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# Space Dynamics Laboratory Payload Challenge: Autonomous Water Sampling UAV

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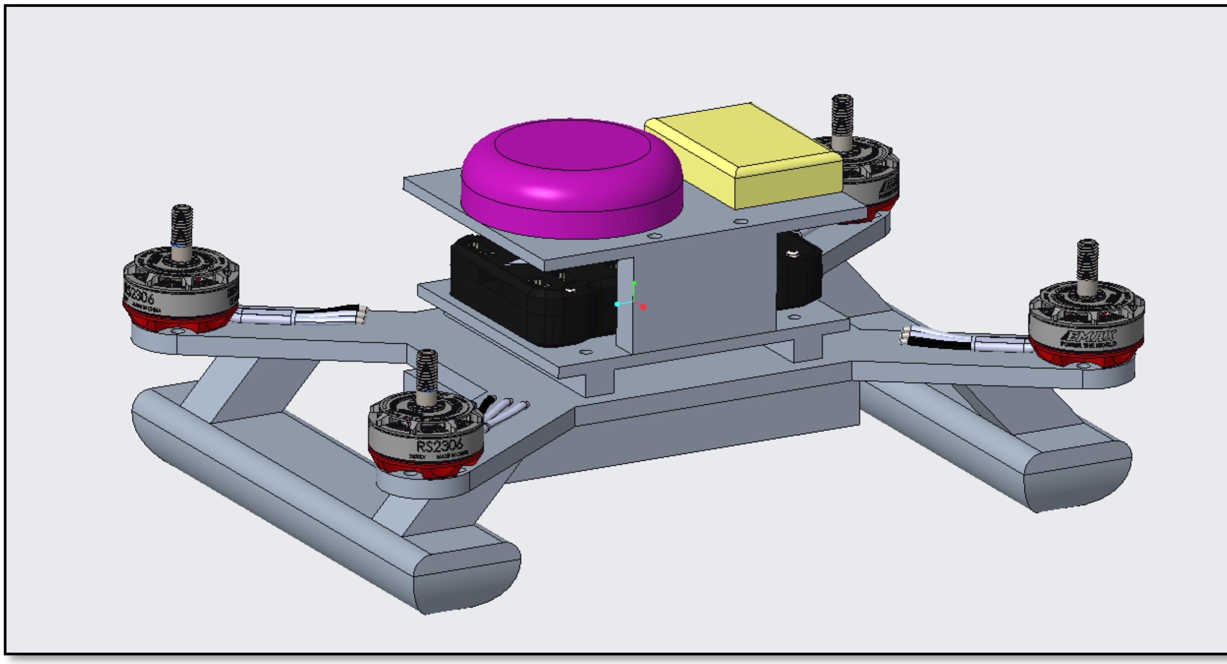


A Subscale Model and Mission Analysis of Flight on Saturn's Moon Titan


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## Executive Summary

The following report has been completed over the course of the Fall 2018 and Spring 2019 semesters at The University of Akron by Joseph P. Stack (Aerospace Systems Engineering), Thomas J. Wheeler (Mechanical Engineering) and Zachary M. Williams (Mechanical Engineering). The purpose of this project was to create a payload system for the Akronauts Rocket Design Team to use at the Intercollegiate Rocket Engineering Competition (IREC) Spaceport America Cup. The Competition as a challenge that is sponsored by Space Dynamics Laboratory specifically regarding payload systems. The challenge in very open-ended and allows student to identify their own scientific experiment and design it to a form that can fit in the launch vehicle.

The team chose to model the experiment for the Senior Design and Honors Research project at UA. The project is an autonomous UAV that deploys from the launch vehicle during descent, flies to a nearby body of water, collects a water sample, and flies back to base camp. This is modeled after a NASA mission planned for 2025 that will send a quadcopter to Saturn's moon Titan. The team scaled down the mission objectives for the sake of prototyping and will focus on the autonomous flight and the sample collection.

Several vehicle options and sample types were considered in the early design phase. Ultimately a quadcopter that can obtain a water sample via a small DC pump and nylon tubing. The UAV will have a 3D printed body with a variety of off-the-shelf components that are compatible with software packages that the team has access to.

## Problem Statement

The 2019 Intercollegiate Rocket Engineering Competition's Payload Challenge has one primary guideline: build a functional, creative scientific experiment[1]. With such a broad topic, the possibilities are endless. The secondary rules of the competition include that it must replace a "boiler plate" ballast, weighing at minimum 8.8 pounds with a 5% margin of error to avoid penalty. It must remain stable and of constant mass inside the launch vehicle until it reaches apogee. It may take any form that the group chooses, however, it may not contain or be constructed with significant quantities of lead or "other hazardous materials." Radioactive materials are only permitted if deemed operationally necessary under the conditions that they are completely encapsulated and are under a 1μC activity limit. The experiment may also not contain any live, vertebrate animals.

In previous years, projects that have won the competition include devices that collect atmospheric samples to evaluate air quality and ejected imaging systems that have meteorological instruments that take live data on ground conditions. For the starting point of this project, the group plans to discuss with industry professionals to develop a device that is unlike anything that has been presented in competition. From there, an initial direction of the project can be determined, and the next steps can begin.

## Brainstorming Conceptual Ideas

To begin the brainstorming process, the team determined what the outcome goals of the project should be. The first goal is to build a working prototype that will compete in the IREC Payload Competition in June 2019. From there, the team investigated what type of scientific experiment would be performed since that is the primary objective of the competition. It was also quickly determined that due to the team's competitive nature, winning the competition was extremely important goal to set for the project. Looking into previous winning projects, a combination of successful functionality and increased style and "wow" points is what would be extremely important to do well in the competition.

The team initially started to brainstorm base idea what would do well in the style and wow factor category. The first base idea the team came up with was to deploy a flying aircraft from the rocket near apogee of the rocket's flight. If accomplished successfully the team decided that it would look very impressive and meet the necessary style factor that the team desired. A secondary base idea the team thought of was a rover system that would deploy from the rocket after landing on the ground. This idea is something that UA rocket team has attempted and had varying success with in the past. Due to the familiarity of the concept, this would be an easier function to accomplish. However, the team also discussed how often this idea was used and determined it would be very difficult to meet the style factor needed to do well in the competition. Also discussed, was a basic fixed probe that would record atmospheric data as the rocket fell from apogee. The goal with this idea would be to experimentally compare atmospheric data at decreasing elevation. Again, this idea was considered more basic, which of course would lead to a higher success rate but a low chance of meeting the style point goals the team is looking for.

From the team's first round of brainstorming base conceptual ideas, the team chose to indulge deeper into the flying aircraft idea discussed previously. With flying aircraft being a very vague visual idea, the team began to tackle more specific methods of flying that could potentially be utilized. After some thought, the following types of flying crafts were determined:

- Plane Flight
- Helicopter Flight
- Quadcopter Flight
- Blimp Flight

Deeper detail discussion for each of these methods begun, but ultimately it was decided that this is an important part of the project that would require much more extensive research. However, these discussions did lead to excitement for the team to want to move forward with setting the base goal of design and building some sort of flying aircraft for the competition.

From this excitement the team turned to their common interest of space travel and research as inspiration for the project. Brainstorming began with researching future NASA missions. A common theme amongst them were research vessels to planetary surfaces on either the moons of Jupiter or Saturn. In the coming years, potential future NASA missions to Europa and Titan made them prime candidates for a subscale replication (could detail full scale plans if funding was available, at least give an overview of actual mission versus the team's scale proposed solution).

Jupiter's moon Europa is of scientific interest due to its abundance of water. By some estimates the icy moon has more water than Earth. Scalability issues include the lack of a substantial atmosphere on Europa, as well as the need to drill through surface ice. Some of this functionality would most likely need to be removed for a subscale payload, thus limiting the similarity and effectiveness of the prototype

Saturn's moon Titan is another candidate. The moon has liquid methane and ethanol lakes, and a very dense atmosphere. This makes the submarine or water vehicle not fully compatible with a typical water submarine. However, the thick atmosphere could potentially allow for a quadcopter or drone flight and delivery of vehicle. (viscosity = 6.5 micro pascals)[2]

With this basic background of future NASA missions determined the team came up with three possible sampling ideas that the team wanted to possibly pursue.

- Soil Sampling
- Water Sampling
- Ice sampling

At this point, the team decided that before more brainstorming for designs of the team's aircraft could continue, some extra research needed to be compiled to keep the project moving.

# Mission Analysis

## Atmospheric Conditions

After selecting a moon and what the device would have to sample, the team began framing what the mission would look like if approaching the problem for Titan. If given no budgetary constraints and sizing constraints of a full-scale interplanetary rocket, the group would need to design a vehicle capable of traversing Titan's atmosphere[2]. These conditions are as follows:

- -180°C Surface Temperature
- Gravity of 1.35m/s$^2$ (14% of Earth)
- Atmospheric density of5.39 kg/m$^3$

- Dynamic viscosity of 6x10$^{-6}$ Pa-s

The group then proceeded to prove that flying on this planetary body would make sense. Based on the properties given above, the relative gravity, and relative coefficients of lift and drag were calculated.

The relative gravity is a simple proportion problem of:

$$Relative\ Gravity = \frac{Gravitational\ Acceleration_{Titan}}{Gravitational\ Acceleration_{Earth}}$$

$$Relative\ Gravity\ on\ Titan = \frac{1.35\ \frac{m}{s^2}}{9.81\ \frac{m}{s^2}} = Titan's\ Gravity\ is\ 13.8\%\ of\ that\ on\ Earth$$

This proves that in terms of overcoming gravity, it will be easier to fly on Titan. Less lift from propellers or wings to take flight will need to be generated. This then led the group to question the ability to generate lift in the atmosphere.

Coefficient of Lift:

Though it will require less lift to take flight, the team found it necessary to determine if it is easier or harder to generate lift relative to Earth based on the basic fluids model:

$$Lift\ Force = .5 * Lift\ Coefficient * density * Velocity^2 * Area$$

The team assumed that the areas and velocities of the propellers would be equal and that it is necessary to lift a 1kg object.

On Earth:

$$mass * gravitational\ acceleration = .5 * Lift\ Coefficient * density * Velocity^2 * Area$$

$$1kg * 9.81\frac{m}{s^2} = .5 * Lift\ Coefficient * 1.225\frac{kg}{m^3} * Velocity^2 * Area$$

$$9.81\frac{kg * m}{s^2} = .6125\frac{kg}{m^3} * Lift\ Coefficient * \left(Velocity\ \left(\frac{m}{s}\right)\right)^2 * Area\ (m^2)$$

$$\frac{16.016}{Velocity^2 * Area} = Lift\ Coefficient$$

On Titan:

$$mass * gravitational\ acceleration = .5 * Lift\ Coefficient * density * Velocity^2 * Area$$

$$1kg * 1.35\frac{m}{s^2} = .5 * Lift\ Coefficient * 5.39\frac{kg}{m^3} * Velocity^2 * Area$$

$$1.35\frac{kg*m}{s^2} = 2.695\frac{kg}{m^3} * Lift\ Coefficient * \left(Velocity\ \left(\frac{m}{s}\right)\right)^2 * Area\ (m^2)$$

$$\frac{0.5009}{Velocity^2 * Area} = Lift\ Coefficient$$

$$\frac{.5009}{16.016} = .031 \approx 32x\ easier\ to\ generate\ lift$$

Under the assumptions made of equivalent areas and velocities, the lift coefficient on Titan would be approximately 3.1% of that on Earth. This means it should be around 32 times easier to generate lift on Titan.

## Mission Vehicle Design

The team would create a device capable of taking liquid samples from the methanol lakes on the surface and run a multitude of analyses on it. It would ideally test for physical properties such as density, it would measure pH, it would perform mass spectrometry with a small onboard unit, as well as have an onboard module to test for anaerobic bacteria. Given the immense freezing temperatures of space and Titan, batteries for a power source would not be much of an option. Solar panels also were ruled out due to the uncertainty of the availability of absorbable light on the surface. The most feasible power source would thus be a radioisotope thermoelectric generator. These take small masses of radioactive materials and generate power from the radiation.

Given that there are strong budgetary constraints and needing to fit the prototype in a 6” diameter rocket, the team will not be able to capture the entire scope of the mission in this prototype. In this instance, the team will be able to ensure flight can occur with the different atmospheric properties and thus make a device capable of flying autonomously by GPS on Earth. The group will also demonstrate the collection of a liquid sample.

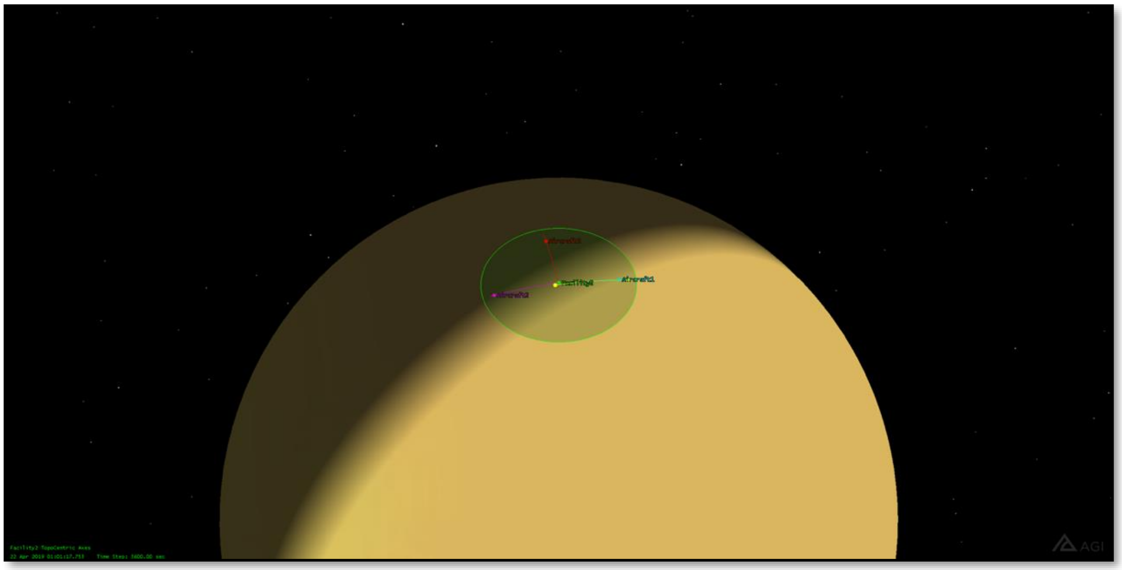


*Figure 1 - Potential aircraft trajectories to various lakes plotted on Titan's surface*

A 2004 mission to Titan with a joint venture of NASA and the European Space Agency sent a reconnaissance probe to land on the surface of Titan and recorded its 3 hour long descent to the surface through dense clouds. The spacecraft landed in what appeared to be a runoff area from nearby lakes. Using the coordinates of the Huygens probe landing site, the team plotted several aircraft trajectories over Titan's surface in Systems Toolkit that could lead to nearby lake beds and would take advantage of an already pre-established landing site.

During the definition of this specific project and the selection of components, the team was also working on a similar and simpler drone concept for the NASA University Student Launch Initiative. During that, the team gained valuable experience in drone design, assembly, the physical and digital interfaces between components, and the software used to program and control drones. Keeping most of the components and weight on or as close to being on a single plane that is the same plane as the propellers will allow for the most stable flight in the sense that it will be less likely to flip over. This will also allow for the simplification of the assembly process. The team also learned about how many of the components interact. One of these things include connecting the receiver to the flight controller and pairing to the Radio Transmitter. That required soldered connections and modification of firmware on receivers and the radio so that they are compatible.

During the competition cycle, the team familiarized themselves with a variety of software packages used to setup, customize and tune drones. These include, BetaFlight, CleanFlight, BLHeli, and Mission Planner. Betaflight and CleanFlight can be used interchangeably to reset the accelerometer and gyroscope, test motors, tune the system with a PID controller, set fail safes on the radio with switch inputs, and re-map the channel inputs from the radio changing the channel order of the throttle, pitch, yaw, and roll. The team also learned how to integrate functional electronics, including servos and other motors, into the flight electronics. This will be very useful knowledge when attempting to interface the pump motor for the water sample collection.

## Subscale Model

Having conducted mission planning and analysis of a full scale UAV, including theoretical calculations about the potential of flying on Saturn's moon Titan, it was time to come back down to earth and focus on the space dynamics lab competition. For the competition, the team will design and build a working prototype of a UAV that will fly on earth. From discussions about the future NASA missions and flying on Titan, the team decided to model a scaled down version of what might be built for this mission.  Some functionality will be lost in a scale model due to size constraints and different environments. During the design process, the mission was modeled as closely as possible to the potential full scale within the requirements of our subscale launch vehicle and platform. Design differences between the two are discussed at more length in Conclusions and Discussions.

# Conceptual Design

To begin the conceptual design phase, the team brainstormed different constraints that the team would be held to along the course of the design. Most of the constraints are due to nature of the rocket that the final product must sit in for launch. The first, and probably most important, constraint the team examined is the size of the body tube of the rocket, which is a 6-inch ID tube. Secondly, the drone needs to be as stable as possible in the air. This is accomplished by spreading out the motors and propellers as far apart as possible, as learned from previous projects. The developed and derived requirements for the design are split into general project requirements and final vehicle requirements.

## Project Requirements

*Table 1 - Project Requirements*

| **Project Requirements** | | | | |
|---|---|---|---|---|
| **Requirement Number** | Requirement | Verification Method | Verification Plan | Status |
| **1.1** | Team will have a faculty advisor or co-advisor in the ME Department | Demonstration | Senior Design title form requires project advisor to sign off | Verified with submission of project title form |
| **1.2** | Team will have weekly meetings with faculty advisor | Demonstration | Progress Report Form Submitted by team in March signed by Faculty Advisor | Verified with submission of progress update form |
| **1.3** | Team will adhere to project deadlines given by both the College of Engineering and Akronauts Rocket Design Team | Demonstration | Continually verified until completion of project | All Deadlines have been met |
| **1.4** | Final Design Report will be submitted in PDF format and adhere to all Akronauts formatting standards | Demonstration | Submitted report will be inspected and verified by Chief Engineer per the Akronauts team constitution | Verified with submission of final report |

## Vehicle Requirements

*Table 2 - Vehicle requirement*

| Vehicle Requirements | | | | |
|---|---|---|---|---|
| **Requirement Number** | Requirement | Verification Method | Verification Plan | Status |
| **2.1** | UAV design, manufacturing, and assembly will adhere to Akronauts standard operating procedures | Inspection | Team Safety Officer and Chief Engineer will be present and active in all phases of project development to verify | Verified continually until completion of project |
| **2.2** | UAV assembly will fit within 6-inch ID fiberglass airframe | Inspection | All Senior Design Projects developed by the design team are approved by Chief Engineer | Verified during Prototyping stage |
| **2.3** | UAV will be retained within the airframe of the rocket using a fail safe retention method | Testing | A test flight will verify the payloads retainment system | Verified with test flight scheduled for late May |
| **2.4** | UAV will fit within a CubeSat standard 10 x 10 cm cross section | Testing | Models have been developed containing sections of body tube to check for potential interference | Constantly verified as new models are created and updated |
| **2.5** | UAV will be a multirotor quadcopter design | Demonstration | Team will verify design of UAV with Chief Engineer | Verified with completion of conceptual design |

Concept Brainstorming

Flight Method:

Plane

Pros:

- Long flight time due to only one motor required for flight

Cons:

- Complex design required, especially to fit inside rocket body
- Less controllable
- Very difficult to land for sample and take off again

Helicopter

Pros:

- Possible Long flight time due to only one large motor required for flight
- Smaller design possible to fit within body tube constraints

Cons:

- Complex design required, especially to fit inside rocket body
- Large motor required to produce entire lift required

Quadcopter

Pros:

- Very stable in flight due to the use of 4 even spread-out motors.
- High availability commercial components, online forum help, and flight control software due to the established market of DIY quadcopter.

Cons:

- Small size of space in rocket will limit the spread of the motors which can affect stability.
- High variance in cost of components.

Blimp

Pros:

- Long flight time and high payload capacity due to the method of lift
- Unique idea niche

Cons:

- Very slow lateral movement
- Limited personal knowledge and existing information on methods of control could lead to difficulties down the road.
- High cost possibility due to the very custom design that would be required and unique materials.

Due to the availability of commercial components and online forum and software support, the team chose to develop a quadcopter. This is also the most feasible option for the space constraint within the launch vehicle. The plane was eliminated due to size constraints. The helicopter was eliminated due to the aerodynamic complexity. The blimp was eliminated due to the complexity of inflation as well as difficulty of navigating through winds.

Sampling Method:

Soil Sample Drilling

Pros:

- Easily accessible at launch location. High feasibility
- GPS location does not have to be as precise
- Minimal travel distance compared to finding natural body of water
- Can land while taking sample to conserve battery

Cons:

- Inconsistency in ground hardness and therefore ease of drilling. Lowers chances of success.
- Added weight for mechanics of drilling device/reverse thrust
- Planet does not have a flyable atmosphere

Ice Sample Drilling

Pros:

- Very relatable to future NASA mission scope

Cons:

- Complex tooling required adding weight and cost to design
- Availability of ice very limited at competition

Liquid Sample-Titan

Pros:

- Lighter Sample taking machinery
- Could set up man-made water pool
- High wow factor if possible, to accomplish sample from natural body of water
- Planet has flyable atmosphere

Cons:

- Potentially lengthy flight to find natural body of water (drift dependent)
- Very precise location needed to take sample from set up pool

To better organize the brainstorming conducted above the team put together a simple morphological chart. This chart allows us to connect the different solutions that perform the sub-functions of the design into different total concepts that can be analyzed as entire solutions to meet the team's desired design criteria.

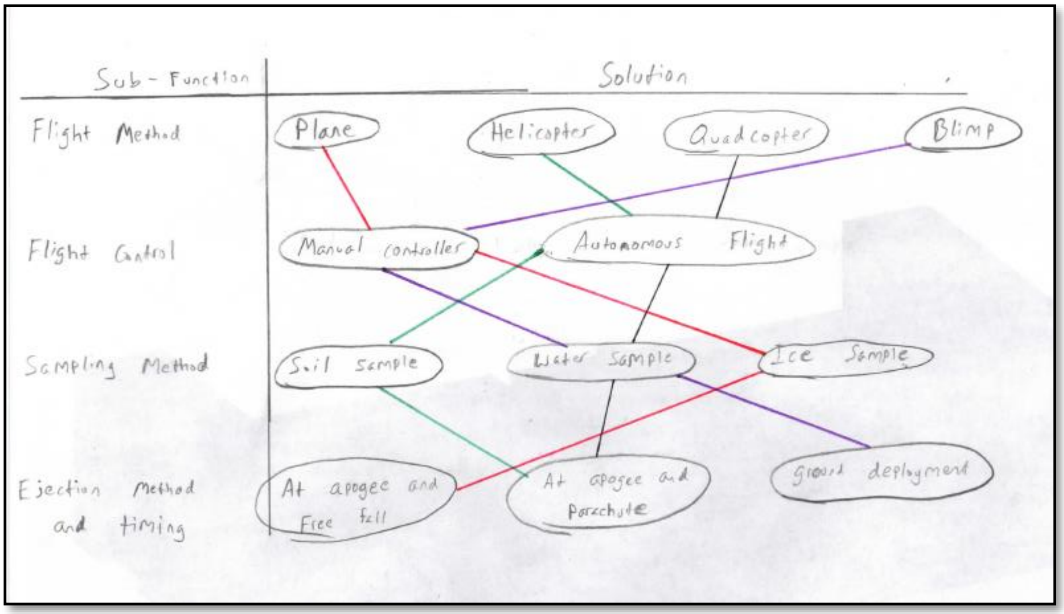



*Figure 2 - Morphological chart*

After completing the morphological chart shown above, the team needed a way to score each of the conceptional solutions the team had come up with. To do this, an objective tree was put together. The objective tree included 3 main categories: cost, functionality, and ease of build and assembly. After choosing these categories each was weighted based on the importance of each to the team's final product. Next each category was then divided further into sub-categories, with each of these also getting weighted scores based on the importance. Cost was broken down into manufacturing cost and the cost of off-the-shelf components. Ease of build and assembly was split into hardware and software assembly. Finally, functionality was broken down into size/weight, stability, flight time, and precise controllability. The final objective tree the group came up with is shown in figure 3.

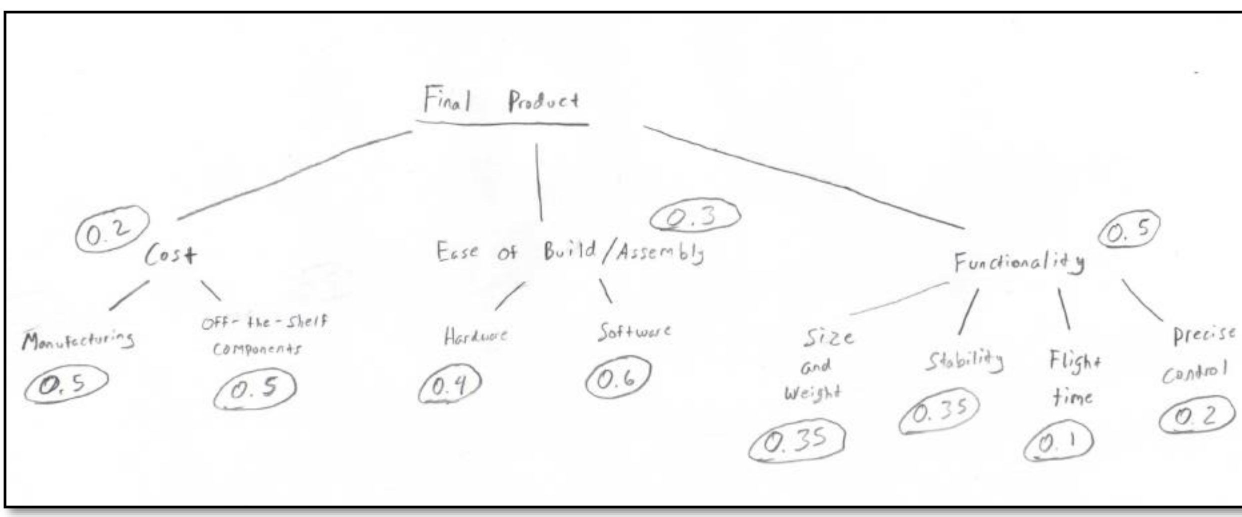



*Figure 3 - Objective tree*

Combining the weighted scores from the objective tree and morphological chart, a decision matrix was put together to score each of the the team's solutions the team had come up with. After

organizing each of the calculated overall weights of subcategories from the objective tree, each solution was scored in each category of the decision matrix. Scores are given based on an 11-point (0-10) scale. Results of the scoring are shown in the decision matrix shown in Table 3. Ultimately, this decision matrix will be a main component used to decide on which of the team's conceptual options the team will move forward with to the embodiment and detailed design phases.

| **DECISION MATRIX** | | Plane | | Blimp | | Quadcopter | | Helicopter | |
|---|---|---|---|---|---|---|---|---|---|
| Evaluation Criteria | Weight Factor | Score | Resultant | Score | Resultant | Score | Resultant | Score | Resultant |
| Manufacturing Cost | 0.1 | 3 | 0.3 | 2 | 0.2 | 4 | 0.4 | 3 | 0.3 |
| Component Cost | 0.1 | 4 | 0.4 | 2 | 0.2 | 7 | 0.7 | 8 | 0.8 |
| Assembly Hardware | 0.12 | 2 | 0.2 | 2 | 0.2 | 7 | 0.7 | 6 | 0.6 |
| Software | 0.18 | 2 | 0.2 | 0 | 0 | 8 | 0.8 | 8 | 0.8 |
| Size/weight | 0.175 | 1 | 0.1 | 7 | 0.7 | 6 | 0.6 | 7 | 0.7 |
| Flight Stability | 0.175 | 7 | 0.7 | 8 | 0.8 | 9 | 0.9 | 4 | 0.4 |
| Flight Time | 0.05 | 8 | 0.8 | 8 | 0.8 | 6 | 0.6 | 5 | 0.5 |
| Precision of Control | 0.1 | 5 | 0.5 | 0 | 0 | 9 | 0.9 | 6 | 0.6 |
| | | **Total:** | 3.2 | **Total:** | 2.9 | **Total:** | 5.6 | **Total:** | 4.7 |

*Table 3 – Decision Matrix*

The results of the decision matrix show that the quadcopter solution scored the highest overall score. The quadcopter will utilize autonomous flight control, a parachute for ejection at apogee, and will sample water. Analyzing the table, the team scored this option very high in the assembly hardware and software category, which are both highly weighted overall. The high scores relate to the availability of many off-the-shelf components and several options for flight control software due to the established market for DIY quadcopter drones. This solution also scored very high in the flight stability, another category that was weighted importantly. This is due to the use of the team's motors spread apart with most of the weight concentrated in the middle of the body. This nature of quadcopters also led to a high score in precision control where this option again scored very high. After this analysis, the group put some more thought into the other options and why the team did not score them as well. Overall, the plane was eliminated due to size constraints. The helicopter was eliminated due to the aerodynamic complexity. The blimp was eliminated due to the complexity of inflation as well as difficulty of navigating through winds. So, with a unanimous decision, the team chose to move forward with the quadcopter as the team's preferred concept.

Due to the many constraints that were determined earlier, the team began some basic drawings of the team's quadcopter concept to determine a visual for the final goal of the product. With the two main constraints counteracting the size of the drone, this visual was very important to get early on to determine the plausibility of success. The team began with a couple of basic hand sketches to determine the approximate size body the team could fit within the tube. As seen in the 2D top view sketch in Figure 5 below, by spreading the motors out to the corners of a 6-inch square the team can increase the

distance from motor to motor. This will allow for increased stability. Then by manually aligning the propellers parallel to each other, the body would still be able to fit inside the body tube.


*Figure 4 - Rocket body tube cross-section area*

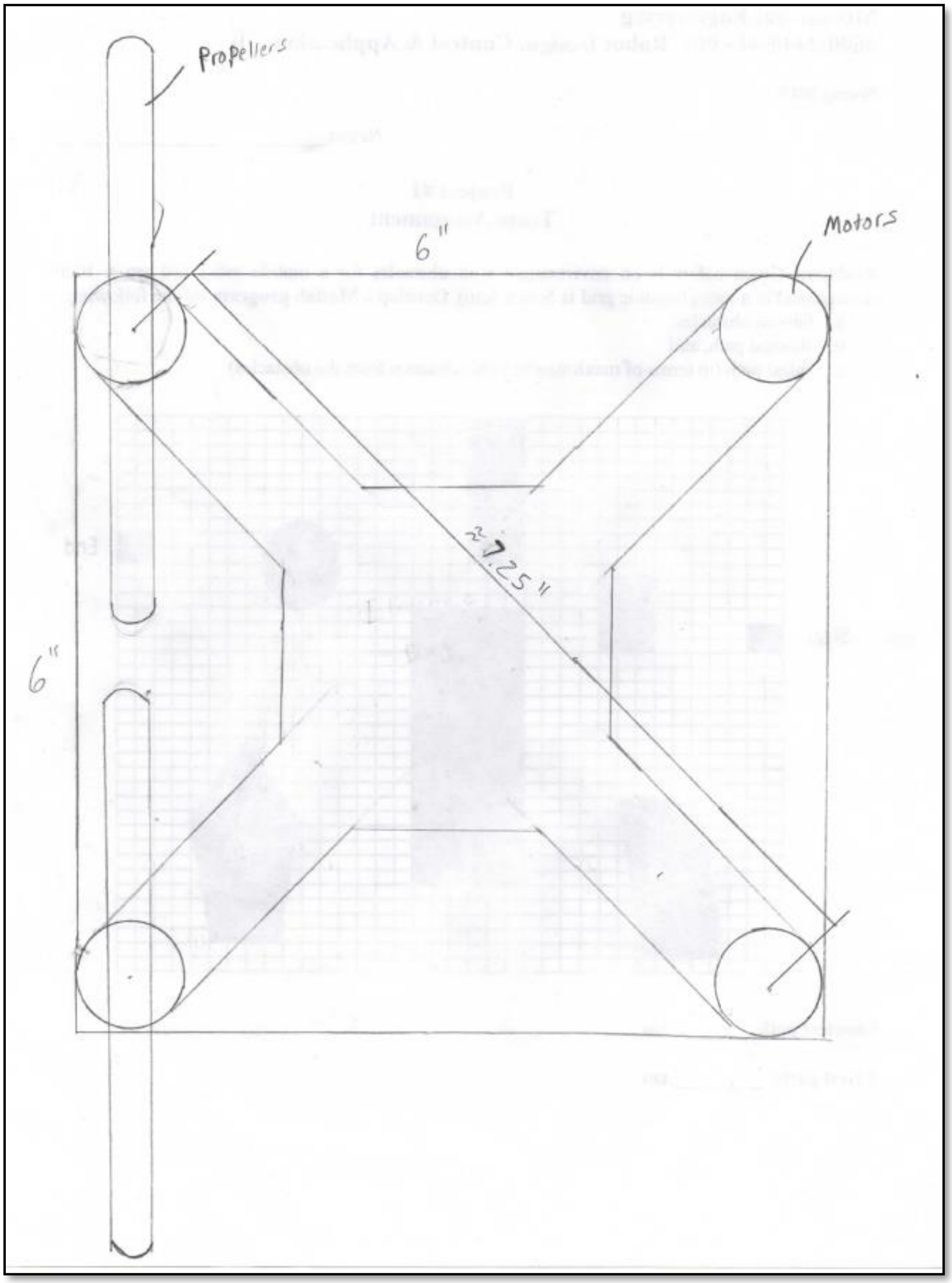



*Figure 5 - Top view concept sketch*

While the hand sketches provided a good start in visualizing a beginning design, the team decided the next step was a start a basic 3D model using SolidWorks. The 3D model would allow for precise measurements correct scaling, and an easy interference check with a modeled section of body tube. Beginning from the sketch in Figure 5, the model shown in Figure 6 was produced. Without any idea of how much space the electronics of the drone would take up, the bay in the center of drone is

sized arbitrarily. One thing this model really helped convey was that the body design would need to be very precise. Therefore, it confirmed that 3D printing would be by far the best route to use when going about manufacturing. This was also a good opportunity to begin to understand the approximate thickness the body would need to be to be strong enough for the intended weight of the overall product. Setting the team's goal to be under 500 grams, the team approximated that around 5-8mm thickness of the arms. This would retain enough strength not to deform under the load of the spinning motors, while keeping the weight of the 3D printed body relatively low. These thicknesses will be revisited when deciding on the chosen 3D printing material later in the project. Finally, the last this the team examined using the concept model is how closely it would fit within the tube. Due to the height of the body thickness and motors that was not accounted for in the hand sketched, the width of the body needed to be cut down slightly to fit without interference. Without having yet chosen the motors that would be used, these dimensions are all approximated. However, by reducing the width by just a few millimeters, the team easily fit the model within the confines of the body tube as seen in Figure 7.

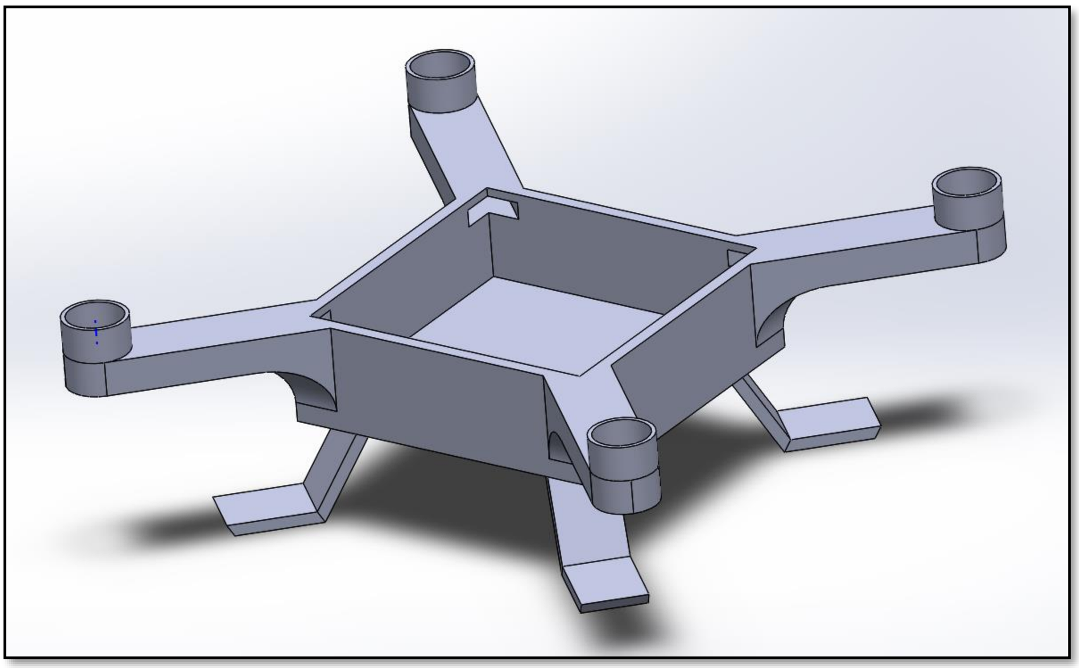


*Figure 6 - First concept model of quadcopter*

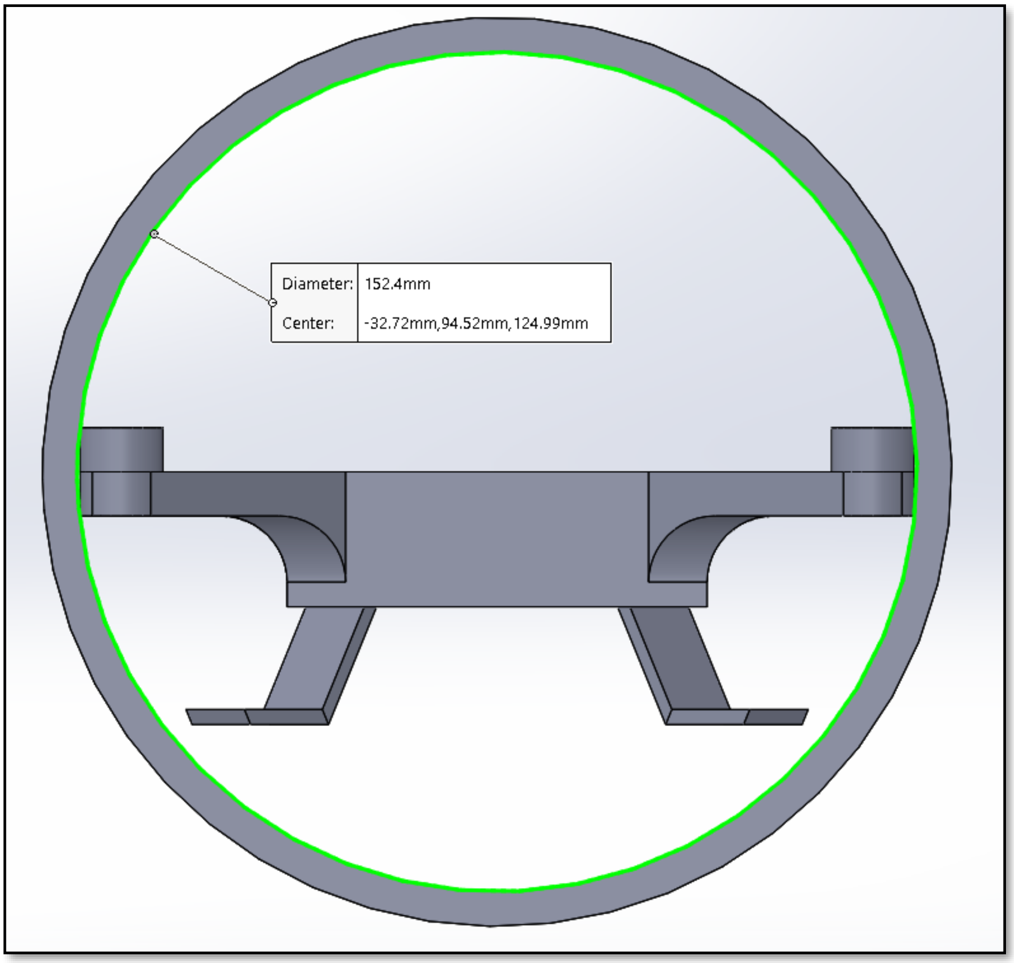



*Figure 7 - Visualization of quadcopter in body tube*

# Embodiment Design

Listed and discussed below are off-the-shelf components

## Flight Controller

The group began looking at electrical components by doing base research on autonomous drones people have made on a variety of online forums. From that research, the group found that the two best options for flight controllers were the 'ArduPilot' by Arduino and the Pixhawk by Auterion. Both products are similar in cost, so the group began to compare functionalities and support. It was determined that the Pixhawk has an easier setup process in terms of connecting other components. It also has more support online for troubleshooting as the Ardupilot is not supported by the most recent updates of the MissionPlanner autopilot software the team plans to use.

## Electronic Speed Controls

The group also looked at a variety of electronic speed controls. Based on the research the group had done on motors it was determined the project would need a 30-amp speed control for each motor. There were a variety of options broken into essentially two groups. There are 4-in-1 speed control plates that all fthe team's motors solder on to. The other option is 4 individual chips that go to the flight

controller from an individual motor. After gaining some experience from building a separate drone, it was determined that issues would be easier to troubleshoot problems with individual parts as opposed to a single chip. The group selected 4 ESC's that have pre-soldered leads so that there was less of a risk of the joints breaking. The industrial solders are significantly stronger than the ones the team can make in the university workspace. The team decided on the Luminiere 30A 32bit Silk ESC.

## Receiver

The team will need the greatest range it can get within an acceptable price range. The standard 2.4GHz frequency that most drones use is not enough as its maximum range is approximately a mile or 2km. It is possible though to take a 2.4GHz radio controller like the FrSky Taranis X9D that the team has and add an adapter that takes the signal down to the 900MHz range. The 900MHz range would allow for communication with the drone up to 10km. The team found a pack that comes with that adapter and a receiver called the X9R slim receiver. The combo comes at a very affordable cost and the receiver is significantly smaller and lighter than most other receivers on the market such as the X8R the team used on a different project.

## Propellers

The diameter of the propellers has been the limiting factor for overall vehicle  size. This means that the size of the team's propellers is very limited. Even before having a final body design, knowing that the maximum inner diameter of the rocket body tube is 6 inches, the team know that the motor to motor dimension must be just under that. So, the two propellers cannot interfere with each with just under 6 inches of space between their rotating centers. Ideally the design would be able to utilize a 5-inch-long propeller to maximize lift, however after going through the initial stages of the design, it was determined that there would not be enough clearance between the adjacent propellers while spinning. Therefore, the team determined that a 4" propeller blade could be used without having interference issues. Having determined the required propeller size, research was conducted and the HQ4045BN propeller was chosen to move forward with in the project.

## Battery

The battery was chosen based of the following criteria: Capacity (mAh), size, weight, and compatibility with electronics. Due to previous development on another drone project, the team had a good idea as to what capacity to look for in a battery for this scaled-up drone. The acceptable range was deemed to be between 1500 and 2500 mAh. The battery also had to be compatible with the electronics. All specifications call for a 3 cell 11.1 Volt battery. From those two specifications the group was then able to narrow down to a 1500, 1800, and 2250 mAh battery. Weights and dimensions were then compared, and it was determined that the 1800 mAh battery would provide the optimal flight time at it's given capacity and weight as well as fitting well on the drone itself.

## Motors

Motor type and size will depend on several variables including the chosen power source, weight of the body, and the size of the propellers. The goal is to choose the most efficient motor and propeller combination to produce the most lift using the least power. Because the overall size of the drone limits the propeller size to the chosen HQ4045BN propellers, the team is limited to a motor size that effectively works with this propeller size. Larger propellers provide more lift at lower speeds but also create increased drag requiring more torque from the motor. Smaller propellers create less drag but

must spin faster to obtain lift. Brushless motors were chosen to be used for this project. Typically, the larger the motor is, the more torque they create, however, larger motors usually have a lower kV rating. A motor's kV rating is the number of revolutions per volt supplied to the motor. Therefore, larger motors require more power to rotate at higher speeds. On the other hand, smaller motors have much higher kV ratings but of course create less torque than the larger motors. Because of these characteristics, large propellers are typically combined with large motors, and smaller propellers are used with small motors. The HQ4045BN propeller is a mid-sized propeller, meaning a mid-sized motor should be chosen.

After researching many motor sizes, a 20-22mm diameter motor with a height of 4-8mm and a kV rating of 1800-2600 would be the most efficient motor sizes used with the chosen propeller. Next, different brands and slightly different sizes needed to be analyzed and compared to find the most efficient motor at the right price. Most manufactures test their motors with several propeller sizes at different power inputs to see the thrust and speed created at certain inputs. Below are several charts showing thrust statistics from several different motors as tested by the manufacturers. Although the manufactures test their motors with multiple propeller sizes, none of the products the team examined were tested with the exact HQ4045BN propeller the team previously chose. As a result, the team used the common HQ5045BN propeller that was tested by all the manufactures listed below, as it is the most comparable size for the team's application. Many other motors were examined, and the team narrowed the choices down to three different Emax motor models: RS2205-2300KV, RS2306-2400KV, and RS2306-2700KV. Then, two T-motor models: F40 2300KV and 2600KV. The manufacture's motor spec sheets for these models are all available in the appendix[5,6].

| Motor Type | Voltage (V) | Propeller | Current (A) | Thrust (G) | Power (W) | Efficiency | Speed (RPM) |
|---|---|---|---|---|---|---|---|
| RS2306-2400KV | 12 | GF5050 Tri-blade | 1.1 | 75 | 13.20 | 5.68 | 6250 |
| | | | 3.1 | 177 | 37.20 | 4.76 | 9400 |
| | | | 5.1 | 262 | 61.20 | 4.28 | 11160 |
| | | | 7.1 | 332 | 85.20 | 3.90 | 12440 |
| | | | 9.1 | 410 | 109.20 | 3.75 | 13810 |
| | | | 11.1 | 472 | 133.20 | 3.54 | 14840 |
| | | | 13.1 | 540 | 157.20 | 3.44 | 15900 |
| | | | 15.1 | 604 | 181.20 | 3.33 | 16710 |
| | | | 17.2 | 660 | 206.40 | 3.20 | 17550 |
| | | | 19.1 | 719 | 229.20 | 3.14 | 18330 |
| | | | 21.1 | 770 | 253.20 | 3.04 | 19080 |
| | | | 23.1 | 825 | 277.20 | 2.98 | 19830 |
| | | | 25.1 | 870 | 301.20 | 2.89 | 20580 |
| | | | 27.1 | 925 | 325.20 | 2.84 | 21090 |
| | | | 29 | 958 | 348.00 | 2.75 | 21470 |
| | | | 30.1 | 984 | 361.20 | 2.72 | 21780 |
| | | T5045 Tri-blade | 1 | 71 | 12.00 | 5.92 | 6320 |
| | | | 3.1 | 182 | 37.20 | 4.89 | 9950 |
| | | | 5.1 | 271 | 61.20 | 4.43 | 12080 |
| | | | 7.1 | 357 | 85.20 | 4.19 | 13850 |
| | | | 9.1 | 425 | 109.20 | 3.89 | 15170 |
| | | | 11.1 | 496 | 133.20 | 3.72 | 16350 |
| | | | 13.1 | 562 | 157.20 | 3.58 | 17440 |
| | | | 15.1 | 629 | 181.20 | 3.47 | 18490 |
| | | | 17.1 | 693 | 205.20 | 3.38 | 19330 |
| | | | 19.1 | 755 | 229.20 | 3.29 | 20210 |
| | | | 21.1 | 816 | 253.20 | 3.22 | 20950 |
| | | | 23.1 | 865 | 277.20 | 3.12 | 21550 |
| | | | 25.9 | 922 | 310.80 | 2.97 | 22380 |
| | | HQ5045 Propeller | 1 | 60 | 12.00 | 5.00 | 6450 |
| | | | 3.1 | 161 | 37.20 | 4.33 | 10100 |
| | | | 5.1 | 245 | 61.20 | 4.00 | 12150 |
| | | | 7.1 | 321 | 85.20 | 3.77 | 13680 |
| | | | 9.1 | 388 | 109.20 | 3.55 | 15060 |
| | | | 11.1 | 448 | 133.20 | 3.36 | 16350 |
| | | | 13.1 | 512 | 157.20 | 3.26 | 17370 |
| | | | 15.1 | 575 | 181.20 | 3.17 | 18350 |
| | | | 17.1 | 630 | 205.20 | 3.07 | 19200 |
| | | | 19.1 | 686 | 229.20 | 2.99 | 20010 |
| | | | 21.1 | 742 | 253.20 | 2.93 | 20640 |
| | | | 23.1 | 786 | 277.20 | 2.84 | 21360 |
| | | | 25.2 | 828 | 302.40 | 2.74 | 22080 |
| | | | 26.4 | 849 | 316.80 | 2.68 | 22430 |

*Figure 8 - Emax RS2306-2400kv Motor assembly*

With all the motors being about the same size, choosing one came down to the best efficiency. From the chart in Figure 8 above, the E-Max RS2306-2400KV has the highest thrust efficiency with the

HQ5045 propeller and therefore the comparable HQ4045 propeller that the team will use. So, from this information the RS2306-2400KV was chosen as the best motor for the team to purchase.

## Water Sampling Mechanism

The team needed a way to collect a water sample. Through the robotics class that Thomas Wheeler and Zachary Williams are enrolled in, Professor Ajay Mahajan introduced them to small micro-pumps that are used in blood pressure monitors. After some further research into these, the team found micro-pumps that are designed for fish tanks and can both suck in a water sample and pump it out into a separate reservoir. This was the perfect component for the team's application.

## Connections

All individual components of the assembled product of the will be designed to be connected using M3 fastener screws of various lengths and M3 lock nuts. Various screw head types may be used depending on the application, but in most cases a hex drive flat head screw will be used. Through holes may be countersunk or counterbored as needed to allow flush fitments without interferences.

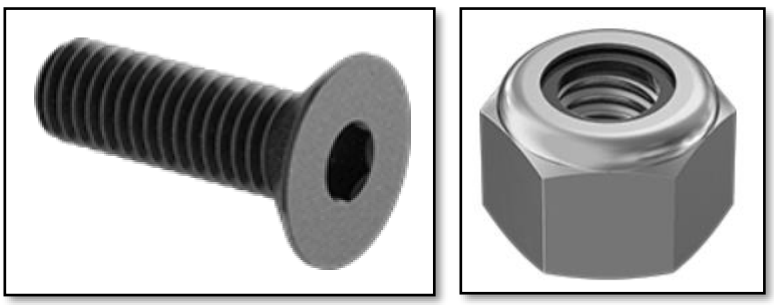


*Figure 9 - M3 Screw and nut fastener*

Other connection points include wire connections. There are several methods to go about connecting wires. For the team's application, most wires will be connected using crimp on quick disconnect pieces to allow for easy assembly and disassembly. Wire connections in tighter locations will be connected using a single crimp butt connecter that cannot be as easily detached.

# Detail Design

## Body Structure

As decided earlier in the conceptual design phase, 3D printing would be the best manufacturing approach for the body structure of the drone. Due to the combination of many different off the shelf electronics and custom water sampling equipment, a lot of time will need to spent designing each component to make assembly of the final product possible. PTC Creo Parametric was the chosen 3D modeling suite the team decided to use. To begin, a few of the electrical components that were chosen in the embodiment design phase were quickly remodeled in Creo to use in assembling the product. Many unnecessary details were left out, but overall dimensions and fastener locations were precisely modeled. These models can be found in the appendix.

With the most important design constraint being the 6" diameter body tube that the final product must fit in without interference, keeping the body compact but also wide enough to be stable is the forefront of the design. To begin, a sketch was created to very similarly replicate the concept hand

sketches done earlier. This is shown in Figure 10. Just from this simple 2D sketch, it was realized that the space available in the center of the body for all the necessary electronics would need to be increased.

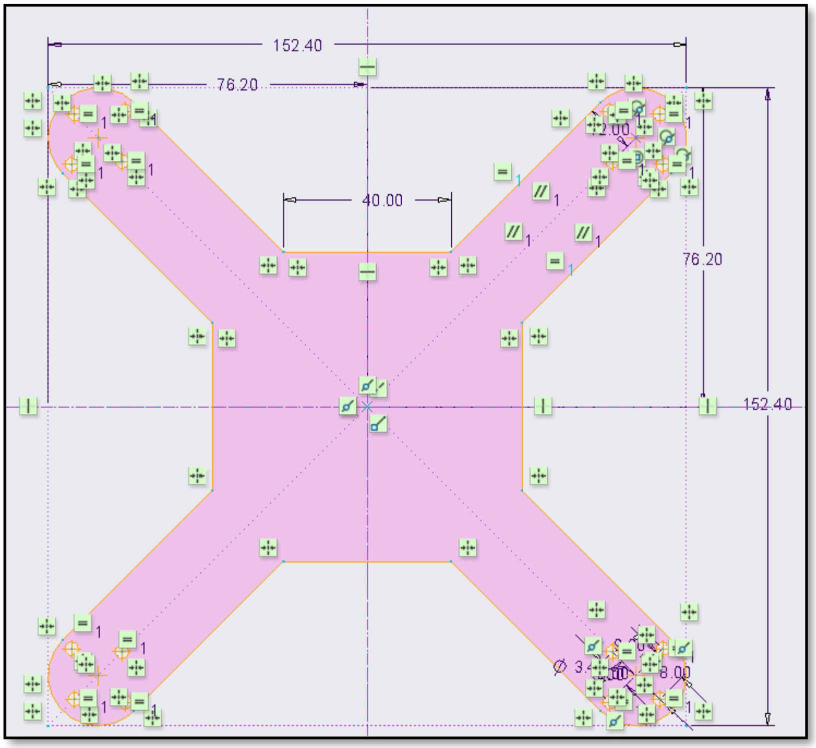



*Figure 10 - Square body shape sketch*

Because the team is maxed out on available space in width, the decision is made to increase the length of body which would create an "H" shape layout for the motors and propellers. Luckily, this layout is supported by the flight control software. To compensate the extra space needed the body is elongated as shown in Figure 11. The sketch is then extruded to a thickness of 5mm to create the base body of the quadcopter.

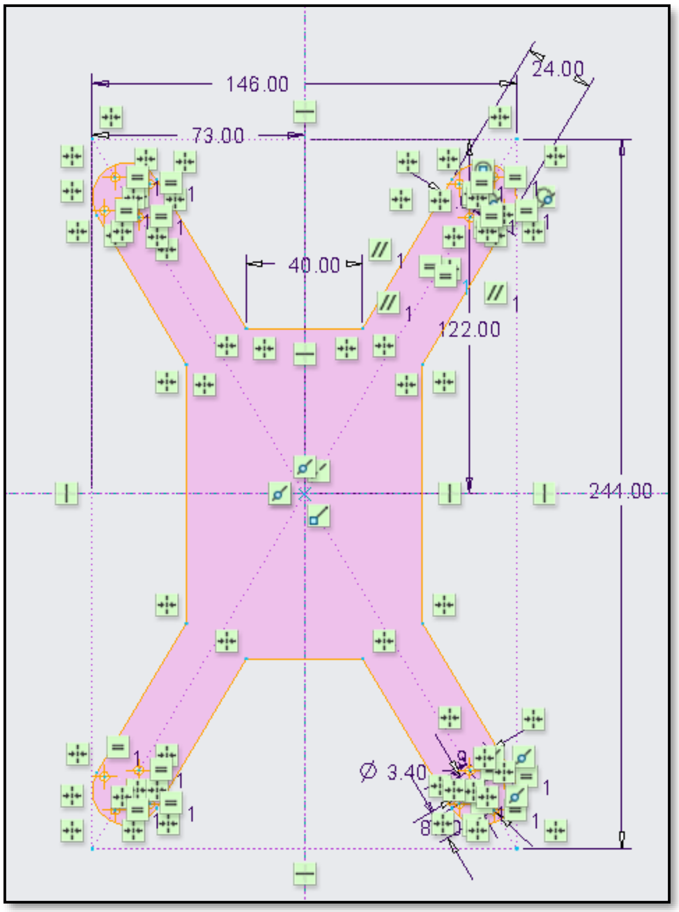



*Figure 11 - Rectangular body shape sketch*

Next, the placement of each motor is designed. The Emax motors are designed from the manufacturer to be attached using the 4 threaded M3 holes on the bottom of the motor frame and the provided fastener screws. Using the provided drawings from Emax, the through holes are spaced accordingly at the end of each support arm on the body. After replicating the through holes on each of the four sides of the body, the placement of the Racerstar ESC is next on the list due to the necessary wire connections between that and the motors. The ESC will be the first component centrally placed in the electronics bay. The roughly 4mm total height of the esc also makes it easy to place first of the base level where it will be easy to design supports above it to hold other components. The ESC will be fastened to the body using the four 3mm holes and the provided nylon hardware screws. Four team's identical through holes are added to the body, which can be seen in Figure 13.

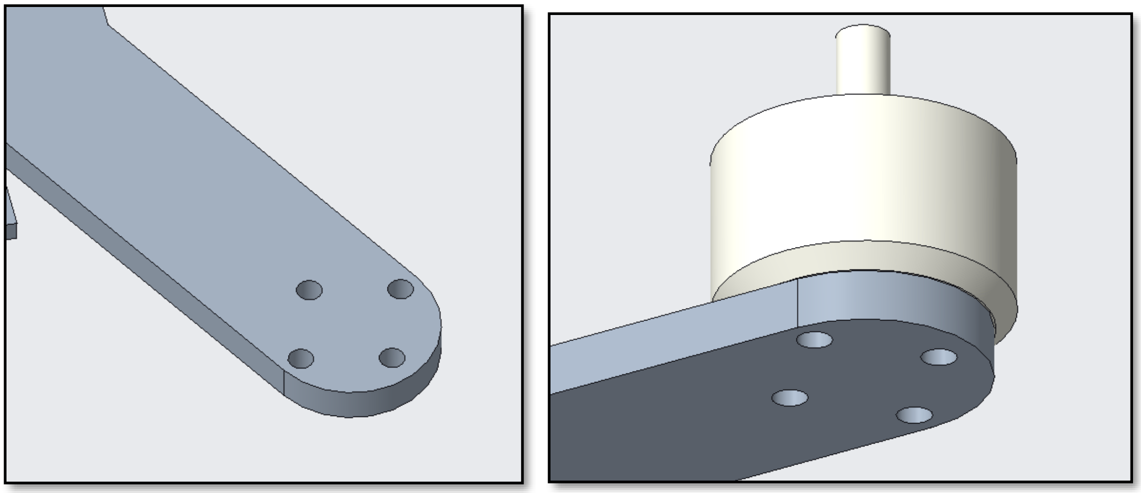


*Figure 12 - Motor screw thru holes*

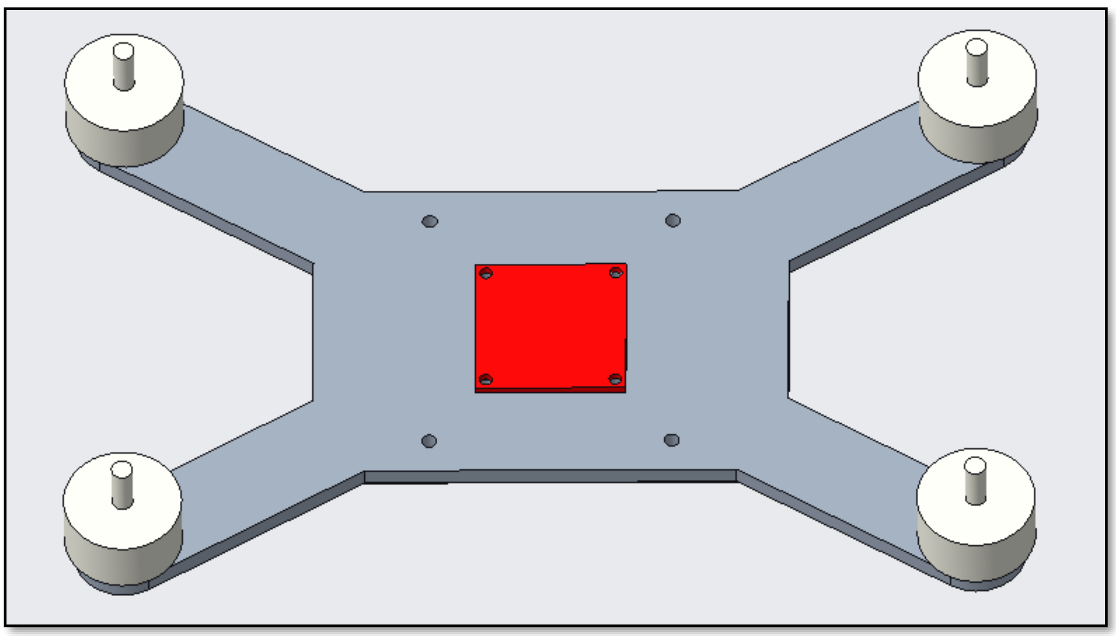


*Figure 13 - ESC Placement*

The team realized early in this design that the components that needed to be placed in the middle will need to sit on top of each other to both fit on the body and evenly distribute weight. So, given this decision, a support was the next thing that needed to be designed to give the team a second surface above the ESC to place the Pixhawk flight controller. The most difficult part of designing this part is leaving space for the wires coming from the ESC that need to reach the motors. So, given the constraint, the support platform is designed and is shown in Figure 14. Four 3.5mm through holes are then added to both the support platform and the base body to attach them together using M3 screws. One downside to the Pixhawk flight controller is that it does not provide any holes for any fastening method. So, the only way to fix the component to the platform is using double sided command strips, where no holes or screws are needed. The gaps on either side of the platform that are pointed out in Figure 15 will leave ample space for the wire leads from the ESC underneath to reach the motors.

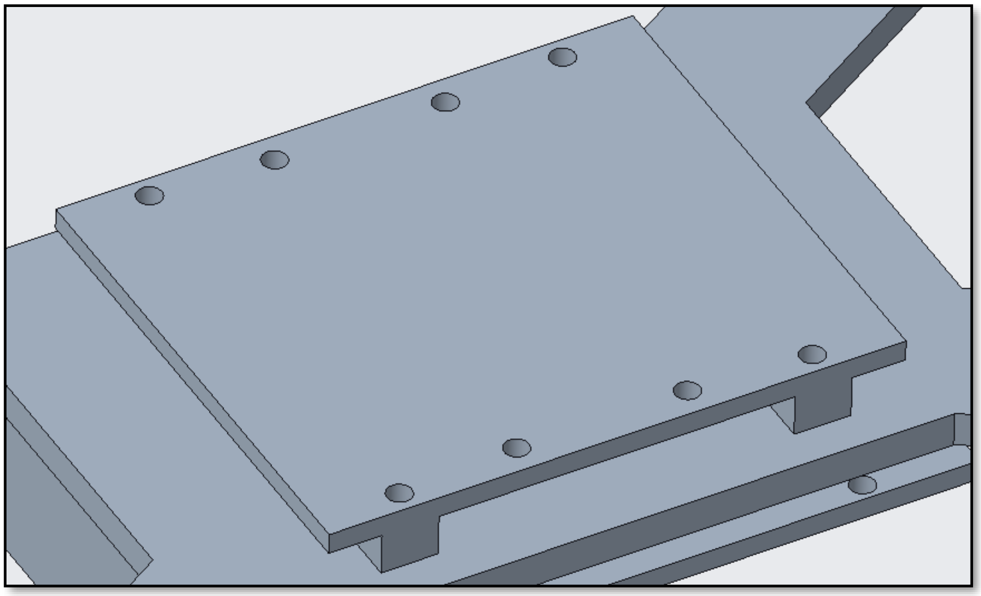


*Figure 14 - Pixhawk suppot platform*

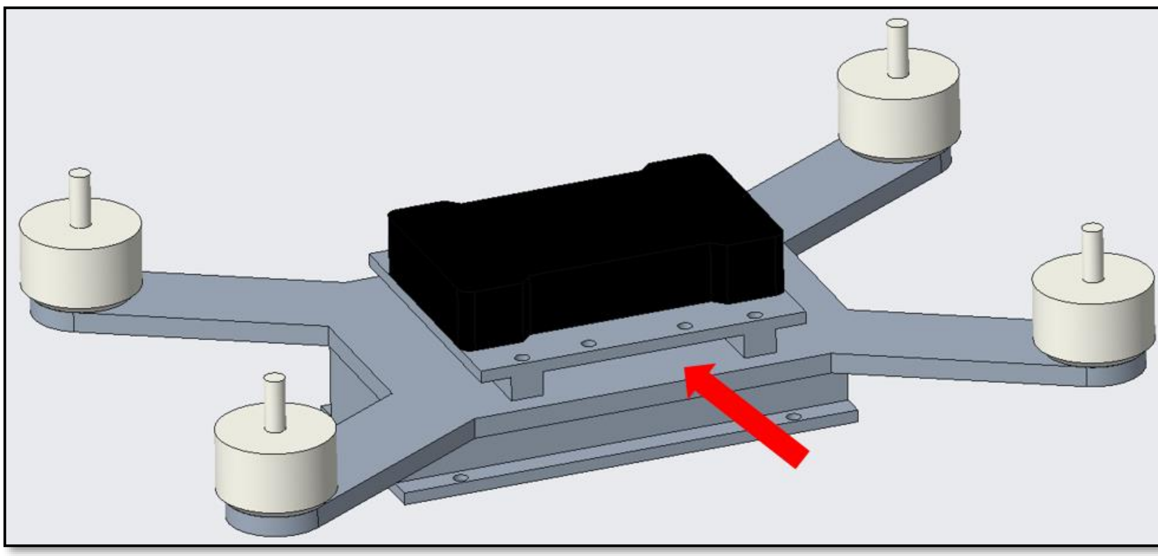


*Figure 15 - Gap placement for wire routing*

Again, another support platform is designed for the GPS and Telemetry modules to sit above the Pixhawk. Due to all the wire connector plugs being located on the top side of the flight controller, extra space needed to be left above. The support is designed to utilize the same M3 screws to attach to the platform below. The top surface is dimensioned to a 70mm x 90mm rectangle to leave enough surface space for both components. Like the Pixhawk, neither components have holes for fasteners to be used, therefore, once again double-sided command strips will be used to fix them to the platform.

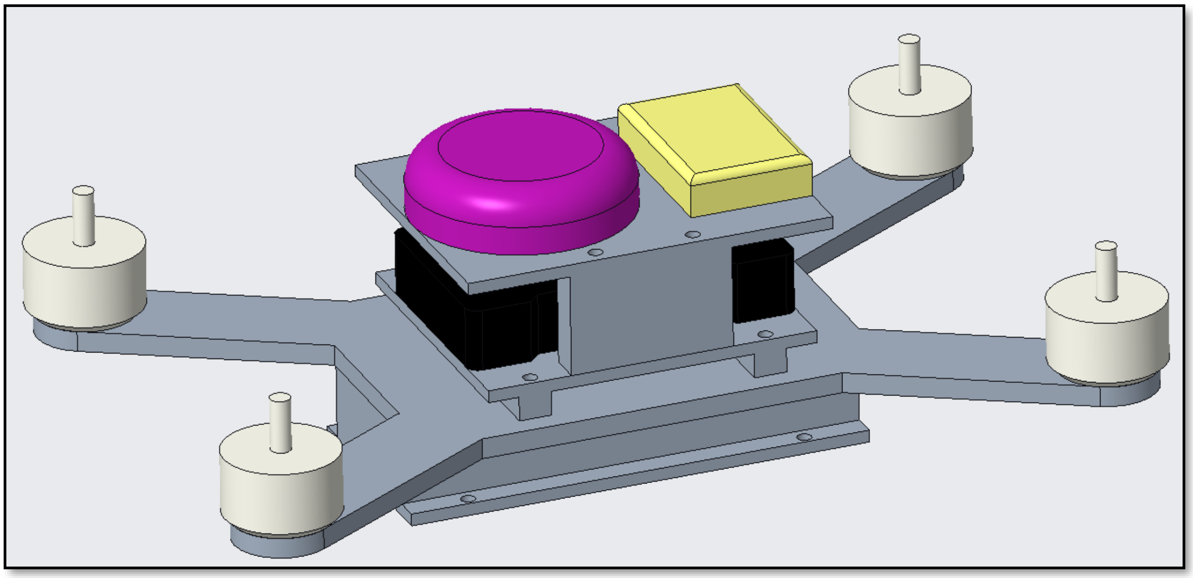


*Figure 16 - GPS and telemetry platform assembly*

To distribute weight in the z-axis, the battery compartment is designed on the bottom side of the body. The advantage of 3D printing allows the team to directly attach this compartment to the rest of the body as one piece. A hole is left on one end of the compartment to accommodate the power wires to attach to the rest of the components. Finally, the simple cover is designed to cover the underside of the battery and hold it in place. The plate is designed to attach using M3 screws and nuts.

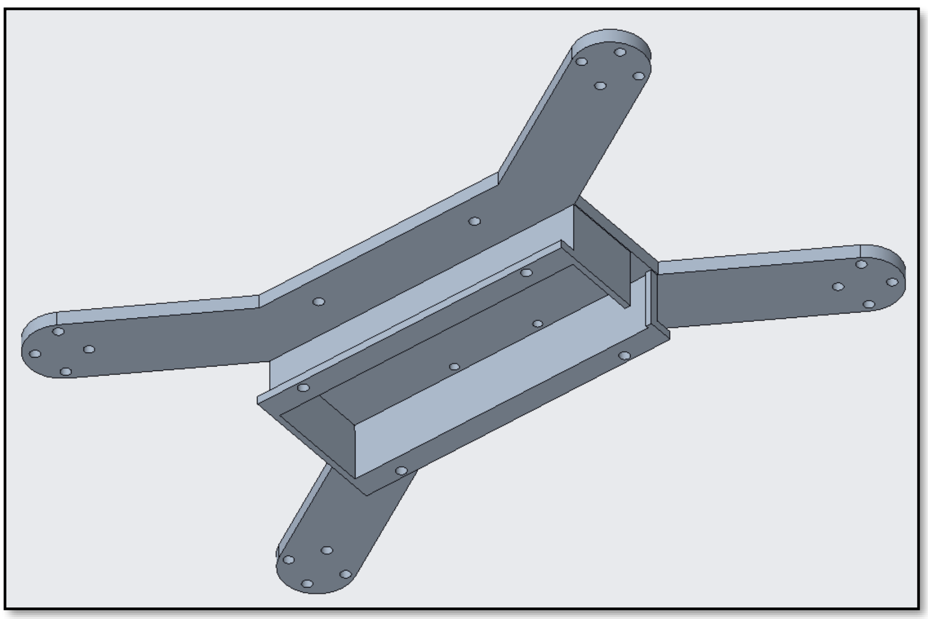


*Figure 17 - Open battery compartment*

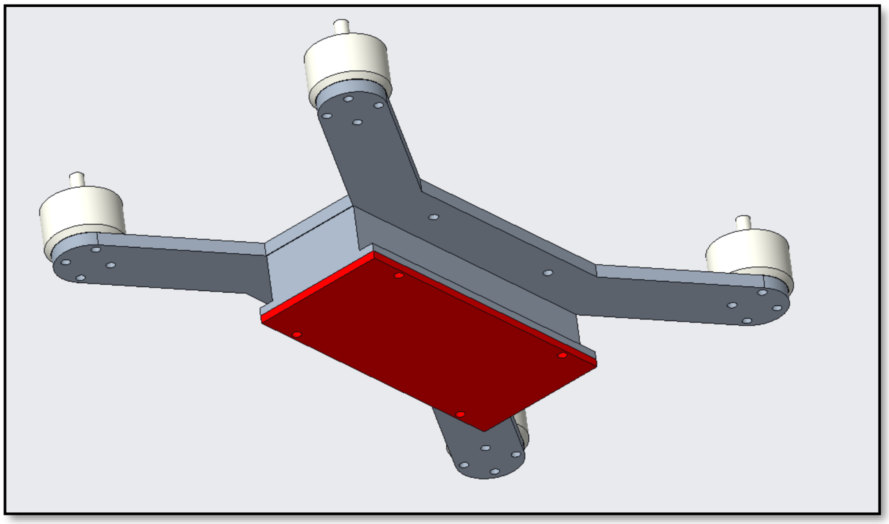


*Figure 18 - Battery compartment cover shown in red*

The extra space on the underside of the body next to the battery compartment, is left to attach the water pump and holding reservoir. At the time of this design, the pump and other sampling components are on backorder, so a detailed design could not be completed. However, both the pump and holding reservoir will attach using similar command strips as the GPS and telemetry modules on the top of the product.

To end the design of the body, the landing gear is the final part to be modeled. With the goal of having the ability to land and float on water for sampling purposes, these will be also be separate parts that will attach using M3 screws. The two parts will be printed using a low 10% infill and a thin wall thickness which will significantly reduce the weight and increase the buoyancy of the product. Figure 19 shows the final assembled product including exact models of the Emax motors and Pixhawk sourced online from GrabCAD.

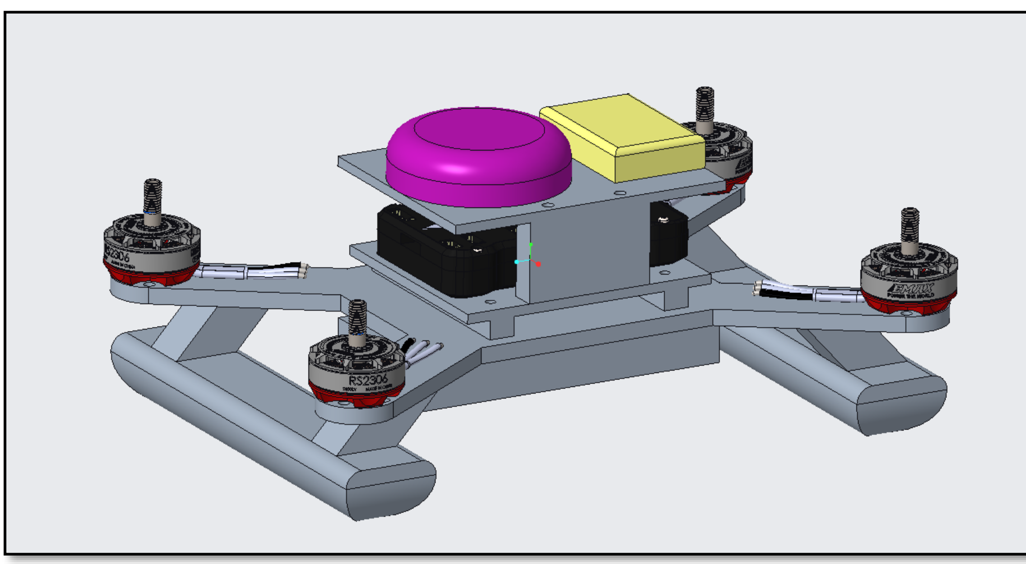



*Figure 19 - Final prodcut assembly*

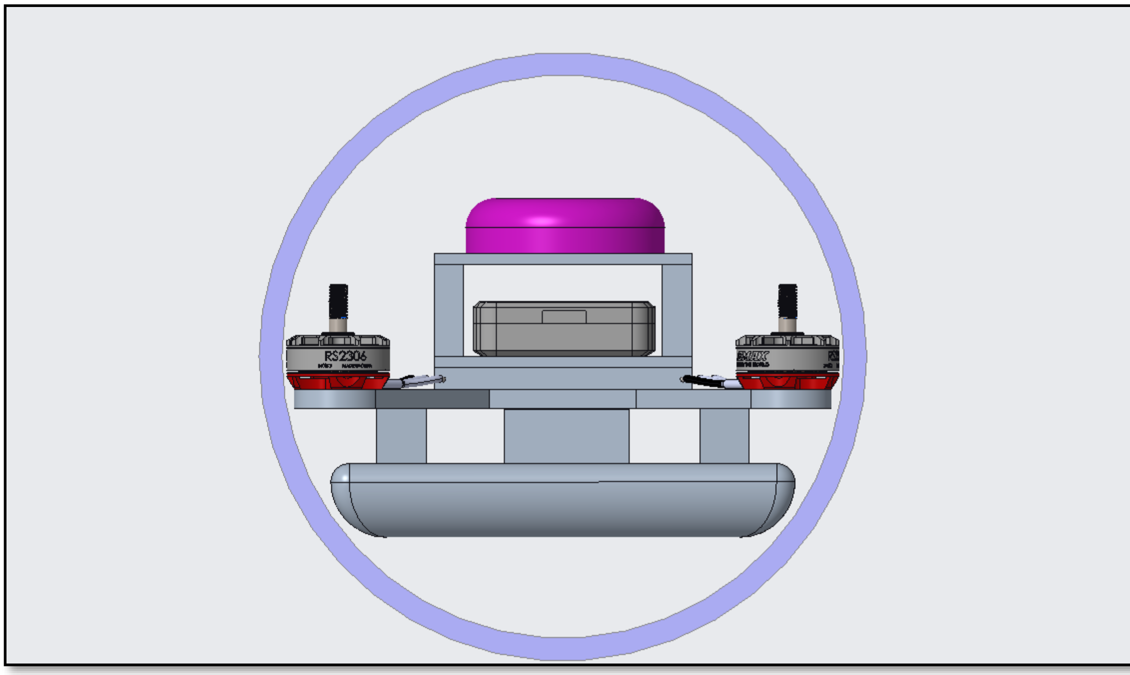



*Figure 20 - Final Product Assembly inside body tube*

## Deployment

As part of the Akronauts' overall rocket design for the IREC rocket the final product will be deployed from, the team will design a multicamera descent module that will be ejected at apogee of the flight. This mechanism will be designed to record a 360-degree view of the descent and will have its own separate parachute from the rest of the rocket. Because this module will sit in the same section of the rocket as the team's product, they will be ejected together. The final drone product will be attached the underside of this module using a Jolly Logic altimeter release. This will allow the team to descend with a parachute until approximately 500 feet, where the altimeter will release the drone from the parachute and begin flying autonomously. Currently, the Akronauts' team does not have a detailed design of their descent recording module so exact specifications for attachment to this are not yet available.

## Materials

For this project, the team will be able to utilize a Markforged Mark2 printer in the lab of a design team sponsor. This printer is capable of printing with advanced composite materials that allow for parts with comparable strength to weight ratios to 6061 aluminum alloys. This printer prints "sandwiches" of composites and plastics meaning it prints with a nylon base material with intermittent layers of continuous thread composites. The composites are Kevlar, a standard fiberglass, a high strength and high temperature fiberglass, and carbon fiber. The team plans to use the "onyx" base material with four concentric layers of carbon fiber every 30 layers. The properties and stress-strain comparisons can be seen below from material data sheets available on Markforged's website[7]:

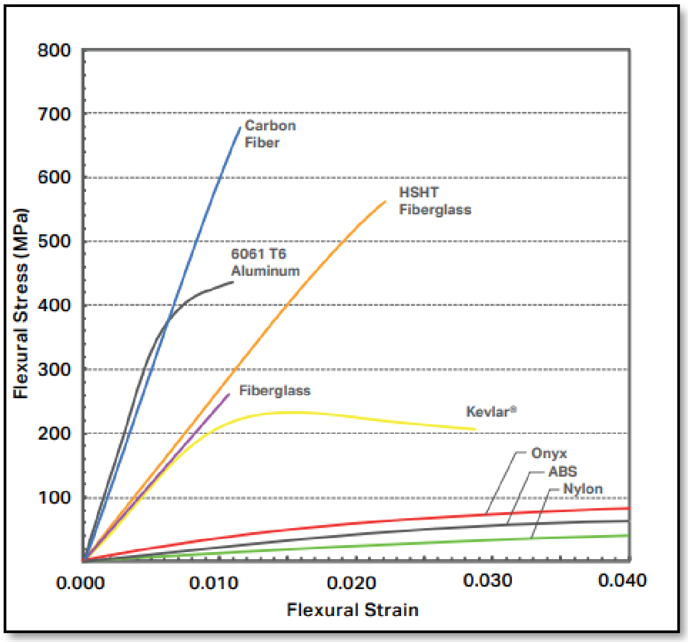



*Figure 21 - Stress vs Strain Curves for common 3D printing materials vs composites*

MATERIAL DATASHEET

# Composites

Markforged

| Plastic Matrix | Test (ASTM) | Onyx | Nylon |
|---|---|---|---|
| Tensile Modulus (GPa) | D638 | 1.4 | 0.94 |
| Tensile Stress at Yield (MPa) | D638 | 36 | 31 |
| Tensile Strain at Yield (%) | D638 | 25 | 27 |
| Tensile Stress at Break (MPa) | D638 | 30 | 54 |
| Tensile Strain at Break (%) | D638 | 58 | 260 |
| Flexural Strength (MPa) | D790[1] | 81 | 32 |
| Flexural Modulus (GPa) | D790[1] | 2.9 | 0.84 |
| Heat Deflection Temp (°C) | D648 B | 145 | 49 |
| Izod Impact - notched (J/m) | D256-10 A | 330 | 1000 |
| Density (g/cm³) | — | 1.2 | 1.1 |

Dimensions and Construction of Plastic Test Specimens:

- Tensile test specimens: ASTM D638 type IV beams
- Flexural test specimens: 3-pt. Bending, 4.5 in (L) x 0.4 in (W) x 0.12 in (H)
- Heat-deflection temperature at 0.45 MPa, 66 psi (ASTM D648-07 Method B)

All Markforged machines are equipped to print Onyx. Nylon is a specialized material that can only be printed on the Mark Two and X7. Machines that print Onyx cannot also print Nylon due to machine conditioning.

Markforged parts are primarily composed of plastic matrix. Users may add one type of fiber reinforcement in each part, enhancing its material properties.

1. Measured by a method similar to ASTM D790. Thermoplastic-only parts do not break before end of Flexural Test.

*Figure 22 – 3D printable composite material properties*

| Fiber Reinforcement | Test (ASTM) | Carbon | Kevlar® | Fiberglass | HSHT FG |
|---|---|---|---|---|---|
| Tensile Strength (MPa) | D3039 | 800 | 610 | 590 | 600 |
| Tensile Modulus (GPa) | D3039 | 60 | 27 | 21 | 21 |
| Tensile Strain at Break (%) | D3039 | 1.5 | 2.7 | 3.8 | 3.9 |
| Flexural Strength (MPa) | D790[1] | 470 | 190 | 210 | 420 |
| Flexural Modulus (GPa) | D790[1] | 51 | 26 | 22 | 21 |
| Flexural Strain at Break (%) | D790[1] | 1.2 | 2.1 | 1.1 | 2.2 |
| Compressive Strength (MPa) | D6641 | 320 | 97 | 140 | 192 |
| Compressive Modulus (MPa) | D6641 | 54 | 28 | 21 | 21 |
| Compressive Strain at Break (%) | D6641 | 0.7 | 1.5 | — | — |
| Heat Deflection Temp (°C) | D648 B | 105 | 105 | 105 | 150 |
| Izod Impact - notched (J/m) | D256-10 A | 960 | 2000 | 2600 | 3100 |
| Density (g/cm³) | — | 1.4 | 1.2 | 1.5 | 1.5 |

*Figure 23 - Fiber reinforcement properties*

## Flight Control Software

Due to the desire to achieve fully autonomous flight movements, the team decided closely examined Ardupilot's Mission Planner software. After reading many online forums about these options, the team determined that this software was one of the best options.

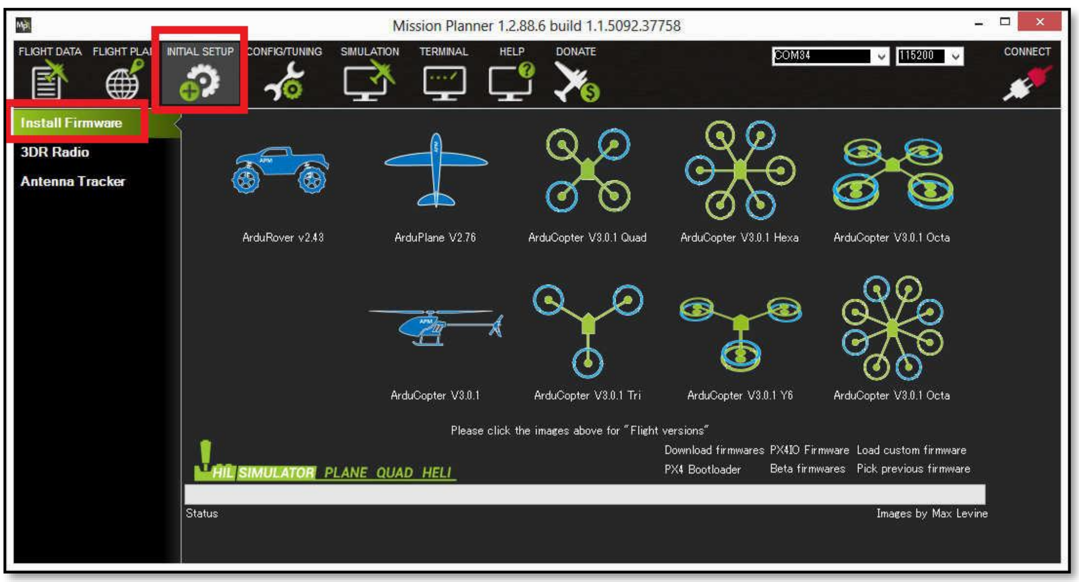



*Figure 24 - Mission Planner Vehicle Setup*

The system is user friendly and allows for the configuration of a variety of autonomous vehicles including the desired quadcopter. The interface allows for easy path planning based on GPS coordinates as seen in Figure 25.


*Figure 25 - GPS Waypoint marking for autonomous flight*

This will allow for a great ease of planning once the team is at the site. Precise points will be gathered on arrival to the launch site. Similar functionality is found in Systems Tool Kit. As shown earlier, the software can be used to map out the flight path of an aircraft given a latitude and longitude. Waypoints radius' can also be controlled for precise landing conditions or for general guidance to a destination. The parallels between mission planning in systems tool kit for a full-scale mission to Titan and a subscale mission in this software was another attractive feature.


*Figure 26 - Live Telemetry Heads up Display*

Mission planner also allows for the receipt of live telemetry data. This will allow the team to monitor the status of the system while the mission is in progress.

# Conclusions and Discussion

## Limitations

A scale mission is limited by its nature; however, testing of any kind is valuable when a full-scale mission would cost on the order of billions of dollars. Inevitably, the retention system, UAV and launch vehicle dimensions, and on-board equipment would be different for a full-scale mission. The aim of this project is to test the forces a payload will experience during launch and flight. It will also test the ability of a small flying vehicle to perform a scientific function useful to planetary exploration and demonstrate a potential cost-effective solution to a technical challenge faced by industry leaders in the space industry.

For a full-scale mission, a design would likely exploit the advantageous conditions for flight on Titan by using smaller propellers or saving battery power by not needing as much velocity from the propellers to achieve lift. Unfortunately, the flight and testing of the designed small-scale model will be conducted here on Earth; thus, the finished product will need to function in this environment and cannot be solely designed for life on another celestial body.

As far as the small-scale quadcopter that will compete in the Space Dynamics Lab competition, the group is very confident in the ability to complete a functioning prototype. The team functioned well together throughout the design from choosing off-the-shelf components, to custom design of the body to be 3D printed. At the time of completing this design, building and testing will be the final steps to complete before the competition. Although there are limitations of the testing that is possible prior to launch, such as deployment from the rocket, the autonomous flying capabilities will be tested and confirmed. At the competition, the team is confident in the ability to not only be successful in launching and flying, but also to finish well against other competing teams.

References:

1. Spaceport America Cup SDL Payload Challenge Guidelines: http://www.soundingrocket.org/sdl-payload-challenge.html
2. Johns Hopkins Study Containing Atmospheric Data of Titan: http://dragonfly.jhuapl.edu/News-and-Resources/docs/34_03-Lorenz.pdf
3. Huygens Probe Landing Site: https://solarsystem.nasa.gov/resources/12878/huygens-landing-site/
4. EMAX Motor Tables: https://www.emaxmodel.com/
5. T-Motor Tables: http://store-en.tmotor.com/
6. Markforged Material Safety Data Sheets: https://static.markforged.com/markforged_composites_datasheet.pdf

# Appendix

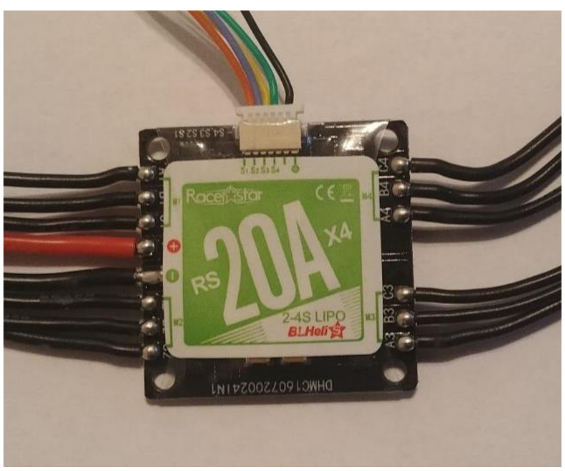
| Motor type | The voltage (V) | Paddle size | current (A) | thrust (G) | power (W) | efficiency (G/W) | speed (RPM) |
|---|---|---|---|---|---|---|---|
| RS2205-2300KV | 12 | HQ5045 BN | 1 | 62 | 12.00 | 5.17 | 6400 |
| | | | 3 | 162 | 36.00 | 4.50 | 10080 |
| | | | 5 | 236 | 60.00 | 3.93 | 12070 |
| | | | 7 | 311 | 84.00 | 3.70 | 13730 |
| | | | 9.1 | 374 | 109.20 | 3.42 | 15100 |
| | | | 11 | 439 | 132.00 | 3.33 | 16320 |
| | | | 13 | 490 | 156.00 | 3.14 | 17350 |
| | | | 15.3 | 548 | 183.60 | 2.98 | 18350 |
| | | | 17.3 | 611 | 207.60 | 2.94 | 19210 |
| | | | 20.7 | 712 | 248.40 | 2.87 | 20080 |
| | 16 | HQ5045 BN | 1 | 76 | 16.00 | 4.75 | 7220 |
| | | | 3 | 183 | 48.00 | 3.81 | 10790 |
| | | | 5 | 283 | 80.00 | 3.54 | 13030 |
| | | | 7.1 | 352 | 113.60 | 3.10 | 14720 |
| | | | 9.1 | 426 | 145.60 | 2.93 | 16180 |
| | | | 11 | 497 | 176.00 | 2.82 | 17150 |
| | | | 13 | 560 | 208.00 | 2.69 | 18460 |
| | | | 15 | 628 | 240.00 | 2.62 | 19270 |
| | | | 17 | 692 | 272.00 | 2.54 | 20270 |
| | | | 19 | 754 | 304.00 | 2.48 | 21060 |
| | | | 21 | 812 | 336.00 | 2.42 | 21840 |
| | | | 23.3 | 878 | 372.80 | 2.36 | 22590 |
| | | | 25.4 | 936 | 406.40 | 2.30 | 23210 |
| | | | 27.3 | 997 | 436.80 | 2.28 | 23920 |
| | | | 29.9 | 1024 | 478.40 | 2.14 | 24560 |

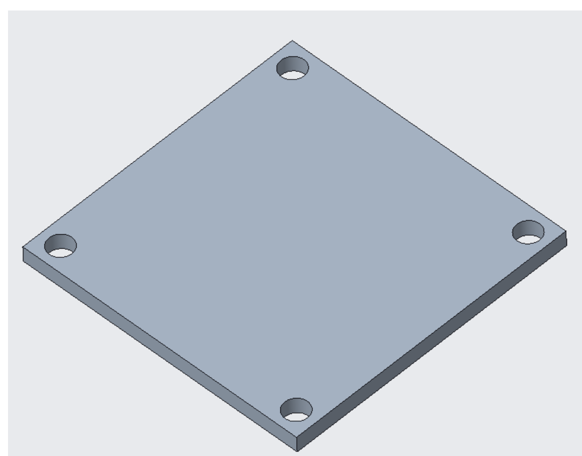
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 12 | T5045 Tri-blade | 1 | 66 | 12.00 | 5.50 | 6420 |
| | | | 3.1 | 176 | 37.20 | 4.73 | 10320 |
| | | | 5.1 | 260 | 61.20 | 4.25 | 12550 |
| | | | 7.1 | 334 | 85.20 | 3.92 | 14240 |
| | | | 9.1 | 405 | 109.20 | 3.71 | 15630 |
| | | | 11.1 | 474 | 133.20 | 3.56 | 16910 |
| | | | 13.1 | 539 | 157.20 | 3.43 | 18030 |
| | | | 15.1 | 597 | 181.20 | 3.29 | 19100 |
| | | | 17.1 | 660 | 205.20 | 3.22 | 19990 |
| | | | 19.2 | 717 | 230.40 | 3.11 | 20660 |
| | | | 21.1 | 761 | 253.20 | 3.01 | 21240 |
| | | | 23.1 | 810 | 277.20 | 2.92 | 21840 |
| | | | 25.1 | 864 | 301.20 | 2.87 | 22450 |
| | | | 27.1 | 911 | 325.20 | 2.80 | 23250 |
| | | | 29.1 | 963 | 349.20 | 2.76 | 23710 |
| | | | 31.2 | 1023 | 374.40 | 2.73 | 24120 |
| | | | 33 | 1080 | 396.00 | 2.73 | 24580 |
| | | | 34.2 | 1118 | 410.40 | 2.72 | 24730 |
| | | HQ5045 Propeller | 1 | 56 | 12.00 | 4.67 | 6200 |
| | | | 3.1 | 152 | 37.20 | 4.09 | 9910 |
| | | | 5.1 | 225 | 61.20 | 3.68 | 11980 |
| | | | 7.1 | 297 | 85.20 | 3.49 | 13550 |
| | | | 9.1 | 356 | 109.20 | 3.26 | 14840 |
| | | | 11.1 | 410 | 133.20 | 3.08 | 16070 |
| | | | 13.1 | 478 | 157.20 | 3.04 | 17080 |
| | | | 15.1 | 538 | 181.20 | 2.97 | 18030 |
| | | | 17.1 | 590 | 205.20 | 2.88 | 19030 |
| | | | 19.1 | 645 | 229.20 | 2.81 | 19730 |
| | | | 21.1 | 698 | 253.20 | 2.76 | 20530 |
| | | | 23.1 | 744 | 277.20 | 2.68 | 21210 |
| | | | 25.2 | 795 | 302.40 | 2.63 | 21900 |
| | | | 27.1 | 842 | 325.20 | 2.59 | 22450 |
| | | | 29.1 | 877 | 349.20 | 2.51 | 23020 |
| | | | 31.3 | 914 | 375.60 | 2.43 | 23530 |
| | | | 33.3 | 958 | 399.60 | 2.40 | 24120 |
| | | | 35.2 | 996 | 422.40 | 2.36 | 24580 |
| | | | 36.3 | 1013 | 435.60 | 2.33 | 24750 |
| | | 6040BN Tri-blade | 1.1 | 85 | 13.20 | 6.44 | 5780 |
| | | | 3.1 | 203 | 37.20 | 5.46 | 8630 |
| | | | 5.1 | 299 | 61.20 | 4.89 | 10250 |
| | | | 10.2 | 490 | 122.40 | 4.00 | 13133 |
| | | | 15.1 | 651 | 181.20 | 3.59 | 15220 |
| | | | 20.1 | 792 | 241.20 | 3.28 | 16820 |
| | | | 25.1 | 941 | 301.20 | 3.12 | 18050 |
| | | | 30.1 | 1057 | 361.20 | 2.93 | 19140 |
| | | | 35.1 | 1145 | 421.20 | 2.72 | 20250 |
| | | | 40.1 | 1262 | 481.20 | 2.62 | 21240 |
| | | | 43.7 | 1328 | 524.40 | 2.53 | 22060 |

**Test Report-F40III**

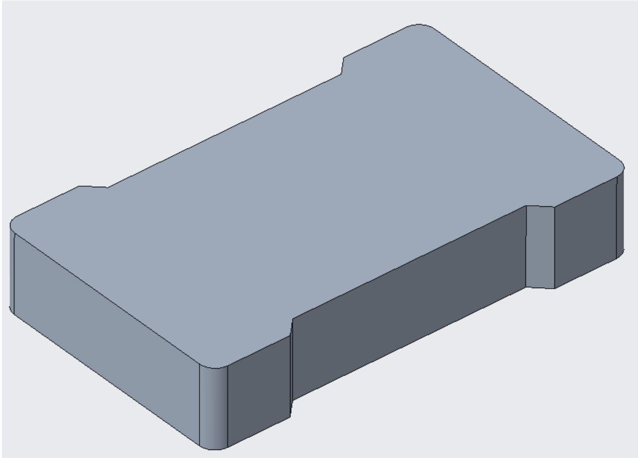
| Item No. | Propeller | Throttle | Thrust (g) | Voltage (V) | Current (A) | RPM | Power (W) | Efficiency (g/W) | Operating Temperature |
|---|---|---|---|---|---|---|---|---|---|
| F40III KV2400 | DAL5045 Tri-Blade | 50% | 496 | 15.98 | 9.28 | 16721 | 148.34 | 3.34 | 84.6℃ (Ambient Temperature：31℃) |
| | | 55% | 556 | 15.95 | 10.81 | 17666 | 172.38 | 3.22 | |
| | | 60% | 628 | 15.90 | 13.07 | 18693 | 207.85 | 3.02 | |
| | | 65% | 710 | 15.83 | 15.88 | 19905 | 251.29 | 2.83 | |
| | | 70% | 779 | 15.80 | 17.40 | 20936 | 274.84 | 2.84 | |
| | | 75% | 857 | 15.74 | 19.79 | 21994 | 311.47 | 2.75 | |
| | | 80% | 942 | 15.69 | 22.40 | 23055 | 351.62 | 2.68 | |
| | | 85% | 1040 | 15.60 | 26.18 | 24194 | 408.39 | 2.55 | |
| | | 90% | 1128 | 15.51 | 29.42 | 25126 | 456.33 | 2.47 | |
| | | 95% | 1213 | 15.40 | 32.95 | 26014 | 507.53 | 2.39 | |
| | | MAX | 1325 | 15.34 | 36.47 | 27228 | 559.45 | 2.37 | |
| Item No. | Propeller | Throttle | Thrust (g) | Voltage (V) | Current (A) | RPM | Power (W) | Efficiency (g/W) | Operating Temperature |
| F40III KV2600 | DAL5045 Tri-Blade | 50% | 530 | 15.98 | 10.60 | 17322 | 169.43 | 3.13 | 96.2℃ (Ambient Temperature：31℃) |
| | | 55% | 595 | 15.94 | 12.37 | 18326 | 197.27 | 3.02 | |
| | | 60% | 679 | 15.85 | 15.57 | 19558 | 246.79 | 2.75 | |
| | | 65% | 750 | 15.73 | 18.13 | 20532 | 285.12 | 2.63 | |
| | | 70% | 839 | 15.65 | 20.52 | 21531 | 321.11 | 2.61 | |
| | | 75% | 912 | 15.57 | 22.27 | 22622 | 346.82 | 2.63 | |
| | | 80% | 1010 | 15.58 | 26.00 | 23826 | 405.20 | 2.49 | |
| | | 85% | 1102 | 15.50 | 29.71 | 24898 | 460.50 | 2.39 | |
| | | 90% | 1189 | 15.41 | 33.10 | 25818 | 510.05 | 2.33 | |
| | | 95% | 1272 | 15.30 | 36.84 | 26745 | 563.70 | 2.26 | |
| | | MAX | 1399 | 15.17 | 40.92 | 27878 | 620.76 | 2.25 | |

*T-motor F-40 2400kv and 2600kv*

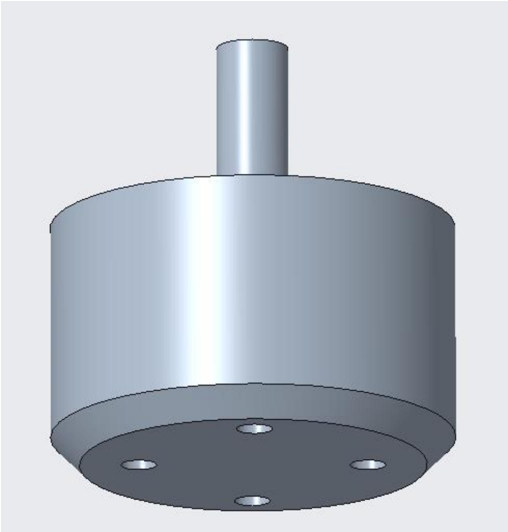


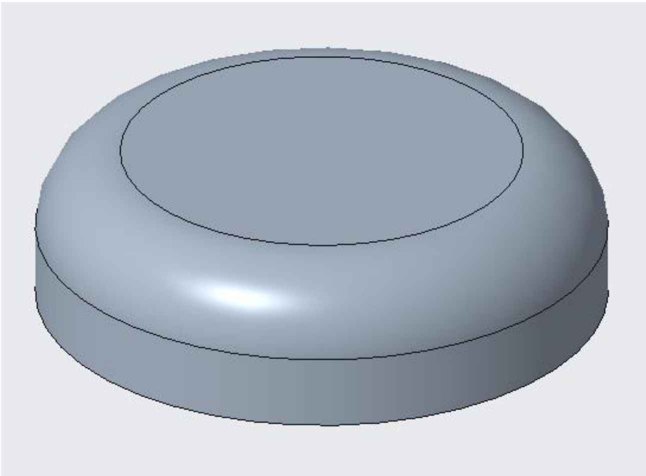

pixhawk
FMU
PWR
B/E
IO
ACT
AUX OUT
MAIN OUT
SBUS
RCIN
BUZZER
SWITCH
SPKT/DSM
TELEM 2
TELEM 1
USB
SERIAL 4/5
GPS
CAN
ADC 3.3V
I2C
ADC 6.6V
SPI
POWER
px4



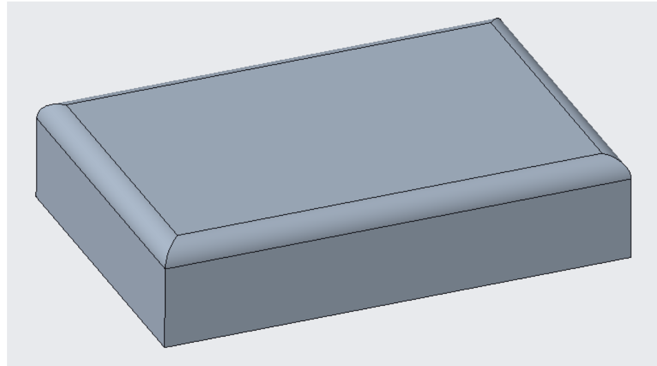

RACE SPEC
EMAX
COOLING
RS2306 2400KV
RS2306
2400KV
MADE IN CHINA



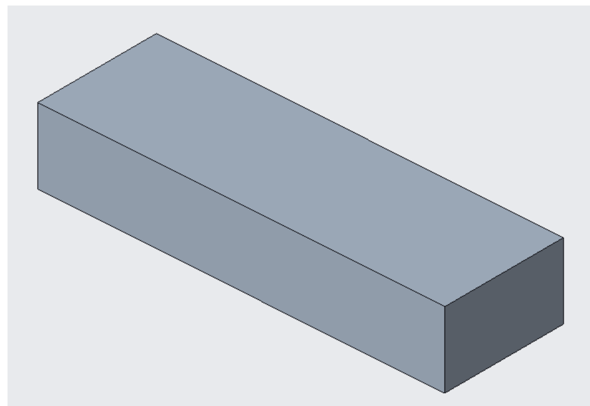

GPS Module
with compass
Powered by Ublox 7M

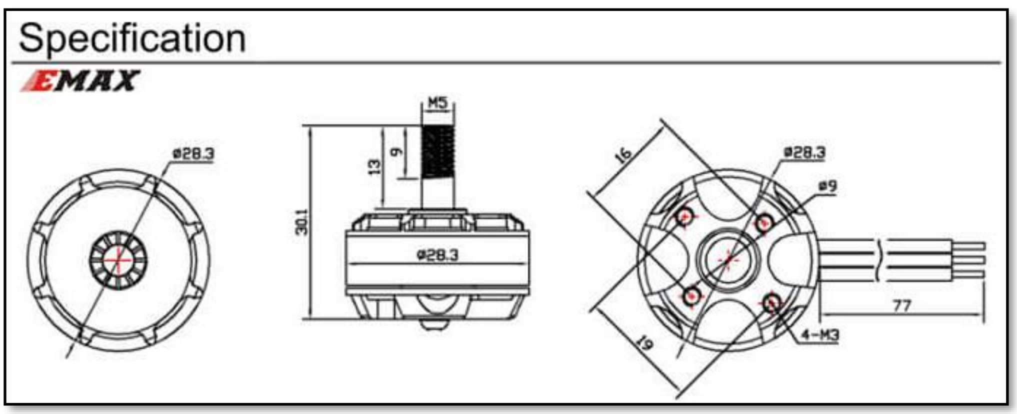



FPV Radio Telemetry
Air Module




1800 mAh
LU
Lumenier
High Discharge Lithium Polymer Battery
3 CELL
35C DISCHARGE
70C BURST
11.1 VOLTS




Specification
EMAX
ø28.3
M5
13
9
30.1
ø28.3
16
ø28.3
ø9
77
4-M3
19