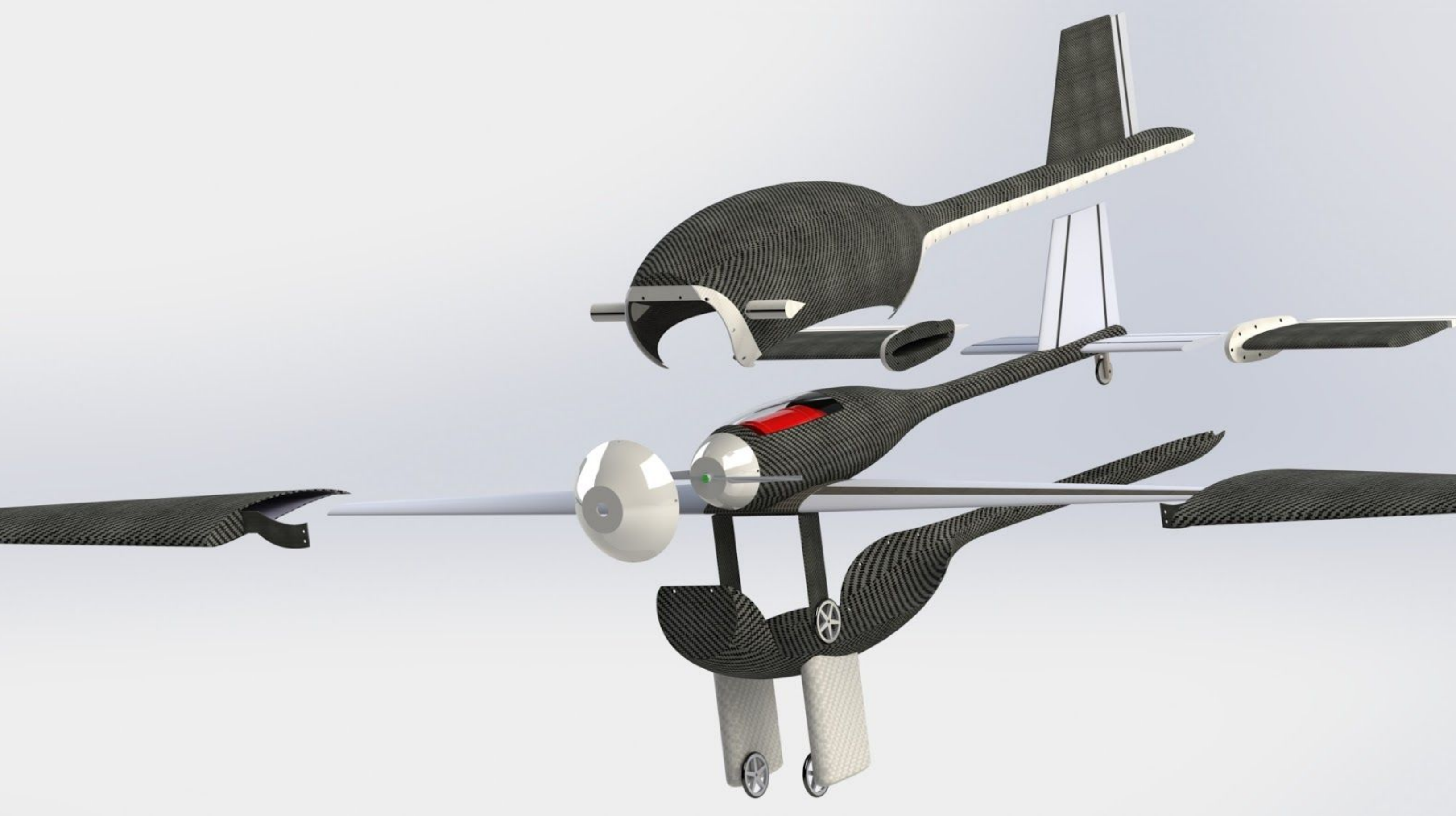
# University of California, San Diego

**Team TLAR**



**UCSD AIAA Student Chapter**

AIAA Design, Build, Fly 2016

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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 2015-2016 competition aircraft. The Team designed the two aircraft to successfully complete three flight missions and one ground mission. The three flight missions consist of one unloaded flight of the Manufacturing Support Aircraft, one loaded flight of the Production Aircraft, and one loaded flight of the Manufacturing Support Aircraft. Aside from successfully completing the missions, the Team's goal was to design a performance conscious Production Aircraft which consists of a single subassembly.

### 1.1 Design Process

The main objective of the Team is to win the competition. To achieve this goal, the Team started with a preliminary design process that would result in two fast, lightweight aircraft to maximize the flight score. By identifying and weighing critical metrics and criteria the Team was able to create the best possible final design from a list of possible conceptual designs. During the preliminary design phase the Team also compared and chose an appropriate battery, propeller, and motor configuration to best accommodate both the selected design and the competition requirements. The Team performed lift, drag, and weight analysis as well as trade studies to determine the optimal configuration for both aircraft. The final design consists of two conventional aircraft which are both fast and light. The Production Aircraft (PA) consists of only one sub assembly. The hollow Manufacturing Support Aircraft (MSA) separates along the transverse plane to accommodate the PA to be placed inside of it.

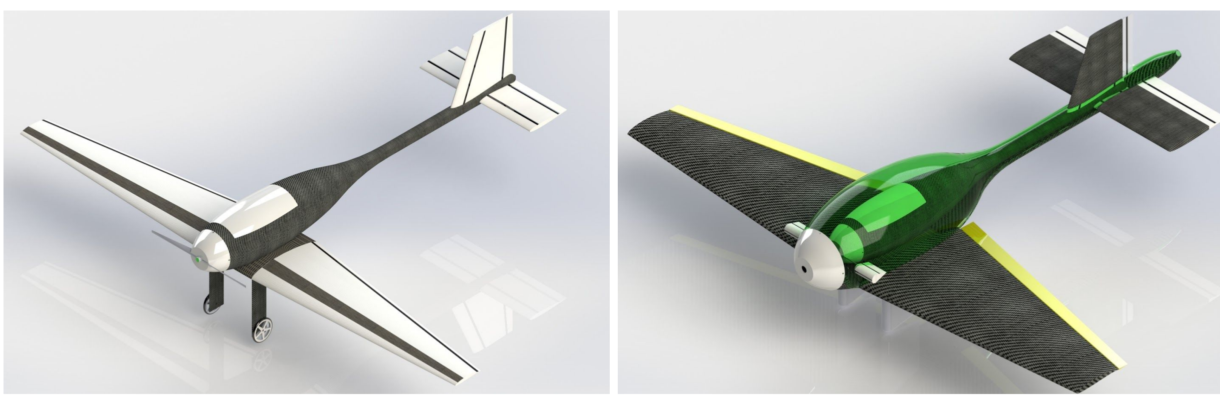


**Figure 1.1 Loaded PSA and MSA**

The Team believes that this is the best possible design because our analysis and trade studies indicate that having only one sub assembly, with both planes being as light as possible, will produce the highest score.

### 1.2 Key Mission Requirements

The challenge presented to the Team for the 2015-2016 DBF competition consists of three flight missions and one bonus ground mission. Mission 1 is an unloaded flight of the MSA where a passing score is awarded if the three laps are completed within five minutes. Mission 2 is a flight of the MSA with a payload, in which the score is determined by whether or not the MSA can carry all sub assemblies of the PA around the course once. Mission 3 is a flight of the PA with a payload, in which the score is a pass if three laps are completed within five minutes. From these mission descriptions, the Team identified three important design elements that should be optimized to improve the final score of the aircraft.

- Empty Weight: Since the mission scores are either pass, fail, or partially pass, without any variation in score based on finishing times before the pass requirement, the final score will depend heavily upon the RAC of the aircraft. For this reason the Team chose materials and designed the aircraft to be as light as possible while still capable of completing all three flight missions.
- Number of Sub Assemblies: The second biggest factor in the RAC after weight is the number of sub-assemblies that the PA must be separated into before transport. This drove the Team's decision of make keeping the number of sub-assemblies low a top priority. The final Production Aircraft design is capable of being carried by the MSA in one sub-assembly.
- Speed: Although there is no flight mission that has a score that varies with time this year, the planes must be capable of completing the flight course within a certain time window in order to successfully gain a passing score on the flight missions. For this reason it is important that the aircraft go at least fast enough to make the required number of laps in the required time limit. The Team kept these requirements in mind when choosing propulsion systems and designing the aerodynamic properties of the planes, in order to ensure the resulting aircraft would be fast enough.

**1.3 Final Capabilities**

The final mission capabilities of the aircraft from flight data are reported below:

- PA
  - Takes off with the payload in 80 feet
  - Completes 1 lap with the payload in 61 seconds with a top speed of 49.6 ft/s
  - Fits into MSA in 1 sub assembly
- MSA
  - Takes off in 75 feet without payload and 90 feet with payload.
  - Completes unloaded lap in 72 seconds with top speed of 54.8 ft/s
  - Completes loaded lap in 84 seconds with top speed of 51.3 ft/s

The remainder of this report details the design requirements and processes the Team used to arrive at the final design. Final aircraft fabrication, flight tests, and final optimizations are ongoing. The Team will use the remaining weeks to finish fabrication of the final aircraft, and to fine tune them for competition.

# 2.0 Management Summaries

## 2.1 Project Management

The Team's structure is designed around the use of sub-teams that have a clear purpose and responsibilities as part of the overall design and construction effort. This structure allows each sub-team to spend a great amount of time and focus on each sub-system, and to introduce new members to the problems and processes involved with each sub-system. The four main sub-teams are shown below in Figure 2.1.1. The Aerodynamics team is responsible for lift and drag analysis and wing sizing. The Structures and Manufacturing team is responsible for the structural design and construction of the fuselage, landing gear, wing structure, and payload containment. The Propulsion team is responsible for battery and motor selection. The Controls team is responsible for stability analysis, and sizing and construction of control surfaces.

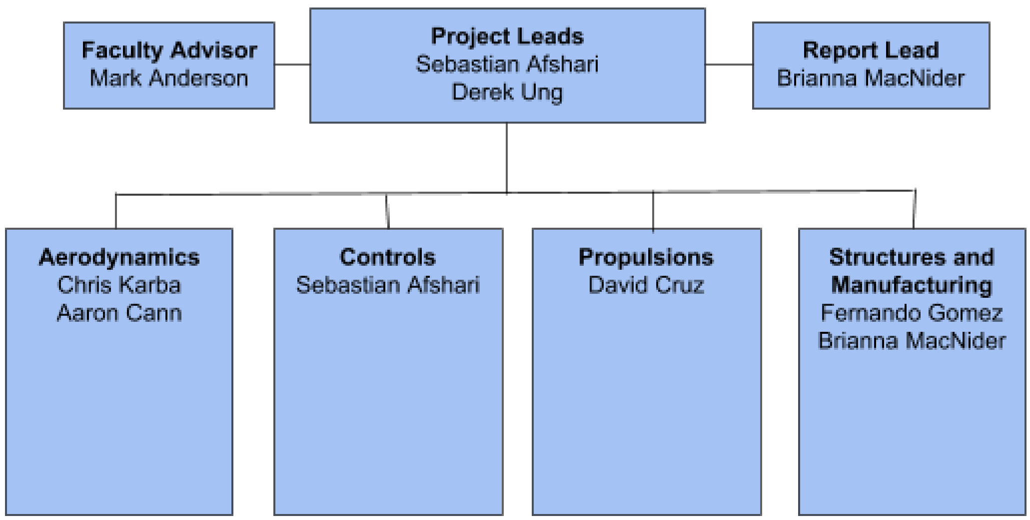



**Figure 2.1**

## 2.2 Milestone Chart

The Team created a milestone table in the form of a Gantt chart in order to determine deadlines for various components of the production and manufacturing plane. The leads of each subgroup were responsible for updating this chart throughout the year. The updated chart was made accessible to all team members, ensuring that each individual had an understanding of the project progress. Figure 2.2.1 illustrates how this Gantt chart, broken into two week intervals, compares the Team's planned deadlines to the actual completion dates.

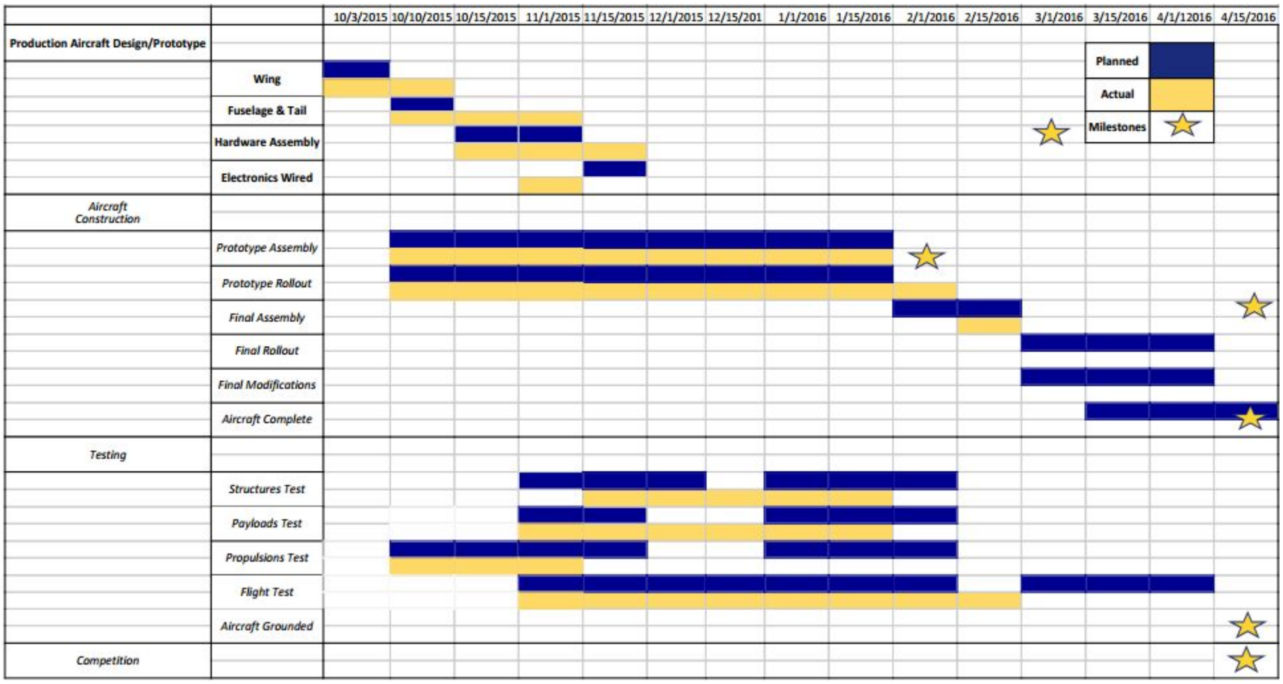



**Figure 2.2 Gantt Chart**

# 3.0 Conceptual Design

### 3.1 Mission Requirements

3.1.1 General Requirements, Limitations, and Concerns

The following are some general requirements for the competition:

- The aircraft must land safely in order to receive a score for each flight.
- The aircraft must take off within 100 feet on each mission.
- There is no stated limit on battery pack weight.
- The aircraft must pass a loaded tip test.

The flight course is another integral 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 both aircraft must take off within a 100 foot runway limit and climb for the first 500 feet of straightaway. At the end of the 500 feet the plane will encounter its first 180 degree turn. After the aircraft completes the first turn it will accelerate and complete a 360 degree turn. After this the aircraft will reach the end of the straightaway and enter its second 180 degree turn. The plane will then accelerate for 500 feet to complete a lap. The aircraft will complete the other remaining laps in the manner described above. After the maximum amount of time or laps has been completed, the aircraft will slow and come to a safe landing, ending the mission. The layout of the flight course is shown below in Figure 3.1.

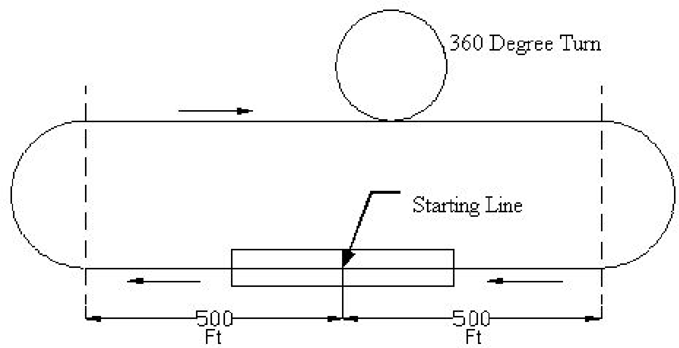



**Figure 3.1 Flight Course Layout**

3.1.2 Ground Crew and Assembly Crew

The ground and assembly crew for the missions shall consist of three people: the pilot, the spotter and the payload loader. Mission 2 will start with the first sub-assembly installed, but after each lap the ground crew must safe the aircraft, uninstall the previous sub-assembly, and install the next sub-assembly if the Team's design consists of more than one sub-assembly.

3.1.3 Mission 1- Manufacturing Support Aircraft Arrival Flight

The arrival flight is distinguished by its lack of a payload. The Manufacturing Support Aircraft (MSA) must take off without a payload and complete three laps within five minutes. The MSA must then perform a successful landing for the score to be reported. It should be noted that the the takeoff runway length is set to 100 feet. Furthermore, the time limit begins at the first advancement of the throttle, regardless of the success of the takeoff. A lap is completed when the plane passes over the starting line in the air.

| MF1 Score | Requirement |
|---|---|
| 2.0 | Aircraft completes the mission |
| 0.1 | Aircraft does not attempt or complete a successful flight |

**Table 3.1 Mission 1 Scoring**

3.1.4 Mission 2- Manufacturing Support Aircraft Delivery Flight

The delivery flight requires the MSA to transport the sub-assemblies of the Production Aircraft (PA). The mission will begin with the first sub-assembly loaded in the MSA. The MSA must take off, complete a single lap, and land successfully in order to complete a delivery. Following the landing, the pilot must taxi the MSA to the ground crew who will disengage the propulsion system, remove the first sub-assembly, insert the second sub-assembly, and engage the propulsion system. At this point the pilot will taxi back to the starting line and prepare for take off. The crew is allowed to fly as many delivery laps as necessary to transport all PA sub-assemblies to the ground crew, however these laps must be flown within a ten minute period. It should be noted that the takeoff runway length remains at 100 feet. Furthermore, the battery pack of the PA is not considered to be a sub-assembly and therefore does not need to be transported. The mission time will end as the MSA passes the starting line in the air during the final sub-assembly delivery, however the MSA must still land successfully in order for the mission score to be recorded.

| MF2 Score | Requirement |
|---|---|
| 4.0 | Aircraft completes all sub-assembly group transport flights successfully within the time window |
| 1.0 | Aircraft completes less than all the sub-assembly flights within the designated time allowance but at least 1 group is successfully transported |
| 0.1 | Aircraft does not attempt or complete a successful flight |

**Table 3.2 Mission 2 Scoring**

3.1.5 Mission 3- Production Aircraft Flight

Mission 3 requires the PA to be flown with a payload while fully assembled. The PA must take off within the 100 foot runway length and fly three laps within five minutes while carrying an unopened 32 ounce Gatorade bottle. Consistent with the two previous missions, the time will start at the first advancement of the throttle and the plane must land successfully in order for the score to be recorded. Again, a lap is completed once the PA passes over the starting line in the air.

| PF Score | Requirement |
|---|---|
| 2.0 | Aircraft completes the required flight within the time period carrying the full payload |
| 1.0 | Aircraft completes less than the required laps or exceeds the time period |
| 0.1 | Aircraft does not attempt or complete a successful flight |

**Table 3.3 Mission 3 Scoring**

3.1.6 Bonus Ground Mission

The Team is eligible to compete in a bonus mission upon completion of Mission 2. The Team will bring the PA to a designated area. The PA will then be disassembled into the same sub-assemblies used for transport in Mission 2. The ground crew must assemble the PA and insert the 32 ounce Gatorade payload in under two minutes in order to obtain a score for the bonus mission. Furthermore, the PA must pass a wing tip test and controls check after assembly is complete to remain qualified.

| Bonus Score | Requirement |
|---|---|
| 2.0 | Aircraft assembled in specified time and passes wing tip lift test |
| 0.0 | Any other result |

**Table 3.4 Bonus Mission Scoring**

3.1.7 RAC

The variables that determine the Rated Aircraft Cost (RAC) are the empty weights of the MSA and PA, the battery weights of the MSA and PA, and the number of sub-assemblies of the PA. These variables are set up in the following equation to create the RAC.

$$RAC = (EW1) \times (Wt\_Battery1) \times (N\_Components) + (EW2) \times (Wt\_Battery2)$$

**3.2 Score Sensitivity Analysis**

The Team wished to analyze the possible scoring outcomes in order to determine the optimal number of sub-assemblies in relation to the weight of the aircraft. While a lower number of sub-assemblies is better for the RAC, increasing the number of sub-assemblies could allow the Team to design an MSA that is lighter, as it would be required to carry less payload weight and bulk. The following analysis was conducted to determine if such a weight savings would be worth the increase in the RAC from having more sub-assemblies.

For the purpose of this analysis, it is assumed that the two aircraft are capable of completing all of the missions in the required time window, and that all parameters other than Empty Weight 2 and Number of Sub-assemblies are ideal. Using predicted aircraft weights, the scoring equations, and varying the MSA weight potentially saved by each added sub assembly, the graphs shown in Figure 3.2 were produced.

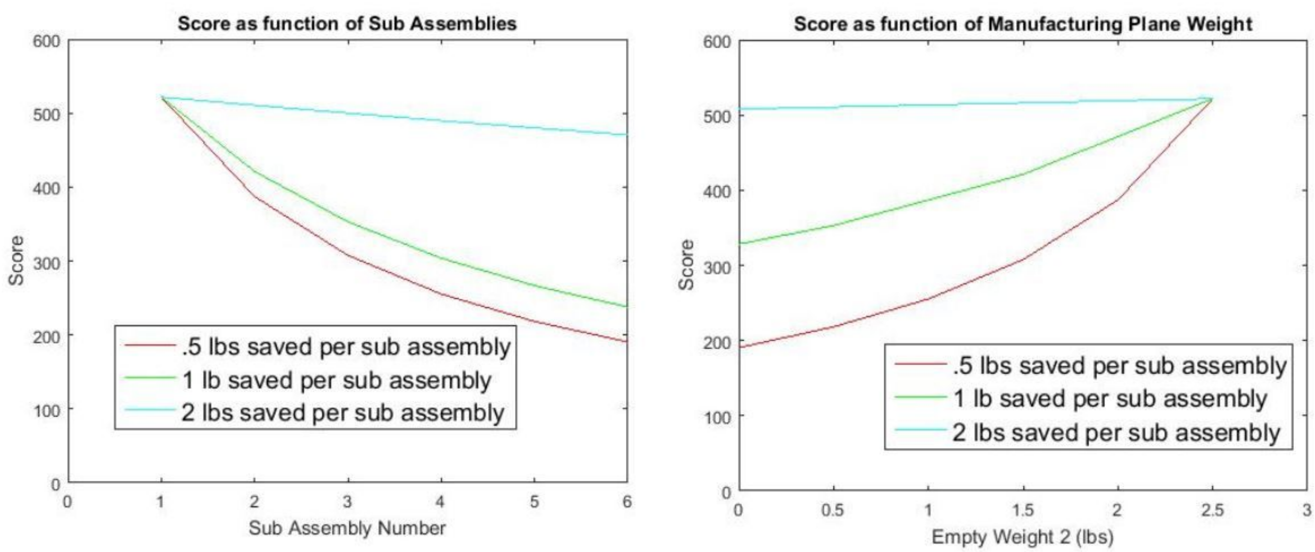



**Figure 3.2: Weight and Sub-Assembly Score Analysis**

The above figure demonstrates that a heavier MSA and fewer sub assemblies is more beneficial to the overall score. Unless adding more sub assemblies saves 2 lbs or more per sub-assembly on the projected MSA weight, one sub assembly will provide a better score than multiple sub assemblies. The Team does not feel that it can reasonably achieve a weight savings of 2 lbs per sub assembly, so the Team's design will use only one.

3.2.1 Propulsion Optimization Analysis

Mission duration and distance act as necessary requirements that must be met when choosing a battery and motor for each plane. Overall RAC will help narrow the selection as weight will be the parameter to minimize. Estimations from manufacturing using history and testing of materials yield a baseline upon which to start sizing motors. An appropriate wattage is calculated based off weight and gravitational and take-off energy requirements. These energy requirements are based off of a specified need to reach a height of at least 100 ft within 5 seconds to allow recovery from gusts and winds. The selection of batteries are also kept in mind to ensure operating voltage and current are within the motor's respective margins. Battery selection entails looking at available watt-hours for the NiMH chemistry and attempting to minimize the weight as much as possible based off the required energy. Minimal weight is what drives battery selection due to its strong effect as a multiplier in the RAC calculation, because of this battery weight should be kept at or below 1 pound to not negatively impact the rest of the score.

### 3.3 Translation to Design Requirements

Mission 1: The MSA must be designed to fly under its own weight

Mission 2: The PA should have a minimal number of sub-assemblies. The MSA payload bay should be designed to hold the sub-assemblies securely and efficiently. The MSA must also be able to lift off loaded with the additional weight of the sub-assemblies.

Mission 3: The PA payload bay must be designed to securely hold the 32 oz. Gatorade bottle. The PA must be able to lift off and fly under the 2 lbs. 4 oz. weight of the payload.

Bonus Ground Mission: The PA sub-assemblies should be designed to be easily and quickly assembled into a full aircraft.

### 3.4 Solutions, Configurations, and Results

*Design Process*

The next stage in the conceptual design process required the Team to decide upon the best design for the major components of both aircraft. The aircrafts were divided into five major design elements: the fuselages, the wings, the propulsion systems, the landing gears, and the payload containments. For this process all ideas and configurations were treated as worthy of consideration, and the design requirements were used to narrow down the many possible choices to the optimal selections.

*Figures of Merit (FOM)*

In order to accomplish this, the Team established Figures of Merit based upon the most important design requirements identified above. Each FOM was then weighed on a 100 point scale based upon their importance to the success and final score of the design, with more important metrics given a stronger weight. The metrics were different from decision to decision because each aircraft component has different needs and considerations.

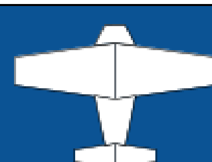
*Selection Weighting System*

The different possible choices for each design element were compared against one another in a Decision Matrix system in order to determine the best possible solution. Each selection was assigned a score of one to five based upon how well that design choice met the design requirement compared to the other possible choices. The scores' corresponding meanings can be seen in the table below.

| | |
|---|---|
| 1 | Poor |
| 2 | Below Average |
| 3 | Average |
| 4 | Above Average |
| 5 | Excellent |

**Table 3.5 Selection Scoring**

3.4.1 Aircraft Configurations

| | Weight |  Flying Wing | |  Conventional | |  Delta Wing | |
|---|---|---|---|---|---|---|---|
| | | **MSA** | **PA** | **MSA** | **PA** | **MSA** | **PA** |
| **Weight** | 30 | 4 | 4 | 3 | 3 | 4 | 4 |
| **Sub-Assembly Number** | 25 | 3 | 5 | 5 | 4 | 3 | 3 |
| **Structural Capability** | 15 | 3 | 3 | 4 | 4 | 3 | 3 |
| **Speed** | 5 | 3 | 3 | 4 | 4 | 3 | 3 |
| **Stability** | 15 | 2 | 1 | 5 | 5 | 3 | 3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Ease of Manufacture** | 10 | 2 | 3 | 3 | 5 | 2 | 3 |
| **Total** | 100 | 655 | | **795** | | 650 | |

**Table 3.6 Aircraft Configuration Decision Matrix**

The main considerations for the configuration of the aircraft were the weight of the aircraft and the ability of the MSA to securely hold the PA in only one sub-assembly. These factors would have the highest impact on the score and the success of the Team's one sub-assembly plan, and were therefore weighted the highest, but factors such as stability and ease of manufacture were important and must also be considered.

While a flying wing configuration for the PA showed promise in the weight of the aircraft and in the PA being long and thin enough to slide into the MSA, the Team ultimately decided that a flying wing small enough to slide into the MSA would be too unstable and difficult to manufacture, and was not a viable design. A conventional configuration would provide enough room for the PA to fit within the MSA by utilizing hollow wings and a hollow tail on the MSA, as well as reliable flight characteristics and ease of manufacturing. The Team also believes that, if manufactured properly, a conventional configuration would not be much heavier than a flying wing or delta wing configuration. For these reasons, the Team chose to make both the PA and MSA configurations conventional aircraft.

3.4.2 Fuselages

| | | Rectangle | | Circle | |
|---|---|---|---|---|---|
| | Weight | MSA | PSA | MSA | PSA |
| **Weight** | 30 | 3 | 3 | 4 | 4 |
| **Sub-Assembly Number** | 25 | 3 | 3 | 3 | 3 |
| **Structural Capability** | 20 | 2 | 2 | 3 | 3 |
| **Speed** | 20 | 2 | 2 | 4 | 4 |
| **Maneuverability** | 5 | 2 | 2 | 3 | 3 |
| **Total** | 100 | 255 | 255 | **350** | **350** |

**Table 3.7 Fuselage Shapes Decision Matrix**

Weight, ease of fitting sub-assemblies inside, general structural and drag properties are the most important factors when considering the shape of the fuselage. A rectangular fuselage would obviously produce a lot of drag, and would have stress concentrations at the corners. An elliptical fuselage may make it difficult to fit sub-assemblies inside depending on the shape of the sub-assemblies, and is overall more complex than a simple circular fuselage. A circular fuselage takes care of the stress concentrations by not having any corners, and produces less drag than a rectangular fuselage would. It also offers an easy space to fit sub-assemblies into for the MSA, and for the PA provides a simple shape to fit within the MSA. For these reasons, the Team determined a circular fuselage shape to be the best choice.

### 3.4.3 Propulsion Systems

The following motors were considered:

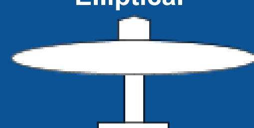
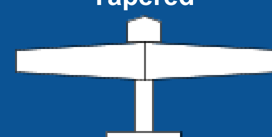
- Single Tractor: Single motor mounted at the front of the fuselage.
- Dual Tractor: Two motors mounted in nacelle housings.
- Single Pusher: Single motor mounted at the rear of the fuselage.

Each propulsion system consideration was scored based on weight, aerodynamic efficiency, and ease of fabrication. A single tractor setup appeared optimal as it is the easiest to manufacture while being of a relatively low weight. A dual tractor was theoretically most ideal due to available clean airflow to the motor; efficiency would take less of a hit. However, fabrication would prove extremely difficult for the MSA due to the hollow wing design. It was also deemed unsuitable for the PA due to size limitations within the MSA.

### 3.4.4 The Wings:

*Shape of the Wing:*

The shape of the wing necessary for best performance was determined by weighing ease of fabrication, aerodynamic efficiency, weight, stability, and sub-assembly packing efficiency. Three wing shapes were considered in the design of this aircraft.

| | Weight | Elliptical  | | Rectangular  | | Tapered  | |
|---|---|---|---|---|---|---|---|
| | | MSA | PSA | MSA | PSA | MSA | PSA |
| Ease of Fabrication | 15 | 3 | 3 | 4 | 4 | 4 | 4 |
| Aerodynamic Efficiency | 25 | 3 | 3 | 2 | 2 | 3 | 3 |
| Weight | 15 | 4 | 4 | 2 | 2 | 3 | 3 |
| Stability | 15 | 3 | 3 | 5 | 5 | 3 | 3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Packing Efficiency** | 30 | NA | 3 | NA | 4 | NA | 4 |
| **Total** | 100 | 225 | 315 | 215 | 335 | **225** | **345** |

**Table 3.8 Wing Shape Decision Matrix**

The most critical factor in the wing shape was the ability to pack the PA wing properly into the hollow MSA wing. A tapered wing was chosen due to its high packing efficiency resulting from the converging geometry. For the MSA, both the elliptical wing and tapered wing received the same score. In order to remain consistent with our manufacturing techniques both the MSA and PSA will use the tapered wing. This wing shape also scores highly on ease of fabrication and has received an average score in the remaining sections. StarCCM verified that the tapered wing has a more favorable coefficient of lift and coefficient of drag ratio when compared to the rectangular wing.

*Wingtips*

Weight, aerodynamic efficiency, ease of fabrication were considered in determining the ideal wingtip.

| | | **Rounded**  | | **Angular**  | | **Hoerner**  | | **Winglet**  | | **None**  | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Weight** | **MSA** | **PSA** | **MSA** | **PSA** | **MSA** | **PSA** | **MSA** | **PSA** | **MSA** | **PSA** |
| **Weight** | 25 | 4 | 4 | 4 | 4 | 3 | 3 | 2 | 2 | 5 | 5 |
| **Aerodynamic Efficiency** | 45 | 3 | 3 | 2 | 2 | 4 | 4 | 4 | 4 | 0 | 0 |
| **Ease of Fabrication** | 30 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 5 | 5 |
| **Total** | 100 | 650 | | 560 | | **690** | | 580 | | 550 | |

**Table 3.9 Wingtip Decision Matrix**

*Wing Location:*

The PA aircraft wing will be placed under the fuselage and directly attached to the landing gear. The main factor taken into account when deciding the location of the wing is the impact this location has on the weight of the rest of the assembly. This low wing configuration decreases the necessary strength of the attachment mechanism, therefore allowing the team to use less material and save weight. Furthermore, this configuration will allow easy access to the payload bay through the top of the fuselage, allowing for the payload to be inserted in a short amount of time. The MSA wing will be placed where required so that the PA wing can fit inside of it when it is loaded.

*Wing Sweep Angle*

The low wing configuration on the aircraft results in a loss of stability. In order to compensate for this lost stability it was decided to add a small sweep angle in the leading edge of the wing. With ease of manufacturing in mind, the Team decided to sweep the leading back 2.90 degrees, such that there is no sweep at the quarter chord.

#### 3.4.5 Landing Gears

For landing gear, the main factor taken into account was weight and maneuverability. Weight has a high impact on the RAC, and the Team has had problems in the past with the landing gear causing the plane to not take off straight, which has impacted the score in previous years. Therefore the landing gear being stable and maneuverable is an important concern in looking at landing gear configurations. A car landing gear configuration would be very heavy, and so was immediately discounted from consideration. Between a tail dragger and tricycle type landing gear, the Team feels that the tail dragger would be slightly more stable and maneuverable, and also easier to fit as a sub-assembly, so the Team decided upon a tail dragger landing gear configuration.

#### 3.4.6 Tails

As there was no limit on servos or controls this year, the Team elected to go with a simple conventional tail configuration. This provides the benefits of being fairly light, making the aircraft very maneuverable, and being a proven design.

### 3.5 Final Conceptual Design

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

- Conventional aircraft configurations
- Circular fuselages
- Single motors/propellers mounted at the nose of the aircraft
- Tapered, swept flat wings with hoerner wingtips
- Tail dragger landing gear configurations
- 1 PA sub-assembly
    - MSA wings and tail hollow
    - PA landing gear extends out of MSA into fairings
    - PA Propeller may also extend into fairings.

These designs were selected because they give the Team the best chance of getting the highest possible score and winning the competition. The PA was roughly predicted to weigh 2 lbs while the MSA was predicted to weigh 3 lbs. The Team estimates that both aircraft should fly fast enough to receive the highest score on all missions.

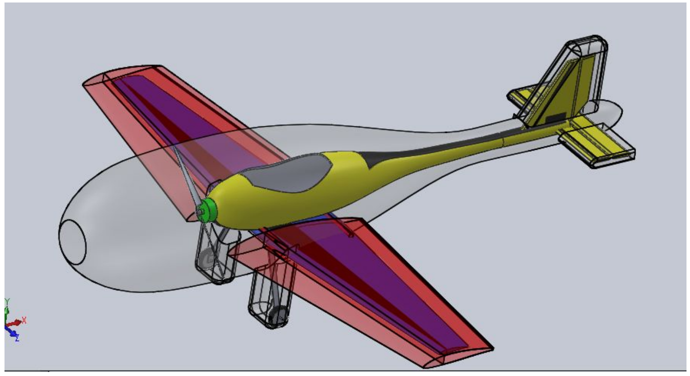


**Figure 3.3: Final Conceptual Design**

# 4.0 Preliminary Design

The preliminary design phase allowed the Team to perform basic analyses in each of the four main sub-teams: structures, aerodynamics, propulsion, and controls. Based upon the results of these analyses, the Team selected components and materials, added detail to the conceptual design ideas, and finalized a more detailed configuration of the aircraft. The Team utilized basic real world tests to back up analyses as needed.

### 4.1 Design and Analysis Methodology

4.1.1 Aerodynamics

There were two important aerodynamic parameters that the Team considered:

*Wing Airfoil Selection*

When selecting the airfoil, the Team focused on airfoils that could provide high lift at low reynolds numbers. The Team also considered using different airfoils at the root and the tip of the wing to improve stall characteristics

*Wing Size*

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

*Aerodynamics Mission Optimization*

The Aerodynamics Team considered different configurations and airfoils for the aircraft with weight, moment, and aerodynamic characteristics in mind. The members of the Aerodynamics Team also took into account the limitations of the flight course and missions, such as the take-off distance of 100 ft and the loaded and unloaded mission time requirements.

### 4.1.2 Propulsion

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

*Battery Selection*

The aircraft batteries must be able to power the plane for 5 minutes, which is the maximum mission time, and be as light as possible. Selection is based off of motor voltage and current requirements necessary to propel the aircraft at the desired specifications. The choice between batteries was ultimately limited to the number of cells and the mAh of the cells, which determines the available voltage and the allowable amount of current draw respectively.

*Motor Selection*

Initial motor selection was centered around wattage per pound of aircraft weight. The initial guideline was set to be 50 watts per pound to supply sufficient power for flight and maneuvering.

### 4.1.3 Structures

*Payload Containment and Deployment Design*

Payload design is driven by the need to fit and secure the PA from mission 2, and the Gatorade bottle from mission 3. The design also needs to be as lightweight as possible and as aerodynamic as possible. The best system, then, would integrate well with the design of the plane, be lightweight, and as aerodynamic as possible.

## 4.2 Design and Sizing Trades

### 4.2.1 Aerodynamic Design and Sizing Trades

*Airfoil:*

One of the keys the airplane's performance is choosing the correct airfoils. Hundreds of airfoils were initially considered for the wings. These were then narrowed down to about 80 airfoils designed for low Reynolds number flight, and were further narrowed down to about 50 airfoils based on thickness and manufacturability.

In order to increase the stiffness of the wings and minimize wingtip deflection, the airfoil must be thick enough to provide ample room for internal structural members. Low thickness airfoils, such as in Figure 4.1 below, does not allow enough room for the structural members needed to provide the wings enough structural rigidity for flight. After structural testing, it was decided that a thickness of at least 10% is needed to allow room for these structural members.

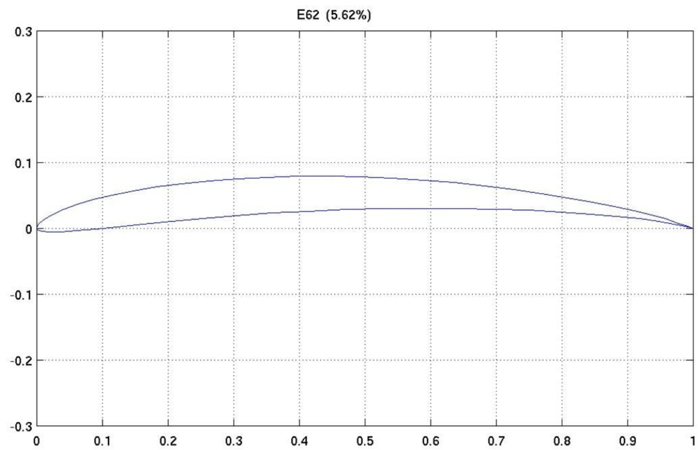



**Figure 4.1 E62 airfoil showing lack of thickness for structural members**

In addition, complex airfoil shapes, such as the one shown in Figure 4.2, can be difficult to manufacture and may result in errors in manufacturing. Geometries such as very sharp leading or trailing edges or excessively high camber may be difficult to fabricate and cause the final wing's airfoil to differ from the intended airfoil shape. These differences may negatively affect the performance of the airfoil and lead to unpredictable aerodynamic characteristics. The airfoil must not have excessive camber or overly thin leading and trailing edges to avoid these imperfections.

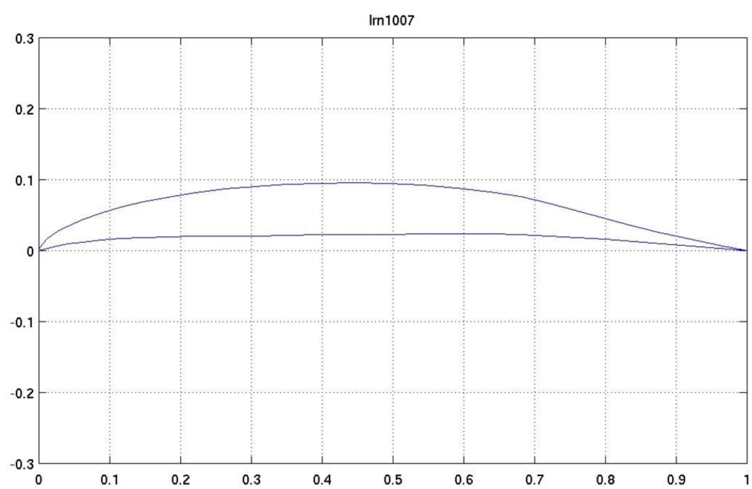



**Fig 4.2 lrn1007 airfoil showing sharp leading and trailing edges**

The remaining airfoils were analyzed at an estimated Reynolds number of 250,000 using XFLR5 airfoil analysis. The team examined the lift, glide ratio, and drag polar to determine the optimal airfoils (one for the root of the wing and one for the tip of the wing). Figures 4.3 to 4.5 below show the results of the XFLR5 analysis comparing the airfoils’ glide ratio, coefficient of lift, and drag polar.

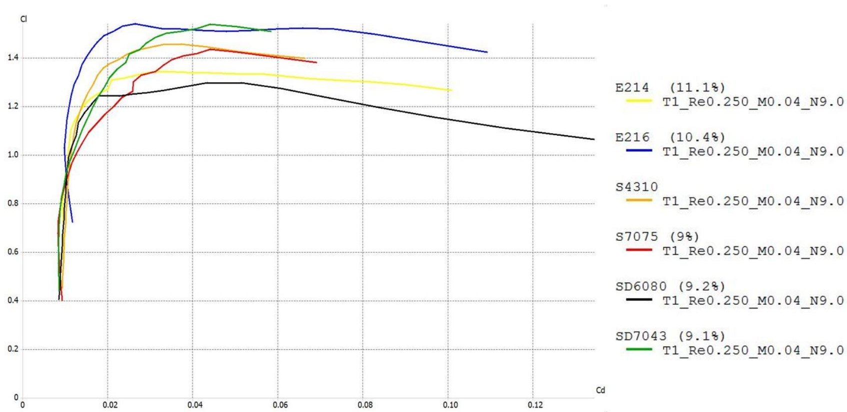



**Figure 4.3 Experimental drag polar for selected airfoils from XFLR5**

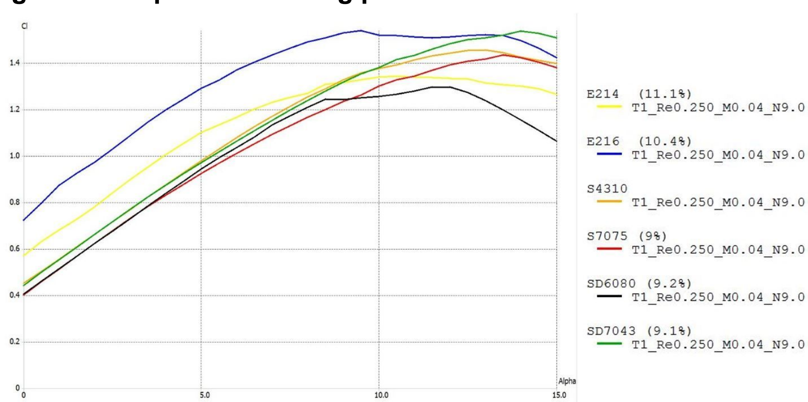



**Figure 4.4 Experimental lift coefficient for selected airfoils from XFLR5**

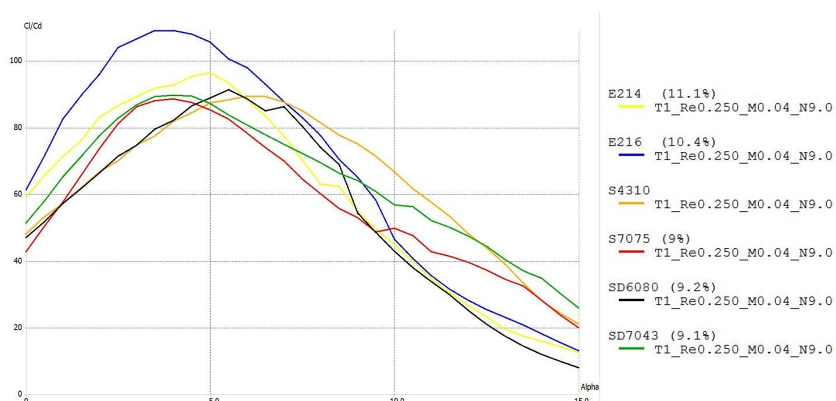



**Figure 4.5 Experimental glide ratio for selected airfoils from XFLR5**

**Root:**

From the analysis, the Team determined that the E216 airfoil has a good coefficient of lift at low speed, which is necessary for a short distance takeoff. Additionally, the E216 airfoil has the highest glide ratio at low angles of attack, making it an efficient airfoil for steady level flight. Further examination of the drag polar shows that the CD stays low and constant over long ranges of CL, which is desirable due to variance in CL caused by downwash and external factors such as wind. Finally, the moderate thicknesses (10.4%) are sufficient for structural stability of the wing, while still remaining thin enough to reduce drag. A cross section of E216 is shown below.

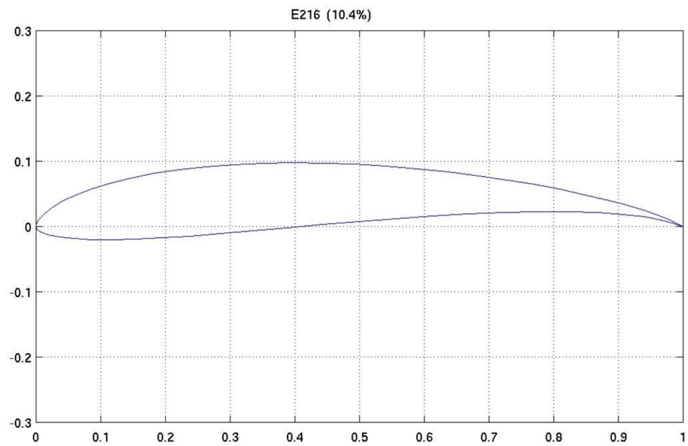



**Figure 4.6 E216 airfoil**

**Tip:**

A consequence of the tapered wing is a tendency to stall at the tips before the root, which would lead to a loss of aileron control near stall angle. To prevent this loss of control, the Team chose to use a different airfoil at the tip to induce aerodynamic twist to the wing. The Team determined that the E214 airfoil had a higher stall angle than E216, and had a similar geometric shape, making the lift characteristics in the middle of the wing more predictable.

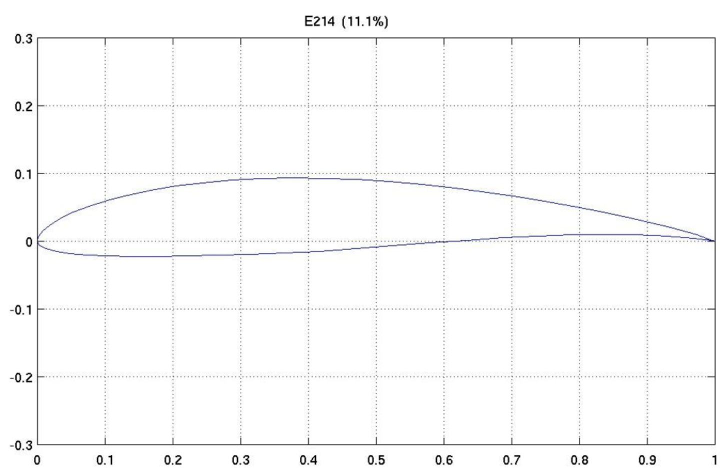



**Figure 4.7 E214 airfoil**

*Initial Wing Sizing:*

The Team sized the wing based off of the predetermined structural and payload weight at takeoff. A factor of safety of F.S. = 1.5 was used during the calculations.

**Production Plane:**

The Team estimated the production plane weight to be 5 lbs.

$$W_{calc} = (F.S.)(W_{estimated}) = (1.1)(5\ lb) = 5.5\ lb = 24.47\ N$$

For initial sizing it was assumed that lift (L) and calculated weight ( $W_{calc}$ ) were directly aligned. A load factor of n=1.5 was used to account for increased loads during takeoff and turning. The resulting vertical force balance for the aircraft was:

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

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

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

The Team set the two lift equations equal to each other, then solved for the needed planform wing area (S):

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

The Team determined that an effective lifting area of $322.4\ in^2$ is needed to take off at 35 mph at the altitude density of Wichita, KS using the chosen airfoils E214 and E216 at an angle of attack of 7 degrees. The Team chose initial sizing dimensions of root chord of 8.25 in (not including inset control surfaces), a tip chord of 3.25 in, and wingspan of 55.3 in.

**Manufacturing Plane:**

Unlike the production plane, the manufacturing plane has two sizing constraints. The first, like the production plane, is a requirement to take off at 35 mph at an estimated weight of 5 lbs. The second is a requirement to house the production plane wing behind the quarter chord. Since the manufacturing plane has the same estimated takeoff speed and weight as the production plane, the second requirement is the constraining condition. The team found that a 14 in root chord, a 5.75 in tip chord, and a 56 in span (not including the width of the fuselage) is required to satisfy this constraint. Figure 4.8 below shows a model of the manufacturing housing the production wing with these dimensions.

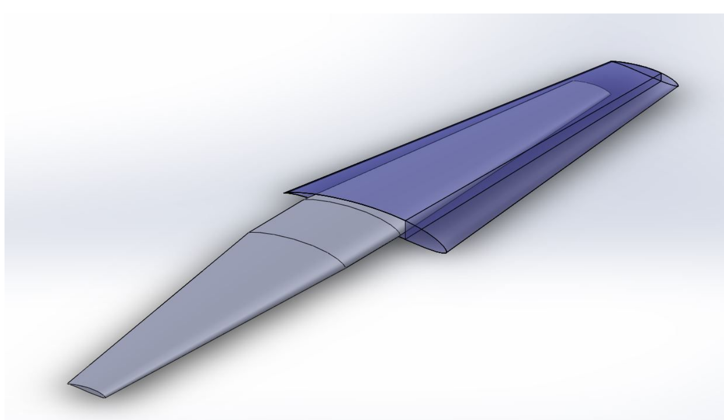


**Figure 4.8 Manufacturing wing housing production wing behind quarter chord**

*Wing Control Surface Sizing*

The ailerons were sized to be 15% of the average wing chord. This sizing is based off of historical remote control airplane design. The ailerons span the length of the wing so that the control arms could be placed near the fuselage; this minimizes drag and simplifies the assembly with the manufacturing plane.

*Final Wing Sizing*

**Production Plane:**

The Team decided to use inset control surfaces, such that the total chord of the wing airfoils includes the chord of the control surfaces. This gives final wing dimensions of:

| Description | Dimension |
|---|---|
| Wing Span | 55.30 in |
| Wing Root Chord | 8.25 in |
| Wing Tip Chord | 3.25 in |
| Wing Area | 333 $in^2$ |
| Aspect Ratio | 9.18 |
| Taper Ratio | 0.39 |
| Aileron Span (For Each Half Wing) | 24.65 in |
| Aileron Root Chord | 1.00 in |
| Aileron Tip Chord | 0.75 in |

**Table 4.1 Final wing sizing for production plane**

Figure 4.9 also shows these dimensions in the model of the wing.

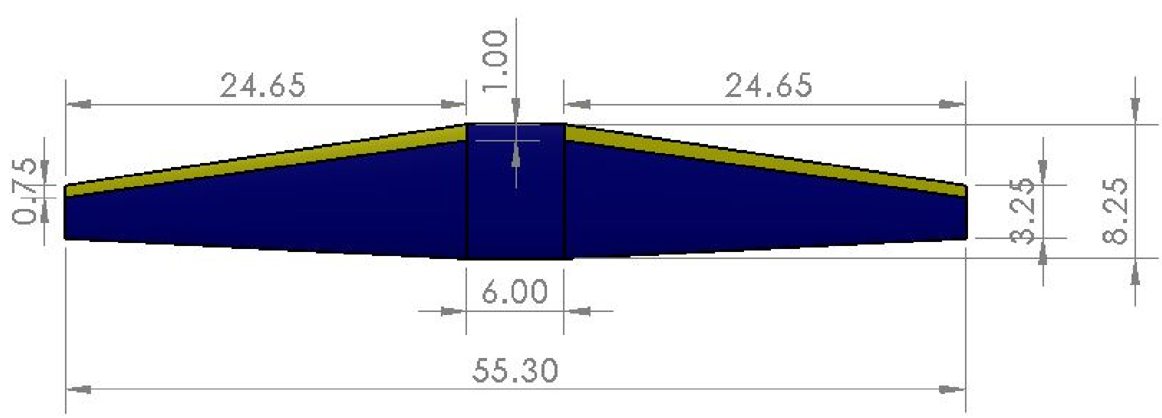



**Figure 4.9 Production Wing Dimensioned Top View**

**Manufacturing Plane:**

For the manufacturing plane, the team decided to use external control surfaces, such that the total chord is the sum of the chord of the wing airfoils and the chord of the control surfaces. This gives final wing dimensions of:

| Description | Dimension |
|---|---|
| Wing Span (Not Including Fuselage) | 56 in |
| Wing Span (Including Fuselage) | 62 in |
| Wing Root Chord (Without Ailerons) | 14 in |
| Wing Tip Chord (Without Ailerons) | 5.75 in |
| Aileron Span (For Each Half Wing) | 28 in |
| Aileron Root Chord | 1.75 in |
| Aileron Tip Chord | 1.25 in |
| Wing Root Chord (With Ailerons) | 15.75 in |
| Wing Tip Chord (With Ailerons) | 7 in |
| Wing Area | 637 $in^2$ |
| Aspect Ratio | 6 |
| Taper Ratio | 0.44 |

**Table 4.2 Final wing sizing for manufacturing plane**

Figure 4.10 also shows these dimensions in the model of the wing.

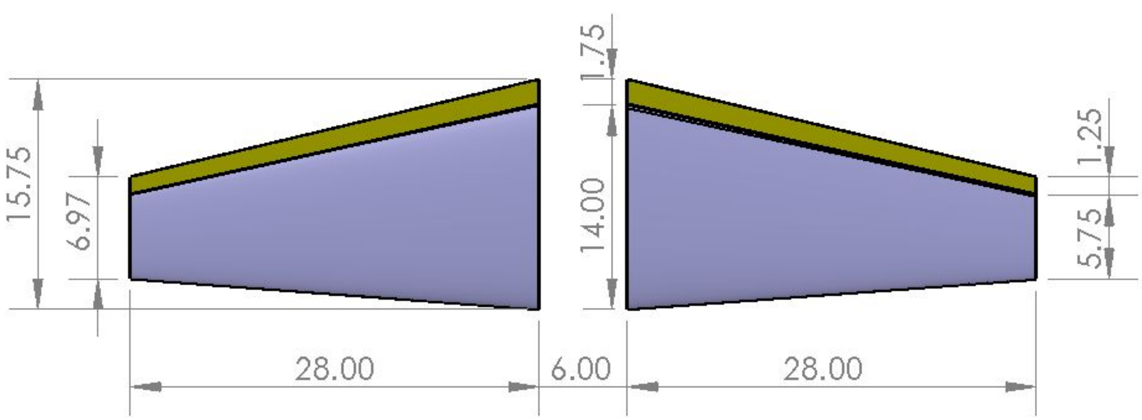



**Figure 4.10 Manufacturing Wing Dimensioned Top View**

4.2.2 Propulsion Design and Sizing Trades

*Battery Selection*

Restriction of the the batteries to NiMH or NiCd points the Team to choose the most energy dense chemistry. Settling on the Elite branded NiMH cells provides 77.3-78.3 Wh/kg (nominal voltage*capacity) as opposed to 48.5 Wh/kg with NiCd. In an attempt to have a score multiplier, a pack weight of 1lb or less is desirable. Energy analysis puts the PA at a 250W requirement and the MSA at 350W. The PA must output 250W for 6 minutes translating to about 0.71lbs of battery weight. MSA is assumed to have a similar lap time in order to comfortably load, taxi, fly, and land. This predicts 0.996 lbs of battery weight for the MSA.

| Battery Description | Capacity [mAh] | Weight [Ounces] | Size [Inches] | Chemistry |
|---|---|---|---|---|
| Elite 1500 2/3A | 1500 | 0.81 | 1.1 x 0.7 x 0.7 | NiMh |
| Elite 2100 4/5A | 2100 | 1.15 | 1.7 x 0.7 x 0.7 | NiMh |
| Tenergy 2200 SC | 2200 | 2.00 | 0.9 x 0.9 x 1.7 | NiCd |

**Table 4.3 Battery Selection**

Based on the two available cell types, the battery packs can be split as follows

| Aircraft | Capacity [mAh] | Cell Count | Weight [Pounds] | Voltage [Volts] | Max Continuous Draw [Amps] |
|---|---|---|---|---|---|
| PA | 1500 | 14 | .71 | 16.8 | 15 |
| PA | 2100 | 10 | .72 | 12.0 | 21 |
| MSA | 1500 | 20 | 1.01 | 24 | 15 |
| MSA | 2100 | 14 | 1.01 | 16.8 | 21 |

**Table 4.4 Battery Splitting**

*Motor Selection*

| Motor | kV | Max Watts (W) | Weight (oz) |
|---|---|---|---|
| Turnigy Multistar 4822 | 390 | 300 | 3.46 |
| Quanum MT 5008 | 335 | 355 | 6.67 |
| Turnigy G10 | 810 | 375 | 4.94 |

**Table 4.5 Motor Selection**

Wattage provides a good indicator of whether a motor is feasible. The motors are chosen based on their compatibility with the battery packs above and matched against a range of props running at approximately 7000 RPM. This number is based off of the propeller manufacturer's data regarding efficiency. Verification of the pitch speed and thrust produced takes place further in the design process.

4.2.3 Structural Design and Sizing Trades

*Fuselage Sizing*

The Team sized the fuselages based upon the dimensions of the payload. The Gatorade bottle that must be carried by the PA has 4 inch diameter, and coupled with the need to fit internal electronic components and still have a stable plane, the Team decided upon a required 5 inches diameter for the PA. The MSA fuselage is required to fit the entire PA fuselage, since the PA will be one sub-assembly, and also a small section of the root of the PA wing where the control horns and servos will be mounted. Based upon these constraints, the Team sized the MSA fuselage to be 8 inches in diameter.

*Internal Structure/Elements*

The Team decided to construct the aircraft out of composite materials this year, as opposed to previous years when flimsier materials such as foam and balsa were used, in order to produce a more reliable and less problem prone aircraft. In order to achieve this, internal structures of both the wing and fuselage were reinforced with carbon fiber tow at strategic points. This allowed the Team to use thinner and lighter fiber for the majority of the structure while retaining the structural ability to bear the required payload and flight loads.

### 4.3 Mission Modeling and Optimization Analysis

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

- Takeoff (Red): The aircraft starts with zero velocity and accelerates down the runway to a takeoff speed of 32.26 ft/s or 38.1 ft/s.
- Liftoff (Blue): The aircraft achieves necessary velocity to liftoff from the ground, and begins its climb to flight altitude.
- Straightaway 1 (Gold/Yellow): After achieving altitude, the aircraft flies level until it passes Flag 1 (approx. 500 feet from takeoff start).
- 180 Degree Turn 1 (Green): After passing Flag 1, the aircraft initiates a 180 degree turn to the right.
- Straightaway 2 (Purple): After completing the 180 degree turn, the aircraft flies level for 500 feet.
- 360 Degree Turn (Black): The aircraft completes a 360 degree turn.
- Straightaway 3 (Grey): After completing the 360 degree turn, the aircraft flies level until it passes Flag 2.

- <u>180 Degree Turn 2 (Brown):</u> After passing Flag 2, the aircraft initiates a 180 degree turn.
- <u>Straightaway 4 (Pink):</u> After completing the 180 degree turn, the aircraft flies level for 500 feet, returning to its starting point and completing a lap.

All subsequent laps start from the “Straightaway 1” section of flight. Figure 4.11 shows the modeled flight path.

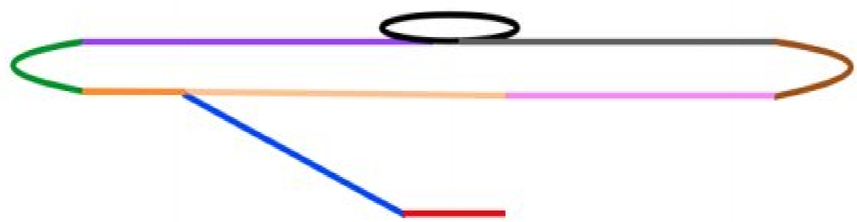


**Figure 4.11 Mission Model Flight Path**

<u>4.3.1 Mission Model Uncertainties</u>

The mission model is only a rough estimation of flight performance, and therefore carries many inherent uncertainties. Not all components (such as the motor) will perform ideally during actual flight, and there may be some discrepancies in lift and drag parameters of the final aircraft due to small variations in manufacturing. There will also be variance in the actual final weights versus the Team’s predicted final weights, due to unaccounted for glue and other manufacturing variances. This means there are some uncertainties in the parameters input into the model, such as thrust, max airspeed, final weight, and cruise speed. Additionally, the average wind speed for Wichita in April was used in the mission model for an approximation, assuming the aircraft will take off into the wind, but there is a high chance the wind speed and direction at competition will vary from this and will fluctuate from day to day. Finally, the mission model assumes max speed during takeoff and climbing, cruise speed on all other legs of the course, and a turn radius of 50 feet, but the exact inputs of the pilot while flying the course will invariably differ from the ideal path analyzed in the mission model. All of these factors contribute to uncertainties in the mission model, which represents ideal conditions for the flights and is expected to vary slightly from actual flights.

**4.4 Lift and Drag Analysis**

<u>4.4.1 Lift Analysis</u>

The Team examined the coefficient of lift, coefficient of drag, and the angle of attack for the wings of each plane. The Team used the aerodynamic analysis program XFLR5 in order to analyze the properties of the airfoils for different Reynolds numbers. The Reynolds numbers examined were determined with the same Airfoil Tools Reynolds Number Calculator.

**Production Plane:**

The Reynolds number calculator yielded Reynolds number of 150,000 for takeoff, 180,00 for climb, and 200,000 for max speed cruise based on the characteristic length of 6.11 in.

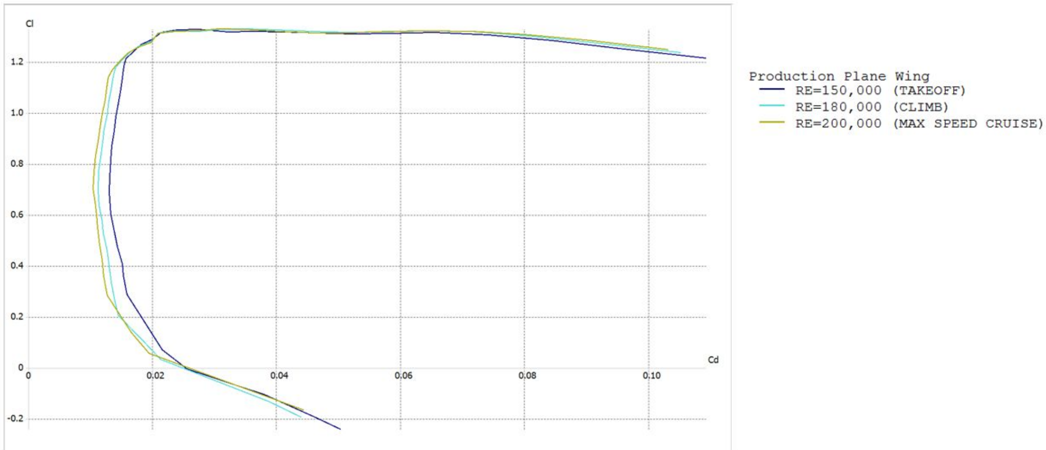



**Figure 4.12 Lift Coefficient vs Drag Coefficient for Production Plane Wing**

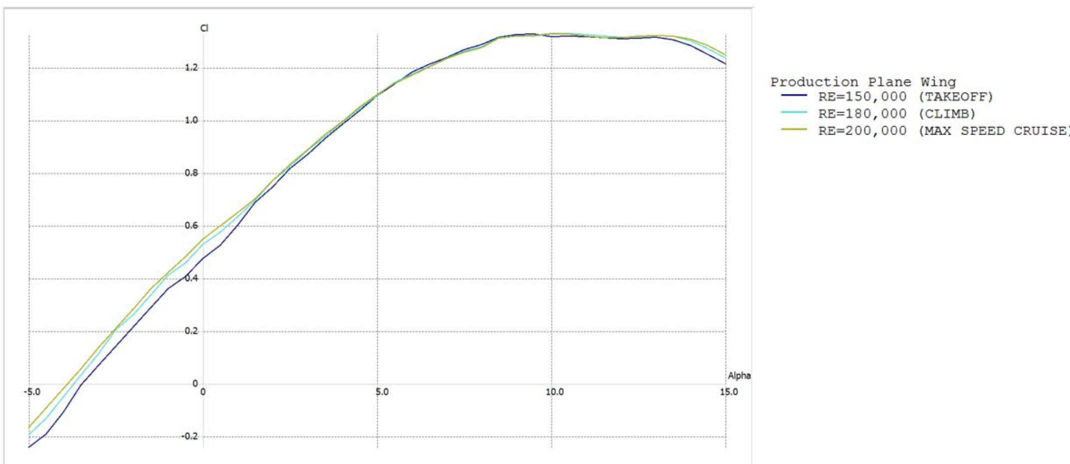



**Figure 4.13 Lift Coefficient vs Angle of Attack for Production Plane Wing**

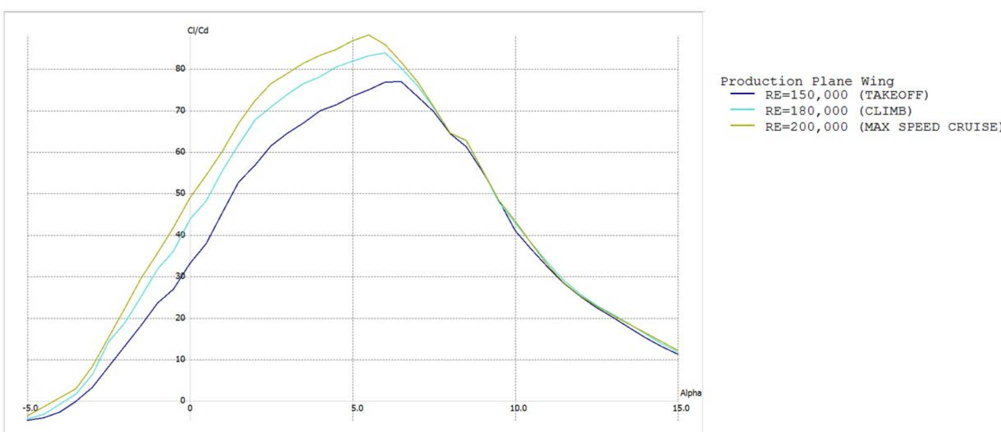



**Figure 4.14 Glide Ratio vs Angle of Attack for Production Plane Wing**

**Manufacturing Plane:**

The Reynolds number calculator yielded Reynolds number of 180,000 for takeoff, 210,00 for climb, and

240,000 for max speed cruise based on the characteristic length of 10.45 in.

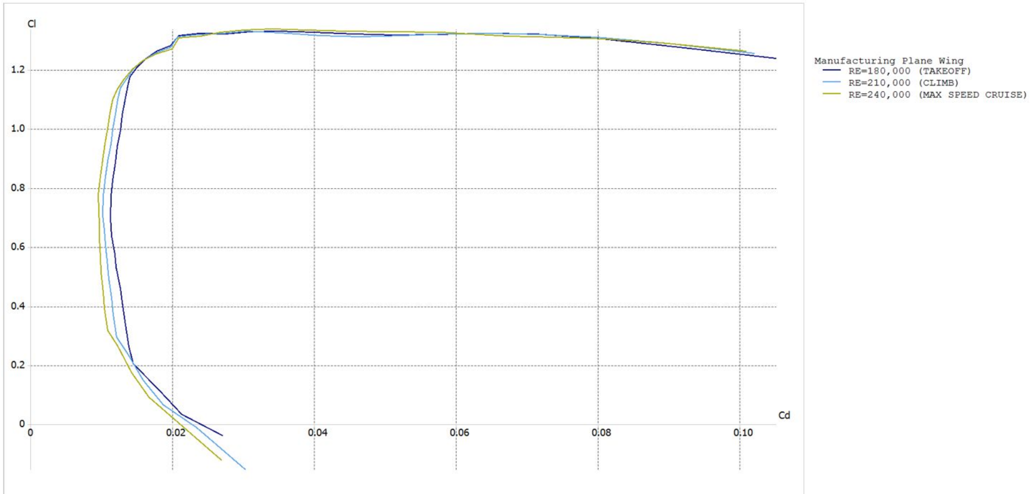



**Figure 4.15 Lift Coefficient vs Drag Coefficient for Manufacturing Plane Wing**

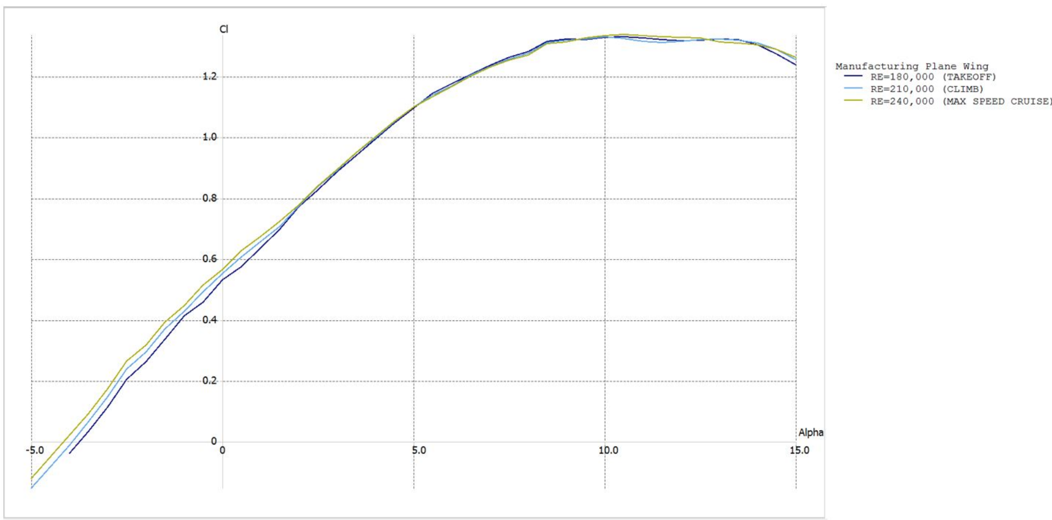



**Figure 4.16 Lift Coefficient vs Angle of Attack for Manufacturing Plane Wing**

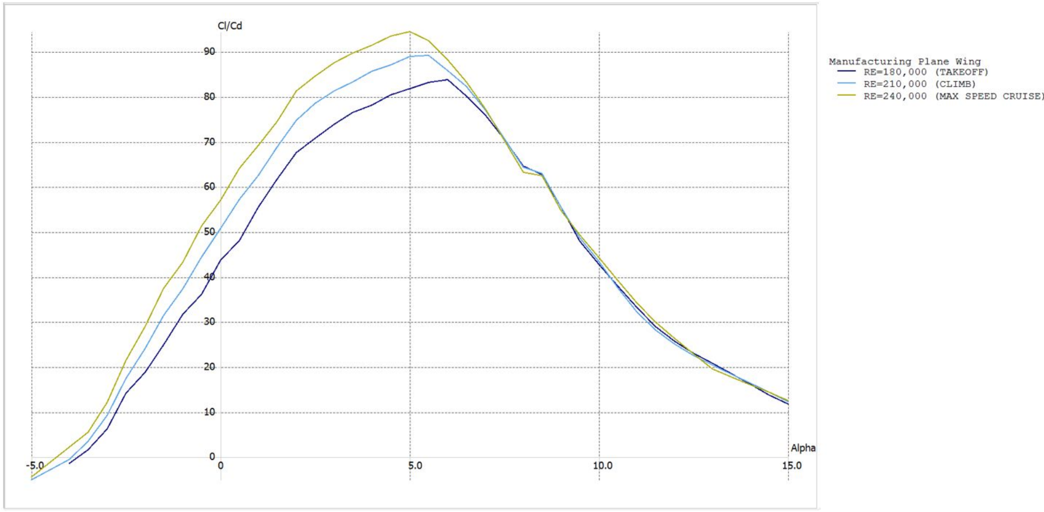



**Figure 4.17 Glide Ratio vs Angle of Attack for Manufacturing Plane Wing**

## 4.4.3 Drag Analysis

Drag on an aircraft comes from two main sources: parasitic drag, which is due to the shape of the aircraft structure and the "wet" surface area (i.e., the amount of surface area exposed to airflow) of those parts, and induced drag, which is due to the aircraft moving through the air. When analyzing the drag characteristics of the aircraft, the Team focused on the parasitic drag because it is a function of aircraft structural and aerodynamic design. Induced drag, on the other hand, is a function of wing planform shape, aspect ratio, and flight conditions. The Team estimated the zero-lift parasitic drag coefficient, $C_{D0}$, using StarCCM+ aerodynamic analysis and the equivalent skin friction method.

**Production Plane:**

The team estimated the $C_{D0}$ for the production to be 0.055. As expected, the wing and fuselage had the greatest contributions to total drag, due to the large planform area and large wetted area, respectively. The results can be seen in Figure 4.18.

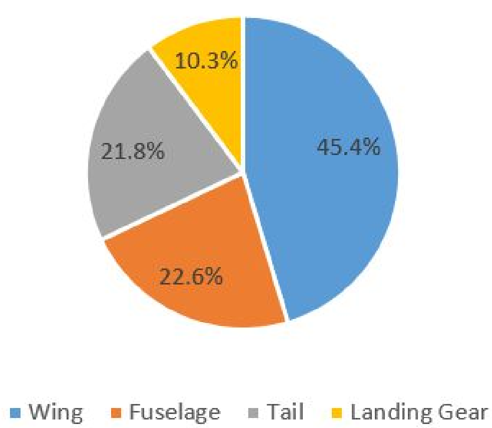



**Figure 4.18: Parasitic Drag Contributions from Major Components of Production Plane**

**Manufacturing Plane:**

The team estimated the $C_{D0}$ for the production to be 0.123. Most of the increase in $C_{D0}$ for the manufacturing plane is due to the increases fuselage size and the fairings added to cover the landing gear and propellor of the production plane. The results can be seen in Figure 4.19.

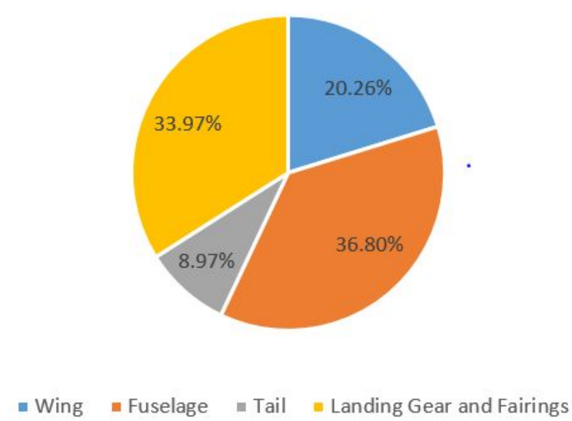



**Figure 4.19: Parasitic Drag Contributions from Major Components of Manufacturing Plane**

### 4.5 Stability and Control Analysis

4.5.1 Horizontal Tail

*Horizontal Tail Sizing*

The Team sized the horizontal tail using the tail volume coefficient equation, which solves for the horizontal tail volume coefficient ( $V_h$ ) with respect to distance between wing Center of Pressure (CoP) and horizontal tail CoP $(l_h)$, wing area $(S_w)$, horizontal tail area $(S_h)$, and mean aerodynamic chord of wing $(\overline{C})$.

$V_h$=1

$$V_h = (l_h S_h)/(S_w \overline{C})$$

The Team determined that the horizontal tail of the Production Plane needed a chord length of 4.75 inches and a span of 14 inches. The Manufacturing Plane was given a chord length of 8 inches and a span of 22 inches.

*Elevator Sizing*

The Team sized the elevator to be 30% of the horizontal tail chord, based off of historical remote control airplane designs.

4.5.2 Vertical Tail

*Vertical Tail Sizing*

The Team sized the vertical tail using the tail volume coefficient equation, which solves for the vertical tail volume coefficient ( $V_t$ ) with respect to distance between wing Center of Pressure (CoP) and vertical tail CoP $(l_t)$, wing area $(S_w)$, vertical tail area $(S_t)$, and wingspan (b). $V_t$=.06

$$V_t = (l_t S_t)/(S_w b)$$

The Team chose the vertical tail of the Production Plane to have a root chord of 8 inches, a tip chord of 5 inches, and a span of 7 inches, and the vertical tail of the Manufacturing Plane to have a root chord of 9 inches, a tip chord of 6 inches, and a span of 7 inches.

*Rudder Sizing*

The Team sized the rudder to be 25% of the average vertical tail chord, based off of historical remote control airplane designs.

4.5.2 Stability Analysis and Static Margin

To be longitudinally balanced, the aircraft requires the total pitching moment coefficient at zero lift to be positive and for the center of gravity to be ahead of the neutral point. To be statically stable, the slope of the total pitching moment coefficient vs alpha should also be negative when the total pitching moment coefficient is zero. Longitudinal stability analysis was done using XFLR5 given the structural dimensions of the aircraft. The static margin was calculated for the Production Plane Mission and each of the 2 Manufacturing Plane Mission Profiles according to its C.G. location with respect to the x-axis using the following equation:

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

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

**Production Plane:**

Figure 4.20 shows the production plane satisfying all requirements for longitudinal stability. The analysis estimated the neutral point to be located 4.3 inches behind the leading edge of the wing. This value was used to calculate the static margin which is shown in table 4.6.

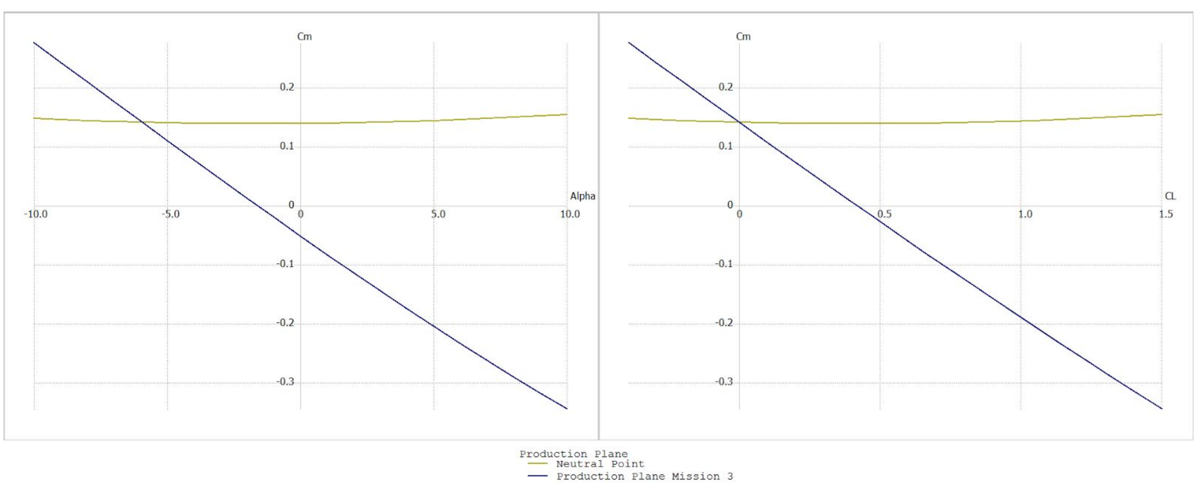



**Figure 4.20 Total Moment Coefficient (Cm) vs Alpha and Total Moment Coefficient (Cm) vs Lift Coefficient (CL) for Production Plane**

| | Mission 3 |
|---|---|
| Static Margin | 36.6% |

**Table 4.6: Static Margin for Production Plane**

**Manufacturing Plane:**

Figure 4.20 shows that the manufacturing plane satisfies all longitudinal stability requirements for both Missions 1 and 2. The analysis estimated the neutral point to be located 7.8 inches behind the leading edge of the wing. This value was used to calculate the static margin which is shown in table 4.7.

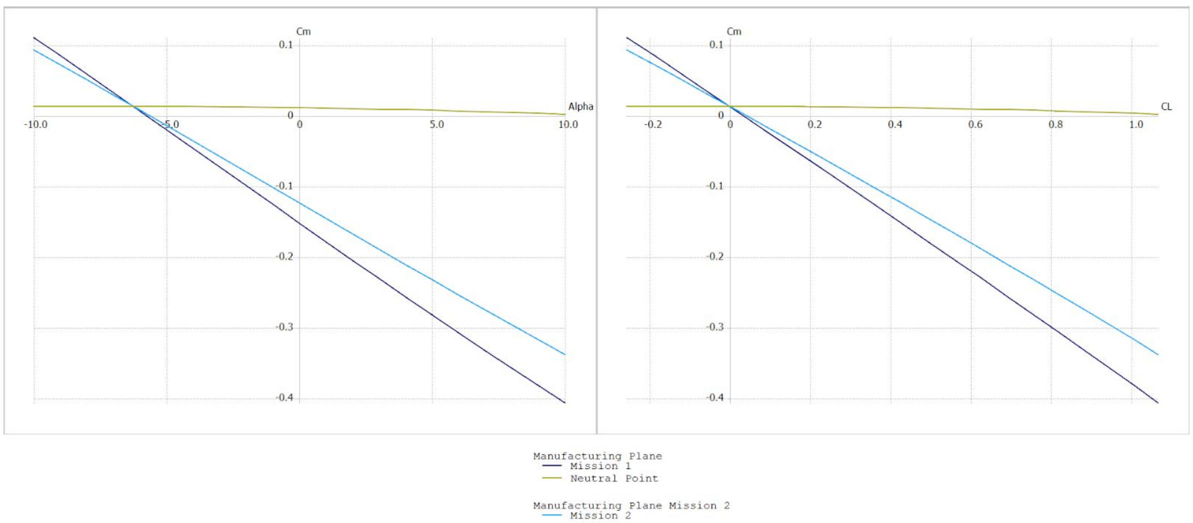



**Figure 4.21 Total Moment Coefficient (Cm) vs Alpha and Total Moment Coefficient (Cm) vs Lift Coefficient (CL) for Manufacturing Plane**

| | Mission 1 | Mission 2 |
|---|---|---|
| Static Margin | 38.5% | 31.7% |

**Table 4.7: Static Margin for Manufacturing Plane**

### 4.6 Estimated Aircraft Mission Performance

With the preliminary design of the aircraft completed, the Team was able to use mission modeling analysis to estimate mission performance. Comparing that to to expected competition performance allowed the Team to estimate final mission scores. The estimated mission scores can be see in Table 4.8 below.

| Mission 1 | | Mission 2 | | Mission 3 | |
|---|---|---|---|---|---|
| Our Time | 3.3 minutes | Our Time | 1.3 minute | Our Time | 2.7 minutes |
| Time Required | 5 minutes | Time Required | 10 minutes | Time Required | 5 minutes |

| Mission 1 Score | 2 | Mission 2 Score | 4 | Mission 3 Score | 2 |
|---|---|---|---|---|---|

**Table 4.8 Estimated Mission Scores**

# 5.0 Detailed Design

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

### 5.1 Final Design Parameters

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

| Overall Dimensions | PA | MSA | Fuselage | PA | MSA |
|---|---|---|---|---|---|
| **Max Length** | 39.26 in | 50.22 in | **Length** | 39.26 in | 50.22 in |
| **Max Width** | 55.30 in | 62 in | **Width** | 5.38 in | 8.23 in |
| **Max Height** | 13.9 in | 15 in | **Height** | 4.9 in | 6.2 in |
| Wing | PA | MSA | Vertical Tail | PA | MSA |
| **Span** | 55.30 in | 56 in | **Root Chord** | 8 in | 9 in |
| **Ave. Chord** | 6.11 in | 10.45 in | **Tip Chord** | 5 in | 6 in |
| **Area** | 333 $in^2$ | 637 $in^2$ | **Span** | 7 in | 7 in |
| **Aspect Ratio** | 9.18 | 6 | **Area** | 45.5 $in^2$ | 52.5 $in^2$ |
| **AoA** | 0 | 0 | **Aspect Ratio** | 1.08 | 0.93 |
| **Sweep Ratio** | 0 | 0 | **Taper Ratio** | 0.625 | 0.667 |
| **Taper Ratio** | 0.39 | 0.44 | | | |
| Horizontal Tail | PA | MSA | Motor/Battery | PA | MSA |
| **Chord Length** | 4.75 in | 8 in | **Motor** | Turnigy G10-810 | Turnigy G10-810 |
| **Span** | 14 in | 22 in | **ESC** | ICE2 HV45 | ICE2 HV45 |
| **Area** | 66.5 $in^2$ | 176 $in^2$ | **Battery Cell** | 1.2V 2100mAh | 1.2V 2100mAh |
| Controls | PA | MSA | **Number of Cells** | 10 in series | 14 in series |
| **Servo** | hs-65 | hs-65 | **Volts** | 12 | 16.8 |

| | | | | | |
|---|---|---|---|---|---|
| **Stall Torque oz.in** | 31 | 31 | **Max Amps** | 26.78 | 30.3 |
| **Speed (sec/60deg)** | .11 | .11 | **Max Power** | 300 | 425 |

**Table 5.1 Finalized Design Parameters**

### 5.2 Structural Characteristics and Capabilities

When designing the aircraft structures, the Team started by considering where the loads would be applied and distributed throughout the structures. With this in mind, the Team first created sketches detailing the places where external loads would be applied. The sketches can be seen below in Figures 5.1 and 5.2

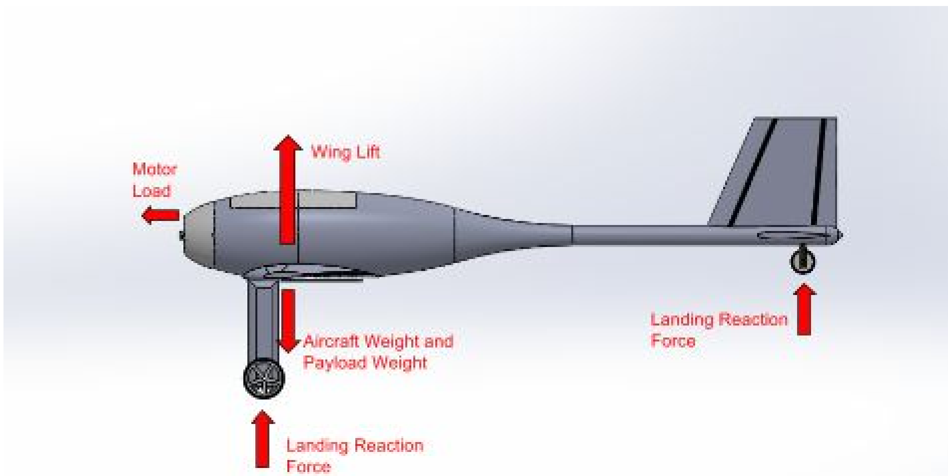



**Figure 5.1 PA External Loads**

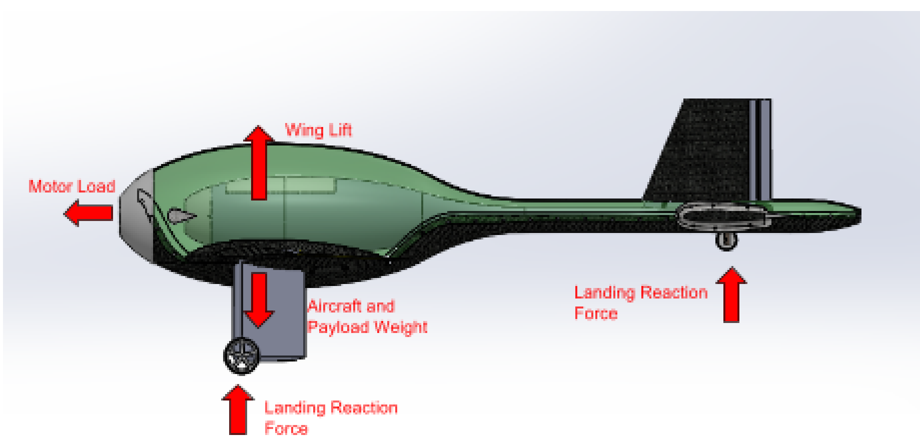



**Figure 5.2 MSA External Loads**

The goal of an aircraft structure, in addition to giving the aircraft shape, is to distribute applied loads so that there are no load concentrations. With this in mind, the Team was able to project how the loads would enter and transfer throughout the structure.

By studying the external loads and the load paths, the Team was able to identify critical load locations on the aircraft. This allowed for design to avoid structural failure at an expected load location. The structural elements and the design solutions are listed in Table 5.2 below. This information led to the addition of carbon fiber tow at strategic locations on the fuselage, as well as along the load heavy wing. This allows for a minimalistic structure that satisfies all load requirements while maintaining the lowest possible weight.

| Structural Element | Applied Load | Description of Design |
|---|---|---|
| **Bottom of PA Fuselage** | Front Landing Gear Impact and Aerodynamic Loads | Several layers of carbon fiber used to absorb landing impact and withstand loads transferred from wings. |
| **Bottom of MSA Fuselage** | Front Landing Gear Impact | Several layers of carbon fiber used to absorb landing impact. |
| **MSA Wing Joints** | Aerodynamic Loads | Spar curves in “u-shape” to be connected in the middle with nylon bolts |
| **Wing Structural Spars** | Tension and Compression From Aerodynamic Loads | Foam core on PA wings and carbon fiber spar at the quarter chord of MSA wings to bear the majority of the aerodynamic loads. |
| **Motor Mounts** | Torque and Tension From Motors | Motor mount and front of plane kept in one piece and reinforced with several layers of carbon fiber to handle vibrations and force of motor pulling forward. |

**Table 5.2 Critical Structural Elements**

### 5.3 System Designs, Component Selection and Integration

#### 5.3.1 Fuselage Structural Design

The fuselage structural designs serve two main purposes. The first is to house the payloads (the Gatorade bottle in the case of the PA, and the PA in the case of the MSA). The second is to provide an aerodynamically beneficial shape through which loads can transfer. The Team felt that it was very important to have as lightweight of a structure as possible while still being strong enough to hold the applied loads. For this reason, the Team elected to construct both fuselages out of composite materials. In order to decrease the required weight, the Team constructed most of the fuselage shells out of thin carbon fiber and added carbon fiber tow reinforcement at strategic points to allow the applied loads to be distributed. The shape and sizing of the fuselages were determined by aerodynamic concerns and the need to fit the Mission 2 and Mission 3 payloads.

*PA*

For the PA, several layers of a carbon fiber weave was added to the bottom of the fuselage where the wings and landing gear attach, as these areas are subject to significantly higher loads.

*MSA*

The MSA was required to be able to come apart in order to allow the PA to be loaded in as one piece. For this reason the Team chose to design the MSA fuselage to split apart down the center so that the PA can be placed inside. The MSA fuselage has a strip of fiberglass on the top half that overlaps the bottom half, allowing the two pieces to be screwed together. The fuselage was given extra reinforcement at this joint, at the point on the bottom of the fuselage where the landing gear attaches, and at the front of the fuselage where the motor is mounted, where heavier loads are expected. In addition, the structure was designed so that the joint where the two halves of the MSA meet leaves the nose of the plane in one piece, in order to avoid a structural weak point at a place where the motor will cause vibration and higher loads. The landing gear and the propeller of the PA are too long to fit within the fuselage, but must still be carried internally, so slots were cut out for them, and covering structures were designed to fit over the protruding PA landing gear and propeller.

**Figure 5.3 MSA Fuselage Structural Design**

5.3.2 Landing Gear

Given the Team's previous issues with aircraft not taking off straight, a maneuverable landing gear was an important requirement. A strong landing gear that could withstand the landing forces of the loaded aircraft was also identified as a critical requirement. As mentioned in Section 3, the Team elected to go with a tail dragger landing gear configuration. The nose landing gear on both planes are split gears that mount to the bottom of the planes by being bolted to the bottom section of the composite fuselage. The rear gears are small single wheels, also bolted to the composite fuselage. The back gears are servo controlled to provide maneuvering ability, to ensure that the aircraft course can be adjusted on the runway in the event that a straight takeoff does not occur. The basic landing gear configuration can be seen in the figure below.

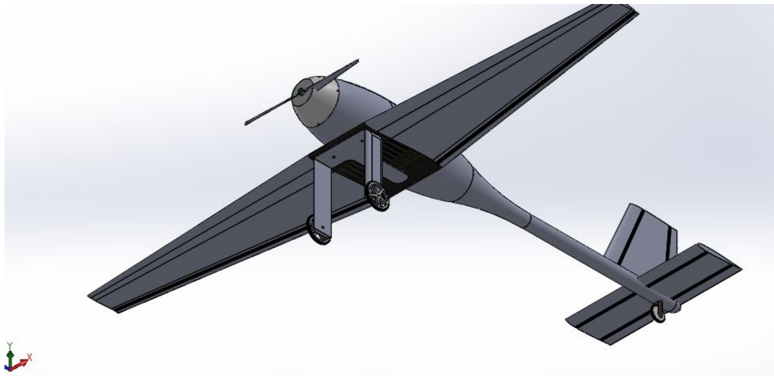


**Figure 5.4 PA Landing Gear Configuration**

*PA Considerations*

In addition, the PA back wheel is very small, allowing the entire tail and landing gear to fit within the MSA tail. The front gear of the PA is vertical, and slides into slots cut for it in the floor of the MSA fuselage.

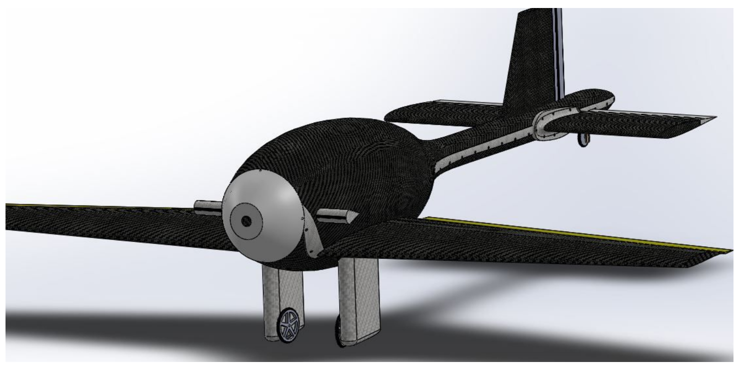


**Figure 5.5 MSA Landing Gear Configuration**

<u>5.3.3 Payload Securement</u>

*PA*

The payload securement system for the PA is quite simple, consisting of the internal compartment of the fuselage and some velcro straps. The PA fuselage is built to be only slightly larger than the Gatorade bottle and required internal components, meaning that the payload fits without moving around very much. Velcro straps are used to further secure the payload, in order to prevent any shifting of the center of gravity during flight maneuvers. A hatch is built into the top of the PA fuselage to allow access to the payload.

*MSA*

The MSA is built in such a way that the PA fits inside of it securely, requiring very little extra considerations for payload containment. The PA wings and tail fit inside of the MSA wings and tail, and the PA landing gear also fits into a space built specifically for it, all of which keeps the PA from moving during flight. Additionally, a hollow canard like structure provides a space for the PA propeller to fit, with covering attaching in a similar manner to the hollow wings and tail. Velcro straps are used for further securing the PA as an extra precaution.

5.3.4 Wing/Fuselage Attachment Systems

*PA*

The wing for the PA is a low wing, and is attached at the bottom of the fuselage. A contour that follows the shape of the top of the wing is cut out of the bottom of the PA fuselage. This allows the wing to rest flush against the fuselage, so that it can be bolted on securely.

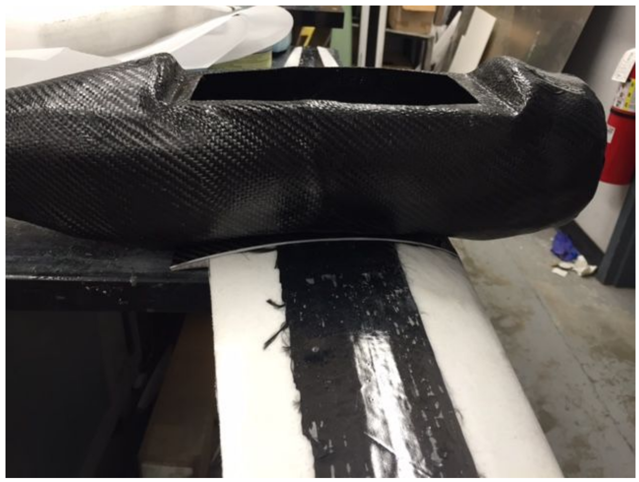


**Figure 5.6 PA Wing Attachment**

*MSA*

The wings for the MSA are positioned higher on the aircraft in order for the PA wings to be able to fit inside while the PA is being carried. They also are required to be able to detach from the fuselage in order to load the PA into the MSA. The attachment system therefore utilizes flanges built into the wing, which overlap with the lip of the fuselage and can be bolted together for a secure attachment. Carbon fiber tabs will also be attached to the spar of each wing, which will extend into the body of the MSA fuselage beneath the PA payload and meet, allowing them to be screwed together to further secure the wings in place.

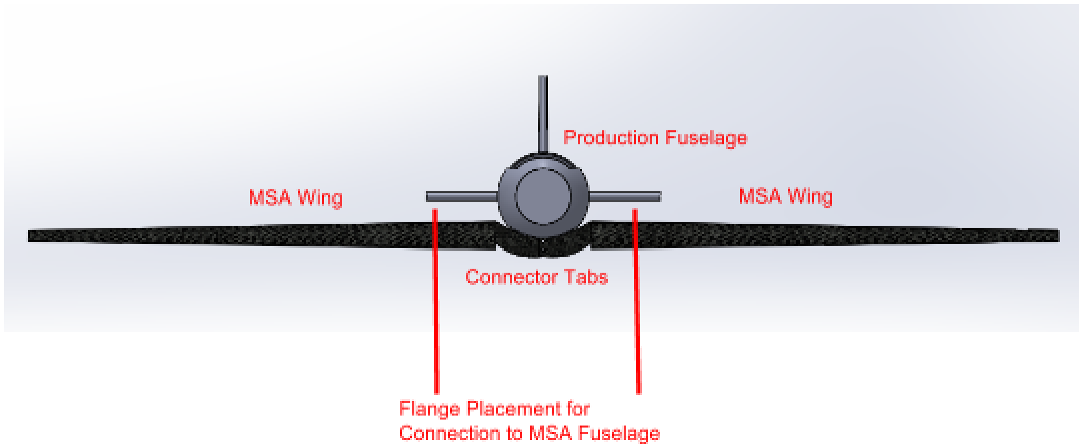



**Figure 5.7 MSA Wing Attachment**

<u>5.3.5 Tail Structure and Attachment</u>

*MSA*

The MSA tail design proved to be troublesome for the Team, as previously determined design constraints require it to fit around the PA tail when the PA is being carried. For this reason the vertical and horizontal tails needed to be hollow, and therefore constructed out of thick carbon fiber to allow the hollow structure to be sturdy enough to take aerodynamic loads. The Team settled upon the vertical tail being permanently affixed to the MSA fuselage, so that it can be lowered over the PA tail, while the horizontal tail pieces detach, and are fixed in place using flanges that allow them to be screwed onto the fuselage.

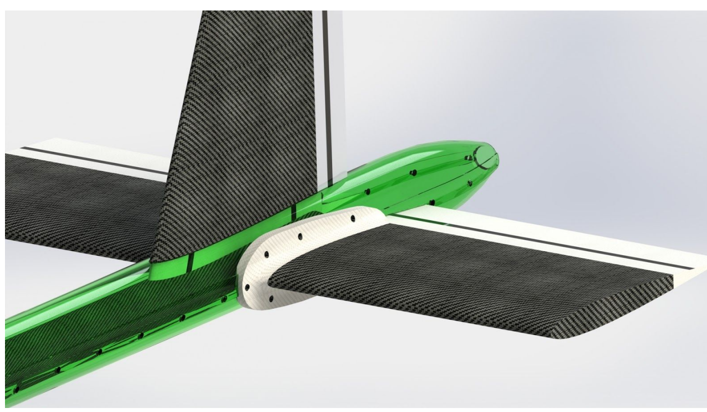


**Figure 5.8 MSA Tail Attachments**

<u>5.3.6 Wing Structural Designs</u>

*PA*

The main concerns for PA wing structure are weight and the ability to take flight and attachment loads. The PA wing has skin made out of a thin layer of fiberglass in order to keep it very light, with strips of unidirectional carbon fiber along the quarter chord to add strength, all wrapped around a foam core that transfers the shear load from bending and acts, all together, as a composite I-beam.

**Figure 5.9 PA Wing Structure**

*MSA*

The MSA wing is required to be hollow inside, in order to leave space for the PA wing. It is constructed from carbon fiber to offset the structural issues that a hollow wing creates, and has a carbon fiber spar placed at the quarter chord of the wing, leaving enough space for the PA wing behind the quarter chord. In addition, there are carbon fiber tow ribs near the wingtips and trailing edge, to provide support to the hollow structure.


**Figure 5.10 MSA Wing Structure**

<u>5.3.7 Electronic Control System</u>

The Controls Team selected the Spektrum DX7 transmitter with an 8 channel receiver combination for competition use . The Team then paired this system with Hitec HS65 servos for the flight control surfaces, which were chosen for their small size. Minimizing the servo size allows the planes to fit together closer for mission 2, which minimizes the size of the MSA.

<u>5.3.8 Propulsion Systems</u>

The final propulsion configuration for the PA was decided to be a Turnigy G10 outrunner motor using a 10 cell, 2100 mAh NiMH battery pack. The motor was changed due to lack of spare parts, namely propeller adapters, for the previous multirotor centric choice. This motor provides 298 watts at maximum power coupled with an 12x8 propeller which resulted in a 34 mph pitch speed during testing.

The final configuration for the MSA was selected to also be a Turnigy G10 outrunner using a 14 cell, 16.8 V NiMH battery pack. This configuration provides 425 watts of burst power for takeoff with a 40 mph pitch speed with an 11x6 propeller.

**5.4 Weight and Balance**

Table for calculating CG location for balance in flight.  Z-direction not included because all components are centered

| | Weight (oz) | | X distance from firewall (in) | | Y distance (thrust line is y=0) (in) | |
|---|---|---|---|---|---|---|
| | PA | MSA | PA | MSA | PA | MSA |
| Fuselage | 9 | 15 | 15 | 15 | 0 | 0 |
| Motor | 5 | 6.7 | -1 | -1 | 0 | 0 |
| Batteries | 8 | 11.5 | 2 | 17.1 | 0 | 0 |
| Wing | 8 | 10 | 7 | 17 | -1 | -2 |
| Landing Gear | 3 | 3 | 4 | 7 | -3 | -5 |
| Tail | 1 | 1 | 41 | 44 | 0 | 0 |
| Payload | 35.274 | 34 | 7.5 | 12.1 | 0 | 0 |
| PA Empty | 34 | ------ | 7.5 | ------ | -.5 | ------ |
| M1 total | ------- | 47.2 | --------- | 12.1 | ---------- | -.94 |
| M2 Total | -------- | 81.2 | -------- | 12.1 | ---------- | -.492 |
| M3 Total | 71.2 | ------ | 7.5 | ------- | -.2454 | ------- |

**Table 5.3 Overall Weight and Balance**

### 5.5 Flight Performance Parameters

Using the aerodynamic data from XFLR5, StarCCM, and the mission model created in MATLAB, the Team was able to identify and list relevant flight performance parameters.

| Parameter | Mission 1 | Mission 2 | Mission 3 |
|---|---|---|---|
| $C_{L\text{-}max}$ | 1.31 | 1.30 | 1.31 |
| $C_{L\text{-}Cruise}$ | 0.16 | 0.33 | 0.35 |
| $C_{L\text{-}Takeoff}$ | 1.20 | 1.20 | 1.15 |
| $C_{D0}$ | 0.123 | 0.123 | 0.055 |
| Takeoff Speed (ft/s) | 32.26 | 38.1 | 38.1 |
| Takeoff Distance (ft) | 88.72 | 91.2 | 86.34 |
| Climb Angle (deg) | 19 | 14 | 16 |

| | | | |
|---|---|---|---|
| Turn Rate (deg/s) | 33.9 | 30.5 | 40.7 |
| Wing Loading (oz/in$^2$) | 0.074 | 0.127 | 0.112 |
| Flight Time (s) | 155.28 | 55.26 | 124.91 |
| Gross Takeoff Weight (lb) | 2.95 | 5.075 | 4.45 |

**Table 5.4 Flight Performance Parameters**

### 5.6 RAC Documentation

The Rated Aircraft Cost, or RAC, is a very important factor that will have a high impact on the overall score. For this reason the Team made every effort to save weight where possible, in order to lower the RAC. The final RAC value is documented in Table 5.5 below, using the RAC equation documented in Section 3.1.7.

| RAC Parameter | Value |
|---|---|
| Empty Weight of PA | 2.12 lb |
| Weight of PA Battery | 0.718 lb |
| Number of Sub-assemblies | 1 |
| Empty Weight of MSA | 2.95 lb |
| Weight of MSA Battery | 1.01 lb |
| **Total RAC** | 4.5 |

**Table 5.5 Final RAC Documentation**

### 5.7 Mission Performance Documentation of Final Design

Using aircraft parameters and mission analysis code, the Team was able to calculate estimated performance for each of the missions. This analysis allowed the Team to identify the critical stages of flight, and see if the aircraft design was deficient in any of these areas. The following tables contain the detailed results of this analysis. It is assumed for these analyses that the aircraft moves against the wind at the starting portion of the course, and with the wind on the opposite side of the course and that the aircraft flies at or close to the maximum possible speed for most of the flight

.

| Mission 1 | Mission Stage | Total Distance (ft) | Final Speed (ft/s) | Time (s) |
|---|---|---|---|---|
| | Takeoff | 88.72 | 32.26 | 5.50 |
| | Climb | 268.04 | 30.93 | 3.16 |

| | | | | |
|---|---|---|---|---|
| | Cruise | 143.23 | 30.93 | 4.63 |
| | 180 Degree Turn | 157.08 | 69.01 | 5.31 |
| | Cruise | 500 | 69.01 | 7.24 |
| | 360 Degree Turn | 314.16 | 69.01 | 10.61 |
| | Cruise | 500 | 69.01 | 7.24 |
| | 180 Degree Turn | 157.08 | 69.01 | 5.31 |
| | Cruise | 500 | 30.93 | 16.16 |
| Tota 1 Lap: | | 2,628 | | 65.17 |
| Total Mission: | | 7,884 | | 201.25 |

**Table 5.6 Mission 1 Performance**

| Mission 2 | Mission Stage | Total Distance (ft) | Final Speed (ft/s) | Time (s) |
|---|---|---|---|---|
| | Takeoff | 91.2 | 38.1 | 6.50 |
| | Climb | 292.27 | 25.93 | 4.77 |
| | Cruise | 83.98 | 25.93 | 3.24 |
| | 180 Degree Turn | 157.08 | 54.07 | 5.90 |
| | Cruise | 500 | 54.07 | 7.80 |
| | 360 Degree Turn | 314.16 | 54.07 | 11.80 |
| | Cruise | 500 | 54.07 | 7.24 |
| | 180 Degree Turn | 157.08 | 54.07 | 5.90 |
| | Cruise | 500 | 25.93 | 19.28 |
| Total 1 Lap: | | 2,628 | | 76.60 |
| Total Mission: | | 2,628 | | 76.60 |

**Table 5.7 Mission 2 Performance**

| Mission 3 | Mission Stage | Total Distance | Final Speed (ft/s) | Time (s) |
|---|---|---|---|---|

| | | (ft) | | |
|---|---|---|---|---|
| | Takeoff | 86.34 | 38.1 | 4.53 |
| | Climb | 315.83 | 40.93 | 3.18 |
| | Cruise | 97.80 | 40.93 | 2.39 |
| | 180 Degree Turn | 157.08 | 49.07 | 4.42 |
| | Cruise | 500 | 49.07 | 6.32 |
| | 360 Degree Turn | 314.16 | 49.07 | 8.85 |
| | Cruise | 500 | 49.07 | 6.32 |
| | 180 Degree Turn | 157.08 | 49.07 | 4.42 |
| | Cruise | 500 | 40.93 | 12.22 |
| Total 1 Lap: | | 2,628 | | 52.66 |
| Total Mission: | | 7,884 | | 162.2 |

**Table 5.8 Mission 3 Performance**

### 5.8 Drawing Package

See following pages

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# 6.0 Manufacturing Plan and Processes

### 6.1 Selection Methodology

The Team looked into and compared several different manufacturing methods and materials for each of the major components of the aircraft. When selecting techniques and materials, the Team weighed the pros and cons of each against the qualities that would be best for the completion of the missions.

When considering possible options for manufacturing, the Team used different criteria then when designing the plane. Five different Figures of Merit were considered, as shown below in Table 6.1.

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

**Table 6.1 Manufacturing Figures of Merit**

When making manufacturing choices the Team was mainly concerned with building a low weight, reliable aircraft that would not need to be repaired often. For this reason strength and weight were given the most consideration during manufacturing selections.

### 6.2 Investigation and Selection of Major Components and Assembly Methods

<u>6.2.1 The Fuselages</u>

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

- **Balsa Truss:** A frame is constructed of balsa wood, then covered in a skin of Mylar.
- **Balsa Semi-Monocoque:** Fuselage bulkheads (ribs) are cut out on the LaserCamm, and then assembled using longerons. A Mylar skin is then used as a covering.
- **Lost-Foam Core:** A block of foam is cut in the desired fuselage shape, then wrapped in carbon fiber and given time to cure. The foam is then melted out using acetone, leaving the carbon fiber fuselage shell.

| FOM | Weight | Balsa Truss | Balsa Semi-Monocoque | Lost-Foam Core |
|---|---|---|---|---|
| Weight | 35 | 5 | 4 | 4 |
| Ease of Fabrication | 15 | 4 | 4 | 3 |
| Ease of Repair | 5 | 5 | 4 | 3 |

| | | | | |
|---|---|---|---|---|
| Cost | 10 | 5 | 5 | 3 |
| Strength | 35 | 2 | 3 | 5 |
| Total | 100 | 380 | 375 | **405** |

**Table 6.2 Fuselage Fabrication Decision Matrix**

After careful analysis, the Team selected the lost-foam core method due to the strength and robustness of the design paired with a relatively low weight. Though a balsa truss would likely have been lighter, the Team took into account that the PA being in only one sub-assembly required some rather complex assembly of the MSA fuse. The Team believed this would make it difficult for a balsa structure to hold up under flight and landing loads, and so elected to go with a more costly but longer lasting composite shell structure for both aircraft. In addition, a plastic vacuum formed cowling and payload hatch cover were constructed to improve the aerodynamic properties of the basic shape.

6.2.2 The Wings

The Team considered three different methods for construction of the wings, as detailed below.

- **Balsa:** Airfoil sections are cut out of balsa using the LaserCamm and are connected using thin balsa spars and stringers. The whole thing is then covered in a Mylar skin.
- **Foam Core:** A foam wing is cut out using a hot wire system, using airfoil shape guidelines at each end. The foam wing is then covered in fiber, with spars of stronger fiber at the quarter chord for extra support, creating a stiff structure.
- **Lost-Foam Core:** A method similar to the foam core technique is followed, but a fiber spar is included at the quarter chord of the wing to add support, and the foam core is removed using acetone.

| FOM | Weight | Balsa | Foam Core | Lost-Foam Core |
|---|---|---|---|---|
| Weight | 35 | 5 | 4 | 5 |
| Ease of Fabrication | 15 | 5 | 4 | 3 |
| Ease of Repair | 5 | 5 | 4 | 4 |
| Cost | 10 | 5 | 4 | 4 |
| Strength | 35 | 2 | 5 | 4 |
| Total | 100 | 395 | **435** | 420 |

**Table 6.3 Wing Manufacturing Decision Matrix**

Again, the robustness of the wing was considered to be of high importance by the Team, along with the weight. Ultimately the Team selected the foam-core technique as the best way to construct the PA wings, since the foam core offers a much stronger wing with less bending than either balsa or a hollow lost foam core wing would.

*6.2.2.1 MSA considerations*

Despite the Team's selection of a foam core wing as the best possible choice, the Team's design calls for the PA wing to be able to slide inside of the MSA wing. This places a design constraint on the MSA wing, requiring it to have enough space to hold the PA wing. For this reason a foam core method does not work for the MSA wing, and the next best design, a lost-foam core, was chosen for the MSA wing. A lost-foam core MSA wing maintains a low weight while leaving space for the PA wing, though the Team knew that bending in the hollow sections might be a concern that would need to be addressed by adding further carbon fiber strips across the top of the wing, in order to provide extra stiffness.

<u>6.2.3 The Landing Gears</u>

When deciding upon landing gear, the Team's main decision was between a store bought solution, which required little assembly but would not be customizable, or custom fabricated landing gear, which would require more time and extra work to design, fabricate, and analyze. The Team started by searching for commercially available landing gear that would meet the design requirements.

The main problem in choosing the PA nose landing gear is that design constraints require it to fit inside of slots built into the MSA fuselage. A wide landing gear, or an angled one, would require more material to be cut from the MSA fuselage, weakening it. Additionally, the tail gear would have to fit inside of the MSA tail space, requiring the wheel to be very small. Because of these unique size and geometry requirements, the Team chose to fabricate carbon fiber landing gear (pictured in Figure 6.1 below), allowing for the shape to be customizable and the pieces to be lightweight and strong.

**Figure 6.1 PA Custom Landing Gear**

Since a faring already had to be designed to fit over the PA landing gear on the MSA, the Team decided to design the fairings to be structurally sound enough to also function as the landing gear for the MSA plane. This saved both design and manufacturing time, as well as weight, as adding another gear to the MSA tall enough for the PA landing gear fairings to clear the ground would have been heavy.

### 6.3 Manufacturing Plan

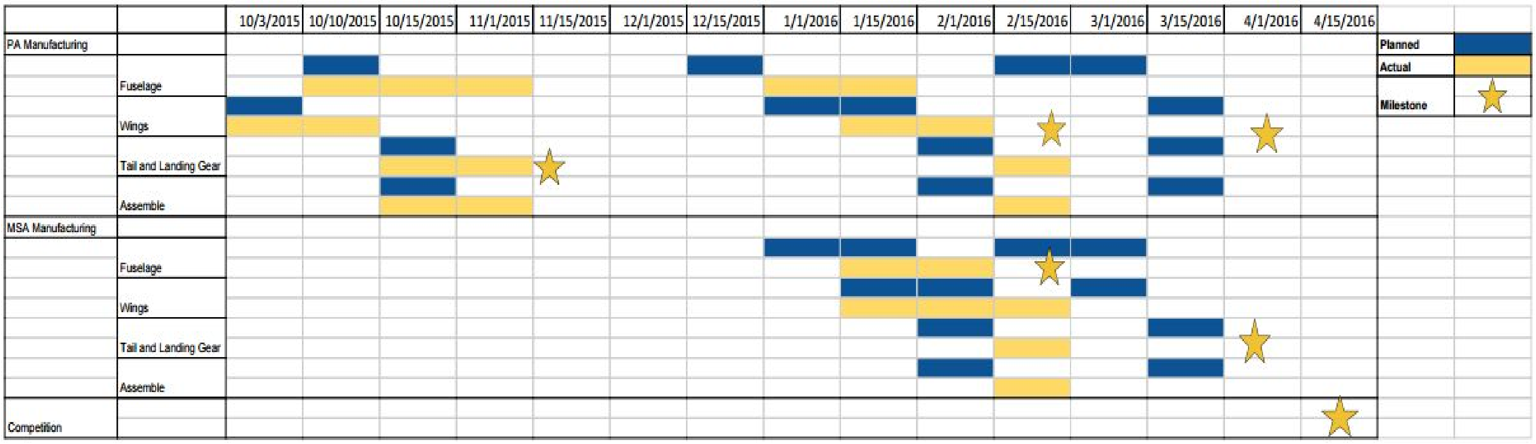


**Figure 6.2 Manufacturing Plan**

The Team's manufacturing plan, pictured above in Figure 6.2, allowed the Team to follow a strict schedule of prototype construction. Since two planes needed to be built this year, it was important to stick to the schedule as much as possible. Though manufacturing did end up slightly behind schedule, the Team is confident that another iteration of planes can be completed and fine tuned before competition.

# 7.0 Testing Plan

### 7.1 Objectives and Schedules

The Team created and executed a comprehensive testing plan to gather data that was later used to improve and optimize the design of the aircraft. The master test schedule for all subsystems is shown below in Figure 7.1. The Structures test is a Tip Test with max payload, verification of structural stability with varying point loading. The flight tests verify controllability and gather flight data. The mission tests verify that the aircraft can complete the required missions. The payload test shows that the PA can be loaded into the MSA within 5 minutes.

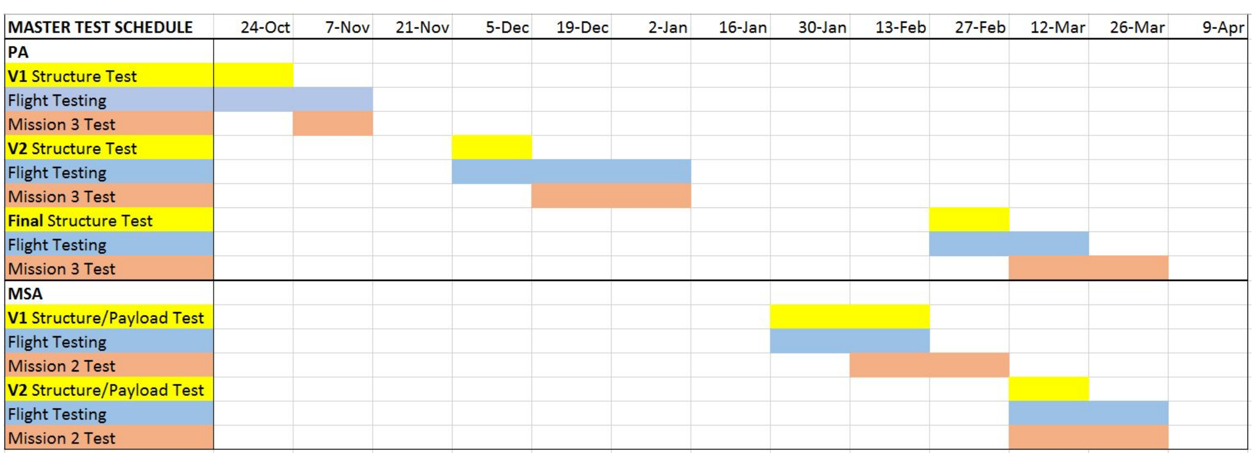

**Figure 7.1 Master Test Schedule**

### 7.2 Propulsion Testing

A motor test stand was utilized to measure thrust and airspeed of different propellor, motor, and battery configurations. These tests were performed to gain a better understanding of the motors' performance and help select the appropriate configuration for the PA and MSA. The tested motors were run at maximum power for five seconds allowing thrust and airspeed data to be collected. Parameters such as initial pack voltage (Vo), voltage at max current draw (V at Imax) and max current draw (Imax) were also recorded for reference. The summarized results of these tests can be seen in Table 7.2.

| Motor Tested | Propeller | Thrust (lb) | Airspeed (ft/s) | Pmax (Watts) | Vo (V) | V at Imax (V) | Imax (Amps) |
|---|---|---|---|---|---|---|---|
| **Turnigy G10-810** | 12x6 | 3.16 | 47.57 | 250 | 12.43 | 11.2 | 22.22 |
| **Turnigy G10-810** | 12x8 | 3.17 | 50.20 | 298 | 12.58 | 10.74 | 26.78 |
| Motor Tested | Propeller | Thrust (lb) | Airspeed (ft/s) | Pmax (Watts) | Vo (V) | V at Imax (V) | Imax (Amps) |
| **Turnigy G10-810** | 11x6 | 4.83 | 60.37 | 425 | 16.4 | 14.05 | 30.07 |
| **Quanum 5008** | 15x6 | 3.44 | 35.10 | 152 | 19.85 | 16.91 | 8.92 |
| **Quanum 5008** | 15x8 | 3.37 | 37.07 | 170 | 19.50 | 16.12 | 10.38 |
| **Quanum 5008** | 16x10 | 4.15 | 32.90 | 229 | 16.63 | 15.27 | 14.80 |

**Table 7.2 Motor Testing**

Among the final motor choices was the Quanum 5008, a multirotor specific motor chosen for its low cost and high torque. However, as shown above the motor proved to be quite lackluster during testing, outputting a relatively low power and having an unacceptably slow speed, too low to reliably fly against the strong winds expected at competition. Ultimately, the Turnigy G10 was selected to become the final motor due to its higher speed, and adequate thrust when in two different configurations, 12x8 propeller with a 10 cell 2100 mAh battery pack for the PA, and a 11x6 propeller with a 14 cell 2100 mAh pack for the MSA.

### 7.3 Structural Testing

In order to verify the structural integrity of the aircraft, the Team performed a number of tests on structural elements, namely the wings and fuselages. To test the stresses and structural integrity of the wings, weights were placed along the lengths of the wings in order to simulate maximum wing loading. In order to test the structural integrity of the fuselages and the wing connections, tip tests were performed.

Then, to test the integrity for missions 2 and 3, both planes were loaded with the payload and new tip tests were performed on the planes. These tests allowed the Team to verify that the aircraft could withstand the flight loads. Some of these tests are documented in the figures below.


**Figure 7.2 PA Loaded Tip Test**

**Figure 7.3 MSA Loaded Wing Test**

### 7.4 Flight Testing

The Team understood the importance of test flights that do not require full mission performance from the 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. The designation is defined by: aircraft-Version-flight (maiden flight MF, Simple test S, Missions M#).

First point of version changes with large airframe changes, second with smaller optimizations.

| Flight Number | Designation | Payload | Designation | Payload |
|---|---|---|---|---|
| 1 | PA-1.1-MF | none | MSA-1.1-M2 | PA-1.2 |
| 2 | PA-1.1-S | none | PA-2.1-MF | none |
| 3 | PA-1.1-M3 | 1kg | PA-2.1-S | none |
| 4 | PA-1.2-MF | none | PA-2.1-M3 | 1kg |
| 5 | PA-1.2-S | none | MSA-2.1-MF | none |

| | | | | |
|---|---|---|---|---|
| 6 | PA-1.2-M3 | 1kg | MSA-2.1-S | none |
| 7 | MSA-1.1-MF | none | MSA-2.1-M1 | none |
| 8 | MSA-1.1-S | none | MSA-2.1-M2 | PA-2.1 |

**Table 7.3 Flight Testing**

### 7.5 Flight Testing Checklists

*Pre-Flight Checklist*

The following checks are performed five minutes prior to flight.

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

**Figure 7.4 Pre-Flight Checklist**

*Final Checklist*

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

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

**Figure 7.5 Final Checklist**

## 8.0 Performance Results

### 8.1 Component and Subsystem Performance

8.1.1 Propulsion

*Batteries*

As predicted, the batteries drained quickly during takeoff as that is the most intensive period of flight due to the need to get off the ground within a short distance. The lower current sustained after takeoff allowed the batteries to continue providing energy for the duration of the mission. Actual draw during an initial four minute test PA flight with a 14-cell pack was approximately 500mAh, using 42% of capacity. A flight with the payload caused draw to reach 850mAh, using 57% capacity. Similar energy consumptions using the 2100mAh 10-cell will leave the PA with a 43% reserve. This is done to promote use of the higher voltage near the beginning of flight, allowing for a higher average output through the duration of the flight. The MSA has only ever used the 14-cell 2100mAh packs and draws closer to 1800mAh due to drag. Both aircraft have a healthy reserve for landing near the end of their flights.

*Motor Performance in Air*

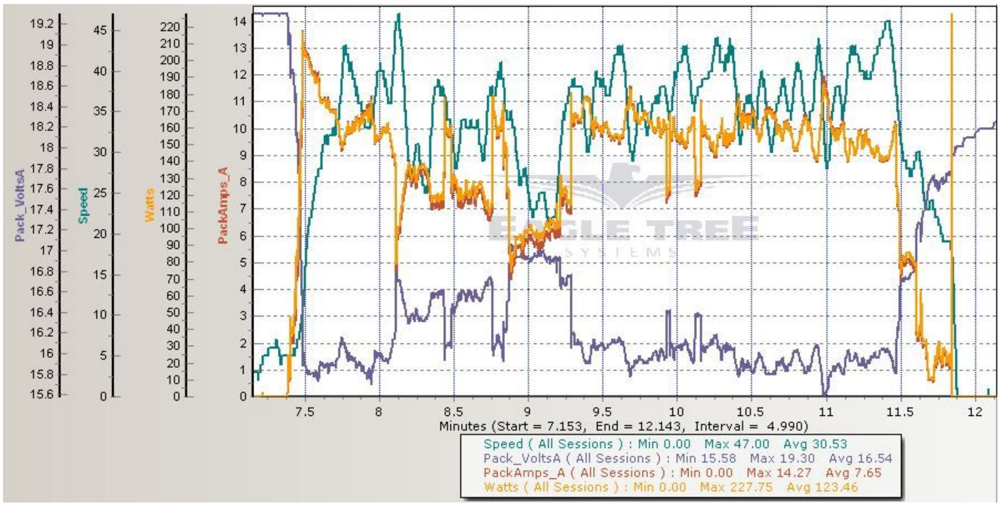


**Figure 8.1 Motor Performance (Empty Weight Reference)**

Once in the air the Turnigy G10-810 proved to be the correct choice for our needs. The lower voltage provided in the PA limited the speed and thrust somewhat compared to the larger pack found in the MSA. However, the lighter weight and more streamlined body of the PA helped to mitigate these limitations. When used on the MSA the extra voltage allows for a larger burst of power to allow the larger aircraft to takeoff in the needed distance and once in the air allowed it to be throttled back to a more reasonable current draw in the low twenties. Excess current draw is also mitigated by unloading of the propeller in flight, with max efficiency being reached at cruise.

<u>8.1.2 Structures</u>

*Fuselage and Wing*

The Team tested both the production and manufacturing wing to support the max payload when tip-tested. The Team tested the fuselage's to support the max payload when supported by the motor mount and very end of the tail to check for failure or bending. Both structures passed the tests and no failures were noted in flight testing.

*Landing Gear*

The Team tested if the landing gear to statically support 10lbs of weight to simulate a 2g impact. The Team selected this an acceptable performance standard. The Team did not observe any failures in flight testing.

<u>8.1.3 Prediction Comparisons and Improvements</u>

All of the structures performed as predicted, fulfilling the minimum requirements and proving sufficient for flight missions. After the next round of prototypes is proven to work, the Team will test all of the structures to failure, and determine if the Margin of Safety is excessive. If so, the Team will lighten structures and remove supports.

**8.2 Complete Aircraft Performance**

| | Turn Rate (deg/s) | Top Speed (ft/s) | 1 Lap Time (s) | Battery Pack Endurance (min) | Takeoff distance |
|---|---|---|---|---|---|
| Actual | 45.4 | 54.8 | 72 | 5.7 | 75 |
| Predicted | 33.9 | 69.01 | 65.17 | 4.2 | 88.72 |

**Table 8.1 Mission 1 Results**

| | Turn Rate (deg/s) | Top Speed (ft/s) | 1 Lap Time (s) | Battery Pack Endurance (min) | Takeoff Distance |
|---|---|---|---|---|---|
| Actual | 58.4 | 51.3 | 84 | 4.6 | 90 |
| Predicted | 30.5 | 64.07 | 76.60 | 4.2 | 91.2 |

**Table 8.2 Mission 2 Results**

| | Turn Rate (deg/s) | Top Speed (ft/s) | 1 Lap Time (s) | Battery Pack Endurance (min) | Takeoff Distance |
|---|---|---|---|---|---|
| Actual | 50.2 | 61.6 | 61 | 5.73 | 80 |
| Predicted | 40.7 | 79.07 | 52.66 | 4.7 | 86.34 |

**Table 8.3 Mission 3 Results**

8.2.2 Prediction Comparisons and Improvements

From the above tables it can be noted that the aircraft outperformed its prediction in turn rate. The overall top speed, however, was lower than predicted. Weather conditions and underestimates in drag meant that the lap times were slightly slower than expected, though still well within enough time to complete all missions successfully. The Team also observed shorter takeoff distances than predicted due to a headwind. The aircraft can be improved minimizing sources of parasitic drag that are not accounted for in the calculations, which would bring the actual speed closer to the predicted speed.

**8.3 Future Work**

From the flight testing plan in section 7.1 it can be seen that the Team intends to build 2 more aircraft, one PA and one MSA. These aircraft will be designed by iterating and optimizing based on the analysis in this report. The Team intends to perform detailed structural testing on all retired components once the new generation is built in order to further verify and optimize structural design. Once the final aircraft are completed they will be flight tested in all missions.