UNIVERSITY OF CALIFORNIA, SAN DIEGO

2017-2018 AIAA Design/Build/Fly Competition

Design Report

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Section 1: Executive Summary

The following report details the design, fabrication, testing and performance of the UC San Diego Design, Build, Fly (DBF) Team's 2018 competition aircraft for the 2018 American Institute of Aeronautics and Astronautics (AIAA) Design/Build/Fly Competition. The team designed an aircraft which simulates the flight of a regional business aircraft. The aircraft will successfully complete three flight missions and one ground mission. The flight missions consist of an unloaded demonstration flight, a loaded speed flight and a loaded range flight. The ground mission consists of servicing the aircraft's components under a time constraint. The team plans to successfully complete all missions, and optimize the speed and weight of the aircraft to achieve the highest score.

Design Process

The team's objective is to win the competition. To achieve this goal, the team started with a preliminary design that would result in a fast, lightweight aircraft to maximize the total score. By identifying critical metrics and criteria, the team selected a design from various conceptual designs. During the preliminary design phase, the team also compared and chose an appropriate battery, propeller, and motor configuration to accommodate the selected design and competition requirements using historical data from winning reports published by AIAA. The team performed lift, drag, and weight analyses as well as trade studies to determine the optimal configuration for the aircraft.

The team selected a conventional high wing aircraft shown in ***Figure 1.1***, consisting of a spine on which the fuselage, wing, tail and motor are mounted. The aircraft will carry a maximum of one passenger and one payload block for loaded missions.

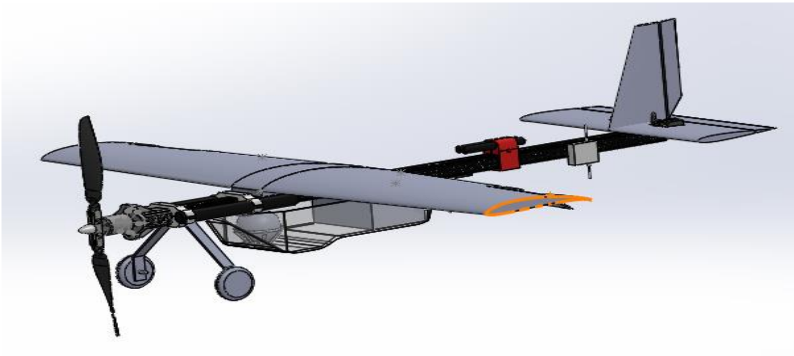


Figure 1.1: Conceptual Plane Design

The modular design allows for rapid iteration of prototypes, and ease of access for servicing components during the ground mission.

Key Mission Requirements

The DBF competition consists of three flight missions and one ground mission. The flight missions are performed by flying laps around a figure-8 flight course of approximately 3000 feet in distance traveled. Mission 1 is an unloaded flight; a passing score is awarded if 3 laps are flown within 5 minutes. Mission 2 is a passenger speed flight. Scores will vary based on how many passengers are carried and how quickly the aircraft can complete three laps. Mission 3 is an endurance flight; the aircraft will carry at least 50 percent of the passengers as well as additional payload blocks. Scores will vary based on the size of the payload and the number of laps completed. The ground mission is a serviceability test. Two team members must be able to successfully service parts of the aircraft under tooling and time restrictions. The team identified three important design elements that were optimized to maximize final score: empty weight, cruise speed, and modularity.

Empty weight is a key factor because its value is included in the Rated Aircraft Cost (RAC), a divisor for the overall score. Also, a lighter aircraft flies faster, and requires less thrust which enables a longer maximum flight time. The team elected to use light composites, plastic and foam for main structures on the aircraft, in order to minimize weight.

Cruise Speed is important because the fastest aircraft in the competition will receive the highest mission 2 score, and will likely achieve the highest overall score for mission 3 as well. The team focused on propulsion choice, minimizing drag and overall cross-sectional area to achieve the highest overall cruise speed. The team selected to only fly one payload block for mission 3. This decision allowed the propulsion system, fuselage and payload bay to be optimized to meet this goal.

Aircraft modularity is a key factor. The aircraft must be able to be serviced easily. By reducing the amount of payloads, and the complexity of various subsystems, the team was able to produce a final design which would enable the ground mission to be easily completed.

Final Capabilities

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

- Completes 1 lap in 50 seconds empty and 55 seconds with payload
- Capable of 5 minutes of endurance at nominal required cruise speed
- Capable of carrying one passenger and one payload block
- Capable of taking off and landing safely on the landing gear

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 optimizations are ongoing. The team will use the remaining weeks to finish fabrication of the final aircraft and fine tune it for competition.

Section 2: Management Summary

The 2017 – 2018 UCSD DBF Team is comprised of ten members. Three are seniors, while the rest are sophomores and juniors. This section outlines how the team is organized to complete the tasks required to compete in the 2018 DBF competition.

2.1: Team Organization Overview:

UCSD DBF has chosen to follow a hierarchical structure for the 2017-2018 competition. The project managers oversee the leads of each sub-team and make final decisions regarding team efforts and prioritization. Each sub-team has a lead member who reports progress in their department to the project managers. The sub-team disciplines that were chosen to organize this year's team include: Aerodynamics, Propulsions and Controls, Structures, Fabrication, Report, and Finance.

Figure 2.1 outlines how the sub-teams are arranged systematically, and ***Figure 2.2*** details what tasks are delegated to each sub-team. Finally, non-lead members are able to join any sub-team, building skills across disciplines. However, they are encouraged to specialize in the operations of one specific sub-team so that expertise is built for following years.

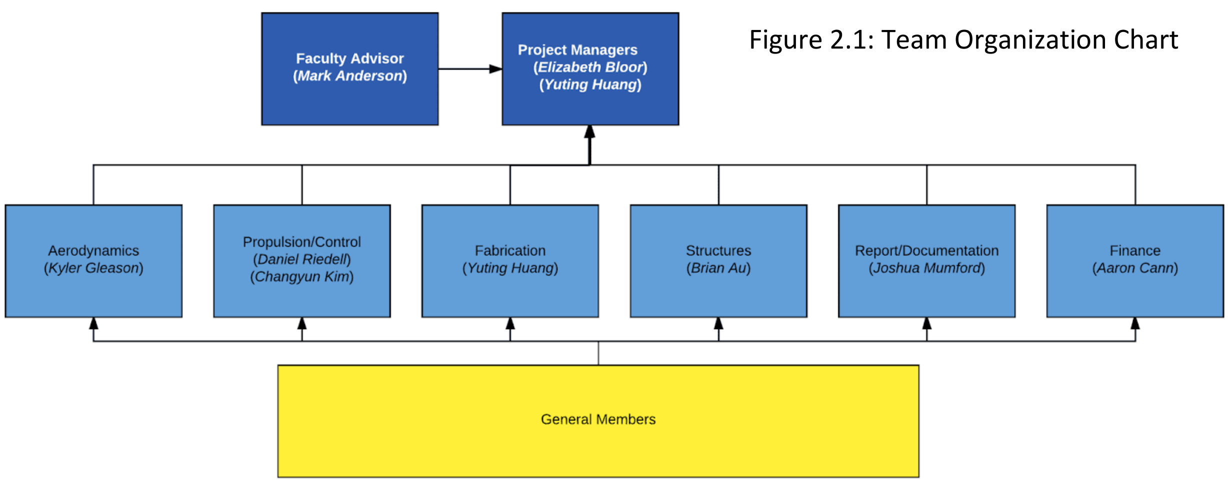


Figure 2.1: Team Organization Chart

Sub-Team	Responsibilities
Aerodynamics	Airfoil Selection, Wing Sizing, Control Surface Design, Drag Minimization Strategies
Propulsions/Control	**Motor Selection, Battery Sizing, Flight Controller Selection, Testing**
Fabrication	Aircraft Component Fabrication, Assembly, Defining Manufacturing Limitations
Structures	**Structural Analysis, Fuselage Design, Landing Gear Design**
Report	Proposal, Final Report, Record Keeping
Finance	**Funding, Team Accounting**

Figure 2.2: Sub-team Task Delegation

2.2: Project Timeline:

The team has developed a Gantt chart project timeline to track the progress for design, manufacturing, and testing of this year's aircraft. This chart is outlined by ***Figure 2.3***. The highlighted sections show which weeks an item of the project is scheduled to take place. Stars represent weeks where milestones occur. These milestones represent the deadline for an objective to be completed. The project managers are responsible for keeping the team working according to this schedule.

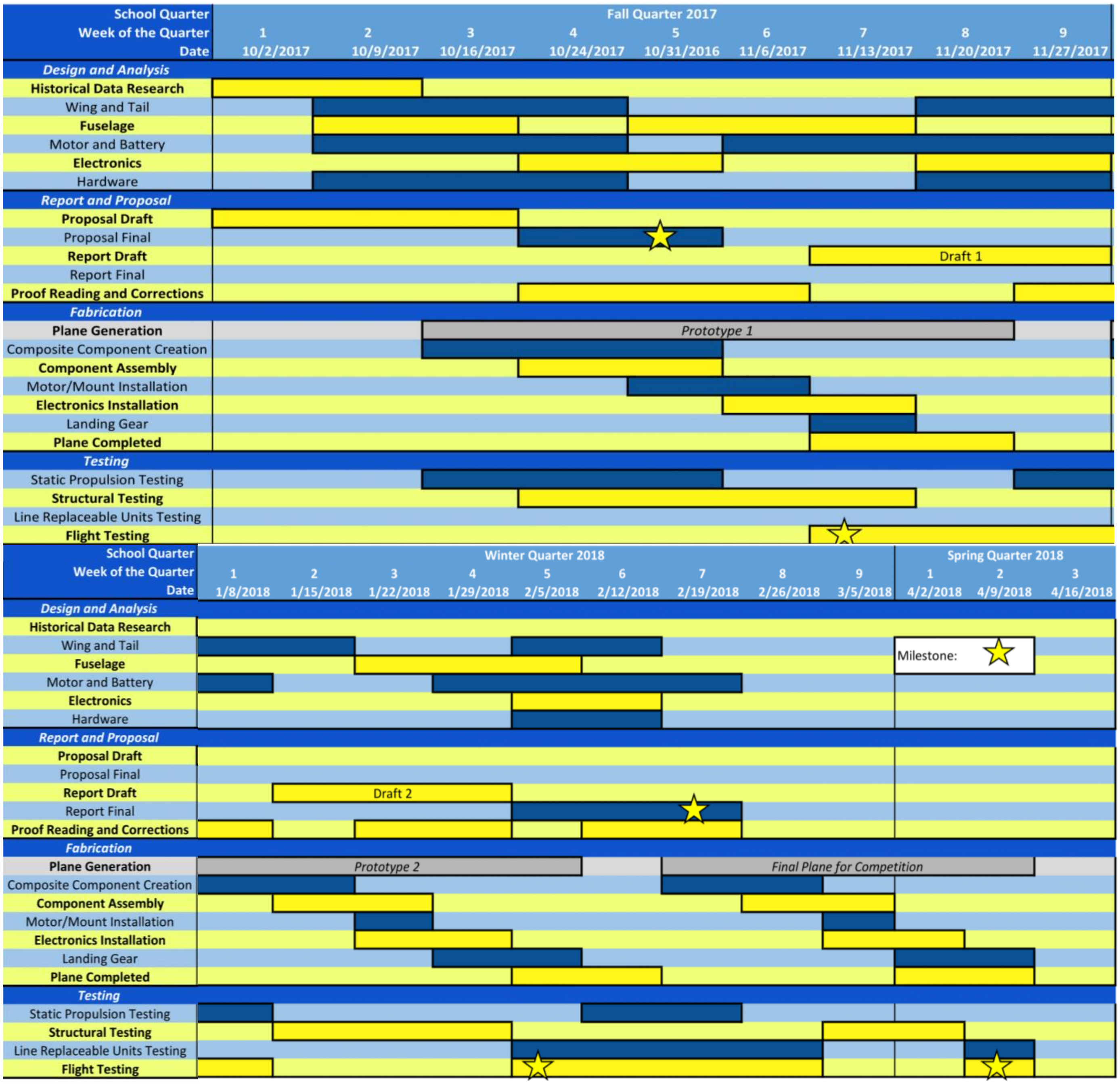


Figure 2.3: Project Timeline

Section 3: Conceptual Design

During the conceptual design phase, the team used the mission requirements, safety regulations, and scoring process devised by AIAA for the 2018 DBF competition to determine the design requirements for the aircraft. From the design requirements, the team set out to develop a concept for the 2018 aircraft which could satisfy those design requirements well and would be deliverable within the given project timeline. This section outlines the process of selecting a design concept.

3.1: 2018 Competition Overview – Mission Summary and Scoring:

The 2018 DBF competition simulates the design of a commercial aircraft, transporting both cargo and passengers. Aircraft will complete three flight missions to test performance for flight capability, capacity, and endurance. The flight capability of the aircraft is demonstrated through mission 1, which is an empty-weight demonstration flight. Prior to mission 2, the aircraft must complete a ground mission, testing for this year's design requirement of Line Replaceable Units (LRUs). This requirement simulates servicing that would occur on a real commercial aircraft between flights. As such, the LRUs must be replaceable within a set amount of time and practical limits to tool access. Capacity can be demonstrated by flying with additional payloads in missions 2 and 3. Endurance will be demonstrated through mission 3, where scoring is increased based on the number of laps completed in a single flight with at least a minimum payload. An additional element of importance will be the overall dimensions of the aircraft, which are accounted for in this year's Rated Aircraft Cost (RAC). An Aircraft that accomplish the goals of each mission and minimize RAC should score well in the competition. All flight missions follow the lap format outlined in ***Figure 3.1***. This lap is comprised of two 1000 ft straight paths connected with two 180º turns and a 360º turn in the middle of the second straight path. To complete a flight successfully, aircraft must depart from the starting line, take off within 150 ft of the starting line, and land intact and crossing the starting line.

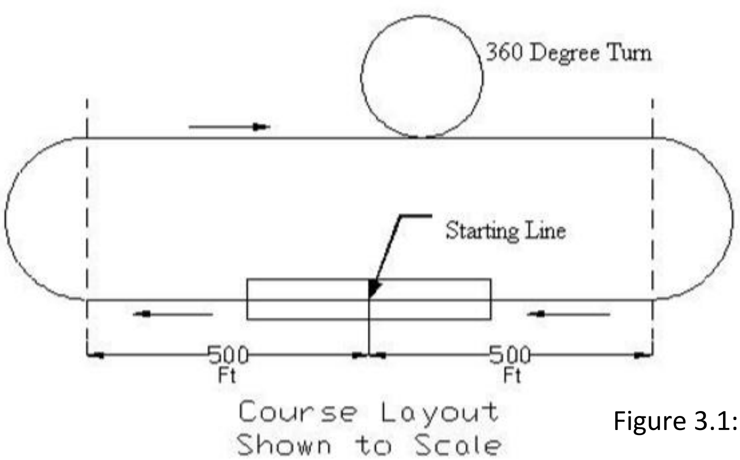


Figure 3.1: AIAA Competition Lap Layout

Mission 1:

The first mission is a demonstration flight. The aircraft must be able to fly three laps in five minutes without any payload to complete this mission. Successful Completion of the first mission gains teams 1 point and allows them to advance to mission 2 once the ground mission is complete.

$$M_1 = 1 \text{ (for successful attempt)}$$

Ground Mission:

During the ground mission, two team members and the team pilot must replace two LRUs in a period of eight minutes. The LRUs are selected for removal by rolling dice. The eight-minute period is split between two stages. The first stage lasts for three minutes, and the second stage lasts for five minutes. Each stage involves the removal of one LRU. To successfully complete the ground mission, the LRUs and tools for removal must start within the payload bay and be properly secured within the time limits provided. A successful completion of the ground mission qualifies a team to fly for mission 2.

Mission 2:

Mission 2 is a short haul flight with passengers. The aircraft may be loaded with passengers up to the maximum number declared during tech inspection. Five minutes will be given to complete three laps. However, a shorter time to complete the three laps will positively impact the score for this mission. The scoring breakdown for mission 2 relies on the individual aircraft's score, but is normalized by the highest mission 2 score of the whole competition. The individual scores are based on the number of passengers and the amount of time taken to complete all three laps (t).

$$M_2 = 2 \cdot \left(\frac{\frac{p}{t}}{\max\{M_2\}}\right)$$

Mission 3:

Mission 3 is a long-haul flight with passengers *and* payload blocks. The dimensions of each payload block must add up to at least 9 linear inches. Ten minutes will be given to complete as many laps as possible with at least half the maximum number of passengers and one payload block. The scoring breakdown for mission 3 relies on the individual aircraft's score but is normalized by the highest mission 3 score of the whole competition. The individual scores are based on the number of passengers, the weight of the payload blocks (W_b), and the number of laps completed (n). R_s

$$M_3 = 4 \cdot \left(\frac{p \cdot W_b \cdot n}{\max\{M_3\}}\right) + 2$$

Rated Aircraft Cost (RAC):

A team's RAC for the 2018 DBF competition is the product of wingspan (WS) and total empty weight (EW). The wingspan will be measured in inches, and the empty weight will be measured in ounces.

$$RAC = EW \cdot WS$$

Total Score:

The total score (T_s) is function of each mission score, the team's report score (R_s), and the RAC.

$$T_s = \frac{(M_1+M_1+M_3)\cdot \mathrm{Rs}}{RAC}$$

3.2: Design Requirements and Objectives:

The mission requirements, scoring, and general requirements enabled the team to generate a set of design requirements and objectives which were used in the selection of a final design concept. The mission design objectives that were translated from the mission requirements are outlined in ***Figure 3.2***. Additionally, the team also took the competition's general requirements into account when considering design concepts. These restraints and objectives enabled the team to produce Figures of Merit, which were used to select the conceptual design for the aircraft.

General Design Restraints:

Propulsion:

- Aircraft must be motor and propeller driven
- All propellers used must be commercially produced
- All motors used must be commercially produced

Power Supply:

- Sole power supply for flight must come from on-board batteries
- No externally assisted take-off power provided
- Batteries must be commercially produced Nickel Cadmium (NiCad) or Nickel Metal Hydride (NiMH) with proper insulation via shrink wrap, and with visible labels on cells documenting the manufacturer

Size and Configuration:

- Total weight must be less than 55lbs
- No lighter-than-air configuration may be used to provide lift
- No rotary wing configuration may be used to generate lift
- No structural components may be dropped mid flight
- Payloads must be fully internal

Size and Configuration Cont.:

- Passengers must be secured in individual "seats", with an adjacent 2-in wide by 2-in tall aisle space
- Payload blocks must be positioned below of behind passengers
- Payload blocks must have combined linear dimensions greater than or equal to 9 in
    - Length + Width + Height $\geq$ 9 in

Score Factor	Objective	Crucial Design Parameters
Mission 1	Complete three laps in five minutes or less	Empty Weight (W_e) Motor Power (P_m) Lift (F_L)
Mission 2	Complete three laps with passengers as fast as possible	Passenger Weight (W_p) Number of Passengers (N_p) Motor Power (P_m)
Mission 3	Complete as many laps as possible in five minutes	Total Weight (W_{tot}) Passenger Weight (W_p) Number of Passengers (N_p) Payload Weight (W_b) Motor Power (P_m) Power Supply (B)
RAC	Minimize wingspan Minimize weight	Empty Weight (W_e) Lift (F_L)

Figure 3.2: Table of Mission Objectives and Design Parameters Affected

Score Sensitivity Analysis:

Through analyzing the objectives of each score factor found in ***Figure 3.2***, the team was able to identify design parameters for further investigation and prioritizing in the design selection process. The weight of the aircraft was identified as a very crucial parameter. Similarly, the amount and weight of payloads affects the scores of missions 2 and 3. From these parameters, the team identified that an in-depth study of how the aircraft's weight and payloads affect overall score would be beneficial to selecting a design concept. Such a study was additionally important, as the weight of the aircraft impacts the lift and thrust required for flight, which ultimately affects performance for all four scoring factors. As a result, the team decided to study how overall weight and the payload weight impact scoring.

Weight effects of Extra Payloads:

The empty weight of the aircraft is proportional to how much the maximum possible payload weighs. This is because the aircraft must be designed to accommodate the mission objectives under the heaviest possible configuration to successfully complete them. For this analysis, the team used the ratio of payload weight to total weight (η) to express the relationship between payload weight and empty weight:

$$W_{total} = W_{payload}/\eta$$

$$W_{empty} = W_{total} - W_{payload} = W_{payload}\left(\frac{1}{\eta} - 1\right)$$

This relationship will always be positive, because the payload weight can't exceed the total weight (η always < 1). That means that a substantial increase in the payload weight will increase the empty weight of the aircraft.

Weight Effects on Lift and Wing Span:

The lift provided by the wings must be enough to support the maximum total weight (W_{total}) in level flight. During this period of flight, the vertical forces on the aircraft are in equilibrium. Therefore, we find:

(1) $\sum F_y = F_L - W_{total} = 0$ (Newton's 2^{nd} law), which becomes $F_L = W_{total}$

Using the equation of lift and wingspan, we can find a relationship between the wing span required and the empty weight of the aircraft.

$$\textbf{(2)}\quad F_L = \frac{1}{2}\rho v^2 C_L \cdot S$$

$$\textbf{(3)}\quad b = \sqrt{S \cdot AR}$$

By using the force balance from (1), we can define S and b (the wing span) in terms of total weight:

$$S = \frac{W_{total}}{\frac{1}{2}\rho V^2 C_L}$$

$$b = \sqrt{S \cdot AR}$$

This enables us to show how the weight of additional payloads will impact the RAC.

Payload Effects on RAC:

As shown previously, the total weight is proportional to the weight of additional payloads. This relationship allows us to express the empty weight in terms of the payload weight. Additionally, it was shown that the wingspan of the aircraft could also be related to the total weight. Therefore, wingspan can be related to the maximum payload. Since RAC is defined as the product of empty weight and wingspan, the previously found relationships enables the relation of RAC to payload weight.

Analysis of this relationship will show that decreasing the payload weight and/or increasing η will decrease the RAC. Because the mission scores are normalized by RAC, the total score will rise if RAC is decreased. While there are practical limits to raising η and lowing the payload weight, this relationship generally shows that keeping the payload weight low will lower RAC, giving a boost in overall scoring.

$$\begin{aligned} RAC &= W_{empty} \times b \\ &= W_{payload}\left(\frac{1}{\eta} - 1\right)\sqrt{\frac{W_{payload}/\eta}{\frac{1}{2}\rho V^2 C_L} \cdot AR} \\ &= \left[W_{payload}^{1.5}\right] \cdot \left[\left(\frac{1}{\eta} - 1\right)\sqrt{\frac{AR}{\eta V^2 C_L}}\right] \cdot \left[\sqrt{\frac{2}{\rho}}\right] \end{aligned}$$

Analysis Conclusion:

From the analysis of the effects of weight on performance, the team decided to focus on minimizing the payload carried in missions 2 and 3. Minimizing the maximum payload does negatively impact mission scoring for missions 2 and 3. However, the scores for missions 2 and 3 are normalized by the best competition score. This means that increasing the payload carried won't guarantee a substantial increase in scoring. However, minimizing RAC will positively impact scoring regardless of performance in any mission. A team that has a low payload capacity could perform better than a team with a high payload capacity if they have a lower RAC. This led the team to conclude that configurations carrying small payloads, allowing the aircraft's empty weight to be minimized, would be the best configurations to consider.

3.3: Configuration Selection:

Design Process

Following the conclusion that smaller designs would be considered, the team needed to decide upon the optimal concepts for major components that would allow for weight and wingspan reduction. The major design elements were: the fuselage, the wings, payload containment, the propulsion system, and the landing gear. Throughout this process, the team considered all suggestions and utilized the design requirements to select and optimize these choices.

Figures of Merit

In order make the best possible selection, the team employed Figures of Merit (FoM) based upon the most important design elements stated above. Each FoM was weighted based upon a 100 point scale dependent on a trait's importance to the success and ultimate score of the design with more significant aspects possessing greater weights. The weight of these traits vary between FoM as each component of the aircraft possesses different needs and considerations.

Selection Weighting System

The different possibilities for each design element were compared against each other through a decision matrix system to determine the ideal solution. Each selection was assigned a score from one to five based upon how well a design choice met the design requirements as compared to the other possibilities. The scores' meaning is outlined in ***Figure 3.3***.

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

Figure 3.3: Selection Scoring

Aircraft Configuration

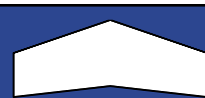
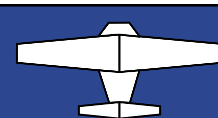
FOM	**Weight**	 **Flying Wing**	 **Conventional**
Mass	40	4	5
Structural Capability	20	4	4
Manufacturability	10	3	5
Stability	30	3	4
Total	100	360	450

Figure 3.4: Aircraft Configuration Table Figure of Merit

The main considerations for the aircraft configuration in ***Figure 3.4*** were the mass and stability. mass was weighted highly because of its impact on the aircraft's RAC. Stability was considered crucial because of the potential for high winds experienced in Wichita, where the 2018 DBF competition is taking place. Structural capability was given moderate weight, while manufacturability was weighted low. The team selected a conventional aircraft configuration to capitalize on improved stability. This airframe can also be constructed modularly, allowing for easy testing of different wing and fuselage combinations and ease of access for LRU components during the ground mission.

Fuselages

FOM	Weight	Round	Horizontal Rectangle	Vertical Rectangle
Mass	30	1	3	2
Drag	20	1	2	2
Structural Capability	20	3	2	2
Manufacturability	10	1	3	3
Landing Surface	20	2	3	1
Total	100	160	260	190

Figure 3.5: Fuselage Configuration Figure of Merit

Weight, drag, structural capability, are the important factors in ***Figure 3.5*** when considering the general shape of a fuselage. With less drag and weight, the aircraft has higher potential speed and less weight also directly improves the overall score. The team decided on a payload bay with a horizontal rectangular cross section. This configuration provides the most stable surface in case the landing gear fails, requires less material, is the easiest to manufacture, and has minimal surface area for friction drag during flight.

Propulsion Systems

The following motor configurations were taken into consideration:

- Single Tractor: A single motor mounted at the nose of the aircraft
- Dual Tractor: Two nacelle-housed motors
- Single Pusher: A single motor mounted behind the wing of the aircraft.

As shown in ***Figure 3.6***, propulsion systems were scored based on weight, aerodynamic efficiency, stability, and ease of assembly. The single tractor setup is ideal as it has a low weight and is easiest to manufacture. A dual tractor system would have the highest aerodynamic efficiency out of these systems because of clean airflow not obstructed by the fuselage. However, supporting the motors in a way that makes them accessible for changing out during the ground mission poses design challenges. A single pusher would cause the CG to move further back on the aircraft, potentially decreasing the stability. For these reasons, a single tractor setup was selected.

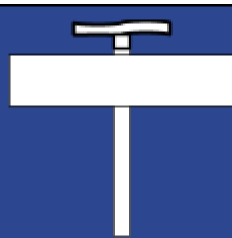
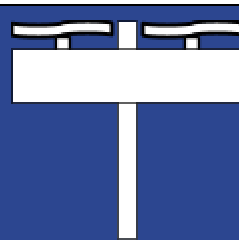
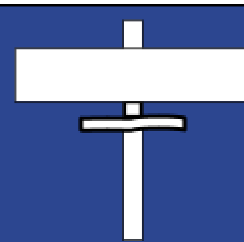
FOM	Weight	 Single Tractor	 Dual Tractor	 Single Pusher
Weight	35	5	4	5
Aerodynamic Efficiency	20	3	5	3
Stability (CG balancing)	20	5	4	3
Ease of Assembly	25	5	3	3
Total	100	**460**	395	370

Figure 3.6: Propulsion Configuration Figure of Merit

Wings

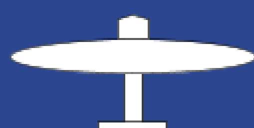
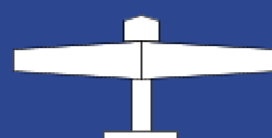
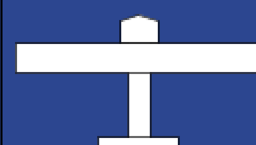
FOM	Weight	Elliptical 	Tapered 	Rectangular 
Ease of Fabrication	10	3	4	5
Aerodynamic Efficiency	40	3	3	2
Mass	30	4	4	3
Stability	20	3	3	5
Total	100	330	340	320

Figure 3.7: Wing Shape Figure of Merit

The shape of the wing for best performance was determined by weighing ease of fabrication, aerodynamic efficiency, weight and stability. Elliptical, Tapered, and Rectangular wing shapes were considered in ***Figure 3.7***. A tapered wing shape was selected to reduce mass and maximize wing area while reducing the wingspan. In addition to wing shape, the team considered the effects of various wingtip options, as outlined in ***Figure 3.8***.

FOM	**Weight**	**Rounded**	**Angular**	**Hoerner**	**None**	**Winglet**
Weight	25	4	4	3	5	2
Aerodynamic Efficiency	45	3	2	4	0	4
Ease of Fabrication	30	3	3	3	5	2
Total	100	325	290	345	275	200

Figure 3.8: Wingtip Configuration Figure of Merit

Hoerner wingtips were selected as they offered the highest aerodynamic efficiency while being easy to manufacture. Additional considerations for the wing were Aspect Ratio (AR) and wing thickness. The team considered wing thicknesses in the medium (10-15%) or high (>15%) ranges and chose between uniform thickness or wings that would taper in thickness from root to tip. The team considered ease of fabrication, weight, and structural stability, deciding on a uniform medium thickness as shown in ***Figure 3.9***.

FOM	**Weight**	**Medium/Uniform**	**High/Uniform**	**Medium/Taper**	**High/Taper**
Ease of Fabrication	40	4	5	3	4
Mass	55	4	2	5	3
Structural Stability	5	4	5	3	4
Total	100	400	335	410	345

Figure 3.9: Wing Thickness Figure of Merit

Landing Gears

For the landing gear, the main factors considered were 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 aircraft 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 decided that the tail dragger would be slightly more stable and maneuverable based on historical implementation. Therefore, the team decided upon a tail dragger landing gear configuration.

Tails

FOM	Weight	Ring	Conventional	Box	Double Fin	Triple Fin	Plus
Landing	20	5	2	5	2	2	1
Ease of Fabrication	15	4	5	4	4	4	4
Drag	25	1	5	1	4	3	4
Surface Area	30	3	3	4	4	4	3
Weight	10	2	5	2	4	4	4
Total	100	295	380	325	360	335	310

Figure 3.10: Tail Configuration

Multiple tail configurations were considered, as shown in ***Figure 3.10***. Considerations included: maximizing surface area for minimum cross section, protection on belly landings, drag, and weight. The team selected a conventional tail design for its ease of fabrication, low drag, and small surface area compared to the other choices.

Controls

FOM	Weight	Full Control	No Rudder	With Flaps
Mass	20	2	3	1
Complexity	30	2	3	1
Stability	40	4	2	5
Manufacturability	10	2	3	2
Total	100	280	260	270

Figure 3.11: Control Scheme Configuration Figure of Merit

The team considered three control schemes: full control (aileron, elevator, rudder), no rudder, and full control with flaps. These choices were compared using weight, complexity and manufacturability. As shown in ***Figure 3.11***, the team selected full control. This decision was primarily due to the need for yaw control during takeoff to keep the aircraft straight, and also to control for potentially strong crosswinds.

3.4 Final Conceptual Design

After creating the decision matrices, the team chose a configuration with the following elements:

- Conventional aircraft configuration with rudder control
- Rectangular fuselage with landing gear
- Single motors/propellers mounted at the nose of the aircraft
- Tapered wings with Hoerner wingtips

These designs were selected because they give the team the best chance of getting the highest possible score and winning the competition. The aircraft is estimated to weigh 35.1 oz and is expected to fly fast enough and long enough to receive decent scores for missions two and three.

Section 4: Preliminary Design

4.1 Design Methodology:

Structure Design Methodology

In terms of structures, the team designed the aircraft to maximize the efficiency while maintaining a high margin of safety for all loading conditions. With that in mind, the team worked towards minimizing the weight of the aircraft without sacrificing strength. The following details the design constraints and parameters in which the team designed various parts of the aircraft. The materials were chosen to resist loads during takeoff, landing, stall, and dive. To meet bare safety requirements, the team decided that the wing would need withstand load factors in the range of -1 and 2.5 $(-1 \leq n \leq 2.5)$.

With an average weight of 36 ounces, the team determined that the wings should be designed to be able to resist about -3 - 7.5 pounds of lift. The rest of the structural components are designed around these lift loads.

Significant Loads to be Considered:

- Lift Off - 7.5 pounds lift
- Dive - 3 pounds downward force
- Thrust - 3 pounds horizontal to aircraft
- Drag - 3 pounds at max speed

Aerodynamics Design Methodology

The two major aerodynamic parameters considered were airfoil selection and airfoil sizing. Computational Fluid Dynamic (CFD) analyses were performed in XFLR5 to verify the design. A tapered wing design was chosen to maximize wing area while minimizing wing span. For the horizontal stabilizer, a non-tapered, rectangular airfoil was considered for ease of manufacturability. For the vertical stabilizer, a symmetric airfoil was considered for stability and control purposes.

Propulsions Design Methodology

In terms of propulsions, the main design concern was the amount of power needed for flight. This mainly involved choosing a battery pack that would provide enough power for the duration of the flight and a motor that can provide enough thrust to take off and maintain flight. More detailed decisions such as propeller and pack voltage/capacity are reserved for later sections.

The battery pack must be able to provide enough power at take-off to ensure the aircraft makes it into the air. The following is how the team calculated the power necessary using historical data [2][3]:

$$P_{Required} = T * V_{min}$$

where T = Thrust required to overcome

Drag V_{min} = minimum velocity required for take-off

$P_{Required}$ = power required from the engine

This gives a required power of at least 200 Watts and provides a lower bound when searching for both batteries and motors. In addition, some motor manufacturers include a thrust value associated with the motor, which can be used to further narrow the scope of acceptable motors. The batteries should be as light as possible so that the overall weight is as light as possible, therefore minimizing the RAC. The choice between batteries is ultimately decided by the number of cells and their mAh, which determines the max voltage and allowable current draw. As more aerodynamic decisions are made, more exact values can be used the calculate power requirement and refine the results.

4.2 Mission Modeling and Optimization Analysis

In order to predict performance during flight, the team created a mission model in MATLAB. With this model, the team can input relevant vehicle information (thrust, weight, lift, drag, max speed, etc.) and receive an output file detailing flight path, performance parameters, and time information. ***Figure 4.1*** shows the modeled flight path that was divided into the following elements [3]:

- Launch (red): The aircraft starts with a 20mph velocity
- Liftoff (blue): The aircraft achieves minimum flight speed of 30mph and begins climb to 100ft.
- Straightaway 1 (gold): after achieving altitude the aircraft flies level until flag 1 (500ft from launch)
- 180 degree turn 1 (green): after passing flag 1 the aircraft initiates a 180 degree right turn
- Straightaway 2 (purple): After completing the 180 degree turn, the aircraft flies level for 500 feet
- 360 degree turn (black): The aircraft completes a 360 degree left turn.
- Straightaway 3 (Grey): After completing the 360 degree turn the aircraft flies level to flag 2 (500 ft)
- 180 degree turn 2 (Brown): After passing Flag 2 the aircraft initiates a 180 degree turn.
- Straightaway 4 (Pink): 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 Straightaway 1 Section of flight, typically only the first lap is modeled.

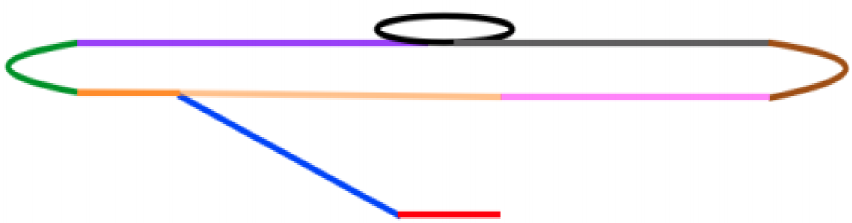


Figure 4.1 Model Flight Path

Mission Model Uncertainties

The mission model is only a rough estimation of flight performance, and carries many inherent uncertainties. Not all components (such as the motor) will perform ideally during actual flight, and there may be discrepancies in weight, lift, and drag parameters of the final aircraft due to variations in manufacturing. This creates uncertainties in the parameters inputted into the model, such as thrust, weight, and cruise speed. Additionally, wind is neglected in the model, and so the presence of wind at competition will change expected performance. Finally, the mission model assumes maximum cruise speed for straight flight, and 2g turns, but the inputs of the pilot will differ from the ideal path analyzed in the mission model. All these factors contribute to uncertainties in the mission model, which represents ideal conditions and is expected to vary slightly from actual flights [3].

4.3 Design Trade Studies:

Propulsions

Design for the propulsion system of the aircraft focuses on the battery size and motor characteristics. Due to the constraints of the competition, only Nickel Metal hydride (NiMH) or Nickel Cadmium (NiCd) cells can be used to power the motor. The team selected NiMH cells due to the high energy density. NimH cells provide 77.3-78.3 Wh/kg (nominal voltage*capacity) whereas NiCd only provides 48.5 Wh/kg. Since the aircraft will have a top speed of 117 ft/s and around 2.5lbs of drag, the aircraft will require around 400 Watts of power with or without payload. Due to this high requirement of power, the energy density of the battery plays a crucial role. Also, due to this year's requirement of the battery pack fitting in the payload bay, the battery pack shape will have to take this challenge into account (as well as aerodynamics). The team will decide between two types of batteries shown in ***Figure 4.2*** [2].

Battery Description	Capacity (mAh)	Weight (ounces)	Size (inches)
Elite 1500 2/3A	1500	0.81	1.1x0.7x0.7
Elite 2100 4/5A	2100	1.15	1.7x0.7x0.7

Figure 4.2: Battery Cells Considered

In addition to battery cell specification, ***Figure 4.3*** displays battery pack size [2]

Capacity (mAh)	Cell Count	Weight (g)	Voltage (V)	Max Continuous Draw (amps)	Capacity/weight (mAh/g)
1500	10	229.7	12	30	65.3
2100	10	326	12	30	64.4

Figure 4.3: Battery Packs Considered

Since the capacity to weight ratio of the 1500mAh and the 2100mAh is nearly identical, battery selection will be based on how much flight time each pack will give at full power. At full throttle the motor will draw around 37 amps of current (refer to scorpion motor table). The 1500mAh battery will last 2.4 minutes and the 2100mAh battery will last 3.4 minutes. A minimum flight time of 5 minutes will be required, so both battery packs will have to double in size and get wired in parallel to support the extra time needed in flight. Wiring two packs in parallel also helps with the max continuous draw of the batteries effectively doubling it from 30 amps to 60 amps.

Motor selection depends on compatibility with the battery pack, propeller, and flight characteristics. The team must decide first on flight characteristics. Flight characteristics can split into two categories. Slow acceleration, but fast cruise speed or fast acceleration, but lower cruise speed. If the former characteristic is chosen, then the motor will require a high kV with a smaller prop. And the latter characteristic requires a low kV with a larger prop. Due to the punishing winds in Kansas, the team will decide on motors with high kV, but will also take low kV motors into consideration. Once speed and acceleration characteristics have been determined, max power needs to be taken into consideration. The team will like to fly at 117 ft/s. According to the aerodynamics team, the total drag force at 117 ft/s will be 3lbs. Using P = F*v, a motor that can provide 400 Watts will be required. ***Figure 4.4*** shows the prospective motors for the aircraft [2].

Motor	kV	Max watts (W)	Weight (oz)
Scorpion SII-3026	1190	1050	7.23
Scorpion SII-3020	1110	840	5.86
Turnigy L3010C	1300	420	3.06
Turnigy LD2840A	1800	400	3.28

Figure 4.4: Motor Selection

After motor selection the team determined the requirements for a propeller. Generally, large propellers have a higher efficiency at low speeds and small propellers have a higher efficiency at high speeds. Additionally, large propellers work best with low kV due to the extra torque needed to spin a larger radius. Since the team decided on a high kV, high speed motor, a smaller propeller within the range of 6-8 inches was considered. Another characteristic needed for propeller selection is the pitch size. Pitch size can be determined by looking at the kV of the motor, max voltage of the battery pack, and top speed of the aircraft. The kV of the selected motor is 1100kV and the max voltage is 12V which yields an rpm of 13200. Using rpm * pitch = velocity and solving for pitch, the pitch required will be 6.38”. ***Figure 4.5*** shows tests from the Scorpion website using the Scorpion SII-3020 with propellers with diameter 8” - 9” and pitch 4.5” - 8” and their performance [4].

Propeller	Thrust(oz)	Voltage(V)	Current(A)	Pitch speed(mph)
8”x8”	37.81	11.1	36.88	82.9
9”x6”	47.68	11.1	30.33	63.9
9”x7.5”	52.4	11.1	45.64	74.6
9”x4.5”	83.47	14.8	43.43	62.5

Figure 4.5: Propellers for Scorpion SII-3020 Considered

4.4 Aerodynamics

When selecting the airfoils for the main wing, horizontal stabilizer, and vertical stabilizer, the team focused on airfoils that could provide high lift at low Reynolds numbers. The team considered approximately 100 airfoils that provided desired characteristics, narrowed down from thousands of options. The collection of airfoils the team used for testing were selected due to their thickness, low Reynolds numbers, and manufacturability. Low thickness airfoils don’t provide enough structural support for the wings during flight so the team decided that a thickness of at least 10%. Many airfoils have difficult geometries including sharp leading edges and excessively high camber which could lead to unpredictable aerodynamic characteristics if there are any errors in manufacturing. Using XFLR5, the team analyzed numerous airfoils and selected an airfoil that had the most desirable characterizes for our mission requirements. The results for various aerodynamic parameters are show in ***Figure 4.6***, ***Figure 4.7***, and ***Figure 4.8*** below.

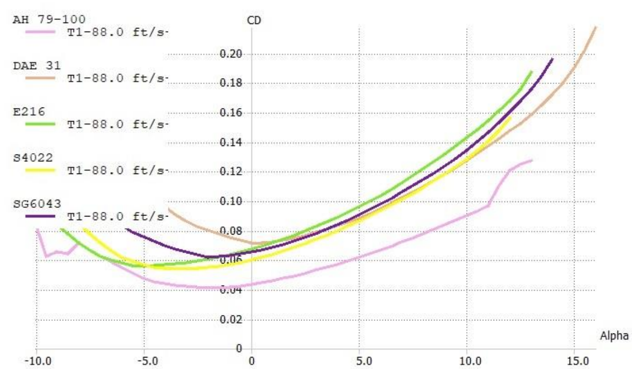


Figure 4.6: Coefficient of drag plotted versus Angle of Attack

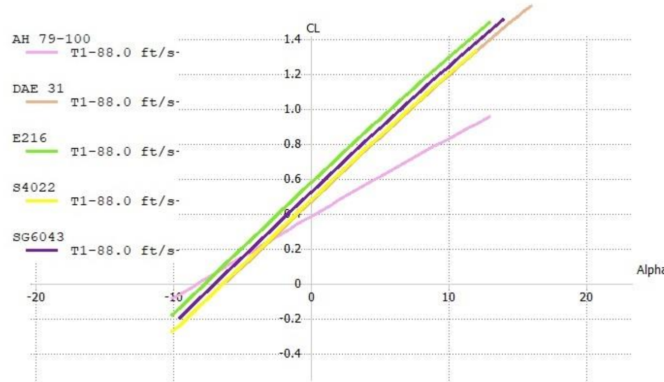


Figure 4.7: Coefficient of lift plotted versus Angle of Attack

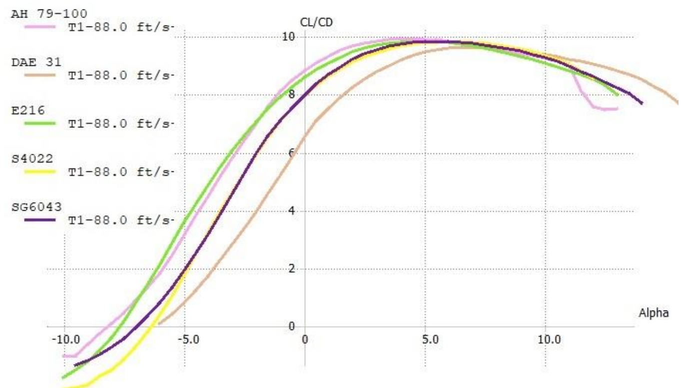


Figure 4.8: glide ratio versus Angle of Attack

From the analysis, the team calculated that the AH 79-100 airfoil has a high coefficient of lift at low speeds which is advantageous for short distance takeoffs. The AH 79-100 also had the best glide ratio at low angles of attack which made it the best option for highly efficient steady level flight. Additionally, its 10% thickness provides the necessary structural stability for the materials that the team uses for manufacturing. AH 79-100 airfoil is depicted in ***Figure 4.9***

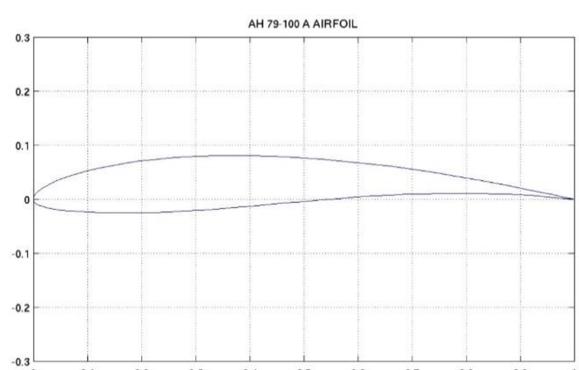


Figure 4.9: Airfoil AH 79-100

Two different airfoils with different stall angles were selected for the purpose of inducing aerodynamic twist in the wing in order to prevent the loss of aileron control near stall angle. The team determined that airfoil E216 had a greater stall angle than AH 79-100 and therefore would be the airfoil at the wing tips. Airfoil E216 is depicted in ***Figure 4.10***

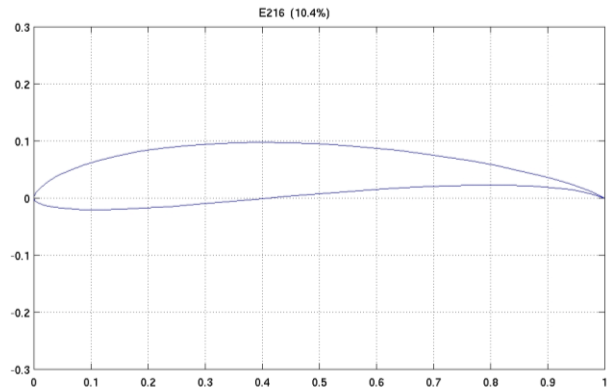


Figure 4.10: Airfoil E216

Airfoil Sizing

When sizing the wing, parameters such as necessary area, wingspan and wing shape were considered. Before making any calculations, it was decided to use a safety factor of 1.1. To determine the wing sizing the Aerodynamics team first calculated the necessary area for the required missions. The team chose a takeoff velocity of 30 MPH as its goal and the total weight of the aircraft was estimated to be 3 lbs. Using $W_{Estimated} = (F.S.) * (W_{Plane})$ the total weight was calculated to be 3.3 lbs with the safety factor. The total wing area was decided using the equation, $S = \frac{2 * W_{Estimated}}{\rho * V_{Takeoff}^2 * C_L}$. The team calculated that a wing area of 210 in^2 was needed [1][2].

The team then analyzed the benefits of wing configuration and shape. From the selected area and shape, the team selected a root chord of 8 in, a tip chord of 6 in, and a wingspan of 30 in. In the middle of the wing the team placed a 2 in by 8 in rectangle that will act as a base for the wing to be fastened to the fuselage. Based on historical data for gliders, the team considered the area of the horizontal stabilizer to be 25% of that of the main wing, and the area of the vertical stabilizer to be 40% of that of the horizontal stabilizer. For the horizontal stabilizer a chord of 4.5 in and a span of 11.67 in which totaled to an area of 52.5 in^2. The vertical stabilizer was designed with a root chord of 4.5 in, a tip chord of 2.5 in, a height of 6 in, and a total area of 21 in^2. ***Figure 4.11*** Shows a table with each aerodynamic parameter for the design. ***Figure 4.12*** Shows the drawings for the final wing and tail designs.

	Main wing	Horizontal stabilizer	Vertical Stabilizer
Tip Chord (in)	6 (E216)	4.5 (E216)	2.5 (S9032)
Root Chord (in)	8 (AH 79-100)	4.5 (E216)	4.5 (S9032)
Span (in)	30	11.67	6
Area (in^2)	210	52.5	21

Figure 4.11: Table of Aerodynamic Design Parameters

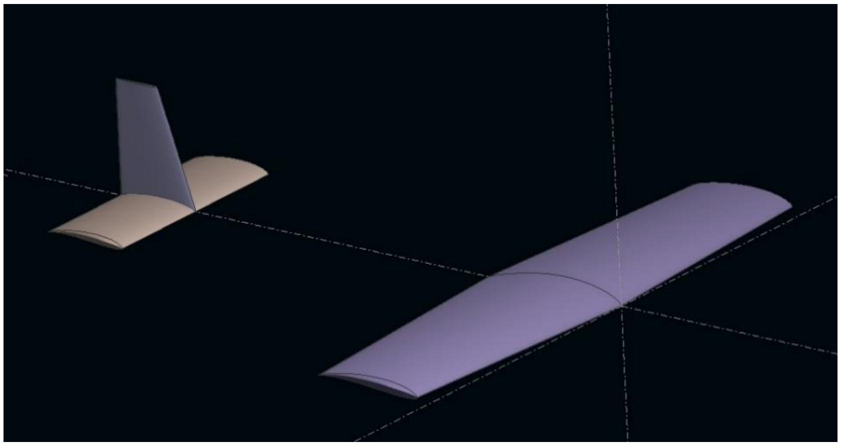


Figure 4.12: Final Wing and Tail Designs

Wing Characteristics

The graphs of the final wing characteristics were generated using additional drag forces that will come from the payload bay. These are shown in ***Figure 4.13***, ***Figure 4.14***, and ***Figure 4.15***

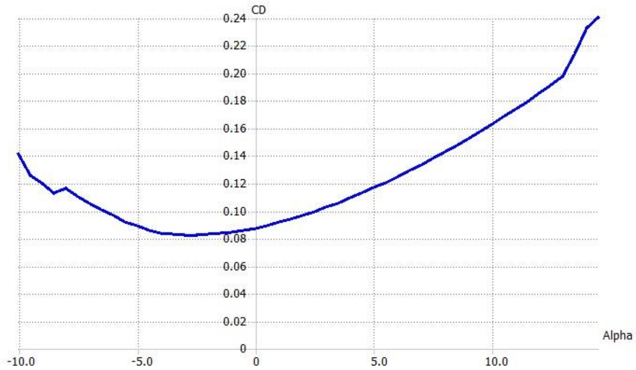


Figure 4.13: Coefficient of Drag plotted versus Angle of Attack

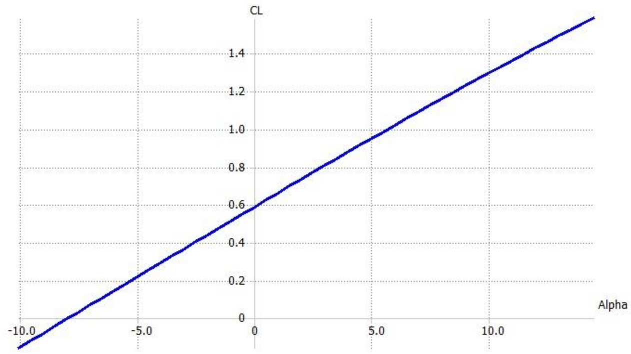


Figure 4.14: Coefficient of Lift plotted versus Angle of Attack

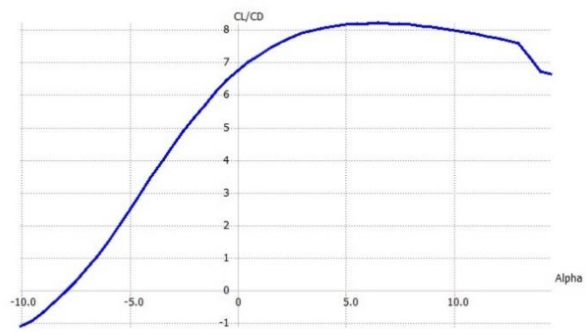


Figure 4.15: Glide Ratio plotted versus Angle of Attack

Drag Analysis

Drag on an aircraft comes from two main sources: parasitic drag, due to the shape of the aircraft and the "wet" surface area (i.e., the amount of surface area exposed to airflow), and induced drag, a by-product of lift. When analyzing the drag characteristics of the aircraft, the team focused on 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}) to be .055 using aerodynamic analysis and the equivalent skin friction method. This drag distribution is shown in ***Figure 4.16***. The wing and fuselage have the largest effect on overall drag, contributing approximately 70%. This is due to their large planform area and large wetted area, respectively [2][3].

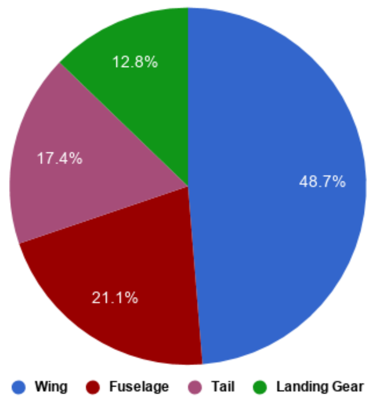


Figure 4.16: Overall Drag Distribution by Component

4.5 Stability and Control:

Static Margin

To be longitudinally stable, the aircraft must have a positive Static Margin. In order to have a positive Static Margin, the CG must always be in front of the neutral point. Longitudinal stability analysis was done using XFLR5 given the structural dimensions of the aircraft. The static margin (S.M.) was calculated using the equation ($S.M. = \frac{N.P. - X_{CG}}{MAC}$). The neutral point was calculated using XFLR5, X_{CG} is the quarter chord and the MAC was calculated using:

$$MAC = rc * \frac{2}{3} * \left(\frac{1 + t + t^2}{1 + t}\right) \; where\ rc = root\ chord\ and\ t = \frac{tip\ chord}{root\ chord}$$

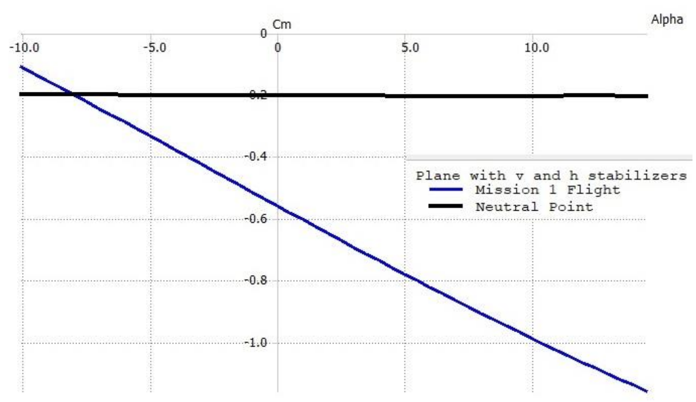


Figure 4.17: Static Margin Documentation

Figure 4.17 shows that the aircraft satisfies requirements for static margin longitudinal stability. XFLR5 calculated a neutral point of 4.3 in, the center of gravity is 2 in, and the MAC is 7.05. Using these values, the S.M. was calculated to be 0.326. Because the static margin is positive, the aircraft will naturally return to the previous angle of attack if its stability is disturbed. This will be true as long as the center of gravity is in front of the neutral point on the wing [3].

4.6 Expected Performance:

With the preliminary design of the aircraft completed, the team was able to use mission modeling analysis to estimate mission performance. The expected mission performance is reported in ***Figure 4.18***. The scores for Mission 2 and 3 cannot be accurately determined but the team predicts moderate performance. The time requirements for Missions 2 and 3 are from historical performance standards for winning teams. Performance estimates show that the aircraft is not fast enough to achieve what the team predicts as a required winning time. Due to the uncertainties in the mission model, the team determined that the times were close enough to the requirement to go ahead with the design. If needed, after the prototype has demonstrated that it can reliably complete all 3 missions, efforts will be made to improve the time.

Mission 1		Mission 2		Mission 3	
Lap Time (s)	47	Lap Time (s)	46.2	Lap Time (s)	47.3
Time Required (s)	100	Time Required (s)	43	Time Required (s)	43
Mission 1 Score	1	Mission 2 Score	1	Mission 3 Score	3

Figure 4.18: Expected Mission Performance

Section 5: 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 ***Figure 5.1***.

Overall Dimensions		Fuselage (incl. payload bay)	
Length	31.5in	Length	31.5 in
Width	30 in	Width	4.20 in
Height	5 in	Height	3.39 in
Wing		Vertical Stabilizer	
Span	30 in	Root Chord	4.5 in
Ave. Chord	7 in	Tip Chord	2.5 in
Area	210 in^2	Height	6 in
Aspect Ratio	4.57	Area	21 in^2
Horizontal Stabilizer		Motor/Battery	
Chord Length	4.5 in	Motor	Scorpion SII 3020 1100 kV
Span	11.67 in	ESC	ICE2 HV45
Area	52.2 in^2	Battery Model	Elite 1500
Controls		Number of Cells	10
Servos	hs-5152mg	Pack Voltage	12 V
Stall Torque (oz.in)	42	Pack Weight	4.87 oz
Speed (sec/60deg)	.17		

Figure 5.1: Finalized Design Parameters

5.2 Structural Characteristics and Capabilities

When designing the aircraft structures, the team started by considering where loads would be applied and distributed through the structures. The team first created sketches detailing the places where external loads would be applied, included as ***Figure 5.2***.

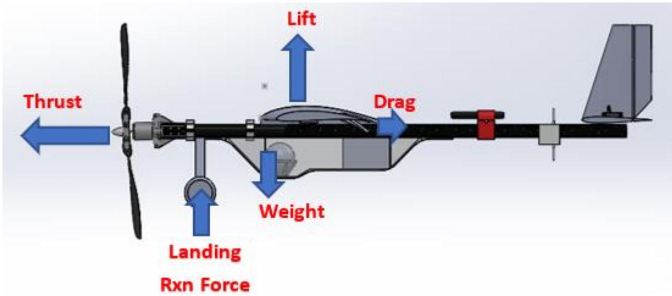


Figure 5.2: Load Diagram

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, associated loads, and design solutions are detailed in ***Figure 5.3***.

Structural Element	Applied Load	Description of Design
Landing Gear	Impact upon landing	Lightweight and stiff. Able to flex but not buckle during landing.
Spine	Point loads at each element connection	Carbon fiber beam with hollow cross-sectional area to diminish bending.
Wing and Tail Connections	Aerodynamic loads	Wing and tail connect to the spine via nylon bolts to transfer lift (and drag) forces.
Wing Structural Spars	Compression and tension due to aerodynamic loading	Unidirectional carbon fiber strip placed along the quarter-chord to sustain lift and drag forces.
Motor Mounts	Tension and torque due to thrust and rotation	3D printed plastic motor mount connects the motor to the spine to transfer thrust.
Structural Element	Applied Load	Description of Design

Figure 5.3: Table of Critical Structural Elements

5.3 System Designs, Component Selection and Integration

Fuselage Structural Design

The fuselage structure houses the payloads and provide an aerodynamically beneficial shape for load transfer. The team designed the fuselage modularly, with a carbon fiber spine on which a payload bay is mounted shown in ***Figure 5.4***. The spine is a commercially available hollow carbon fiber tube, with a 1 square inch carbon fiber cross section. The payload bay is mounted below the tube, under the center of gravity location. The main structure is constructed of mylar with a carbon fiber composite spine for structural integrity during landings.

Figure 5.4: Payload Bay and Spine

Payload Securement

The payload bay is sized to contain one passenger and one payload block, as shown in ***Figure 5.5***. The payload bay will be loaded separate from the spine, covered, and then bolted to the aircraft. This guarantees the containment of the payload, and that the center of gravity does not shift during flight. Payload bay location ensures that unloaded and loaded flight configurations have the same center of gravity. Passengers will be secured using rubber bands and a 3D printed cone, that will act as the seat for each size of passenger. The payload block will be secured using a Velcro strap or tape.

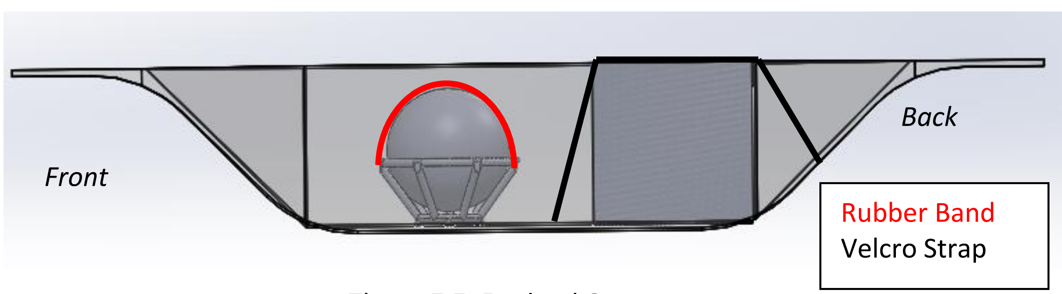


Figure 5.5: Payload Securement

Wing Structure

The wing is constructed out of foam with uni-directional carbon fiber laid span-wise along the quarter-chord location as a spar. The wing shape is cut out of foam using a hot wire cutting system. The spar is then wrapped around the wing and left to cure in a vacuum bag. The final wing structure is shown in ***Figure 5.6***.

Figure 5.6: Wing Overview

Tail Structure and Attachment

The tail is constructed in the same manner as the wing with uni-directional carbon fiber epoxied to at the quarter chord of the horizontal and vertical stabilizers for structural support. The horizontal stabilizer and vertical stabilizers are connected using epoxy to form the tail assembly. The tail assembly is then epoxied onto the carbon fiber spine aircraft. ***Figure 5.7*** illustrates the layouts of the tail components.

Figure 5.7: Vertical and Horizontal Stabilizers

Electronic Control System

The team selected the Spektrum DX6i transmitter with a 6 channel receiver. The receiver has a built in 3 axis control system, and the team will be able to adjust gains to improve flight stability and performance. The control system will be tuned by the pilot observationally during flight tests. The team chose Hitec HS-5152MG servos because of their slim (10 mm) profile, which allows for easy integration in the wings with minimal effects on aerodynamics.

Propulsion System

The final propulsion configuration is the Scorpion S11 3020, 1100 kV motor, powered by a 10 cell 12v 1500mAh NiMH battery pack. This setup provides 260W peak power and a pitch speed of 72 feet/sec when coupled with an 11in x 8in pitch folding propeller.

5.4 Weight and Balance

Component weights, locations from the nose (x distance), and locations above and below the thrust line (z distance) are included in ***Figure 5.8***, along with the resultant weight and CG locations for all configurations. Distances in the y direction are not considered because the aircraft is symmetric about the centerline (x-z plane).

Component	Case	Weight (oz)	X distance from motor mount (in)	Z distance (thrust line is Z=0) (in)
Fuselage	**All**	1.00	4.7	-2.75
Motor	**All**	5.29	-1.4	0
Batteries	**All**	9.74	4.75, 18.13 (avg. 11.43)	0
Receiver	**All**	1.22	21.9	0
Wing	**All**	6.33	9.6	0.7
Spine/mounts	**All**	5.96	12	0
Tail	**All**	5.8	31.6	0.75
Landing Gear	**All**	1.76	4	-5.33
Passenger 1	**1**	0.40	9.25	-3.25
Passenger 2	**2**	0.67	9.25	-3.25
Passenger 3	**3**	1.12	9.25	-3.25
Passenger 4	**4**	1.85	9.25	-3.25
Passenger 5	**5**	2.39	9.25	-3.25

Component	Case	Weight (oz)	X distance from motor mount (in)	Z distance (thrust line is Z=0) (in)
Block Payload	**M3**	1.00	14	-3
M1(empty total)	**N/A**	35.1	13.05	-0.1
M2 Total	**1**	35.5	13	-0.13
	2	35.77	12.98	-0.15
	3	36.22	12.93	-0.20
	4	36.95	12.86	-0.25
	5	37.49	12.8	-0.3
M3 Total	**1**	36.5	13.08	-0.2
	2	36.77	13.03	-0.23
	3	37.22	13	-0.27
	4	37.95	12.97	-0.33
	5	38.49	12.95	-0.37

Figure 5.8: Weight and Balance Table

5.5 Flight Performance Parameters

Using the aerodynamic data from CFD analyses, the team identified relevant flight performance parameters for various angles of attack representing level flight, cruise and takeoff. These values are listed in ***Figure 5.9*** for Mission 1, ***Figure 5.10*** for Mission 2, and ***Figure 5.11*** for Mission 3.

Angle of Attack	$C_{L\text{-}Max}$	C_{D0}	Turn Rate (deg/s)	Takeoff Weight (lbs)
0	0.585	0.087	32.2992	3
4	0.874	0.109	39.4793	3
8	1.155	0.143	45.3842	3
12	1.424	0.185	50.3927	3

Figure 5.9: Mission 1 Flight Performance

Angle of Attack	$C_{L\text{-}Max}$	C_{D0}	Turn Rate (deg/s)	Takeoff Weight
0	0.585	0.087	30.5085	3.36
4	0.874	0.109	37.2905	3.36
8	1.155	0.143	42.8680	3.36
12	1.424	0.185	47.5990	3.36

Figure 5.10: Mission 2 Flight Performance

Angle of Attack	$C_{L\text{-}Max}$	C_{D0}	Turn Rate (deg/s)	Takeoff Weight (lbs)
0	0.585	0.087	30.7961	3.3
4	0.874	0.109	37.6420	3.3
8	1.155	0.143	43.2721	3.3
12	1.424	0.185	48.0476	3.3

Figure 5.11: Mission 3 Flight Performance

5.6 Rated Aircraft Cost Documentation

The Rated Aircraft Cost (RAC) has a high impact on overall score. The team focused on minimizing weight and wingspan to lower the RAC. The final RAC value is documented in ***Figure 5.12***, computed using the equation for RAC from section 3.1.

RAC Parameter	Value
Maximum Empty Weight (oz)	35.1
Maximum Wingspan (in)	32
Total RAC	1123.2

Figure 5.12: Rated Aircraft Cost Documentation

5.7 Mission Performance Documentation of Final Design

The team simulated of our performance in each mission using the parameters obtained from the aircraft and mission analysis MATLAB code. This enables to the team to identify the weaknesses of the aircraft and then iterate design until performance is satisfactory. This simulation particularly accounts for the following: aircraft loading, airspeed, turn rate, bank angle, climb angle, and altitude. As stated earlier, the load factor must be in the range of $-1 < n < 2.5$ and slightly less for heavier configurations of the aircraft, so this simulation will also test the load factor and therefore verify the structural integrity of the aircraft. As shown in the figures, at no point in either mission does the aircraft stall, exceed the maximum loading, and follows a feasible flight trajectory, meaning that each simulation represents a successful flight. ***Figure 5.13***, ***Figure 5.14***, and ***Figure 5.15*** demonstrate the simulated mission performance.

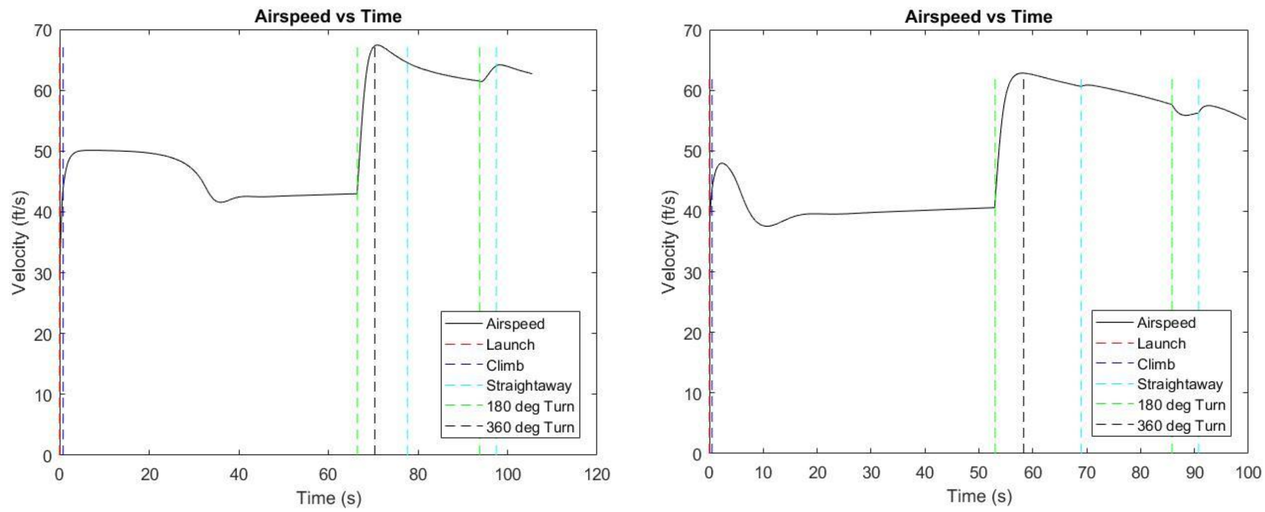


Figure 5.13: Simulation -- Airspeed plotted versus Time for Mission 1 and Mission 2

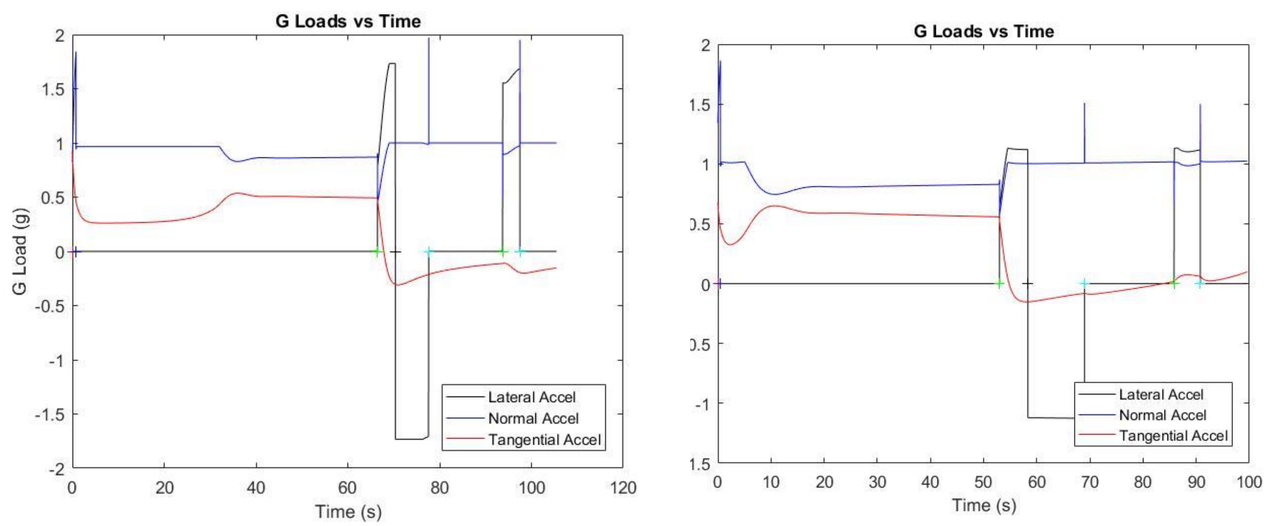


Figure 5.14: Simulation – Wing Loading versus Time for Mission 1 and Mission 2

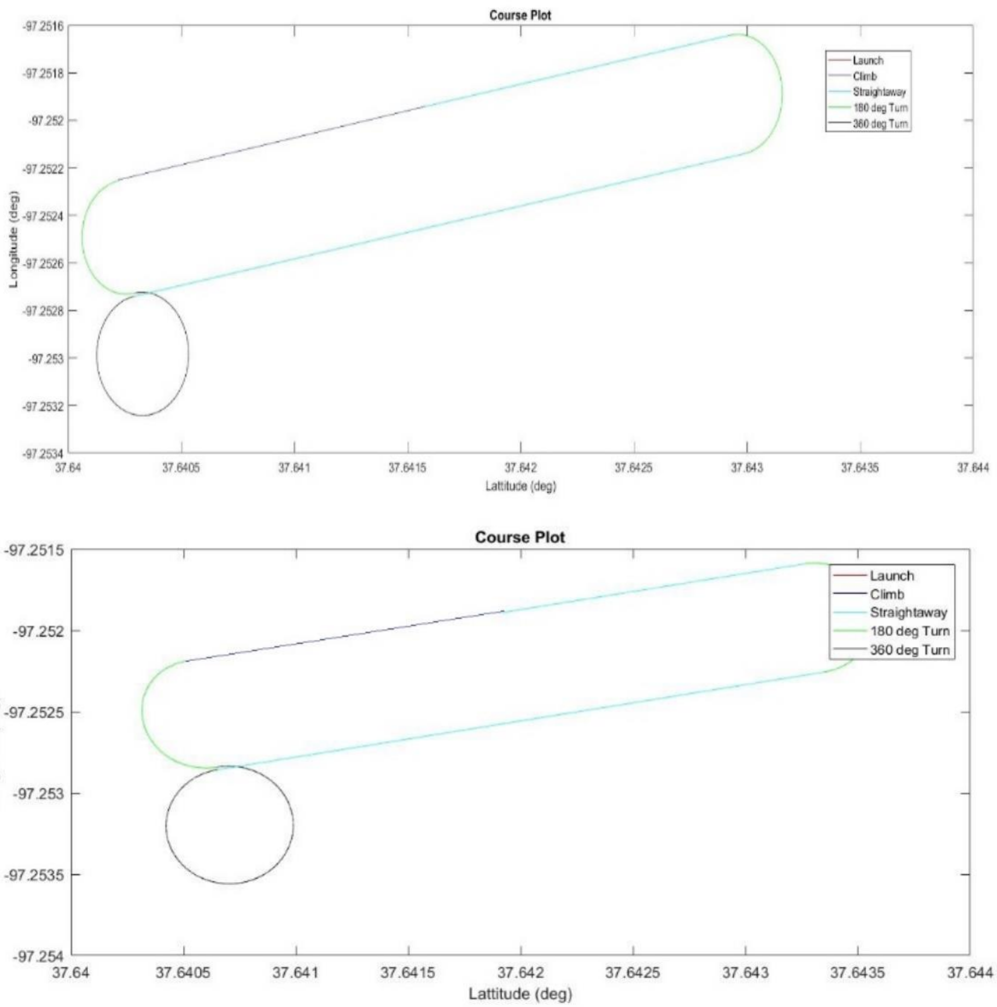
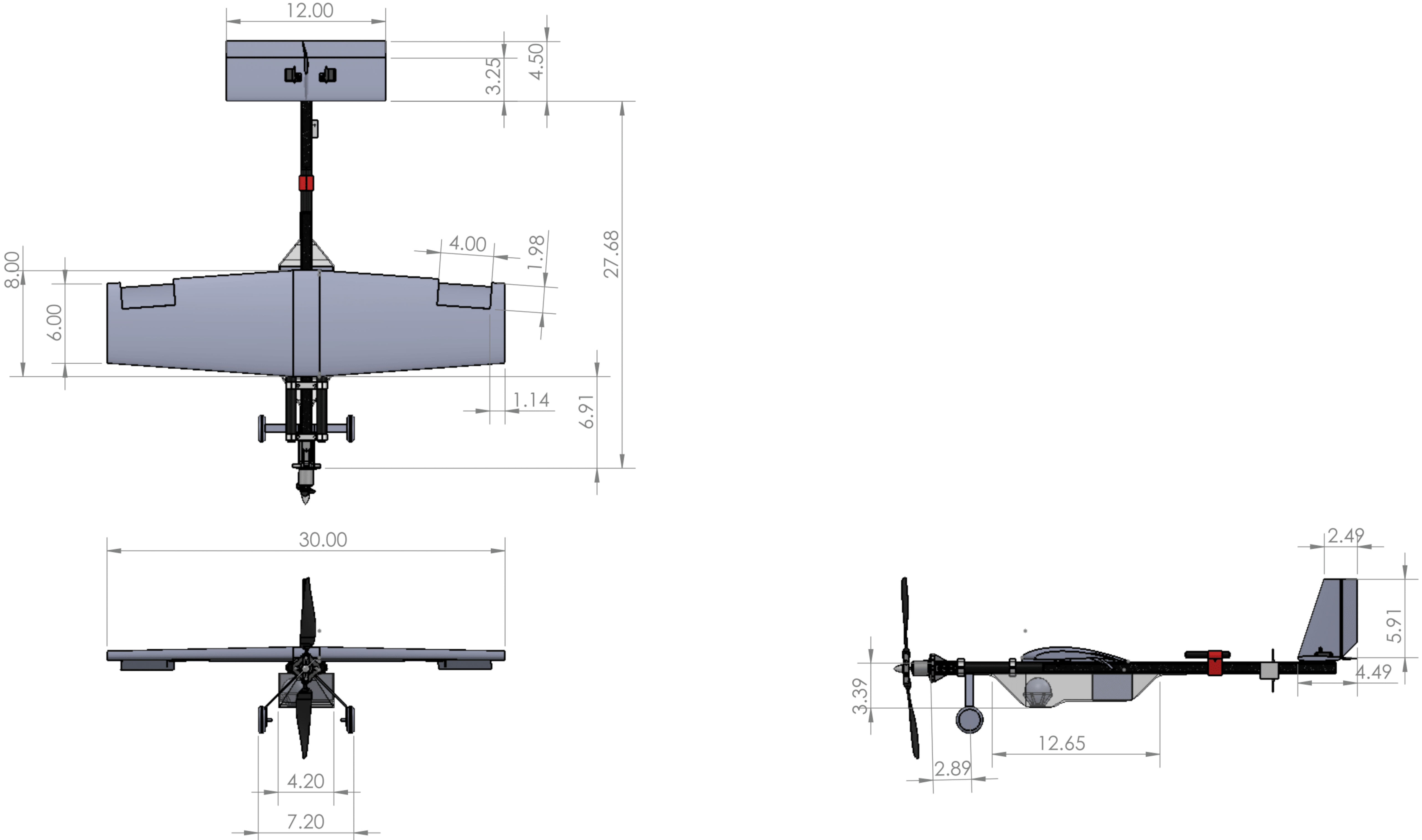


Figure 5.15: Simulation – Course Plot for Mission 1 and Mission 2

5.8: Drawing Package:

The next pages contain the drawing package for the UCSD 2018 DBF competition aircraft. In order, they are: a three view drawing, a structural layout drawing, a system layout drawing, and a payload accommodation drawing.



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MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

University of California, San Diego

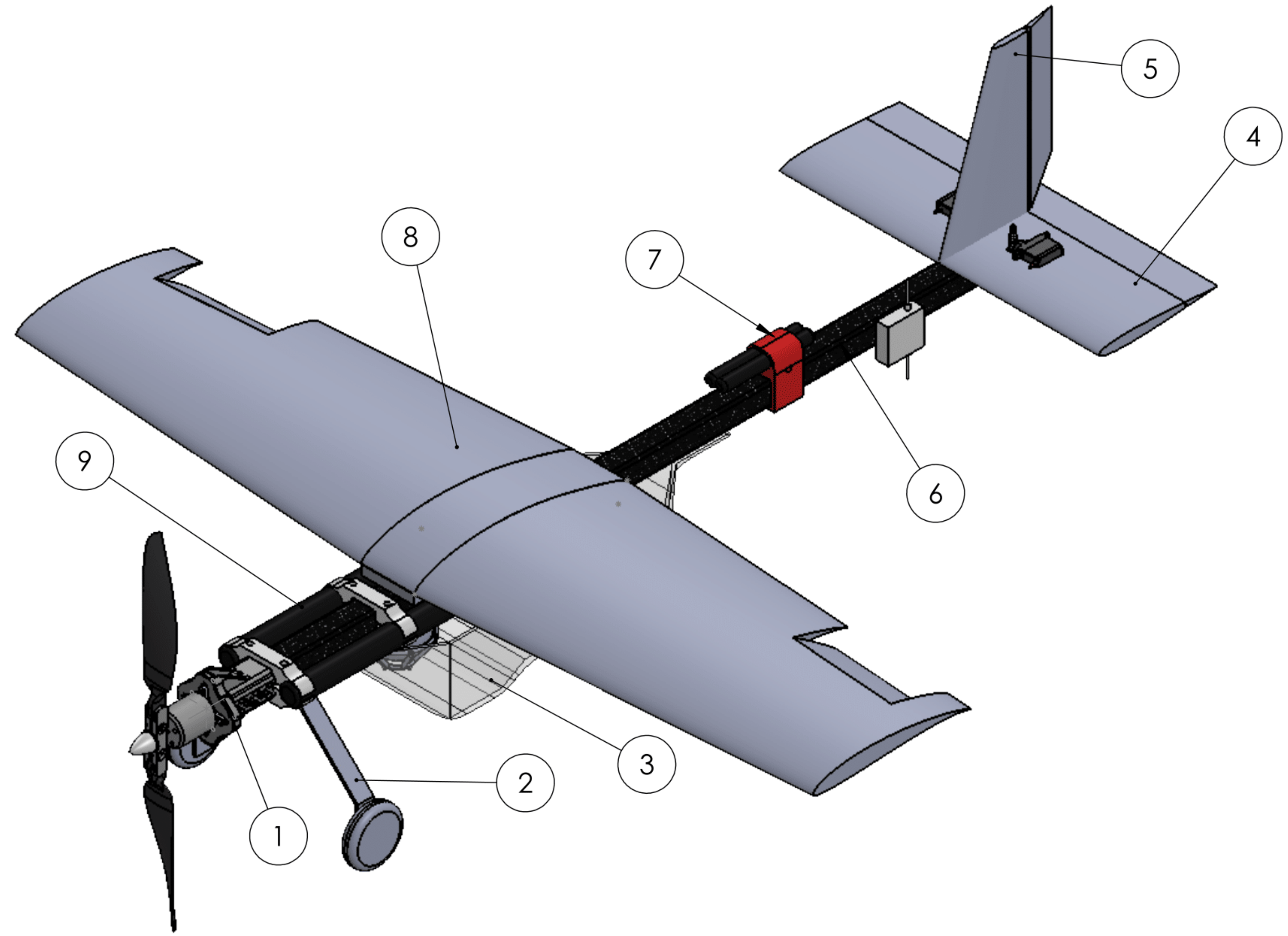
TITLE:

Tritonado

SIZE	DWG. NO.	REV
B	1	

SCALE: 1:12 WEIGHT: SHEET 1 OF 1

#	Component
1	Motor Mount
2	Landing Gear
3	Payload Bay
4	Horizontal Stabilizer
5	Vertical Stabilizer
6	Spine
7	Rx Battery Mount
8	Main Wing
9	Battery Mount



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Q.A.		

COMMENTS:

University of California, San Diego

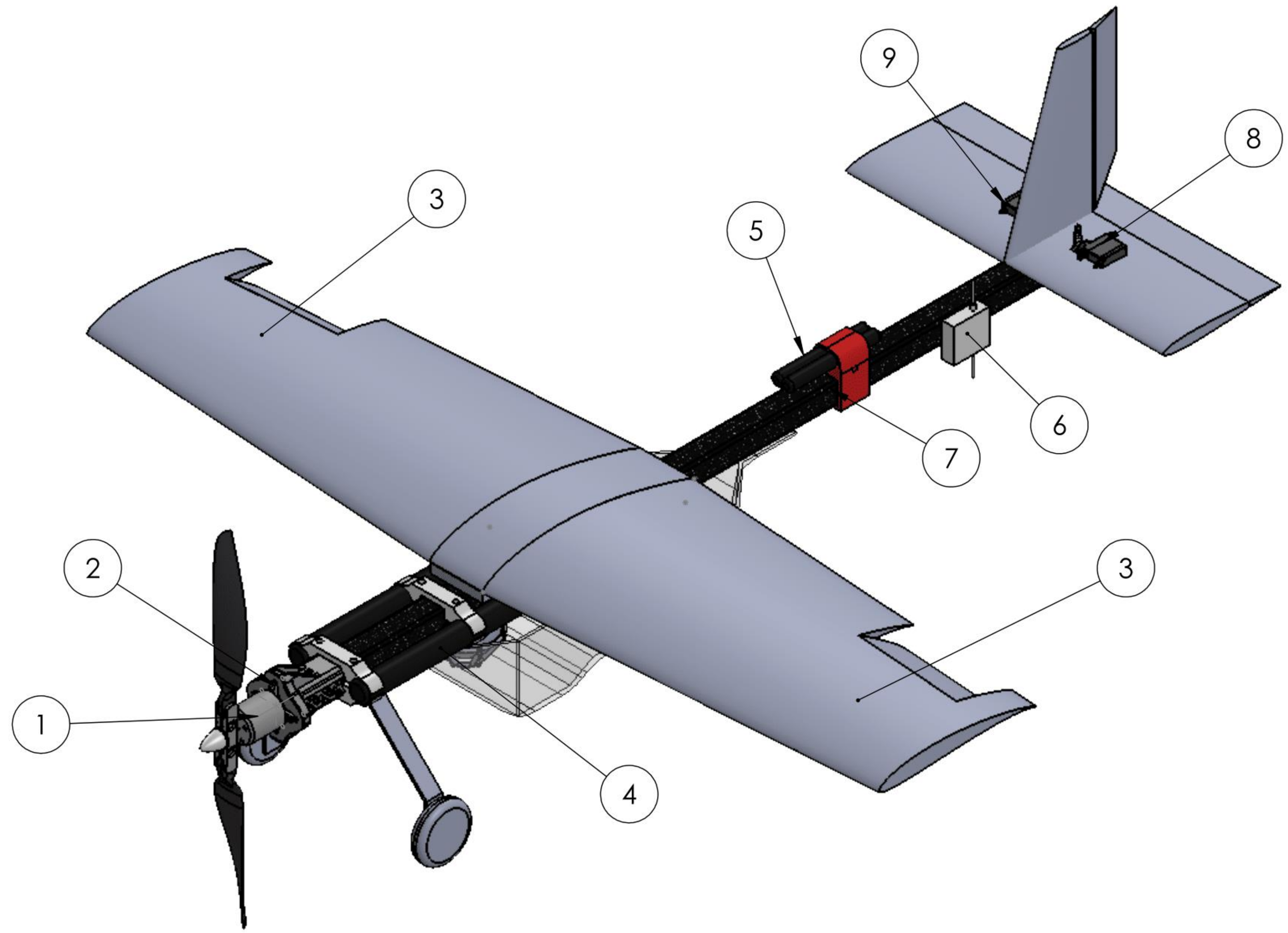
TITLE:

Tritonado

SIZE B | DWG. NO. 1 | REV

SCALE: 1:12 | WEIGHT: | SHEET 1 OF 1

#	Component
1	Motor
2	ESC
3	Aileron Servos (Under)
4	Main Batteries
5	Receiver Batteries
6	Satellite Receiver
7	Receiver
8	Elevator Servo
9	Rudder Servo



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APPLICATION

University of California, San Diego

TITLE:

Tritonado

SIZE B | DWG. NO. 1 | REV

SCALE: 1:12 | WEIGHT: | SHEET 1 OF 1

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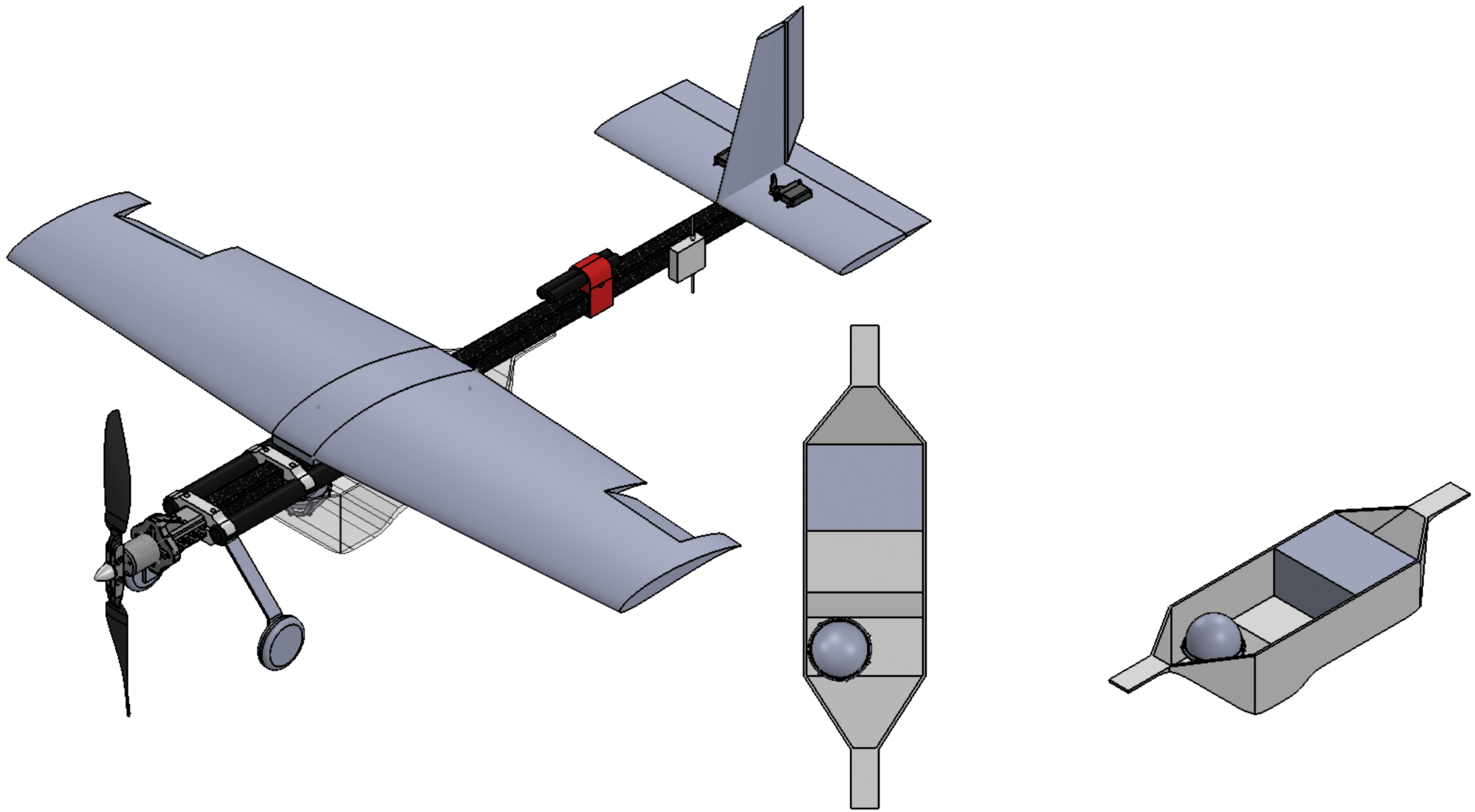

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MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

University of California, San Diego

TITLE:

Tritonado

SIZE	DWG. NO.	REV
B	1	

SCALE: 1:12 WEIGHT: SHEET 1 OF 1

Section 6: Manufacturing Plan

6.1 Selection Methodology

To compare the different methods available for manufacturing the major components of the aircraft, a list of merits and the corresponding importance were selected based on the mission requirements. The weights of each merit is listed in ***Figure 6.1*** with higher weight bearing greater importance.

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

Figure 6.1: Manufacturing Figure of Merit

The weight is the most important since it directly impacts the RAC of the aircraft, thus, having a huge importance of the final score. Ease of fabrication is listed as the second important because the manufacturing speed and quality both depends on the capability of the fabrication team and the designs had to be iterated quickly. Strength is relatively less important since no drop test or other structurally intensive testing are present in the competition and runway takeoff and landing should not place too much stress on the structure under normal conditions. Cost is listed as the least important for the small size of the aircraft and sufficient material. And ease of repair is less important because the modular design enables easy part replacement when damaged.

6.2: Investigation and Selection of Major Components and Assembly Methods

Fuselage

Balsa truss, lost-foam core, and carbon fiber square tube were different methods considered for the construction of the fuselage. These configurations are compared in ***Figure 6.2***.

- Balsa Truss**:** A skin of Mylar covering a frame constructed of balsa wood.
- Lost-Foam Core: Carbon fiber and fiber glass is wrapped around a block of foam cut to the desired fuselage shape with hot wires. After curing of epoxy the foam is then melted out using acetone, leaving the carbon fiber/fiber glass fuselage shell.
- Carbon Fiber Square Tube: a premade carbon fiber square tube for a primary load bearing spine.

FOM	Weight	Balsa Truss	Lost-Foam Core	Carbon Fiber Square Tube
Weight	35	5	4	5
Ease of Fabrication	30	2	4	5
Ease of Repair	5	2	4	3
Cost	5	5	4	3
Strength	25	3	4	5
Total	100	345	400	**480**

Figure 6.2: Fuselage Fabrication Decision Matrix

The team had very limited experience on balsa truss manufacturing. Although the team had a lot of experience on lost foam core production, the carbon fiber square tube was still a much better option, both because of its high stiffness and easy manufacturing process. What is more, the square tube allows a modular design concept, where all the critical components can be bolted on and removed easily, allowing rapid prototyping of modules and a flexible adjustment of CG for better balancing, especially considering the possible variation of payload weight this year.

Wings

The following three methods were considered for the construction of the wing:

- Wood Ribs: Airfoil sections are cut out of balsa using a Laser Cutter, then connected using thin balsa spars and stringers. The wing is then covered in a Mylar skin.
- Foam Core Composite: A foam wing is cut out using a hot wire CNC cutter. A carbon fiber spar is epoxied onto the foam wing, and then covered with fiber glass.
- Hollow Composite with Spar: Similar to the foam core technique, but a fiber spar is included at the quarter chord of the wing to add support, and then the foam core is removed with acetone.

FOM	Weight	Wood Ribs	Hollow Composite	Foam Core Composite
Weight	35	5	4	3
Ease of Fabrication	30	3	4	5
Ease of Repair	5	2	4	4
Cost	5	4	3	3
Strength	25	3	4	5
Total	100	370	395	**415**

Figure 6.3: Wing Fabrication Decision Matrix

Foam core composite is the easiest to manufacture with access to a CNC foam cutter and with the experienced team. It also has great strength, at a slight cost of an increase in weight. The wings are made with foam core, reinforced with carbon fiber at the quarter cord and covered with fiber glass for a smooth aerodynamic finish. This composites design is chosen considering the strength, weight, and the team's previous manufacturing capability. ***Figure 6.3*** outlines this decision.

Tail

Wood ribs and foam core were considered for the construction of the tail. These are the same methods as described for the wing. ***Figure 6.4*** outlines these choices.

FOM	Weight	Wood Ribs	Hollow Composite	Foam Core Composite
Weight	35	5	4	3
Ease of Fabrication	30	3	4	5
Ease of Repair	5	2	4	4
Cost	5	4	3	3
Strength	25	3	4	5
Total	100	370	395	**415**

Figure 6.4: Tail Fabrication Decision Matrix

The foam core method was chosen for the same reason as for the wings: its strength, toughness, and ease of manufacture.

Payload Bay

Wood ribs and lost-foam core were the two methods considered for the construction of the payload bay. These are the same methods as described for the fuselage and the wing.

The lost-foam core method was selected mainly because it is easy to manufacture. The strength is also much better than wood ribs. The payload bay is mainly made of fiber glass, with uni-directional carbon fiber tow reinforcement at the center to sustain the loading. ***Figure 6.5*** outlines these choices.

FOM	Weight	Wood Ribs	Lost-Foam Core
Weight	35	5	4
Ease of Fabrication	30	3	4
Ease of Repair	5	2	4
Cost	5	4	3
Strength	25	3	4
Total	100	370	**395**

Figure 6.5: Payload Bay Manufacturing Figure of Merit

Landing Gear

The landing gear is made out of aluminum sheet metal. Aluminum is easy to fabricate with the sheet metal shear and brake in the machine shop, and provides high yield strength to absorb the impact on landing. Lastly, compared with carbon fiber and plastic ones that can provide adequate strength, aluminum landing gears are thinner, therefore, adding less drag towards the aircraft.

Motor and Electronics Mounts

All of the mounts for electrical components including the motor are constructed out of 3D printed PLA plastic. 3D printing these components allows them to be modeled to fit the complex shapes of the electronics not capable of being manufactured with other techniques. Although relatively heavier than composites parts, 3D printing provides fast prototyping ability, and can be clamped or pinned to the spine without much fabrication work.

Key Composite Manufacture Procedure

The main parts of the aircraft were made of composites: wing, tail, payload bay and landing gear. And the key procedures for composite manufacturing are explained below:

1. Design and export the top and side profiles into AutoCAD to generate G-codes for the CNC machine.
2. Use CNC foam cutter to cut foam core into desired shapes.
3. Sand the edges to remove sharp corners created by the foam cutter, especially the leading edge for wing and tail.
4. For payload bay only, cover foam with tape and apply model release
5. Wet lay the unidirectional carbon fiber on cord of wing and tail pieces and center of payload bay for reinforcement.
6. Wet lay with fiber glass.
7. Lay with Mylar with model release applied.
8. Seal and vacuum the bag.
9. For payload bay only, remove the foam core.
10. Sand the edges, and drill holes for mounting.

6.3 Manufacturing Plan:

The team's manufacturing plan, shown in ***Figure 6.6***, allowed the team to follow a strict schedule of prototype construction. At the beginning of the year, extra time was allocated for the design process and for new team members to get familiar with the fabrication process. After the initial iteration, the team was able to speed up the fabrication process since the process was similar.

Week of the Quarter	1	2	3	4	5	6	7	8	9		1	2
Payload Bay												
Wing												
Tail												
Landing Gear												
Assemble		`										
Spare Parts												

Figure 6.6: Manufacturing Plan Gantt Chart

Section 7: Testing Plan

7.1 Aircraft and Subsystem Testing Plan

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.

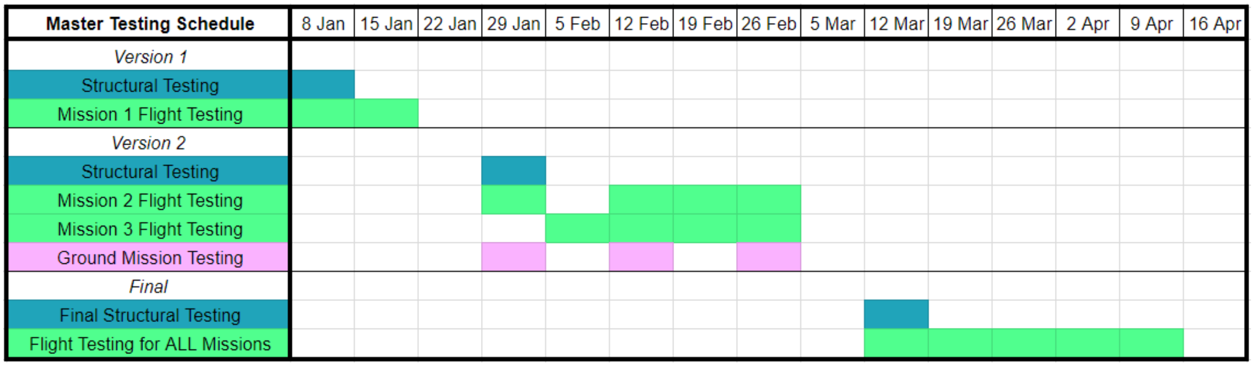

Figure 7.1 Master Test Schedule

Propulsion Testing

Thrust tests were conducted using a motor test stand (RC Benchmark Dynamometer). The flight propulsion system was tested to measure thrust, motor RPM, voltage, and current with respect to ramping the ESC signal. The Scorpion SII-3020 was tested, and the results are shown in ***Figure 7.2***

Motor Tested	Propeller	Thrust (lb)	Airspeed (ft/s)	Pmax (Watts)	Vo (V)	V at Imax (V)	Imax (Amps)
Scorpion SII-3020	**7” x 4.5”**	4lb	30	600	0.5	11.5	43.62

Figure 7.2: Motor Testing Results

Structural Testing

To verify the structural integrity of the aircraft, the team performed several 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 to simulate maximum wing loading. to test the structural integrity of the fuselage and the wing connections, tip tests were performed. Then, to test the integrity for missions 2 and 3, the aircraft was loaded with the passengers and payload and new tip tests were performed on the aircraft. These tests allowed the team to verify that the aircraft could withstand the flight loads. The wing tip test is documented in ***Figure 7.3***.

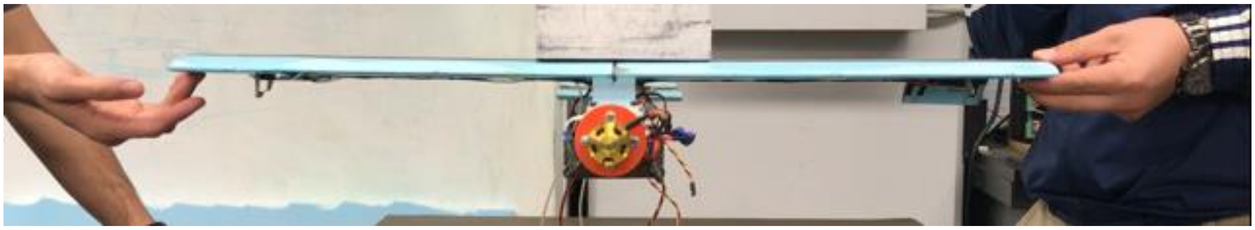

Figure 7.3: Documentation of Wing Tip Test

Furthermore, in order to ensure the aircraft will maintain structural integrity in unfavorable events such as crashes, the team conducted a point load test on a wing prototype as documented in ***Figure 7.4.*** The wing yielded with minimal bending when a weight of 11.2 lbs was applied on the 0.3 lb wing equating to approximately 37 times the weight of the wing.

Figure 7.4: Wing Point Load Test

7.2 Flight Testing

The team understood the importance of test flights that do not require full mission performance from the outset. 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: Version-flight (maiden flight MF, Missions M#). Due to necessity, additional flights may be undertaken following minor alterations to the aircraft resulting from flight testing data. These planned flights are listed in ***Figure 7.5***.

Flight Number	Designation	Payload
1	1-MF	None
2	1-M1	None
3	2-MF	1 Small Passenger
4	2-M2	1 Large Passenger
5	2-M3	1 Large Passenger and 1 Payload Block
6	F-MF	None
7	F-M2	1 Large Passenger
8	F-M3	1 Large Passenger and 1 Payload Block

Figure 7.5: Flight Testing Table

7.3 Flight Testing Checklists

Pre-Flight Checklist

The following checks are performed five minutes prior to flight [3].

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 7.6: Pre-Flight Checklist

Final Checklist

The following checks are performed immediately before the aircraft's takeoff [3].

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

Figure 7.7: Final Checklist

Section 8: Performance Results

8.1 Component and Subsystem Performance

Batteries

The batteries drained quickly during takeoff as that is the most intensive period of flight. The lower current sustained after takeoff allowed the batteries to continue for the duration of the mission. A test flight of mission 1 ended with 75% voltage capacity. Mission 1 tests were successful for propulsion performance, except for landing, for which the propeller hub and blades were rendered unfit for flying. Some landings damaged propeller blades, because the motor was still spinning on landing. This was anticipated, and the team plans to use a metal hub instead of the plastic one during competition. The team will also program a motor brake to stop propeller motion for landing.

Motor

Once in the air the Scorpion SII-3020 proved to be the correct choice for our needs. It was able to provide enough thrust to operate for the duration of flight. Excess current draw is mitigated by unloading of the propeller in flight, with maximum efficiency being reached at the cruise speed.

Fuselage and Wing

The team tested both the wing to support the maximum payload when tip-tested. The team tested the fuselage's ability to support the maximum 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 the landing gear to statically support 10lbs of weight to simulate a high impact. The team selected this an acceptable performance standard. The team did not observe any failures in flight testing of the landing gear.

Prediction Comparisons and Improvements

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 (ft)
Actual	55	40	50	5.7	55
Predicted	50	46.4	46.2	6	50

Figure 8.1 Mission 1 Results

	Turn Rate (deg/s)	Top Speed (ft/s)	1 Lap Time (s)	Battery Pack Endurance (min)	Takeoff Distance (ft)
Actual	50	40	50	5.2	60
Predicted	45	62	47.3	6	56

Figure 8.2 Mission 2 Results

	Turn Rate (deg/s)	Top Speed (ft/s)	1 Lap Time (s)	Battery Pack Endurance (min)	Takeoff Distance (ft)
Actual	50	40	55	5.2	60
Predicted	45	62	47.3	6	55

Figure 8.3 Mission 3 Results

Prediction Comparisons and Improvements

Figure 8.1, ***Figure 8.2***, and ***Figure 8.3*** show that the aircraft outperformed its prediction in turn rate. The overall top speed was lower than predicted. Weather conditions and underestimates in drag meant that the lap times were 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

The team plans on continued prototype iterations accompanied by flight testing in order to provide a continuous improvement in aircraft performance. This will be accompanied by small adjustments in the aircraft that will go towards the maximization of score such as the minimization of weight and wing sizing adjustments. The team plans to perform continued structural tests on retired prototype components as a way to achieve these goals. Once an optimal design is achieved, the team will construct a competition aircraft that will be test flown, tuned, and prepared for competition in Wichita.

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