Iowa State University

CONCEPTUAL DESIGN REPORT

StratoShield

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Glossary

$\frac{L}{D}$	lift over drag ratio. *(p. 10, 11)*
$\left(\frac{C_L^{\frac{3}{2}}}{C_D}\right)_{\mathbf{max}}$	characteristic endurance ratio. *(p. 22, 24)*
b	wingspan. *(p. 9)*
b_t	tail wingspan. *(p. 9)*
c	chord length. *(p. 9)*
c_g	center of gravity. *(p. 17)*
c_t	Tail chord length. *(p. 9)*
c_v	vertical stabilizer chord length. *(p. 9)*
h_v	height of the vertical stabilizer. *(p. 9)*
l_t	tail moment arm, *i.e.*, the distance from the leading edge of the wing to the tail. *(p. 9)*

Acronyms

AGL above ground level. *(p. V, VI)*
AoA angle of attack. *(p. iii, 12, 13, 15, 24)*
AOI area of interest. *(p. 1, 2, 10, V)*
AR aspect ratio. *(p. 9)*

BOM bill of materials. *(p. 27)*

CAD computer-aided design. *(p. 9, 27)*
CFD computational fluid dynamics. *(p. 12, 22)*
CNC computer numerical control. *(p. 26)*
COTS commercial off-the-shelf. *(p. 2, VI)*
cUAS counter-unmanned aerial system. *(p. 3)*

DHS Department of Homeland Security. *(p. 1, 2)*

GTOW gross takeoff weight. *(p. VI)*

PETG polyethylene terephthalate glycol. *(p. 17, 19–21, 26–28, 30)*
PLA polylactic acid. *(p. 7)*

RC remote-controlled. *(p. 2, 17, V, VI)*

SDR software defined radio. *(p. 6)*
sUAS small unmanned aerial systems. *(p. 1–3, 25, V, VI)*

UAV unmanned aerial vehicle. *(p. iii, 1–4, 6, 7, V, VI)*

1 Introduction

In recent years, small unmanned aerial systems (sUAS), commonly known as drones, have emerged as a significant security threat to United States citizens and national infrastructure. These threats include hostile surveillance, espionage, smuggling of illegal payloads, GPS spoofing, signal jamming, and weaponization. The increasing misuse of drones for illicit activities highlights the critical need for effective countermeasures to safeguard sensitive areas from these airborne threats.

To address this challenge, the Department of Homeland Security (DHS) is accepted bids to develop an unmanned aerial vehicle (UAV) capable of detecting and neutralizing hostile sUAS. In response, StratoShield has designed an aircraft, The Banshee, equipped with advanced technology to jam sUAS control signals. The Banshee will be capable of patrolling an area of interest (AOI) for up to 45 min, ensuring the protection of buildings and persons in the area. The mission's primary objective is to identify and disable sUAS threats using non-destructive electronic countermeasures.

At the time of writing, StratoShield has completed an initial design, iterated the design through several trade studies, and prepared a final conceptual design for review by the DHS. This report describes that process, concluding with a presentation of the current conceptual design and the resources required to proceed with prototyping The Banshee.

From the engineers at StratoShield, we extend our sincere gratitude for your time and consideration in reviewing this report. We are honored to contribute to the noble mission of safeguarding our cherished nation, and we trust that you will recognize the potential of the design we are so proud to present.

2

Mission and Requirements

The primary objective given by the DHS is to design and develop a UAV capable of detecting and neutralizing hostile sUAS. To guide the design process, the DHS has provided the following requirements:

- The UAV shall prevent a hostile airborne sUAS from reaching an area of interest (AOI) where the AOI is at most a circular area of 100 acres.
- The UAV shall support autonomous flight.
- The UAV shall be capable of completing a full no-engagement flight cycle of at least 45 min.
- The UAV shall be capable of engaging a hostile sUAS for at least 10 min.
- An operator shall be capable of changing the UAV battery within 5 min.
- The UAV shall be capable of flying in similar conditions to commercial off-the-shelf (COTS) sUAS.

Additionally, the design of The Banshee was constrained by a number of business requirements that restricted the aircraft to a small, easily-manufacturable fixed-wing remote-controlled (RC) aircraft (Table B.1). From these two sets of requirements, StratoShield composed a list of 50 derived requirements (Table B.1). This is not a comprehensive list of requirements but rather a starting point for designing a formal test plan or scorecard in the prototyping phase. Due to the high endurance requirement dictated by the DHS, The Banshee's mission and design would be endurance-focused. A high-level overview of the mission profile is visualized in Figure 2.1.

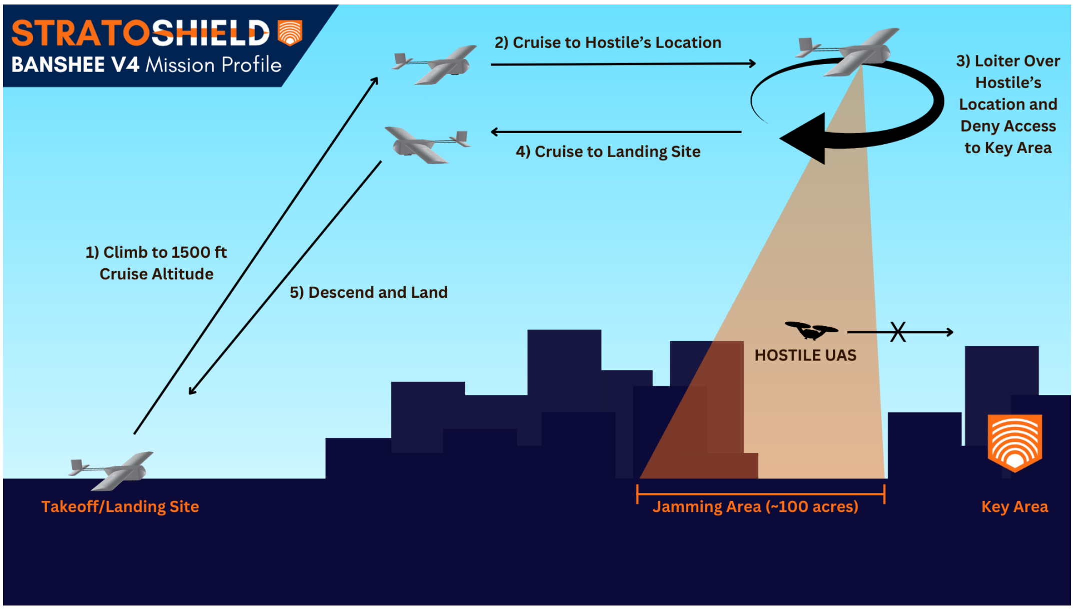


Figure 2.1: *The Banshee's mission profile*

3

Market Survey

Several products in the quadcopter form factor, such as Anduril's Anvil and Fortem Technologies' DroneHunter F700, exist to combat the threat posed by hostile sUAS (Anduril Industries, 2024; Fortem Technologies, 2024). These products not only underscored the necessity for such defensive products but also highlighted a technological gap: from our research, the team was unable to identify any commercially-available counter-unmanned aerial system (cUAS) products in the UAV form factor. UAV are larger and more powerful, enabling them to carry significantly larger payloads, enhancing their effectiveness. Furthermore, due to their longer range and endurance compared to traditional quadcopters, The Banshee would be particularly suited for patrolling vast areas or following extended convoys. With this market niche identified, StratoShield commenced researching UAV in the desired form factor that aligned with the mission requirements.

3.1 Similar UAV

With the mission well-defined, StratoShield conducted a market research study to identify UAV that could meet or exceed the mission requirements. Key criteria considered during the search for similar aircraft included maximum altitude, flight time, flight speed, and weight. After reviewing various UAV, StratoShield selected the following models for further research: the AeroVironment RQ-11 Raven, the Hunter 2-S, and the MyFlyDream Nimbus (AeroVironment, 2024; Edge Group, 2024; BANGGOOD, 2024).

(a) *RQ-11 Raven* **(b)** *Hunter 2-S* **(c)** *MyFlyDream Nimbus*

Figure 3.1: *UAV selected for market research*

The AeroVironment RQ-11 Raven (Figure 3.1a) is a small hand-launched UAV that was first used in the United States military for surveillance missions. The Raven's desirable characteristics were the narrow boom and the conventional-style tail. The Hunter 2-S (Figure 3.1b) is a tube-launched UAV that, when launched, flies to a specified area and loiters while searching for targets. Once a target is spotted, the Hunter 2-S then engages with the target with the goal of a kinetic impact. A design concept that the team found interesting within the Hunter 2-S was the wing mounted to the top of the fuselage. The final UAV the team researched was the MyFlyDream Nimbus (Figure 3.1c), which is a recreational UAV. Some characteristics that the team liked about the MFD Nimbus design are its narrow boom, compact fuselage, and dual motors.

Figure 3.2 shows the comparison of the maximum flying altitude above ground level for the RQ-11 Raven, Hunter 2-S, and MFD Nimbus. The red line on the figure shows the target flying altitude above ground level for The Banshee, which is 400 ft. All three UAV are able to fly above the required altitude.

Figure 3.3 shows the comparison of flight times for RQ-11 Raven, Hunter 2-S, and MFD Nimbus. The red line on the figure shows the target flight time for The Banshee of 45 min. Both the RQ-11 Raven and MFD Nimbus surpass the flight-time goal, while the Hunter 2-S does not.

Figure 3.4 shows the comparison of the weights for the RQ-11 Raven, Hunter 2-S, and MFD Nimbus. The red line on the figure shows the maximum aircraft weight of 12 lbs. Both the RQ-11 Raven and the MFD Nimbus are under the maximum weight while the Hunter 2-S is 3.5 lbs heavier than the maximum weight.

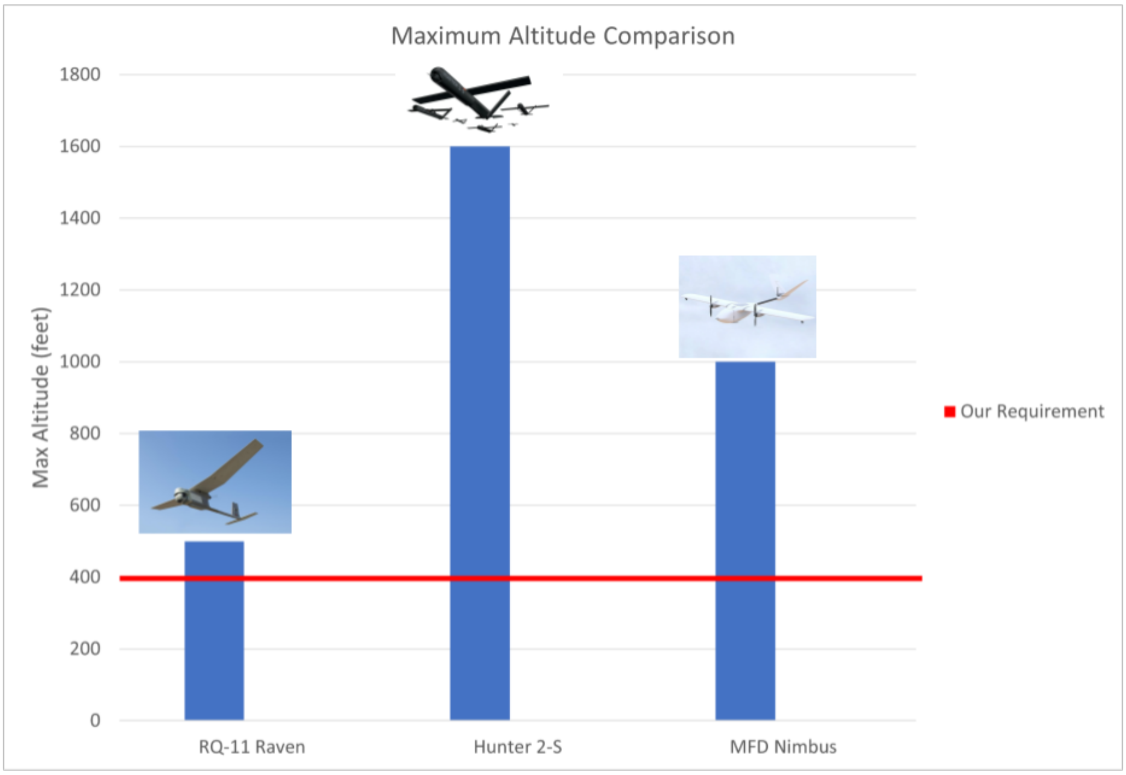


Figure 3.2: *Altitude comparison*

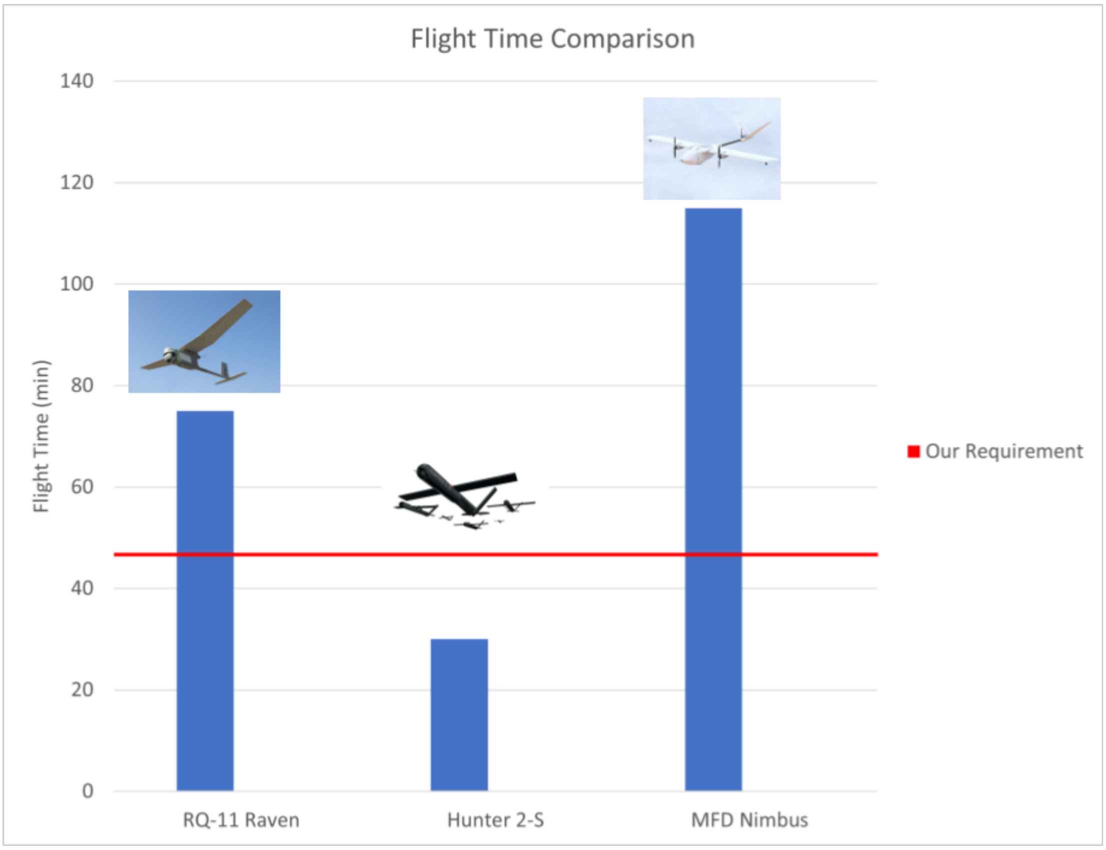


Figure 3.3: *Flight time comparison*

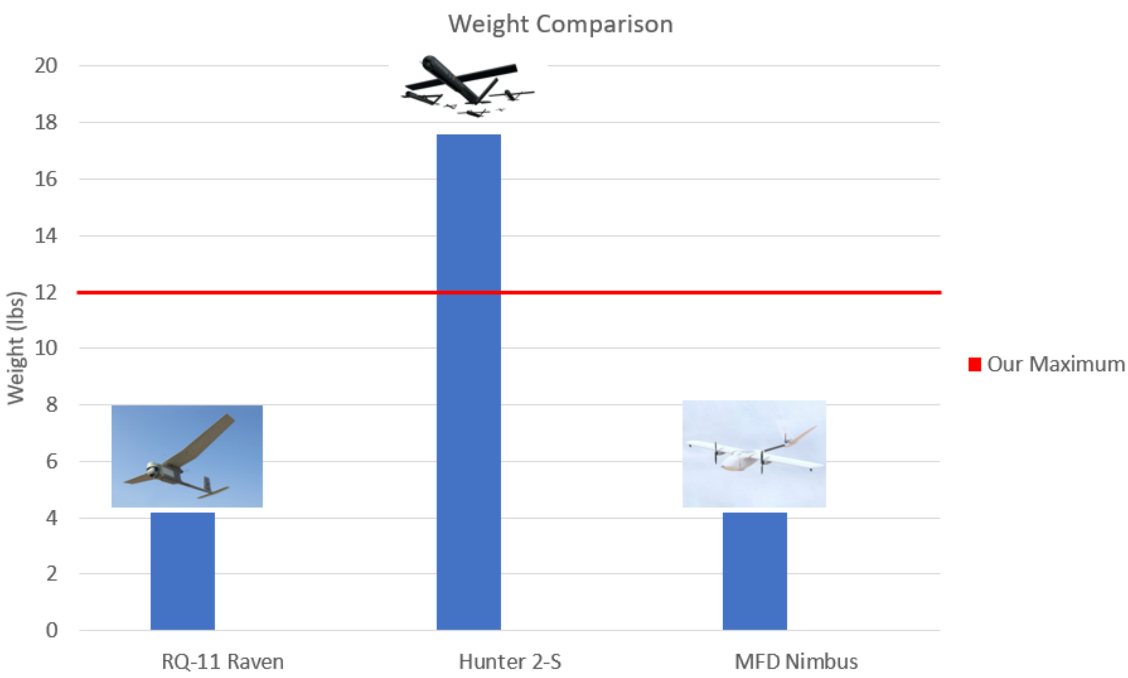


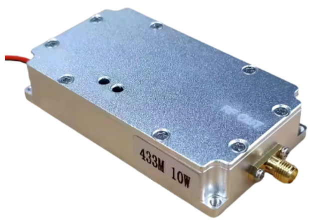
Figure 3.4: *Aircraft weight comparison*

3.2 Technologies

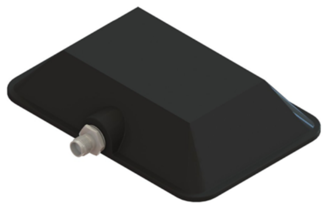
Once the team had researched similar UAV, technologies were researched that would need to be included in The Banshee. The main technology that was researched for The Banshee was technology that can jam and detect drones in The Banshee's vicinity. After consulting with an electronics subject-matter expert, StratoShield selected a jamming antenna, a jamming module, a drone detector software defined radio (SDR), and a detector antenna. The jamming antenna will be mounted on the outside of the fuselage and the other three technologies will be inside of the fuselage.

(a) *Drone detector SDR*

(b) *Drone detector antenna*



(c) *Jamming module*



(d) *Jamming antenna*

Figure 3.5: *Researched technology*

The drone detector SDR (Figure 3.5a) and the detector antenna (Figure 3.5b) will listen for a hostile drone's control signal by scanning for the most common frequency of 2.4 GHz. This will let an operator know when a drone is detected in The Banshee's vicinity. If a drone is detected in the vicinity, The Banshee will enable its jamming module (Figure 3.5c). The jamming module takes advantage of voltage from the battery and sends a signal to the jamming antenna (Figure 3.5d) which will be emitted in a conical shape downwards from The Banshee.

4

Initial Design Concept

After concluding the market research and getting a comprehensive idea of the technologies The Banshee would need to employ, the engineers at StratoShield met to design an initial concept for The Banshee. Initially, the team wanted to design a hybrid kinetic impact and jamming UAV, but after building out the requirements, it became clear that it would be better to pick one. Pursuing both neutralization approaches would result in a UAV capable of both tactics, but lacking proficiency in either. Given the mission objectives, StratoShield resolved to base their initial design upon a jamming and detection craft. Based on the market research findings, a dual-engine configuration was deemed optimal, but the specific body or fuselage shape remained undecided. Three distinct designs were meticulously drafted and considered.

4.1 Concept Sketches

4.1.1 Initial Design I

Figure 4.1 shows the team's first initial design for The Banshee which features a rectangular 9 in × 9 in × 27 in fuselage with a wingspan of 85 in and chord length of 8 in. This wingspan was chosen to be as close as possible to the maximum span allowed for the craft. With a larger span, our wing planform would be larger and would produce high lift. The chord length was then chosen to bring the main wing aspect ratio close to 10, a value comparable to our market research candidates. The first initial design also features a horizontal tail span of 15 in and a vertical tailspan of 7.5 in, and both have a chord length of 6 in. The red lines within initial design I represent carbon fiber spars and the blue lines within the figure represent a 3D-printed polylactic acid (PLA) frame. The black lines represent the outlines of the purple foam.

4.1.2 Initial Design II

Figure 4.2 shows initial design II. The only change that was made to this design compared to the design that is seen within Figure 4.1 is the fuselage. The team envisioned a fuselage that would be flatter as well as wider than design I. This design did not move forward in the design process due to the increased weight and material needed within the fuselage.

4.1.3 Initial Design III

Figure 4.3 shows initial design III, which is similar to both the first and second initial designs, with the fuselage varying once again. The idea with this design was to have a fuselage that smoothly connects with the airfoil in order to minimize drag. The team decided not to move forward with this design due to the complicated manufacturing process.

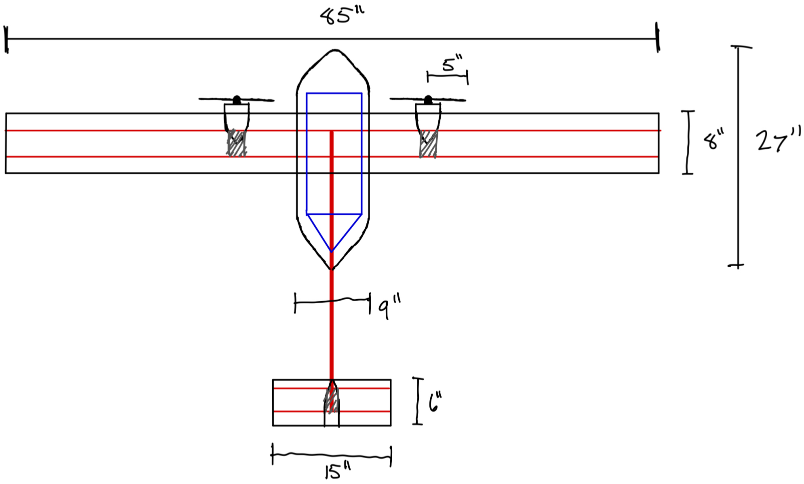


Figure 4.1: *Initial design I for The Banshee*

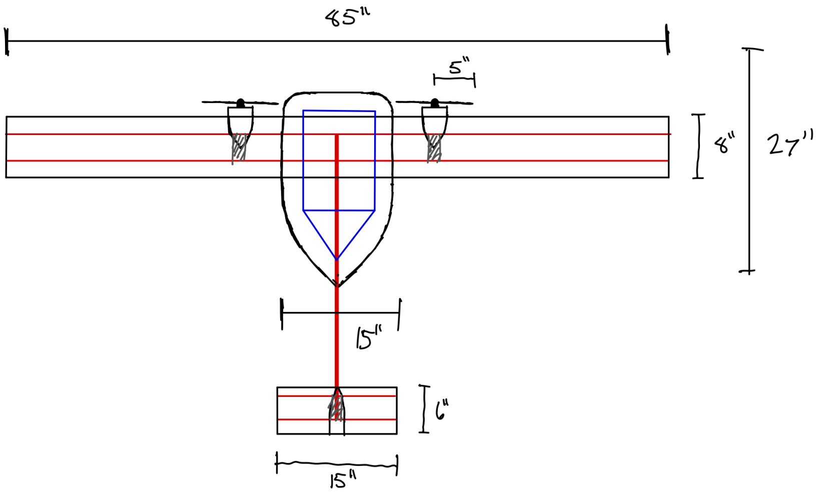


Figure 4.2: *Initial design II for The Banshee*

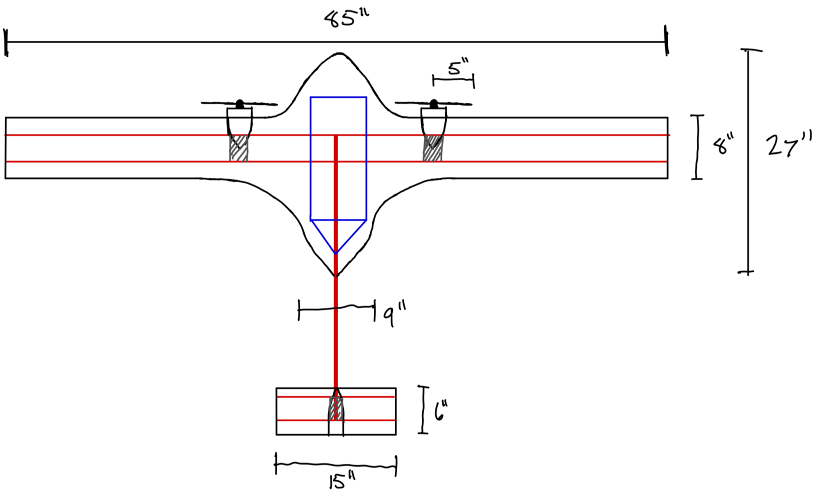


Figure 4.3: *Initial design III for The Banshee*

4.1.4 Selected Design

Figure 4.4 shows the selected initial design for The Banshee, which resembles the design shown in Figure 4.1 but rendered as a computer-aided design (CAD) model. The team selected initial design I over initial design II and III due to the ease of manufacturing compared to the other versions.

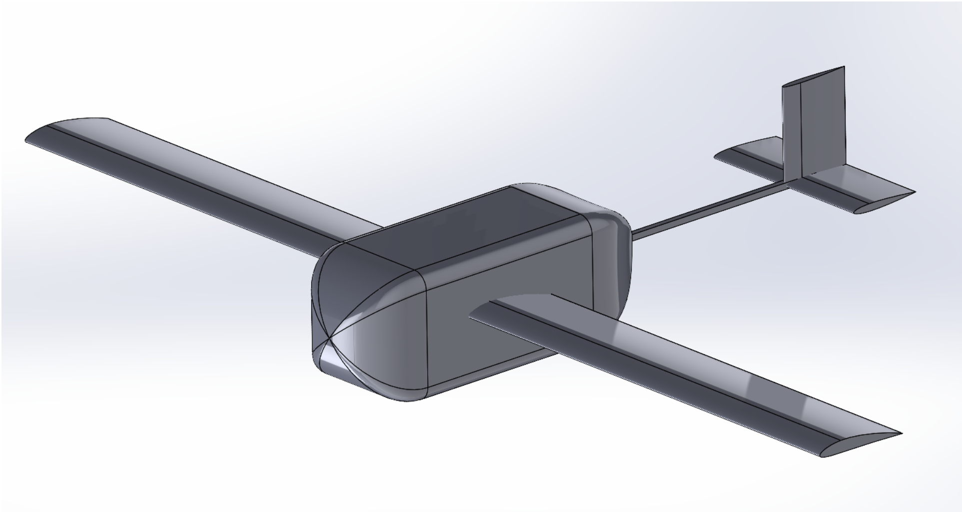


Figure 4.4: *Selected initial design for The Banshee*

4.2 Initial Sizing

The flight performance and structural teams collaborated during the initial design process to generate the table of initial wing sizes shown in Table 4.1.

Table 4.1: *Initial wing sizing parameters*

Name	Variable	Dimension
wingspan	b	85 in
wing chord	c	8 in
tailspan	b_t	11.6 in
tail chord	c_t	5.9 in
vertical stabilizer height	h_v	7.3 in
vertical stabilizer chord	c_v	7.87 in
tail moment arm	l_t	34.6 in

The primary driver for the measurements in Table 4.1 is the requirement to achieve a loiter time of at least 45 min. Aircraft designed for long endurance typically feature extended wingspans and high aspect ratio (AR), which directly resulted in the selections of b and c. The remaining dimensions were determined by referencing similar high-efficiency, glider-type aircraft as well as using tail sizing equations(see Appendix D).

For the Banshee to hold the payload components, batteries, and electronics required to complete its mission, the initial fuselage was designed to be 16 in × 9 in × 9 in. This volume would later be reduced once more specifics about the internal avionics were determined.

5 Trade Studies

Upon concluding the initial design process, the team initiated a series of trade studies to refine the design. As these studies were conducted concurrently and iteratively throughout the design process, they are presented here by subsystem rather than chronologically. The majority of our design process was dedicated to aerodynamic performance, propulsion configurations, and structural stability. The subsequent sections provide a detailed overview of StratoShield's research and development process.

5.1 Aerodynamics

5.1.1 Initial Airfoil Selection

To patrol an AOI for up to 45 min, The Banshee needs endurance and flight time to be prioritized in its design. To this end, airfoils that could produce high lift at low speeds, minimizing the power draw of the motors, were investigated. This characteristic is measured by a wing's lift-to-drag ($\frac{L}{D}$) ratio, where a higher ratio is more efficient. Additionally, the airfoil needed to be easy to manufacture to meet our business requirements (Chapter 2). Based on this analysis, the airfoil candidates were narrowed down to the NACA 4412, NACA 6409, and MH 60 (Figure 5.1). Each are common airfoils that exhibited high lift at low speeds.

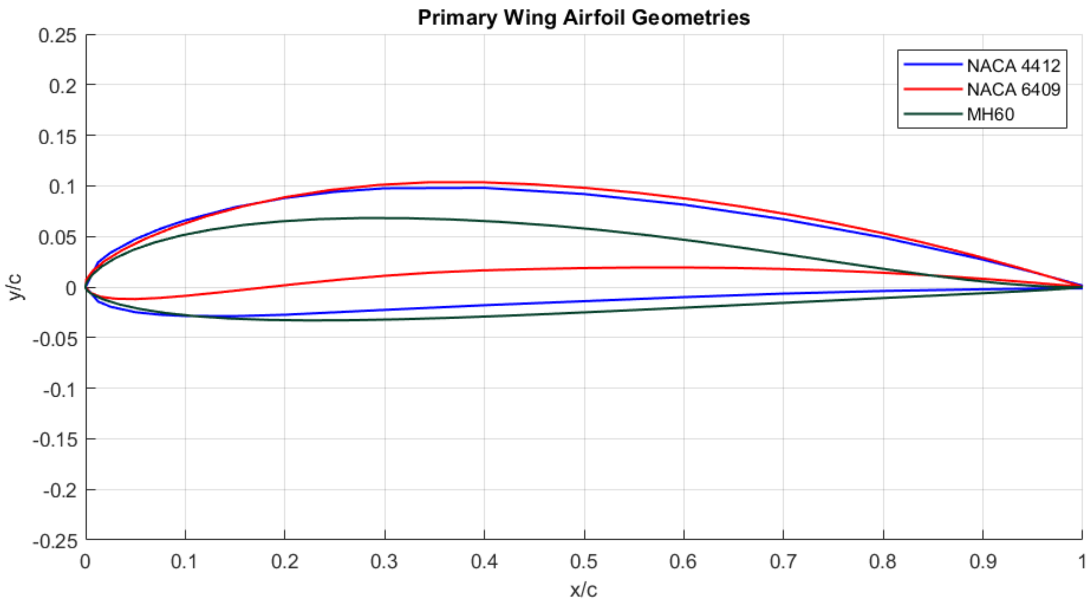


Figure 5.1: *Initial airfoil selection*

To further analyze the airfoils and determine their $\frac{L}{D}$ ratios, the mission flight conditions needed to be defined. The mission conditions for the analysis were defined as follows:

- **Altitude:** 1500 ft (approximately the elevation of Ames plus 400 ft)
- **Density:** 0.0023 slug/ft^3
- **Temperature:** 53.96 °F
- **Viscosity:** 3.707×10^{-7} slug/ft s

The results of the 2D airfoil analysis are presented in Figure 5.2. The MH 60 had the lowest overall lift coefficients but a high stall angle of attack. The NACA 6409 had the highest lift coefficients but a lower stall angle of attack and large negative pitch moment coefficients for all angles of attack. The NACA 4412 was a compromise between these two airfoils and had the highest $\frac{L}{D}$ ratio of the three at 19.3. Therefore, we chose to use the NACA 4412 for our initial design iteration.

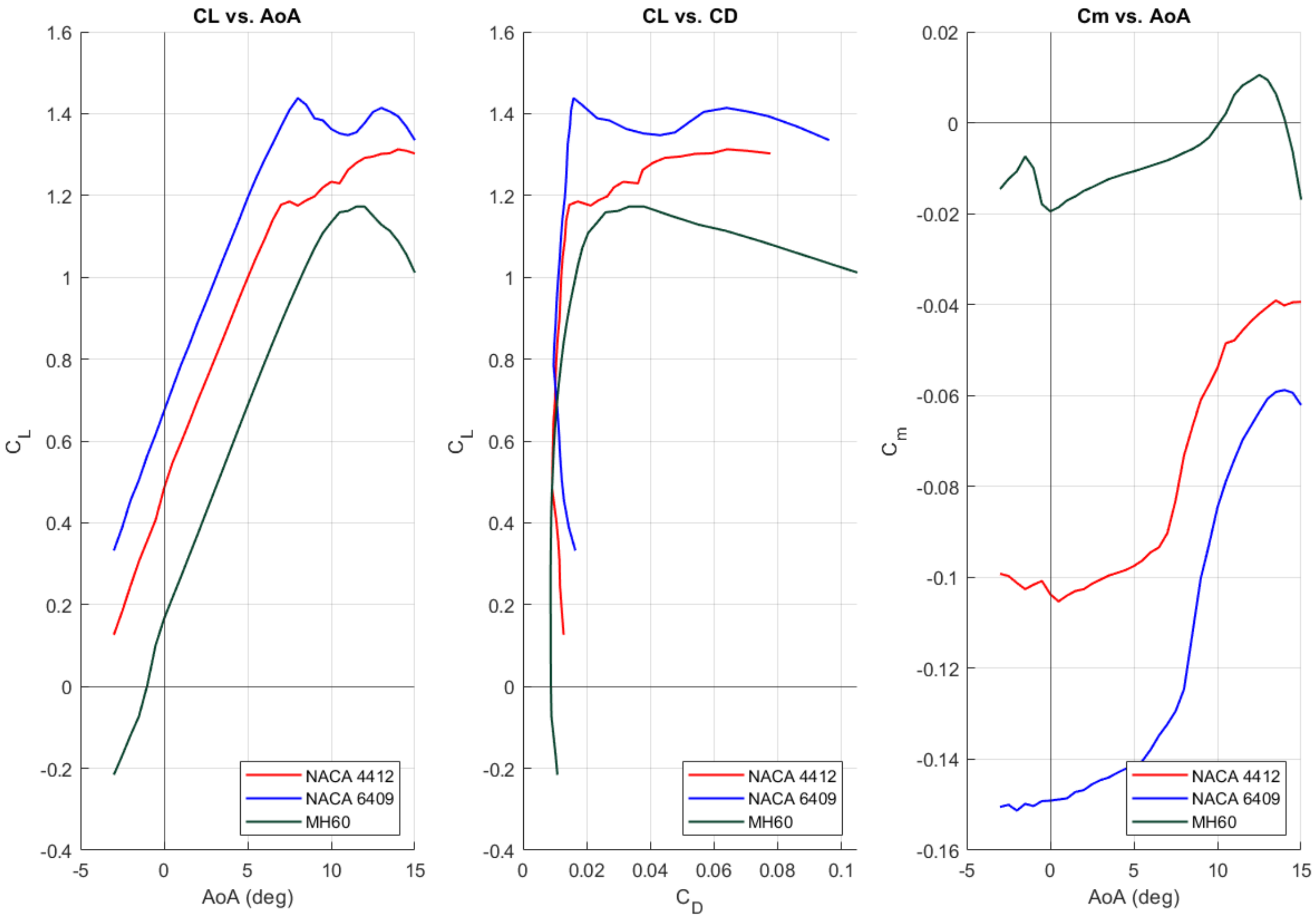


Figure 5.2: *Wing airfoil selection coefficient plots*

For the initial horizontal and vertical stabilizer airfoils, the symmetric NACA 0009 and NACA 0010 airfoils were tested in the same conditions (Figure 5.3). Additionally, the Eppler 423 was also analyzed due to its high lift production; however, this airfoil is non-symmetric and would produce unwanted forces at steady-level-flight. It was not considered further.

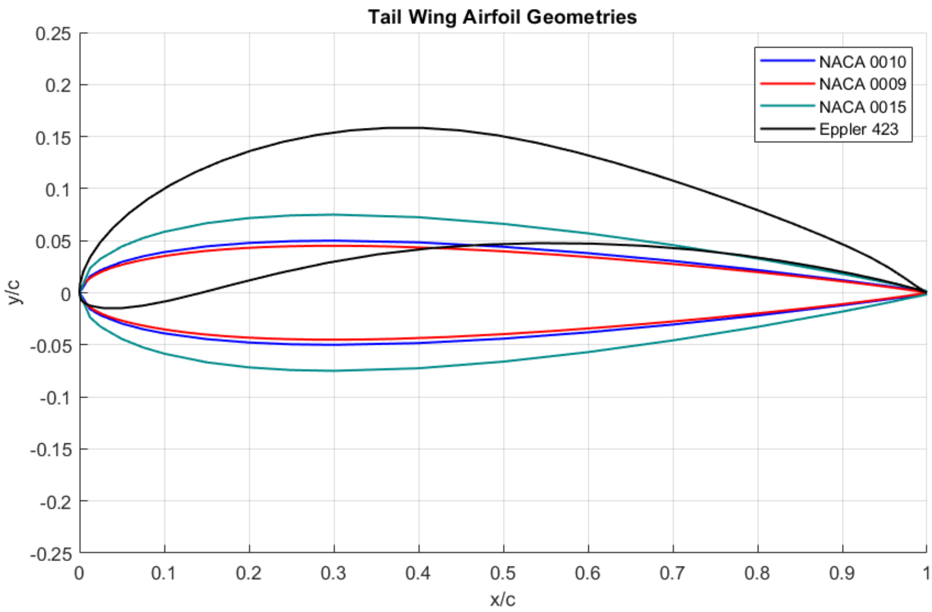


Figure 5.3: *Tail airfoil selection*

The results from the NACA 0009 and NACA 0010 analyses were almost identical, so the NACA 0010 was initially selected for its higher thickness. Later, the team found the NACA 0010 may be too thin to fit the structural carbon fiber spars; so, the NACA 0015 was selected to preserve the desired symmetric shape with an increased the thickness to fit the spars.

5.1.2 Longitudinal Stability

To assess the longitudinal stability of the design, STAR-CCM+ was used to run computational fluid dynamics (CFD) analyses. The resulting lift and drag characteristics were expected but the pitching moment—a measurement of longitudinal stability that predicts whether the nose of the aircraft will pitch up or down for a given angle of attack (AoA)—was unacceptable. Ideally, the pitching moment curve will intersect the origin, resulting in an aircraft that will naturally level itself at a 0° AoA, a form of passive control like a boat leveling itself on water. This effect is quantified by the static margin parameter:

$$\text{Static Margin} = \frac{x_{\text{aerodynamic center}} - x_{\text{center of gravity}}}{\text{wing chord}} * 100 \tag{5.1}$$

In an attempt to address the unacceptable pitching moment, fifteen different configurations that varied the tail shape and main wing position were run through a CFD simulation. The results of three of these iterations are shown in Figure 5.4.

Even after changing the tail shape and the wing position, the Banshee was still experiencing negative pitching moments over all practical AoA. Version 1.1.6 (green) and 1.1.9 (red) had static margins well outside of the recommended range of 5 % to 25 %. Version 1.1.12 (blue) had a reasonable static margin of 17.61 %, but it was still less than ideal.

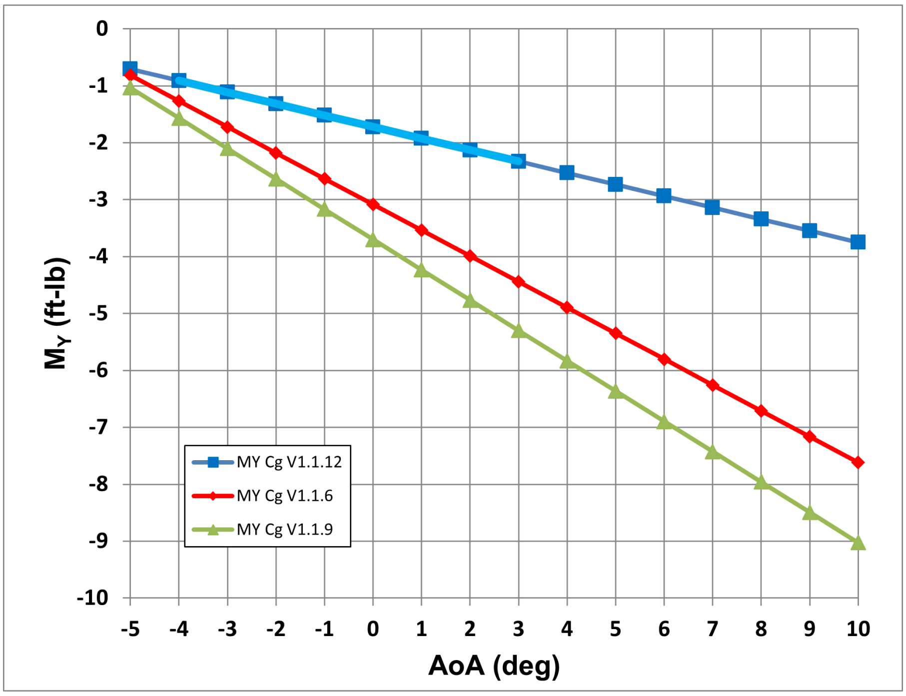


Figure 5.4: *Initial pitching moment vs. AoA. Data was generated with a NACA 0015 and varying wing positions.*

None of the 15 iterations yielded desirable longitudinal stability; so, further aerodynamic trade studies were conducted to find new wing airfoil with less negative pitch moment coefficients. The NACA 2412 airfoil (Figure 5.5) was recommended by a subject-matter expert and chosen for analysis. It is geometrically similar to the NACA 4412, the main difference being a slightly less aggressive camber.

The results of the 2D airfoil analysis comparing the NACA 2412 and the NACA 4412 are summarized in Figure 5.6. The pitching moment coefficients for the NACA 2412 are smaller compared to the NACA 4412, but the NACA 2412 still produced high lift and had a high stall angle of attack. The NACA 2412 also had lower drag coefficients and parasitic drag due to its less aggressive camber.

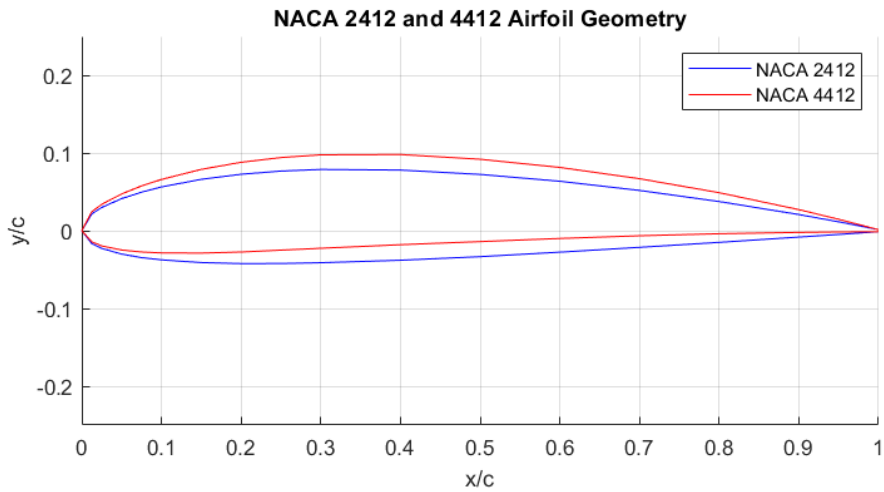


Figure 5.5: *NACA 4412 vs. NACA 2412*

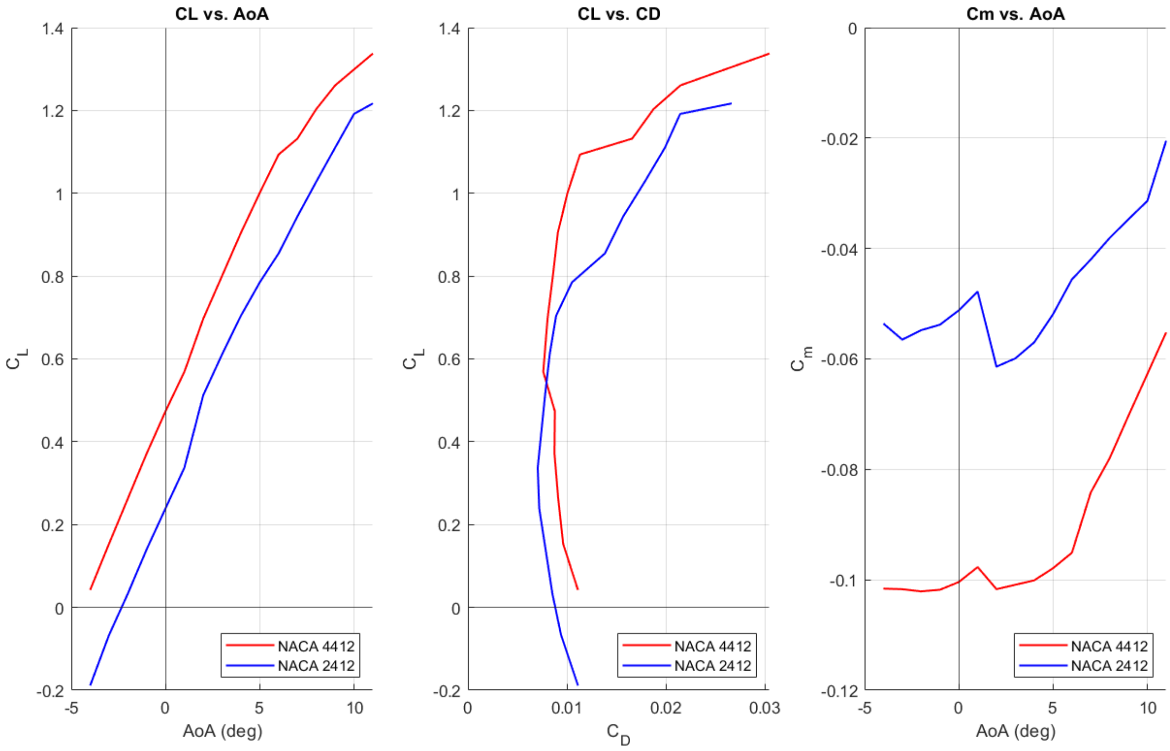


Figure 5.6: *Comparison of the NACA 4412 and NACA 2412 airfoil*

Based on these results, the flight performance team returned to the wing positioning study. The objective, once more, was to find the optimal wing placement that produced an ideal static margin and a pitching moment that intersected the axes near the origin. This time, however, the study was done with the NACA 2412 instead of the NACA 4412.

Six design iterations were modeled, three with varying wing chords (10 in, 12 in and 14 in) and three with varying wing leading edge distances from the nose. As observed previously, chord length has less of an effect on longitudinal stability; so, the results of varying the wing position are presented in Figure 5.7.

As shown in Figure 5.7, the pitching moment curve still did not intercept the axes at the origin, but the 7" configuration was closest. This configuration also has the added a benefit of a shallow moment curve which should result in a more controllable craft. Based on these results, the team decided to move forward with a wing positioned 7 in from the nose.

5.1.3 Efficiency

After largely resolving the longitudinal stability problems, a subject-matter expert suggested increasing the main wing chord length to 14 in to improve endurance while not compromising our longitudinal stability. However, this change necessitated modifications to the horizontal and vertical tail as well. To guide these changes, the flight performance team used tail sizing coefficients to estimate more appropriate sizes. The results of these changes are summarized in Chapter 6 since they were among the final changes to the current craft.

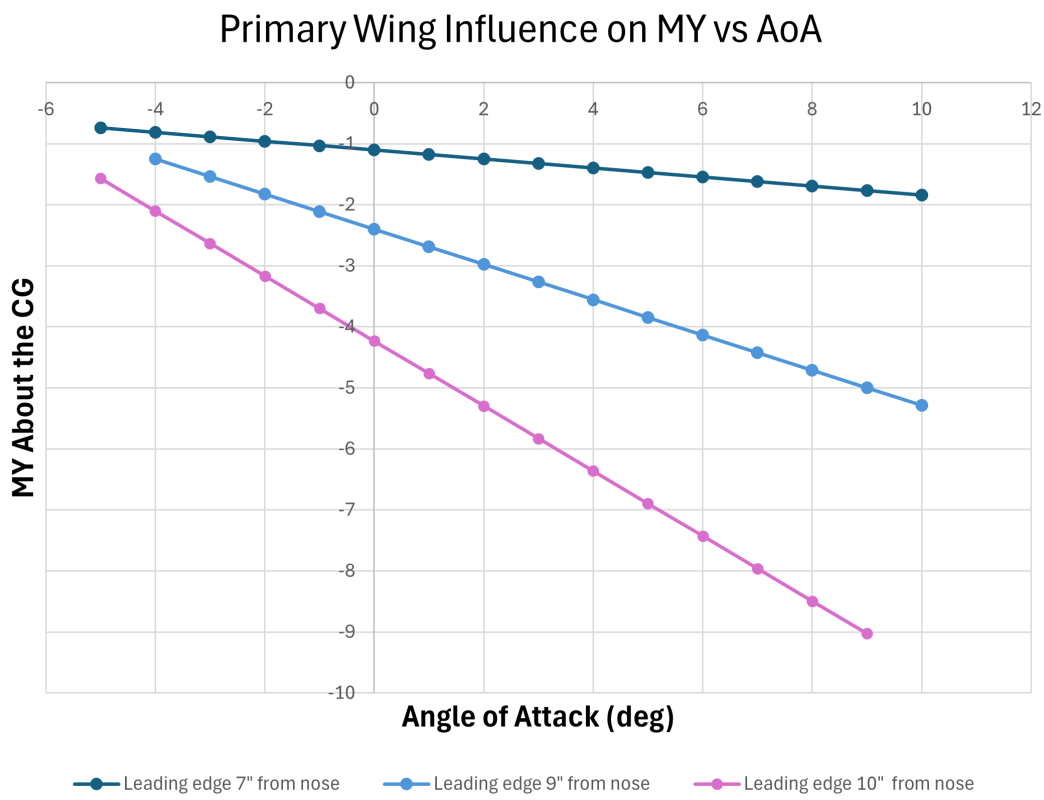


Figure 5.7: *Pitching moment vs AoA for various wing positions*

5.2 Propulsion

Based on the initial design concept (Chapter 4), The Banshee was designed to carry two motors, one mounted on each wing. An analysis of 10 different of battery, propeller, and motor combinations was conducted, with initial selections based on specifications for similarly sized aircraft. Simulations using MotoCalc were performed to analyze thrust output, efficiency, power draw, and flight time against airspeed for various throttle configurations. The objective was to identify a combination that would provide the required thrust at the tentative cruise speed of 35 MPH, while maintaining good efficiency and minimizing battery power draw. From this trade study, the best-performing combination consisted of Thunder Power 5S 5000 mA h batteries (one for each motor), APC 13x6.5E propellers, and E-Flite Power 32 (770 Kv) motors (Figure 5.8 and Figure 5.9).

However, it was later determined that this propulsion system configuration would fail during takeoff due to an excessive power draw requirement of 2300 W at 100 % throttle (Figure 5.8). The solution was to switch to a smaller battery, specifically the Thunder Power 4S 3850 mA h battery, while retaining the same motor and propeller models. This adjustment reduced the system's power draw to 1470 W at 100 % throttle during takeoff, staying below the motor's maximum power rating of 1600 W (or 735 W at 100 % throttle for a motor maximum of 800 W individually).

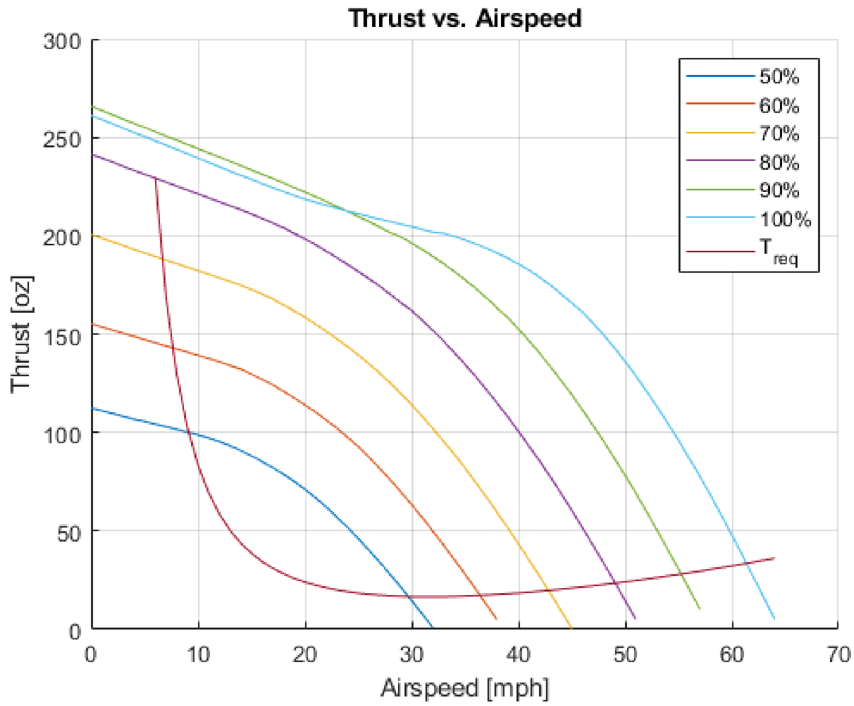


Figure 5.8: *Thrust vs. airspeed for the best performing propulsion system, Thunder Power 5S* 5000 mA h *batteries, APC 13x6.5E propellers, and E-Flite Power 32 (770 Kv) motors. The configuration in graph consists of two batteries, two motors, and two propellers.*

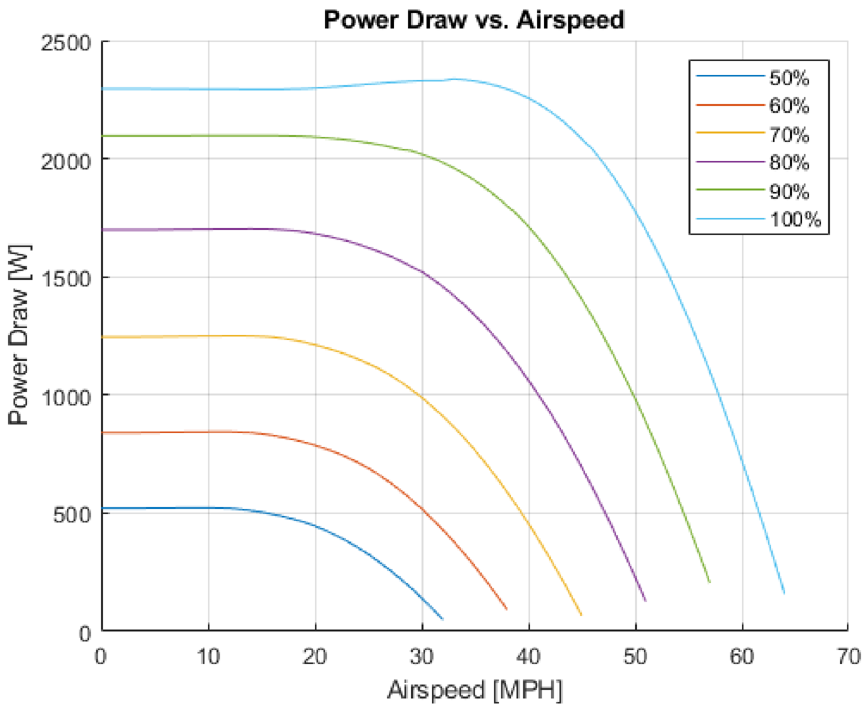


Figure 5.9: *Power draw vs. airspeed for the best performing propulsion system, Thunder Power 5S* 5000 mA h *batteries, APC 13x6.5E propellers, and E-Flite Power 32 (770 Kv) motors. The configuration in graph consists of two batteries, two motors, and two propellers.*

5.3 Structures

A critical part of The Banshee's design process was ensuring that the structure of the aircraft was sound under normal and abnormal operating conditions, while also remaining as lightweight as possible. Remote control (RC) scale aircraft structures are typically constructed out of a carbon-fiber or fiberglass skeleton and given shape by an outer profile made of lightweight foam.

The first step in designing the structure of The Banshee was to determine the paths loads take to reach the aircraft's center of gravity c_g, and then ensure that there is a load-safe element—like a carbon-fiber spar—there to take the force. At no point in the aircraft can non-trivial loads be concentrated in a weak space-filling material such as foam. With this paradigm, an initial concept for the structural "skeleton" of The Banshee was created (Figure 5.10). As shown in Figure 5.10, every force experienced by the aircraft has a path reinforced by carbon fiber or 3D-printed polyethylene terephthalate glycol (PETG) as it travels towards the c_g.

Figure 5.10 also details the overall layout of the structural elements of The Banshee. The Banshee uses two span-wise carbon fiber spars in the wing to strengthen them against bending and twisting. These spars are connected to a 3D-printed PETG joiner block, to which the two carbon fiber booms are also connected. These booms join up with the tail spars of the aircraft through another 3D-printed PETG block.

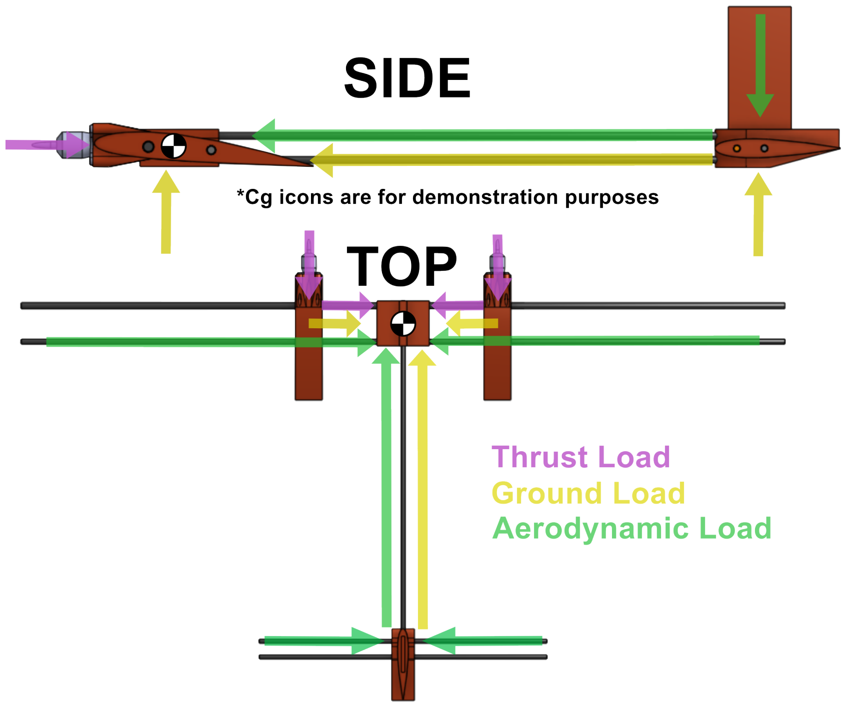


Figure 5.10: *Structural load map diagram*

Building off this structural configuration, the next step was to analyze and optimize the sizes of carbon fiber spars and booms—one of the more expensive components—used in The Banshee. The first iteration of analysis was done to figure out a baseline wing spar size that could hold the weight of the aircraft during steady level flight. Three different sizes of spars were imported into Ansys Mechanical 2024 R2, a structural analysis program, and were subjected to 10 lbs of weight. Figure 5.11 details the results of this analysis. The 5/8" diameter spar was selected for the wings as it deformed the least of the tested options.

After determining the baseline spar size, further structural optimization was performed by increasing the fidelity of the simulations and by using different sized spars for regions with different loads. The objective was twofold. First, to save weight and cost, since using the same 5/8" spar for both the fore and rear spar would be wasteful and inefficient. Secondly, if the wing had two 5/8" spars, there would be a torque generated when the

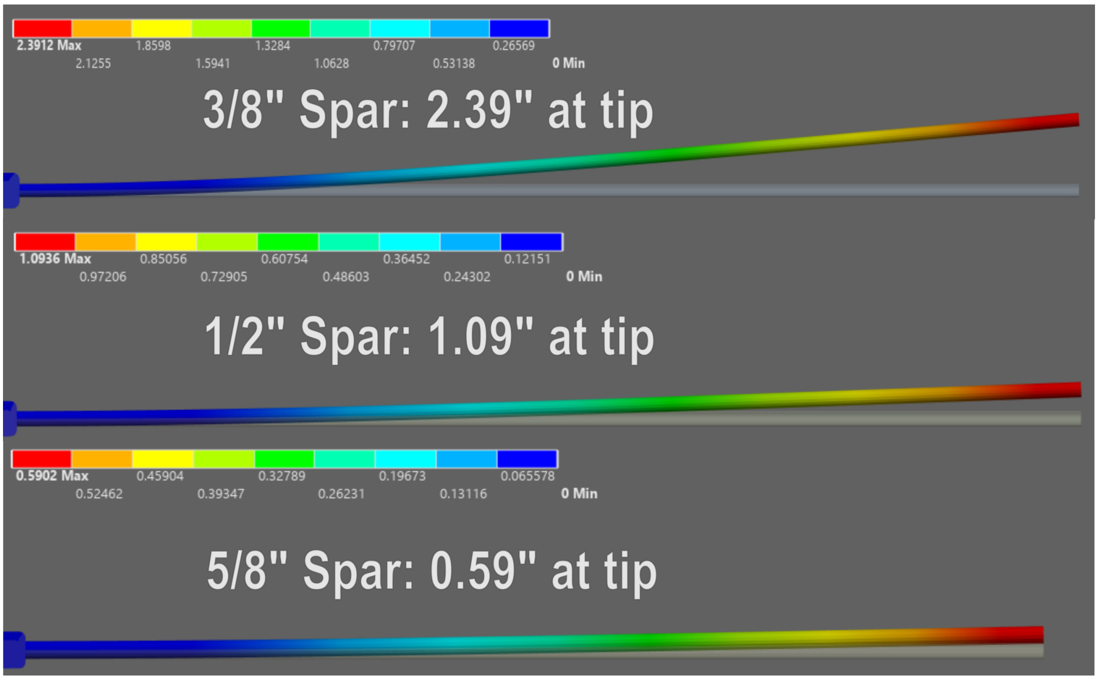


Figure 5.11: *Structural analysis iteration one*

wing is under lift because 70 % of a wing's lift is generated forward of the quarter-chord. This would result in uneven deformation of the wing spars, and consequently, a twist induced in the wing that would hamper aerodynamic performance significantly.

For these reasons, the selection criterion for the second round of structural analysis was not which spar deformed the least but which combination of fore and rear spars deformed most similarly under a 3g[1] load condition. The results of this analysis are detailed in Figure 5.12, where the best combination of spars was the 5/8" in front, and the 1/2" spar in the back.

Figure 5.12: *Structural analysis iteration two*

[1] three times the expected weight of the aircraft; to account for increased stress during high-stress maneuvers like takeoff/landing

6
Current Design Concept

In this section, StratoShield is proud to present the current conceptual design of The Banshee. It is the culmination of weeks of design work and analysis. Below is a description of The Banshee's structure, aerodynamic performance, propulsion system, and avionics.

6.1 Structures

The current design for The Banshee (Figure 6.1) features a dual-motor propulsion system connected to a 3D-printed PETG frame. The PETG frame that the motors are connected to is modeled to be flush with the shape of the NACA 2412 purple foam airfoil. The airfoil's span is 85 in and has a chord length of 13.93 in with a 5/8" carbon fiber spar in the fore and a 1/2" in the rear of the airfoil, both spanning the length.

The fuselage of The Banshee features a rectangular body with two extruding 3/8" carbon fiber booms coming out of the back connected to a 3D-printed PETG tailpiece. Connected to the tailpiece are two 3/8" carbon fiber spars spanning the entire horizontal tailspan of 32 in. The vertical tail span is 10.24 in, and the horizontal and vertical tails have a chord length of 7.97 in. The total estimated weight of The Banshee is 9.45 lbs. A more detailed view of the dimensions for The Banshee is shown in Figure 6.2.

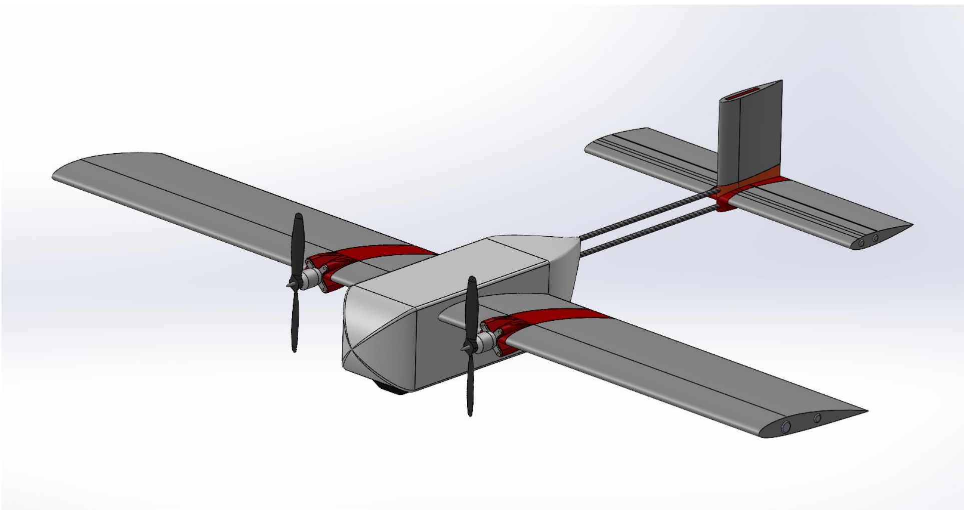


Figure 6.1: *Current design for The Banshee*

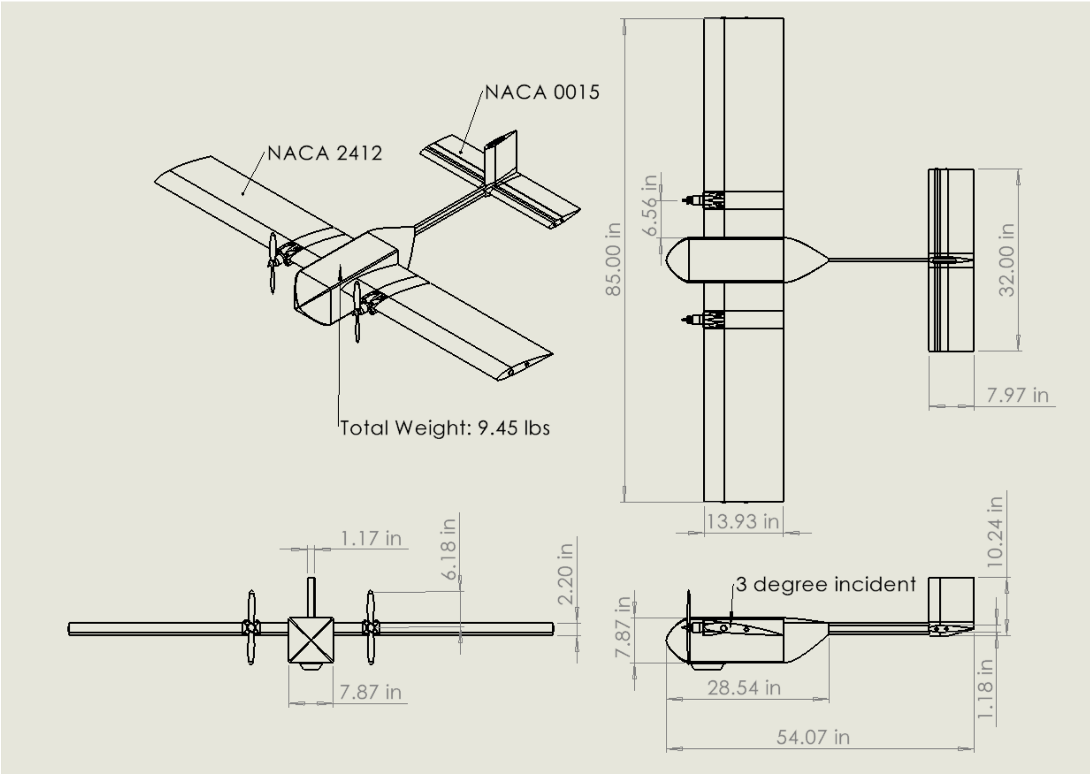


Figure 6.2: *Drawing of the dimensions for the Banshee*

Materials that the team plans on using to create The Banshee are shown within Figure 6.3. Purple foam is what will be used to make the fuselage and airfoils. Carbon fiber spars will be the main material used for the aircraft's structure. Within the fuselage, lite ply will be used to build the internal box containing all avionics. The motor blocks and the tail connector piece will be made through 3D printing using PETG.

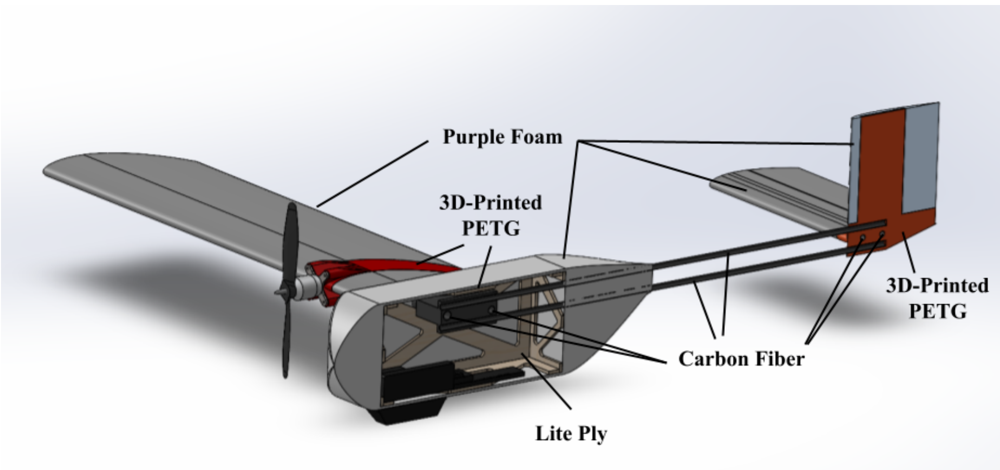


Figure 6.3: *Materials used to create The Banshee*

Figure 6.4 shows the team's plan for points of connections within the structure of The Banshee. Carbon fiber ferrules will be used to split up the length of the 85 in carbon fiber spars within the main airfoil. The ferrules will be glued to the inner carbon fiber spar, and a metal pin will be inserted through the outer spar and ferrule. The purpose of splitting up the 85 in carbon fiber spars is for ease of transport of The Banshee. The middle carbon fiber spars within both the main and horizontal airfoils will be glued to the 3D-printed PETG blocks.

The two carbon fiber booms will also be glued to the 3D-printed PETG blocks. The purple foam main airfoil and horizontal airfoil will be inserted onto the carbon fiber spars and glued into place. The purple foam vertical stabilizer will be glued to the PETG tail block.

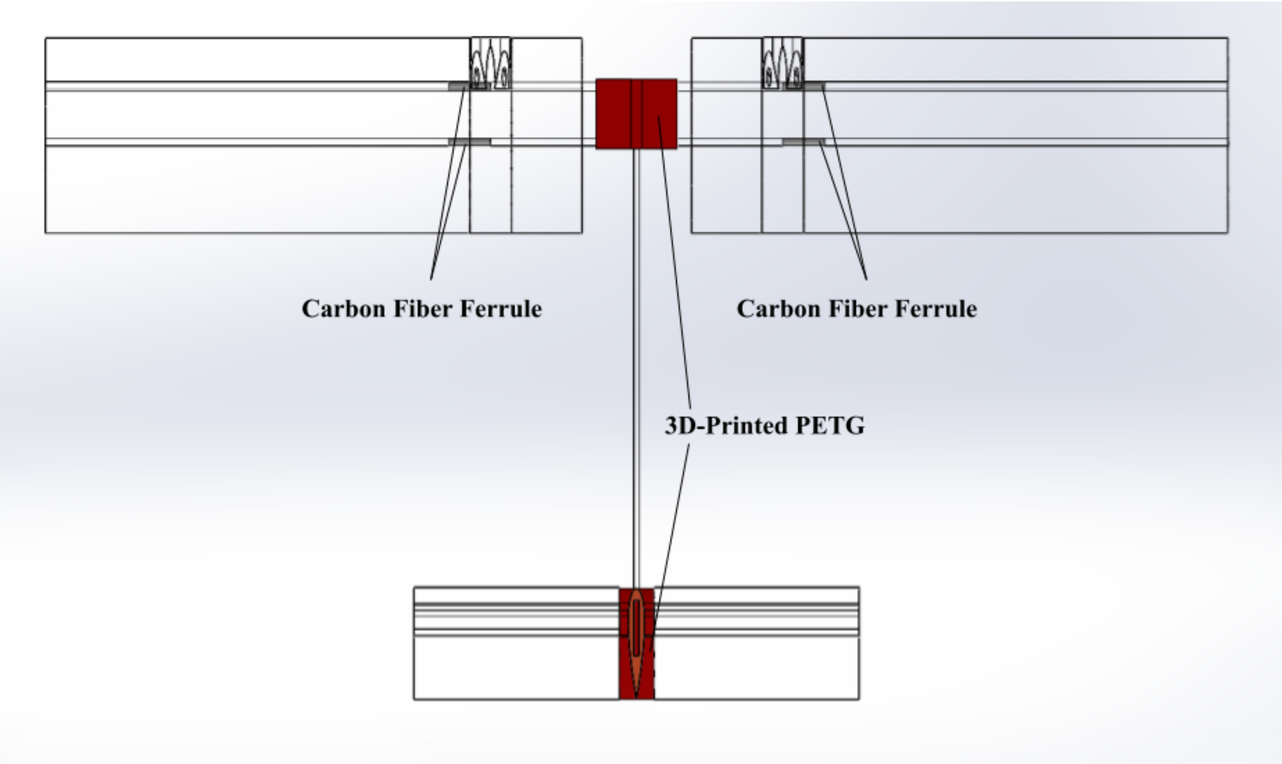


Figure 6.4: *Top view of the points of connections for the structure of The Banshee*

6.2 Aerodynamics and Performance

To assess the performance of the current conceptual design, an extensive aerodynamic analysis was performed. The details of this analysis are presented here in all their gorey detail.

For reference, the following is a list of the most crucial mission flight performance parameters:

- **Cruise Altitude:** 1500 ft
- **Ground Altitude:** 1000 ft
- **Stall Speed:** 18.8 MPH
- **Required Runway Distance:** 35.2 ft
- **Total Takeoff Distance:** 295 ft
- **Gross Takeoff Weight:** 9.45 lbs
- **Desired Climb Angle:** 12°
- **Required Climb Velocity:** 44.74 MPH
- **Endurance:** 10.8434min
- **Total Flight Duration:** 52 min

The most crucial aerodynamic parameters to note in an aircraft is, of course, the lifting surfaces. The following list itemizes a large number of these parameters for reference.

- **Wing Position (Nose to Leading Edge):** 7.00 in

- **Wing Chord:** 14.0 in
- **Wing Span:** 85.0 in
- **Wing Planform:** 1190 in^2
- **Incident Angle of Attack of Wing:** 3.00°
- **Horizontal Tail Chord:** 8.00 in
- **Horizontal Tail Span:** 32.0 in
- **Horizontal Tail Planform:** 256 in^2
- **Vertical Tail Chord:** 8.00 in
- **Vertical Tail Span:** 10.0 in
- **Vertical Tail Planform:** 80.0 in^2

These parameters directly affect the aerodynamic performance plots presented in Figure 6.5, Figure 6.6, and Figure 6.7. These figures, generated from CFD analyses, show The Banshee

- is an efficient glider and has a safe stall angle (Figure 6.5),
- does not produce excessive drag (Figure 6.6), and
- has a high $\left(\frac{C_L^{\frac{3}{2}}}{C_D}\right)_{\max}$ resulting in efficient flight (Figure 6.7).

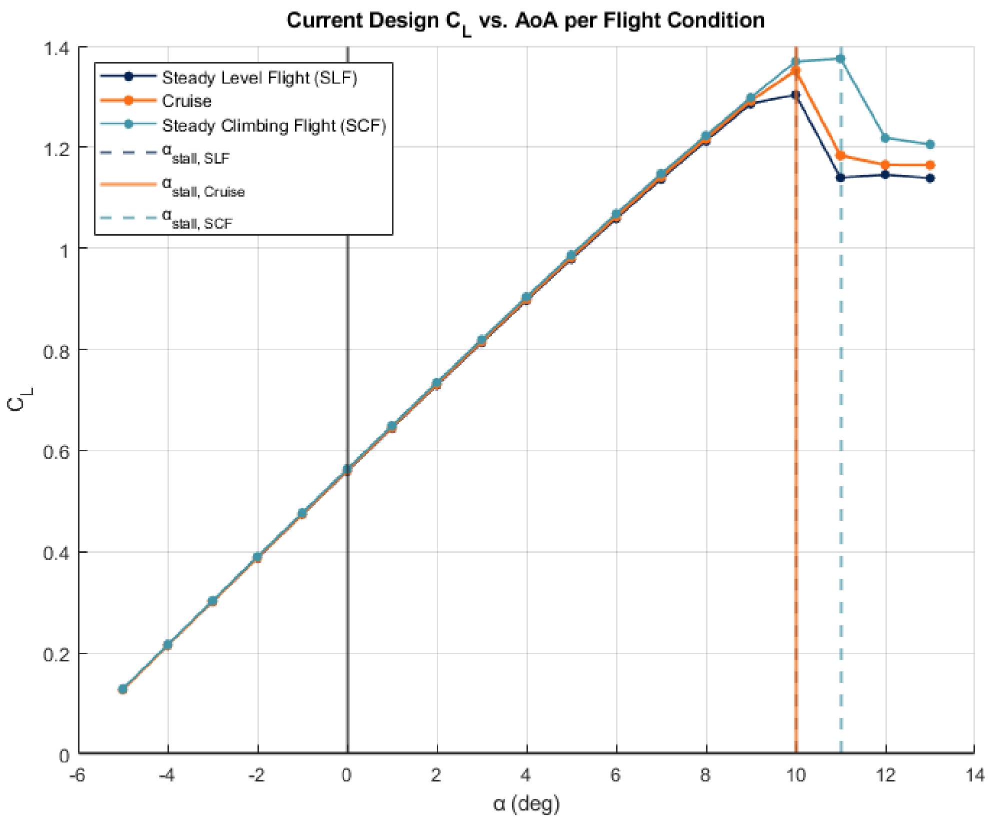


Figure 6.5: *Flight Parameter Lift Coefficient Plots for Current Design*

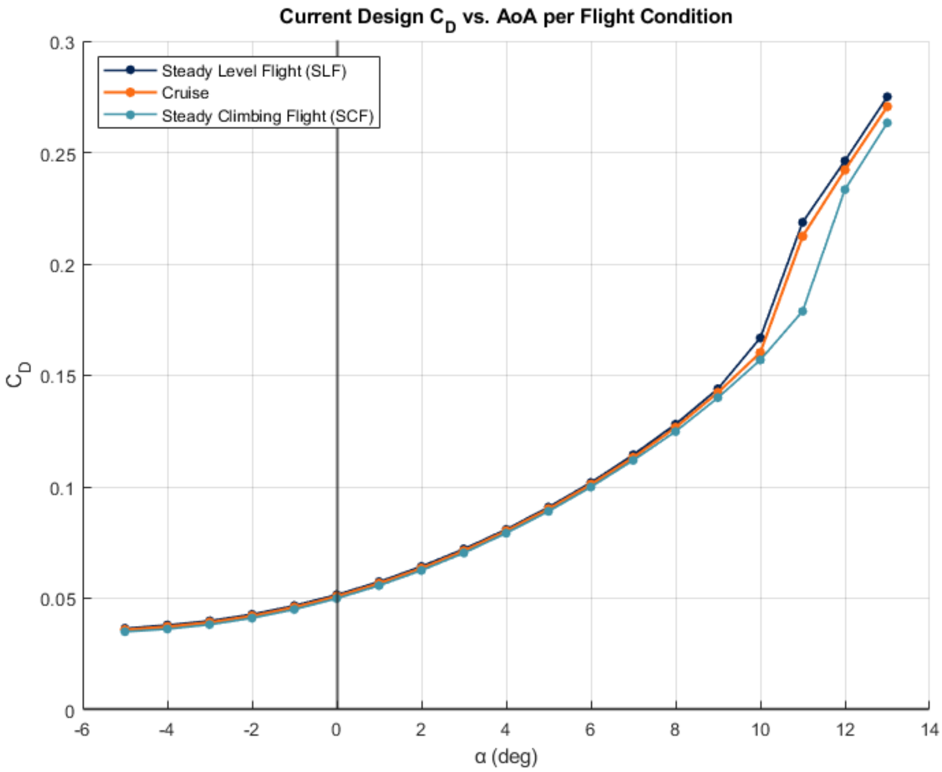


Figure 6.6: *Flight Parameter Drag Coefficient Plots for Current Design*

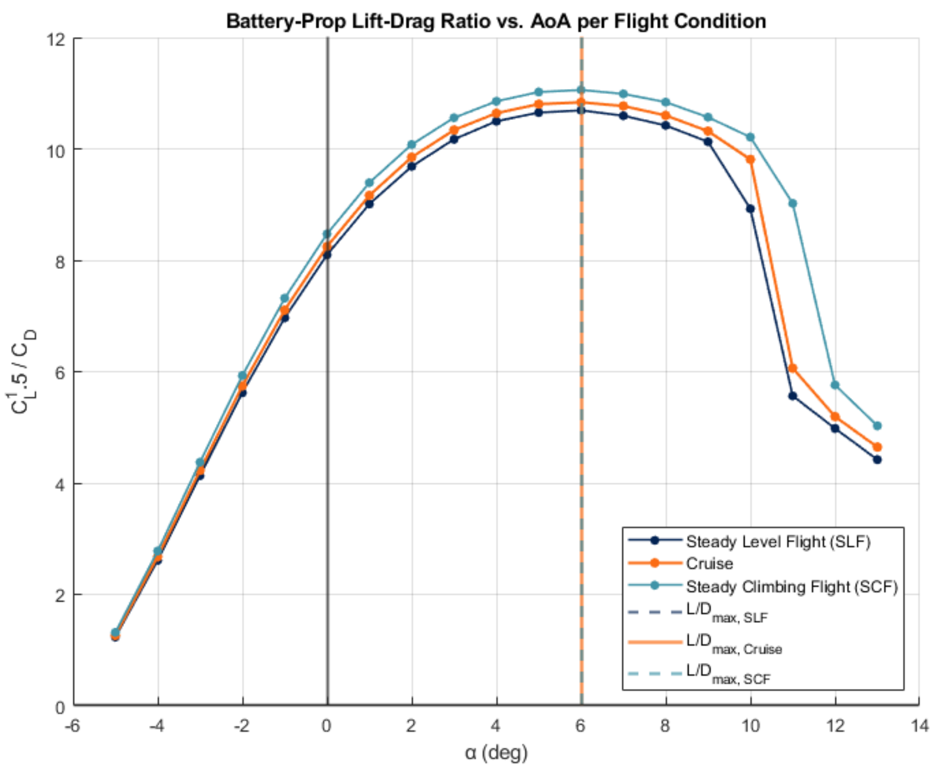


Figure 6.7: *Flight Parameter Lift-Drag Ratios for Current Design*

Of particular interest to evaluate longitudinal stability, the list of characteristics is itemized:

- **Center of Gravity (Rel. to Nose):** 9.92 in
- **Neutral Point (Rel. to Nose):** 13.6 in
- **Static Margin:** 26.2 %

Lastly, an important characteristic of an endurance craft is its stall angle and $\left(\frac{C_L^{\frac{3}{2}}}{C_D}\right)_{\max}$. These values under different flight conditions are summarized in Table 6.1.

Table 6.1: *Flight characters under different flight conditions for the current design of The Banshee*

Condition	Stall AoA [°]	$\left(\frac{C_L^{\frac{3}{2}}}{C_D}\right)_{\max}$
cruise (35 MPH)	10	10.84
steady level flight	10	10.61
steady climbing flight	10	10.61

6.3 Propulsion System

The current propulsion system is composed of Thunder Power 4S 3850 mA h batteries, APC 13x6.5E propellers, and E-Flite Power 32 (770 Kv) motors, one combination mounted on each wing (Figure 6.1). Presented following are the Thrust and Power Draw vs. Airspeed for different throttle configuration graphics for the propulsion system (both motors and batteries included).

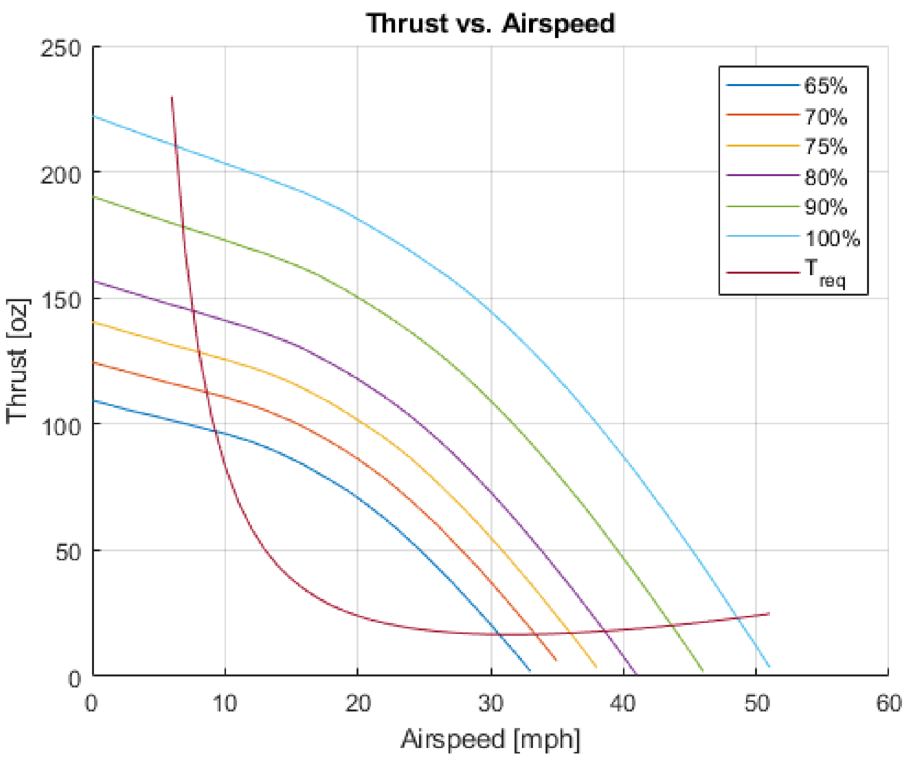


Figure 6.8: *Thrust [oz] vs. Airspeed [MPH] for different throttle configurations.*

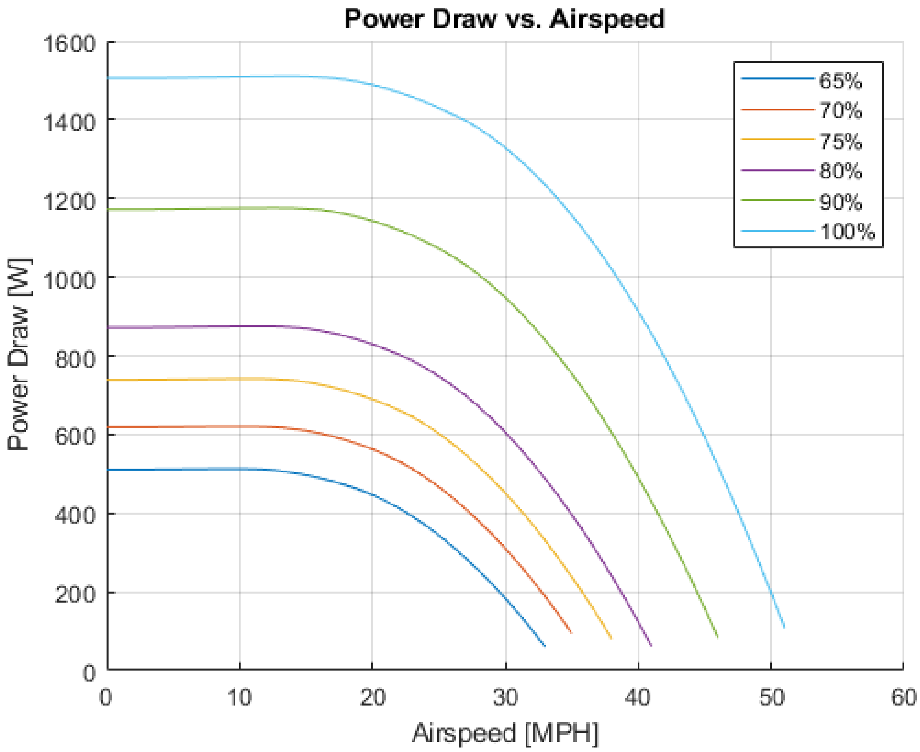


Figure 6.9: *Power Draw [W] vs. Airspeed [MPH] for different throttle configurations.*

From Figure 6.8, at a cruise speed of 35 MPH, a throttle configuration of approximately 75 % is required to produce the thrust required with a margin of safety. The total efficiency is 42 %. Looking at Figure 6.9, the power draw at 35 MPH is 238 W. The Banshee is capable of cruising at it's required speed without an excessive power draw and within a reasonable efficiency percentage.

Also, the aircraft needs to achieve 29 MPH airspeed at 100 % throttle configuration to take-off. From Figure 6.8, at this configuration and airspeed, the thrust available is 149 oz, while the thrust required is 16.8 oz. Thus, we would be taking of with a excess thrust of 132 oz. From Figure 6.9, the power draw is 1354 W. It will be capable to take-off without violating the motors maximum power limit.

6.4 Avionics

The Banshee avionics system is composed of various avionics equipment for flight control and other electronics which serve to jam and detect sUAS. An electrical connection schematic is shown for reference in Figure C.1.

7

Prototype Proposal

In the development of the design described in Chapter 6, a significant amount of consideration was given to manufacturability. In this chapter, StratoShield's proposal to manufacture a prototype of The Banshee is presented. The team's proposed build plan, tentative schedule, resource requirements, and costs are described in the following sections.

7.1 Build Plan

Manufacturing The Banshee will involve a combination of manufacturing methods and materials to ensure structural integrity, lightweight design, and ease of assembly. This section will first detail what materials each component of The Banshee is constructed from, then discuss specific manufacturing strategies for each component, and finish with a preliminary manufacturing timeline.

7.1.1 Materials

The Banshee will be constructed from the following materials, which are also shown in Figure 6.3[1]:

- **Foam:** 4′ x 8′ x 2" sheets - to manufacture the fuselage and airfoils by computer numerical control (CNC) milling or hot wire cutting.
- **Lite Ply:** 12″ x 24″ sheets, 1/8″ to 1/4″ thick - to reinforce the fuselage electronics bay.
- **Carbon Fiber:** 5/8", 1/2", and 3/8" diameter tubes of varying length - to add structural reinforcement to our wings, tail, and boom. These make up the "skeleton" of The Banshee.
- **3D Printed Parts:** Manufactured out of PETG plastic - to mount the motors, join carbon fiber tubes, and used in place of spars on the vertical tail.
- **Ferrules and Pins:** To enable partial disassembly a requirement for transportation (Chapter 2), the wings will be split after the motor mounts. The joints between the two wing segments will be secured with ferrules inside each of the carbon fiber spars and pinned to prevent unplanned disassembly.

7.1.2 Fuselage Construction

For the fuselage, foam is the primary material because of its low density and ease of manufacturing. The fuselage will be manufactured in two halves to fit into the CNC machine. A rectangular internal cavity will be milled into each half of the fuselage and reinforced with a box made of light ply panels. This leaves plenty of internal space for avionics.

[1] Epoxy resin, and the pins for carbon fiber joints are not referenced in Figure 6.3

7.1.3 Wing Construction

Foam reinforced with carbon fiber will form the wing structure. The wings will be machined from foam using a hot-wire cutting machine. Because the wings have a uniform cross-sectional profile, they can be cut on the hot-wire machine quickly and easily. Carbon fiber spars are inserted into the wing at the quarter-chord and the three-quarter-chord to resist both bending and twisting under flight loads.

7.1.4 Tail Construction

The tail is constructed in a similar manner to the wing, using carbon fiber to reinforce the foam airfoil profile. The horizontal portion of the tail uses two 3/8" carbon fiber spars as its reinforcement, with the vertical section of the tail being strengthened by a rectangular extrusion extended from the 3D-printed PETG block joining the tail to the boom.

7.2 Assembly Schedule

This section details our preliminary schedule that we will use to take The Banshee from CAD to craft. Additional detail is included as appropriate.

- **Week 1:** Finish design changes, complete safety trainings.
  - Finalize any final design changes including weight optimization, integration of pinned joints and landing gear into the 3D model, design and integration of access hatches into the fuselage, and final aerodynamic optimization.
- **Week 2:** Order critical items, begin manufacturing process.
  - Plan out the construction process in more detail. Begin ordering critical prototype items like spars and motors. This week will also serve as a buffer period to finalize any design changes.
- **Week 3:** Work on Design Sign-Off, order rest of items.
  - Finish the Design Sign-off Report. Cut the carbon fiber spars and ferrules to their proper lengths. 3D print the wing-boom and tail-boom joiner boxes. Order the rest of the required prototype materials as the design will now be fully finalized.
- **Week 4:** Design Sign-Off Report due, construct fuselage and wing section.
- **Week 5:** Wing/fuselage wind tunnel testing, 3D Print motor blocks.
- **Week 6:** Motors wind tunnel testing, start full construction.
- **Weeks 7-10:** Continue construction, buffer time.
- **Weeks 11-12:** Test flights, finishing touches.
- **Week 13:** Final fly-off.
- **Week 14:** Start work on Preliminary Design Review Presentation.
- **Week 15:** Preliminary Design Review Presentation.

7.3 Resource Requirements and Cost Estimate

In this section, the bill of materials (BOM) and cost estimate for The Banshee prototype is presented. The primary purchased parts are listed in Table 7.1 followed by Table 7.2 which itemizes the materials provided free of cost by the AERE 4620 course facilitators. For the customer model, the jamming system and its auxiliary components will be implemented, as well as non-testing batteries. Table 7.3 provides a list of these customer-owned parts.

Table 7.1: *Bill of materials I - purchased parts*

Part	Quantity	Total Cost [$]	Vendor
Power 32 Brushless Outrunner Motor	2	173.98	E-Flite
13x6.5E Propeller	2	5.73	APC Propellers
Super Strength Landing Gear	1	23.49	Du-Bro
Treaded Lightweight Wheel (3.5")	2	45.90	Du-Bro
Semi-Scale Tailwheel System #957	1	24.66	Du-Bro
5/8" X 0.695" Carbon Fiber Tube 72" Length	2	120.00	Clearwater Composites
1/2" X 0.570" Carbon Fiber Tube 72" Length	2	110.00	Clearwater Composites
Ferrule Tubing for 5/8" ID	2	12.50	Clearwater Composites
Ferrule Tubing for 1/2" ID	2	12.00	Clearwater Composites
3/8" X 0.445" Carbon Fiber Tube 72" Length	2	90.00	Clearwater Composites
Ferrule Tubing for 3/8" ID	2	10.00	Clearwater Composites
Total		628.26	

Table 7.2: *Bill of materials II - provided parts*

Part	Quantity
Testing Battery	2
Autopilot PX6C	1
Power Module PM07	1
Pitot Tube	1
Pitot Sensor Board	1
Telemetry Radio	1
GPS Module	1
RC Receiver	1
ESC	2
Servos (Aileron, Flap, Elevator, Rudder)	8
Control Rods (Aileron, Flap, Elevator, Rudder)	8
Purple/Blue Foam	1.059 ft^3
Lite Ply	6 sheets
PETG Plastic	0.11 ft^3

Table 7.3: *Bill of Materials III - Customer Model Parts.*

Part	Quantity	Total Cost [$]	Vendor
TP3850-4SR70	2	259.98	Thunder Power
Raspberry Pi 3 – Model B	1	35.00	PiShop.us
Jammer Module	1	Quote	TX Jammer
Jammer Antenna	1	379	Unmanned Systems Source
Drone Detector SDR	1	33.95	RTL-SDR
Detector Antenna	1	9.99	Amazon
Total		717.92 + Quote	

Finally, our cost breakdown—divided into structures, motors/electronics, and landing gears—is presented in Figure 7.1. At the time of writing this report, the project exceeded the allocated test prototype budget by $128. At the beginning of the prototyping phase, StratoShield will investigate multiple ways to reduce this overage before proceeding with construction. The most promising idea currently is using more affordable motors and landing gear.

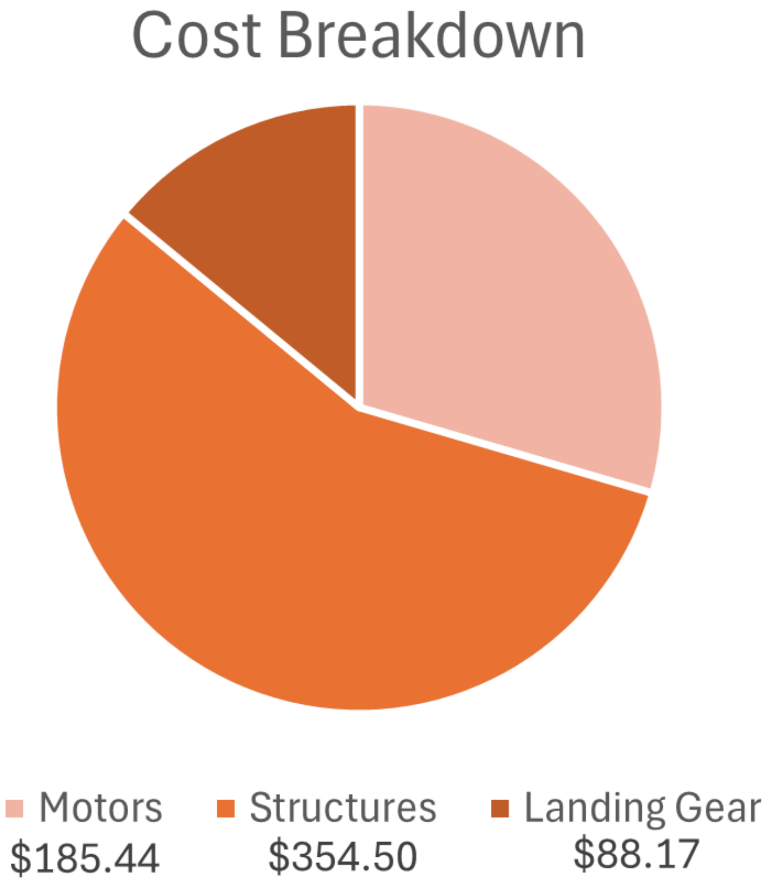


Figure 7.1: *Bill of Materials Cost Breakdown.*

8

Conclusion

In conclusion, The Banshee showcases a thoughtful and balanced design, carefully crafted to meet the mission's requirements. The structure, built from a combination of 3D-printed PETG and carbon fiber spars, offers both strength and lightweight efficiency. The NACA 2412 airfoil is designed to provide the necessary lift, endurance and stability, while the tail configuration preserves the overall aerodynamic performance. The design is also focused on practicality, with modular connections like carbon fiber ferrules and 3D-printed blocks that make the aircraft easy to assemble and transport without compromising its strength or reliability.

The propulsion system, featuring Thunder Power 4S batteries and APC 13x6.5E propellers, provides the power needed for takeoff, climb, and flight. With an estimated weight of 9.45 lbs and a cruise altitude target of 1500 ft, the design hits the mark on key performance goals, such as climb velocity and stall speed. The Banshee's static stability at various flight conditions further assures that it will perform safely and reliably. As The Banshee moves forward from design to build, this solid foundation will guide its development and ensure that it is ready to tackle the challenges ahead with confidence.

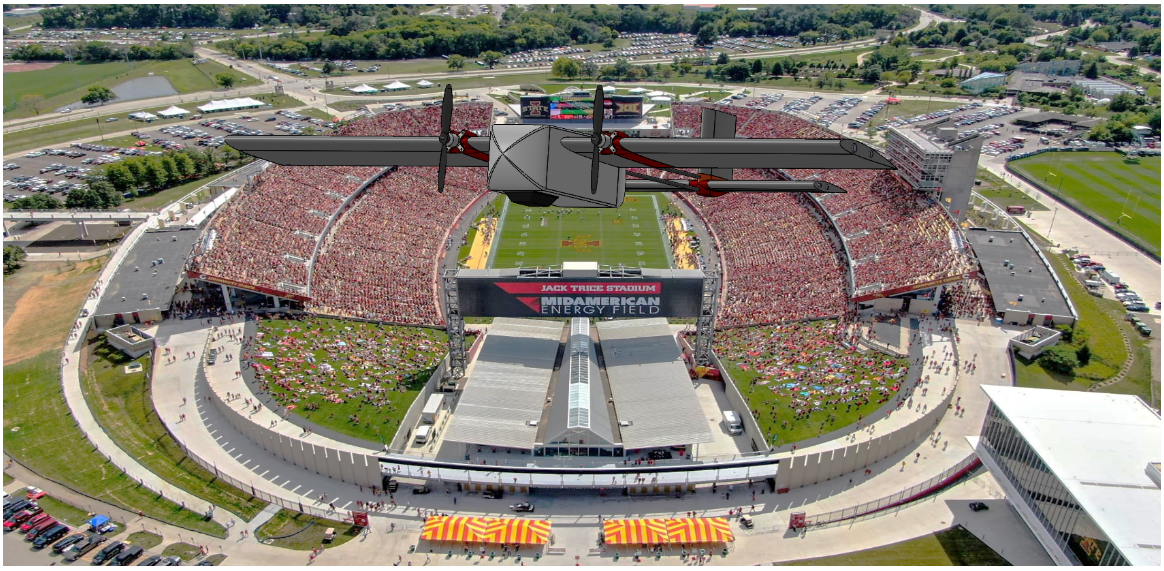


Figure 8.1: *The Banshee Flying Over Jack Trice Stadium.*

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A

Appendix A

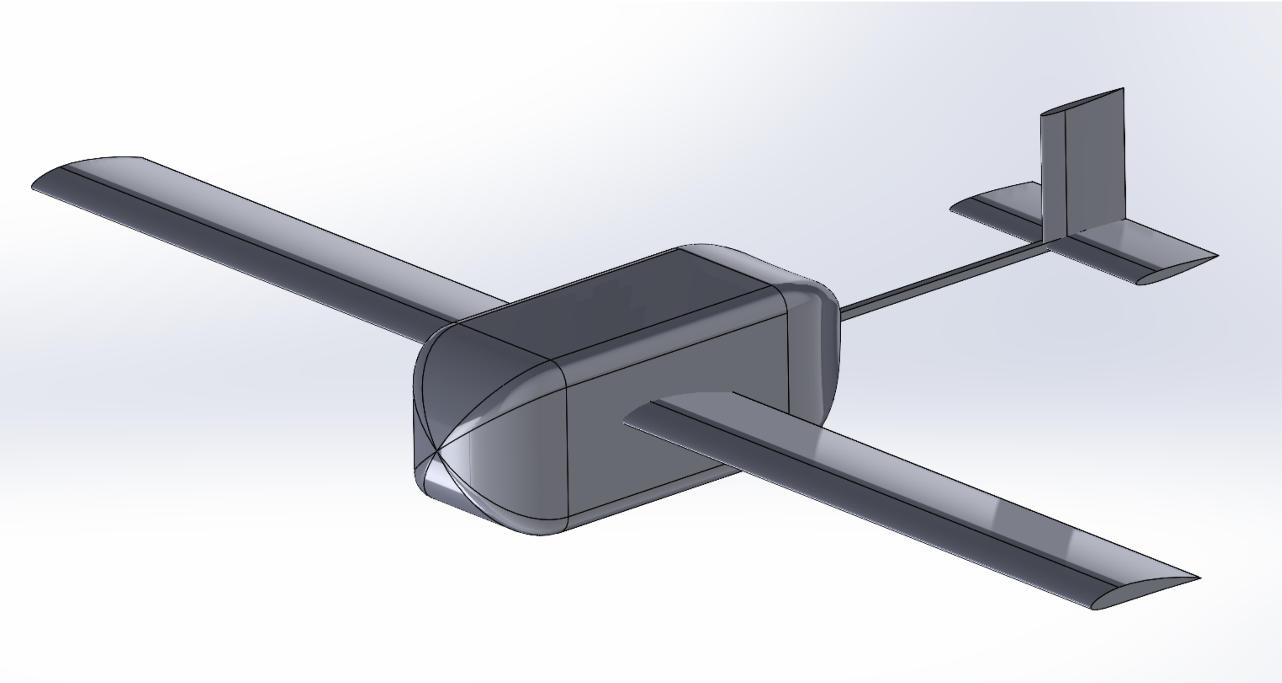


Figure A.1: *Major design iteration I*

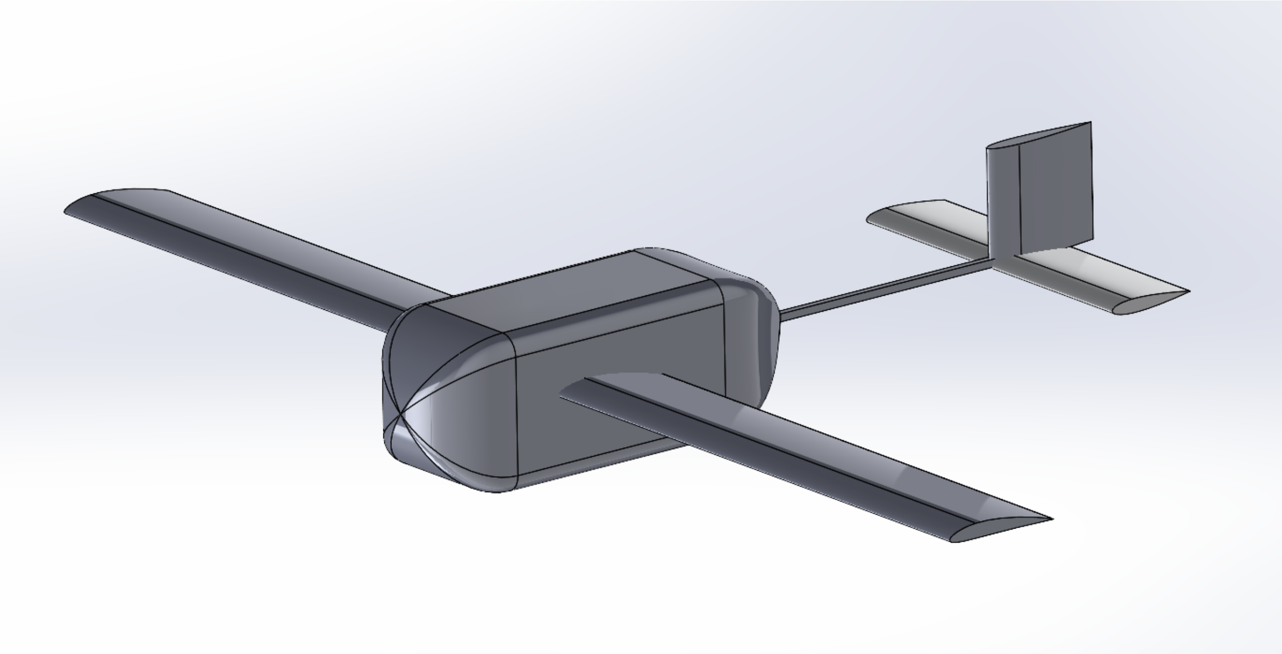


Figure A.2: *Major design iteration II*

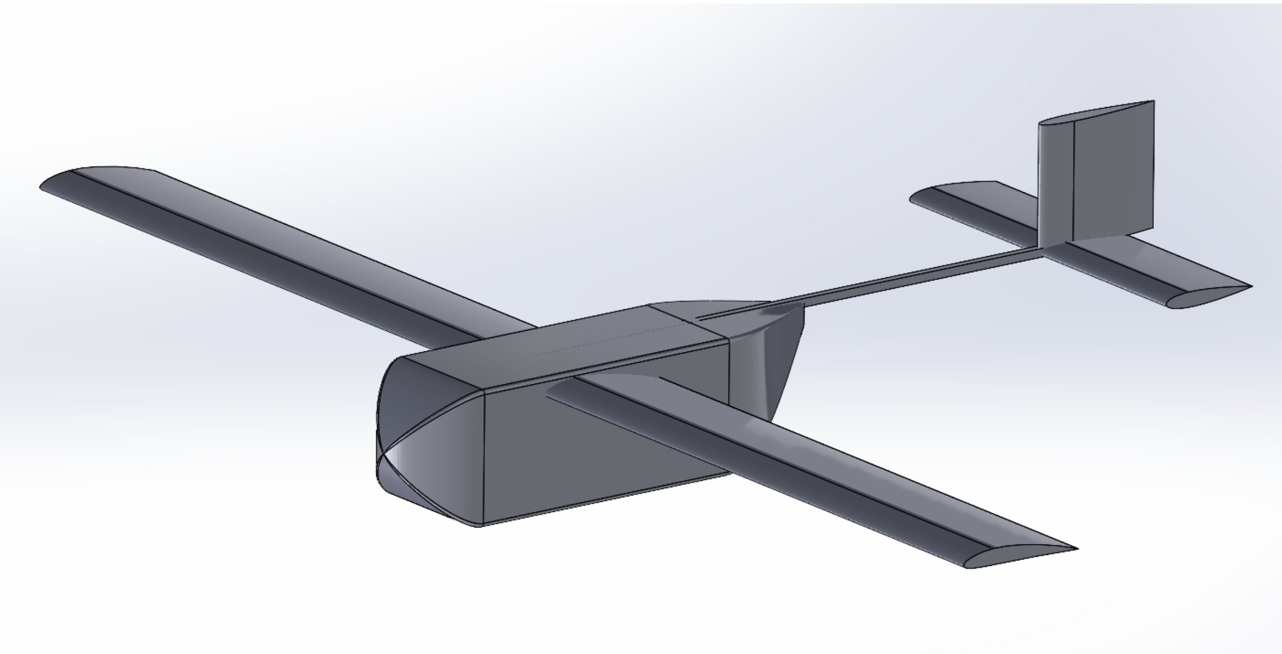


Figure A.3: *Major design iteration III*

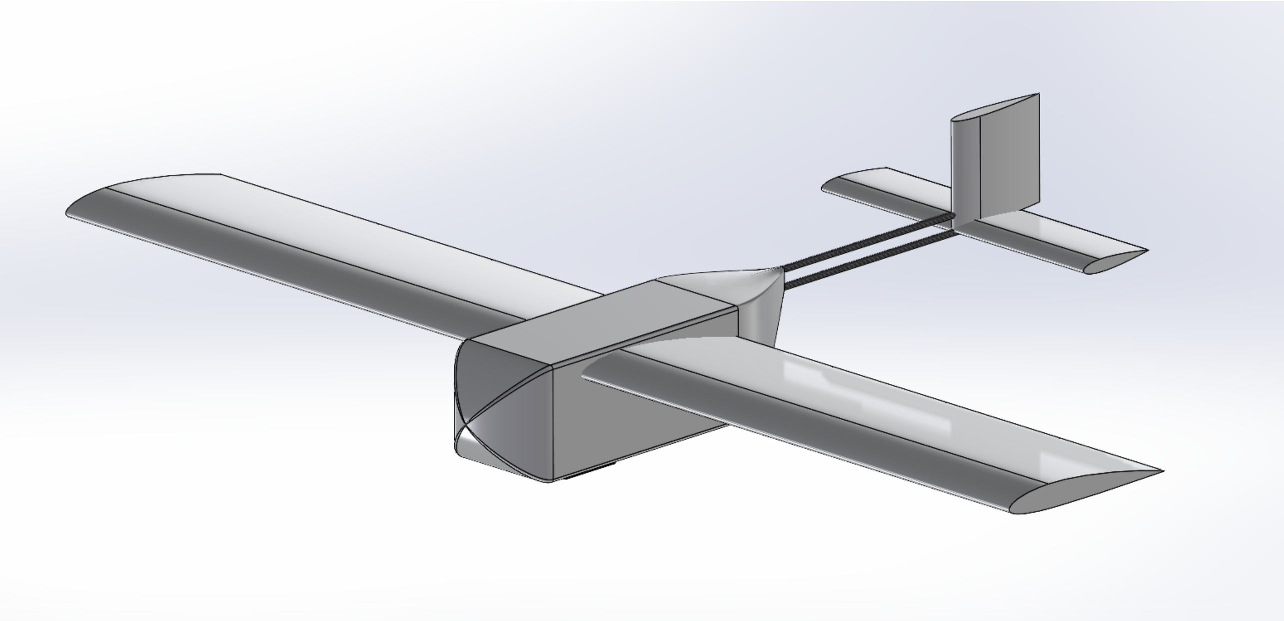


Figure A.4: *Major design iteration IV*

B

Appendix B

Table B.1: *List of all written system requirements*

ID	Requirement	Type
L1-01	The UAV shall prevent a hostile airbone sUAS from reaching a key area in an AOI where the key area is at most a circular area of 98.84 acres.	Customer
L2-01-01	The UAV shall be equipped with equipment capable of jamming a sUAS.	Interface
L3-01-01-01	The UAV shall be equipped with a jamming module set to 2.4 GHz.	Interface
L3-01-01-02	The UAV shall be equipped with an antenna suitable for jamming a sUAS.	Interface
L3-01-01-03	The UAV's jamming equipment shall be capable of jamming an area sufficiently large such that the UAV can continuously jam an sUAS while loitering above.	Functional
L2-01-02	The UAV shall be capable of reaching a hostile sUAS before the sUAS reaches the key area.	Functional
L2-01-03	The UAV shall be capable of detecting an airbone sUAS.	Customer
L3-01-03-01	The UAV shall be equipped with equipment capable of detecting a hostile sUAS.	Interface
L3-01-03-02	The UAV shall be capable of detecting a hostile sUAS from 50 ft to 400 ft AGL.	Functional
L1-02	The UAV shall be controllable via a wireless remote.	Functional
L2-02-01	The UAV shall be equipped with a transmitter capable of communicating with an RC aircraft controller.	Interface
L2-02-02	The UAV transmitter shall maintain a continuous radio connection with the controller throughout the entire flight cycle.	Reliability
L2-02-03	The UAV transmitter shall maintain a continuous radio connection with the controller at any location in the AOI.	Reliability
L1-03	The UAV shall support autonomous flight.	Customer
L2-03-01	The UAV shall be capable of taking off autonomously.	Functional
L2-03-02	The UAV shall be capable of landing autonomously.	Functional
L2-03-03	The UAV shall initiate a landing sequence when the UAV battery no longer has the capacity to engage a hostile sUAS in the AOI and land safely.	Functional
L2-03-04	The UAV shall autonomously enable the jammer when a hostile sUAS is detected.	Functional
L2-03-05	The UAV shall be capable of loitering autonomously.	Functional
L1-04	The UAV shall be capable of flying sufficiently long to ensure constant coverage of the AOI with two aircraft.	Functional
L2-04-01	The UAV shall be capable of completing a full no-engagement flight cycle of at least 45 min.	Customer

Continued on next page...

ID	Requirement	Type
L2-04-02	The UAV shall be capable of engaging a hostile sUAS for at least 10 min.	Customer
L1-05	An operator shall be capable of changing the UAV battery.	Customer
L2-05-01	An operator shall be capable of changing the UAV battery while maintaining a safe distance from the propellers.	Safety
L2-05-02	An operator shall be capable of changing the UAV battery within 5 min.	Customer
L1-06	The UAV shall be designed in a manner that allows safe use.	Course
L2-06-01	The UAV shall have arming and diasarming components that are easily accessible.	Course
L2-06-02	The UAV shall only use electric RC aircraft motors.	Course
L2-06-03	The UAV shall have a maximum stall speed of 25 MPH.	Course
L2-06-04	The UAV shall be capable of avoiding obstacles while in flight.	Safety
L1-07	The UAV shall be capable of operating with a constrained runway.	Functional
L2-07-01	The UAV shall be capable of achieving takeoff within a maximum runway length of 100 ft.	Course
L2-07-02	The UAV shall be capable of landing within a maximum runway length of 100 ft.	Course
L1-08	The UAV shall be designed to be manufactured using tools available to students.	Course
L1-09	The UAV shall be easily transportable in a vehicle.	Course
L2-09-01	The UAV shall have a maximum GTOW of 12 lbs.	Course
L2-09-02	The UAV shall have a maximum wingspan of 90 in.	Course
L1-10	The UAV shall be capable of fixed-wing flight.	Course
L2-10-01	The UAV shall be constructed with fixed wings.	Functional
L1-11	The UAV shall have enough capacity to power all onboard electronics for a full flight cycle.	Performance
L1-12	The UAV shall be capable of flying in similar conditions to COTS sUAS.	Customer
L2-12-01	The UAV shall be capable of flight with wind speeds exceeding 20 MPH.	Course
L2-12-02	The UAV shall be capable of flying at 400 ft AGL or higher.	Performance
L2-12-03	The UAV shall be capable of operating in temperatures from 14° to 104°F.	Environmental
L1-13	The UAV shall be capable of stable flight.	Performance

Appendix C

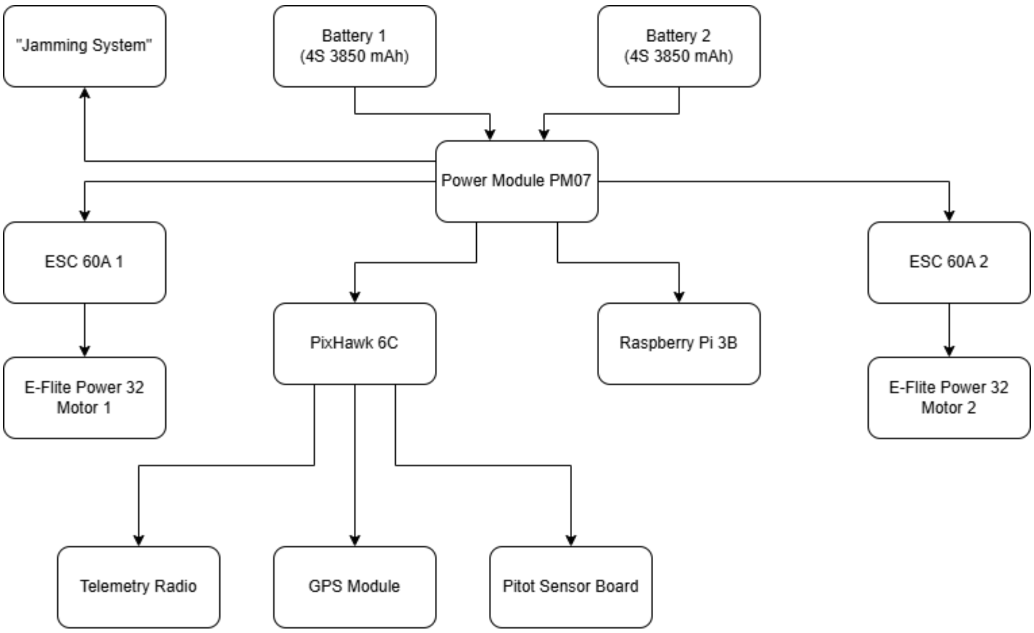
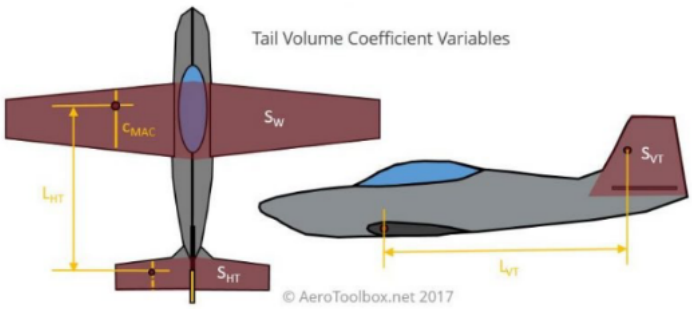


Figure C.1: *Aircraft Electrical Schematic.*

D

Appendix D



Sizing for the Tail:

Horizontal tail volume coeff.

$$C_{HT} = \frac{S_{HT} L_{HT}}{c S_{Ref}} \qquad (1)$$

Most fall between .3 and .6.

Vertical tail volume coeff.

$$C_{VT} = \frac{S_{VT} L_{VT}}{b S_{Ref}} \qquad (2)$$

Most fall between .02 and .05.

Assume that the cg is at ¼ chord of wing

CG = 12.5cm+9.99cm+4.995cm = 27.485cm from nose
S_Ref = 19.98cm x 216cm = 4315.68
C = 19.98cm
B = 216cm

If we would like to keep our Carbon Fiber Spar length of 91.44 cm(36in), assuming it starts at 27.485 cm from the nose:
L_HT & L_VT = ~88 cm (giving room for second CF moment reinforcement)

Figure D.1: *Initial tail sizing calculations*

HORIZONTAL TAIL:
In the middle of what most C_HT falls between, we get a value of 0.45.
Plugging values into eq 1 and solving for S_HT, we get that S_HT = **440.935**cm^2

Here, I will assume that we would like a **15 cm chord length (NACA0010)**
That gives **Horizontal tail span = 29.396cm**

VERTICAL TAIL:
In the middle of what most C_VT falls between, we get a value of 0.035.
Plugging values into eq 2 and solving for S_VT, we get that S_VT = **370.756**cm^2

Here, I will assume that we would like a **19.98 cm chord length (NACA 0010)**
That gives the **Vertical tail span = 18.556cm**

Numbers are subject to change after CFD testing

Figure D.2: *Initial tail sizing calculations*