Michigan State University

2016-17 AIAA Design-Build-Fly Competition

Sparty III

Terminology

Terminology

MSU	Michigan State University
DBF	Design - Build - Fly
AIAA	American Institute of Aeronautics and Astronautics
RAC	Rated Aircraft Cost
EW_{max}	Max Aircraft Empty Weight
TW	Tube Weight
L	Tube length
C	Tube circumference
UAV	Unmanned Aerial Vehicle
CAD	Computer Aided Design
NACA 6412	NACA airfoil of type 6412
NACA 0006	NACA airfoil of type 0006
L_N	Nose cone length
R	Radius
D_F	Fuselage Diameter
L_F	Fuselage Length
V_E	Elastic impact velocity,
σ_Y	Yield stress
E	Young's modulus
ρ	Density
C_L	Chord length

1.0 Executive Summary

SpartyWorks from Michigan State University is designing a stowable aircraft and launch tube for the purpose of winning the 2016-17 AIAA DBF competition in Tucson, AZ. Achievement in this competition will be obtained through a well written report, a high total mission score, and a low RAC. A high total mission score is achieved through maximizing stability and performance of the aircraft. A low RAC is achieved through keeping the weight of both the aircraft and launch tube minimized along with the length and circumference of the tube minimized.

The 2016-17 AIAA DBF competition requires the team to build one aircraft and one launch tube. The aircraft will be used in all three flight missions along with the ground mission. The launch tube will be used in the ground mission. Mission one requires the aircraft to be hand thrown into the air and complete 3 laps in a 5 minute flight window without carrying a payload. Mission two requires the aircraft to be hand thrown into the air and complete 3 laps in a 5 minute flight window while carrying a payload of 3 regulation hockey pucks (6 oz. per puck) internally. The final flight mission, mission three, requires the aircraft to be hand thrown and complete as many laps as possible while internally storing any number of regulation hockey pucks; however, the number must be approved during tech inspection. Given that the aircraft will travel 2000 ft for each lap with a 360 degree turn on the back stretch of the track, the team calculated that the aircraft must travel a minimum speed of 25 ft/s to complete the 3 laps within the 5 minute time window with a minute to spare for any unfavorable weather conditions.

For the ground mission, the launch tube must be strong enough withstand three separate 1 ft drops; The first drop on the side and one on each end, all while keeping the aircraft stowed inside completely intact. Any aircraft surfaces that move in order to be stowed inside the launch tube must be self-locking when transitioned to the flight condition.

To ensure of highest possible mission performance, Table 1.0.1 displays our estimated maximum performance capabilities of our UAV.

Table 1.0.1: Maximum UAV Performance Capabilities

UAV Performance Capabilities	
Parameter	**Value**
Max Speed (ft/s)	75.46
Max Thrust (lb)	1.52
Max Flight Time at Max Thrust (s)	900
Max Lift Capacity at Max Speed (lb)	19.65

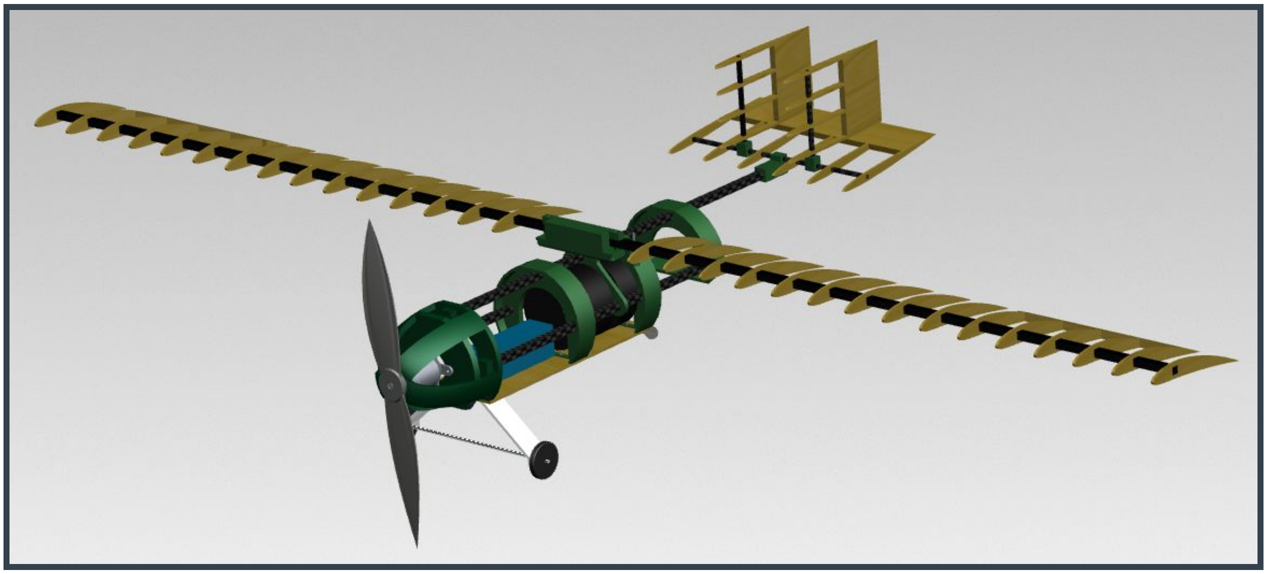

Figure 1.0.2: Sparty 3.3 CAD Flight Condition Model

2.0 Management Summary

On its third year of competing in Design-Build-Fly, the 2016-17 SpartyWorks team consists of ten members in total, with two remaining founding members. The team's faculty advisor, two seniors, three juniors, two sophomores, and two freshmen all contribute to the design process, allowing the team to benefit from active training of underclassmen.

2.1 Team Organization

On the SpartyWorks team, the chief engineer oversaw and scheduled meetings for the two main teams, mechanical and electrical. The mechanical and electrical team leads communicated with the chief engineer to finalize decisions about the design process, while other members of the team attended weekly meetings to provide input. The equal collaboration of the team's members on generating ideas for all the systems of the plane is what drove the team to organize itself in this way and not with separate into sub teams for each major subsystem. The general hierarchy of the team is illustrated in Figure 2.1.1 below.

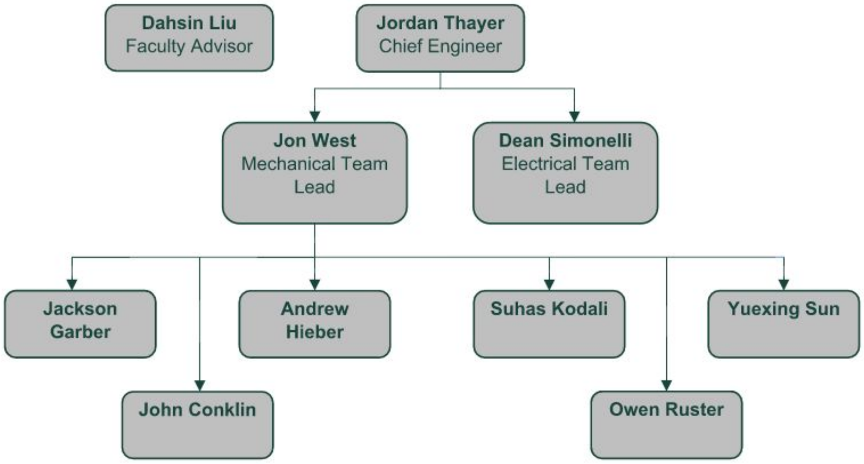

Figure 2.1.1: Organizational Structure

2.2 Milestone Chart

Figure 2.2.1 represents the design, build, and test goals for the team in order to successfully compete in the 2016-2017 competition. The lighter green represents the actual progress towards the desired goal and the darker green represents the expected progress towards the desired goal. As the season went, unexpected events resulted in the team having to begin the first optimization period prior to UAV manufacturing.

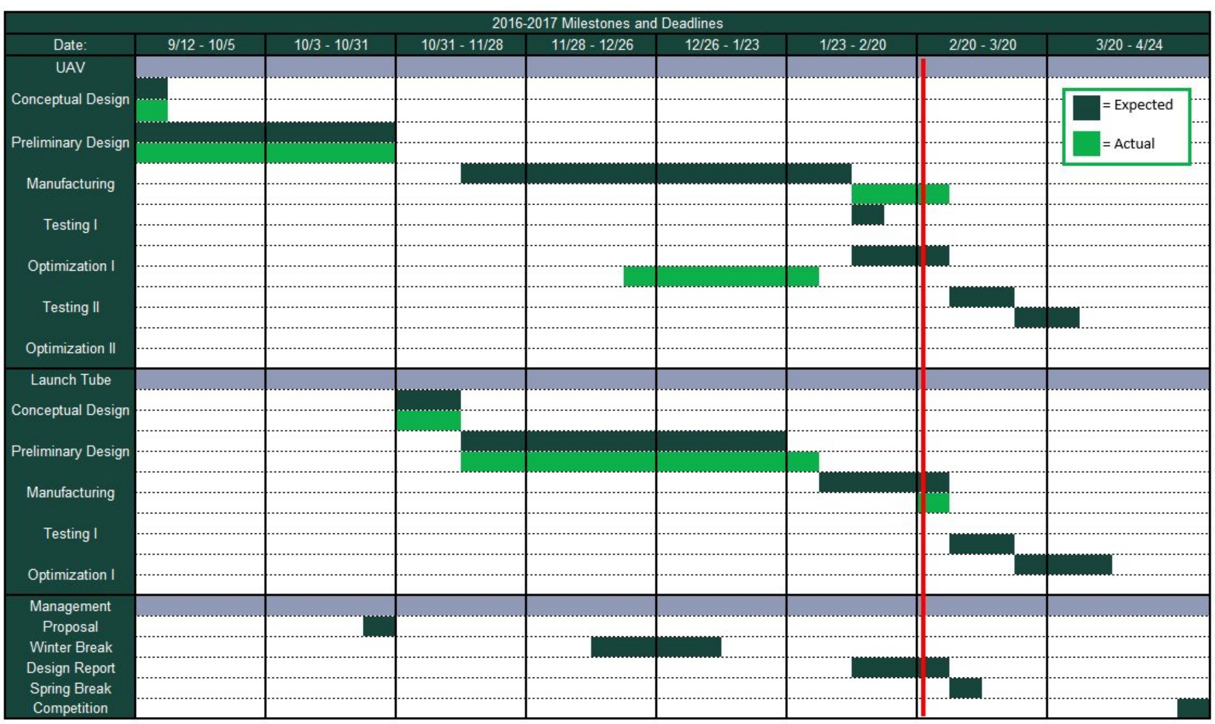

Figure 2.2.1: Milestone and Deadline Gantt Chart

2.3 Budget Chart

Table 2.3.1 illustrates the budget for the 2016-2017 competition season, including specific line items for the UAV and Launch Tube along with general team costs, such as transportation and lodging in Tucson, AZ.

Table 2.3.1: 2016-2017 Design-Build-Fly Budget

2016-2017 MSU DBF Budget	
UAV	
Item	Cost
Balsa and Plywood	$75.00
Carbon Fiber	$130.00
Electronics	$64.66
3D Printing	$85.54
Miscellaneous Hardware	$15.00
Total	$370.20
Launch Tube	
Item	Cost
Cardboard Tube	$250.00
3D Printing	$75.00
Foam	$35.00
Sobrothane	$100.00
Total	$460.00
Competition	
Item	Cost
Transportation	$4,500.00
Lodging	$1,000.00
Meals	$735.00
Total	$6,235.00
Grand Total	$7,065.20

3.0 Conceptual Design

The conceptual design is derived from the requirements posed by the four competition missions: three flight and one ground. The missions had to be adequately analyzed before any designing is started, to ensure all possible scenarios were accounted for.

3.1 Mission Summary

The Design Build Fly competition is scored from the written report score, total mission score, and rated aircraft cost (eq 3.1).

SCORE = Written Report Score * Total Mission Score / RAC **(3.1)**

The written report score is the score given to the submitted design report for the contest. The total mission score is the sum of the individual mission scores shown later in this section (eq 3.2), and the RAC, the rated aircraft cost, is dependent on the weight and dimensions of the aircraft and the launch tube (eq 3.3).

Total Mission Score = M1 + M2 + M3 **(3.2)**

RAC = (EW_{max} + TW) * (L + C) **(3.3)**

Mission 1: Demonstration Flight

For its demonstration flight, the SpartyWorks aircraft must complete three laps around a track in a time window of 5 minutes, which begins when the first attempt at a hand launch is made. Each complete lap is satisfied when the UAV passes the start/finish line. The landing is not included in the 5-minute time window for mission 1, and a score will not be awarded unless the landing is successful. A payload is not to be carried in this mission. The mission 1 scoring (M1) is determined by the following:

- Successful mission: M1 = 1.0

Mission 2: Speed Flight

The speed flight mission tests the UAV's minimum time to complete three laps around a track, with each completed lap determined by the UAV passing over the start/finish line. The time starts with the first attempt at a hand launch and stops when the aircraft passes the finish line at the end of its third lap; the maximum time window the aircraft can complete the mission in is 5 minutes. A payload of three regulation hockey pucks is to be internally carried by the UAV. A successful landing, not included in the time window, is required to receive a score. The mission 2 scoring (M2) is determined by the following:

- M2 = 2 * (Fastest Team's Time for three laps / Tested Team's Time)

Mission 3: Range Flight

The third mission is an endurance flight to test the number of laps the UAV can complete carrying a chosen number of internally carried regulation hockey pucks. The time window for this mission is five minutes, beginning with the initial hand launch attempt. Like the other flight missions, each lap is indicated by the aircraft passing over the start/finish line and a proper landing, not included in the time window, is required to receive a score. The mission 3 scoring (M3) is determined by the following:

- M3 = 4 * ((N_Pucks * N_Laps) / (Max_Pucks * Max_Laps)) + 2
    - Where N_Pucks and N_Laps are the number of pucks the tested team's UAV carried and the number of laps it carried them for, respectively. Max_Pucks and Max_Laps are the maximum number of pucks carried and laps completed with that payload for any team.

Ground Mission

The competition also requires a ground mission, for which the team must conduct a series of drops of the aircraft while it is stowed inside of a water tight, protective launch tube. The launch tube built for the mission must be right cylindrical, have sealed end caps, exist in a length to diameter ratio of at least 4, void of access holes or perforations, and cannot require tools for sealing and unsealing. The overall length, circumference, and empty weight are all calculated into the RAC. During tech inspection, the maximum payload weight will be determined and the UAV will be sealed into the launch tube. When the ground mission begins, a mission official will oversee as an assembly crew member drops the configuration three times onto a hard surface from the required height of at least 12 inches. The first drop will be onto the longitudinal axis of the cylinder, the orientation of which to be decided by the official. Drop 2 is onto one of the ends of the cylindrical launch tube, while the third drop is on the opposite end. The UAV will then be removed from the launch tube configured to flight condition to check the functionality of the subsystems and flight controls and conduct a wing tip test. If the mission official rules that the drops caused no apparent major damage to the structural integrity of the launch tube or the UAV itself, it is cleared. If the ground mission is considered a success in scoring, then the team will be able to continue to the proceeding flight tests.

3.2 Design Requirements

Prior to the design phase, the mechanical and electrical sub-teams discussed the mission requirements and extrapolated design ideas to accomplish the mission requirements. The mission requirements cover the following constants of each mission: going around turns, being hand-thrown, and the specifics of each of the 4 missions, 1 ground and 3 air. The most important parameters for each mission requirement were then listed and analyzed. The total score is divided by RAC; thus it is crucial to minimize weight and size of the aircraft since a smaller aircraft means a lower circumference and length of the launch tube. Cruise speed was the next parameter, because one of the three flight missions, mission 2, depend on how quickly laps can be completed. For mission 3, each additional regulation hockey puck increases score by a factor of 4, but also increases the empty weight due to larger required supporting structure and increased lifting area, potentially increasing the length and circumference of the tube. An increase in lifting area also means a slight increase in drag, decreasing our potential performance on mission two. . After listing and analyzing all of the design parameters for each mission requirement, the team determined that the aircraft’s size was the most important parameter going into the design phase. This single parameter affects the RAC the most, since a larger airplane increase the empty weight, weight of the tube, and size of the tube in both length and circumference. A smaller plane also allows our mission two performance to increase, which also affects our final score. In order to maximize this parameter, the team focused on selecting light and strong materials, maximizing the power of our propulsion system, and minimizing the area exposed to drag forces. The aircraft's lift capacity was another highly important parameter, but would have adverse effects on the RAC if too high. Along with aircraft design parameters, design goals were also set for the launch tube. Since the weight of the launch tube is factored into the RAC, a lightweight launch tube is the only logical choice. Along with the weight of the tube, the launch tube must possess shock absorbing properties, because the launch tube must keep the UAV undamaged after the three 1 foot drops. To maximize these parameters, light, shock absorbing, but strong materials were the primary focus for this design. The shock absorbing properties of the launch tube could also be enhanced through the overall design, not just the material selection. Table 3.2.1 shows a summary of the design requirements

Table 3.2.1: Design requirement study based on mission requirements

Design Requirement Study	
Mission Requirement	Design Requirement(s)
Hand-thrown take-off	Light weight UAV with high lift
Must perform turns	Optimized aileron design
Survive a 1 foot drop	Strong structural properties for UAV and Launch Tube
Carry at least 3 hockey pucks	High lift and strong structural properties for fuselage and payload bay
Complete mission 2 quickly	Light weight UAV and maximized propulsion system
RAC	Light weight UAV and Launch Tube, small UAV frame, and many folding surfaces

3.3 Configurations and Concepts

The configuration selection of each part of the aircraft followed the listing and analysis of the mission and design requirements. Multiple designs were considered for various parts of the aircraft, the wing configuration, fuselage configuration, empennage configuration, and landing gear configuration, along with the general configuration for the aircraft. Nearly each choice is a result of three parameters: simplicity of the design, manufacturability, and potential RAC influence.

Aircraft Configuration

Four general aircraft configurations were considered by the team: monoplane, biplane, flying wing, and flying body. Due to the simplicity of the design, manufacturability, known stability characteristics, and potential RAC influence, the monoplane configuration was the choice the team made. Due to the lack of formal aerospace engineering courses at Michigan State University, the complex stability characteristics of the flying wing and body made those choice obsolete almost immediately. Since the plane must be collapsable with self-locking features, collapsing a flying wing or body into a cylindrical tube did not appear to be advantageous. The biplane was then not chosen due to the potential launch tube circumference increase that would be a result from the front airfoils being off-center and the additional locking features that would result from a biplane configuration.

Table 3.3.1: Aircraft configuration parameter study

Airfoil Configuration

Three potential airfoil configurations were considered by SpartyWorks: swept, straight, and tapered. Given our limited background in aerodynamics, the simplest configuration for manufacturing and calculating lift and drag would be advantageous for the team, leading to the choice of a straight airfoil. A straight airfoil would also make the design of the internal structure of the launch tube simpler. The potential airfoil configurations are illustrated in Table 3.3.2. Three potential airfoil mounting locations were considered by the team: top, side, and bottom. The parameter that had the biggest effect on the design choice would be the potential RAC influence. In the stowed condition, top and bottom mounted airfoils would be off center, leading to two potential outcomes: a smaller chord and much longer span, or a larger circumference launch tube. A side mounted airfoil would also make the self-locking mechanism much more complicated, given potential interference with other aircraft geometries during folding. This led the team to choosing a top mounted airfoil with a smaller chord and larger span, allowing the circumference of the launch tube to remain optimized and interference with other aircraft geometries kept to a minimum.

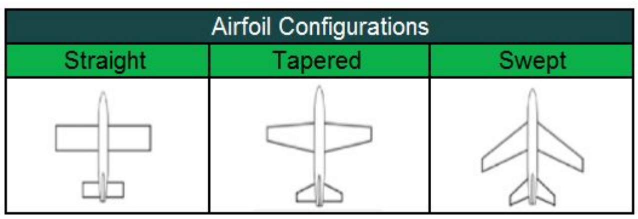

Figure 3.3.2: Airfoil configurations

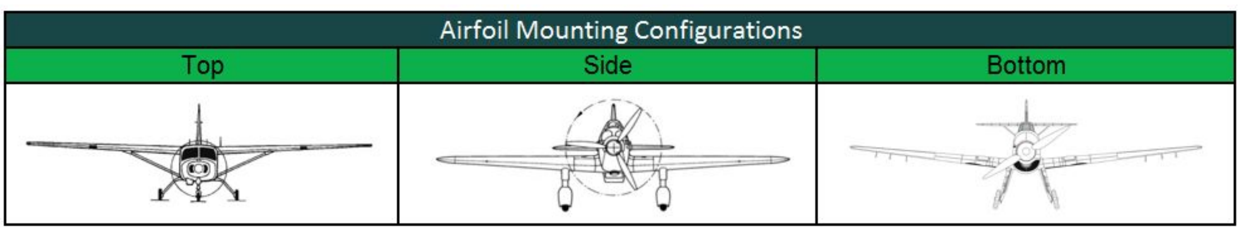

Figure 3.3.3: Airfoil mounting locations

Self-Locking Mechanisms

The main design requirement that was to be achieved was a lightweight and strong way to pivot and connect the wings to a “flight” condition. To design the locking mechanism, the core concepts that were looked into were folding wings to reduce maximum inner diameter of the tube and pivoting wings to allow for stowed condition. Several concepts were drafted up and deliberated on in core group meetings.

One of many concepts were to use folding wings. In this design, the wings would be compartmentalized into sections that would fold together similar to an accordion. This idea was chosen not to be ideal as it created many points of failure during the “stowed” to “flight” transition. Another concept that was theorized was to have the wings on a track type system either on the ribs of the body, or the body’s spine. This way the wings could slide up the side of the plane and then pivot into position on the top allowing for minimum launch tube diameter. This idea was also ruled out as it was believed the creation of a circular track would not benefit the diameter enough to make the potential issues and complications worth the risk.

Trying to make the self-locking mechanism much simpler, the team considered both running screws through the airfoil spars to secure the airfoil in the flight condition and utilizing a spring loaded pin in some fashion. Given the rules clearly state the team cannot manipulate the locking mechanism when bringing the surfaces to the flight condition, screws were quickly ruled out, because a tool had to be used to manipulate this mechanism. Velcro was also considered, was ruled out due to breaking competition guide lines. The spring loaded pin concept is similar to how a door works, but instead of the pin remaining fully extended before reaching the desired location to spring into, the pin should remain compressed before reaching the desired location to ensure self-locking can be achieved.

Engine Locations

Although a single pull motor configuration was chosen early on in the design process. The team briefly considered other possible engine locations. These engine locations included a wing configuration and a pusher configuration. The advantages of using the wing configuration are increased power and differential thrust. The disadvantages being the added weight and complexity. The advantages of a rear mounted motor include mainly aerodynamics. Disadvantages being complexity and decreased maneuverability.

Therefore, a single pull motor configuration was selected. Advantages include simplicity, center of gravity and maneuverability. Some disadvantages include aerodynamics, but having chosen a front mounted motor in the past, it was decided to continue using this motor location.

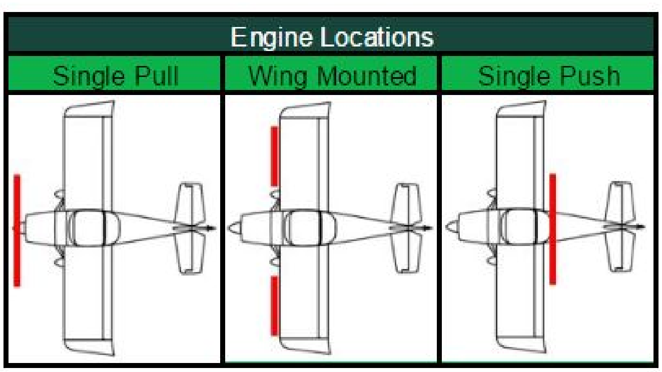

Figure 3.3.4: Engine Location Configurations

Landing Gear Configuration

Two main configurations were considered for the landing gear; they are the tricycle configuration, and tail wheel type configuration shown in Figure 3.3.5.

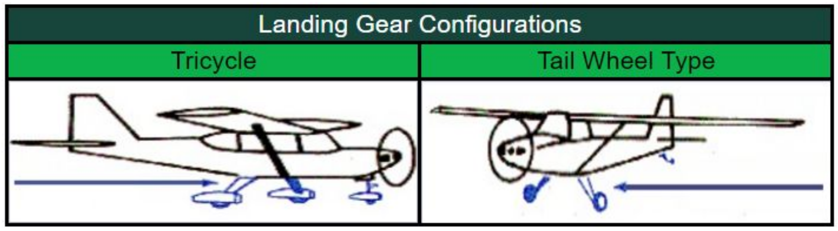

Figure 3.3.5: Landing Gear Configurations

The tail wheel type configuration was chosen for the following three main reasons: its lower weight and drag, its superior stability with low rudder control, and its effectiveness on rough surfaces.

Due to landing being a relatively small and unimportant portion of the missions, it was thought to be important to minimize the space and weight taken by the landing gear, and the tail wheel type configuration fits these parameters. Further, because of the small size of the airplane and relatively weak rudder control provided at low speeds on landing, a freely rotating tail wheel will provide a relatively long lever arm to help pull the aircraft straight at low speeds. This same principle also applies for landing on rough surfaces which is likely for a plane which has had its size and weight minimized.

Empennage Configuration

Similarly to the airfoil, the team determined it would be best to find the simplest empennage configuration due to the team’s limited aerodynamics knowledge. The simplest empennage configuration would also come with manufacturing simplicity and save time in this regard. After considering empennage shapes such as T-tail and Y-tail, it was found that the H-tail shape would not only provide the aerodynamic and manufacturing simplicity that the team was looking for, it would be the most lightweight option as well.

The constraints of the launch tube also had to be taken into consideration. The H-tail was the only configuration that was considered feasible to fit inside of the launch tube. The other choices were found to possess uncertainties, such as added height and width of the aircraft. This made the decision clear: the empennage should be shaped as an H-tail in order to take advantage its simplicity.

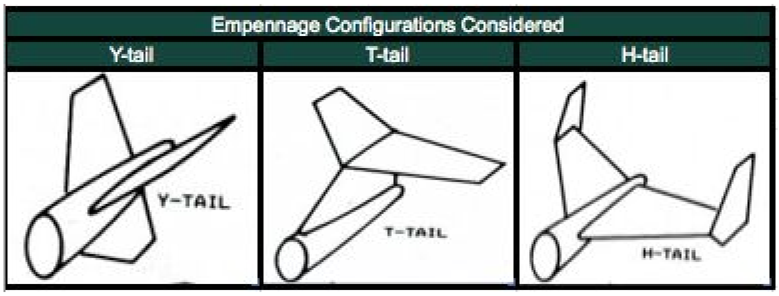

Figure 3.3.6: Empennage Configuration Study

The H-tail configuration decided on by the team included two rudders on each vertical tail and one elevator on the horizontal tail. These control surfaces were included to provide stability to the aircraft, and will be discussed in more detail in upcoming sections.

Payload Bay Configuration

Two characteristics of the payload bay had to be considered before design on the fuselage began. These were the shape of the bay, which could be tubular or flat (figure 3.3.7), and the payload removal mechanism, which would depend on the shape of the bay.

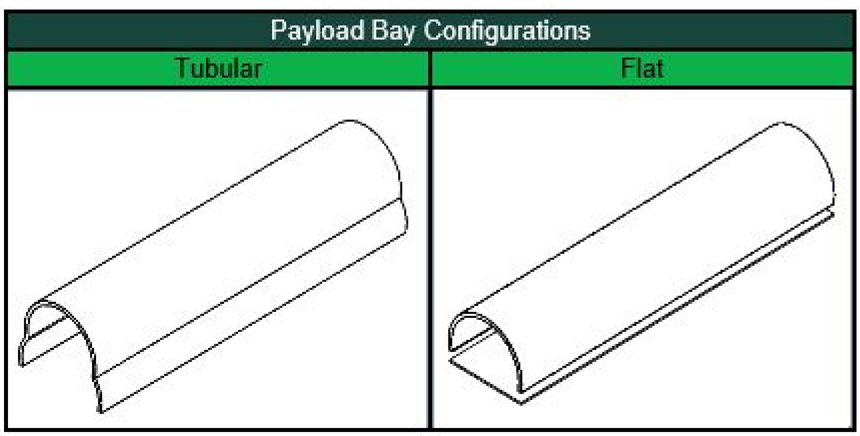

Figure 3.3.7: Payload Bay Configurations

For the shape of the payload bay, a tubular shape would provide better aerodynamic efficiency, but would add difficulty to the manufacturing process, add weight, and add complexity to the removal mechanism. It was quickly and easily decided that the flat configuration for the payload bay was preferable to tubular due to its benefits far outweighing its aerodynamic drawback.

With the flat configuration decided upon, it was then a choice between a simple hinge mechanism or simple bolts to remove the bottom of the payload bay. Again, for the sake of simplicity and weight, the method of simple bolts was chosen to avoid a heavy hinge attachment.

Launch Tube Configuration

The Launch Tube must be sealed with no cuts, visible cracks, or perforations after all three 1 ft drops are conducted. The Launch Tube's circumference, weight, and length must all be minimized while also maintaining the strength to withstand impact on drop, and the space to accommodate the plane and padding components. The inner diameter of the tube must be large enough to accommodate the plane and 1/4 inch of padding. The padding must be designed in a way to completely constrain the plane from movement, and allow it to slide in and out easily, while also keeping weak components such as airfoil ribs from experiencing undue stress.

Multiple materials and configurations were considered for the launch tube before the final concept was decided upon. First, three different materials for the tubular casing, polyvinyl chloride (PVC), polyurethane, and paper tubing (cardboard), were analyzed for their various qualities. This analysis is represented by the Figure of Merit Table shown below (table 3.3.8), where each characteristic (figure of merit) of each material is given a different weight and multiplied by the given score (1, -1, or 0) for that material in that characteristic. These scores are summed up and the material with the highest total score is chosen for the launch tube.

Table 3.3.8: Launch Tube Material Parameter Study

Figures of Merit for Launch Tube Material				
Figure of Merit	FOM Value	Paper Tube	PVC	Polyurethane
Weight	50	1	-1	-1
Manufacturability	20	1	1	0
Strength	30	-1	1	0
Total	**100**	**40**	**0**	**-50**

In a similar vein, the material for the ribs that will constrain the airplane in place was decided upon using a comparable parameter study. First, the axial and radial loading experienced by the material was conceptualized as shown in figure 3.3.9.

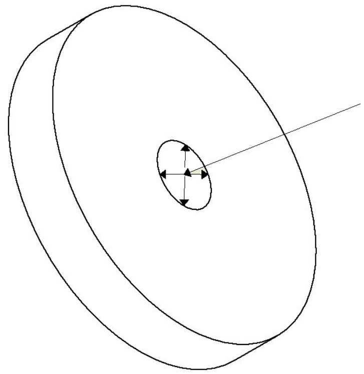

Figure 3.3.9: Loading of Padding Ribs

Then a figures of merit table (Table 3.3.10) was created with the same scoring convention as the launch tube material parameter study.

Table 3.3.10: Padding Material Parameter Study

Figures of Merit for Padding Material				
Figure of Merit	FOM Value	Wood	Polystyrene	Polyurethane
Damping Coefficient	40	-1	0	1
Manufacturability	10	1	1	1
Stiffness	50	1	1	-1
Total	**100**	**20**	**60**	**0**

From the figure of merit table, polystyrene, more commonly known as styrofoam, emerged as the clear winner for its superior stiffness, manufacturability, and moderate damping coefficient.

It was further conceptualized that the polystyrene ribs must be placed inside the cardboard tube so as to ensure that the fuselage and nose cone of the plane take the brunt of the impact, keeping all force off of the wings and empennage.

4.0 Preliminary Design

Following the processing the mission design requirements and forming a conceptual design, SpartyWorks created the first preliminary design for the UAV and Launch Tube, Sparty 3.3 and Launch Tube 1.0.

4.1 Design and Analysis Methodology

To ensure that the UAV could perform adequately in the three flight missions, the Launch Tube was not designed until after the UAV was finished; however, the Launch Tube RAC constraints were kept in mind during the entire design process of the UAV as previously mentioned. The team began the design by designing around the constants set by the team leaders: the payload, engine, and battery. The engine and battery performance minimums were figured out by determining how long the UAV would have to be in the air and a general lap time. From there, a general shape and layout for the fuselage was determined, which allowed for the nose cone to be developed. Once all of the main supporting structure sizing of the UAV was determined, the aerodynamic surface sizing was computed. After an alpha model for the first iteration of the UAV was complete, the design for the first iteration of the Launch Tube commenced. Eventually, the two designs were optimized in parallel to ensure competition standards were met and the RAC was adequately optimized. Figure 4.1.1 below illustrates the design flow for both the UAV and Launch Tube preliminary designs.

Figure 4.1.1: Preliminary design methodology for the UAV and Launch Tube

4.2 Design/Sizing Trades

Fuselage

The dimensions of the fuselage, not including the nose cone, were optimized to hold the battery, motor, and the payload, minimizing empty space as much as possible, while having a flat bottom for simple removal of the payload. ABS plastic ribs and carbon fiber spars were utilized to ensure that the fuselage would be the strongest and most rigid part of the UAV.

The nose cone was used to make the fuselage as aerodynamic as possible. Where the main goal in the fuselage design was minimizing space, the nose cone's main goal was maximizing aerodynamic efficiency. This was done using well-established equations and relations for subsonic flight. The most common and generally aerodynamically superior nose cone is elliptical at expected speeds.

First, the nose cone's length (L_N) was determined using equation 4.1 below. It is found by attempting to achieve a length to diameter ratio of 6:1 for the fuselage and nose cone together.

$$L_N = 6D_F - L_F \quad \textbf{(4.1)}$$

This resulted in a calculated nose cone length of 3.5 inches. After obtaining this dimension, equation 4.2 for an ellipsis of radius R and length L_N was used to find the overall shape of the nose cone.

$$y = L_N\sqrt{1 - x^2/R^2} \quad \textbf{(4.2)}$$

However, the Radius was not constant throughout. Due to the flat payload bay, the radius on the bottom is 0.9931 inches compared to 1.625 inches on the rest of the nose cone. As such, a different plot was used on the bottom. These plots were traced in CAD from a cross section of the fuselage, creating the nose cone.

The nose cone is also the mounting location for the motor, so a cross section of the nose cone was placed along its radial axis to support the motor and give plenty of room for wiring and electrical components, as well as cooling airflow.

Self-Locking Mechanism

One of the key mission requirements for this year's competition is that the UAV must fit entirely inside of a launch tube in a "stowed condition." There were many requirements to properly complete this task. The first being that all movable surfaces need to be moved to a "flight" position from a "stowed" condition. Next, all surfaces and features on the aircraft had to be moved using hinges, pivots, or other captive mechanical mechanisms without any temporary attachments. Finally, the locking mechanisms of said mechanical devices had to be hand rotated into position without the use of any tool or direct contact of the mechanism with hands.

After many design considerations, the team settled on using a spring loaded pin in some fashion to securely lock the front airfoil into the flight condition without hand manipulation. The preliminary design of the self-locking mechanism uses a 3D printed piece that the 2 wing spars would pivot on separately on that would be connected to a fixed pin. When in the flight condition, a spring pin goes through a hole in the 3D printed piece, locking the airfoil into place. To bring the UAV to the stowed condition, the spring pin is compressed and the plate keeps the pin in compression when the airfoil is rotated forward. While bringing the airfoil back to the flight condition, the tip of the spring pin catches a fillet and springs back through the hole, effectively locking the airfoil into place. The spring pin is taller than the height of the spar, so compression of the pin during flight would be impossible. Figure 4.2.2 below illustrates the action the pin will take in both the stowed and flight condition

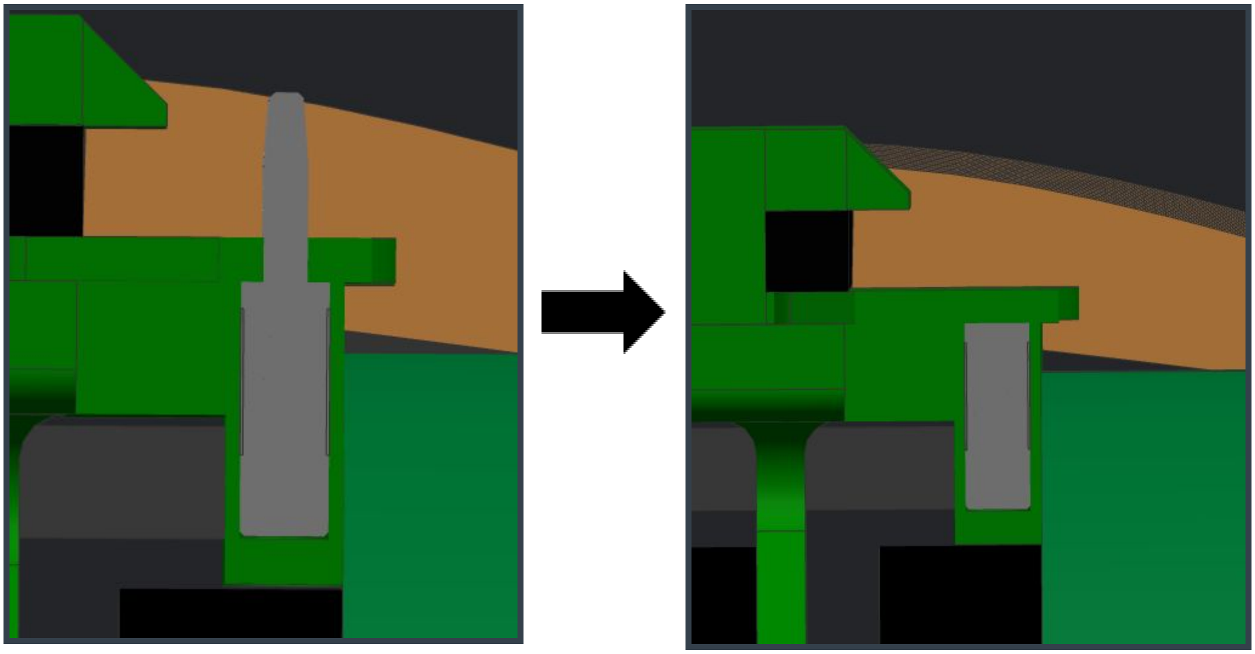

Figure 4.2.2: Airfoil Self-Locking Mechanism Action

Launch Tube

With the initial configuration of a cardboard launch tube with foam polystyrene ribs decided upon in the conceptual design phase, the specific dimensions and shapes of the materials were to be determined from the experimentally verified properties of the material.

The wall thickness and the inner diameter were tuned using the following equations for elastic impact velocity (eq 4.3), minimum tube diameter (eq 4.4), and real impact velocity (eq 4.5). The elastic impact velocity (V_E), the approximate velocity at which the tube deforms plastically, is dependent on yield stress (σ_Y), Young's modulus (E), radius (r), moment of inertia (I) and density (ρ) as shown. The yield stress and other material properties of the material were found after contacting the manufacturer of the paper tube

$$V_E = \sigma_Y/(E * r)\sqrt{EI/\rho} \quad \textbf{(4.3)}$$

The tube outer diameter is dependent on the chord length of the wing airfoil profile and the distance between them (C_L, 0.78 in), the wall thickness (T_w), and an added distance (0.1 in) to ensure that the fragile airfoil ribs have room to deflect.

$$\text{Tube OD} = 2 * C_L + 0.78\text{ in.} + 0.1\text{ in.} + 4 * T_w = \text{ID} + 2 * T_w \quad \textbf{(4.4)}$$

The real impact velocity is dependant on the gravitational constant at earth's surface and the outer diameter of the tube (OD) as shown.

$$V_I = \sqrt{(2 * (386.09\tfrac{in}{s^2}) * (OD))} \quad \textbf{(4.5)}$$

With a wall thickness of 0.25 inches, these calculations yield a factor of safety (FS), upon drop from 1 foot, of 1.69 (eq 4.6). The values used in these calculations are available in table 1.0.2.

$$FS = V_E/V_I \quad \textbf{(4.6)}$$

This was determined to be an acceptable factor of safety to safeguard the tubular casing from plastic deformation. However, for the inner tube, constraining the aircraft in place will require greater factors of safety to protect vital aircraft components from coming loose or becoming damaged, preventing mission failure.

Landing Gear

With a tail wheel configuration for the landing gear decided upon, the goal was to minimize the size, weight, and drag of the landing gear so as to minimize the launch tube size, and the RAC along with it. The main constraining factor for this goal was the size of the landing gear support (figure 4.2.3).

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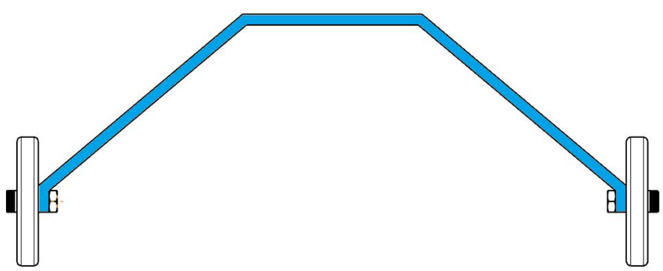


Figure 4.2.3: Landing gear assembly

The smallest landing gear support found online did not adequately minimize the space used, and was actually wider than the one currently in the team's possession. So the decision was made to cut the current support down to an adequate height of 1.875 inches. This height minimizes the launch tube circumference by placing the widest portion of the plane close to the center axis of the tube, while also providing for a safe landing, clearing the propellor of the ground.

4.3 Mission Model

There are 5 certainties derived from all four missions:

- Take-Off: The UAV must be hand-thrown. This means the airfoil must have a high lift coefficient, the structure of the UAV must be able to handle at least 2 g's for the adequate airspeed to be reached, and the propulsion system must be powerful enough to be able to fly in a short take-off.

- Climb: The UAV must be able to climb at an angle of 10 degrees without stalling with the engine at max thrust to reach an acceptable altitude.
- Cruise: The UAV must be able to run at max thrust for at least five minutes, the desired time window for the first two flight missions.
- Turns: The UAV must be able to handle 180 and 360 degree turn. This means the aircraft must have ailerons, giving the aircraft the ability to roll.
- Landing: The UAV must be able to land on concrete, so the landing gear must be robust enough to handle a potential harsh landing.

After accessing the certainties the mission provides, SpartyWorks determined the following uncertainties:

- Weather/Wind: These are not able to be accurately provided to the team until at most a week prior to flight. To ensure these uncertainties will be minimized, the body of the aircraft was kept as aerodynamic as possible, keeping the velocity change to a minimum.
- Drag: Due to unknown flight day conditions and the lack of ability to accurately account for all types of drag force, this parameter was over-estimated during the design to ensure our propulsion system was powerful enough.

4.4 Performance Estimation

Aerodynamic and Stability Characteristics

There were three main variables that were considered in the creation of the wings.

- Airfoil: The airfoil for the airplane was chosen carefully to maximize our C_L to C_d to minimize wing area and weight of the plane.
- Planform area: The area was chosen to provide the required lift and power to the plane based on our lowest speed during hand launch.
- Chord variation along span: A constant chord was chosen minimizing manufacturing difficulty and allowing for easier manufacturing of launch tube foam to form fit the wings.

The airfoil selection involved evaluating C_L and C_d for a number of different airfoils to best fit our flight mission. One of several main goals is to keep the wings to a minimal size thus reducing the diameter of the launch tube and reducing tube weight. This made the main desire for our airfoil to have a high C_L to α that is also stable over the desired Reynold's number.

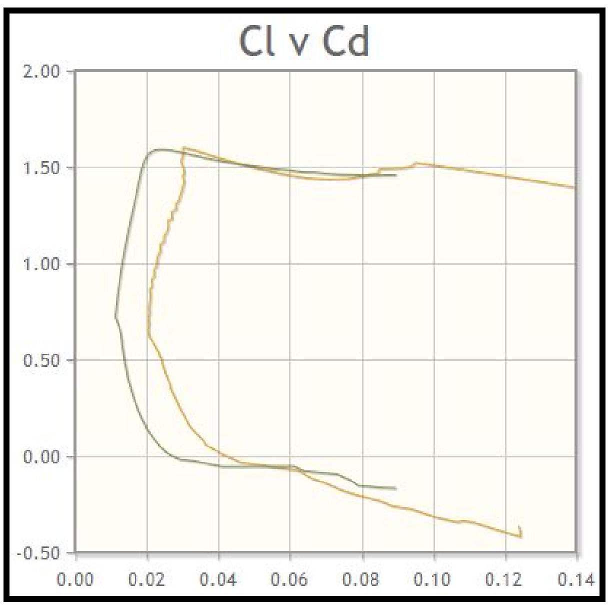
The airfoils were evaluated at hand launch take off speed and at cruising speed. For take off speeds the Reynold's number 100,000 was equated using our estimate throwing speed. Then for cruising speed a

Reynold's of 200,000 was determined.

Table 4.4.1: Study of NACA 6412 airfoil profile

Airfoil Profile Study					
Airfoil	Reynold's Number	Plotted Shape	α (degrees)	C_L	C_d
NACA 6412	100,000		9	1.5229	0.02963
	200,000			1.5355	0.01946

Airfoil Tools was used to obtain data for all the different airfoils and make the above table. For the take off Reynold's number of 100,000 the C_L and C_d was found to be 1.5229 and 0.02963 respectively. For the cruising speed Reynold's number of 200,000 the C_L and Cd was found to be 1.5355 and 0.01946 respectively. Thus the values matched the overall needed criteria of lift for the missions. The C_Lv C_d and C_L v alpha graphs considered for the selection of the NACA 6412 airfoil profile are displayed below in Figures 4.4.2 and 4.4.3



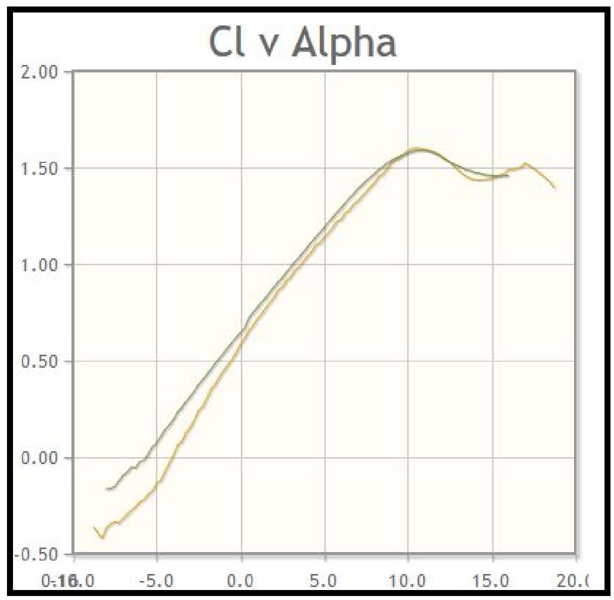


Figure 4.4.2 (left): Coefficient of Lift comparison to the coefficient of drag for NACA 6412.

Figure 4.4.3 (right): Coefficient of Lift comparison with the α (alpha) for NACA 6412

Vertical and Horizontal Stabilizers

Much like the airfoil selection, the horizontal stabilizer selection involved evaluating C_L and C_d for a number of different horizontal stabilizers to best fit our flight mission. By calculating the moment of the aircraft, the amount of needed counter-lift could be found. Using the results of the calculation, the necessary area of the horizontal stabilizer could be calculated. The width of the horizontal stabilizer was chosen to be no wider than the width of the aircraft in the stowed condition. Using the calculated area and the determined width, the chord of the horizontal stabilizer could also be found.

The vertical stabilizers were sized in coordination with the aileron. Through research it was found that the best way to determine the size of each vertical tail was to use the following ratio:

$$\frac{\text{(area of vertical tail)*(moment arm of vertical tail)}}{\text{(area of airfoil)*(airfoil wingspan)}} \quad (4.7)$$

If this ratio was calculated to be between .02 and .05, the aircraft's vertical stabilizers would be sized correctly. By plugging in the known values of the ratio, the area of each vertical tail could be determined. From there, the chord and span could be found based on the constraints of the launch tube. Table 4.4.4 below illustrates the stability constraints that govern the sizing of the vertical stabilizers, horizontal stabilizers, and overall sizing of the UAV.

Table 4.4.4: UAV Stability Characteristics

Stability Characteristics	
Characteristic	Value
Horizontal Tail Volume Coefficient	0.346
Vertical Tail Volume Coefficient	0.035
Spiral Stability	13.614

The horizontal tail volume coefficient and vertical tail volume coefficient give an estimate for the static stability of the empennage, since those surfaces counter the moment produced the the front airfoil. The acceptable range for the horizontal tail volume coefficient is between .3 and .6. Spiral stability gives an estimate for the dynamic stability of the empennage, to ensure the pilot will have adequate control of the UAV during flight. Typically, a spiral stability number greater than 5 is acceptable.

Drag

An estimation for the drag force experienced by the entire plane is expressed below in Table 4.4.5, utilizing equation 4.8.

$$F_D = \frac{1}{2}\rho u^2 C_D A \quad (4.8)$$

Table 4.4.5: Drag Force Approximations based on UAV Component

Drag Force Approximations	
Component	Drag Force (lb)
Airfoil	0.3334
Fuselage	0.0241
Horizontal Stabilizer	0.0046
Vertical Stablizer	0.0024

Control Surfaces

With the size of the aircraft not yet finalized, it was important for the control surfaces' sizing to be determined relative to the size of the aircraft's airfoil, vertical stabilizers and horizontal stabilizer. This made resizing the control surfaces much more simple and much less time consuming when necessary changes were made to the airfoil, vertical stabilizers, or horizontal stabilizer. Tables 4.4.6 through 4.4.8 provide general guidelines to follow when designing ailerons, rudders, and elevators.

Table 4.4.6: Aileron Sizing Study

Aileron	
Considered Design Parameters	Movement/Sizing Data
Aircraft Movement Affected:	X-Axis (roll)
Area:	5-10% of selected airfoil area
Chord:	15-25% of selected airfoil chord
Span:	20-30% of selected airfoil span
Distance Between Each Aileron:	60-80% of total wingspan (positioned symmetrically)

Table 4.4.7: Rudder Sizing Study

Rudder	
Considered Design Parameters	Movement/Sizing Data
Aircraft Movement Affected:	Y-Axis (Pitch)
Area:	20-40% of vertical stabilizer
Chord:	20-30% of vertical stabilizer chord
Span:	80-100% of vertical stabilizer span

Table 4.4.8: Elevator Sizing Study

Elevator	
Considered Design Parameters	Movement/Sizing Data
Aircraft Movement Affected:	Z-Axis (Yaw)
Area:	15-40% of horizontal stabilizer
Chord:	20-40% of horizontal stabilizer chord
Span:	80-100% of horizontal stabilizer span

Due to the aircraft's low weight, it was determined that the highest values for the chord and span parameters would be used for the design of the control surfaces. This allowed for maximum control over the aircraft.

Estimated Mission Performance

Assuming maximum thrust for each mission, Table 4.4.8 displays the estimated mission performance for the UAV.

Table 4.4.8: Estimated Mission Performance

Estimated Mission Performance Characteristics			
Characteristic	Mission 1	Mission 2	Mission 3
Weight (lb)	3.187	4.312	4.312
Cruising Speed (ft/s)	75.46	75.46	75.46
Distance (ft)	6000	6000	67916
Time (s)	79.51	79.51	900.00

Table 4.4.9 displays the estimated mission performance for the Launch Tube during the ground mission. The impact velocity was determined by using the law of conservation of energy.

Table 4.4.9: Estimated Launch Tube Performance

Estimated Ground Mission Performance Characteristics					
Characteristic	Tube Weight	Aircraft Weight	Impact Velocity	Tube Yield Velocity	Factor of Safety
Units	lb	lb	ft/s	ft/s	N/A
Value	12.92	3.19	8.22	13.91	169%

5.0 Detail Design

Once the preliminary and conceptual design of both the UAV and Launch Tube were finalized, SpartyWorks began to focus on finalizing the details and dimensions for the designs.

5.1 Dimensions

Tables 5.1.1 through 5.1.7 illustrate the dimensions for the UAV final design. Table 5.1.8 displays the overall dimensions for the Launch Tube final design.

Table 5.1.1: UAV Overall Dimensions

UAV General Dimensions	
Design Parameters	Sizing Data
Flight Condition Length (ft):	2.268
Stowed Condition Length (ft):	3.590
Fuselage Frontal Area (ft^2):	0.101
Max Height (ft):	0.815
Max Width (ft):	0.914
Mission 1 Weight (lb):	3.187
Mission 2 Weight (lb):	4.312
Mission 3 Weight (lb):	4.312

Table 5.1.2: Airfoil Dimensions

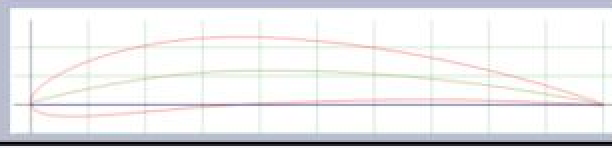
Airfoil	
Design Parameters	Sizing Data
Profile	NACA 6412
Planform Area (ft^2):	1.904
Chord (ft):	0.444
Span (ft):	4.265
α (degrees):	9.000
Shape:	

Table 5.1.3: Vertical Stabilizer Dimensions

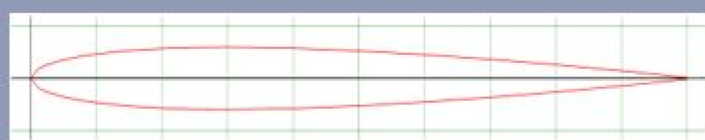
Vertical Stabilizer	
Design Parameters	Sizing Data
Airfoil:	NACA 0006
Area (ft^2):	0.280
Chord (ft):	0.560
Span (ft):	0.500
Airfoil Shape:	

Table 5.1.4 Horizontal Stabilizer Dimensions

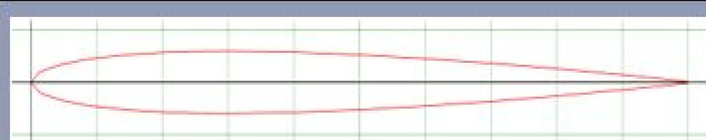
Horizontal Stabilizer	
Design Parameters	Sizing Data
Airfoil:	NACA 0006
Area (ft^2):	0.294
Chord (ft):	0.501
Span (ft):	0.587
Airfoil Shape:	

Table 5.1.5: Rudder Dimensions

Rudder		
Considered Design Parameters	Vertical Stabilizer Final Sizing Measurements	Rudder Final Sizing Measurements
Total Area (ft^2):	0.085	0.034
Chord (ft):	0.500	0.060
Span (ft):	0.568	0.568

Table 5.1.6 Elevator Dimensions

Elevator		
Considered Design Parameters	Horizontal Stabilizer Final Sizing Measurements	Elevator Final Sizing Measurements
Total Rudder Area (ft^2):	0.090	0.036
Chord (ft):	0.500	0.061
Span (ft):	0.587	0.587

Table 5.1.7: Aileron Dimensions

Aileron		
Considered Design Parameters	Airfoil Final Sizing Measurements	Aileron Final Sizing Measurements
Area Per Each Aileron (m^2):	0.177	0.009
Chord Per Each Aileron (m):	0.136	0.034
Span Per Each Aileron (m):	1.300	0.195
Distance Between Each Aileron (m):	N/A	1.040

Table 5.1.8: Launch Tube Dimensions

Launch Tube	
Design Parameters	Sizing Data
Length (in)	47.865
Circumference (in)	37.593
Cross-Sectional Area (in)	9.202
Wall Thickness (in)	0.250

5.2 Structural Characteristics and Capabilities

Fuselage

The main structural supporting body of the aircraft is the fuselage. The fuselage houses all electrical components, except for the wing mounted servos, and the payload, so the fuselage must be strong to ensure the UAV can sustain normal and abnormal flight conditions. Given that the team wanted to increase the amount of 3D printing for the 2016-2017 DBF competition, the available printing materials are PLA and ABS. After research, ABS was the clear choice because of its superior mechanical properties compared to PLA. ABS is rated for having high impact resistance, strength, and stiffness, along with having great machinability and cost efficiency. To ensure the aircraft does not flex during aerodynamic maneuvers, such as pitching, rolling, or yawing, carbon fiber was selected for the spine and fuselage supports because of the high bending modulus of carbon fiber. Since carbon fiber experiences a brittle fracture failure mode under slight bending, a rear fuselage rib was placed towards the rear to offset the potentially large bending moment due to the empennage counter-lift and weight. Figure 5.2.1 below displays the fuselage structure.

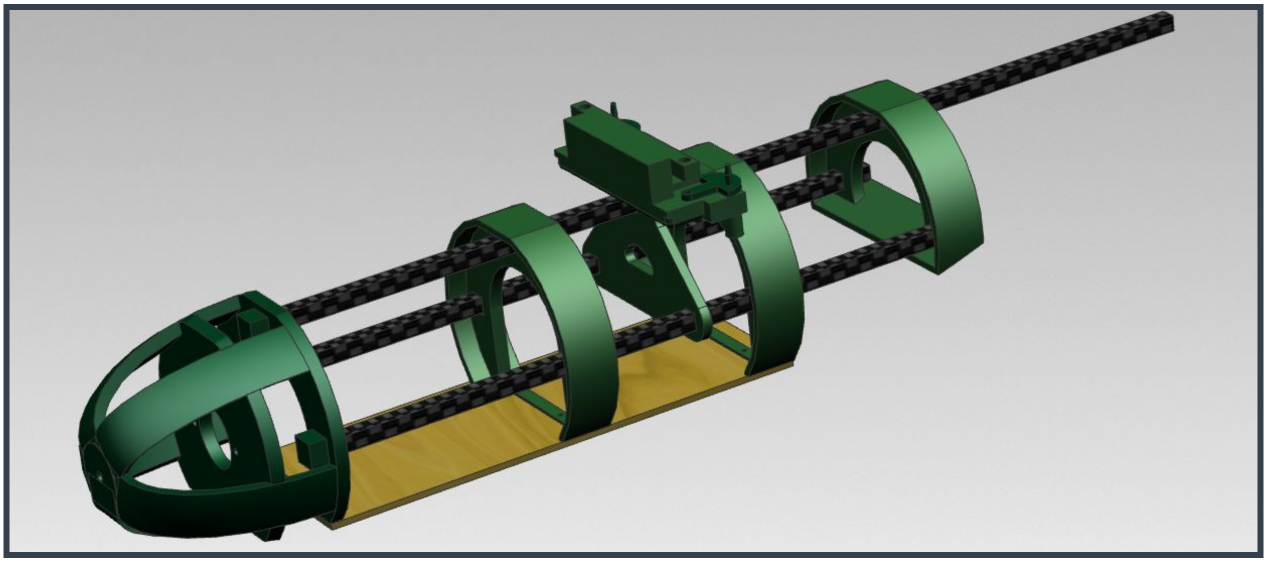


Figure 5.2.1: Fuselage structure

A Finite Element Analysis was run on the fuselage rib as shown in figure 5.2.2. In this simulation, the rib is assumed to take the full force of the tube impact, which is highly unlikely. However, if this were the case, the stress experienced by the rib would exceed the yield stress for ABS plastic, yielding a factor of safety of 0.9. In order to mitigate the possible risk however, contact points with the rib will be padded additionally with Sorbothane shock-absorbing material.

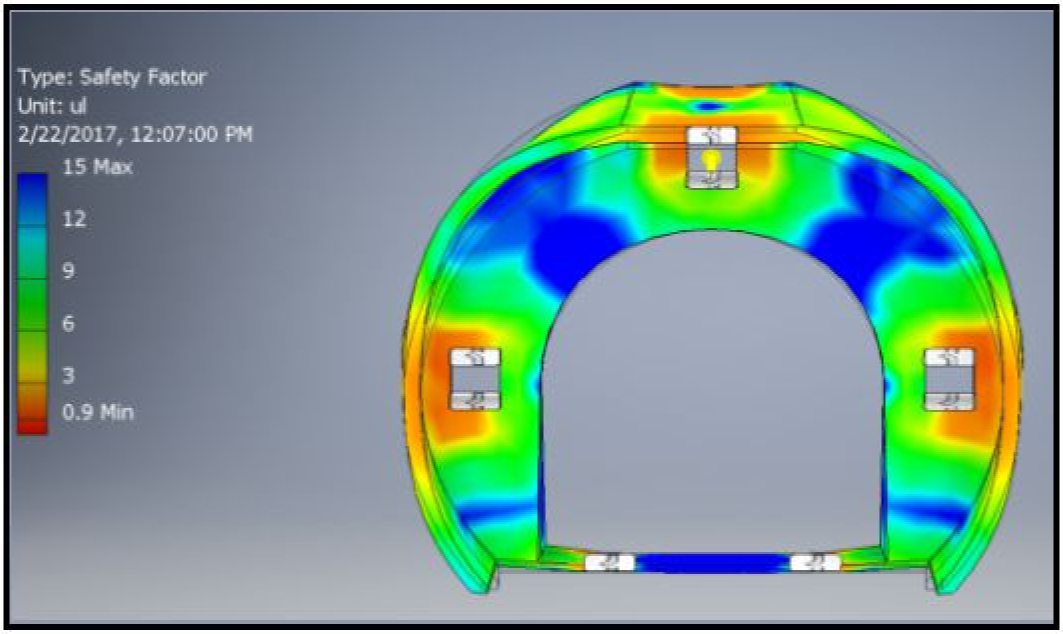


Figure 5.2.2: FEA Analysis for Fuselage Rib

Airfoil

To ensure the airfoil is capable with handling the stress of flight, a shear and bending moment analysis was conducted for the forces experienced at cruising speed. Figures 5.2.2 and 5.2.3 display the results of the shear and bending moment analysis.

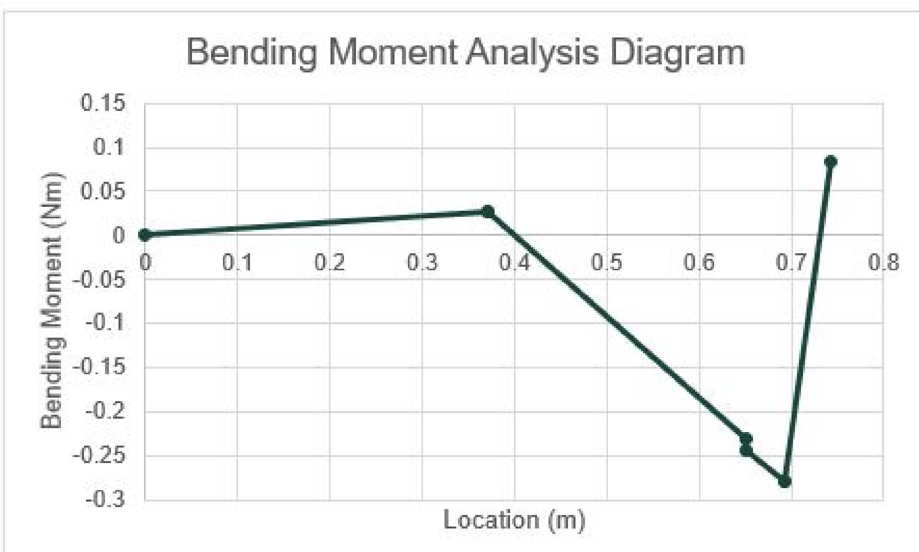


Figure 5.2.3: Bending Moment Diagram for Airfoil Spar

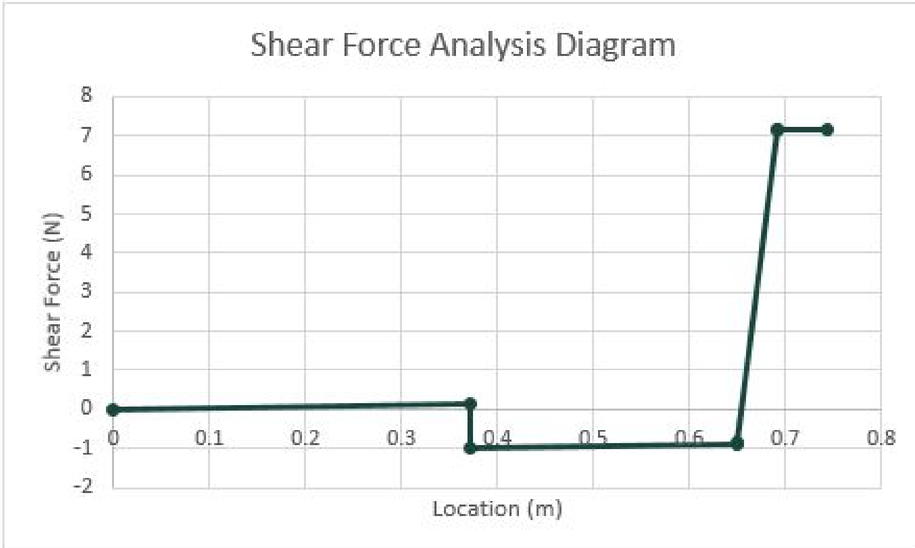


Figure 5.2.4: Shear Force Diagram for Airfoil Spar

After the bending moment and shear diagrams were created from the known forces acting on the airfoil, the maximum shear stress was calculated to ensure the carbon fiber spar could handle the stress. Table 5.2.3 displays the results of the stress analysis on the spar.

Table 5.2.5: Airfoil Spar Stress Analysis

Airfoil Spar Stress Analysis	
Parameter	Value
Maximum Shear (N) :	7.18
Cross-Sectional Width (m):	8.00E-03
First Moment of Inertia (m^4):	3.42E-10
Second Moment of Inertia (m^3):	6.40E-08
Maximum Shear Stress (Pa):	1.68E+05
Ultimate Shear Stress (Pa):	7.00E+07
Shear Stress F.S.:	416.07

Given that the airfoil could withstand the conditions of flight with an enormous factor of safety, the ground mission had to be considered. In the event that the internal design fails for the Launch Tube and the airfoil takes some of the load experienced by the fall, an axial stress and buckling analysis had to be conducted to ensure the spar would not fail. By the laws of conservation of momentum and energy, the experienced load on the cap was found by calculating the average impact force. The results of this analysis is displayed in Table 5.2.4 below.

Table 5.2.6: Airfoil Spar Axial Stress and Buckling Analysis

Airfoil Spar Buckling Analysis	
Parameter	Value
Experienced Load (N):	1961.00
Cross Sectional Area (m^2):	6.40E-05
Axial Stress (Pa):	3.06E+07
Effective Length Factor:	7.00E-01
Length (m):	6.92E-01
Young's Modulus (Pa):	1.35E+11
Critical Load (N):	1939.75
Cricital Load F.S.:	0.99
Axial Stress F.S.:	1.35E+02

Assuming all of the force is taken by the spar, which would not happen in reality, the airfoil would not fail from the one foot drop.

Empennage

The empennage is built similarly to the front airfoil: carbon fiber spars epoxied to balsa airfoil profiles. The empennage is attached to the spine via 3D printed ABS connector with fittings for the spars to be epoxied to. Aerodynamic characteristics begin to change if the lifting surface is deforming, so it is advantageous to have a strong, stiff spar to absorb the forces experienced during flight. The structure of the empennage is displayed below in Figure 5.2.6.

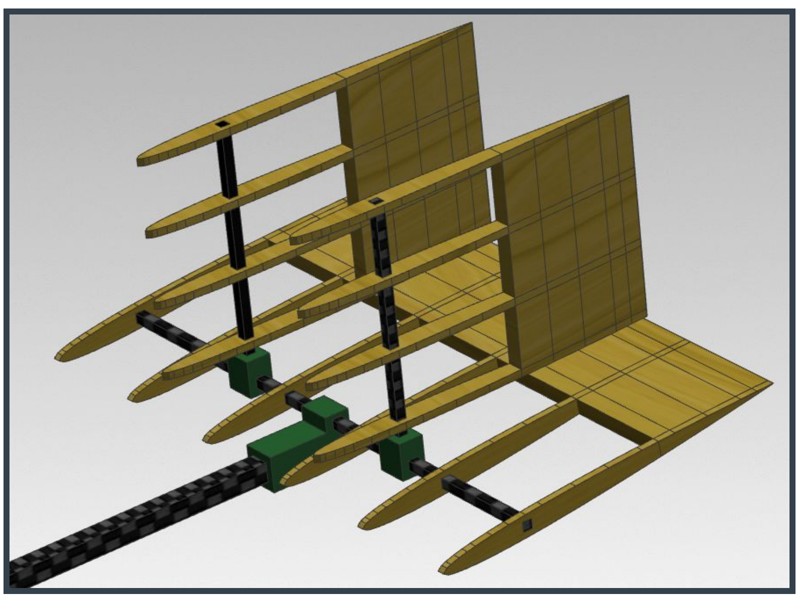


Figure 5.2.7: Empennage Structure

Launch Tube Padding

Similar methods to the impact velocity analysis used for the tube were also utilized to analyze whether the polystyrene would survive the force taken, or would shear. With a calculated impact force of 441.9 lbf as shown in table 5.2.8, a Finite Element Analysis in AutoDesk Inventor was run on the polystyrene ribs. A minimum factor of safety from permanent shear of 1.45 was found among the thinnest portions of the rib. Though the deformation is exaggerated in the simulation (figure 5.2.7), the polystyrene should deform, elastically, less than a millimeter. While this is acceptable, the manufacturing process will attempt to make the ribs as thick as possible. Table 5.2.9 displays the impact analysis conducted on the launch tube.

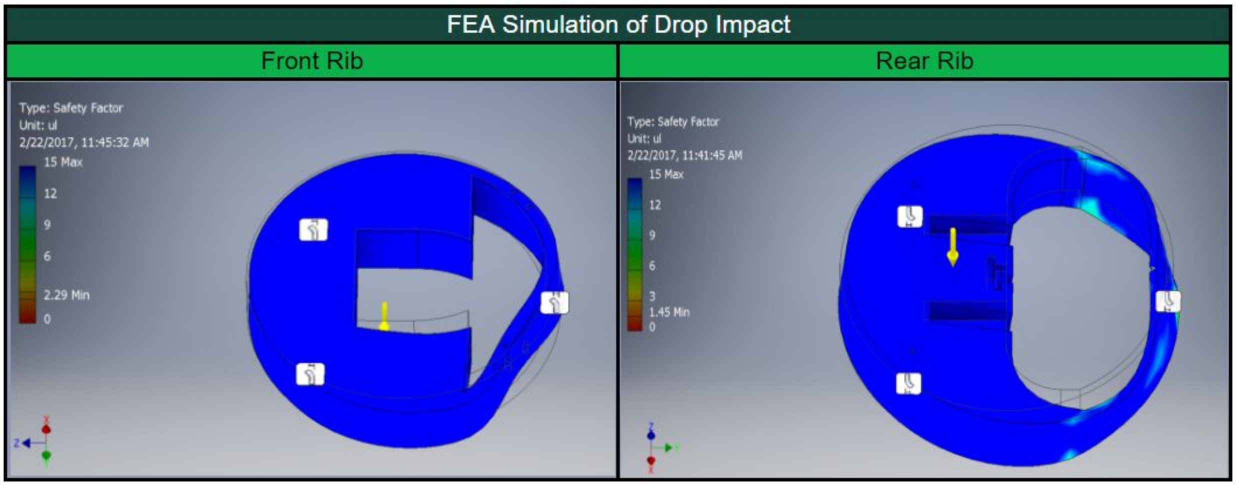


Figure 5.2.8: FEA of Polystyrene Padding

Table 5.2.9: Impact analysis

Tube Impact	
Parameter	Value
Height after Impact (in)	0.5
Average Impact Force (lb)	441.913
Area (in^2)	9.697
Normal Stress (psi)	47.573
Deformation (in)	0.005

5.3 Systems Integration and Architecture

Propulsion

The propulsion system will consist of a single motor with a 10x6 inch propeller. The motor chosen is a Power 15 Brushless Outrunner Motor, rated at 950Kv. The propeller was chosen based on the recommended propellers given by the motor manufacturer. A 40 Amp Sky Walker ESC will be controlling the motor, along with 2 NiMH 7.2V 1200mAH Venom battery connected in parallel to increase capacity to

2400mAh while maintaining 7.2V. This battery was chosen to meet weight requirements along with enough capacity to last every mission. Testing has begun on the electrical system and will continue to ensure that the aircraft meets mission requirements. Further information can be obtained in the testing section. The commercial specifications for the engine and battery the team selected are displayed in Tables 5.3.1 and 5.3.2 below.

Table 5.3.1: Engine Specifications

Engine Specifications	
Type	Brushless outrunner motor
Size	15-size
Bearings	One 5x14x5mm, One 5x11x5mm
Wire Gauge	16
Prop Range	10x6 - 13x6.5 inches
Voltage	7.4 - 14.4V
RPM/Volt	950Kv
Resistance	0.03 ohms
Idle Current	2A @ 10V
Continuous Current	34A
Max Burst Current	42A (15 seconds)
Cells	8-12 NiMH
Speed Control	40-45A brushless
Weight	152g
Overall Diameter	35mm
Shaft Diameter	5mm
Overall Length	50mm

Table 5.4.2: Battery Specifications

Battery Specifications	
Type	Nickel Metal Hydride
Volts	7.2
Capacity	1200mAh
Cell Count	16
Cell Config.	6-Cell
Charge Rate	1C
Wire Gauge	20 AWG Silicone Wire
Plug Type	Micro/Molex Plug
Dimensions	101.3x17x30mm
Watt Hours	8.64
Weight	130.4g

Controls

The main control system will consist of a Spektrum AR610 Receiver, paired with a Spektrum DX6i Transmitter. The receiver will be programmed with a failsafe which will activate if the receiver loses contact with the transmitter. If the receiver were to lose contact with the transmitter, the aircraft would close the throttle, select elevator up, right rudder and right aileron.

The receiver and servos will be powered by 4 AAA batteries. The aircraft will consist of 4 HiTec HS-311 servos which will provide sufficient force to control the ailerons, rudder and elevator. Two servos will be used to power each aileron, 1 servo to power both rudders, and 1 servo to control the elevator.

5.4 Weight and Balance

To ensure of a stable flight, every ounce and the slightest moment had to be accounted for when designing the UAV. Since mission 1 requires the UAV to fly with no payload, the team designed the payload bay to limit the effect the hockey pucks would have on the total gravitational moment by placing them directly underneath the target center of gravity. Thus keeping the center of gravity in front of the center of pressure (about 25% of the chord) of the airfoil in all three missions. Early on, the team gathered an approximate weight of all non-lifting structures on the UAV to design the lifting structures of the UAV, since lift will also produce a moment about the center of gravity. Once the dimensions and effective lift force for the airfoil and the lift force generated by the vertical thrust vector of the engine was determined, the adequate effective counter-lift and dimensions of the empennage were determined. Table 5.4.1 displays the weight and force balancing the team conducted for each mission.

Table 5.4.1: UAV Force Balancing and CG Placement

Force Balance Chart							
Component	Weight (lb)	Arm (in)	Gravitational Moment (lb-in)	Lift (lb)	Lift Moment (lb-in)	Thrust (lb)	Thrust Moment (lb-in)
Propellor	0.037	10.680	0.395	-	-	-	-
Engine	0.092	9.197	0.844	See Thrust	See Thrust	0.116	-1.070
Nose Cone	0.178	8.275	1.469	-	-	-	-
Front Connector	0.170	-0.711	-0.121	-	-	-	-
Floor	0.088	1.958	0.172	-	-	-	-
Battery	0.850	3.916	3.329	-	-	-	-
Fuselage Rib 1	0.059	1.791	0.106	-	-	-	-
Fuselage Rib 2	0.059	-2.209	-0.130	-	-	-	-
Fuselage Rib 3	0.044	-6.204	-0.275	-	-	-	-
Empennage	0.212	-12.000	-2.549	-0.275	-3.305	-	-
Rear Servo 1	0.100	-12.000	-1.200	-	-	-	-
Rear Servo 2	0.100	-12.000	-1.200	-	-	-	-
Hockey Puck 1	0.375	0.854	0.320	-	-	-	-
Hockey Puck 2	0.375	-0.146	-0.055	-	-	-	-
Hockey Puck 3	0.375	-1.584	-0.594	-	-	-	-
Front Landing Gear	0.151	6.203	0.937	-	-	-	-
Back Landing Gear	0.066	-2.397	-0.158	-	-	-	-
Front Airfoil	0.218	-1.000	-0.218	4.383	4.383	-	-
Front Servo 1	0.100	-1.000	-0.100	-	-	-	-
Front Servo 2	0.100	-1.000	-0.100	-	-	-	-
Fuselage Support 1	0.078	0.933	0.072	-	-	-	-
Fuselage Support 2	0.078	0.933	0.072	-	-	-	-
Spine	0.166	-6.540	-1.086	-	-	-	-
Totals:	4.312	N/A	-0.069	4.108	1.078	0.116	-1.070
Mission 1		Mission 2		Mission 3			
UAV Weight (lb):	3.187	UAV Weight (lb):	4.312	UAV Weight (lb):	4.312		
UAV CG (in):	9.891	UAV CG (in):	10.310	UAV CG (in):	10.310		
Chord Percentage (%)	11%	Chord Percentage (%)	19%	Chord Percentage (%)	19%		

5.5 Performance

Due to Sparty III not having made its first flight yet, the team was unable to make a concrete measure of mission performance. However, an estimate for the mission performance for the final design of the UAV is displayed in Table 5.5.1. Along with an estimate for the mission performance, an estimate for the RAC is displayed in Table 5.5.2.

Table 5.5.1 Estimated Mission Performance

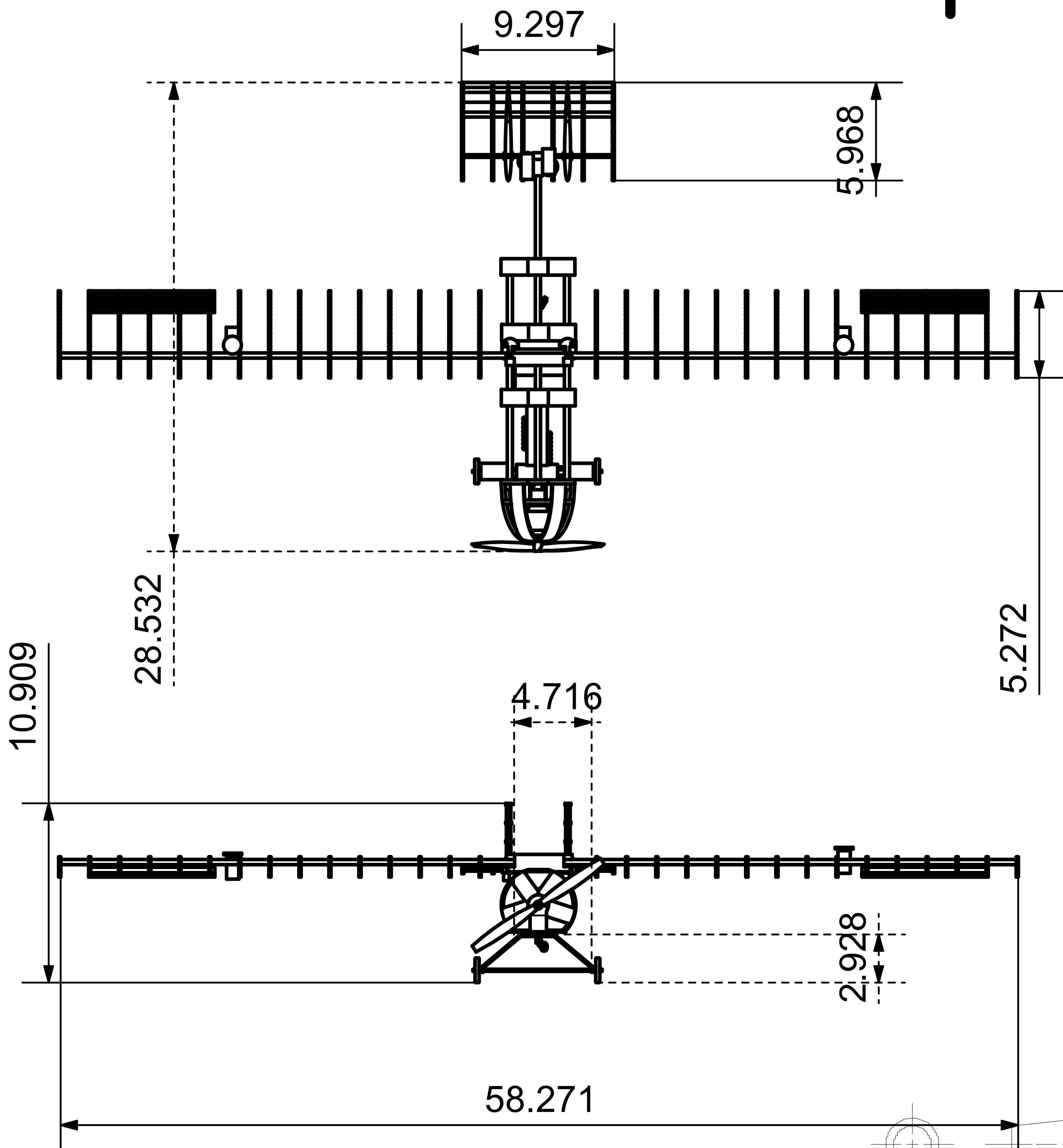
Estimated Mission Performance Characteristics			
Characteristic	Mission 1	Mission 2	Mission 3
Weight (lb)	3.187	4.312	4.312
Cruising Speed (ft/s)	75.46	75.46	75.46
Distance (ft)	6000	6000	67916
Time (s)	79.51	79.51	900.00

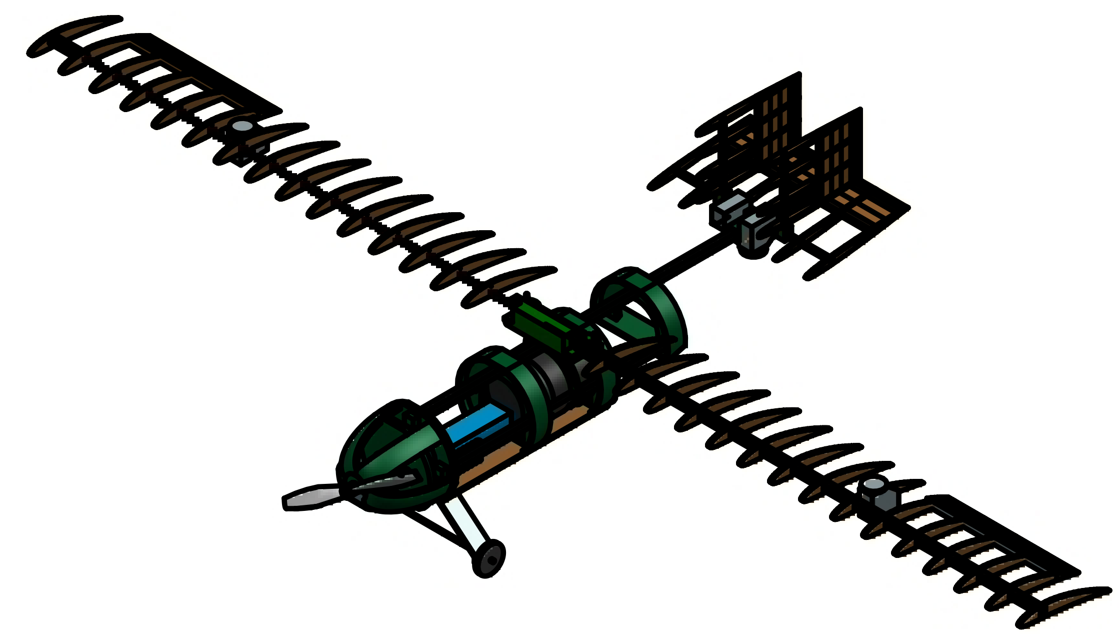
Table 5.5.2: Estimated RAC

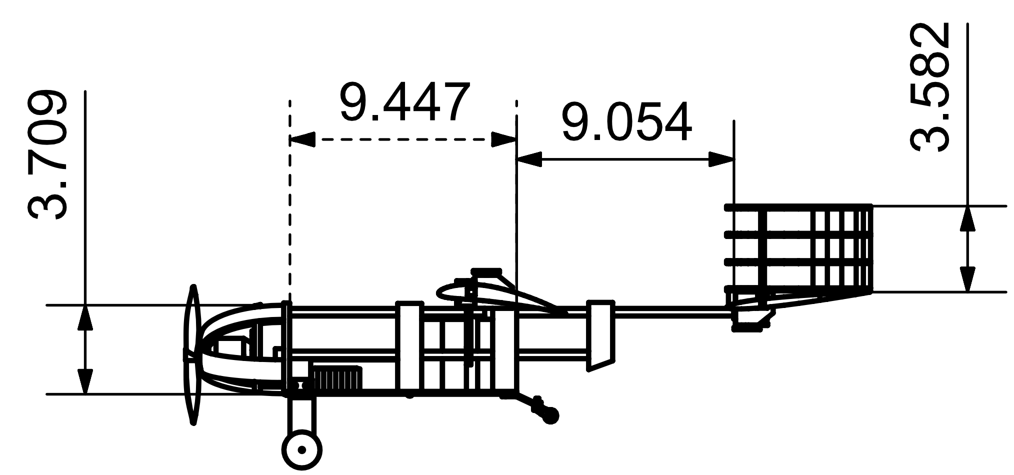
Estimated RAC					
Component	EWmax	TW	L	C	RAC
Units	lb	lb	in	in	lb-in
Cost	3.19	12.92	47.86	37.59	1376.67

5.6 CAD Drawing Package

The CAD drawing package features 3-view drawings with dimensions and structural arrangement drawings for both the UAV and Launch Tube along with a systems layout drawing and payload accommodation drawing for the UAV by itself.

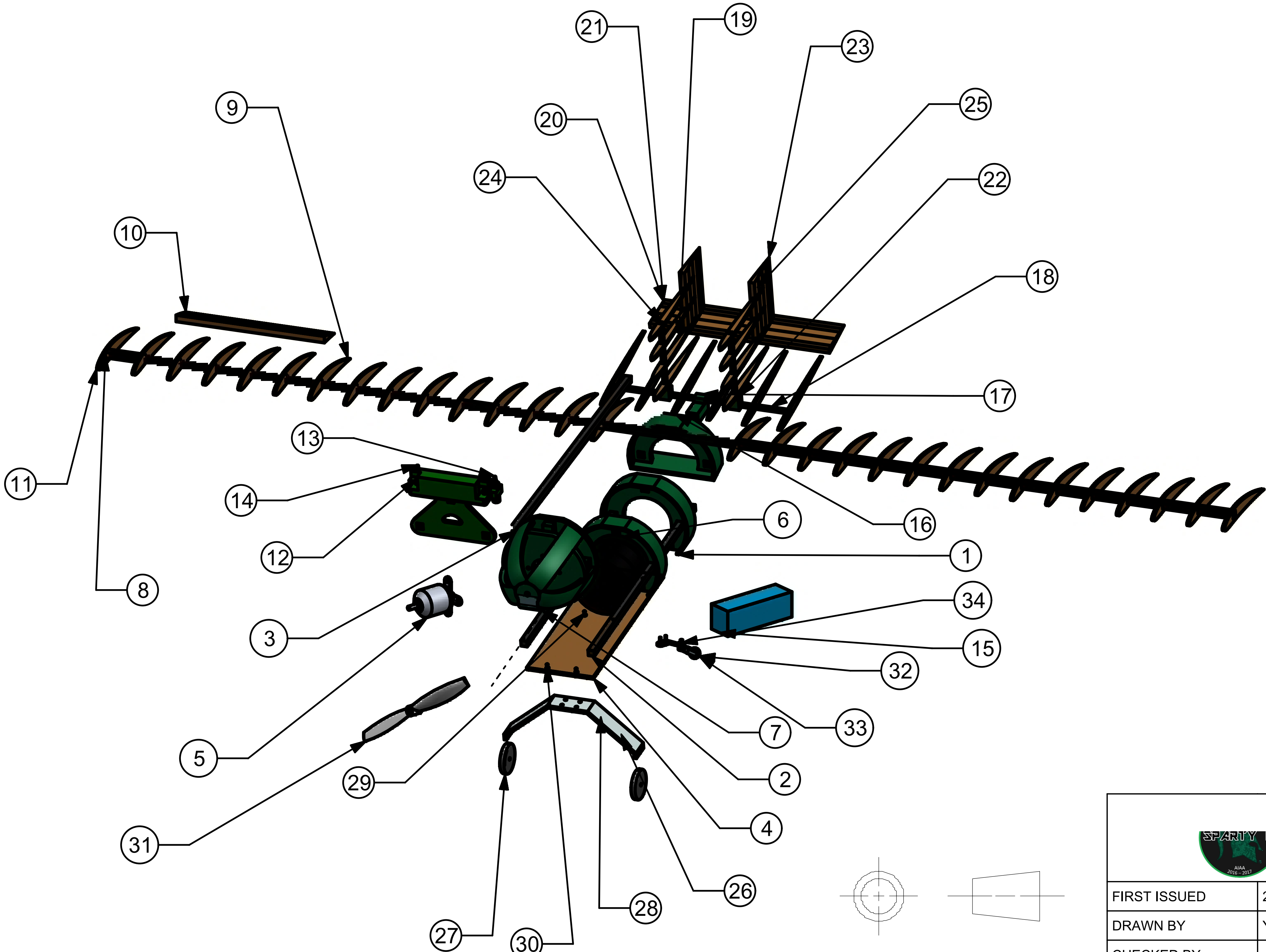






ALL DIMENSIONS IN INCHES

		Michigan State University Design-Build-Fly		
FIRST ISSUED	2/22/2017	TITLE		
DRAWN BY	Yuexing Sun			
CHECKED BY	Jordan Thayer	Sparty III		
APPROVED BY	Jordan Thayer	SIZE B	DWG NO. 3-View with Dimensions	SHEET REV A
		SCALE 1:1		SHEET 1 OF 7



PC NO	PART NAME	QTY
34	REAR LANDING GEAR SUPPORT	1
33	REAR LANDING GEAR	1
32	REAR WHEEL	1
31	PROPELLER	1
30	BRASS MACHINE SCREW	6
29	HEAT SET INSERT	6
28	FRONT LANDING GEAR	1
27	WHEEL	2
26	FRONT LANDING GEAR SUPPORT	1
25	VERTICAL STABILIZER	2
24	VERTICAL STABILIZER SPAR	2
23	RUDDER	2
22	VERTICAL STABILIZER CONNECTOR	2
21	HORIZONTAL STABILIZER	1
20	ELEVATOR	1
19	NACA 0006 PROFILE	14
18	HORIZONTAL STABILIZER SPAR	1
17	HORIZONTAL STABILIZER CONNECTOR	1
16	FUSELAGE BACK RIB	1
15	BATTERY	1
14	FRONT CONNECTOR RIB	1
13	FRONT CONNECTOR PIN	2
12	FRONT CONNECTOR ROTATING PLATE	2
11	FRONT AIRFOIL	2
10	AILERON	1
9	NACA 6412 PROFILE	30
8	FRONT AIRFOIL SPAR	2
7	NOSE CONE	1
6	REGULATION SIZE HOCKEY PUCK	3
5	ENGINE	1
4	PAYLOAD BAY	1
3	SPINE	1
2	FUSELAGE SUPPORT SPAR	2
1	FUSELAGE FRONT RIB	2

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Michigan State University Design-Build-Fly

FIRST ISSUED	2/22/2017
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CHECKED BY	Jordan Thayer
APPROVED BY	Jordan Thayer

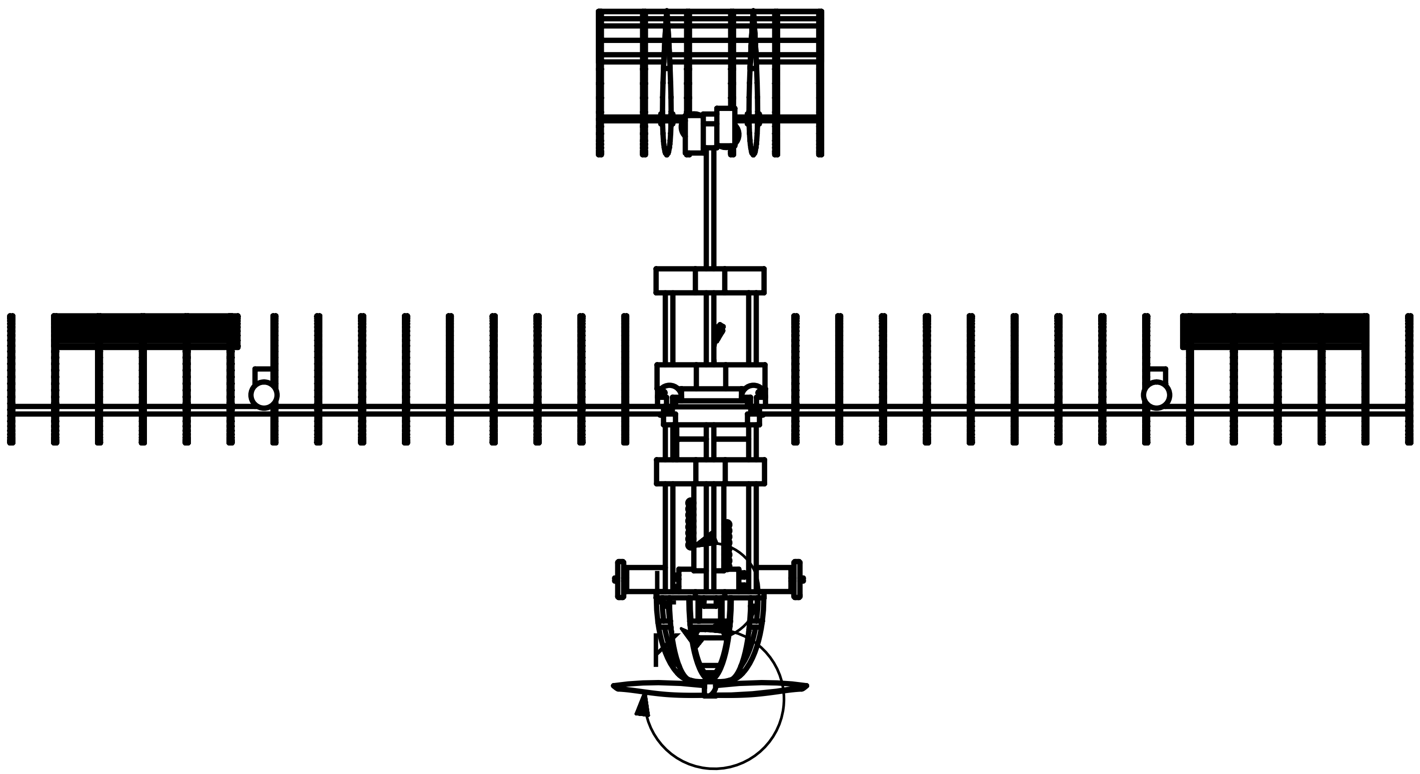
TITLE

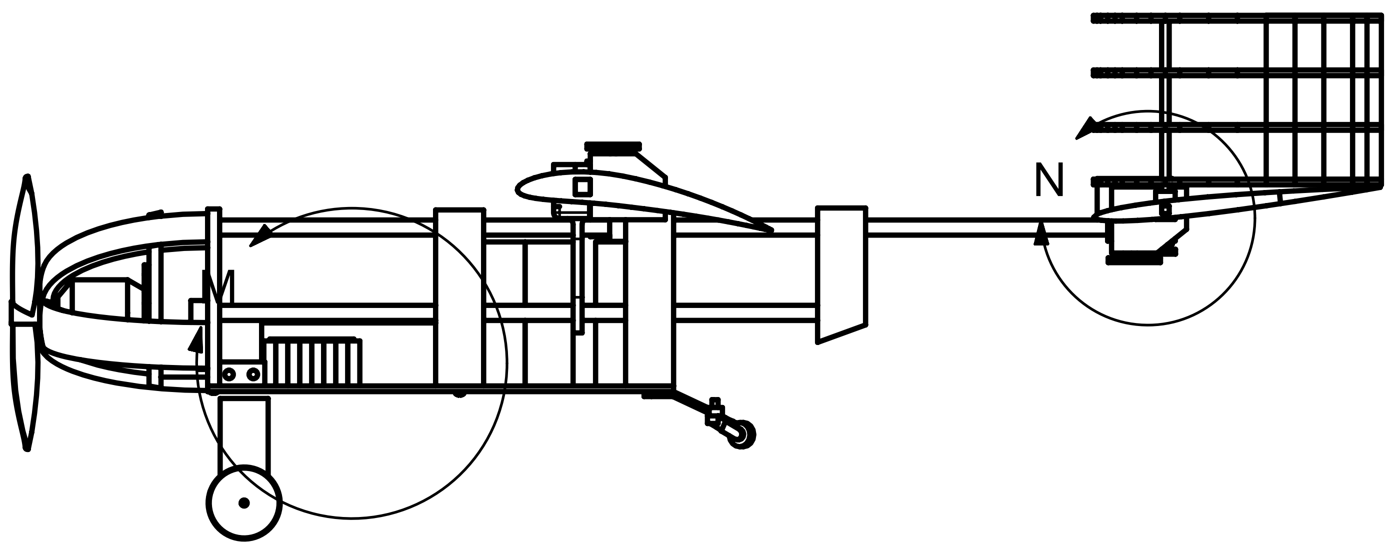
Sparty III

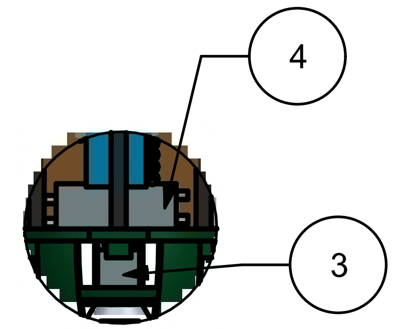
SIZE B | DWG NO. Structural Arrangement | SHEET REV A

SCALE 1:1 | SHEET 2 OF 7

	PART	QTY.
1	MOTOR	1
2	MOTOR BATTERY	1
3	RECIEVER	1
4	ESC	1
5	SERVO	4
6	AAA BATTERY PACK	2







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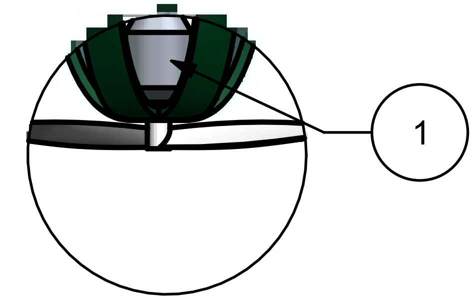
SCALE 1:4



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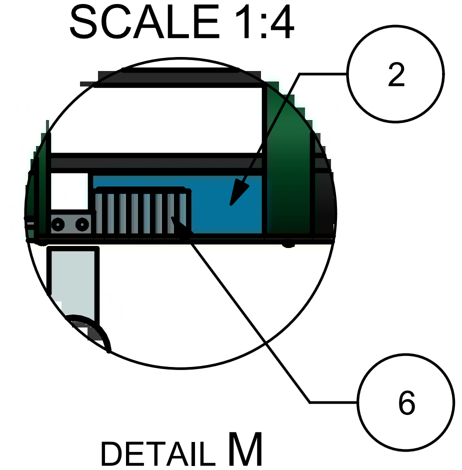

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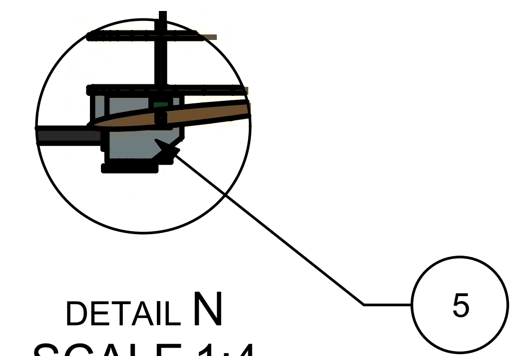

DETAIL N
SCALE 1:4

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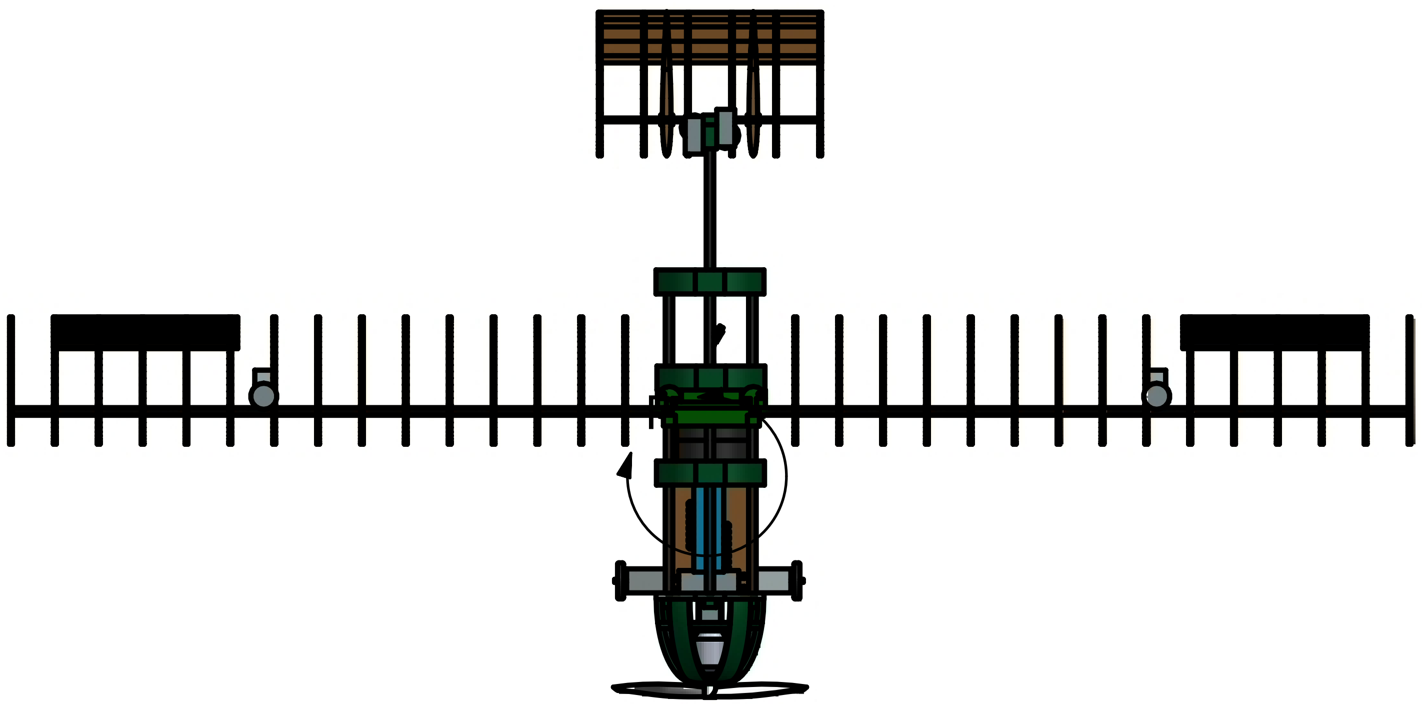
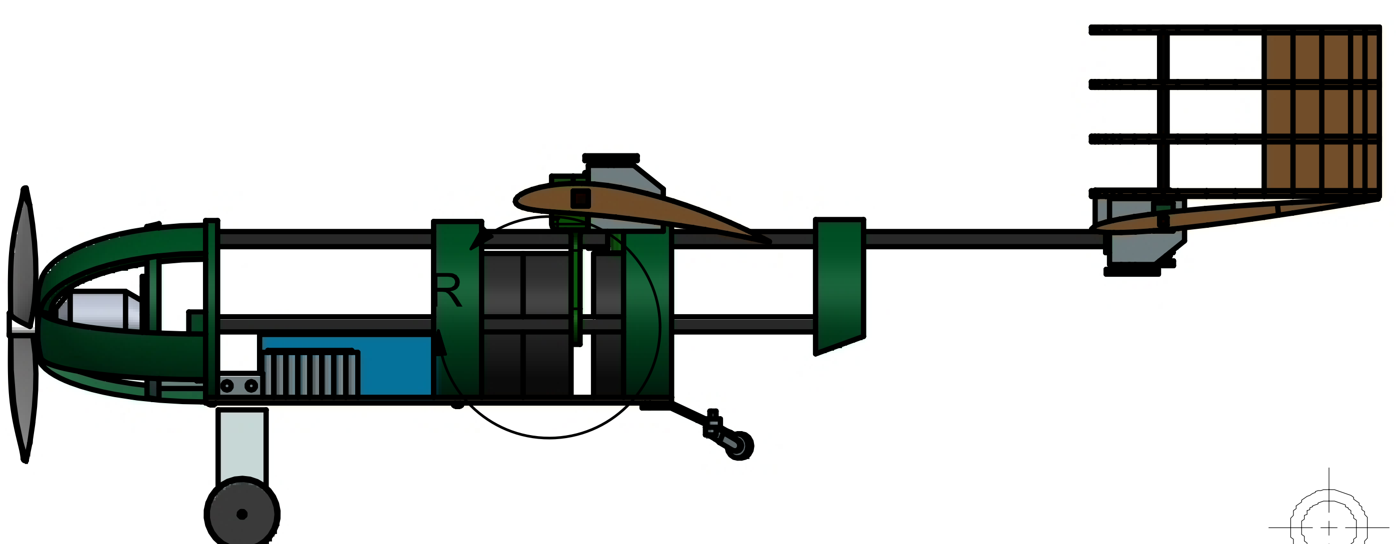
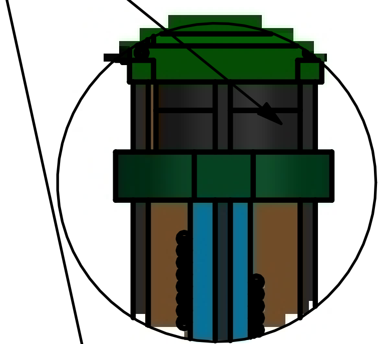
Michigan State University Design-Build-Fly	
FIRST ISSUED	2/22/2017
DRAWN BY	Yuexing Sun
CHECKED BY	Jordan Thayer
APPROVED BY	Jordan Thayer
TITLE	Sparty III
SIZE	B
DWG NO.	Systems Layout
SHEET REV	A
SCALE 1:1	SHEET 3 OF 7





REGULATION SIZE HOCKEY PUCK



DETAIL P
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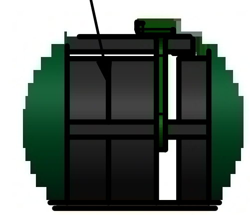

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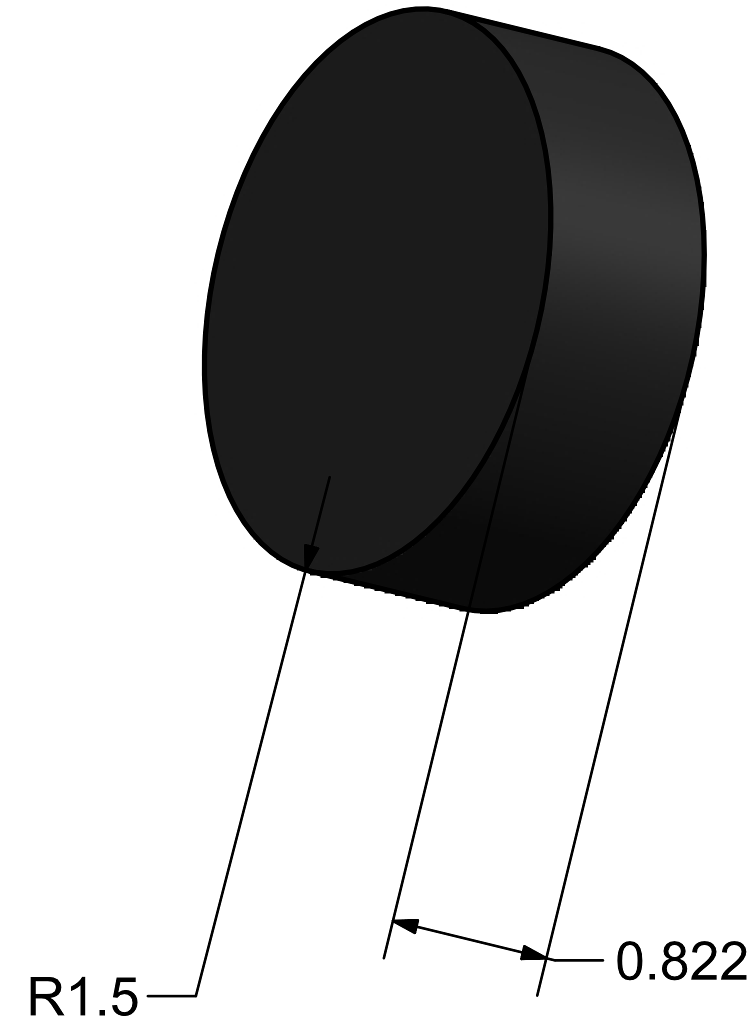

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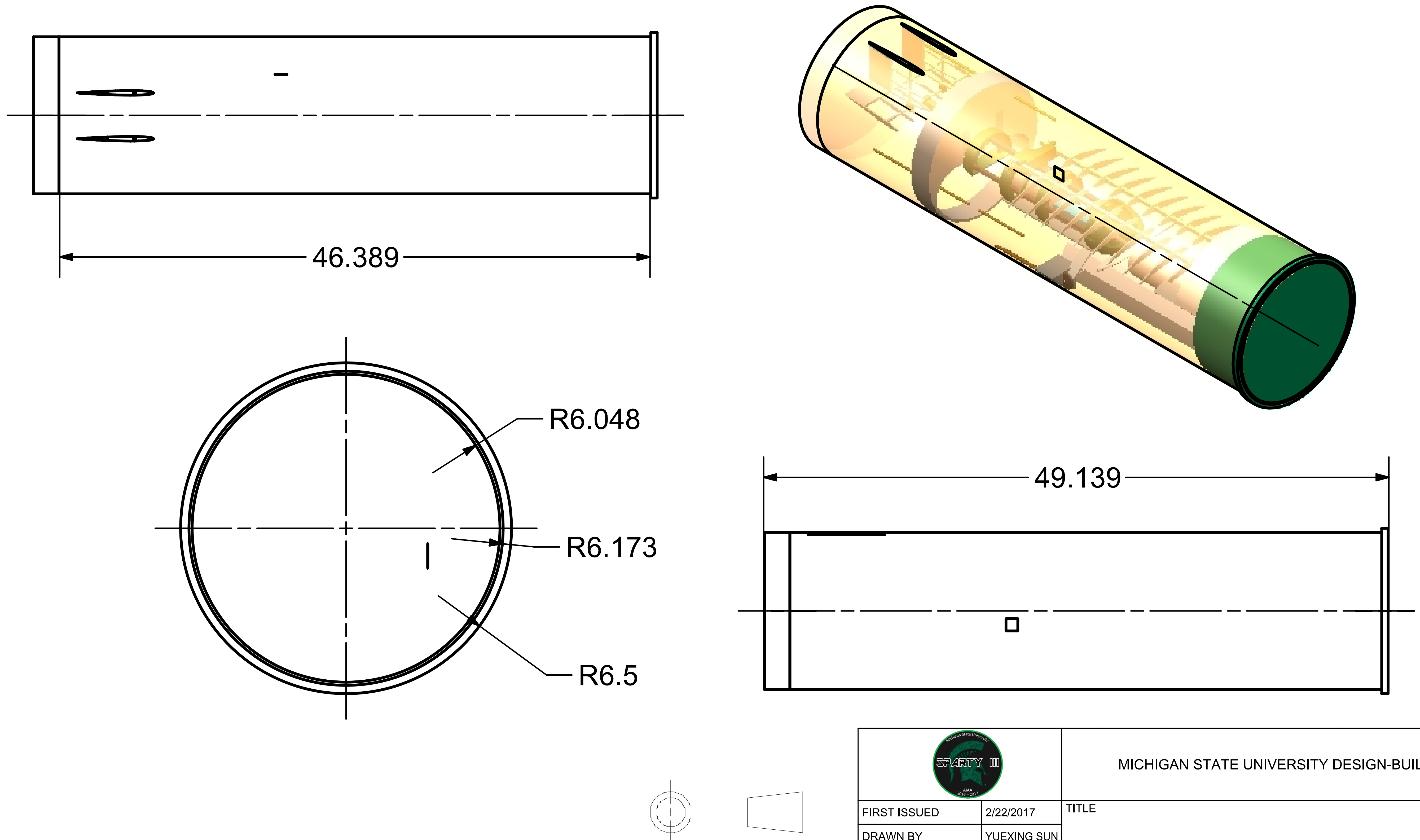
SPARTY III		Michigan State University Design-Build-Fly
FIRST ISSUED	2/22/2017	TITLE
DRAWN BY	Yuexing Sun	
CHECKED BY	Jordan Thayer	Sparty III
APPROVED BY	Jordan Thayer	SIZE B · DWG NO. Payload View · SHEET REV B
		SCALE 1:1 · SHEET 4 OF 7



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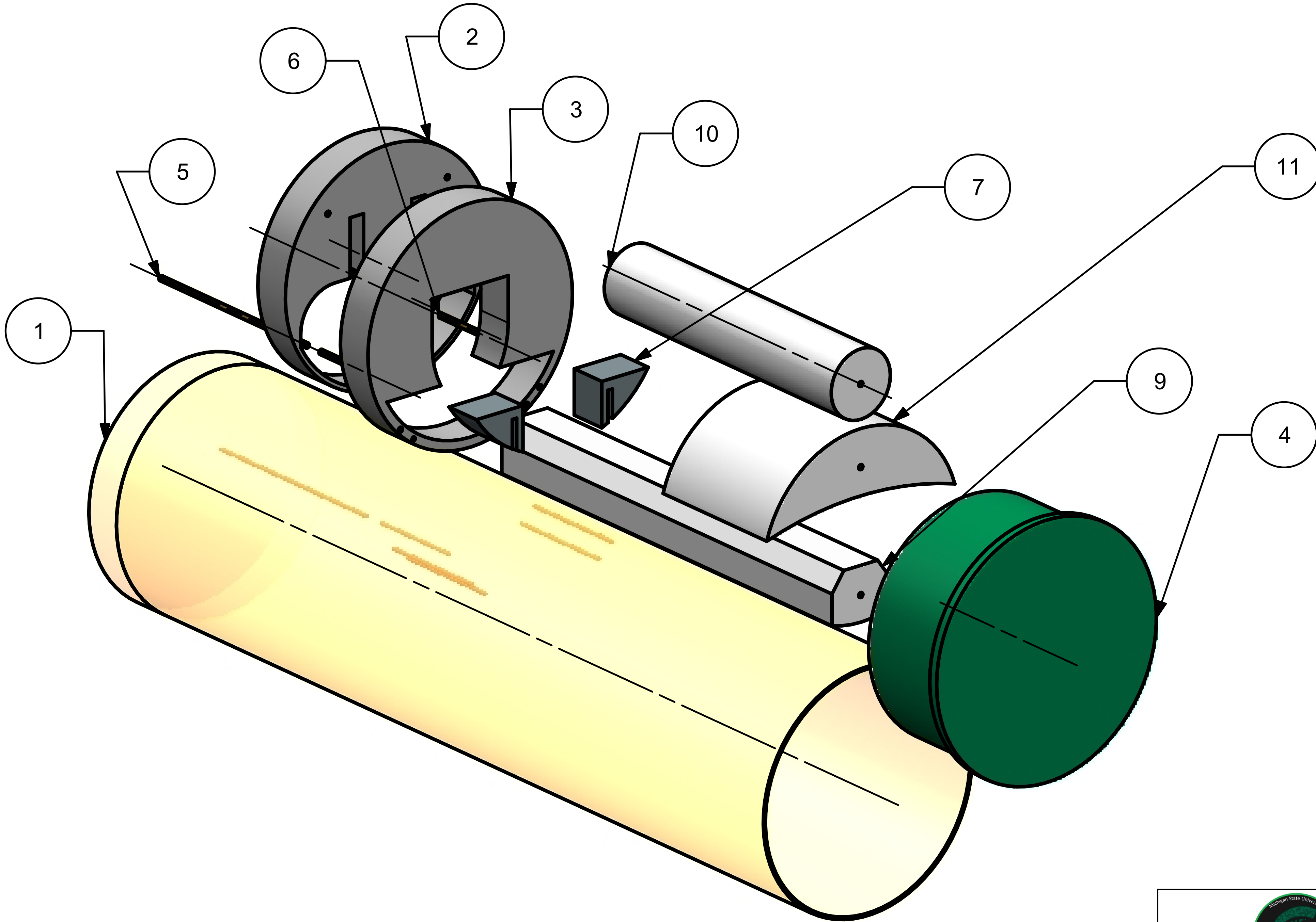
		MICHIGAN STATE UNIVERSITY DESIGN-BUILD-FLY
FIRST ISSUED	2/22/2017	TITLE
DRAWN BY	YUEXING SUN	
CHECKED BY	JORDAN THAYER	LAUNCH TUBE
APPROVED BY	JORDAN THAYER	SIZE B · DWG NO. LAUNCH TUBE 3-VIEW WITH DIMENSIONS · SHEET REV A
		SCALE 1:1 · SHEET 5 OF 7

PC NO	PART NAME	QTY
11	WING FOAM	1
10	NOSE CONE FOAM	1
9	TRACK FOAM	1
8	FRONT SUPPORT SPAR	4
7	WHEEL SUPPORT	1
6	MIDDLE SUPPORT SPAR	3
5	SUPPORT SPAR	3
4	END CAP	1
3	MIDDLE FOAM	1
2	REAR FOAM	1
1	OUTER TUBE	1



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MICHIGAN STATE UNIVERSITY DESIGN-BUILD-FLY

FIRST ISSUED	2/22/2017
DRAWN BY	YUEXING SUN
CHECKED BY	JORDAN THAYER
APPROVED BY	JORDAY THAYER

TITLE

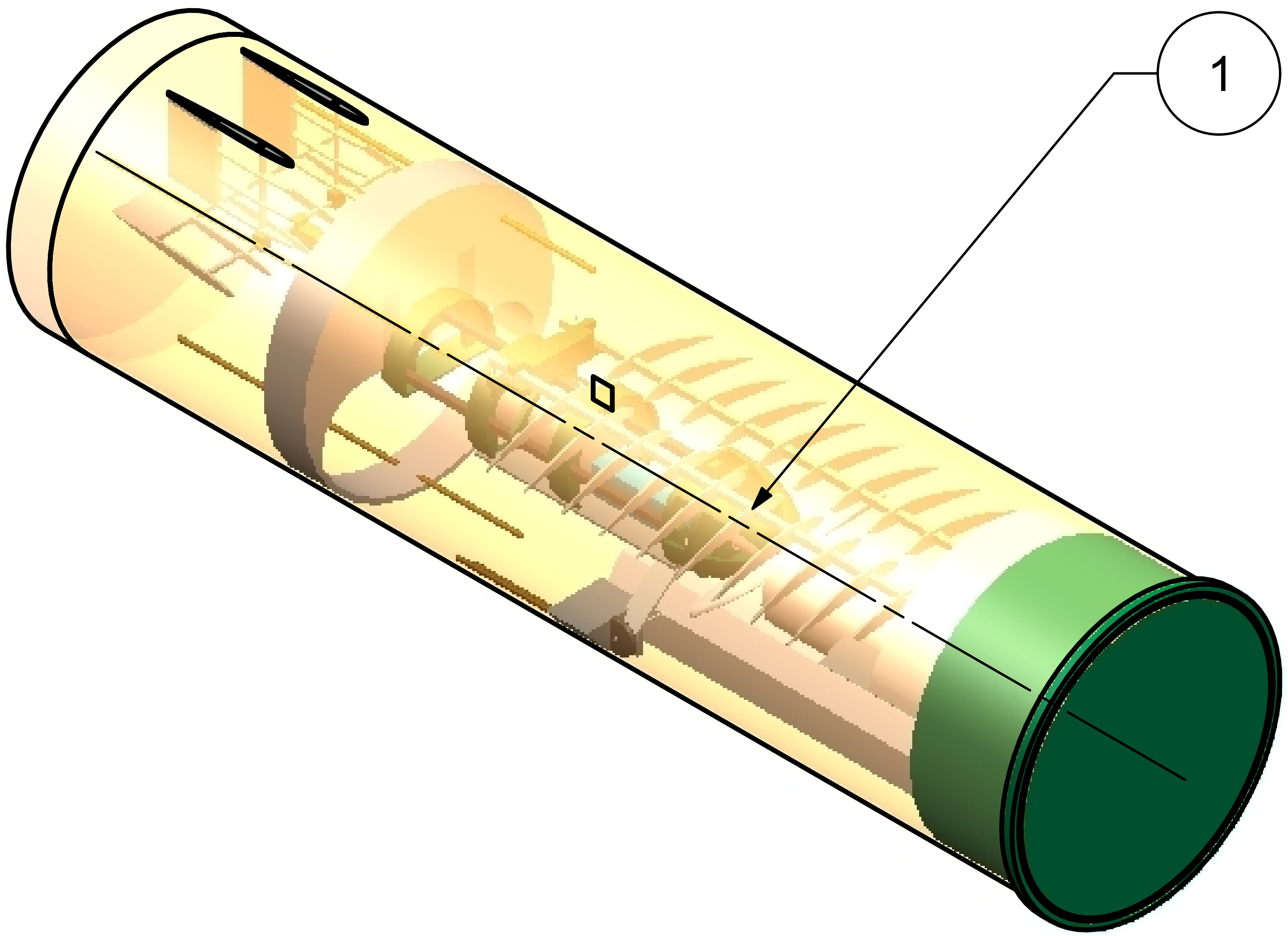
LAUNCH TUBE

SIZE	DWG NO.	SHEET REV
B	LAUNCH TUBE STRUCTURAL ARRANGEMENT	A

SCALE 1:1

SHEET 6 OF 7

	PART	QTY.
1	SPARTY III	1



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	MICHIGAN STATE DESIGN-BUILD-FLY		
FIRST ISSUED	2/22/2017	TITLE	
DRAWN BY	YUEXING SUN		
CHECKED BY	JORDAN THAYER	LAUNCH TUBE	
APPROVED BY	JORDAN THAYER	SIZE B	DWG NO. LAUNCH TUBE PAYLOAD	SHEET REV A
		SCALE 1:1	SHEET 7 OF 7

6.0 Manufacturing Plan

Due to early funding issues, manufacturing of the UAV has commenced much later than expected, beginning after the team expected to be finished. Potential design complications were also brought to light during the finalization of the launch tube design, forcing the team to shift the first UAV optimization phase before the manufacturing of the UAV commenced, to ensure both designs adequately worked together. With both designs finalized and one optimization phase complete, manufacturing has commenced for the team, starting with the 3D printing of the ribs for the UAV fuselage.

6.1 Manufacturing Processes

For selection of manufacturing processes, the team focused on two key parameters: precision and speed. In the past, SpartyWorks has relied on hand modifications following an initial CNC machining process, resulting in many parts being out of specification and a lot of wasted material. On top of a lack of a precise manufacturing process, manufacturing also took months to complete. To combat both of these problems, SpartyWorks set a goal to increase the amount of 3D printing and reduce the amount of hand modifications to nearly zero. CNC machining remains a staple in the manufacturing process, but machining and part tolerances were more carefully considered in the design phase to reduce the amount of wasted material. Along with the benefit of high precision, 3D printing and CNC machining also allow the team to rapidly create prototypes, cutting a process that originally took months to a couple weeks. The 3D printer the team has chosen to use is the Fortus 250mc 3D printer. Benefits of using this 3D printer include high part resolution, large build volume, and the ability to use ABS as the printing material. The CNC mill the team has chosen to use is the Shapeoko2 CNC mill. Benefits of using this CNC mill include availability, large routing area, and compatibility with Siemens' NX 11 manufacturing software, which generates the required g-code for routing based on a precise CAD model.

Fuselage

Since the UAV has to have the ability to absorb any impact force not dissipated by the launch tube, the team determined a stronger material than balsa wood was required. Since using metal in large quantities was determined to be highly unnecessary, CNC milling for most of the fuselage was eliminated from consideration. After investigation of available 3D printers at Michigan State University, the settled on the Fortus 250mc 3D printer for printing most of the components of the fuselage: nose cone, ribs, and airfoil connector. The primary load bearing structures for the fuselage, the spine and side supports, were selected to be carbon fiber by the team early on in the design. Solid square cross-section unidirectional carbon fiber rods were purchased from Rock West Composites based out of West Jordan, UT and cut to length by the team. Spring loaded pins were purchased from McMaster-Carr for the self-locking mechanism in the airfoil connector. Clearance holes are drilled into the payload bay to ensure proper fuselage rib, front landing gear, and rear landing gear locations are achieved during finally assembly. Brass heat-set inserts are melted into the nose cone and fuselage ribs for the payload bay to be screwed in and secured to the UAV.

Airfoil

The airfoil has a large area, so the team determined it would be advantageous to select balsa wood, a lightweight material. In order to produce airfoil ribs in a rapid and precise manner, CNC milling was chosen as the manufacturing process for most of the airfoil, since you cannot 3D print wood. The necessary g-code for the CNC mill is generated from Siemens' NX 11 manufacturing software and translated by the Shapeoko2 CNC mill for routing. The load bearing structures were selected to be carbon fiber early on by the team. Solid square cross-section unidirectional carbon fiber rods were purchased from Rock West Composites based out of West Jordan, UT, cut to length by the team, and holes for airfoil connector pins were drilled out by a drill press.

Empennage

The empennage will be produced in a fashion identical to the airfoil. The ribs of the horizontal and vertical stabilizers will be made of lightweight balsa wood. CNC milling is the chosen manufacturing process that will be used to create the ribs, again due to its rapid and precise production. The load bearing structures were chosen to be consistent with the airfoil load bearing structures: solid square cross-section unidirectional carbon fiber rods purchased from Rock West Composites. The rods will be cut to length by the team.

UAV Assembly

To securely assemble the UAV, a study had to be conducted on the selection of the appropriate adhesive. The team selected epoxy resin to ensure different kinds of materials would be properly bonded together.

Once all of the components for the fuselage are printed, the spine and side supports are epoxied into the nose cone. The payload bay is then screwed into nose cone. The fuselage ribs are slid into the corresponding location set by the clearance holes in the payload bay, along with the wing connector. Once the fuselage ribs and wing connector are in the exact location, epoxy is applied to the spine and supports connection with the fuselage ribs. Spring pins for the self-locking mechanism are loaded into the airfoil connector. The airfoils are then placed inside the airfoil connector and epoxy is applied onto the contact surface between the airfoil spars and the rotating plates of the self-locking mechanism. The spar pins are then loaded into the airfoil connector, securing the rotating airfoils to the UAV. The empennage is then secured via epoxy. At this time, all electronics and the propulsion system are then connected and secured inside the UAV. Once the entire UAV is assembled and tested, monokote is applied to the outside of the UAV, ensuring the UAV will remain aerodynamic during flight.

Launch Tube

Upon or near completion of the UAV, the manufacturing phase of the Launch Tube will start. During that phase, the tube will be ordered to the correct diameter and wall thickness: 12.1 inches and 0.25 inches respectively, as decided in the preliminary design phase, and a length of 90 inches as is standard for the manufacturer, Western Container Corporation. The tube will be cut down to the calculated minimum length of 47 inches required to provide adequate room for the stowed plane configuration and the empennage. After these dimensions are confirmed, and the UAV is measured to confirm that it does fit as expected, two 8” x 12” x 2” polystyrene blocks, one 19" x 13" x 12" polystyrene block, and one sheet of 6” x 6” x 0.25” Sorbothane shock-absorbing material to line critical contact points will be obtained. These blocks and sheets will be cut down to the shapes illustrated in figure 5.2.7 using a hot wire foam cutter. However, the rear rib will be cut thicker than originally designed at first, and slowly chiseled down to a point that allows them to work as intended. This will bring the factor of safety up for the padding. Wooden spars of adequate length to connect these pieces to the tube will also be obtained. Finally, end caps to fit on to the tubes will be 3D-printed with a tight tolerance to the inner diameter of the tube to ensure a secure fit.

Launch Tube Assembly

After the parts have been received and cut to size, they must be assembled. All permanent fits will be bonded with epoxy resin in accordance with the adhesive selection study in table 6.1.2. During assembly, after each polystyrene rib is placed, the UAV will be inserted to test the efficacy of the rib, adjusting the ribs as necessary to ensure the ability of the plane to move in and out with ease. Finally, the end caps will be assembled, one permanently fixed to the rear end of the tube (the end corresponding with the rear of the plane), and the other fitted with layers of polystyrene with a support spar running through the center. These pieces will be fastened together using the same epoxy resin, however, the tube and the front end cap will not be permanently attached, but will rather be constrained during drop with a translational location fit.

6.2 Manufacturing Milestones Chart

Based on the required manufacturing processes for all UAV and Launch Tube components, the team generated a manufacturing milestone chart. The manufacturing milestone is illustrated by figure 6.2.1 below.

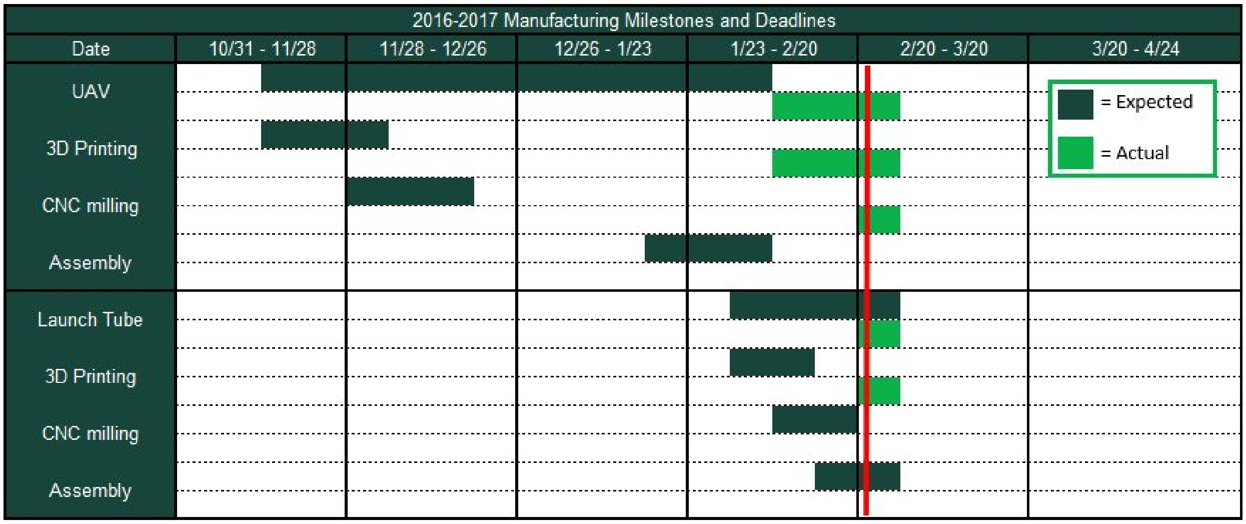

Figure 6.2.1: 2016-2017 Manufacturing Milestones and Deadlines for the UAV and Launch Tube

7.0 Testing Plan

The desired testing objectives set by SpartyWorks are primarily focusing on design validation and estimating mission performance of both the UAV and Launch Tube. Before any flight tests are conducted, the team will go through the pre-flight checklist for safety purposes and conduct several static tests: wing tip test with maximum payload loaded inside, static thrust testing, battery burnout testing, control surface testing, and propeller testing. In order to achieve design validation, short test flights are set to be conducted, to ensure the UAV is properly balanced and stable. The short test flights will simulate hand launched take-off, climbing, banking, and landing. After data is compiled and analyzed by the team, optimization of the UAV is necessary to ensure the potential mission performance is maximized. All three flight missions and one ground mission will be tested prior to competition and compared with our calculated benchmarks to get an estimate of our potential score. The Launch Tube will be shock tested without the UAV inside prior to a simulated ground mission being conducted for design validation.

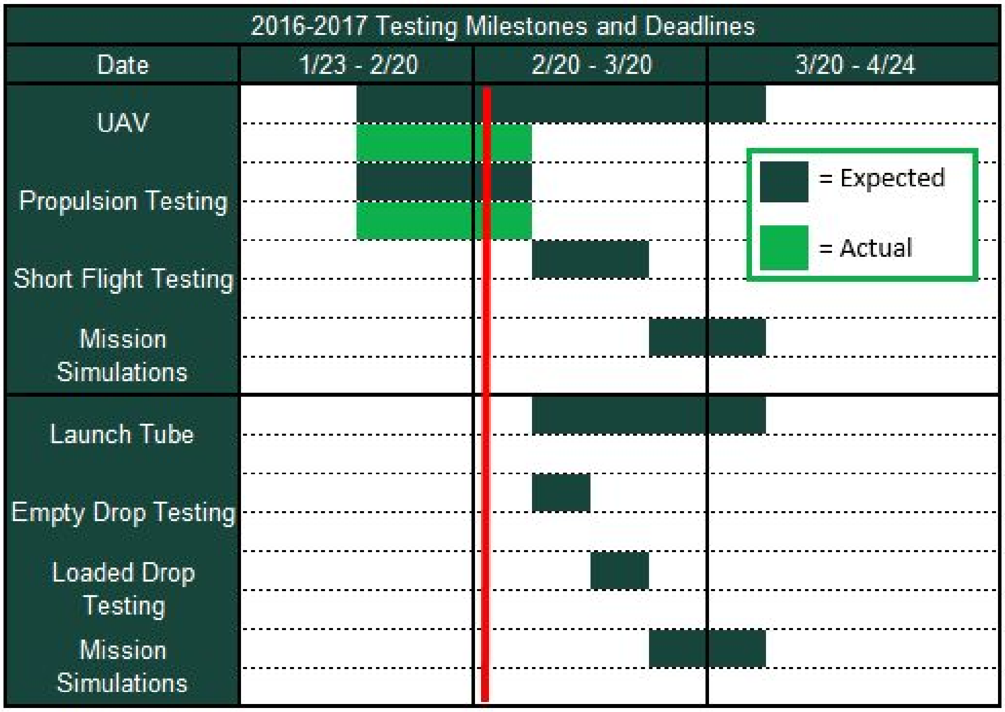

Figure 7.0.1: Testing Objectives Schedule

7.1 Pre-Flight Checks

Pre-flight checks are not only essential for team safety and aircraft safety, but also required to compete in the DBF competition. To increase accountability and safety, the leaders of both the mechanical and electrical sub-teams are tasked with ensuring that their systems and system connections met the pre-flight checks. An immediate shutdown and analysis is performed if cracks, fractures, or irregularities in any part of the system are detected. Table 7.1.1 below displays all of the required checks that must be done prior to flight during both testing and the competition.

Table 7.1.1: Required Pre-Flight Safety Checks

Pre-Flight Checklist		
Component	(Y or N)	Check
General Systems		Receiver battery type is NiCAD or NiMH and not connected to propulsion
		Motor/servos/wheels/landing gear is secured properly
		Control rods are securly attached to control horns
		Control horns are secured to control surfaces
		Control and airfoil surfaces are of adequte flutter and resistance
Propulsion		Propeller commercial availability and mounted properly
		Electric motor is unmodified and bought commercially
		Fuse is connected to all positive battery terminals
		Fuse is securely mounted externally behind propeller
		No bare wires and fully-insulated
Propulsion Battery		Battery connectors are fully insulated
		Commercially bought and visible NiCAD or NiMH
		Shrink wrap over all contact points and solder joints
Tip Test		Weight is under 55lbs
		Students lift aircraft from wingtips without structural damage
		Reasonable CG mark for all possible mission configurations
Transmitter Range		Transmitter works at 2.4GHz and 72Mhz
UAV General		Engine does not work with fuse pulled and all controls work
		At 1/4 power, right roll, left roll, right yaw, left yaw, nose up, nose down, throttle cut-off, and thruttle 1/4
		Throttle closed, full up elevator, full right rudder, full right aileron, and full flaps down when transmitter is turned off

8.0 Performance Results

Static Thrust Test

A static thrust was performed to ensure that the engine and propeller would generate enough thrust to lift the plane. Testing included a 10x6 inch propeller and a 8x6 inch propeller. This test was conducted by attaching the motor with the propeller to a scale. Throttle was applied and results were recorded. The test was successful as the 10x6 propeller will produce a surplus amount of power for our aircraft. Future tests may include other propellers which could increase speed of air to generate more horizontal speed for the aircraft.

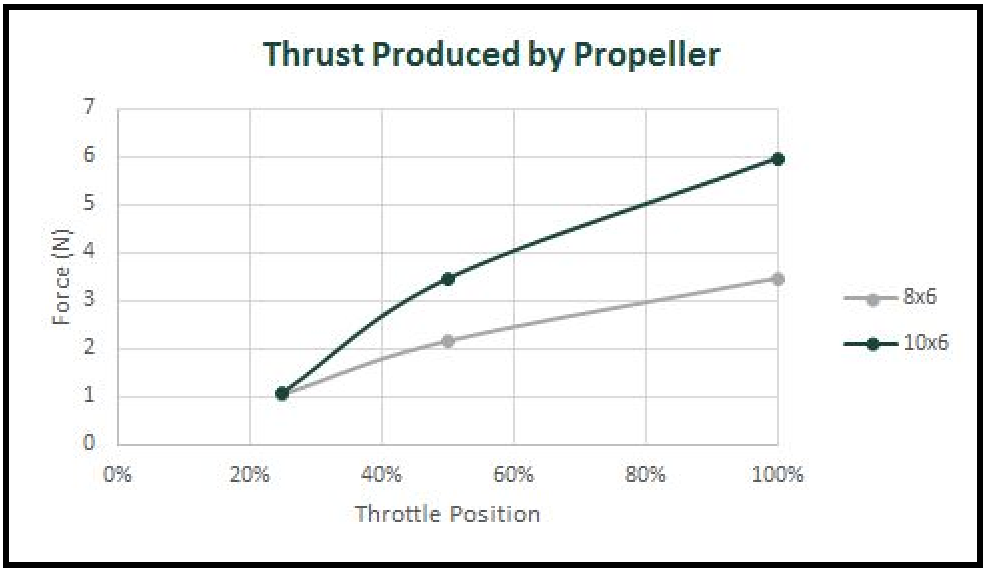

Figure 8.0.1: Static Thrust Test based on propeller size

Battery Runout Test

A battery runout test was performed to ensure the battery would last the required missions. Many more tests will be performed on the battery to determine length. Some of which include variable throttle testing and half throttle testing. These test will be accompanied with voltage monitoring and current draw monitoring of the battery. Test performed at full throttle have been calculated and are shown in graphs below. These tests were conducted with the 10x6 propeller attached to the motor.

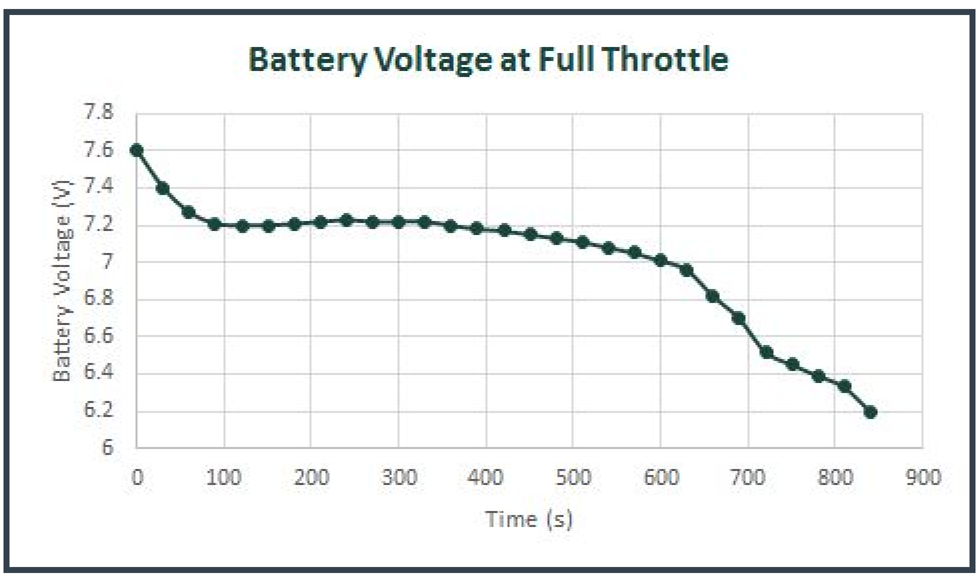

Figure 8.0.1: Voltage Change Results from Battery Runout Test

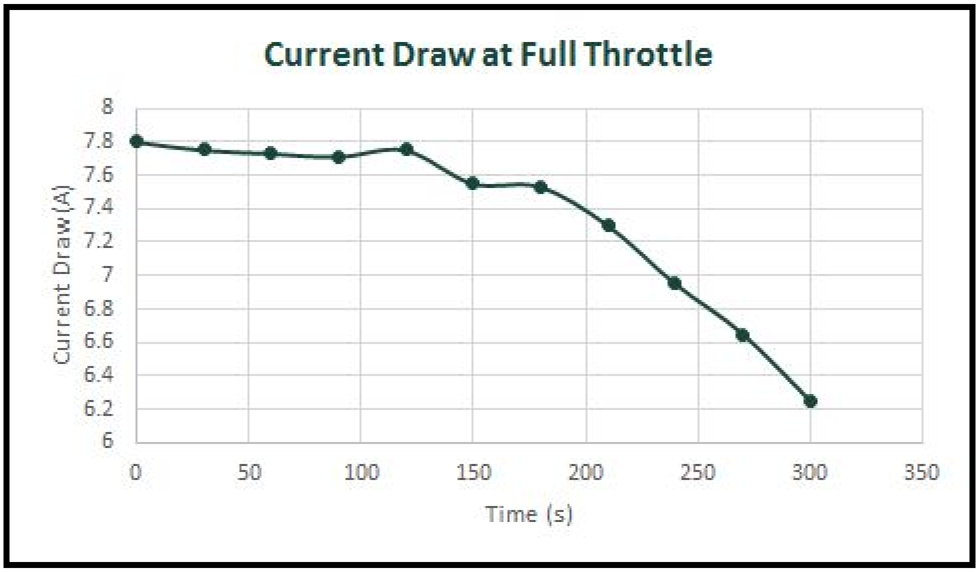

Figure 8.0.2: Current Draw Results from Battery Runout Test

Unexpectedly current was dropping quickly over time in the above test. A possible cause of this rapid current drop is the heat build up in the multimeter, as noticed when touching the input wire. This heat build up would increase resistance in the wires and multimeter circuits, causing less current to flow. Future tests will include monitoring of temperature and use of alternate multimeters.

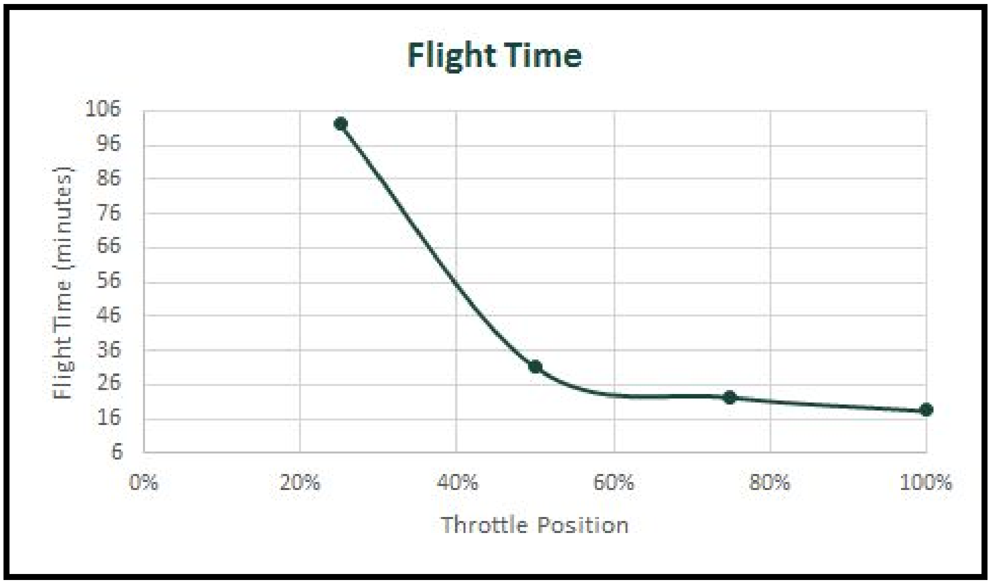

Figure 8.0.3: Flight Time for various throttle positions

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