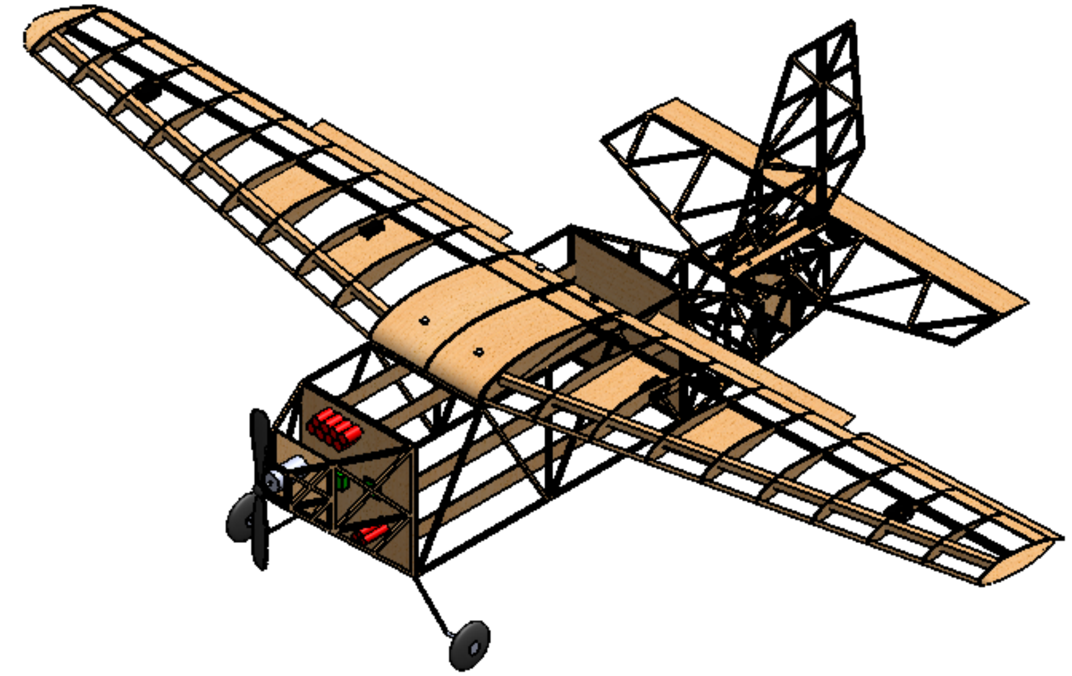
The goals for Mission 3 are short takeoff and completion of as many laps in 4 minutes as possible. This is similar to Mission 1; however, Mission 3 requires the payloads to be carried externally, resulting in both increased weight and increased drag. These factors will slow the flight of the plane, thereby reducing the number of laps completed. The Team estimates that the aircraft will complete 2 laps in 4 minutes, which is half of the number from Mission 1. Using the same proportions for the maximum number of laps, the Team estimates that their score for Mission 3 will be 3.

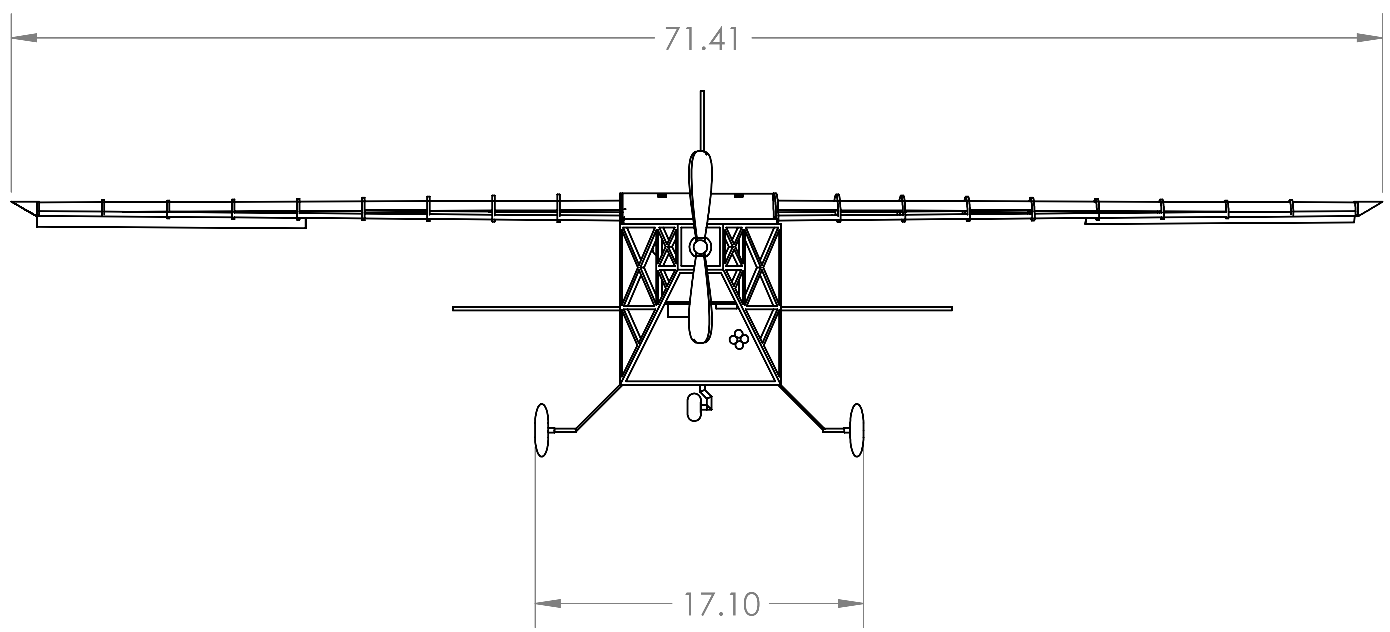
5.6.5 Rated Aircraft Cost

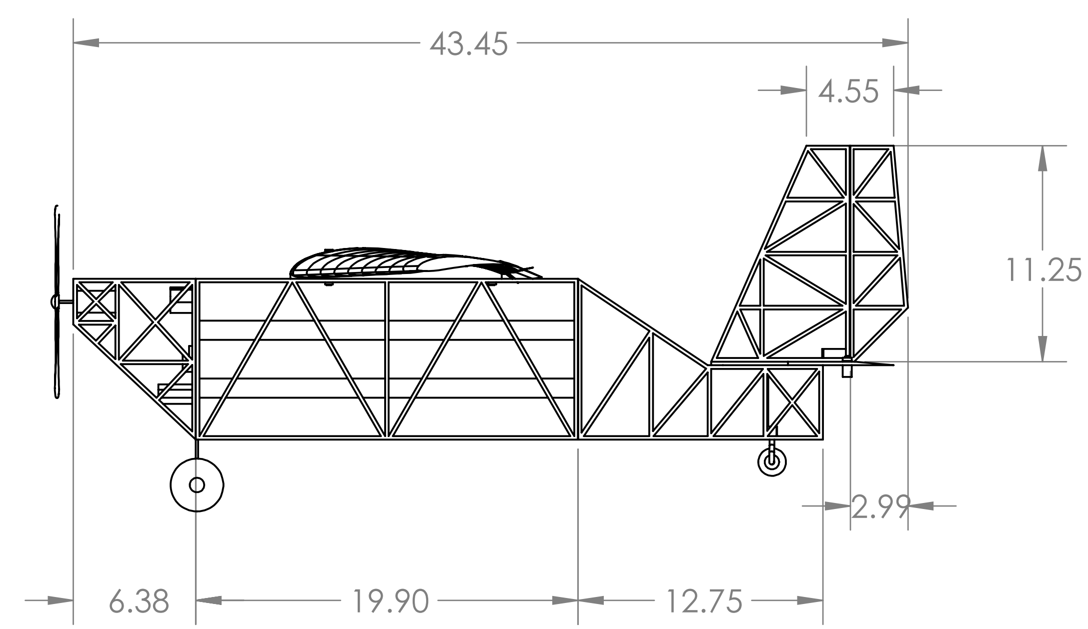
After defining all parameters of the final aircraft, the Team calculated the RAC of the aircraft. This quantity is very important to the final score, because the overall score is divided by the RAC. Knowing that the final dimensions of the aircraft were an aircraft length of 43 inches, an overall wingspan of 71 inches and a maximum empty weight of 4 lbs, the Team found that the RAC of the competition aircraft to be 2.68. The Team feels that this RAC gives the aircraft a good chance to score well in the competition.

5.7 Drawing Package (see following pages)









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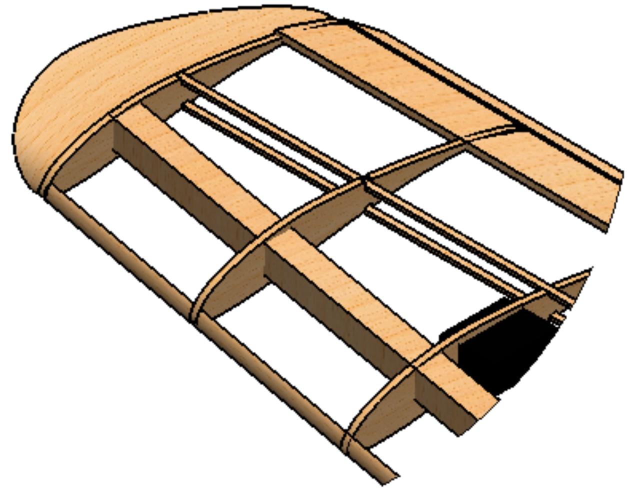
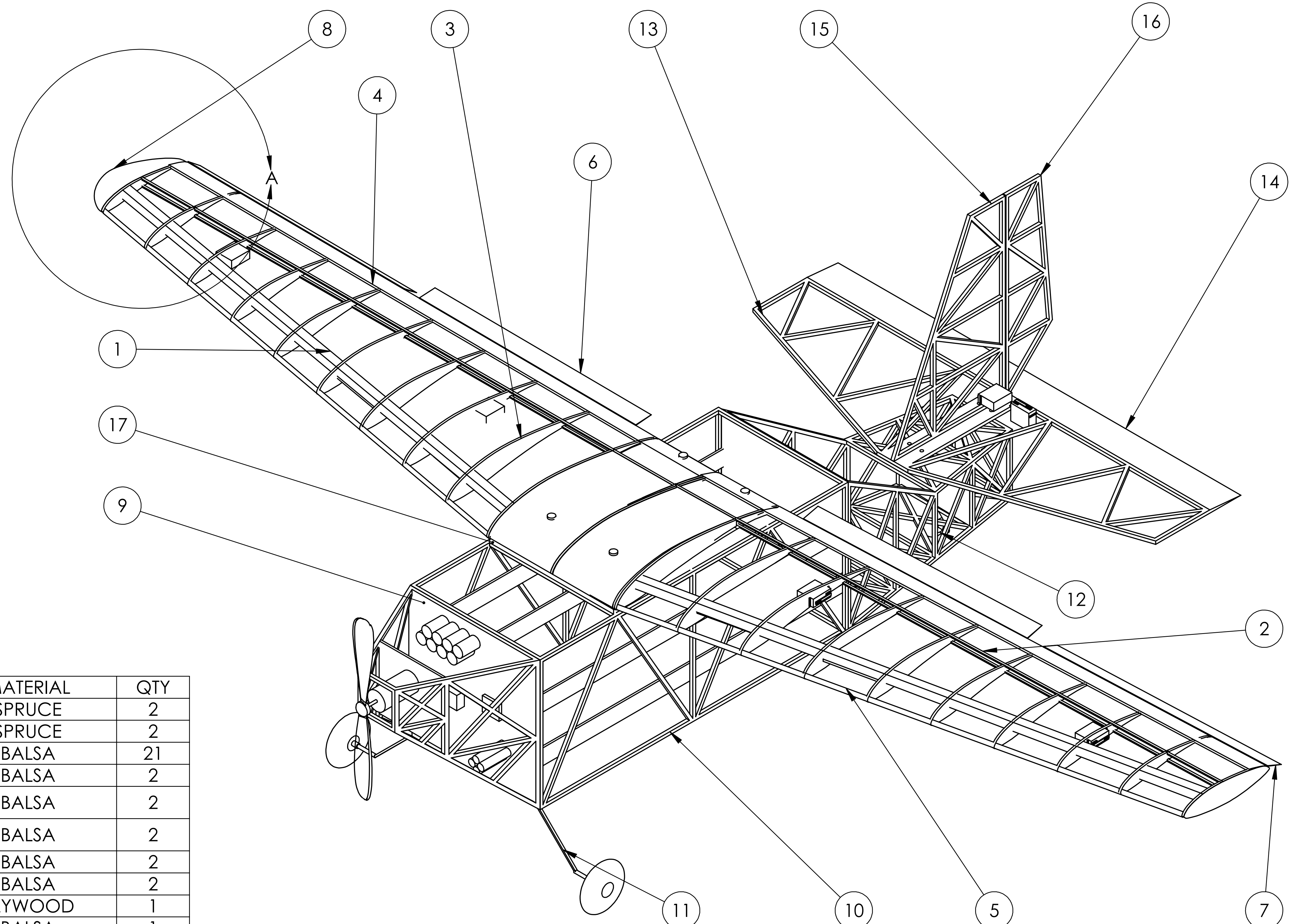
DRAWN	S. JACOBSON	2/18/13			
APPROVED	M. ANDERSON	2/22/13			
COMMENTS: ALL UNITS ARE GIVEN IN INCHES UNLESS OTHERWISE SPECIFIED			SIZE B	REPORT SECTION: DRAWING PACKAGE	REV A
			SCALE: 1:10		SHEET 1 OF 7



DETAIL A
SCALE 2 : 5



ITEM NO.	NAME	MATERIAL	QTY
1	WING SPAR	SPRUCE	2
2	WING STRINGER	SPRUCE	2
3	WING RIB	BALSA	21
4	WING TRAILING EDGE	BALSA	2
5	WING LEADING EDGE	BALSA	2
6	FLAPS	BALSA	2
7	AILERONS	BALSA	2
8	WING TIP	BALSA	2
9	FIREWALL	PLYWOOD	1
10	FUSELAGE	BALSA	1
11	MAIN LANDING GEAR	METAL	1
12	TAIL LANDING GEAR	METAL	1
13	HORIZONTAL STABILIZER	BALSA	1
14	ELEVATOR	BALSA	1
15	VERTICAL STABILIZER	BALSA	1
16	RUDDER	BALSA	1
17	WING ATTACH PLATE	BALSA	1

	NAME	DATE
DRAWN	S. JACOBSON	2/18/13
APPROVED	M. ANDERSON	2/22/13

COMMENTS:
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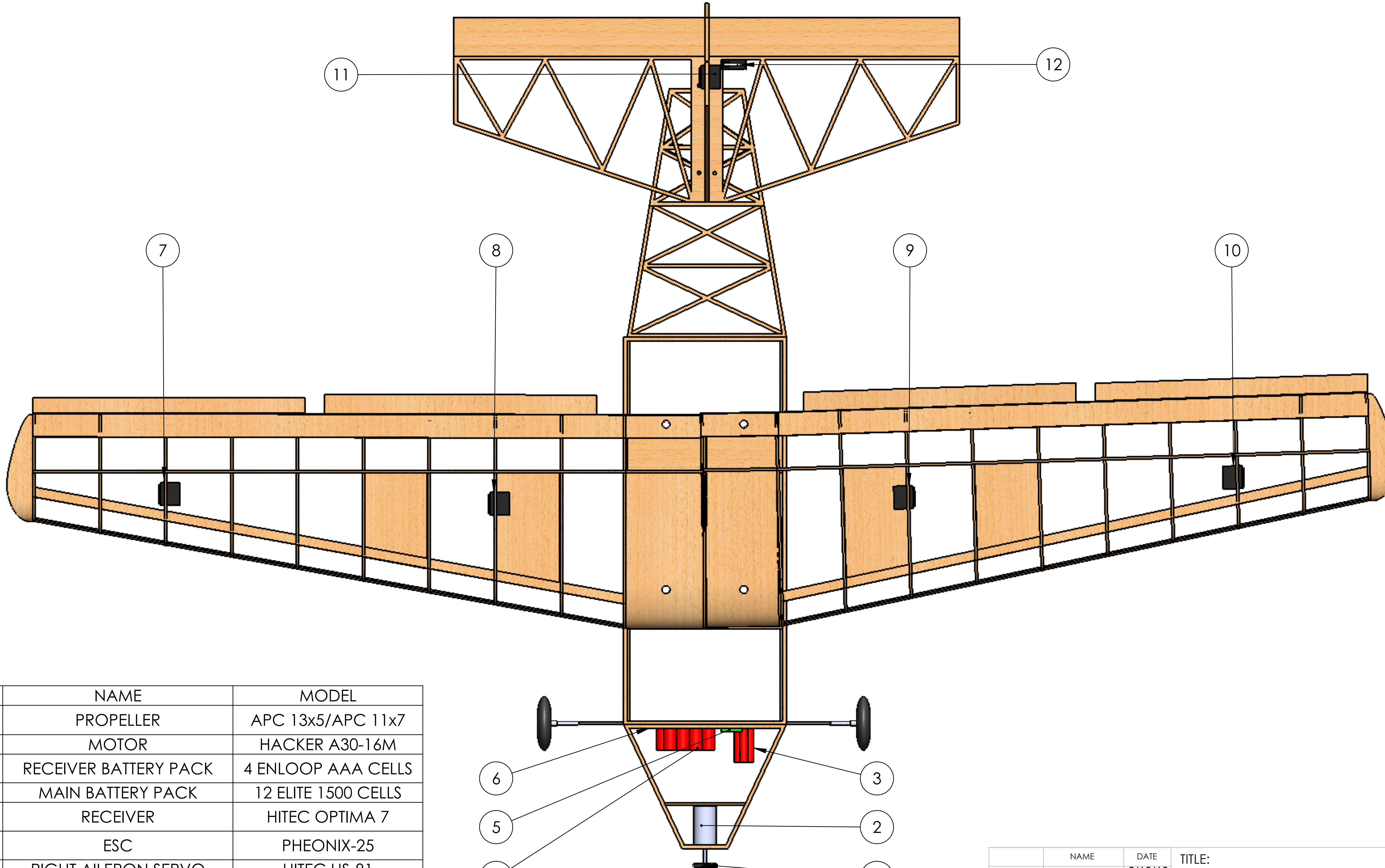
TITLE:
STRUCTURAL ARRANGEMENT

SIZE: B
REPORT SECTION: DRAWING PACKAGE
REV: A

SCALE: 1:5
SHEET 2 OF 7



ITEM NO.	NAME	MODEL
1	PROPELLER	APC 13x5/APC 11x7
2	MOTOR	HACKER A30-16M
3	RECEIVER BATTERY PACK	4 ENLOOP AAA CELLS
4	MAIN BATTERY PACK	12 ELITE 1500 CELLS
5	RECEIVER	HITEC OPTIMA 7
6	ESC	PHEONIX-25
7	RIGHT AILERON SERVO	HITEC HS-81
8	RIGHT FLAP SERVO	HITEC HS-81
9	LEFT FLAP SERVO	HITEC HS-81
10	LEFT AILERON SERVO	HITEC HS-81
11	RUDDER SERVO	HITEC HS-81
12	ELEVATOR SERVO	HITEC HS-81

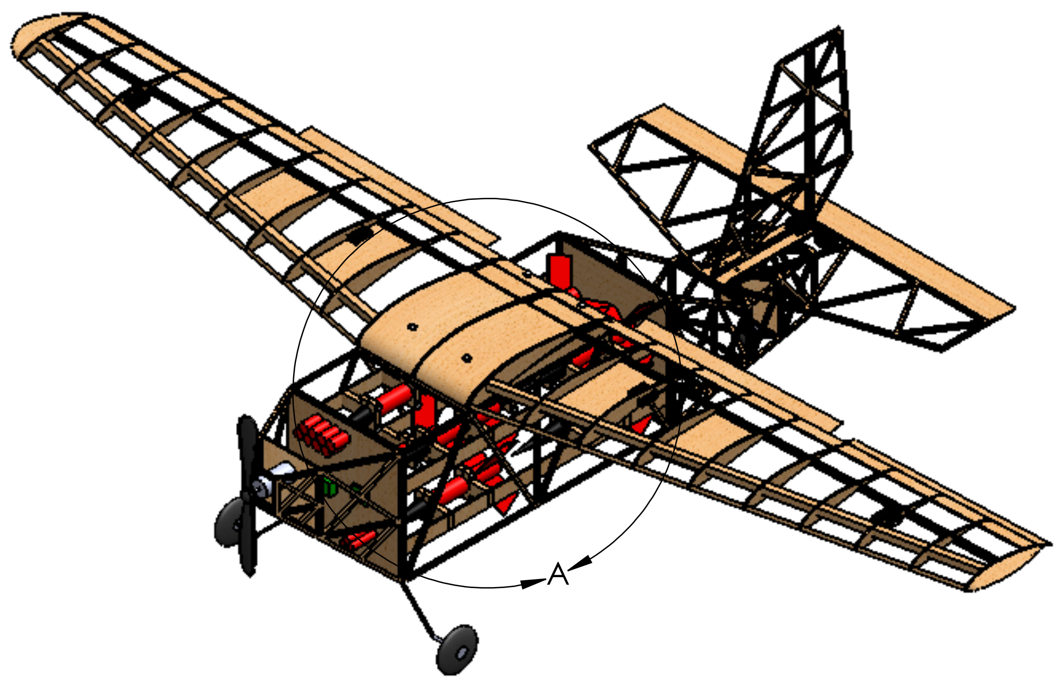
	NAME	DATE
DRAWN	S. JACOBSON	2/18/13
APPROVED	M. ANDERSON	2/22/13

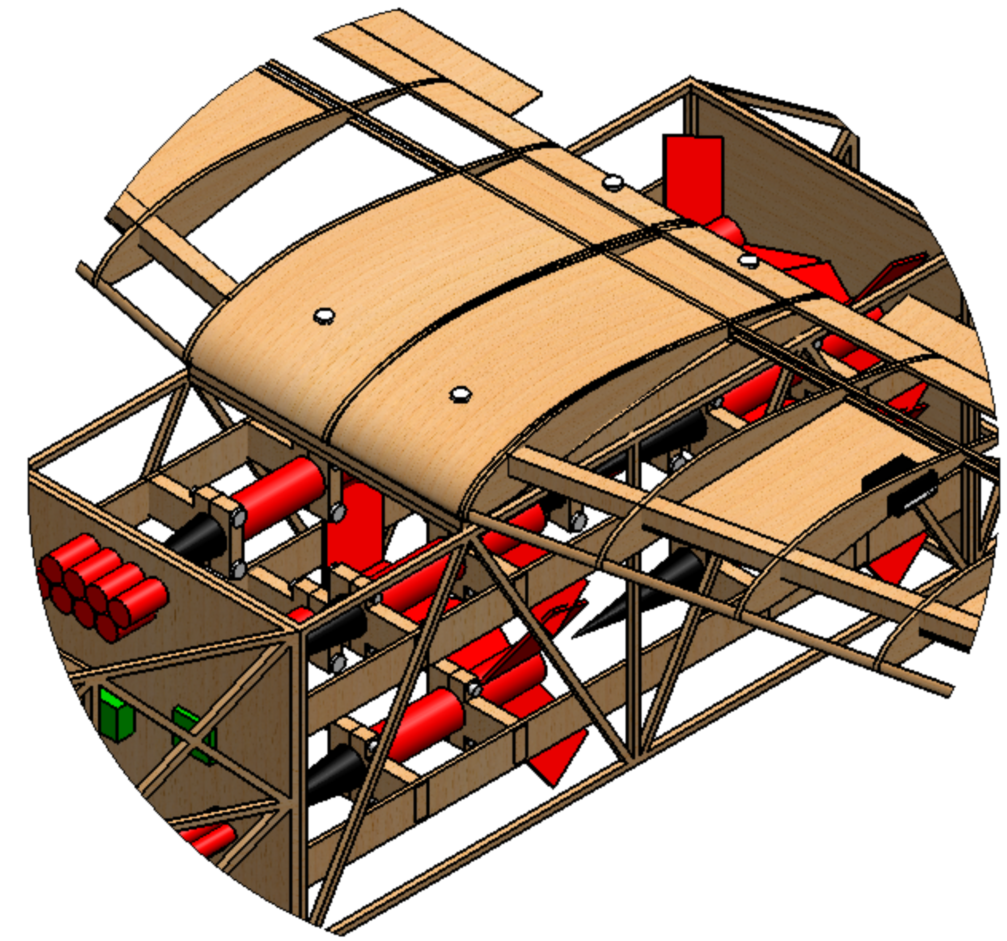
COMMENTS:
ALL UNITS ARE GIVEN IN INCHES UNLESS OTHERWISE SPECIFIED

TITLE:
SYSTEMS LAYOUT

SIZE: B
REPORT SECTION: DRAWING PACKAGE
REV: A

SCALE: 1:5
SHEET 3 OF 7





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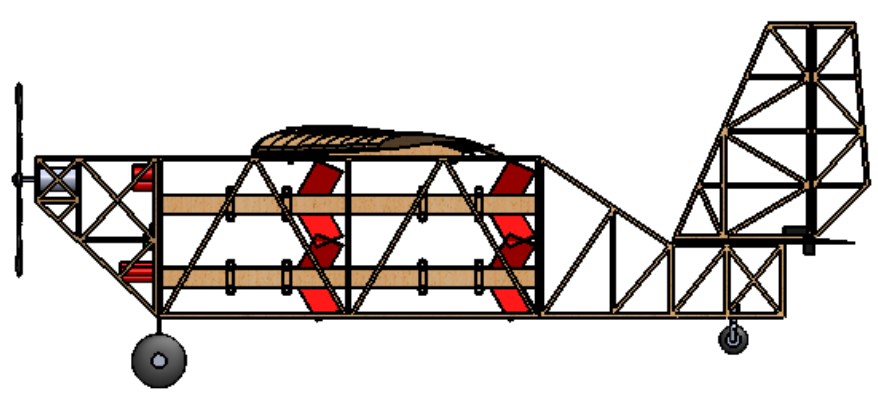

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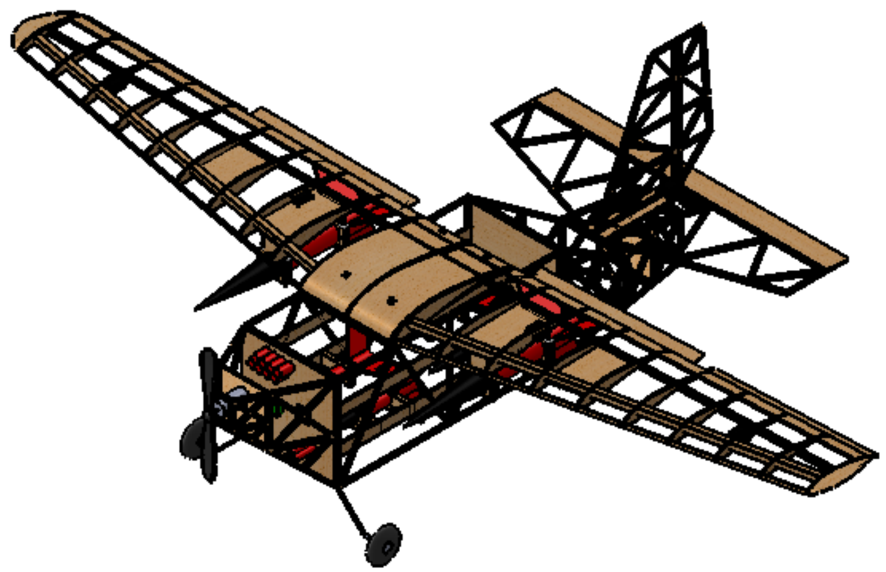
DRAWN	S. JACOBSON	2/18/13	
APPROVED	M. ANDERSON	2/22/13	

COMMENTS:
ALL UNITS ARE GIVEN IN INCHES UNLESS OTHERWISE SPECIFIED

SIZE	REPORT SECTION:	REV
B	DRAWING PACKAGE	A

SCALE: 1:10

SHEET 4 OF 7



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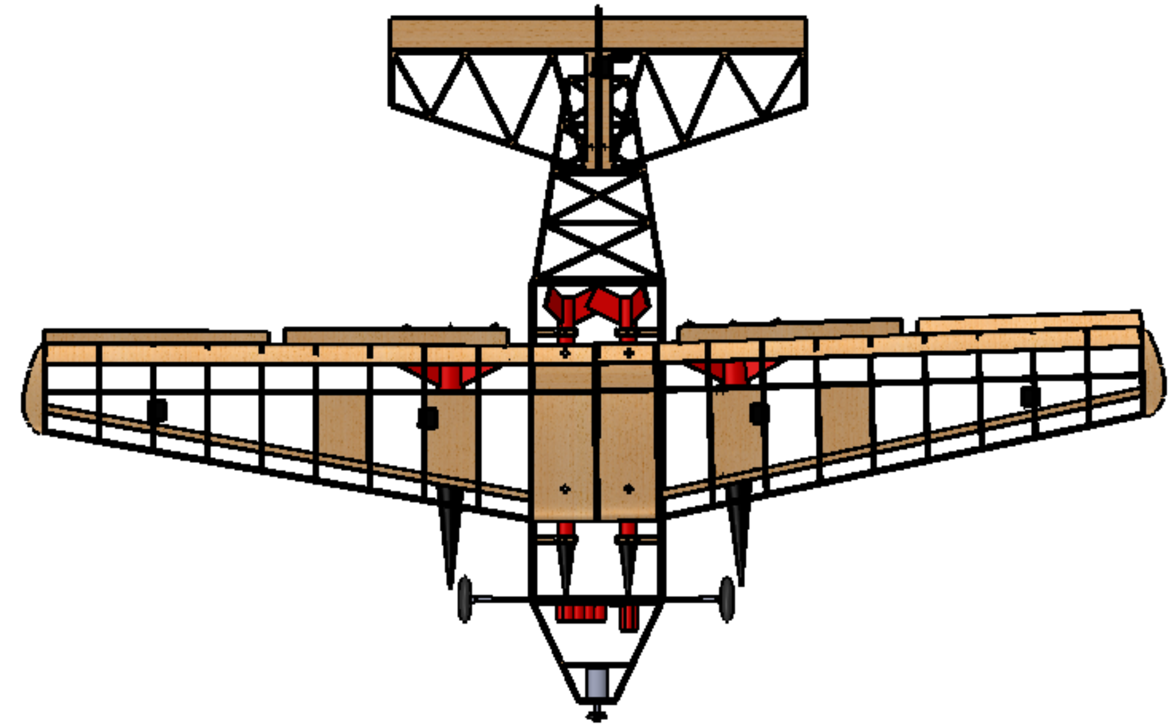

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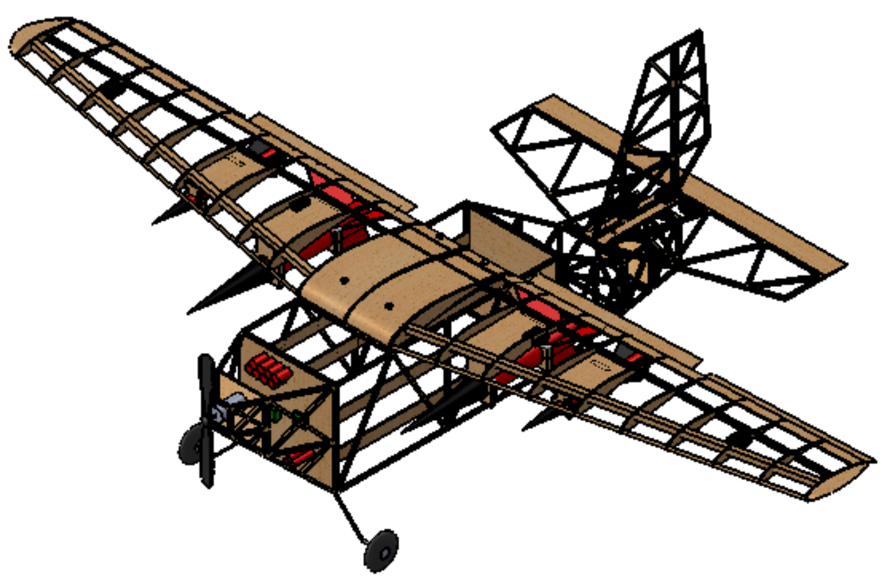

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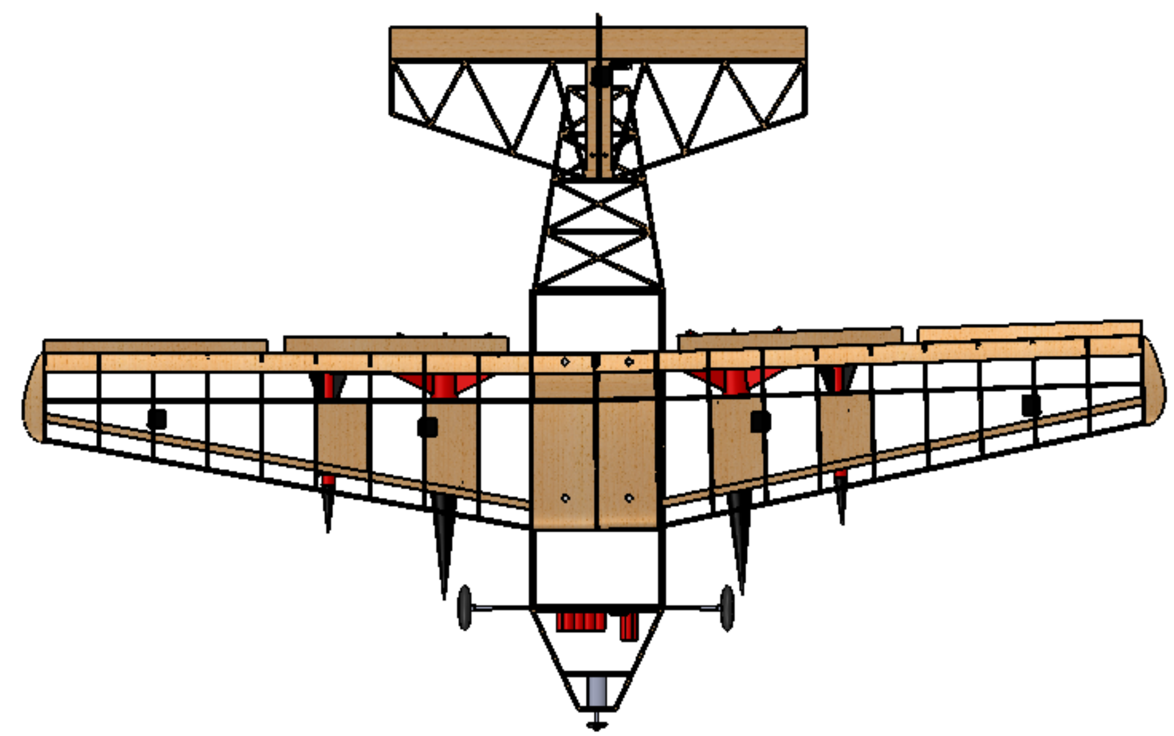

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DRAWN	S. JACOBSON	2/18/13			
APPROVED	M. ANDERSON	2/22/13			
COMMENTS: ALL UNITS ARE GIVEN IN INCHES UNLESS OTHERWISE SPECIFIED			SIZE B	REPORT SECTION: DRAWING PACKAGE	REV A
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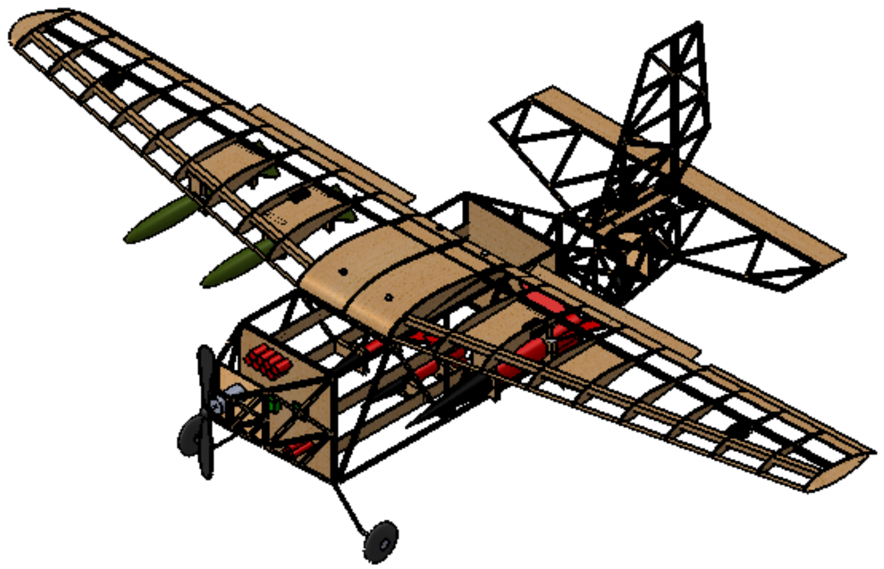

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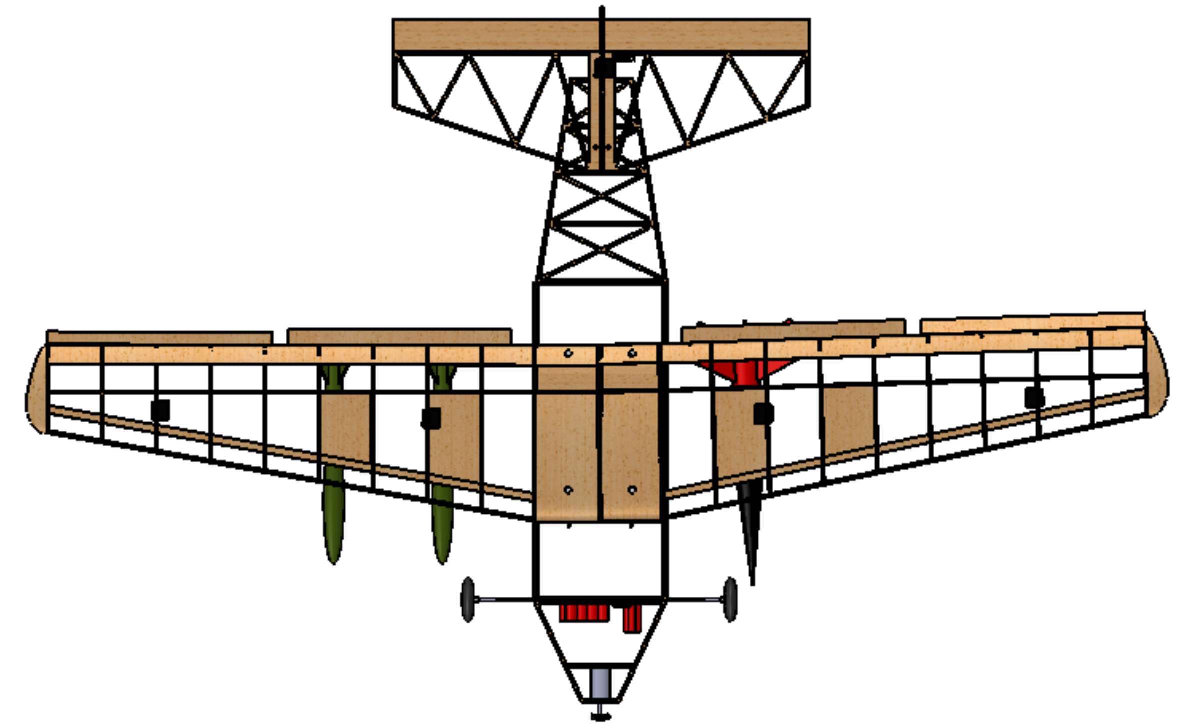

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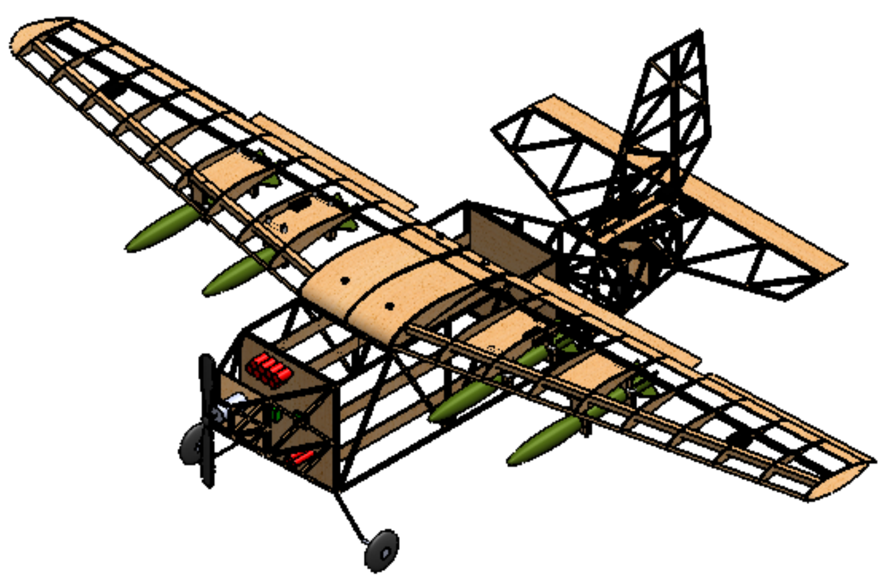

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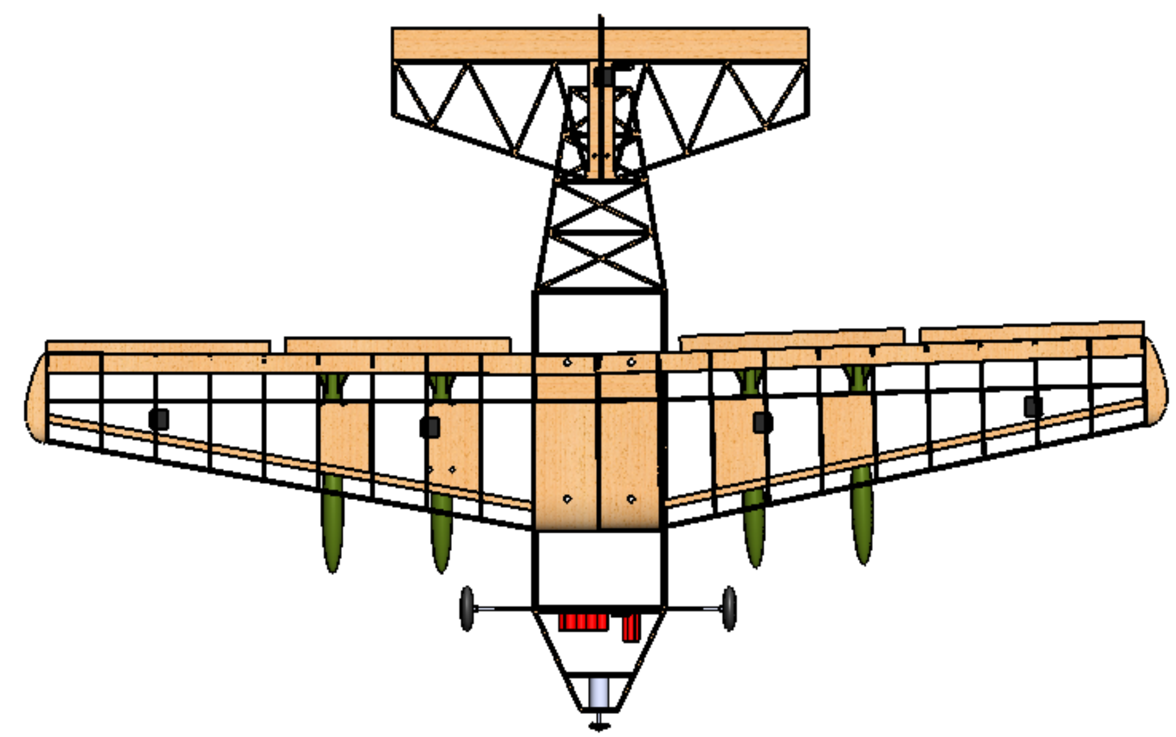

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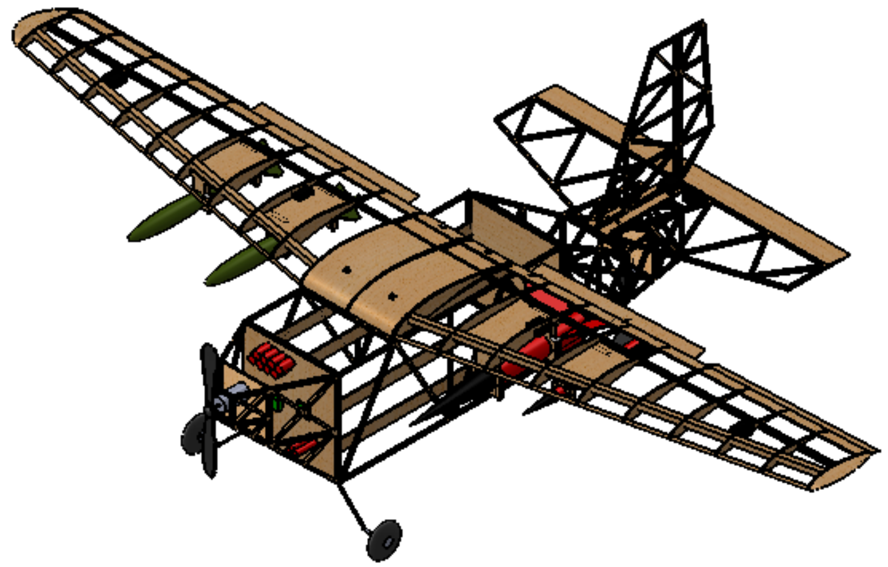
DRAWN	S. JACOBSON	2/18/13		
APPROVED	M. ANDERSON	2/22/13		
COMMENTS: ALL UNITS ARE GIVEN IN INCHES UNLESS OTHERWISE SPECIFIED			SIZE B	REPORT SECTION: DRAWING PACKAGE	REV A
			SCALE: 1:12	SHEET 6 OF 7



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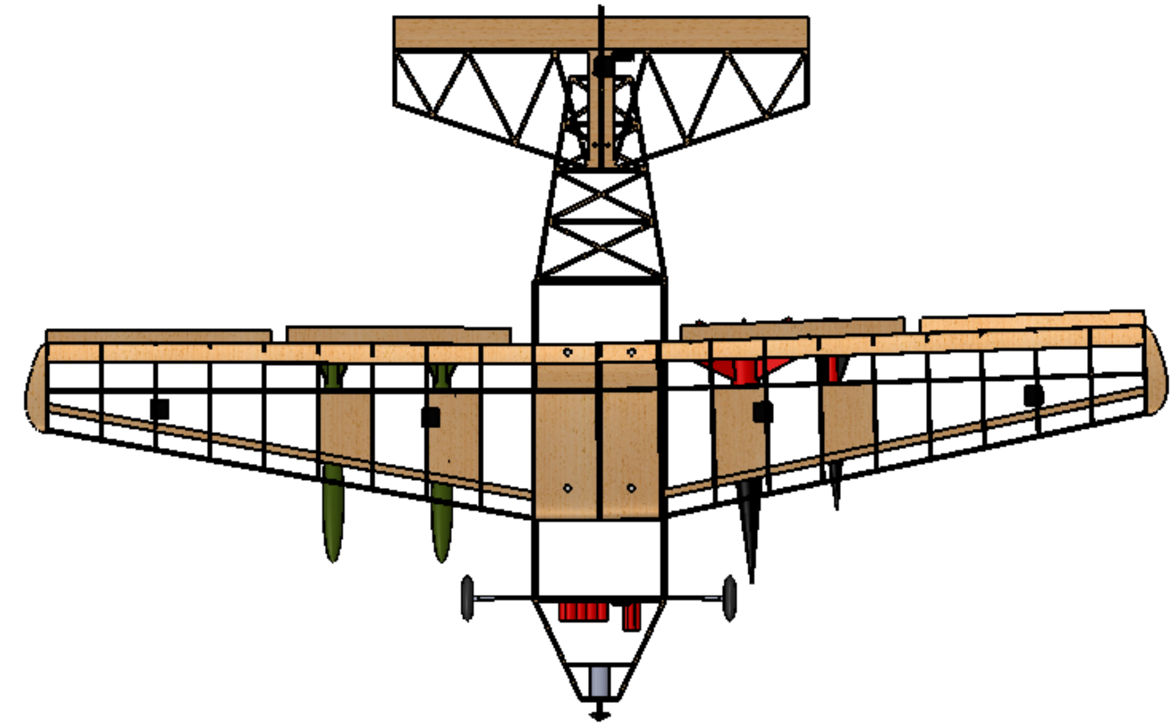

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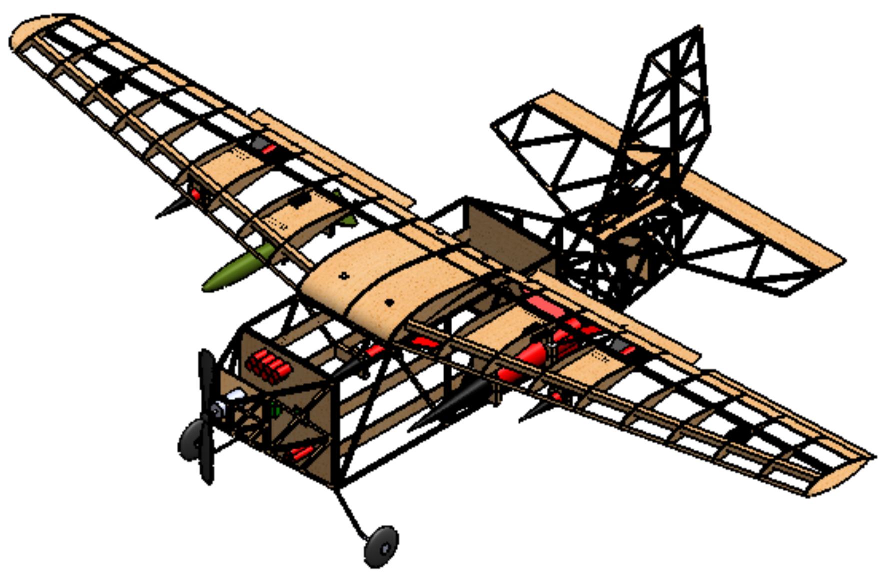

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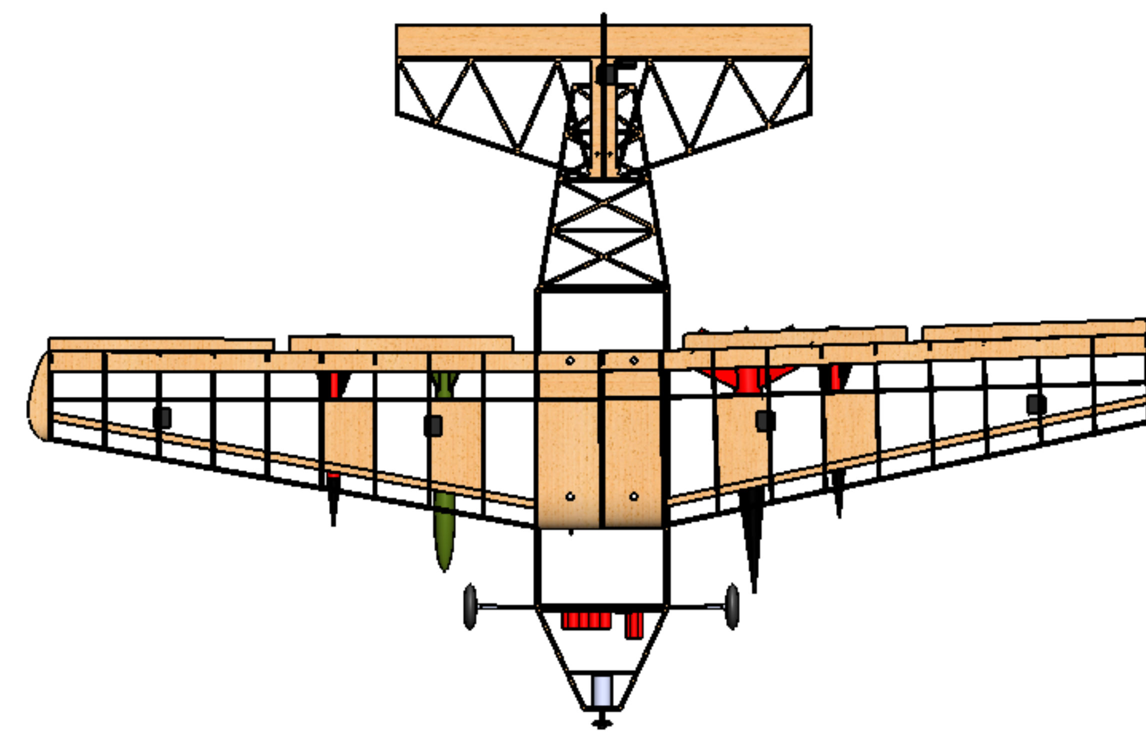

MISSION 3 - ROLL 6

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DRAWN	S. JACOBSON	2/18/13			
APPROVED	M. ANDERSON	2/22/13			
COMMENTS: ALL UNITS ARE GIVEN IN INCHES UNLESS OTHERWISE SPECIFIED			SIZE B	REPORT SECTION: DRAWING PACKAGE	REV A
			SCALE: 1:12		SHEET 7 OF 7

6.0 Manufacturing Plan and Processes

6.1 Selection Methodology

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

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

Metric	4	8	12	16	20	24	28	32	36
Weight									36
Ease of Fabrication					20				
Ease of Repair							28		
Cost	4								
Strength			12						

Figure 6.1: Figures of Merit for Manufacturing

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

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

- **Balsa:** A frame is constructed of balsa wood beams and then covered in a skin of balsa wood. The whole body is then covered using Mylar.
- **Lost Foam Core:** A block of foam is cut out in the shape of the fuselage. Then the center is removed to create room for the payload and electronic systems.
- **Mold:** A foam model is created and then covered in gypsum. This allows the Team to create a mold from which a fiberglass shell can be made.

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

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

Figure 6.2: 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.
- **Lost Foam Core:** A block of foam is cut out in the shape of the wing and tail.
- **Mold:** A foam model is created and then covered in gypsum. This allows the Team to create a mold from which a fiberglass wing and tail can be made.

Using the decision matrix below, balsa was selected because it was lightweight and easy to repair.

FOM	Weight	Balsa	Lost 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**

Figure 6.3: Wing Fabrication Decision Matrix

6.2.3 The Landing Gear

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

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

6.2.4 Store Mounts

After deciding on the collar design described in Section 5.3, the Team considered possible materials and fabrication techniques. Given the large number of collars needed, the Team focused on the need for a lightweight material and the need to automate the process to reduce fabrication time. For the material, the Team considered both plastic and balsa wood. For the fabrication method, the Team considered hand cutting, laser cutting, and molding. The Team decided that, in terms of weight and strength, the plastic and balsa were equally good choices, and therefore the fabrication technique should drive the material selection. Due to the relative thinness of the collars (.375 in), the Team decided to use the university's laser-cutter for producing the uniform shape needed to properly secure the rockets. This made balsa the material of choice, since the laser cutter cannot cut plastic. To cut the vertical clearance holes for the nylon bolts, the Team used a drill press, which allowed for long, straight holes.

6.3 Manufacturing Plan

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

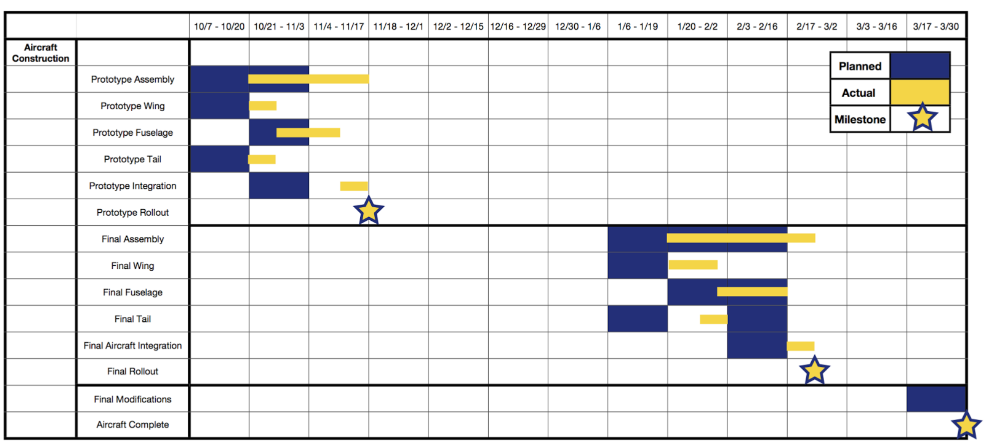

Figure 6.4: Manufacturing Schedule

7.0 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.

7.1.1 Components

Structures

In order to verify the structural integrity of the aircraft, the Team performed a number of tests on structural elements, namely the wing and the fuselage. To test the stresses and structural integrity of the wing, weights were placed along the wing in order to simulate maximum wing loading. In order to test the integrity of the fuselage, it was loaded with its maximum payload and rotated. This test allowed the team to verify that the payload would remain in the fuselage even if the aircraft were to become destabilized in flight.

Aerodynamics

The aerodynamics of the aircraft were tested and optimized with a combination of computer modeling and 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. In order to prevent this failure, the landing gear was subjected to drop tests to insure that it would support the weight of a fully loaded aircraft during a less than ideal landing.

7.1.2 Propulsion Testing

Battery Testing

The batteries were tested both individually to certify that they charged and discharged as expected, as well as in an assembled pack to verify that the battery pack produced enough power for the motor. 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 ensured 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, ensuring that the batteries had enough capacity to complete the missions and that the fuse wouldn't fail at peak loading.

7.1.3 Payload Testing

Internal Store Mounts

Before the internal mounting structures were attached to the aircraft, they were subjected to various stress and strain tests to ensure they were able to handle the weight of the internal stores. When the aircraft was built, the internal stores for Mission 2 were placed within the aircraft and subjected to rotational moments to insure that the mounting structures tightly secured the internal stores. Also, a check of the center of gravity was performed to certify that the aircraft would remain stable during flight.

External Store Mounts

Like the internal mounting structures, the external mounting structures were tested to determine whether they could handle the weight of the various external stores before attaching them to the aircraft. Stress and strain tests were used to check the strength of the external mounting structures. The team tested each possible payload configuration and ensured the stability of the aircraft. Each configuration underwent a center of gravity check to verify the stability of the aircraft while in flight. Furthermore, the external mounting structures were tested by administering the aircraft through multiple rotational moments to check the security of the external and internal stores for the different configurations.

7.1.4 Flight Testing

After completing tests on the subsystems of the aircraft and verifying their performance, the Team felt comfortable moving ahead with flight testing. The goal of flight testing was to certify the capabilities and performance of the aircraft as a whole. 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.

During flight testing, the Team used a flight recorder to measure a number of values that would help gauge performance, including speed, g-forces, altitude, power draw and GPS location. Additionally, the Team's pilot reported on the stability and handling of the aircraft while in flight.

7.2 Master Test Schedule

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

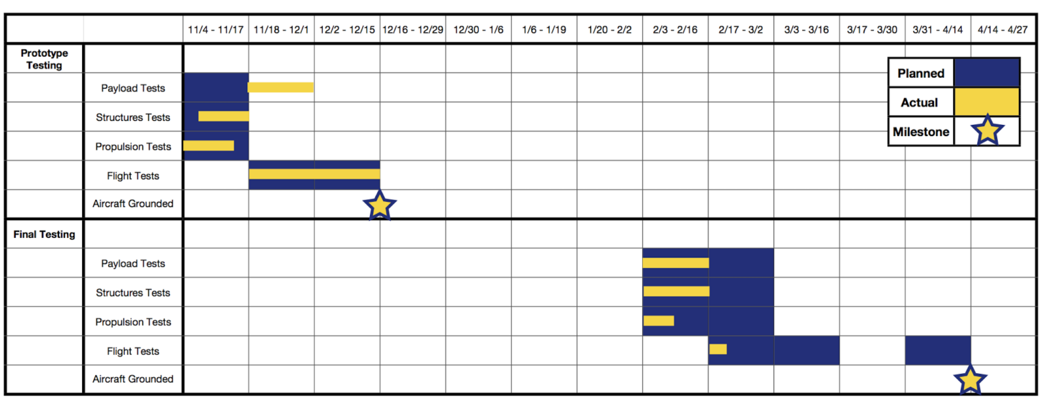

Figure 7.1: Master Test Schedule

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.

Flight Number	Flight Designation	Payload	Description
1	MF	None	First test flight. Test flight worthiness and basic maneuvers.
2	ST	None	Short takeoff tests. Done unloaded
3	M1	None	Full speed on flight course. Used to verify speed performance
4	M2	Internal Stores	Test takeoff distance, endurance of aircraft when loaded for Mission 2.
5	M3-1	Dice Roll 1	Test takeoff distance, endurance and stability for Mission 3, configuration 1.
6	M3-2	Dice Roll 2	Test takeoff distance, endurance and stability for Mission 3, configuration 2.
7	M3-3	Dice Roll 3	Test takeoff distance, endurance and stability for Mission 3, configuration 3.
8	M3-4	Dice Roll 4	Test takeoff distance, endurance and stability for Mission 3, configuration 4.
9	M3-5	Dice Roll 5	Test takeoff distance, endurance and stability for Mission 3, configuration 5.
10	M3-6	Dice Roll 6	Test takeoff distance, endurance and stability for Mission 3, configuration 6.

Figure 7.2: Flight Test Manifest

7.4 Flight Testing Checklists

Insuring the aircraft is ready to fly immediately before takeoff increases the Team's chances of repeated success. In order to prevent unintended damage to components or structures while testing, the Team performed the tasks below prior to each test flight.

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

Figure 7.3: Pre-Flight Checklist

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

Figure 7.4: Final Checklis

8.0 Performance Results

8.1 Component and Subsystem Performance

8.1.1 Propulsion

Batteries

The Team did a number of real world tests to 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 4 minutes and 37 seconds, which is sufficient to complete any of the missions.

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

Motor Thrust

The Team used a motor test stand to measure the force generated by the motor. The Team expected that the motor would produce 1.5 lbf of thrust based on MotoCalc. According to the force meter mounted on the test stand, the motor produced 3.2 lbf of thrust. This verified the expected thrust values and insured that the aircraft had enough thrust to overcome the expected drag of 0.625 lbf. In addition, airspeed, which was measured using an anemometer, reached 30 mph compared to an airspeed of 24 mph based on MotoCalc. A picture of the motor mounted on the test stand can be seen in Figure 8.1.

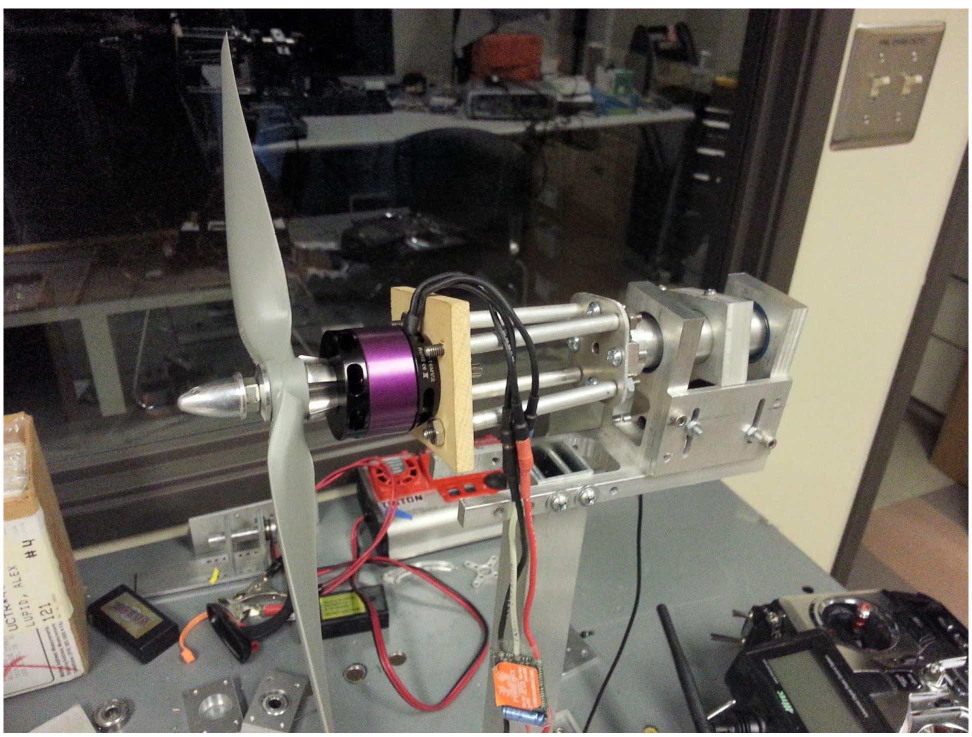

Figure 8.1: Motor on Test Stand

8.1.2 Structures

Fuselage

After completing construction of the fuselage, the Team tested the torsional stiffness of the fuselage. In particular, the Team was interested in studying how the fuselage transferred shear stresses between the different segments, since the nose, payload bay, and tail were built separately and joined. To test this shear stress performance, the Team fixed the nose and then rotated the tail counterclockwise. The fuselage proved to be very stiff, with very little rotation.

Next, the Team tested the center of gravity of the fuselage. The design predicted the CG 5 inches forward of the middle of the payload bay, which is over the predicted CG of the completed aircraft. In reality, the CG was located in the center of the fuselage, which the Team hopes will prevent a nose-heavy aircraft. A picture of the fuselage CG test can be seen below in Figure 8.2.

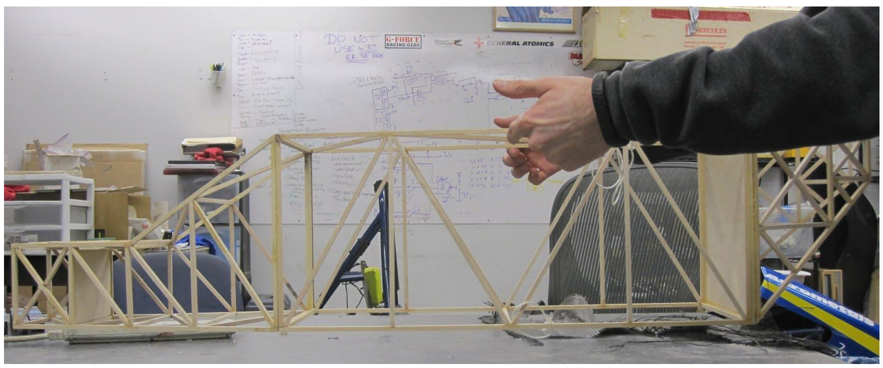

Figure 8.2: Fuselage CG Test

Wing

During the construction of the wing, the Team tested the left wing's bending stiffness to verify that the structure was as stiff as expected. The wing was shown to be very stiff, and the Team continued with the fabrication process. The wing bend test can be seen below in Figure 8.3.

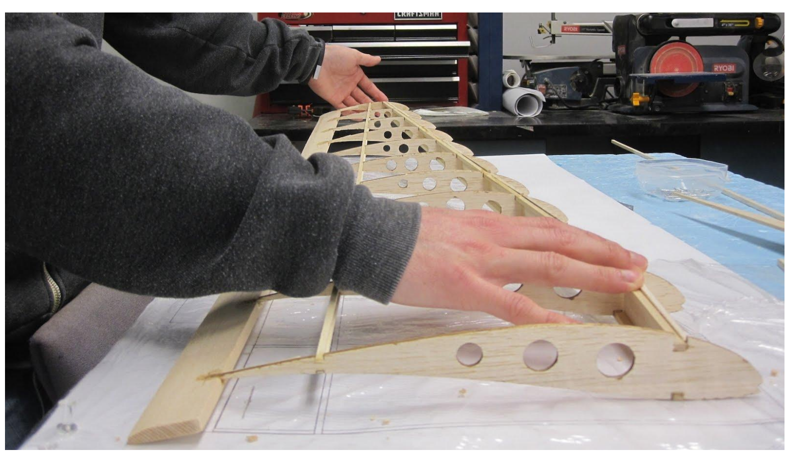

Figure 8.3: Wing Bending Test

Landing Gear

When testing the landing gear, the Team wanted to insure that the gear would support the aircraft, even in the event of a hard landing. Two tests were completed. For the first one, the Team dropped the fuselage from different heights, starting at 2 inches and working up to 18 inches. This simulated a hard, vertical landing. The landing gear performed well during these tests, with no failure. In the second test, the Team wanted to test the deflection of the landing gear. This was done to make sure that the aircraft could not “bottom out” when landing with a heavy load. As can be seen in the figure below, the maximum deflection was 3 inches on either side, and did not cause the gear to fail.

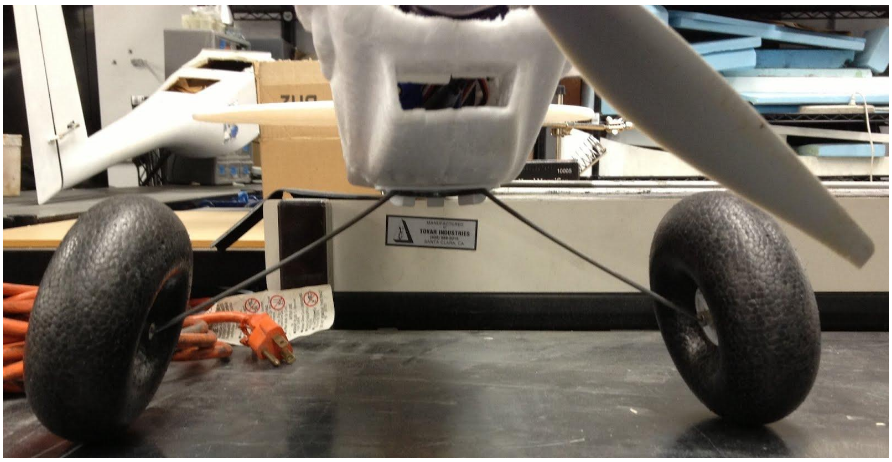

Figure 8.4: Landing Gear Deflection Test

Tail - Fuselage Attachment

Given the importance of the tail to stability, the Team wanted to insure that it was strongly attached to the fuselage. After constructing the tail and fuselage separately, they were mated using nylon wing bolts. The fuselage - tail assembly was then put in tension to verify the strength of the attachment. The tail did well, staying firmly attached up to a 10 lbf load. The tail - fuselage mate can be seen below in Figure 8.5.

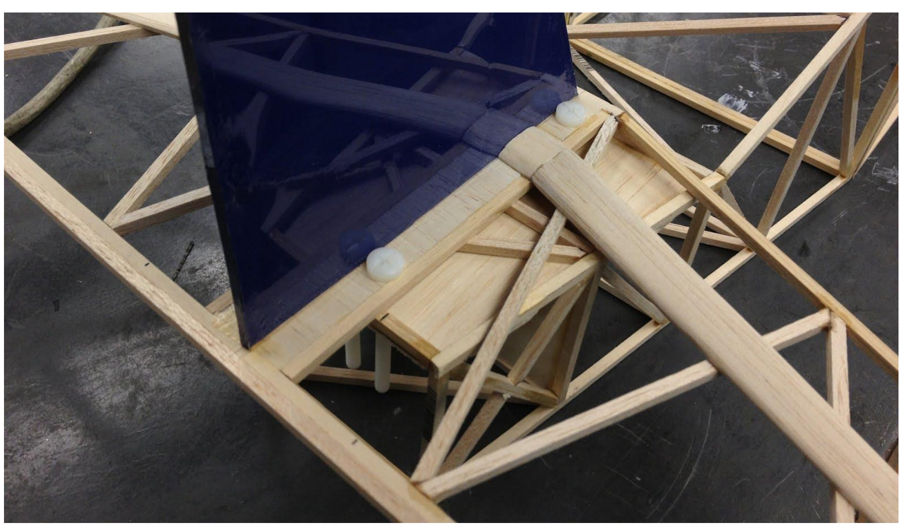

Figure 8.5: Tail - Fuselage Attachment

8.1.3 Payload

Internal Stores

The internal store stability was tested in two different ways. First, the internal stores were mated to their collar mounts to insure solid connection. Next, the collars were mated the inside of the fuselage, and the rockets were attached to the collars. The fuselage was then tipped, rotated and shaken to insure that the payload would not detach during a rough flight.

External Stores

Similar to the internal stores, the external stores were first tested with their respective collar mounts to insure a good tight fit. Once the collar fit was verified, the Team then simulated flight conditions by vibrating and bending the collars to insure their strength and stability.

8.2 Complete Aircraft Performance

Before completion of the final aircraft, the Team constructed a prototype aircraft to test basic capabilities and prepare the pilot for the competition aircraft. To save construction time, the Team purchased a commercially available kit plane, and then modified it so that its performance mirrored the expected performance of the competition aircraft. These modifications included ballasting it to the correct empty weight, using the designed motor and battery combination and resizing the tail and control surfaces. The following flight performance data comes from this prototype, and will be used fine tune the final design.

8.2.1 Flight Testing

Takeoff Distance

The Team conducted a number of unloaded takeoff attempts to generate a data set of takeoff distance data. Across the set, the average takeoff distance was 26.5ft. This verified that the design was capable of taking off within the 30 foot requirement.

Mission 1 Results

The aircraft completed a number of Mission 1 laps, giving the Team a good set of flight data for the aircraft. From this data, the Team was able to measure climb rate, turn rate, maximum speed, time to complete 1 lap, and battery pack endurance. The flight performance data can be seen in Figure 8.6, and a plot of speed and altitude can be seen in Figure 8.7. Additionally, the Team created a diagram of the flight test path, which can be seen in Figure 8.8. Finally, the prototype in flight can be seen in Figure 8.9.

Climb Rate	Turn Rate	Top Speed	1 Lap Time	Battery Pack Endurance
8 ft/s	73 deg/s	42 MPH	50 sec.	4:32 (min:sec)

Figure 8.6: Flight Performance Data

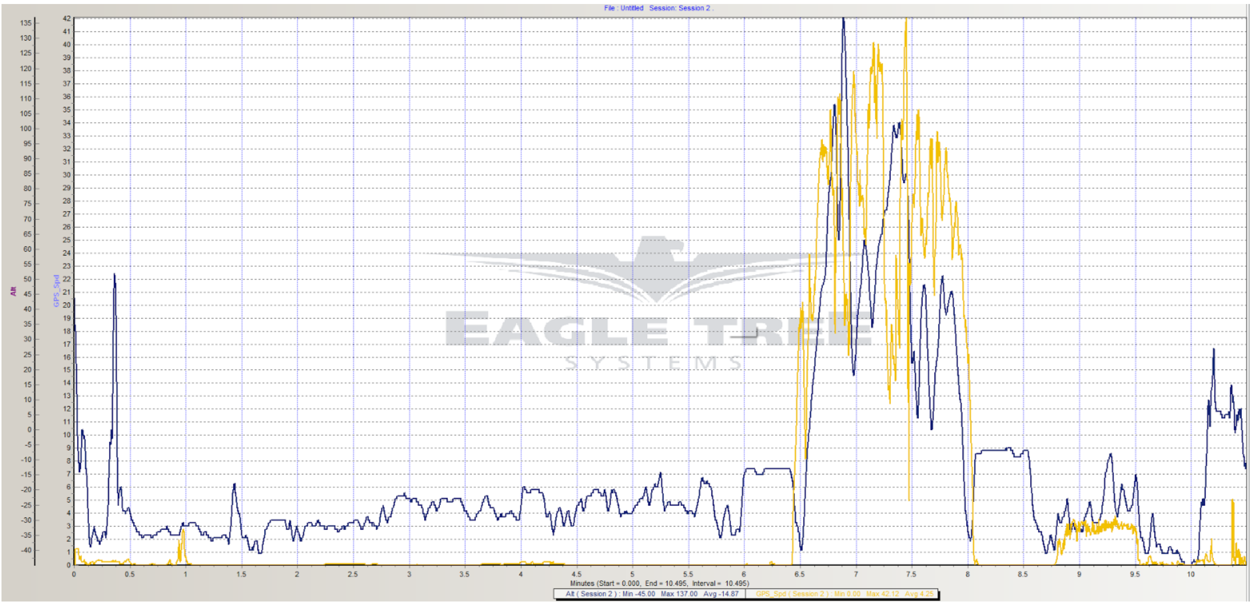

Figure 8.7: Plot of Speed and Altitude vs Time for Test Flight

Figure 8.8: Aircraft Flight Test Path

Figure 8.9: Prototype in Flight

Pilot-Rated Performance

After completing some test flights, the Team consulted with the pilot for his thoughts on the aircraft's performance and ease-of-flight. The pilot noted that the aircraft's pitching was very sensitive and that the ground control was lacking. However, the pilot was pleased with the stability during gusts and the durability during rough landings. Overall, the pilot felt that the aircraft flew very well.

8.2.2 Future Work

After completing this round of flight testing, the Team identified a few areas of improvement. Firstly, the Team wanted to further optimize the elevator controls so that the aircraft had a smoother pitching motion. Secondly, the Team wanted to increase the size of the tail wheel, in the hopes that this will increase the ground stability and control. The next round of flight tests will be done with the competition aircraft, and will focus on testing Missions 2 and 3.