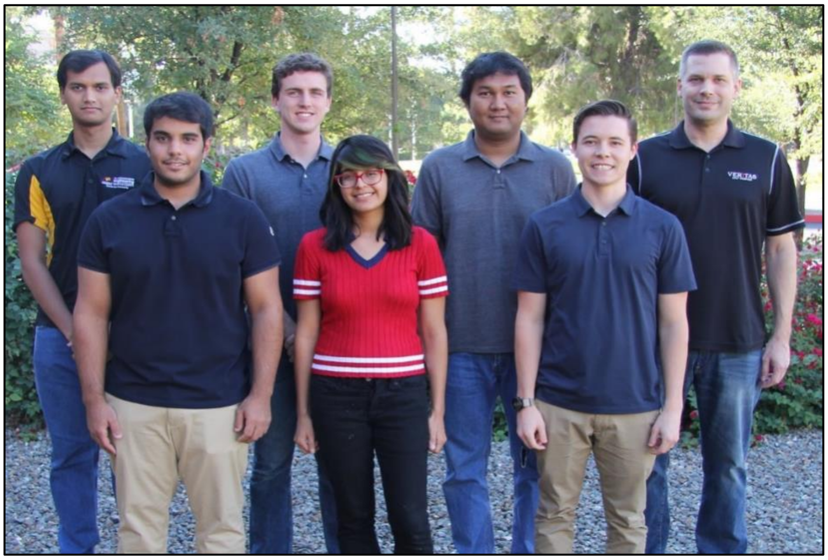
Shark Attack Victim Response & Repellant System (SAVRRS)



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Sponsors:
Ira A. Fulton Schools of Engineering, Arizona State University
Cure Putters

Completed on 4/19/19

Team Member Authorization

Each member of A.T.S Systems has contributed to the final report and has reviewed the contents in its entirety. By signing below, each member agrees that the contents are accurate and represent the sole work of A.T.S Systems.

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Executive Summary

Team Air-to-Shark (A.T.S.) Systems has successfully designed and manufactured a prototype device for use by lifeguards during shark attack response. During the event of an attack, the lifeguard responsible for making the rescue inherits additional risk for a secondary attack. The team sought to solve this problem by creating the Shark Attack Victim Response & Repellant System (SAVRRS) that would be able to reach the victim and disperse a repellant that would cause the shark to vacate the area. Thus, creating a predator-free environment for the lifeguard to perform the rescue. Team A.T.S followed the IPDS process to brainstorm, design, analyze, create and test the final prototype produced over the span of two semesters while at Arizona State University. This report outlines the process that the team performed to create the final SAVRRS prototype including the full system comprised of a UAV body designed entirely by the team, as well as a distribution vessel subsystem. Through the process of testing, development, and validation, the team was successful in creating the device, and met all requirements set by the team during the initial phases of product development. Overall team performance and success is discussed in the following sections of this report.

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ABET Criteria/Final Report Cross Reference Table

ABET Criterion	Target Level of Mastery	Best-Evidence Report Section Location
1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.	Analysis	5.6, 7.1, 9.2
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.	Analysis	1.2, 1.5, 1.6, 3.2, 4, 10
3. an ability to communicate effectively with a range of audiences.	Application	All sections in report
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.	Application	1.5, 4.2, 6.4, 7.1.6, 11, 12, 13
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.	Application	3.2, 5.6.1, 6.7.1, 9.1, 11
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.	Analysis	2.1.2, 5.6, 6.5, 6.6, 7.1, 9, 10
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.	Application	1.6, 3.2.4, 6.6, 7.1, 8.4, 9.2

1. Introduction

The report is a summary of the work complete in the MAE 488/489 Capstone Design Project at Arizona State University (ASU) during the time period of August 16th, 2018 to April 26th, 2019. Team Air to Shark Systems (ATS) has designed a product during this timeframe following the Integrated Product Development and Support (IPDS) process. The goal of the project is to create a device which aids in the rescue of shark attack victims. The deliverables of ATS project have three categories which are a full development report, a project notebook and a final prototype. The sponsors for the project are Ira A. Fulton School of engineering, Arizona State University, and Dr. Abdelrahman Shuaib. The project will be developed by Team ATS. The members of the team are Abdullah Aldawood, Angelica Guzman, Derek Jensen, Joshua Morton, Kyaw Htoo, Michael Davis and Sajana Ratnayake.

This section will outline the societal problem that ATS Systems will attempt to solve using our device.

1.1 Design need

The Capstone project outlined in this report is designed to create a safe environment for beach lifeguards to preform rescue preform rescue procedures in the event of a shark attack. The current protocol prevents lifeguards from entering the water or rescue attempts to take place if there is still a shark presence near the victim, due to the legal and liability issues involved. However, since the leading cause of death post-shark attack is blood loss and not blunt force trauma, it is paramount that the rescue efforts are initiated as quickly as possible. Therefore, there is a customer need of a device that safely and effectively removes the shark presence near the victim, without endangering any other patrons, which will ultimately create a safe environment for lifeguards to begin their rescue attempt.

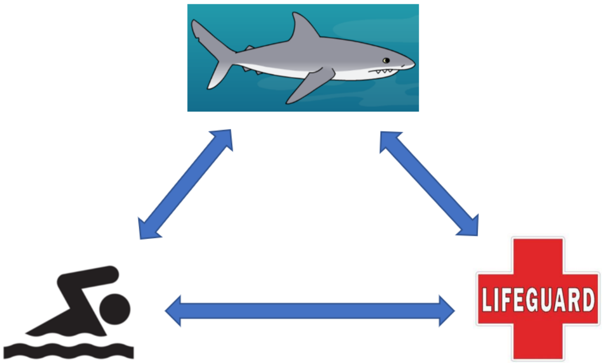


Figure 1.1.1: Shark attack relationship balance during rescue attempt

The team has created Figure 1.1.1 to demonstrate the overall balance of the components of the shark attack scenario and the relationship between each variable. The goal would ultimately be to distance the shark from the victim that allows the lifeguard to get closer for a rescue attempt, all while keeping each party safe from one another (shark included).

1.2 Problem Statement

The design need dictates a human-less vehicle that can deter the shark from remaining in the vicinity, without causing more harm to the victim and puts the lifeguards in the best scenario to have a successful rescue as quickly as possible. This conclusion drawn by the team is the outcome of research, interviews and needs as designated by the customer. Because of the design need, the team developed the following problem statement for the project.

> Problem Statement: *Shark activity near the presence of humans has dramatically increased. This augmentation in proximity frequency has consequently* ***increased the number of attacks and created a "gray area" of responsibility for lifeguard units****. The SAVRRS device is the unmanned repellent-dispersing solution that will improve shark-attack response without endangering more patrons or lifeguards during rescue attempts.*

Industry developed repellent for diving purposes is the most efficient method of deterring a shark from an area. By designing a vehicle that could reach the victim and disperse the potent repellent quickly, Team Air-to-Shark (ATS) believes that it could accomplish the goal of decrease the response time, as well as increase the success rate, for all future shark-attack rescue attempts.

It is noted that the original consideration for the project was from a preventative viewpoint. The project concept was centered around the idea of an artificial intelligence platform that would scan shorelines to identify potential predator proximity threats. However, due to capstone course providing limited time and budget resources, the project was recalibrated to be a final line of defense to aid lifeguards in rescue attempts.

The ultimate customer need is a commercial production product with an estimated production of 3000 units per year for five years. This would allow every lifeguard tower that lies within a known shark-attack area on the western and eastern seaboards (of the United States) to have the product. However, the scope of the project will be limited to a prototype design that addresses the problem statement due to labor and cost restraints of the capstone course. The key production unit needs are integrated into the final prototype requirements and a commercialization plan for future development is addressed in this report.

1.3 Physics Involved

The following are some of the physics involved in our project.

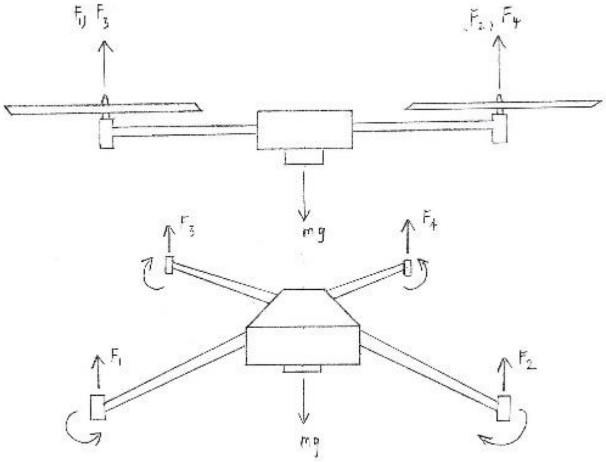


Figure 1.3.1: Free body diagram of quadcopter

The equations of motion for the free body diagram above are as follows:

$$F_t = F_1 + F_2 + F_3 + F_4$$
$$\Sigma F_x = 0$$
$$\Sigma F_y = F_t - mg$$

Where

$$F_t = F_{total}$$
$$F_1, F_2, F_3, F_4 = Force\ by\ Propellers$$
$$\Sigma F_x = \ Sum\ of\ Forces\ in\ x\ direction$$
$$\Sigma F_y = \ Sum\ of\ Forces\ in\ y\ direction$$
$$m = Mass$$
$$g = Gravitaional\ field\ strength$$

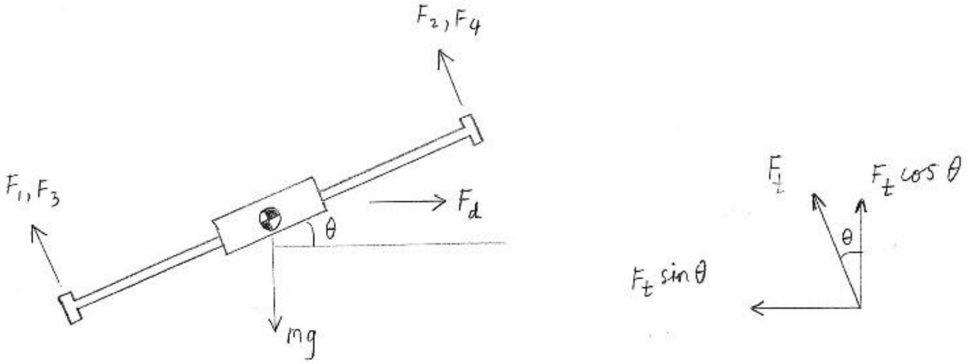


Figure 1.3.2: Free body diagram of quadcopter

The equations of motion for figure 1.3.2 are as follows:

$$F_t = F_1 + F_2 + F_3 + F_4$$
$$\Sigma F_x : F_t \sin(\theta) - F_d = ma$$
$$\Sigma F_y : F_t \cos(\theta) - mg = 0$$

Where

$$F_t = F_{total}$$
$$F_1, F_2, F_3, F_4 = Force\ by\ Propellers$$
$$\Sigma F_x = \ Sum\ of\ Forces\ in\ x\ direction$$
$$\Sigma F_y = \ Sum\ of\ Forces\ in\ y\ direction$$
$$m = Mass$$
$$g = Gravitaional\ field\ strength$$
$$F_d = Drag\ Force$$
$$a = Acceleration$$
$$\theta = Angle\ from\ Horizonatal$$

The selection of the right propellers for the system is one of the important things to do in this project. Unlike from other flying objects, such as an air plane and helicopter, all of the flight maneuvers of the quadcopter are done by the four propellers. The speed of each propeller is the only mechanical movement in quadcopter operation. Therefore, the design of the propeller is one of the most important parts of the system. For hover still, the net force between thrust from propeller and gravitational force must be equal, sum of the thrust and gravitational force is equal to zero. While ascending, the total thrust is greater than gravitational force and for descending, thrust is less than gravitational force. Yaw is rotating either left or right. Which can be done by the speed array of diagonal propellers. For example, in hover still, all propeller speed is rotating equally or 25% each but yawning to the right, the speed of front right propeller and rear left propeller will greater than front left propeller and rear right propeller. Similarly, for yawning to the left, the speed of front left propeller and rear right propeller will greater than front right propeller and rear left propeller. Pitch is the movement of the quadcopter either forward or backward. Which is done by the propeller speed array of front two propellers and rear two propellers. To move forward, the speed of rear two propeller must be greater than that of two in rear. To move backward, the speed of front two propeller must be greater than that of two in front. Rolling is like pitch but drifting left or right. For rolling to the right, the speed of two propellers from the left must be greater than that of two propellers from the right. For rolling to the left, the speed of two propellers from the right must be greater than the that of two propellers from the left.

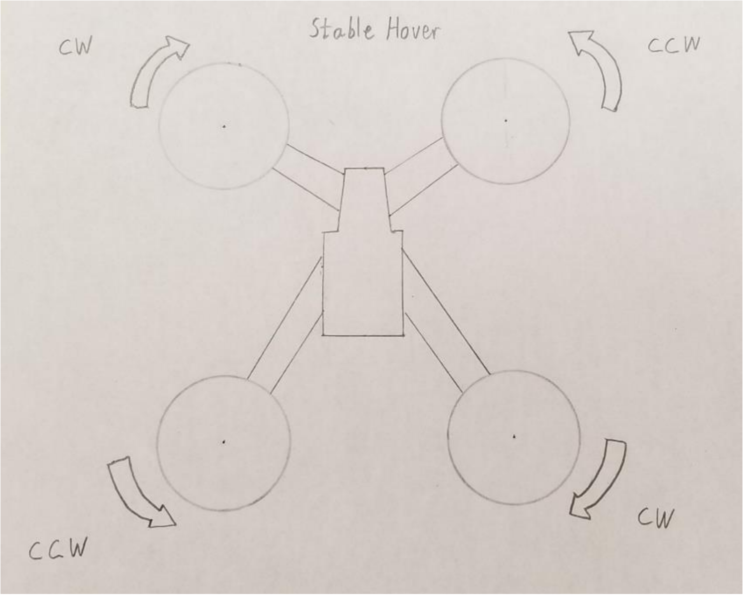


Figure 1.3.3 Top view of the quadcopter and direction of propeller rotation

The amount of thrust produced by a propeller is called static thrust. The static thrust can be calculated the power transmitted by motors to the propellers in term of its rotational speed. The power can be calculated by using the formula shown in the following.

$$P = PC * \omega \tag{1.1}$$

Where,

P = Power

PC = Propeller Constant

ω = rotational speed of propeller

The thrust produced by propeller can be calculated by using following formulas.

$$T = \frac{\pi}{4} * D^2 * \rho * v * \Delta v \tag{1.2}$$

Where,

T = Thrust
D = Diameter of Propeller
v = Velocity of Air at Propeller
Δv = Velocity of Air accelerated by Propeller
ρ = Density of Air which is (1.225 kg/m^3)

The relation between mass and power can be calculated by using following formula.

$$m = \frac{\left[\frac{\pi}{2} * D^2 * \rho * P^2\right]^{1/3}}{g}$$

Where,

m = mass
g = gravitational constant which is 9.81 m/s^2

1.4 Project Scope and Limitations

The project scope that follows defines all project components and variables that the team is responsible for over the life of the project. This includes and is limited to the designing and manufacturing the vehicle that will reach the victim's location, the container to hold the repellent during travel, and the rig that will attach the container to the vehicle's chassis. The team will also create an actuation device that will enable the disbursement of the repellent once the vehicle has reached the target.

The team will not be responsible for any of the repellent features itself and have accepted the effectiveness rate of the manufacturer's formula, as well as the corresponding statistics. The shark repellent will be purchased from BCB International Ltd. and the specific shark repellent that will be utilized is MM208 Shark Repellent. For more information and safety data sheet[1], refer the team notebook's conceptual design section. The team will also be held accountable for the functionality of the prototype. The UAV as designed by the team will be assembled based on existing market components but will not manufactured directly from raw materials based on time and budget constraints.

All future standards required for legal operation and mass implementation will be reserved to the sole responsibility of user and adapting entities. Further alterations needed or requested will be determined to lie outside the scope and will require privatized retrofit assembly. Team ATS states its release from liability in any event of future use without intended success.

1.5 Societal Impact

As a team of engineers, our goal is to create a product that benefits society. The problem statement clearly demonstrates how there is a societal need to improve marine safety measures. Not only will Team ATS that will increase the safety for lifeguards and patrons attempting to save a shark-attack victim, this is also increasing the likelihood of a successful rescue of the victim themselves. This sequence of improvements will ultimately lead to a decrease in secondary attacks on rescuers and lower fatality rate of shark-attack victims.

1.6 Applicable Contemporary Engineering Issues

The team has implemented a series of 21st century engineering instruments in addressing key issues of the project. Modern engineering applications to be used include: 3-D printing for weight savings and rigidity, CNC machining for precise manufacturing dimensions and tolerances, as well as FEA and optimization techniques to meet optimum design points using SolidWorks and ANSYS. Other current technologies utilized to accomplish the project functions are a team-constructed UAV controllable via digital signal.

Furthermore, it should be noted that the project focus is centered on the idea of repellent dispersal. Currently, repellent is used via one-time use metallic bags that are opened individually by ocean goers. The team's system would allow for a refillable actuation device that ultimately eliminates the need for the use of metallic bags. The actuation device will be comprised of an Pix-hawk 2 Cube flight control module, servo motors and an actuator trigger.

All modes of modern engineering applications have been vetted to produce an efficient, reliable, and effective prototype as part of the MEE 488/489 standards.

1.7 ABET Accreditation and the Assessment Fair

The MEE 488/489 capstone project serves as a method of evaluating Arizona State University's mechanical engineering program. The completion of the project and final report facilitates a portion of the University's evaluation. The ABET Accreditation and Assessment fair are how the assessment is completed. ABET board members will be able to successfully find objective and conclusive evidence that each of the corresponding criterion as outlined in the MEE 488/489 capstone text book. For a specific list of examples for ABET outcomes, refer to the ABET report cross reference table at the beginning of this report.

1.8 Report Organization

The overall report is divided into thirteen sections. Section 1 introduces the societal need, problem statement, and the overall purpose of the project. Section 2 presents the final design in prototype form as the solution to the finalized problem statement. The following eight sections give details of the development process including the Design Process and Project Plan, Requirements, Conceptual Design, Preliminary Design, Detailed Design, Prototype Fabrication and Assembly, Development and Validation. Section 11 outlines Team ATS's effectiveness over the life of the project. Section 12 and 13 include project conclusions and future recommendations, respectively. The Appendices are provided after Section 13, these will house extensive analysis and additional information which the team deemed important, but unnecessary to include in the formal report.

1.9 Project Notebook

Team ATS has organized all its work into a Team Project Notebook that is used throughout MEE 488/489 to document all work pertaining to the project. The notebook contains detailed descriptions of all trade studies, analyses, tests and team decision making processes. The final report is written as a comprehensive document that can solely represent the project in its entirety. However, it refers to the notebook as needed to direct the reader to more detailed information regarding the design and manufacturing process.

2. Final Design Description

The completed Shark-Attack Victim Response and Repellent System was designed to create a shark-free environment by disbursing a predator repellent, deterring the animal from the victim's location, that would enable lifeguards to preform safe rescues as needed. The prototype is made up of two independent sub-systems: the UAV and distribution system. The UAV is comprised of a T-6 6061 aluminum body, assembled using standard ASME hardware for easy construction. The electronic components are made up of the main control board and power supply, both of which are detailed within this report. The distribution system was largely constructed using 3D-printed polycarbonate plastic and is completed with a transparent piece of polycarbonate (manufactured via CNC) that enables users a direct line of sight in to the functional actuation of the vessel. These two subsystems are adjoined through the slider mechanism, also polycarbonate plastic for weight purposes, which acts as the mating point and supports the load carried by the UAV. The two sub-systems were designed as separate entities allowing for one distribution vessel to be removed and another quickly attached to eliminate the need for intermediary refueling. The following sections of this chapter provides an overview of the prototype, it's operational capabilities and the functional results of the system.

2.1 Design Description Overview

SAVRRS is a UAV based system which carries a container in which there is liquid shark repellent. The idea is that when a shark attack occurs along the shore, coastal guard can use the device to aid in the rescue effort. It will fly to the attack area and release the repellent over the area without needing to go to the water. That way the SAVRRS project can mitigate the risk from the shark attack to coastal guards. Since the product uses a UAV is flying over the ocean, light weight and corrosive resistance are some concern for the team. The frame of the UAV is constructed with aluminum and container is made with ABS plastic and polycarbonate top cover. Polycarbonate is strong and transparent. Therefore, by using polycarbonate at the top of the container, customer can see inside the container easily. This feature is shown in figure 2.1.3. There is a rubber stopper at the top of the container which allows user to refill the repellent easily. For the user convenience, the container can attach and detach from the UAV body. The upper slider will attach with the UAV body shown in figure 2.1.2 which can perfectly connect the lower slider form the repellent container. As well as there is key between upper slider and lower slider. Upper key is directly attached to the servo motor and the lower key is attached with the locker which controls the container's door.

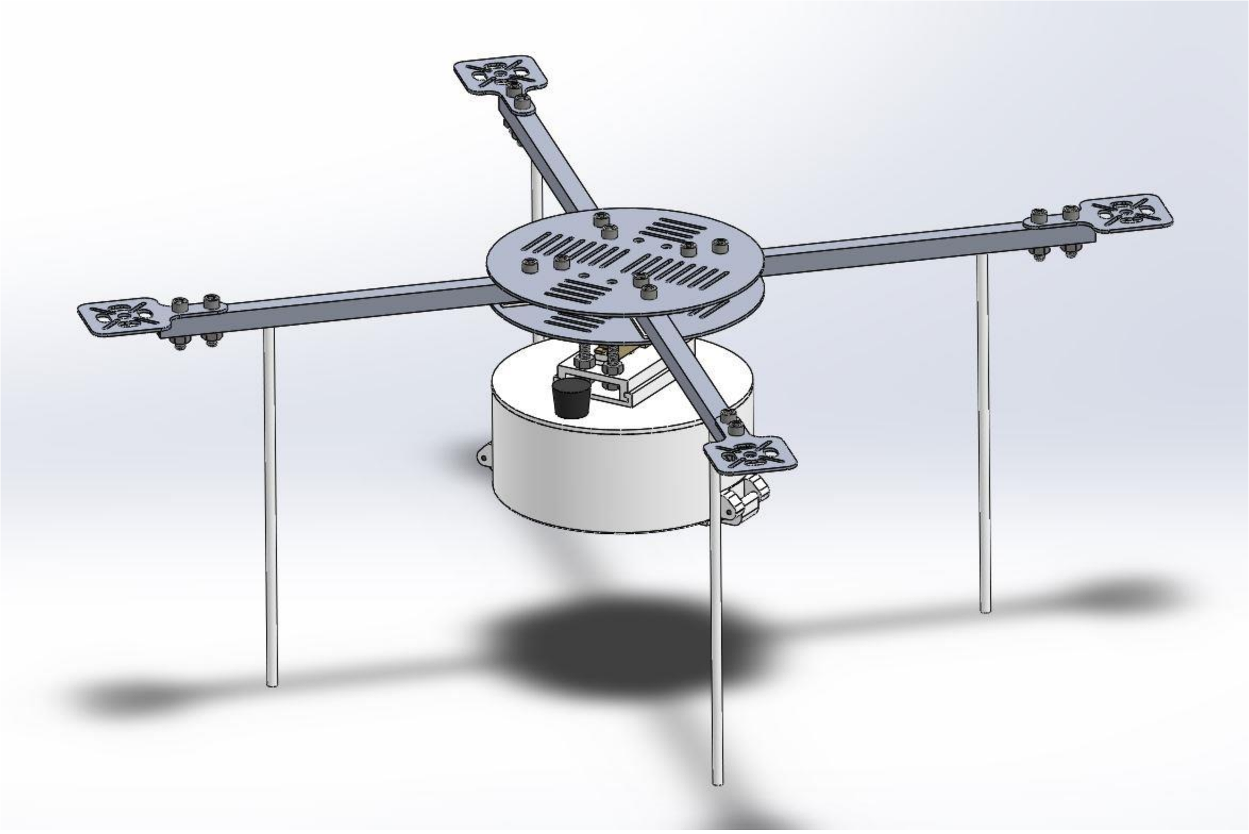


Figure 2.1.1: Full assembly of the Shark-Attack Victim Response and Repellent System

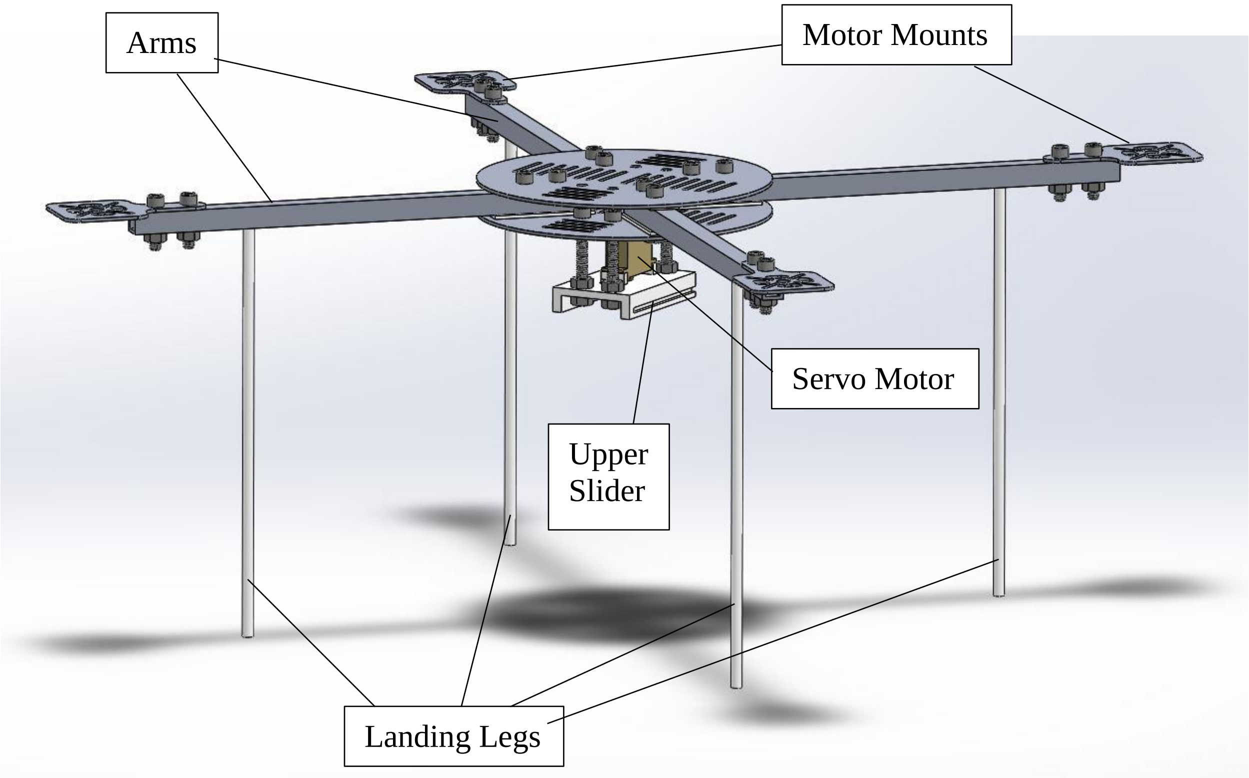


Figure 2.1.2: Isometric View of the UAV Subsystem

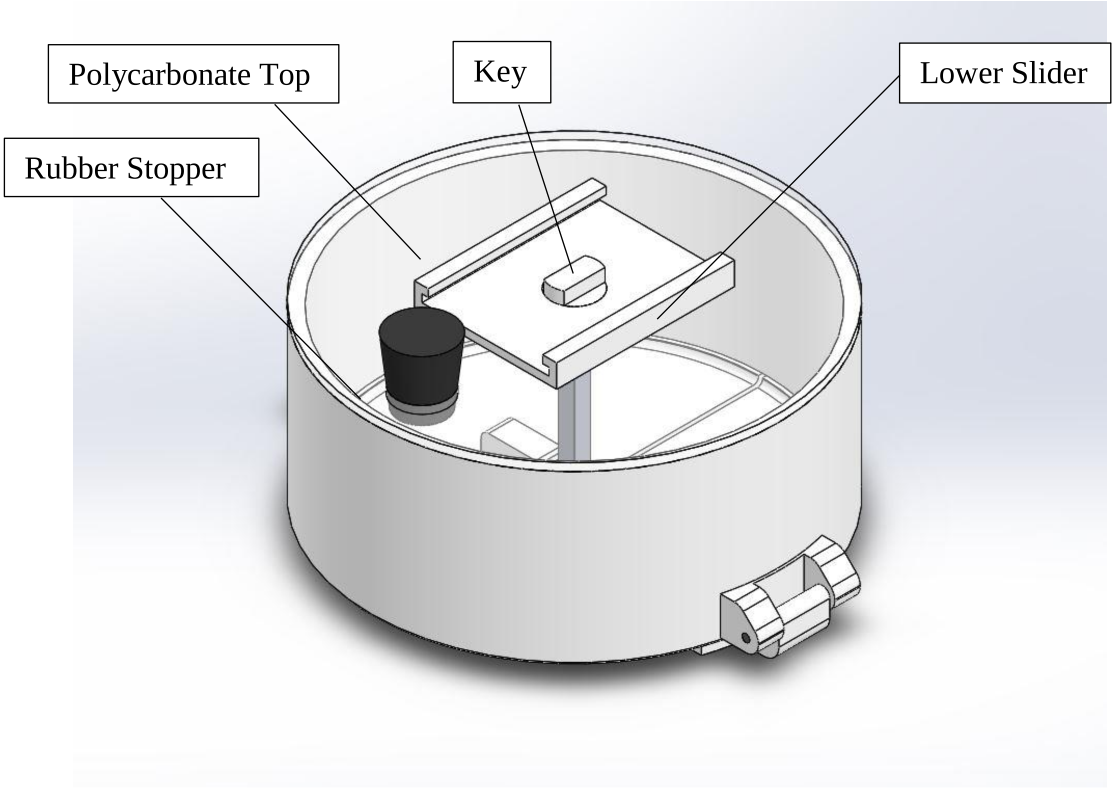


Figure 2.1.3: Isometric View of the Repellent Container Subsystem

Table 2.1. Characteristic Table for SAVRRS

Characteristic	Results
Weight	1.8 kg
Dimensions	682 mm (diagonal)
Speed	45 km/h
Operation Altitude	10 m
Container Volume	1 liter

2.2 Method of Operation

The user will at the start of the day engage the Ardu-Pilot “Mission Planner” software from the base station computer to be ready for action. The reservoir is designed to be leak-free and will be pre-filled with shark repellant fluid in the event of an attack. If a shark attack occurs the user will mount the filled reservoir to the UAV via the slider attachment mechanism, taking care the align the connector on the top of the reservoir as marked for fit. Operation of the flight and payload release will take place a handheld 900 MHz dual toggle stick RC transmitter/receiver. The user will next connect battery power to the flight control module via XT-90 power connector and the flight control module will be flight ready. In the commercial version the user will activate the Hero7 camera on the front of the unit that will transmit live footage to the user’s cell phone or base station before supplying power to the flight control and motors.

Ardu-Pilot software is set up for fly by wire giving user intuitive up to go up, down to go down, forward to go forward, back to go back, left to go left, and right to go right controls with the toggles while maintaining orientation from base station control. The commercial version will feature preset cruising altitude, take off, and landing routines. The user will activate the payload release via simple servo activation switch on RC unit. The user will then return the UAV to its station and resume lifeguard activities. In the commercial version the user will activate automatic return flight plan upon payload release and instantly resume lifeguard activities. Once emergency lifeguard activity has concluded the user will trigger the servo return with the reservoir doors still open and power down the unit from the base station. The user will then disconnect the battery and recharge it. Once the servo return occurs the reservoir may be detached, and the doors may be closed and relocked.

2.3 Key Features and Benefits

The SAVRRS is designed to exhibit a variety of beneficial features for the user. Given that the primary customer for this product will be lifeguards, a series of features were implemented specifically with them in mind. Table 2.3.1 below lists a variety of features and their corresponding benefits pertaining to the SAVRRS device.

Table 2.3.1: Features and Benefits of SAVRRS

Feature	**Benefit(s)**
High Capacity Battery	• Allows for longer flight time • Sufficient power output for all mechanical and electrical components
Liquid-Tight Reservoir	• Retains shark-repellant fluid until desired distribution time • Easy refilling without fear of losing fluid
Bomb-Bay Style Disbursement Doors	• Quick distribution onto target • Easy sealing before mission
Removable Reservoir System	• Allows for many backups to be kept for quick mission setup • Simple loading and unloading of reservoir
Quad-Copter Propeller Configuration	• Enhanced maneuverability • Better flight control and accuracy
Remote Servo Actuation	• Fluid may be distributed while vehicle is above victim
Clear Reservoir Lid	• Easy to see fluid level • Much easier to lock doors when they are visible
Manual Door-Locking System	• Ensures no mechanical error when closing the doors post-mission

2.4 Key Performance Results

The most important key performance characteristics for SAVRRS device are flight time, flight velocity, payload and dispersion system. Following table is shown the key performance and results of SAVRRRS device.

Table 2.4.1 Key Performance Results of the SAVRRS System

Key Performance	Results
Flight Time	9 minutes
Flight Velocity	8.2 m/s
Flight Payload	4.5 kg
Dispersion System (Impact Diameter)	1.4 meter from 10 meters

The goal of the project is to stop the shark attack as quickly as possible. Therefore, velocity of the UAV is one of the key performances of the prototype. The maximum velocity of SAVRRS could reach approximately 8 m/s which could reach to the victim within 20 second. Another key performance are flight time payload and impact diameter. As our test result, all major key performance was passed. We could also extend our flight time by upgrading higher capacity battery.

2.5 Cost Results

This section will discuss about the cost status of the project while manufacturing of the prototype. The table that follows gives a summary of all purchases made to complete the product.

Table 2.5.1: Purchases Made During the Construction of the Prototype

Component	Actual Price
Carbon Fiber Propeller 14*5.5	$24.92
Pix-hawk 2 CUBE Flight Control Module	-
SW0250MG - Waterproof Micro Digital Servo .11/69@6V	$27.99
3510-350kV Carbon Case multi-rotor brushless motor	$160.40
Multi-Star 30A Brushless ESC 32 bit 2-6s	$39.96
6s 12c 6600 mAh Turnigy Lipo-pack w/ XT90	$82.70
Pix-Hawk 2 900MHz Telemetry Antennae	-
5.8GHz 200 mW Transmitter/Receiver & RC-FPV 800 TVL	-
LED Screen	-
Remote Controller	-
Gasket	$15.09
Camera	$0.00
Passivated 18-8 Stainless Steel Pan Head Phillips Screw, 1/4"-20 Thread, 1" Long (91772A542)	$17.52
Hex Nut (90762A112)	$26.85
18-8 Stainless Steel Socket Head Screw, 1/4"-20 Thread Size, 2-1/2" Long, Fully Threaded (92196A821)	$10.00
Velcro Straps	$9.18
Black UV Stabilized 12” Nylon Cable Ties	$7.78
Polycarbonate Sheet	$16.17
3D Print Cost	$100.00
ABS Filament	$20.00
Stainless Steel Rod (for hinge)	$2.70
Square Rod for Actuation System	$1.16
Square Hollow Aluminum Rod	$7.77
Aluminum Sheet	$31.56
Fiberglass Rod	$5.00
Additional Screws	$4.00
Tax	$3.85
Shipping	$56.16
Total Price	**$670.76**

The items containing dash lines with no monetary value represents personal items that are already in hand by teammates that will be used in the prototype process as these items will add on more costs and are expensive to obtain.

To better visualize this data, the pie chart that follows contains the percentage of the expenditure that was used per item.

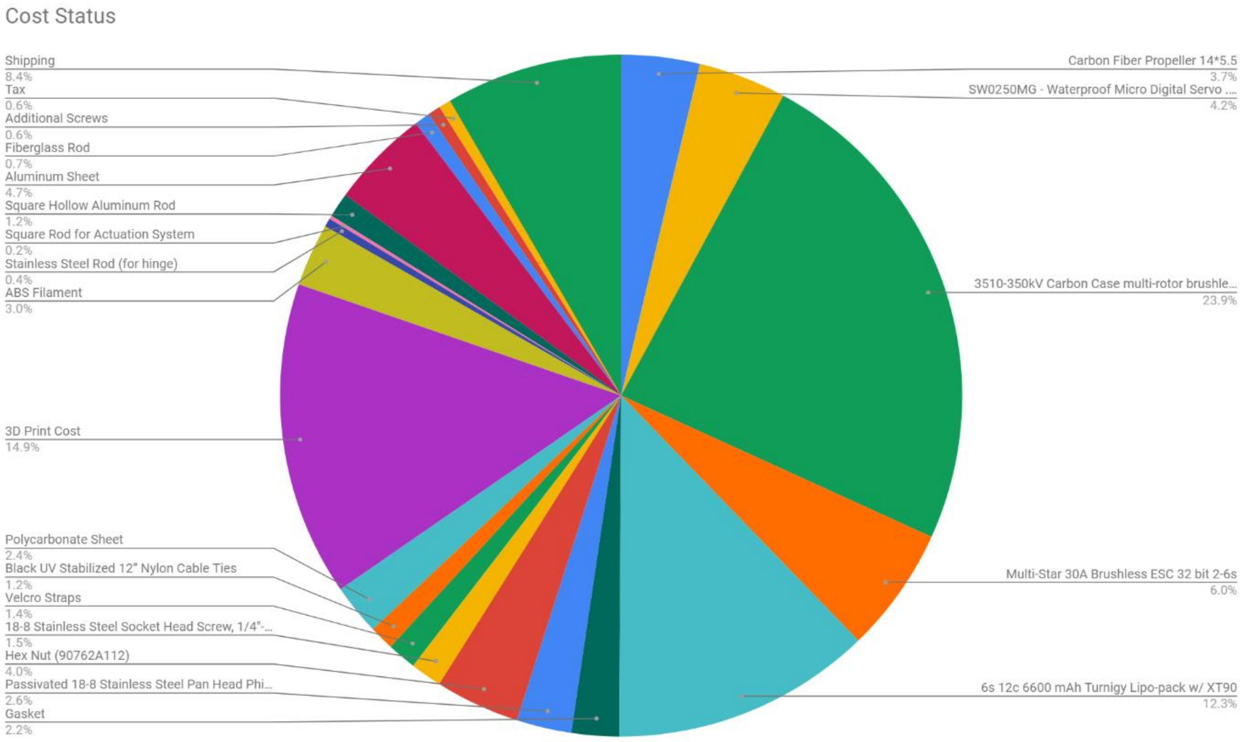


Figure 2.5.1: Percentage Price Breakdown of Expenditures

As it can be seen, a large component of the budget was allocated for the motors purchased and the 3D print costs. This makes sense from the team's perspective as it is vital that the motors function properly to ensure the product works optimally and the container and other 3D printed items are of high use and requires better precision and more strength. The next most expensive item was the battery, and this again makes sense as the team can then conduct testing and optimization better by allowing the prototype to run for extended periods of time and during the actual usage by the customer, the customer won't have to keep recharging the product in between runs.

The team has managed the budget very well and made sure the prototype was on target to the allocated budget. The remainder of the budget will be used for printed material during the capstone ABET Accreditation Fair and other items that may need to be purchased last minute to complete the project.

2.6 Requirements/Validation Matrix

Team Air to shark transformed the voce of costumer VOC into measurable engineering requirements. The team did an interview to know the costumer's need and then comes with 20 requirements to be tasted and studied for the prototype. These requirements are address the design to meet the costumer's expectations. The below table shows the requirement, method of validation which explain the method for every requirement, Validation result which shows the track for every requirement, and the reference page which shows the page for every test or analysis for every requirement. NOTE: The team has retroactively included the completion status for each of these requirements even though they had not yet been completed during this design phase.

Table 2.6.1: Requirements Validation Matrix

No.	Prototype Requirement	Method of Validation	Validation Result	Reference Section
1	Storable in 2.5 m x 2.5 m x 2.5 m lifeguard tower	Analysis	Complete	7.2, 8.3, 10.2.1
2	UAV capable of flying with 4.5 kg of additional weight	Analysis and Testing	A: Complete T: Complete	9.2.7, 10.2.2
3	Repellent reservoir can hold 1 liters of liquid	Analysis	Complete	9.2.2, 10.2.3
4	Flight time to be less than 45 seconds. Flight time is equal to cold start, fly 100 meters offshore, and drop payload	Analysis and Testing	A: Complete T: Complete	9.2.6, 9.2.7, 10.2.4
5	Time from actuating drop-sequence to surface impact of full payload less than 3 seconds	Demonstration	Complete	9.2.4, 10.2.5
6	Drop payload within 1.5 m radius	Analysis and Testing	A: Complete T: Complete	9.2.5, 10.2.6
7	Drops payload within 1.5 m of designated target 98% of trials	Analysis and Testing	A: Complete T: Complete	9.2.5, 10.2.7
8	Material and manufacturing costs less than $700	Calculations	Complete	11.4, 10.2.8
9	Operate and carry payload using a 6600 mAh power supply, and minimize the power needed to actuate disbursement	Analysis	Complete	9.2.7, 10.2.9
10	Maintain 25 km/hr with payload to satisfy response time requirement	Analysis and Testing	A: Complete T: Complete	9.2.7, 9.2.8, 10.2.10
11	Hover 10 m above drop zone	Demonstration and Testing	D: Complete T: Complete	9.2.6, 9.2.7, 10.2.11

12	Fly with payload up to 15 m above sea level	Analysis and Testing	A: Complete T: Complete	9.2.6, 9.2.7, 10.2.12
13	Operate between 10° C and 40° C	Demonstration	Complete	9.2.1, 9.2.2, 9.2.3, 9.2.4 9.2.6, 9.2.7, 9.2.8, 10.2.13
14	Operate above sea level	Demonstration	Complete	9.2.6, 9.2.7, 10.2.14
15	Withstand sand and saltwater corrosion, to operate without repair for 6-months	Inspection	Complete	10.2.15
16	Someone can be trained to use device within 8 hours of training and is intuitive operation	Testing	Complete	9.2.6, 9.2.7, 9.2.8, 10.2.16
17	UAV allows for guards on the outer 90° of blades to be protected from contact	Demonstration	Complete	10.2.17
18	Design and production must be accomplished within 6 months with 7-team members	Demonstration	Complete	11.1-11.5, 10.2.18
19	Power supply can allow for 20 minutes of flight without recharging	Analysis and Testing	A: Complete T: Complete	9.2.7, 10.2.19
20	Disbursement system comprised of less than 5 components, to reduce failure probability	Demonstration	Complete	8.3, 10.2.20

2.7 Drawing Package Overview

The design of SAVRRS has been done by using Solid Works software. The formal drawing sheets cover all components that required to manufacture by the team. Therefore, vendor parts including motors, propellers, control board, electronic speed controller (ESC), battery, etc., are not performed in the drawing sheet. However, they are included on bill of materials (BOM) from the drawing sheets. The detail drawings are in Appendix B.

2.8 Prototype Hardware

This section will go through the components that can be seen on the prototype built. This will help to visually understand where each component was utilized in the prototype. Please note as of the current compiling of this document the final prototype is yet to be assembled. Updates will be made to this section as progress goes forward, primarily containing to combining all subsystems and connecting the electronics to the prototype.

Figures 2.8.1 and 2.8.2 shows how the body of the drone was compiled to bring together the drone subassembly.

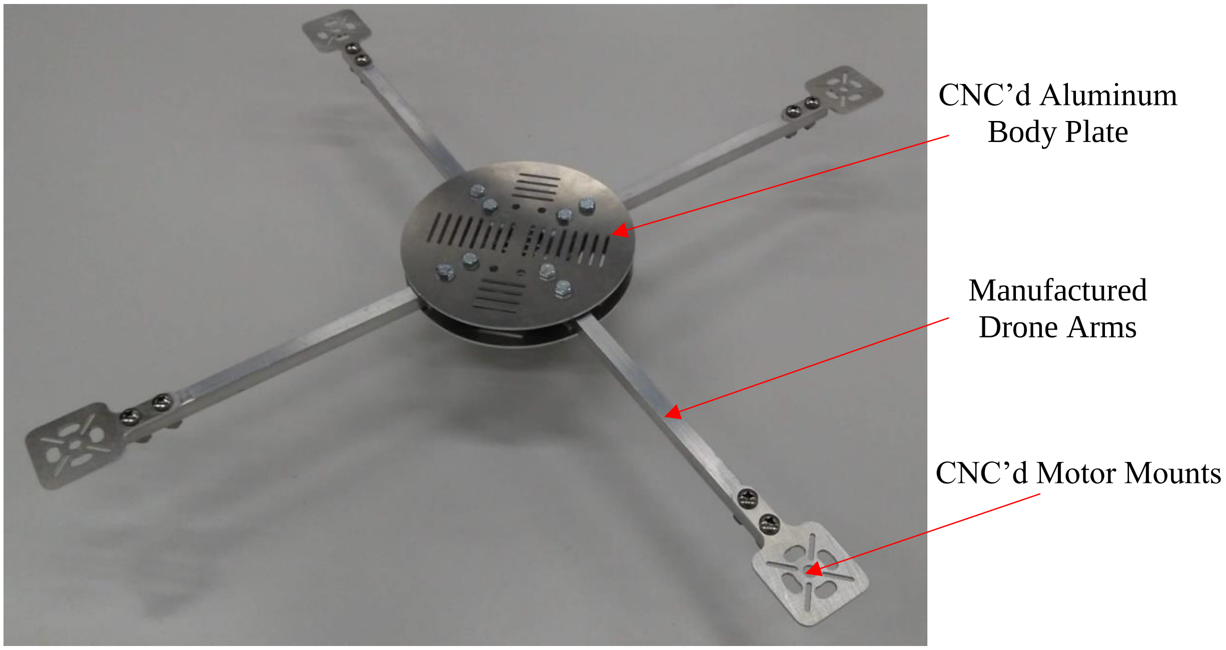


Figure 2.8.1: Drone Subassembly view 1

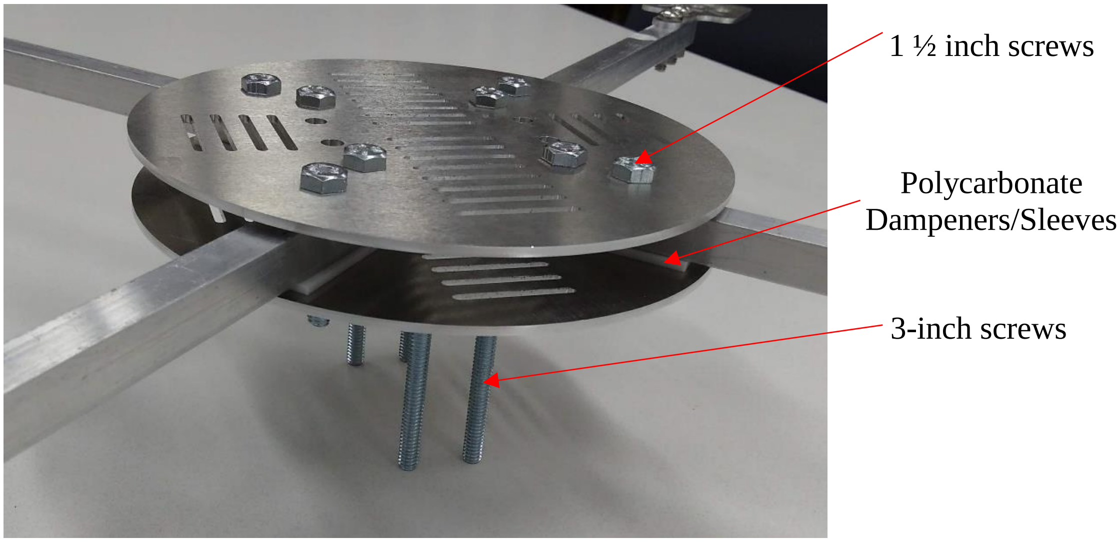


Figure 2.8.2: Drone Body Subassembly view 2

Figures 2.8.2 and 2.8.3 shows how the container subassembly was assembled and also contains the actuation system and slider attachments.

Figure 2.8.4 shows the slider attachment and the actuation system which will connect to the container subassembly.

Figure 2.8.4 Distribution System Prototype Assembly

Figures 2.8.5 through 2.8.7 show a final assembly of the prototype with all the electronic components attached and all subassemblies assembled from three views.

Figure 2.8.5 SAVRRS Final Prototype View 1

Figure 2.8.6 SAVRRS Final Prototype View 2

Figure 2.8.7 SAVRRS Final Prototype View 3

2.9 Intellectual Property Considerations

The SAVRRS device provides a real customer need that is currently not being met by products readily available on the market. There are other competing prototypes with unique functionalities, independent of the SAVRRS operational features, but all remain in the early developmental phases of trial testing. Therefore, the SAVRRS device in its entirety has been determined *not eligible* for patented protection at this time.

At an independent component level, however, the slider attachment device has the capability of being patented for its functionality. The slider attachment designed by Team Air-to-Shark is entirely proprietary of the team because of the design and optimization efforts. This component was designed with the dual purpose of attaching the disbursement vessel to the underbody of the

UAV and safely securing it during operation, as well as providing easy on-and-off attachment. In the event multiple repellent disbursements are needed, the slider attachment device could allow operators to detach an empty disbursement container and reload a full vessel. Thus, eliminating a need for refueling and reducing the intermediate downtime. Although, the SAVRRS prototype does not have this same capability due to project budget and time constraints, the slider attachment device was originally designed for this purpose—making it unique to all competing options*. This qualifies as a “useful” characteristic under USPTO qualification of being a clear, identifiable benefit for utility patent protection. While research efforts are ongoing for novel and non-obvious qualification standards, no other attempts have been made to secure a patent for the device at this time.

2.10 Product Unit Description

Our team’s problem statement was to design a remotely controlled vehicle to help facilitate safe and fast rescue of shark attack victims. Sharks most often deliver the initial bite to mortally wound the target and return to the prey after bleeding out. This fact and the current rules preventing lifeguards to enter the water and attempt rescue when there is a known shark presence make rescue of victims difficult and problematic for lifeguards. By delivering almost 3 times the amount of shark repellent required to the victim’s area immediately upon attack the shark is not only prevented from returning to finish the victim off, but the lifeguard can also make the reasonable assumption that the immediate vicinity is shark free and attempt rescue without further delay.

The prototype manufactured will be similar in most regards to the production unit with the major addition of a wireless 4K live streaming camera, a secondary base station GPS module allowing for more complex and automated flight controls, and more carbon fiber will be substituted for the existing aluminum, all at greater expense outside project budget constraints. These additions will upgrade the prototype to a fully functioning end user product that satisfies every need of the problem statement.

2.11 Commercialization Plan Summary

The commercialization plan is essentially adding what could not be afforded in the initial budget. This is a camera system, base station GPS, and higher quality materials for UAV body. Manufacturing methods would necessarily change to accommodate a larger volume of manufacturing. To move forward with a commercial product an LLC at minimum would need to be established to secure the companies legitimacy and any intellectual property available to the product.

1. Upgrade design of UAV frame with extensive carbon fiber replacement of existing Aluminum.
2. Upgrade design to include base station with Here2 GPS for automatic UAV flight routines.
3. Upgrade design of UAV with Gimbled Hero7 wireless 4K camera with built in live streaming.
4. Establish Company: Air-To-Shark Systems LLC.
5. Investigate intellectual property possibilities and secure any available.
6. Change manufacturing methods of Aluminum from CNC to Die and Stamp for higher production volume.

7. Change reservoir manufacturing method from 3D print to injection molding for higher production volume.
8. Begin individual sales work or hire sales people depending on financial backing.
9. Find investors or gain capital necessary to ramp up production.
10. Sell product and save lives!

2.12 Rationale for Being the Optimum Prototype Design

Our focus throughout this design and manufacturing process has been accomplishing as much of the proof of concept functionality of the intended product as possible. We focused on flight capability at full weight, ease of use of mechanism, and dependability of delivery mechanism. Other issues than were given secondary concern due to cost were video transmission, and automatic flight routines. Though these will be integral parts of the final commercial product they were ultimately unnecessary in the prototyping.

Video transmission or streaming has become so simple that the latest GoPro can do it on your phone or anywhere else on the internet and requires very little actual engineering. The automatic flight routines will be preprogrammed in as much detail as possible without actual use of base station GPS and will be ready for the eventual end user with minimal modification. The actual motors, rotors, ESCs, and the battery power necessary to get 3+ kg off the ground are quite expensive. The flight control and GPS are expensive as well leaving the project very little room with one-off manufacturing of all components. Sacrifices were made but in the end, we have developed a prototype that shows it is capable of doing the job that is needed and will produce and end product that will perform in the environment.

3. Design Process and Project Planning

Over the course of this project, the team followed the six phase Integrated Product Development and Support (IPDS) process. The rational for this is so that the team can obtain the optimum product design within the limited recourses available. Section 3 outlines the team's initial plan for completing the 30-week IPDS project.

It is important to note that this section does not reflect the exact series of events performed by the team, but rather it is the plan developed during the pre-conceptual phase. For this reason, the following sections are written in future tense since the team had not yet performed any of the tasks.

For a complete presentation of the team's actual conduct in terms of schedule and budget, refer to Section 11.

3.1 Integrated Product Development and Support (IPDS) Process

The IPDS process consists of six unique phases designed to enable the team to create an optimal product. The six phases consist of the following:

- Phase 1: Pre-Conceptual Design (Proposal) Phase
- Phase 2: Conceptual Design Phase
- Phase 3: Preliminary Design Phase
- Phase 4: Detailed Design Phase,
- Phase 5: Fabrication, Assembly and Testing Phase
- Phase 6: Production and Commercialization

For the purposes of this class, the project will fulfill phases 1 through 5. Phase 6, Production and Commercialization will not be completed by the end of the 30-week project. The team will still act as though the Production and Commercialization phase will be performed, thus motivating the creation of an optimum final design.

Figure 3.1.1 is a diagram mapping out the process in an easy to understand manner. Each of the six phases are represented by a box, and the expected outcome of each phase is shown in a blue ellipse.

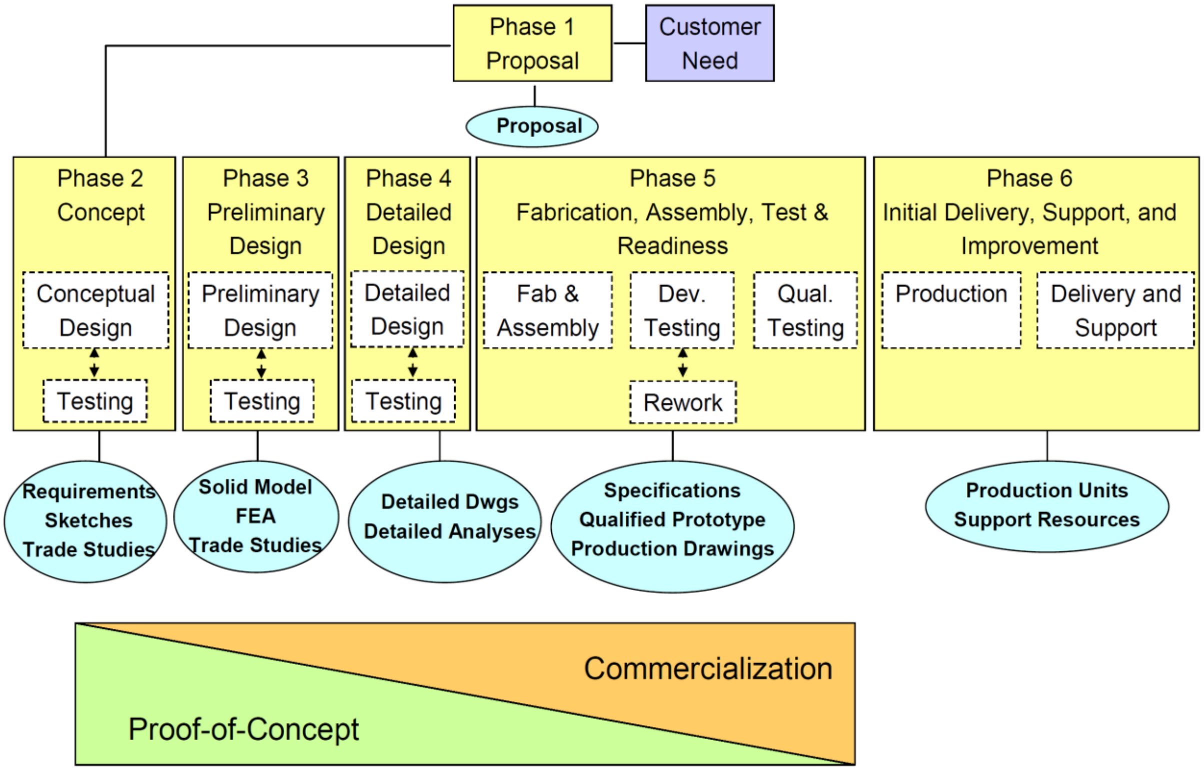


Figure 3.1.1: A block diagram outline of the IPDS Engineering Process[2]

At the end of each phase, our team will participate in a design review where the professor and his assitants will provide feedback and make sure the deliverables of each phase are met.

A.T.S Systems hopes that by following the IPDS process, an optimal prototype can be created by the end of the semester. Ideally, the rigin nature of our methodology will allow for an increased awareness of the needs, functions, flaws, and optimizations of the shark repellent distribution system. Keeping the customer needs as the higest priority, we plan on creating a practical product that not only meets, but exceeds the functional requirements.

3.2 Project Plan

This Project Plan details the organizational responsibilities of the team to secure the ideal design and execution while staying inside the financial and time restrictions imposed while serving as the governing document for the project. The following subsections outline this plan.

3.2.1 Overview

The project plan being imposed carefully lists every step of the project planning phase starting with the customer need and problem statement and culminating in a final proposal containing a complete professional project plan.

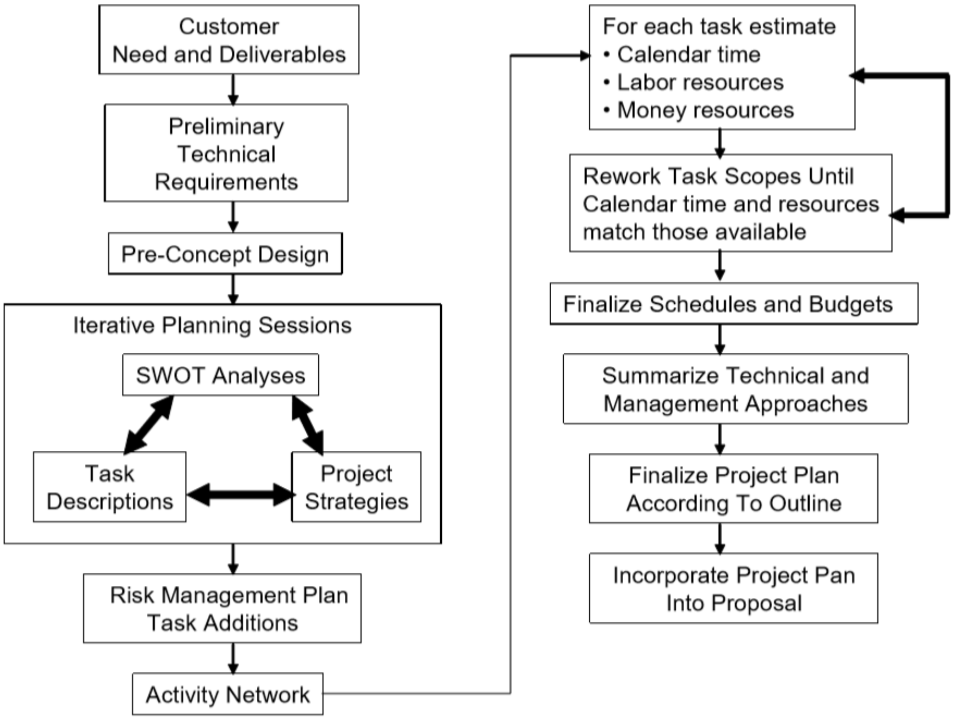


Figure 3.2.1.1. Project Plan Preparation Flowchart[2]

Both online in a team drive and physically in a three-ring binder will be kept exact documentation of the plan, process, execution, and the ABET accreditation standards that have been met. This documentation along with a fabricated prototype are the project deliverables The Team is responsible to produce for the sponsors; Professor Abdelrahman Shuaib and the Ira A. Fulton Schools of Engineering at Arizona State University. The Team was formed blindly by filling out questionnaires on catme.org and being placed in a team by a diversity selection algorithm. The team members are; Abdullah Aldawood, Michael Davis, Kyaw Htoo, Derek Jensen, Joshua Morton, Sajana Ratnayake, and Angelica Guzmán.

Recent climate change has driven sharks further in to the coastline and increased the number of shark attacks on US shores and internationally. Sharks moving ever closer to our swimming areas and existing in such proximity to people is inherently and increasingly dangerous for both the sharks and humans. Cities, counties, and states all have a vested interest in maintaining safety of both their local population and tourism. A method for detecting or deterring shark presence within a dangerous proximity is beneficial for both species by enhancing safety for all. Many methods currently being employed to minimize shark presence involve large, costly, and dangerous physical deterrents such as nets and traps. A need for a more cost effective and less intrusive method to keep shorelines safer. At current when a swimmer is attacked by a shark, lifeguards are unable to get into the water and attempt rescue without ensuring the shark has left the area. This current deficit between attack and the available window of time to respond is unacceptable and very dangerous for swimmer and lifeguard alike. The Team will design a device that can be mounted to a RC UAV to respond to a shark attack and dispense shark repellent on and around the victim in order to give the lifeguards on duty the best chance of reaching and saving the shark attack victim. Pre-concept design is used to identify the main constraints and necessary performance characteristics of the intended product. The following section describes the process and the conclusions reached.

3.2.2 Pre-Concept Design

A pre-concept design, while ultimately being disposable upon future in-depth investigations, provides a detailed list of the customer needs and the constraints those needs impose on the project. The following are the main requirements of the project to date:

Table 3.2.2.1. Pre-set of Engineering Requirements

Physical Dimensions	Storable in 8 ft. x 8 ft. x 8 ft. storage shed
Payload Capacity	> 15 lbs.
Launch/Landing Requirements	Able to depart within 30 seconds and return from and to a set location within 1.5 minutes
Navigational Requirements	Able to fly by wire to observe the assigned area and locate victim within 1 square mile of lifeguard tower
Sensing Requirements	Identify shark attack victims optically 300-meter radius within and around beaches occupied by people via camera
Physical Action	Maneuver to within 5 meters of shark attack victim to dispense repellent into water
Information required	Visual data and images regarding shark attack detection and action taken
Course Correction	After shark attack location and repelling, vehicle must return to waypoint navigation home within 1.5 minutes to recharge
Power Requirements	Must have 30 minutes continuous runtime and be able to manually charged/refuel at minimum twice per day
Self-Monitoring Requirements	Sense fuel/power levels and at specified limit 20% batter life, signal alarm to execute emergency return to set location
General Safety Requirements	Do not harm humans or marine wildlife. Defect rate in accordance with 6σ standards (1 part per million)

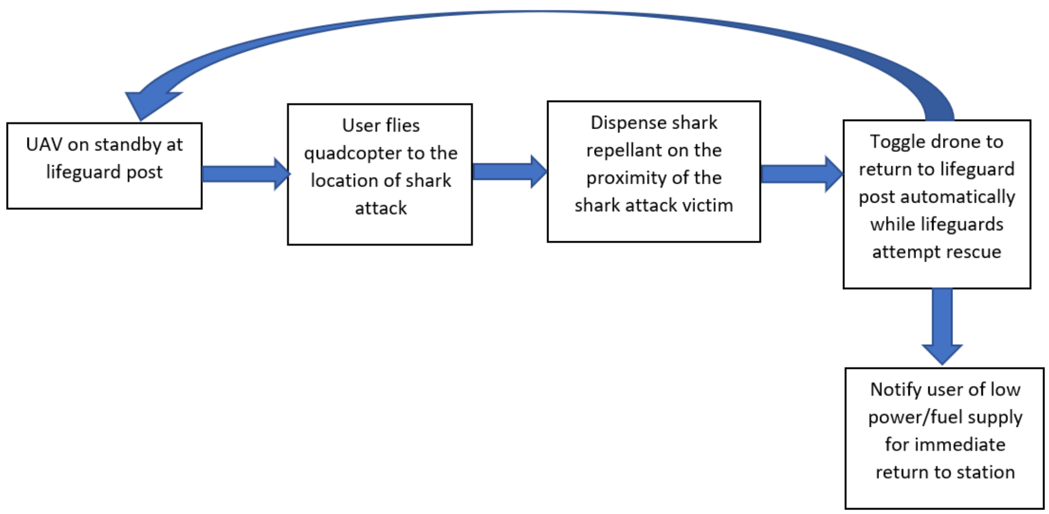


Figure 3.2.2.2. Functional Block Diagram interpreting Pre-Concept design

The device will need to depart and return to a set location. Once deployed, the lifeguard and device must locate shark attack victims, via fly-by-wire, and dispense shark repellent in enough quantity to deter the shark from returning after initial contact to claim its kill as is their habit. Once detection and distribution of repellent have occurred, the device must be able to return to waypoint navigation home and continue ready to intervene and prevent more fatal shark attacks. The device also monitors its own energy supply and will return to launch/landing site at a determined critical value (20% battery life) for replenishment. Additional information and requirements about the design will procured from interviews with customers (Voice of the Customer) and experts until the entire design scope has been deliberated.

3.2.3 Strategies to Address Key Issues

Since Arizona State University Tempe is under a no UAV zone, we are not able to test our project around campus. There is a FAA drone testing center at ASU East AMT Learning Laboratory, we could use that lab to test our UAV. Also, most recreation beaches do have a lot of air traffic such as air-tours, coastal guard and air field, we need to concern very carefully not to conflict with other aircraft. The rule and regulation of unmanned aircraft can be studied www.faa.gov. As well as the behavior of shark and other marine live, season and weather changes in each beach. We will also need to study over them before developing our project design. The UAV must be as light as possible to carry more payload and the use of it will mostly over beaches and shores, the material usage plays major role in this place. Although aluminum is light, durable which is one of the most suitable to use in aircraft design. On the other hand, aluminum can cause the corrosion with salt water and creating aluminum oxide, we will need to concern about the better material. Carbon fiber offers stiffness, strength and even lighter than aluminum, it will better suitable for our project.

Table 3.2.3.1. SWOT Analysis for Strategies to Address Key Issues

Strengths	• Mechanical Analysis. • Have experience in thermodynamic and fluid mechanic. • Have RC flying experience. • Proficient in creating SolidWorks model and printing.
Weakness	• Less knowledge on Zoology and marine live. • Need more Programming and AI technologies skills. • Need knowledge the best type of repellent to fit with the UAV
Opportunity	• Have chance to protect people from live threating sharks. • ASU East has UAV testing center • The device will be first used in US.
Threat	• Environment of ASU Tempe is in no UAV zone • No beach in Arizona to test • Hard to find the UAV to carry certain payload by allowance budget.

3.2.4 Technical Approach

Once the shark attack occurs, the coastal guard will operate the UAV to deploy the repellent over the that place. The radius of the repellent will be around 1.5 meters. The UAV will maintain the altitude between 10 to 15 meters while deploying repellent by using electronic barometer (altitude sensor) which is include in the flight board of UAV system. The combination of UAV itself plus equipment would be around 7.7 lbs. and which can fly about 30 minutes continuously. Around 6600 mAh power battery will be used in the system. Since the battery can be changeable, the UAV system can be used non-stop operating under any circumstance. Once the battery is low, operator can be call back the UAV system by using return-to-home system which is also integrated in flight board, then replace with the new fully charged battery and operated again by another 30 minutes. These processes can be done by any duration as long as the operation needs.

To correctly work on those functions, the UAV will be equipped with elevation sensor, compass sensor, GPS and navigation sensor. There are several techniques and shark repellents such as electrical repellents, magnetic repellents, acoustic repellent, spray repellent, etc. Among them, we will use the chemical shark repellent bag which is cheap and only have 115 grams each payload that best fit with the UAV device. Before actual production, UAV maximum payload, flight time, durability and safety will be calculated. Sketching, SolidWorks modeling and Ansys simulation will be used during production. Another concern is that the effectiveness of the concentration of shark repellent and dilution in the ocean. How much maximum repellent needs is effect on the payload and flight time. Therefore, calculation of those relation will be the key in this project.

3.2.5 Project Management Approach

The team manages the project to ensure maximum success, in project planning we define the objective and the goals to be achieved, defining steps necessary to progress the project, what we need and how we will finish. In team organizing, we assign what tasks need to be accomplished and divide the work load between the group members. The team will meet at least twice a week at ASU Noble library. The team will discuss all pertinent issues in the meeting and make sure that the team is working effectively on their delegated roles. Post action we will evaluate how well the team is achieving our goals and takes corrective action.

Successful teams need to have clearly defined rules, in our group decisions will be made by all group members investigating the situation in detail and generating good alternatives to select the best solution. It is important to us that we make sure all members opinions are accounted for, differences will be addressed by sitting-down together and talk about the issues that let up to these differences and find a solution that we all can agree on. Our process to resolve problems that we discuss about the project will be equitable and inclusive to arrive at a solution to satisfy all parties. Also, teammates must accomplish assigned tasks on time, help each other, and engage in collaborative working to ensure success in our project.

3.2.6 Risk Management Plan

The project contains inherent risks such as physical injury, financial loss and professional reputation. The team possesses individual skills and experience that can be used to mitigate the risks associated with the capstone design project. Below shows a table with some of the risks identified by the team, in addition to the plans to be implemented to mitigate these factors.

Table 3.2.6.1. Risk Management Plan ratings and mitigation plans

Risks	Probability	Mitigate risks
Reach the limit of money we have	High	Calculate cost with shipment for all parts before we order any part, to not reach the limit we have
Unable to complete the project on time	Medium	Time management be on time and do not delay on work
Unable to drive in difficult weather conditions during testing phase	Medium	Make tests for the UAV to know the maximum wind speed that UAV can drive on
UAV material failure	Low	Conduct researches and material testing to find out how far the material can withstand the corrosions and the rough weather

3.2.7 Work Breakdown Structure and WBS Dictionary

The following is the Work Breakdown Structure for the project, along with the work breakdown structure dictionary.

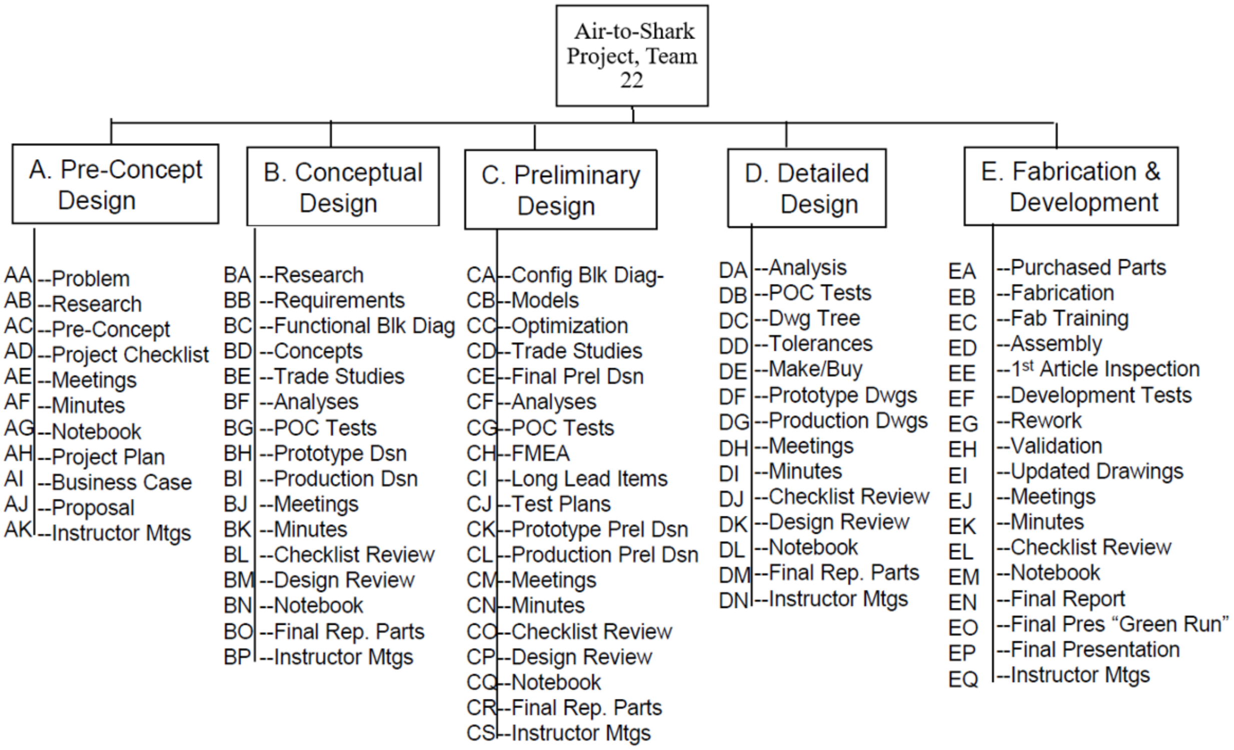


Figure 3.2.7.1. Shark-repellant dispersing UAV WBS Diagram, MEE 488/MEE 489[2]

The Work Breakdown Structure is accompanied by the WBS Dictionary found in tables 3.2.7.2 through 3.2.7.6. The letter-assigned tasks (i.e. AA, AB) are described in the WBS Dictionary with additional detail corresponding to the activities associated with each of the tasks. For a full timeline representation of the Work Breakdown Structure activities, please see the Project Schedule.

Table 3.2.7.2. Task A: Shark-repellant dispersing UAV WBS Dictionary

	TASK	DETAILS AND DESCRIPTION
A	**Pre-Concept Design**	
AA	Define problem	Define a societal problem that the group is tasked with solving through brainstorming and group discussion. Preliminary research is also conducted to obtain baseline understanding of the problems. This task is to be completed by Week 2.
AB	Research problem	In-depth research is carried out by the team members to get a complete understanding of the problem, in addition to separate components of the solution that will be applied. This will be accomplished by the end of Week 3.
AC	Pre-Concept	Identify the needs of the customer (those who will benefit from the implementation of our product). From these needs, a list of corresponding engineering specifications will be developed. A pre-conceptual design is defined and is used to guide the initial stages of the project task. Completed by Week 4.
AD	Project Checklist	The Project Checklist is a team document prepared to make sure that the project meets the minimum requirements ensuring that is an acceptable capstone design idea. This is completed prior to finishing of the Project Plan in Week 5.
AE	Meetings	Team meetings will occur at least twice a week. Meetings will consist of announcements, individual updates, and goal setting for following week deadlines. Completed semi-weekly. Minutes to be included in team notebook.
AF	Minutes	Team minutes will be taken from every team meeting following capstone guidelines. Included in each team minute’s document will be the topics discussed, decisions made, labor loading update, and the weekly Revolving Action Item List (RAIL).
AG	Notebook	The Notebook is the instrument by which the team documents the project progress and process over its life. The team maintains the notebook with all work that is contributed to the project. At this phase, the notebook will consist of all team meeting minutes, individual WAR reports and the Project Plan through Phase 1, as well as copies of the 488 Design Review presentations made.
AH	Project Plan	The Project Plan is critical to IPDS Phase 1. This document allows the team to have direction for where the project is headed prior to the completion of Phase 2 – Conceptual Design. It consists of various charts and tables outlining the general checkpoints and timelines for the project. It is to be completed in Week 5, as part of the Pre-Concept Design.
AJ	Proposal	Proposals are submitted based on criteria and work performed in Phase 1: Pre-Concept Design as exit criteria to proceed to Phase 2: Conceptual Design. To be completed after Design Review Presentation 1, Week 6.
AK	Instructor Meetings	Exit criteria and Design Review Presentation 1 are approved by the instructor according to guidelines by the end of Week 6.

Table 3.2.7.3. Task B: Shark-repellant dispersing UAV WBS Dictionary Part 1

	TASK	**DETAILS AND DESCRIPTION**
B	**Conceptual Design**	
BA	Research	Conduct refined research that will give team more in-depth understanding on the project system and components in addition to the research conducted in the Pre-Concept design phase. Completed in Week 6 and intermittently throughout Phase 2: Conceptual design.
BB	Requirements	Create a list of “customer” requirements that the product will have that solve the issue that the team had originally chosen to solve. By week 6 of 488, refine the original engineering specifications developed in the Pre-Concept task (AC).
BC	Functional Block Diagram	This diagram is a visual aide that depicts the essential operations that the device will be tasked with carrying out. It is a simple description that allows for those main ideas to be expanded upon further in the detailed sections of the report. This depiction should be developed simultaneously with tasks BA and BB in Week 6.
BD	Concepts	Main concepts that the device will be designed around need to be developed by the team to ensure that the project meets at least four mechanical system subjects. These will be compared using a weighted-criteria matrix. Completed within first week of Phase 2: Conceptual Design.
BE	Trade Studies	Concepts and requirements will be used to conduct trade studies that will allow the team to determine which of the plausible solutions for the customer needs is most viable. Trade studies give validity to the option selected. This team activity is to be conducted Week 7 of 488.
BF	Analyses	Initial rounds of analysis are conducted with the pre-concept and conceptual designs that have been created at this point to give continuous validation to the team’s results thus far. Analysis will be conducted at each phase from Phase 2 forward. First analysis is to be completed within Week 7.
BG	POC Testing	To validate each component in the conceptual design phase, Proof of Concept testing will be conducted to analyze and confirm each component individually. Initial POC testing will be completed in Weeks 7 and 8.
BH	Prototype Design	A wholistic conceptual prototype will be completed by the team in Phase 2 to determine the functionality of the system, after having completed POC testing on individual components. This will ensure that the system is optimized with prelim FMEA by the beginning of Week 9.

Table 3.2.7.3. Task B: Shark-repellant dispersing UAV WBS Dictionary Part 2

BI	Production Design	The production design will build upon the findings of conducting the Prototype Design and will allow the team to assess how the product will be manufactured. This will give the team another chance in the Conceptual Design phase to refine the complex components to reduce the difficulty in manufacturability. Complete by end of Week 9.
BJ	Meetings	Team meetings will continue to occur at least twice a week during Phase 2. Meetings will consist of announcements, individual updates, and goal setting for following week deadlines. Completed semi-weekly. Minutes to be included in team notebook.
BK	Minutes	Team minutes will be taken from every team meeting following capstone guidelines. Included in each team minute's document will be the topics discussed, decisions made, labor loading update, and the weekly Revolving Action Item List (RAIL).
BL	Checklist Review	Preliminary review of all Phase 2 components that are to be reviewed by the team members and the instructor. Will be finalized during final Instructor Meeting of this phase at the end of Week 9.
BM	Design Review	Design Review Presentation #2 will be conducted in class where the team will present the findings from Phase 2. The presentation will cover the Prototype and Production requirements, the Final Conceptual Design, validation components, and analysis on the design. Presented in Week 9.
BN	Notebook	The Notebook is the instrument by which the team documents the project progress and process over its life. The team maintains the notebook with all work that is contributed to the project. At this phase, the notebook will consist of all team meeting minutes, individual WAR reports and the Project Plan through Phase 2, as well as copies of the 488 Design Review presentations made.
BO	Final Report Parts	Final Report chapters 1, 3, 4, and 5 need to be completed at the end of Phase 2: Conceptual Design. The instructor will review and approve them as part of the Exit Criteria.
BP	Instructor Meetings	Meetings to ensure that the team has met all Exit Criteria expectations by Week 9. Instructor will review and approve each component of Phase 2: Conceptual Design.

Table 3.2.7.4. Task C: Shark-repellant dispersing UAV WBS Dictionary Part 1

	TASK	DETAILS AND DESCRIPTION
C	**Preliminary Design**	
CA	Configure Block Diagram	As successor to the Functional Block Diagram, the Configurational Block Diagram is preparatory to FMEA that will take place on the design. It is a representation of each component as a block to see the entire system in a simple graphic. Completed in Week 9.
CB	Models	Creation of a detailed model of the product will need to take place to begin examining actual size and shape of components. This model can be altered and changed according to the needs of the team but should be an in-depth representation of what the final product should look like. Complete in Week 10 of 488.
CC	Optimization	Optimize the model created in Week 10 to evaluate where size and material could be improved. Factors such as time, budget, and manufacturability should be considered when conducting optimization. To be completed during the same week that the model is completed.
CD	Trade Studies	Additional trade studies are conducted at this point of Phase 3 to assess different design options that meet the needs of the product as found in the optimization conducted in Week 10. Trade study results will be shown in a chart to show how the decision was reach. This will be completed by the beginning of Week 11.
CE	Final Preliminary Design	An updated design should be reached by the team following the additional optimization and trade studies prior to the following tasks. This will be used to conduct the subsequent tasks. Complete prior to end of Week 11.
CF	Additional Analyses	Conduct additional analysis on the updated final prelim design and show the results in a flowchart. The analysis will also need to include an updated FMEA that will ultimately be repeated after POC testing in task CH.
CG	POC Testing	The second round of Proof of Concept testing will be conducted to ensure that the updated design has met the requirements of Phase 3.
CH	FMEA	This iteration of FMEA is to demonstrate how the update design completed in Phase 3 has improved over the design completed in the conceptual design phase. The top 5 failure modes should be listed and discussed at this point and is to be completed in Week 12.
CI	Long Lead Items	Items and components that will require long lead times should be addressed in Week 12 as well. Descriptions should be included as to why they are considered long lead items and what measures the team is taking to ensure that the items do not cause the team to fall off schedule.

Table 3.2.7.4. Task C: Shark-repellant dispersing UAV WBS Dictionary Part 2

CJ	Test Plans	At the beginning of Week 12, test plans need to be carried out to demonstrate that the prototype design is meeting all expectations and requirements for the project up to this point. Functionality, tolerances, budgets and adequate prelim results should all be considered successful up to this point.
CK	Prototype Prelim Design	A detailed CAD drawing of the entire system, comprised of its individual components, will be created and displayed. Discussion of key features and functionality will be provided to elaborate. This will be completed by the end of Week 12.
CL	Production Prelim Design	All components of the prototype prelim design should indicate that the manufacturing phase and production of the product will be successful. A design chart will be constructed to show how the manufacturing and production will take place. Completed with CK during Week 12.
CM	Meetings	Team meetings will continue to occur at least twice a week during Phase 3. Meetings will consist of announcements, individual updates, and goal setting for following week deadlines. Completed semi-weekly. Minutes to be included in team notebook.
CN	Minutes	Team minutes will be taken from every team meeting following capstone guidelines. Included in each team minute's document will be the topics discussed, decisions made, labor loading update, and the weekly Revolving Action Item List (RAIL).
CO	Checklist Review	Preliminary review of all Phase 3 components that are to be reviewed by the team members and the instructor. Will be finalized during final Instructor Meeting of this phase at the end of Week 12.
CP	Design Review	Design Review Presentation #3 will be conducted in class where the team will present the findings from Phase 3. The presentation will cover the final updates of the Prototype and Production designs from Phase 3, and how the overall product design has improved from Phase 2 concepts. Presented in Week 13.
CQ	Notebook	The Notebook is the instrument by which the team documents the project progress and process over its life. The team maintains the notebook with all work that is contributed to the project. At this phase, the notebook will consist of all team meeting minutes, individual WAR reports and the Project Plan through Phase 3, as well as copies of the 488 Design Review presentations made.
CR	Final Report Parts	Final Report chapters 1, 3, 4, 5, and 6 need to be completed at the end of Phase 3: Preliminary Design. The instructor will review and approve them as part of the Exit Criteria.
CS	Instructor Meetings	Meetings to ensure that the team has met all Exit Criteria expectations by Week 13. Instructor will review and approve each component of Phase 3: Preliminary Design.

Table 3.2.7.5. Task D: Shark-repellant dispersing UAV WBS Dictionary Part 1

	TASK	DETAILS AND DESCRIPTION
D	**Detailed Design**	
DA	Analysis	Final analysis is to be performed in the initial stages of the Detailed Design Phase. Most analyses should be completed during Phases 2 and 3, but additional assurance following the changes during the Preliminary design phase will resolve any minute details that may need team attention. Completed by the beginning of Week 13.
DB	POC Testing	The second round of Proof of Concept testing will be conducted to ensure that the updated design that meets the requirements and parameters for Phase 4.
DC	Drawing Tree	A drawing tree will provide the professional or conceptual drawing of each individual component that will be assembled to complete the entire system. This will be used to complete the drawing package which will complete depict the final design. Complete by end of Week 13.
DD	Tolerances	Assignment of acceptable tolerances will need to be determined by the team during Week 13. These will allow the team to determine the minimum complexity of the manufacturing process while still ensuring that the system will be able to be assembled with the specified dimensions.
DE	Make vs. Buy Analysis	Determine the components that will need to be manufactured by the team, or items that can be bought to save on cost and manufacturing time. This information will be provided in a chart that will justify the decision for Make vs. Buy on each component. Completed by Week 13.
DF	Prototype Drawings	Finalized drawings for the product and system designed should be assembled. Prototype drawings will include final dimensions, tolerances and aesthetics of the system. These drawings will be part of the drawing package to be completed by Week 14.
DG	Production Drawings	Construction and assembly of the final product will be outlined in the Production Drawings. These will be included with the final prototype drawings that will be assembled as the drawing package of the project. This will be completed simultaneously with task DF in Week 14.
DH	Meetings	Team meetings will continue to occur at least twice a week during Phase 4. Meetings will consist of announcements, individual updates, and goal setting for following week deadlines. Completed semi-weekly. Minutes to be included in team notebook.

Table 3.2.7.5. Task D: Shark-repellant dispersing UAV WBS Dictionary Part 2

DI	Minutes	Team minutes will be taken from every team meeting following capstone guidelines. Included in each team minute's document will be the topics discussed, decisions made, labor loading update, and the weekly Revolving Action Item List (RAIL).
DJ	Checklist Review	Preliminary review of all Phase 4 components that are to be reviewed by the team members and the instructor. Will be finalized during final Instructor Meeting of this phase at the end of Week 15.
DK	Design Review	The Final Design Review will be conducted in class where the team will present the findings from Phase 4 and the entirety of work from MEE 488. The presentation will cover the final updates of Phase 4, as well as the completion of the design process with its corresponding validations. Presented in Week 1 of MEE 489.
DL	Notebook	The Notebook is the instrument by which the team documents the project progress and process over its life. The team maintains the notebook with all work that is contributed to the project. At this phase, the notebook will consist of all team meeting minutes, individual WAR reports and the Project Plan through Phase 4, as well as copies of the 488 Design Review presentations made.
DM	Final Report Parts	Final Report chapters 1, 3, 4, 5, 6, and 7 need to be completed at the end of Phase 4: Detailed Design. The instructor will review and approve them as part of the Exit Criteria.
DN	Instructor Meetings	Meetings to ensure that the team has met all Exit Criteria expectations by Week 2 of MEE 489. Instructor will review and approve each component of Phase 4: Detailed Design. The team will be fully prepared to move onto fabrication, development and testing after the completion of this phase.

Table 3.2.7.6. Task E: Shark-repellant dispersing UAV WBS Dictionary Part 1

	TASK	**DETAILS AND DESCRIPTION**
E	**Fabrication, Development & Testing**	
EA	Purchase Parts	Parts will be purchased from 3rd party manufacturers starting January 2018, so that the items prototype assembling can begin to ensure that the product is completed on time.
EB	Fabrication	A container for the shark repellent liquid and other components will be manufactured starting January 2018. Additional components such as a trigger might also be manufactured to snap on to the remote controller.
EC	Fabrication Training	Team members will begin learning 3D printing and machining throughout the Fall 2018 semester, so they will be prepared to use the equipment when needed in MEE 489.
ED	Assembly	After all the components are manufactured, the team will combine all systems onto the Unmanned Aerial Vehicle and Remote Controller. This will likely happen around the end of February 2018 or early March 2018.
EE	1st Article Inspection	After the prototype is built, the prototype will be compared against drawings and any differences in features, dimensions and tolerances will be listed. For each of the differences, the drawing will be updated, or the hardware will be altered to reflect the drawing.
EF	Development Tests	The prototype will be tested component-wise and as a complete product to get information to ensure that the product meets expected standards. This will likely occur during March/April 2018.
EG	Reworking	If any issues are found in the device during testing, the team will work on the faulty system or component to ensure the device is in best working condition. Then the product will be re-tested to ensure that the problem is fixed, and no other faults have developed.
EH	Validation	The product will be checked against a validation checklist to ensure that the requirements of the device have been met. This will occur after the group has tested the product multiple times and is satisfied with the tests carried out.
EI	Updated Drawings	If any alterations were made on the original drawings, the team will go back into the file and make the adjustments, so the device can be duplicated when/if needed in the future. If a new version of the drawing is needed, the team will make a new drawing for the component or device.

Table 3.2.7.6. Task E: Shark-repellant dispersing UAV WBS Dictionary Part 2

EJ	Meetings	Team meetings will continue to occur at least twice a week during Phase 5. Meetings will consist of announcements, individual updates, and goal setting for following week deadlines. Completed semi-weekly. Minutes to be included in team notebook. Additional team meetings during this phase are to be expected for manufacturing and testing completion.
EK	Minutes	Team minutes will be taken from every team meeting following capstone guidelines. Included in each team minute's document will be the topics discussed, decisions made, labor loading update, and the weekly Revolving Action Item List (RAIL).
EL	Checklist Review	Preliminary review of all Phase 5 components and results that are to be reviewed by the team members and the instructor. Will be finalized during final Instructor Meeting of this phase at the end of Week 13 of MEE 489.
EM	Notebook	The Notebook is the instrument by which the team documents the project progress and process over its life. The team maintains the notebook with all work that is contributed to the project. At this phase, the notebook will consist of all team meeting minutes, individual WAR reports and the Project Plan through Phase 4, as well as copies of the 488 and 489 Design Review presentations made.
EN	Final Report	All portions of the Final Report need to be completed at the end of Week 14 in MEE 489. The team will compile all work pertaining to the project and submit it in a professional report.
EO	Final Presentation "Green"	A Final Presentation is prepared and shared with the other teams of MEE 488/489. This presentation will be a collection of processes, project progression, testing, and overall results of the capstone design experience. This will be presented in Week 15.
EP	Final Presentation	In addition to the Final Presentation in class, the team will also present the project findings and prototype at the Assessment Fair held at the end of MEE 489. This will demonstrate the project progression and results of the capstone course to the ABET accreditation board.
EQ	Instructor Meetings	Meetings to ensure that the team has met all Exit Criteria for MEE 488 and 489. Instructor will review and approve each component of Phase 5: Fabrication, Development and Testing.

3.2.8 Project Schedules

The project schedules for the team are outlined in the Gantt charts provided below. They are made up of the tasks outline in the WBS and WBS Dictionary. The project will take place over two semesters, with MEE 488 during Fall 2018 and MEE 489 during Spring 489.

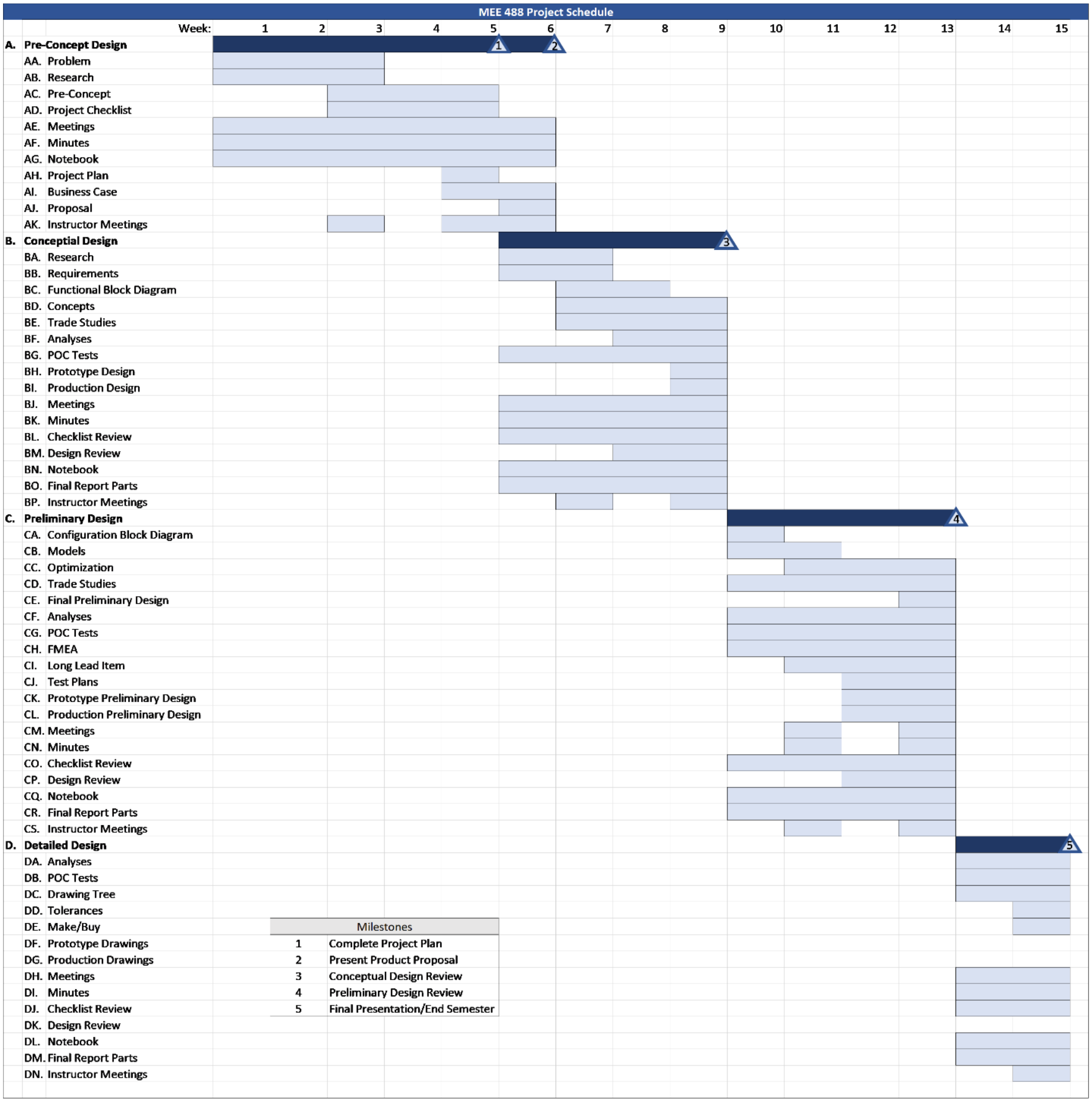


Figure 3.2.8.1. Gantt Chart for MEE 488

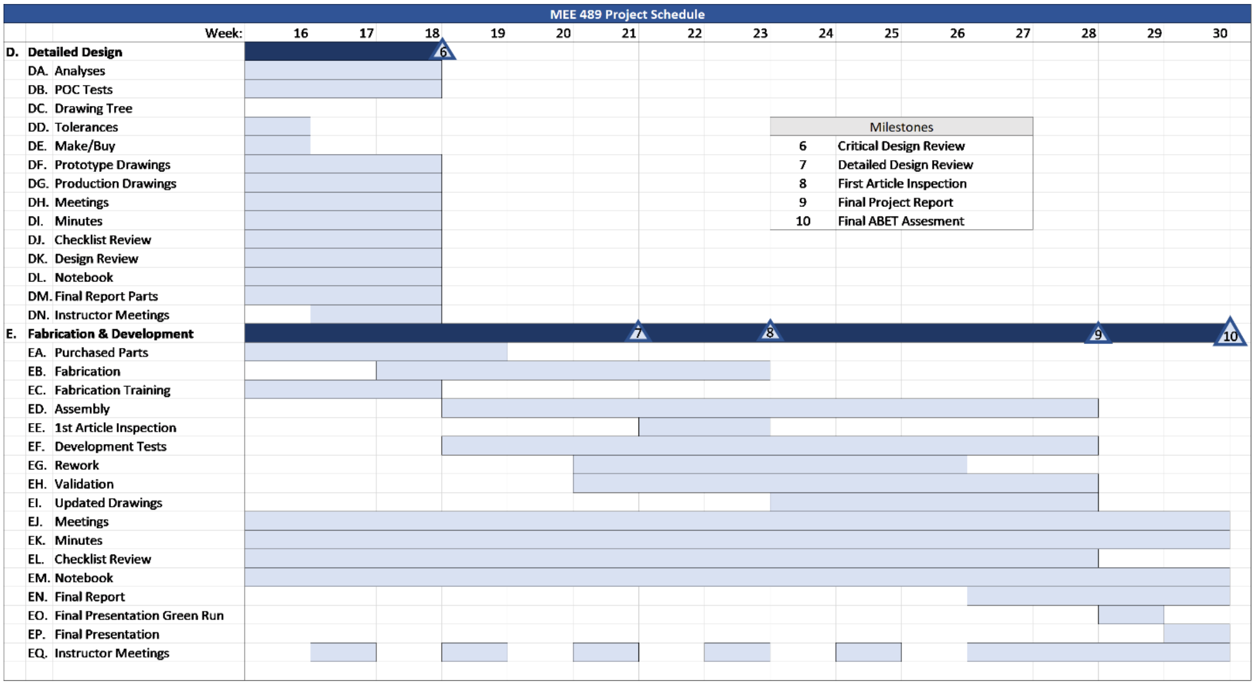


Figure 3.2.8.2. Gantt Chart for MEE 489

3.2.9 Labor Loading and Labor Budget

To accomplish each of the tasks by the appropriate deadlines, as shown in the Gantt Charts, labor loading charts were assembled to measure the progress of each of these tasks as they pertain to each team member. The labor loading charts for MEE 488 and 489 are included below.

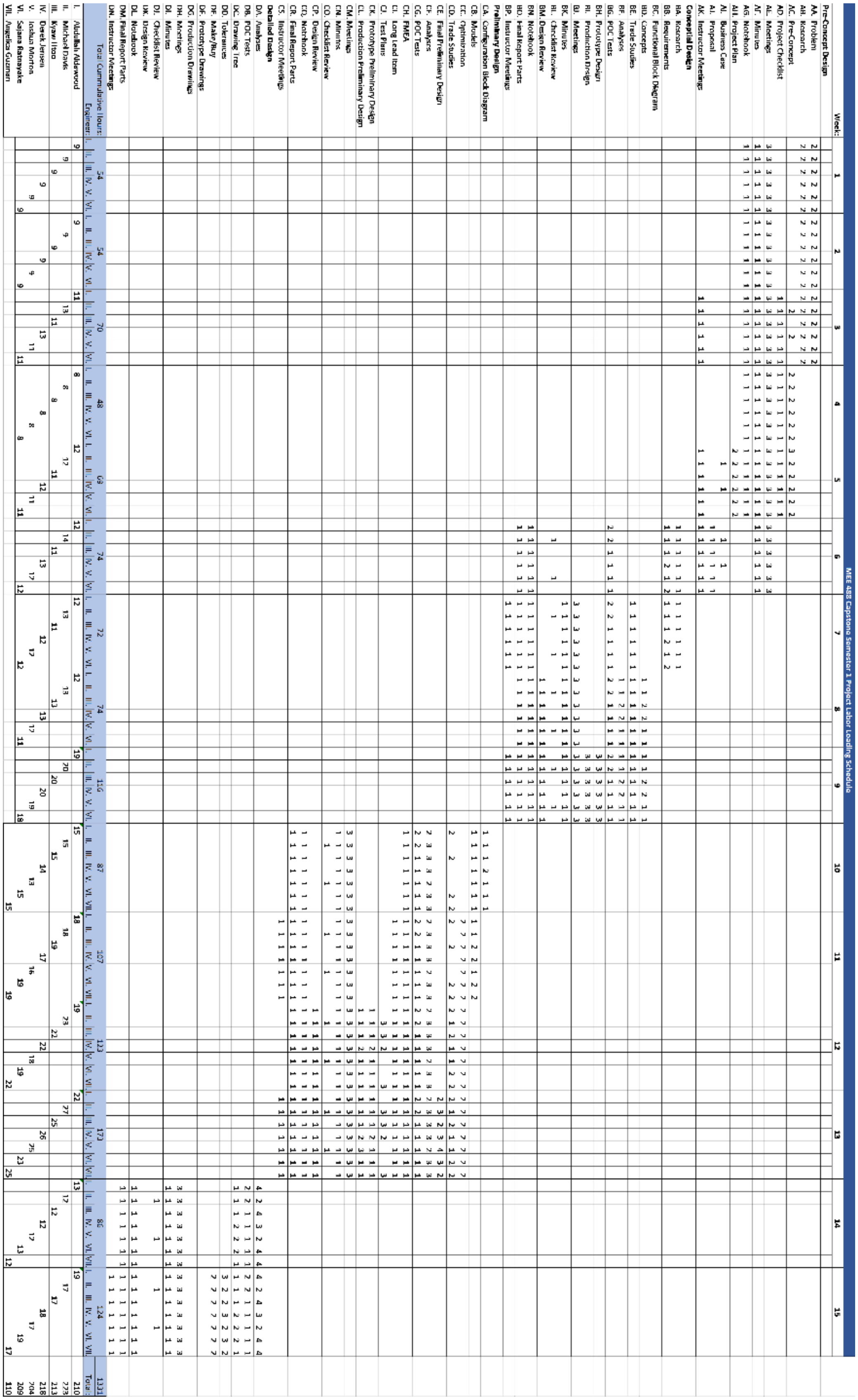


Figure 3.2.9.1. Labor Loading chart for MEE 488 during fall 2018.

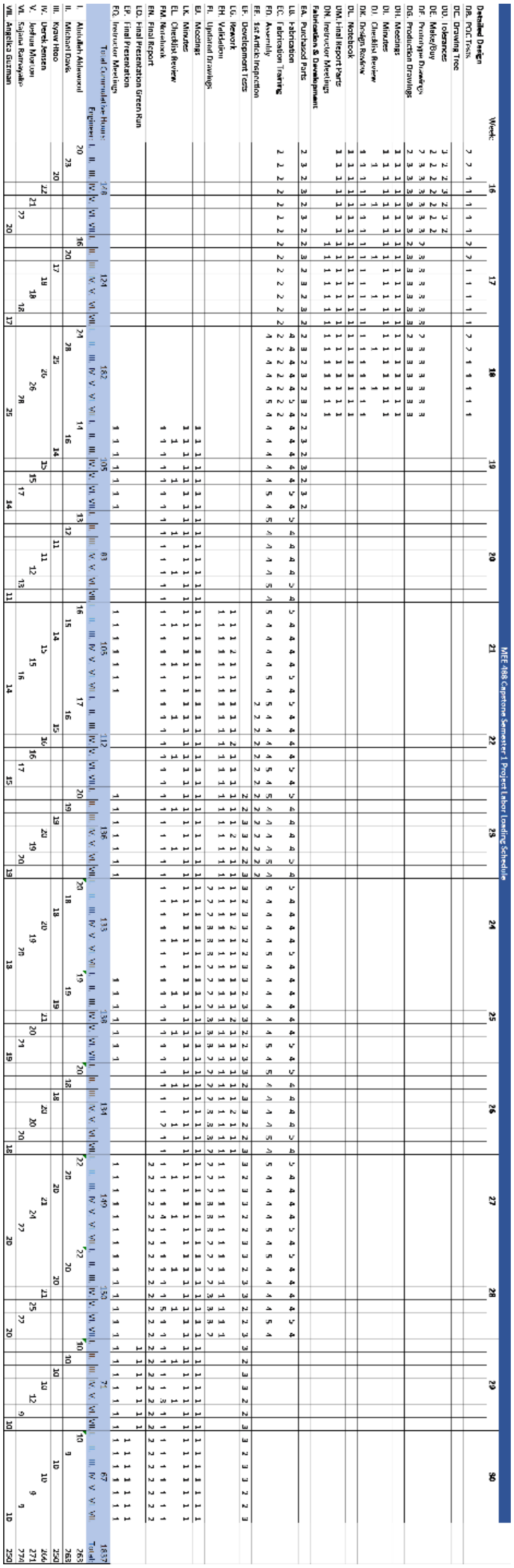


Figure 3.2.9.2. Labor Loading chart for MEE 489 during spring 2019.

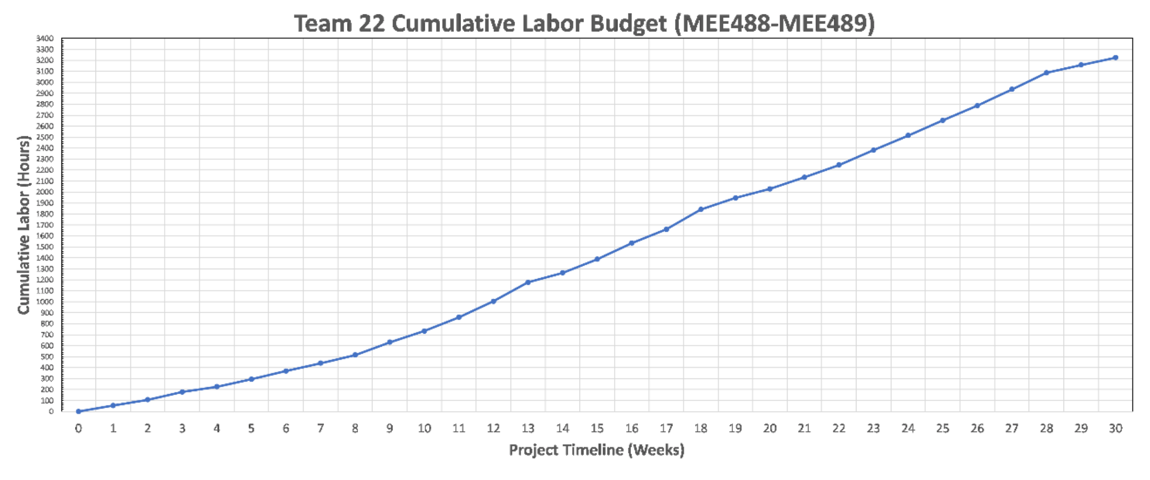


Figure 3.2.9.3. Labor chart showing the cumulative labor over the life of the project.

From these charts, we can extrapolate the number of total hours the team is to devote to the project. The total number of hours worked by the team over the life of the project will be 3224. Ideally, this is an overestimate of how many hours the project will require. Our intention in budgeting this much is to ensure each member is aware of the absolute extreme amount of work hours expected of them. In addition to human work hours, the team needs to consider the financial limitations of the project as well. These limits will be covered in the following section.

3.2.10 Monetary Budget

All funding for the project will come from the budget ASU provides ($700). None of this will be utilized for MEE 488 as we will not require to buy any items until the prototype designing starts. Hence, the money will only be utilized in MEE 489 to purchase the required items.

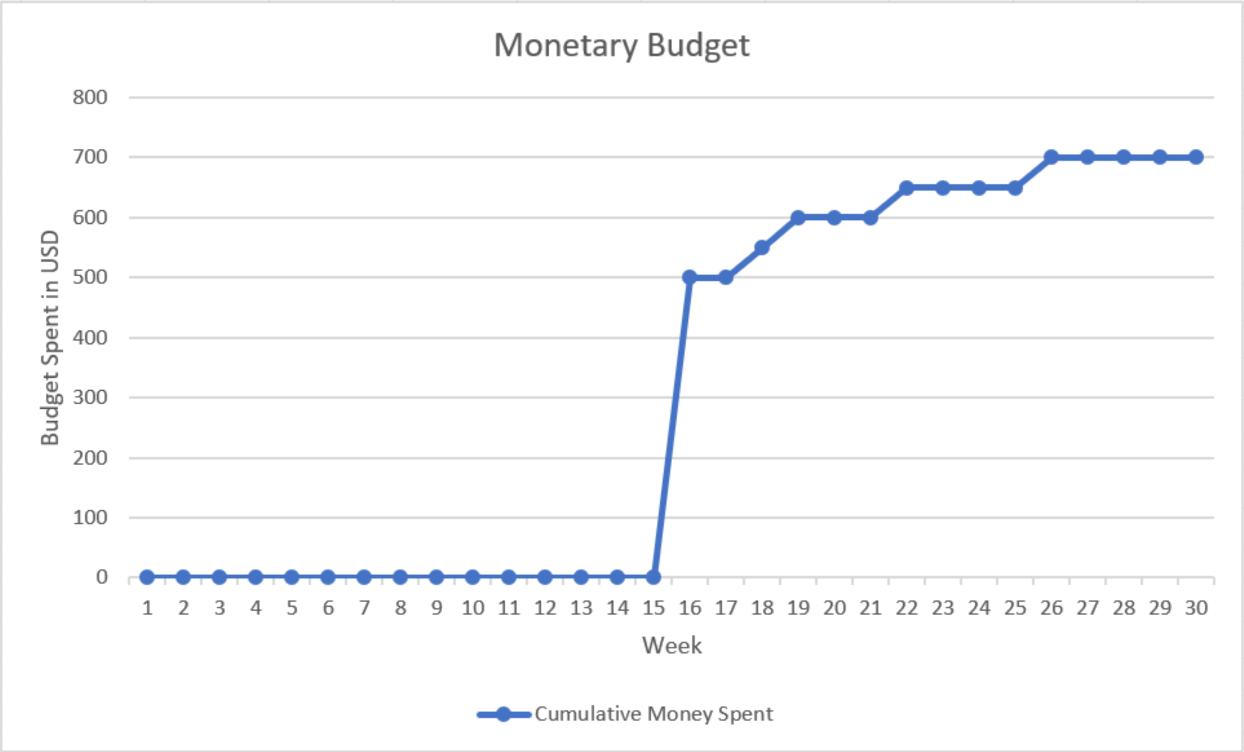


Figure 3.2.10.1. Estimated Monetary Budget

As it can be seen from figure 3.2.10.1, most of the budget will be needed during the month of January 2018 to purchase the items required to start building the prototype for the shark repellant system. This initial purchase will contain the components needed to start building the quadcopter and manufacturing a container and fixtures that will be needed initially. The remaining items will be purchased in the months that follow to complete the product on time.

Table 3.2.10.1. Budget Estimate and Utilization Approximations

Item	**Value (USD)**
Quadcopter Components	400
Electronics for Actuation	75
Fixtures and Connectors	75
Material for Container	60
Material for Actuation System	50
Miscellaneous	40
Total	**700**

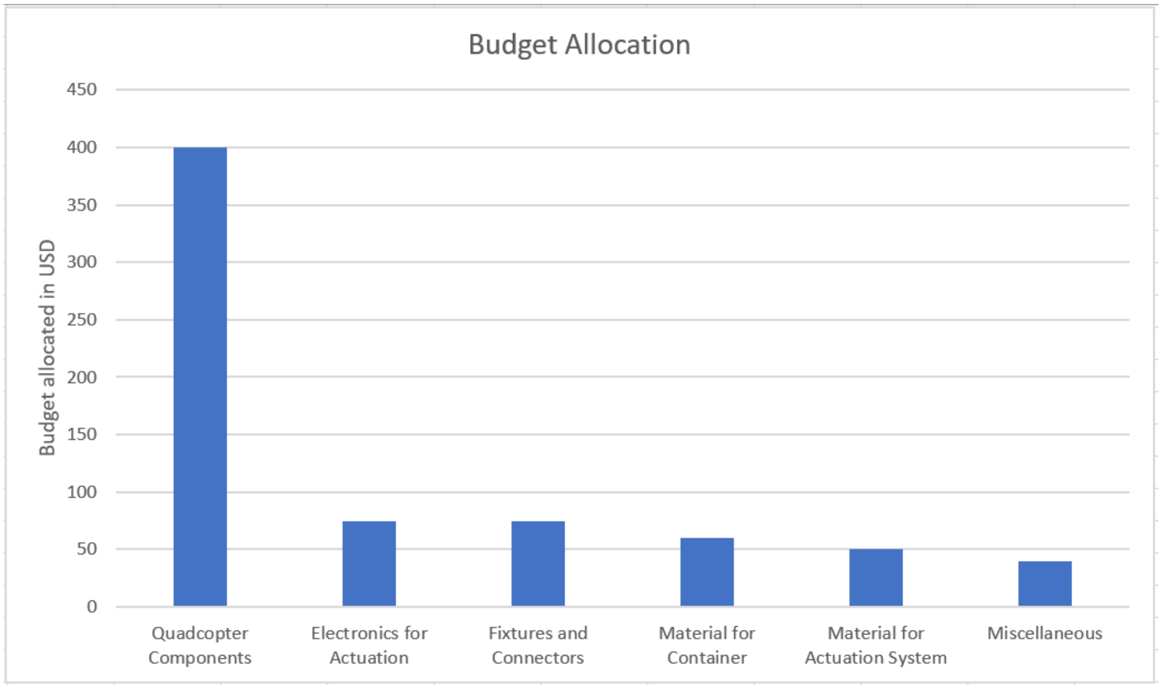


Figure 3.2.10.2. Budget Allocated for Purchasable Items

The values estimated for the budget allocation are only estimates now and further discussion and research needs to take place to finalize the expected costs. As it can be seen most of the budget goes into buying the Remote Controlled Unmanned Aerial Vehicle and the remaining budget goes into the designing and production of the Shark Repellant System. An updated budget allocation will be prepared in the upcoming weeks as the team makes decisions on what items are to be purchase.

3.2.11 Project Success Factors

Every project has critical factors that ensure the success of the group and project. Ensuring that these factors are addressed throughout the project ensures the success of the product. Listed below are the 5 most critical key factors that will ensure the success of team 22.

Factor 1:

Ensuring all members in the group are knowledgeable of the decisions made – It is vital that all individuals in team 22 are knowledgeable about the product being designed and manufactured. It is also important that all team members are aware of any decisions or changes being made to ensure that the project runs smoothly, and the product is manufactured on time and to the required specification. To ensure that every member is aware of the information, the team will meet at least twice a week to ensure that everyone is up to date on the project. If a member is unable to attend in person, a telecommunication medium will be utilized, or the team member(s) will be updated via phone call, message and/or meeting minutes.

Factor 2:

Studying and understanding existing shark locating and repelling systems – Research will be conducted on existing shark locating devices as well as shark repelling products to understand the most effective and efficient methods to design and manufacture the product. These studies will then be used to improve the product design before prototyping and manufacturing takes place.

Factor 3:

Improving and optimizing the product to meet customer requirements – The team will consult potential customers of the product (i.e.: lifeguard services, groups that save animal life, resort owners, etc.) and obtain input from the client and improve the design of the product. In addition, the practicality and usability of the product will be verified by contacting individuals/groups who have experience in responding to shark attacks and groups interested in saving marine life.

Factor 4:

Testing the product multiple times to ensure product is reliable – After the prototype is manufactured, the device will be tested multiple times to ensure that the device works at the expected standards. The device will also be further analyzed for safety and reliability and then optimized as needed to ensure the customer gets a working product that gets the task done.

Factor 5:

Ensuring monetary and labor budget are followed according to plan – When the prototyping and manufacturing process begins in MEE 489, the team and responsible individuals will ensure that tasks are being completed on time and the project is not overbudget. This will ensure there are no delays or unexpected expenses towards the end of the project. In addition, individuals will be held responsible for completing assigned tasks on time for both MEE 488 and MEE 489 classes.

4. Requirements and Constraints

Team Air-to-Shark did an interview to know the customer's need. VOC was ben studied carefully and then transformed customer's need into measurable engineering requirements and constraints. The requirements/validation matrix is created to gauge how well the design meets the pre-determined requirements.

4.1 Needs to Requirements

By interview the Directors of Lifeguard Operations for San Clemente and Carlsbad, California. The team studied the interview carefully and collect all the needs then transformed it into measurable engineering requirements, which shown in the below Table 4.1.1.

Table 4.1.1. Voice of Customer Table

VOC Need	Quantifiable measurements
Physical dimensions	Storable in 2.5 m x 2.5 m x 2.5 m lifeguard tower
Payload (Rig/Reservoir/Repellent)	UAV capable of flying with 4.5 kg of total weight
Volumetric Capacity	Repellent reservoir can hold 1 liter of liquid
Response Time	Flight time to be less than 45 seconds. Flight time is equal to cold start, fly 100 meters off shore, and drop payload
Disbursement Time	Time from actuating drop-sequence to surface impact of full payload less than 3 seconds
Accuracy	Drop payload within 1.5 m radius
Precision	Drops payload within 1.5 m of designated target 98% of trials
Cost	Material and manufacturing costs less than $700
Power Requirement	Operate and carry payload using a 6600 mAh power supply, and minimize the power needed to actuate disbursement
Air speed	Maintain 25 km/hr with payload to satisfy response time requirement
Positioning	Hover 10 m (or less) above drop zone w/o sea level
Stability	Fly with payload 15 m above sea level
Temperature Durability	Operate between 10º C and 40º C
Humidity Durability	Operate between 40% to 90% humidity at sea level
Reliability	Withstand sand and saltwater corrosion, to operate without repair for 6-months
Ease of Use	Someone can be trained to use device within 8 hours of training and is intuitive operation
Safety	UAV allows for guards on the outer 90º of blades to be protected from contact
Manufacturability	Design and production must be accomplished within 6 months with 6-man team
Length of Operation	Power supply can allow for 20 minutes of flight without recharging
Simplicity	Disbursement system comprised of less than 5 components, to reduce failure probability

4.2 Applicable Standards and Regulations

Team Air-to-Shark picked out standards and regulations that related to the project design. Based on (ASME) American Society of Mechanical Engineers, manufacturing processes standard will be included to prove efficiency and meet safety to the design[3]. Furthermore, (AIEE) American Institute of Electrical Engineers standards will be used to ensure that the team use the right regulations for electrical parts which include battery. Therefore, UAV will operate between 10º C and 40º C and 40% to 90% humidity, by these regulations the team will guarantee the temperature humidity will not affect the device and for safety purposes[4].

In addition, for safety purpose team used (FAA) Federal Aviation Administration small unmanned aircraft rule part 107. Which does not allow the UAV to fly over 400 feet above the ground and fly directly over people. It also limits the UAV's speed to fly at or less than 100 mph. UAV must weigh less than 55 pounds including payload. The team followed all the rules to ensure people safety[5].

By following Department of life guard operations Carlsbad, California rules and (USLA) United States Lifesaving Association standards, the device can be helpful to life guards and can reach their needs[6].

4.3 Validation Methods

There are many methods that validate the requirements. For Air-to-Shark project calculations, computer modeling (Solid Works), inspection, demonstration and analysis have been used for requirements to be validated.

- Calculations: include written analysis and theoretical equations.
- Computer modeling, using CAD, FEM and Solid Works to model details and design the prototype.
- Inspection: includes testing and examining the prototype to make sure it meets all the requirements.
- Demonstration: includes that the prototype meets all the requirements.

4.4 Requirements/Validation Matrix

A.T.S Systems have a design goals want to reach. The requirements in the below Table are apply to the prototype design without reaching the budget allocated. These requirements address the prototype design so, with these requirements the design will meets the customer's expectations.

Table 4.4.1 below shown the prototype requirement and methods of validation in details, and how the requirement can be validated. The Table below also shows the status. Our team will constantly work updating these requirements it and the table will be up to date with the completion of the project.

Table 4.4.1. Requirements Validation Matrix Part 1

No.	Prototype Requirement	Method of Validation	Status
1	Storable in 2.5 m x 2.5 m x 2.5 m lifeguard tower	Initial design suggests that device will be easily storable. Exact dimensions will be calculated in prelim design.	Incomplete
2	UAV capable of flying with 4.5 kg of total weight	Power calculations complete and are acceptable for battery. Moving forward to theoretical and numerical testing.	Incomplete
3	Repellent reservoir can hold 1 liters of liquid	Initial power and battery calculations suggests that this is feasible. Subtle fluctuations in mass and design should not inhibit functionality.	Incomplete
4	Flight time to be less than 45 seconds. Flight time is equal to cold start, fly 100 meters offshore, and drop payload	Current research points to adequate quadcopter flight time within our set specifications.	Incomplete
5	Time from actuating drop-sequence to surface impact of full payload less than 3 seconds	Bomb door dropping device is predicted to be able to deliver payload within 3 seconds.	Incomplete
6	Drop payload within 1.5 m radius	Preliminary physical design and studies show target radius being met in final design.	Incomplete
7	Drops payload within 1.5 m of designated target 98% of trials	Meets engineering judgement. Team does not expect variation in overall results based on conceptual design.	Incomplete
8	Material and manufacturing costs less than $700	Prelim estimates for UAV and repellent delivery system are currently less than $700.	Incomplete
9	Operate and carry payload using a 6600 mAh power supply, and minimize the power needed to actuate disbursement	Current calculations predict that 6600 mAh battery will be sufficient for flight requirements as well as power needed for remote actuation.	Incomplete
10	Maintain 25 km/hr with payload to satisfy response time requirement	Average 30 km/hr, team accounts for minor velocity restrictions based on added mass.	Incomplete
11	Hover 10 m above drop zone	The quadcopter being purchased is capable of hovering above target without drifting its position.	Incomplete
12	Fly with payload 15 m above sea level	The motors and propellers for the quadcopter are capable of carrying the quadcopter as well as the payload at the required cruising altitude.	Incomplete

Table 4.4.1. Requirements Validation Matrix Part 2

13	Operate between 10º C and 40º C	The climate in a beach environment during operating hours when a lifeguard is present is between 10º C and 40º C.	Incomplete
14	Operate between A at sea level	Further research into effects of the humid environment on quadcopter performance will need to be performed.	Incomplete
15	Withstand sand and saltwater corrosion, to operate without repair for 6-months	Further research into effects of the harsh environment on quadcopters will need to be performed.	Incomplete
16	Someone can be trained to use device within 8 hours of training and is intuitive operation	Quadcopter controlling medium is determined to be decently intuitive and straightforward.	Incomplete
17	UAV allows for guards on the outer 90º of blades to be protected from contact	Quadcopter design allows for easy mounting of blade protectors.	Incomplete
18	Design and production must be accomplished within 6 months with 6-man team	Project is determined to be within the scope of the course.	Incomplete
19	Power supply can allow for 20 minutes of flight without recharging	Research into battery and power supplies determine that adequate market products exist to meet requirements.	Incomplete
20	Disbursement system comprised of less than 5 components, to reduce failure probability	Bomb door design is simple, and requires about 4 unique components to function, meeting this requirement.	Incomplete

5. Conceptual Design

This section describes and shows the work completed by our team during the Conceptual Design Phase of the IPDS Process. This is where the concepts and requirements of the product are fleshed out and explored based on the requirements of our problem statement. This section is where the functions of our final product begin establishing. With careful consideration put towards the problem statements, the voice of customer requirements, as well as our own design and budget requirements, the team will begin to determine solutions. Much research and simple analysis is conducted, resulting in a set of three potential conceptual design options. The team will then refer to the voice of customer requirements in the form of trade studies to narrow down which option is most optimal.

Through trade studies and weighted criteria matrices, a final conceptual design option is chosen. Basic conceptual analyses are performed, and a final conceptual prototype is generated. The primary deliverables of this phase are concept sketches, a list of requirements, and trade studies. The process of reaching these deliverables is outlined in this section.

5.1 Functional Block Diagram

The Function Decomposition Block Diagram, Configuration Block Diagram, Physical Decomposition Block Diagram and Product-Function Block Diagram are attached below for the updated Air-To-Shark System. These diagrams help visualize which component is responsible for various functions of the Air-To-Shark System.

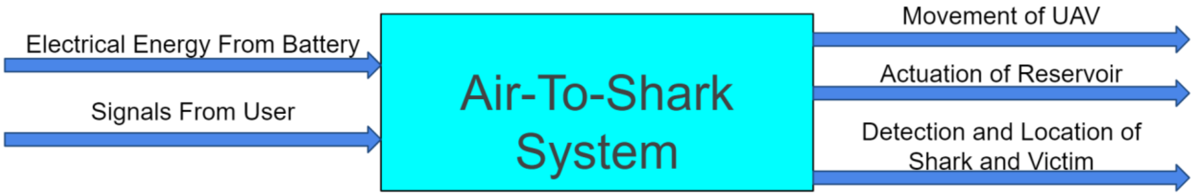


Figure 5.1.1. Top-Level Function Decomposition Block Diagram

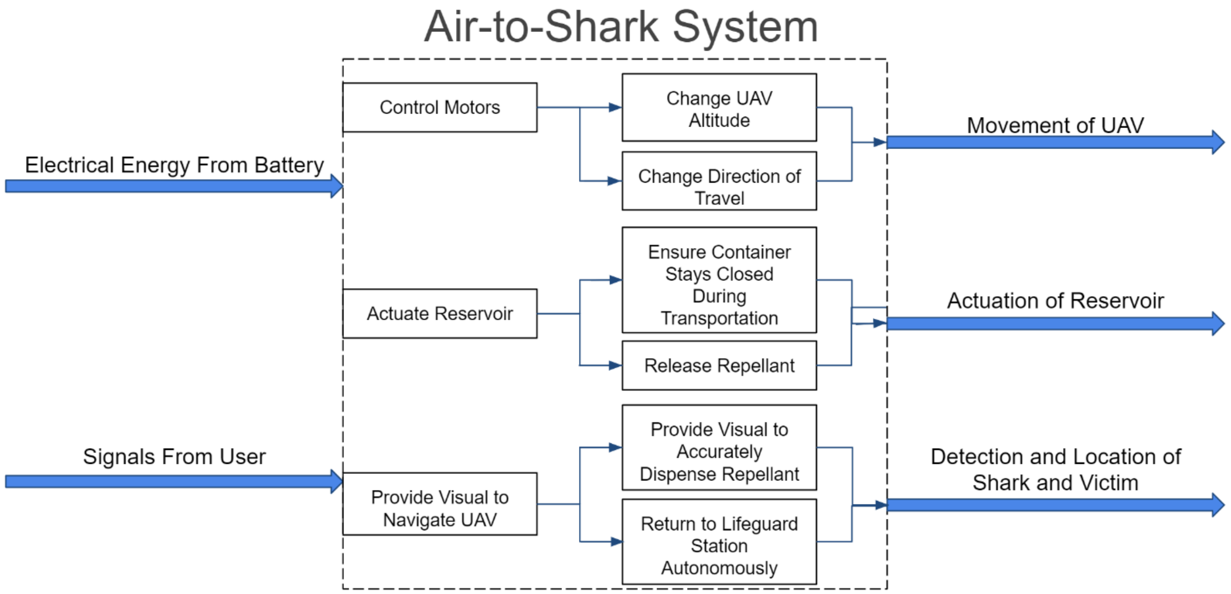


Figure 5.1.2. Detailed Function Decomposition Block Diagram

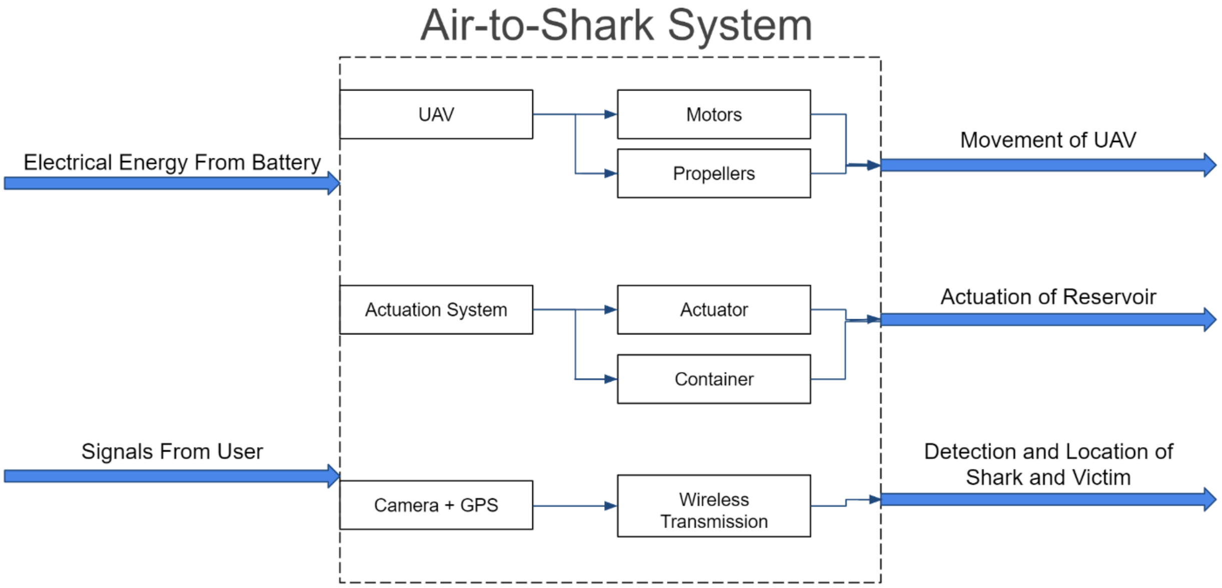


Figure 5.1.3. Detailed Configuration Block Diagram

The diagrams in Figures 5.1.1 to 5.1.3 above are based on the new requirements of the system which was designed after interviewing lifeguards from California. This new system is the refined version where the ATS system reacts to shark attacks, instead of preventing shark attacks (which was the initial team idea). Refer to the problem statement for more info on this. The individual components used are shown in the Physical Decomposition Block Diagram below. These tools are useful in allowing A.T.S Systems identify which components and functions should go into the product design.

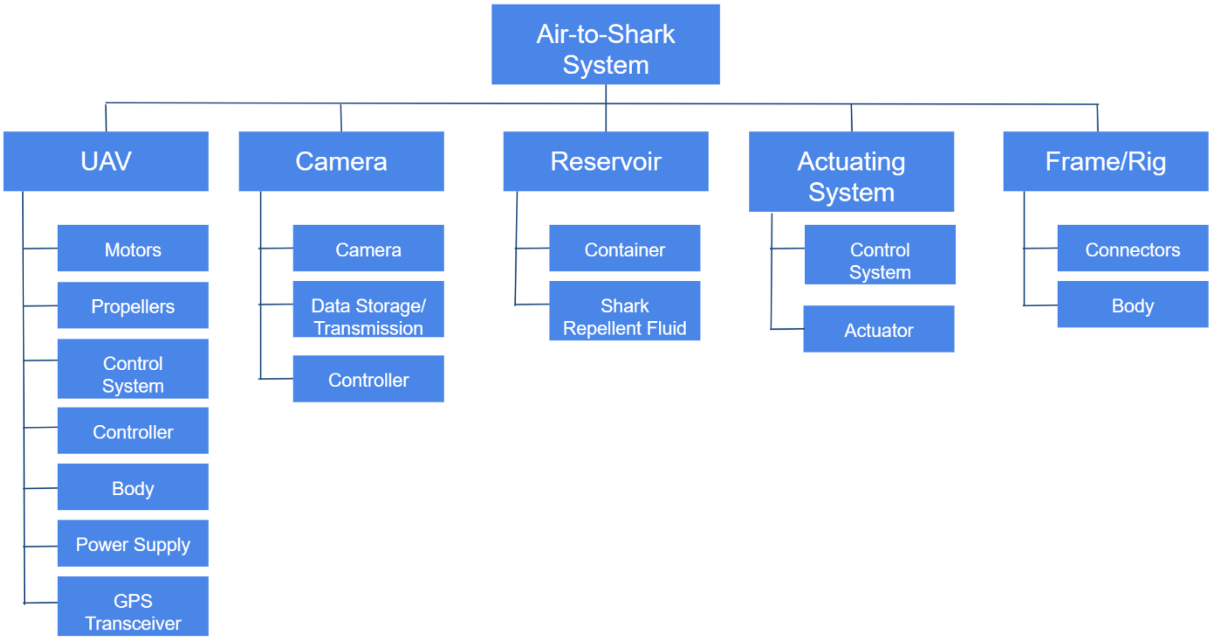


Figure 5.1.4. Physical Decomposition Block Diagram

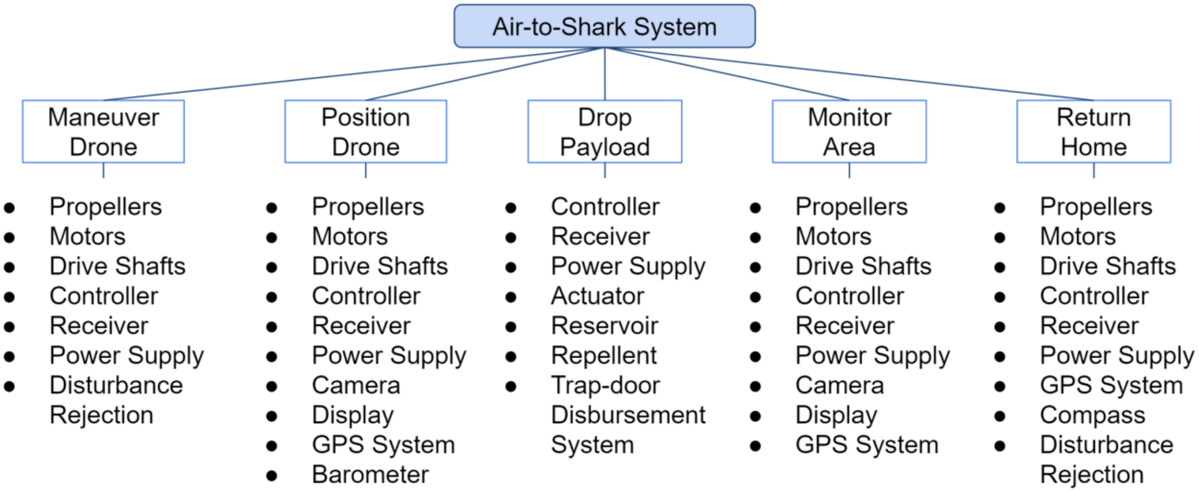


Figure 5.1.5. Product-Function Component Tree

5.2 Research Prior Art

Team ATS researched on options that lifeguards use to save victims or prevent shark attacks from occurring and found out that lifeguards are not allowed to get in waters when there is a shark presence in the area. For the complete summary of customer interview comments, refer to refer to Doug Fraser's report in our references[9]. Hence, this encouraged Team ATS to develop a platform that is capable of evacuating sharks from an area of the beach so that lifeguards and emergency services can get in the water to save the victim before the shark returns.

Initially Team ATS wanted to manufacture a system that always keeps the beach free of sharks using an autonomous UAV that always monitors the beach and acts to repel sharks from the areas that patrons are present in. However, after doing further research and talking to lifeguard services in California, Team ATS found out that there are always sharks present in the water and that the current systems that repel sharks cost tens of thousands of dollars. Hence, A.T.S. Systems changed the scope of our project to help lifeguard services by providing an alternate option that will help lifeguards succeed in their rescue operations during the event of a shark attack.

Team ATS was keen on making the autonomous UAV that always monitors the beach at regular intervals. However, after analyzing the budget and the technology available for the price range, Team ATS had to alter their product to react to shark attacks instead of preventing them. Team ATS consulted with lifeguard services and they agreed that the product would be very useful as they will be able to purchase the product for the price expected and save many lives as a result.

Team ATS also looked at existing solutions such as the ‘Little Ripper’[8] in Australia to better understand what to expect from the product and improve the product. ‘Little Ripper’ drones are drones capable of using AI software to distinguish sharks from other objects in the water such as boats, dolphins and other marine life. NOTE: After further consideration and research, Team ATS decided that making an AI capable of detecting sharks will take a lot more time and team members. It will also require learning to code more in depth to detect sharks from other objects in the coastal region. So, Team ATS reached out to California Lifeguards and they informed us that being able to get in the water after a shark attack is an issue as that would put another life at risk. Hence, the team decided to make a UAV capable of reacting to shark attacks which will render the area safe for lifeguards to enter to save a patron’s life.

5.3 Conceptual Design Options

To make the best selection as a team for design options two different systems had to be considered. First the UAV platform was considered and then the distribution system for the repellent itself.

The first design option for the UAV platform is a quadcopter. As seen below it is a UAV platform with 4 vertical lift rotors with pairs of those rotors in opposing rotation for stability.

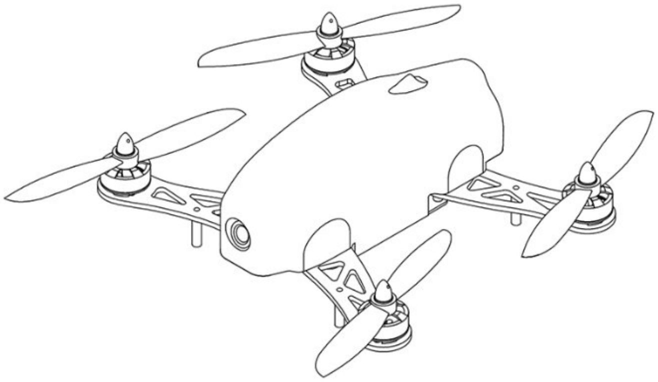


Figure 5.3.1. Quadcopter Rotor Configuration Conceptual UAV Option[7]

The second design option for the UAV platform is conventional single rotor helicopter platform. As seen below it is a UAV platform with a single vertical lift rotor and a single rotational stability rotor.

Figure 5.3.2. Single Rotor Configuration Conceptual UAV Option[7]

The third design option for the UAV platform was a conventional fixed wing aircraft platform. As seen below it is a fixed wing single propeller design using wings, fins, and ailerons to provide stability and direction while gaining forward thrust from the propeller.

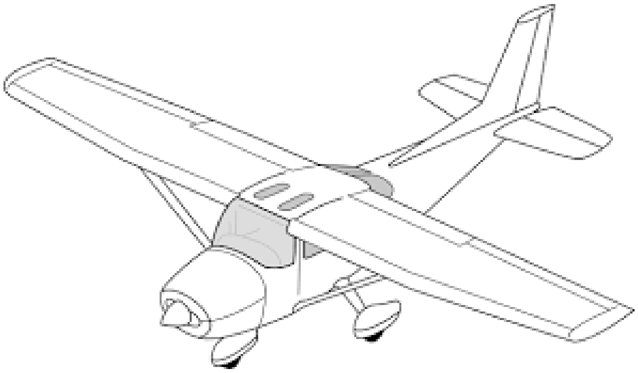


Figure 5.3.3. Fixed Wing Configuration Conceptual UAV Option[7]

The first design option for the project was the distribution system for the repellent itself and for this feature, three more options were considered. The first of which being a ball valve which, as seen below, operates as a fully opened or fully closed orifice and provides a solid stream of fluid upon release.

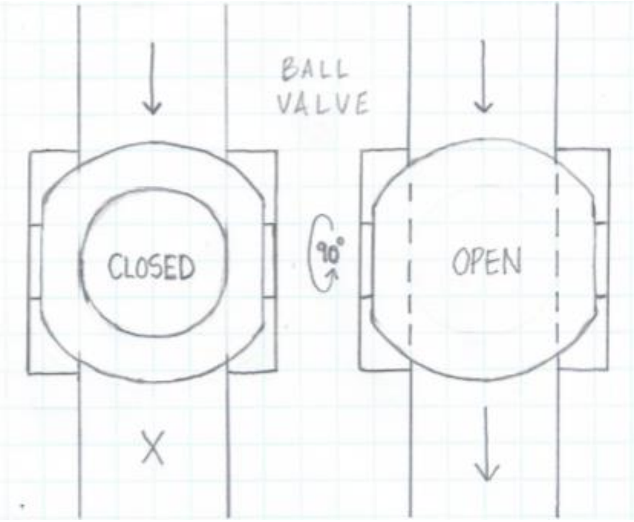


Figure 5.3.4. Ball Valve Conceptual Distribution System Option

The second design option for the distribution system is a gated nozzle that operates fully open or fully closed. As seen below when open the nozzle provides for a cone of fluid upon release.

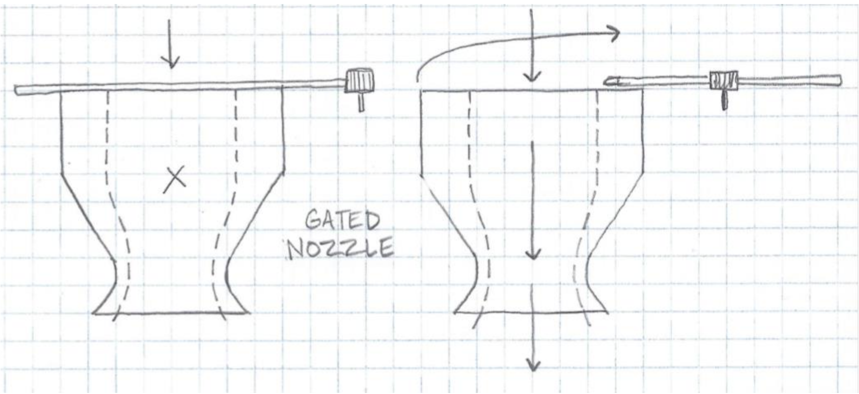


Figure 5.3.5. Gated Nozzle Conceptual Distribution System Option

The third design option for the distribution system is "trap door" system that operates fully open or fully closed. As seen below in the illustration, the "floor" of the vessel will be two downward opening doors that will upon actuation release the full body of the fluid instantly.

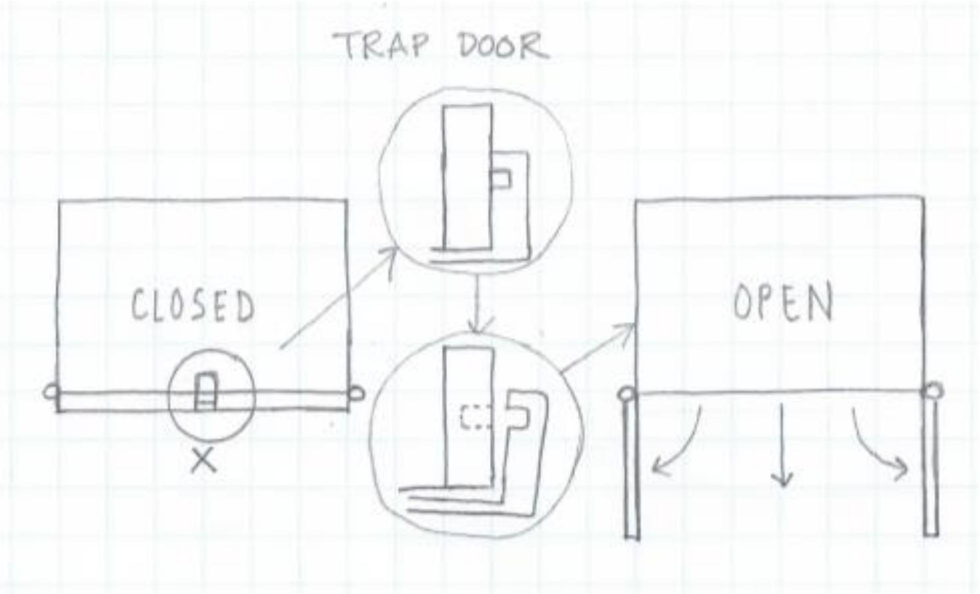


Figure 5.3.6. Trap Door Conceptual Distribution System Option

5.4 Method of Selecting Final Conceptual Design

The criteria were chosen based on interviews conducted with two Directors of Lifeguard Operations for the cities of San Clemente and Carlsbad, California. The results obtained from the interviews were used as the voice of customer (VOC) that determined the selection criteria for both subsystems that comprise the totality of the project. For more information on the source of some of these comments, see Doug Fraser's report in our references[9]. In addition to the suggestions set forth by the customers, the team also added selection criteria based on needs found through research, as well as time and budget restraints laid out by the MEE 488/489 capstone course.

Since the UAV and disbursement/actuation systems are diverse in technical and manufacturing processes, the selection criteria for each conceptual design was separated into two distinct categories respectively.

UAV System selection criteria:

Payload (8): Since the UAV would be required to carry two liters of repellent, as well the disbursement rig, the selected vehicle would need to be able to fly unimpeded with 5 to 6 additional kilograms of weight. The normal volume of a single repellent deployment is 0.4 liters. Nonetheless, given the variables during a rescue attempt (i.e. swell, ocean current, and wind), the team determined that is was critical to increase the volume to mitigate the potential uncertainty of these variables. Therefore, finding a given UAV platform that is capable of carrying the additional weight is paramount for a successful project result.

Response Time (10): The response time was a top priority for the customer, as time is of the essence in any given rescue attempt. The goal that the directors specified was a total flight time of less than 45 seconds. Flight time was defined by the team and is equal to a cold start of the UAV, fly 100 meters off shore, and drop payload.

Air Speed (3): Since response time was specified as the most important parameter given by the customer, the response time is contingent on the air speed capability of the UAV platform. The required air speed needed to reach the team's goal of reaching 100 meters offshore within 45 seconds is 8.5 m/s while fully loaded and heading into a 10 km/hr headwind.

Cost (6): Although cost is primarily a factor dictated by the budget restrictions of the MEE 488/489 course, it was also brought up during the interviews conducted with the customer. Right now, funding cannot exceed $1000 for each device to reach every lifeguard tower. Due to our budget constraints, the entirety of the project cannot exceed $700. The UAV platform should not exceed 60% of the total project budget due to this.

Maneuverability (8): The accuracy of the device is dependent on the UAV's maneuverability. Since the victim's location is a constant variable, and other unknown parameters could affect the position of where the repellent needs to be disbursed, the ability to change position quickly and effectively is another important criterion selected.

Stability (10): Flying over the open ocean presents a number of aerodynamic variables including wind and pressure differences. Since the UAV will have an added structure attached beneath it holding two liters of unstable liquid repellent, a platforms capability to remain stable during flight and delivery is crucial.

Ease of Use (4): The majority of lifeguards stationed in towers are under the age of 30 and have regular training sessions. Given these parameters, the customer asked that the product be designed with "ease of use" to decrease possible user error and reduce the amount of time required to effectively train their employees.

Disbursement Method:

Disbursement time (8): The time taken for the disbursement of the repellant after getting to the location of the victim is important as the product has to be able to get sufficient volume of repellant to the victim's vicinity in a short amount of time.

Accuracy (10): Ensuring that the shark repellant is dropped in the vicinity of the victim is important to ensure the shark evacuates from the vicinity of the victim and not towards other patrons using the beach. The larger volume using the trap doors helps with this as the larger volume of liquid disbursed ensures that the repellant does not get blown away due to strong winds in the beach area.

Precision (10): Being able to repeat the process with the same results is important to ensure that the product is reliable. This ensures that the product can be used under various conditions with the same results.

Cost (3): It was important to keep the budget low, but it was more important that the system is reliable. Team ATS decided that cost was not a major factor for deciding the disbursement method. Especially because if the disbursement method fails, the entire system is compromised.

Power requirement (6): It was important to keep the weight of the entire system minimal. This means if the power requirement is kept minimal, the weight increase due to battery needed to power the actuation system would be less.

Simplicity (7): Having a more complex design increases the possibility of failure as it increases the number of modes available for failure to occur. Hence, it was decided that the system would be kept as simple as possible to reduce the possibility of failure of the actuation system.

5.5 Final Selection Comparison and Rationale

The matrices constructed for the selection processes of the conceptual design options for the UAV platform and distribution system are listed below and discussed in detail.

Table 5.5.1: UAV Platform Comparison Matrix

		Quadcopter		Fixed-Wing		Single Rotor	
Criteria	**Weighting**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Payload	8	8	64	5	40	9	72
Response Time	10	9	90	6	60	9	90
Air Speed	3	6	18	9	27	4	12
Cost	6	7	42	4	24	5	30
Maneuverability	8	10	80	3	24	6	48
Stability	10	10	100	4	40	8	80
Ease of Use	4	9	36	6	24	5	20
Weighted Totals			430		239		352
		Selected option					

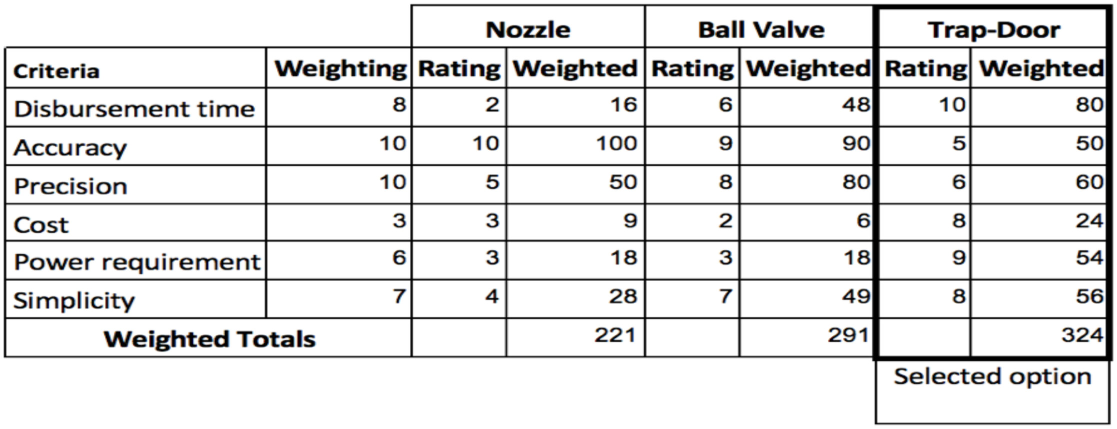
<u>Quadcopter</u>:
- Payload rating 8: good carrying capacity, not as high as fixed wing potential or single rotor
- Response time rating 9: able to take off instantly from small location
- Air speed rating 6: lower speed than fixed wing, but higher than single rotor
- Cost rating 7: least expensive option available, but still a costly item
- Maneuverability rating 10: most agile platform able to make instant change of direction
- Stability rating 10: able to hover perfectly level and fixed position
- Ease of Use rating 9: Intuitive, similar in operation to common toys and drones

<u>Fixed-Wing</u>:
- Payload rating 5: good potential carrying capacity (price), not as high as single rotor
- Response time rating 6: needs runway and time to get airborne
- Air speed rating 9: highest speed UAV platform
- Cost rating 4: most expensive option available, payload potential very expensive
- Maneuverability rating 3: makes large radius turns and long sweeping flight patterns
- Stability rating 4: zero hover capability and difficult to maintain perfectly level flight
- Ease of Use rating 6: Simple, but uncommon to have experience operating

<u>Single Rotor</u>:
- Payload rating 9: good carrying capacity, not as high as fixed wing potential
- Response time rating 9: able to take off quickly from small location
- Air speed rating 4: lowest airspeed rating of available options
- Cost rating 5: less expensive than fixed-wing, but still expensive
- Maneuverability rating 6: able to make rapid change in direction with minimal difficulty

- Stability rating 8: able to hover in fixed position with minimal difficulty
- Ease of Use rating 5: Simple, but again experience in operation is uncommon

Table 5.5.2: Distribution System Comparison Matrix



		Nozzle		Ball Valve		Trap-Door	
Criteria	**Weighting**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Disbursement time	8	2	16	6	48	10	80
Accuracy	10	10	100	9	90	5	50
Precision	10	5	50	8	80	6	60
Cost	3	3	9	2	6	8	24
Power requirement	6	3	18	3	18	9	54
Simplicity	7	4	28	7	49	8	56
Weighted Totals			221		291		324
						Selected option	

<u>Nozzle</u>:

- Disbursement time rating 2: Through a restricted orifice the flow rate will be very slow
- Accuracy rating 10: able to consistently hit target pattern beneath the UAV
- Precision rating 5: very vulnerable to cross winds
- Cost rating 3: expensive to manufacture and control
- Power Requirement rating 3: requires high power comparatively to other options
- Simplicity rating 4: large moving parts and high friction of operation do not add simplicity

<u>Ball Valve</u>:

- Disbursement time rating 6: Through a semi-restricted orifice the flow rate will be slower
- Accuracy rating 9: able to consistently hit target directly beneath the UAV
- Precision rating 8: less vulnerable to cross winds
- Cost rating 2: very expensive to manufacture and control
- Power Requirement rating 3: requires high power comparatively to other options
- Simplicity rating 7: rotational friction, moving parts, and seals add complexity

<u>Trap-Door</u>:

- Disbursement time rating 10: entire volume instantly evacuated
- Accuracy rating 5: able to hit larger target pattern beneath the UAV
- Precision rating 6: least vulnerable to cross winds, chaotic drop pattern
- Cost rating 8: cheap to manufacture and control
- Power Requirement rating 5: requires lowest power of all options
- Simplicity rating 8: Smallest and fewest moving parts make for simplicity of design

5.6 Analyses

This section includes a compilation of the key analyses performed during the conceptual design phase. These simple analyses represent the team’s efforts to run simple calculations and quantify design parameters for the project. Section 5.6.1 shows the analysis plan which outlines the timeline of some of the basic analyses performed in this phase. Sections 5.6.2 through 5.6.5 are summaries of the analysis performed. For the complete analysis calculations in more detail, refer to the appendices.

5.6.1 Analysis Plan

It is important for our team to validate key components of the design before moving into the next phase. As a result, a few numerical calculations were performed to give a design basis for moving forward with our project. Figure 5.6.1.1 shows a simple block diagram for the analyses performed during this phase and how they fit into the overall project timeline.

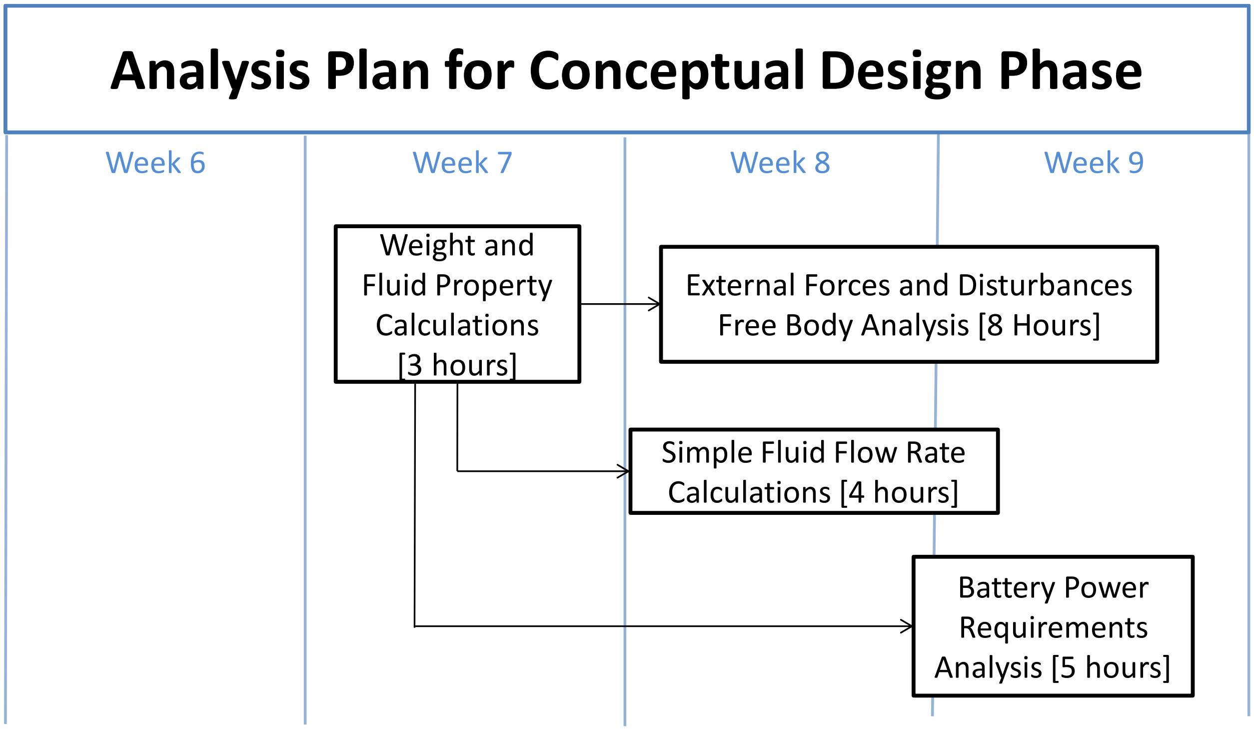


Figure 5.6.1.1: Analysis Plan for the Conceptual Design Project Phase

5.6.2 Weight and Fluid Property Calculations

Problem Statement:

The fluid properties of the shark repellent must be determined for further analysis to know the corresponding mass for the volume selected.

Approach:

Using the values provided on the online product description page for the shark repellent, values for mass and density of the fluid can be approximated. The manufacturer gives the repellent density and volume per sample. Through this, we can determine the volume needed per payload, as well as its corresponding mass. In addition, the final calculation will need to be converted from volume in length units to fluid units.

Defining Equations:

$$\rho = \frac{m}{V} \tag{5.1}$$

Where,

$$\rho = density$$
$$m = mass$$
$$V = volume$$

Density of repellent: $\rho = 1097\ kg/m^3$

Volume per sample: $12.7^3\ cm^3 = 2048\ cm^3 = 2.048\ liters$
$\therefore V \approx 2\ liters$

Mass of repellent: $m = \rho V = \left(1097\ \frac{kg}{m^3}\right)(2\ L) * \left(\frac{0.001\ m^3}{1\ L}\right) = 2.194\ kg$
$\therefore m = 2.194\ kg$

Results:

The fluid density is approximated to be 1097 kg/m^3. The mass of two liters of fluid is approximated as 2.194 kg. The initial assumption was that we would use 2 liters of fluid but was reduced to 1 liter due to weight restrictions, resulting in a total liquid weight of 1.097 kg.

Conclusions:

From these calculations, we now know the additional weight that the drone will need to carry with the fluid properties accounted for. Aside from the repellent container (will be designed in later calculation), the repellent will add approximately 1.1 kg of payload. This can now be used to conduct further analysis on power requirements.

5.6.3 External Forces and Disturbances Free Body Analysis

Problem Statement:

Using the values calculated in the Weight and Fluid Property Calculations, we need to determine the full set of potential forces acting on the system during a mission.

Approach:

By drawing a free body diagram which represents our system, we can approximate forces required to stabilize and move the product based on approximate physical properties of our system.

Defining Equations:

$$F = m * a \tag{5.2}$$
$$\tau = F * d \tag{5.3}$$

Where

$$F = Force$$

$$a = Acceleration$$
$$\tau = Torque$$
$$d = Distance$$

Results:

$$F = 1 * 3 * 9.8 = 29.4N$$

Considering 3Gs of maximum acceleration and 1kg of fluid in the reservoir.

$$\tau = 29.4 * 0.16 = 4.7Nm$$

Considering a maximum reservoir diameter of 0.16m.

Conclusion:

As it can be seen from the results above, the force due to the fluid moving around in the reservoir is very small (4.7Nm). So, the propellers can easily correct for this force that will be applied from the fluid in the reservoir. In addition, it can be recommended to fill the container to the maximum position so that the movement of the fluid in the reservoir will be very minimal.

5.6.4 Battery Power Requirements Analysis

Problem Statement:

To operate the UAV, a sufficient power source must be provided to supply the necessary power required to operate and maintain the system.

Approach:

We approached the problem from a analytical method, using industry determined effective power ratings and the governing equations as shown below for a four-motor quadcopter system.

Defining Equations:

$$P = I * V \tag{5.4}$$

$$I_{total} = (16A * 4) + 4A \tag{5.5}$$
$$A_{total} = 68A$$

$$I = 68 + (.15 * 68)$$
$$I_{Effective} = 78.2A$$

$$\frac{n_{cells} * C_{battery}}{1000} = A$$

$$\frac{12 * 6600}{1000} = 79.2A$$

Where: P = Power in Watts

I = Current in amps

n = Number of cells

C = Capacity of battery in mAh

1 mAh = 3.6 Coulombs

Results:

After performing the calculations, and considering various time and power requirements, we determined that for the conceptualization of our device, we need a battery capacity of 6600mAh.

Conclusions:

After calculating the needed power from the equations above, the system will require more than 5000mAh originally assumed do the run time.

Recommendations:

Use a 6600mAh battery for enough run time and power distribution.

5.7 Proof of Concept Testing

No proof of concept testing was performed by the team during the conceptual phase of the design process.

5.8 Prototype Final Conceptual Design

As discussed in the decision matrices from section 5.5.1 and 5.5.2 the quadcopter UAV platform and trap-door distribution method were selected for the final conceptual design. Below is the final conceptual design rendering with key features and benefits highlighted

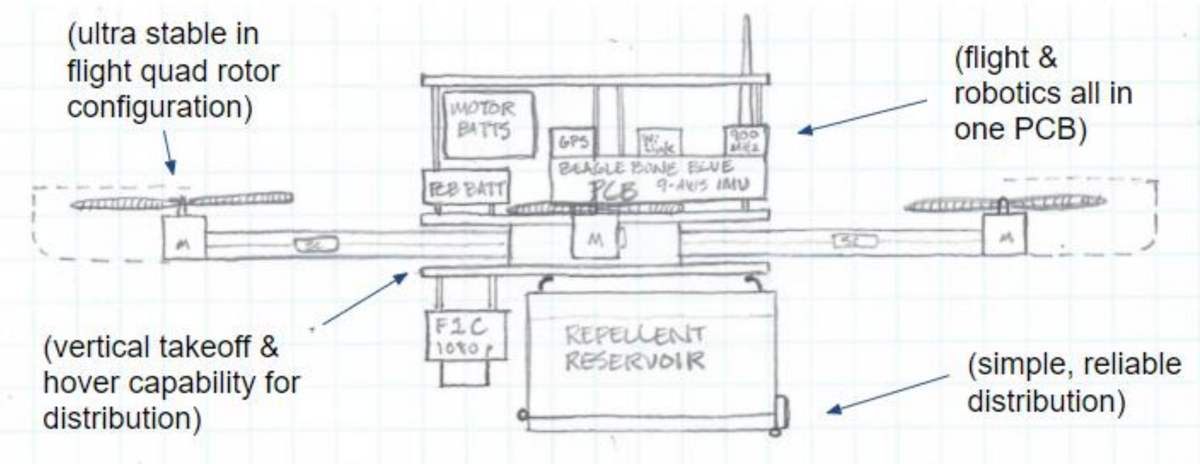


Figure 5.8.1: Final Conceptual Design

Our conceptual design will be optimized and further developed in the upcoming phases. The general idea of our product will not vary much from this concept, however.

Table 5.8.1: Requirements Validation Matrix Part 1

No.	Prototype Requirement	Method of Validation	Status
1	Storable in 2.5 m x 2.5 m x 2.5 m lifeguard tower	Initial design suggests that device will be easily storable. Exact dimensions will be calculated in prelim design.	Complete
2	UAV capable of flying with 4.5 kg of total weight	Power calculations complete and are acceptable for battery. Moving forward to theoretical and numerical testing.	Complete
3	Repellent reservoir can hold 2 liters of liquid	Initial power and battery calculations suggests that this is feasible. Subtle fluctuations in mass and design should not inhibit functionality.	Complete
4	Flight time to be less than 45 seconds. Flight time is equal to cold start, fly 100 meters offshore, and drop payload	Current research points to adequate quadcopter flight time within our set specifications.	Complete
5	Time from actuating drop-sequence to surface impact of full payload less than 3 seconds	Bomb door dropping device is predicted to be able to deliver payload within 3 seconds.	Complete
6	Drop payload within 1.5 m radius	Preliminary physical design and studies show target radius being met in final design.	Complete
7	Drops payload within 1.5 m of designated target 98% of trials	Meets engineering judgement. Team does not expect variation in overall results based on conceptual design.	Complete

Table 5.8.1 Requirements Validation Matrix (Part 2)

8	Material and manufacturing costs less than $700	Prelim estimates for UAV and repellent delivery system are currently less than $700.	Complete
9	Operate and carry payload using a 6600 mAh power supply, and minimize the power needed to actuate disbursement	Current calculations predict that 6600 mAh battery will be enough for flight requirements as well as power needed for remote actuation.	Complete
10	Maintain 25 km/hr with payload to satisfy response time requirement	Average 30 km/hr, team accounts for minor velocity restrictions based on added mass.	Complete
11	Hover 10 m above drop zone	The quadcopter being purchased is capable of hovering above target without drifting its position.	Complete
12	Fly with payload 15 m above sea level	The motors and propellers for the quadcopter are capable of carrying the quadcopter as well as the payload at the required cruising altitude.	Complete
13	Operate between 10º C and 40º C	The climate in a beach environment during operating hours when a lifeguard is present is between 10º C and 40º C.	Complete
14	Operate above sea level.	Further research into effects of the humid environment on quadcopter performance will need to be performed.	Complete
15	Withstand sand and saltwater corrosion, to operate without repair for 6-months	Further research into effects of the harsh environment on quadcopters will need to be performed.	Complete
16	Someone can be trained to use device within 8 hours of training and is intuitive operation	Quadcopter controlling medium is determined to be decently intuitive and straightforward.	Complete
17	UAV allows for guards on the outer 90º of blades to be protected from contact	Quadcopter design allows for easy mounting of blade protectors.	Complete
18	Design and production must be accomplished within 6 months with 6-man team	Project is determined to be within the scope of the course.	Complete
19	Power supply can allow for 20 minutes of flight without recharging	Research into battery and power supplies determine that adequate market products exist to meet requirements.	Complete
20	Disbursement system comprised of less than 5 components, to reduce failure probability	Bomb door design is simple, and requires about 4 unique components to function, meeting this requirement.	Complete

5.9 Commercialization

The final commercial product will go through a ruggedization process strengthening it against the elements which the device will interact with in the beach environment such as water, salt, sand, etc. During the commercialization process, continued development of Android and IOS applications will be carried out to as part of the continuing Research and Development for the SAVRRS product.

For final product commercialization, Team ATS will look at alternative manufacturing methods such as casting and other bulk manufacturing methods to be environmentally friendly and waste less material. In addition, some of the components may be made of different materials such as carbon fiber composites as large-scale manufacturing will make these materials cost effective and environmentally friendly.

Team ATS will also investigate adding other lifesaving equipment to the payload, such as a floatation device, which can be delivered to not only shark attack victims, but also swimmers in distress.

However, the scope of the project for this class will be limited to a prototype design of the SAVRRS device. This prototype will be a UAV capable of repelling sharks from beach environments and providing lifeguards the opportunity to get in the water if a shark attack has occurred and ensuring the shark attack victim is safe from a secondary attack.

6. Preliminary Design

In Preliminary design, the team will remain open to changes to the conceptual design, to adjust it to meet the design requirements. Therefore, in this section an explanation will be provided to discuss what have been done regarding the changes during the transition from the conceptual design to the preliminary design. Thus, the section consists of some trade studies that the team has conducted, an optimization plan, test plan, some analyses, and other parts which serve the transition of the preliminary design.

6.1 Configuration Block Diagram

The configuration block diagram below shows the improvements made to the configuration block diagram to include more detail as to where signals originate and how components are related to one another. As is shown in figure 6.1.1 below, all major components such as the Pix-hawk 2 CUBE controller, motors and actuating system are seen to visualize how the components interact with each other. This figure also shows how the autopilot was programmed to return to the lifeguard post autonomously after disbursement of the repellant.

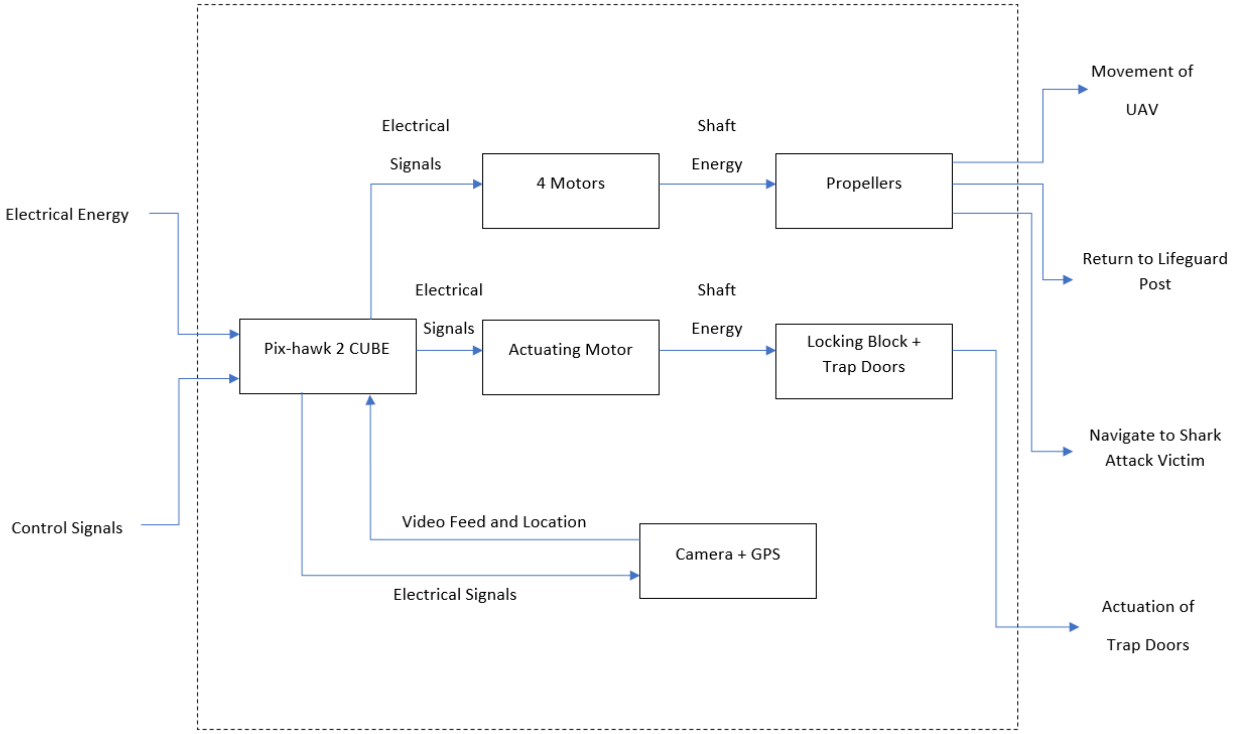


Figure 6.1.1: Configuration Block Diagram for Air-to-Shark System

6.2 Trade Studies

During the preliminary design phase, many components and features of our system must be determined. As a result, a series of different trade studies will be performed for the various components within the product. For each individual trade study, the use of a weighted criteria matrix is employed. Sections 6.2.1-6.2.9 below outline the different trade studies performed. Please note that the order of the trade studies listed below do not represent the order in which they were performed.

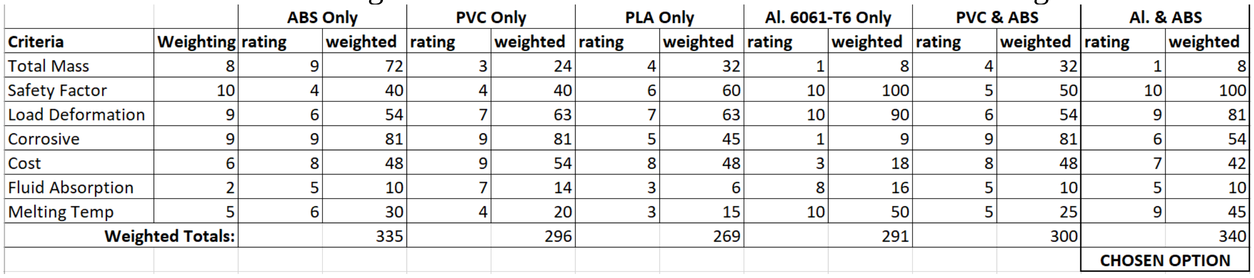
6.2.1 Internal Actuation for Disbursement Trade Study

For the internal actuator shaft and locking block system, a trade study was performed for the various material combinations that could potentially be used in our system. The components were evaluated based on the following parameters, total mass, safety factor, deformation, corrosiveness, cost, fluid absorption, melting temperature. A description of each of the parameter weightings and justification is below:

- Total mass was weighted an 8 due to the necessity of keeping the mass in the actuation system at a low value. Having the mass too high would add to the overall weight of the device and increase the power requirements.
- Safety factor is weighted a 10 due to how important it is to avoid failures in the actuation. If any kind of yielding were to occur, the system would fail.
- Load deformation was weighted a 9. If the device is to deform too much, the mechanism might misfire due to lack of support on the device.
- Corrosiveness is significant for our operation, given the fact that we are using a fluid. It was weighted a 9 due to the potential failures that may arise due to corrosion.
- Cost was weighted a 6 because these parts are not all that expensive. We are potentially talking about a piece of the device that is the size of a pencil. Regardless of the material, cost doesn’t seem to be that big of a factor.
- Fluid absorption is kind of insignificant since the dropper device will have 5 times the recommended dosage of shark repellant anyway. If the plastic absorbs some of the fluid, it is inconsequential since there is still so much extra.
- Melting temperature was weighted a 5 because although it is important, it is unlikely that the temperatures of the environment will allow for the melting of the material anyway.

Table 6.2.1.1 below shows the final weighted criteria matrix, and the weighted values of each parameter for the 6 considered options.

Table 6.2.1.1: Weighted Criteria Matrix for Actuator Shaft and Locking Block



		ABS Only		PVC Only		PLA Only		Al. 6061-T6 Only		PVC & ABS		Al. & ABS	
Criteria	**Weighting**	**rating**	**weighted**	**rating**	**weighted**	**rating**	**weighted**	**rating**	**weighted**	**rating**	**weighted**	**rating**	**weighted**
Total Mass	8	9	72	3	24	4	32	1	8	4	32	1	8
Safety Factor	10	4	40	4	40	6	60	10	100	5	50	10	100
Load Deformation	9	6	54	7	63	7	63	10	90	6	54	9	81
Corrosive	9	9	81	9	81	5	45	1	9	9	81	6	54
Cost	6	8	48	9	54	8	48	3	18	8	48	7	42
Fluid Absorption	2	5	10	7	14	3	6	8	16	5	10	5	10
Melting Temp	5	6	30	4	20	3	15	10	50	5	25	9	45
Weighted Totals:			335		296		269		291		300		340
												CHOSEN OPTION	

The final selected preliminary option was the two-part ABS plastic block and aluminum shaft. This is primarily since ABS plastic is corrosion resistant, cheap, strong, and the analysis shows that there is minimal deflection and a good safety factor. The aluminum allows for additional strength and reliability as well as greater rotational durability. Due to 3D printing restrictions in the ASU manufacturing shop, all designated ABS 3D-printed parts will be polycarbonate printed (explanation and analysis will follow in section 7.1) The aluminum will be manufactured as usual.

6.2.2 Reservoir and Trap Door Material Trade Study

Table 6.2.2.1 shows the trade studies carried out to determine what material will be used to manufacture the container that will be used to carry the repellant. As it can be seen, it was important to choose a material that was resistant to elements it may face in beach environments such as salt, water and sand. It was also important to choose a material that was strong enough to withstand any unexpected forces that may be applied on the container to prevent any cracks occurring that may compromise the disbursement system.

Table 6.2.2.1: Container and Trap Door Material Trade Study

		ABS		Aluminum		PLA	
Criteria	**Weighting**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Resistance to Elements	10	9	90	5	50	6	60
Structural Integrity	10	8	80	10	100	6	60
Ease of Manufacture	7	8	56	5	35	10	70
Cost	7	8	56	5	35	10	70
Weighted Totals			282		220		260

As a result, it was determined that ABS would be used to manufacture the repellant container and trap doors. NOTE: Due to manufacturing constraints and availability, for the final prototype, a combination of polycarbonate and ABS was used for the components deemed ABS.

6.2.3 Sealing Ring Material

The table below shows trade study for seals material, there are three options in the table which are Fluorocarbons, Polyurethane and Fluorosilicone. The most important criteria’s in the table below are the temperature range and if the material can be installed on dynamic seals. For temperature range the Fluorocarbons can work between 13°to+446°F, Polyurethane can work between -30°F to +175°F and Fluorosilicone can work between 75°F to +400°F. Polyurethane the only material between these three which can work on a dynamic seals, the selected option is Polyurethane since this material have the highest weight as shown in table6.2.3.1.

Table 6.2.3.1: Seals Trade Study

		Fluorocarbons		Polyurethane		Fluorosilicone	
Criteria	Weighting	Rating	Weighted	Rating	Weighted	Rating	Weighted
Cost	9	6	54	6	54	7	63
Strength	8	8	64	8	64	8	64
Temperature range	8	10	80	10	80	4	32
Installed on dynamic seals	10	0	0	10	100	0	0
Ease of manufacture	4	5	20	5	20	5	20
Weighted Totals			218		318		179
				Selected Option			

6.2.4 Slider Attachment Trade Study

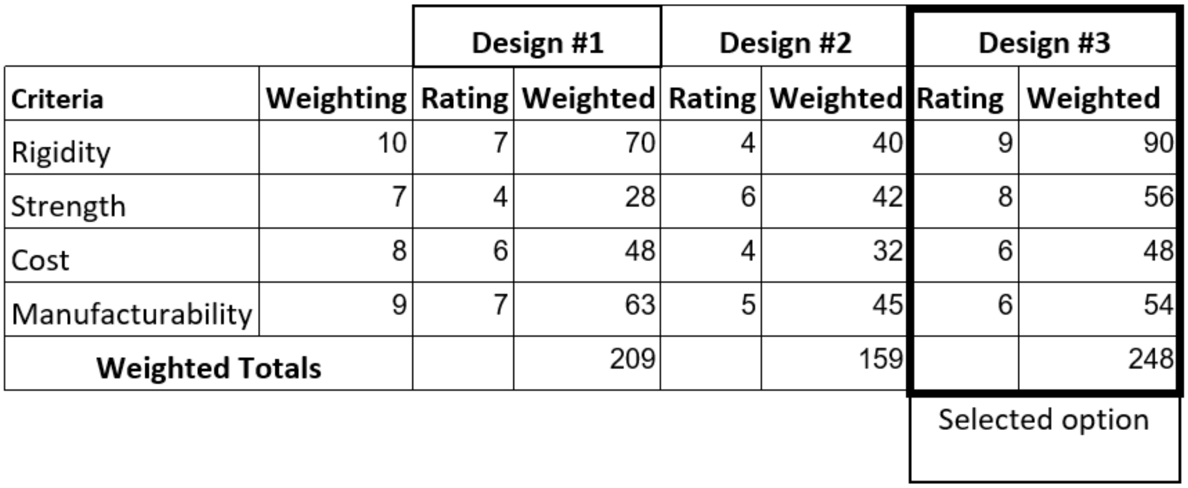
The following table 6.2.4.1 shows the benefits and concerns of the different slider designs for our system. For a visual representation of each design option, refer to the analysis conducted in section 6.6.3 of the report.

Table 6.2.4.1: Component trade study matrix comparing the distinctive design options and benefits.

	Positives	Concerns
Design #1	• Simplistic design • Easy to manufacture	• Design could cause significant stress concentrations • Needs to be optimized for weight
Design #2	• Improved stress distribution at points of concern • Reduced material	• Could require additional structure support at fixed edge • Potential for undesirable stress concentrations
Design #3	• Potential improvement for reinforcement at stress loading • Least likely for system failure in use	• Design could require more material and add weight to structure • Difficult to manufacture

There are numerous positives and concerns with each design – most of which have been unsupported claims and assumptions up to this point in the design considerations for the attachment device. A trade study weighted criteria matrix was created to compare the designs in consideration. Further analysis is conducted on each design in Section 6.6.3 of this report.

Table 6.2.4.2: Weighted Criteria Matrix for Slider attachment design considerations



		Design #1		Design #2		Design #3	
Criteria	**Weighting**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Rigidity	10	7	70	4	40	9	90
Strength	7	4	28	6	42	8	56
Cost	8	6	48	4	32	6	48
Manufacturability	9	7	63	5	45	6	54
Weighted Totals			209		159		248

Selected option

6.2.5 Hinge and Pin Trade Study

For the hinge and pin trade study, each component was considered separately. Table 6.2.5.1 below shows the criteria vs the materials for the hinge and table 6.2.5.2 shows the same for the pin.

Table 6.2.5.1: Weighted Matrix comparing different materials for the hinge against chosen criteria.

		ABS Plastic		Aluminum Alloy		Steel	
Criteria	Weight	Rating	Weighted	Rating	Weighted	Rating	Weighted
Mass	8	9	72	3	24	5	40
Safety Factor	10	7	70	8	80	8	80
Deformation	9	6	54	8	72	8	72
Corrosion	5	9	72	6	48	5	40
Cost	8	9	72	6	48	7	56
	Total		340		272		288

Table 6.2.5.2: Weighted Matrix comparing different materials for the pin against chosen criteria.

		Titanium		Aluminum Alloy		Steel	
Criteria	Weight	Rating	Weighted	Rating	Weighted	Rating	Weighted
Mass	8	4	24	6	36	4	24
Safety Factor	10	8	80	8	80	8	80
Deformation	9	8	72	9	81	9	81
Corrosion	5	7	56	7	56	6	48
Cost	8	5	40	7	56	6	48
	Total		272		309		281

There are many combinations of material that could have been used for both the hinge or the pin but given the criteria and the weights that rank the importance of each criteria, ABS plastic was chosen for the hinges and aluminium was chosen for the pins.

6.2.6 Camera Trade Study

The following table reflects the trade study performed for the camera during the conceptual design phase. Ultimately, however, the team decided to not pursue a camera for the prototype design to save costs.

Table 6.2.6.1: Weighted Criteria Matrix for Camera

		CMOS		**Hero**		**F1C**	
Criteria	**Weighting**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Cost	8	9	72	4	32	8	64
Image	9	9	81	10	90	9	81
Ruggedization	8	4	32	9	72	8	64
Weighted Totals			195		192		209

Selected option

Hero Cam, F1C, and a CMOS connecting board camera were examined for feasibility with the key differences being cost and durability. The hero is water proof and time tested, but very expensive. The PCB camera is cheap but requires ruggedization and integration. The F1C camera does 1080p and fits into the same waterproof shell designed for the Hero making it the ideal option for our visual sensing.

6.2.7 Motor Trade Studies

Table 6.2.7.1 below shows the weighted criteria matrix for the motor analog vs digital specifications.

Table 6.2.7.1: Weighted Criteria Matrix for Motor Analog vs Electronic Computation

		DC		**BLDC**	
Criteria	**Weighting**	**Rating**	**Weighted**	**Rating**	**Weighted**
Cost	5	8	40	4	20
Maintenance	6	4	24	8	48
Performance	9	8	72	9	81
Precision	9	7	63	9	81
Weighted Totals			199		230

Brushless motors cost more because they require ESCs so they lose in the cost comparison. Brushless motors do not drop voltage across physical brushes because they are commuted 100% electronically and have a higher precision (ESCs) and performance. Brushless motors have no brushes to maintain so require less maintenance than a brushed motor over the same lifespan. Overall the BLDC is preferred.

Table 6.2.7.2 below shows the weighted criteria matrix for the motor magnet winding orientation specifications.

Table 6.2.7.2: Weighted Criteria Matrix for Motor Permanent Magnet and Winding Orientation

		Inner-Mag		**Outer-Mag**	
Criteria	**Weighting**	**Rating**	**Weighted**	**Rating**	**Weighted**
Cost	5	5	25	6	30
Heat Dissipation	7	8	56	5	35
Agility	10	9	90	8	80
Cogging Torque	6	6	36	8	48
Weighted Totals			207		193

Both motor styles have a similar cost so only minor advantage to the Inner mounted. Inner mounted have a higher heat dissipation rate than the outer mounted. The inner mounted also have a faster effective response to input controls that increase agility and performance. The advantage to Outer mounted is that they have relatively low cogging torque. Overall the inner mounted motor is preferred.

6.2.8 Rotor Blade Trade Study

Table 6.2.8.1 below outlines the decision making rational for the rotor blade selection.

Table 6.2.8.1: Weighted Criteria Matrix for Rotor Blades

		CF rotor		**Poly rotor**	
Criteria	**Weighting**	**Rating**	**Weighted**	**Rating**	**Weighted**
Cost	4	4	16	6	24
Heat Dissipation	8	9	72	6	48
Agility	8	9	72	6	48
Weighted Totals			158		120

Both rotors are relatively inexpensive, however the carbon fiber blades have a higher rigidity and strength with lower weight than do the polymer blades making the minor cost increase worth the upgrade in equipment.

6.2.9 Flight Controller Trade Study

Table 6.2.9.1 below outlines the decision making rational for the flight controller used in the final prototype.

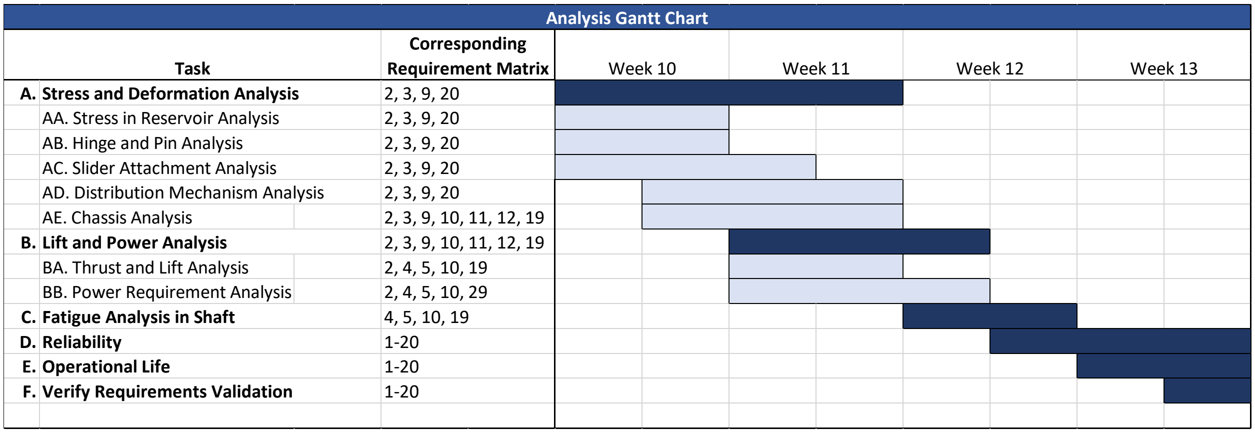
Table 6.2.9.1: Weighted Criteria Matrix for Flight Controller

		Arduino		**BBB**		**Pix Hawk**	
Criteria	**Weighting**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Cost	10	9	90	4	40	9	90
Security	7	5	35	6	42	8	56
Simplicity	8	6	48	9	72	6	48
Operation	9	7	63	8	72	8	72
Weighted Totals			236		246		268
						Selected option	

The Beagle bone Blue is an all in one flight controller but is almost as expensive as the entire budget of this project. The Pixhawk having an inboard 9-axis IMU, GPS connection, and GSM2 connectivity slightly edged out the Arduino offerings all being very similar in price. Updates on this item are included in section 7.1.

6.3 Analysis Plan and Results

It is important for our team to validate key components of the design before completing the preliminary design phase. This is the phase where more in-depth calculations are required to prepare for a more complete preliminary design. Failure to perform adequate analysis and calculations may result in greater failures later down the road. Figure 6.3.1 shows a Gantt chart for the analyses performed during the preliminary design phase and how they fit into the overall project timeline.



Task	Corresponding Requirement Matrix
A. Stress and Deformation Analysis	2, 3, 9, 20
AA. Stress in Reservoir Analysis	2, 3, 9, 20
AB. Hinge and Pin Analysis	2, 3, 9, 20
AC. Slider Attachment Analysis	2, 3, 9, 20
AD. Distribution Mechanism Analysis	2, 3, 9, 20
AE. Chassis Analysis	2, 3, 9, 10, 11, 12, 19
B. Lift and Power Analysis	2, 3, 9, 10, 11, 12, 19
BA. Thrust and Lift Analysis	2, 4, 5, 10, 19
BB. Power Requirement Analysis	2, 4, 5, 10, 29
C. Fatigue Analysis in Shaft	4, 5, 10, 19
D. Reliability	1-20
E. Operational Life	1-20
F. Verify Requirements Validation	1-20

Figure 6.3.1 Gantt Chart for Preliminary Analysis Plan

The team has decided to perform each of the analyses outlined in Figure 6.3.1 to ensure that the most critical components of the system do not experience any failure during typical operation. Reliability and operation life were too deemed important so that the final product may have an estimated reliability and product life. More information on the results of these analyses are outlined in Section 6.6.

6.4 Failure Modes and Effects Analysis (FMEA)

An FMEA has been conducted outlining the most common failure modes and their potential effects on our system.

Table 6.4.1 shows the entire FMEA table for the preliminary phase. For further risk reduction and FMEA updates, refer to section 7.1.6.

Table 6.4.1a: FMEA for ATS project part 1

													Action Results				
Find No.	**Part Name**	**Function**	**Potential Failure Mode**	**Potential Failure Effect**	**SEV**	**Potential Causes/Mechanisms of Failure**	**OCCUR**	**Current design Controls**	**DETECT**	**RPN**	**Recommended Actions**	**Responsibility & Target Completion Date**	**Action taken**	***pS***	***pO***	***pD***	***prpn***
1	Propellers	Transmits power by converting rotational motion into thrust. Makes the drone move	vibrational stress causes propellers to shatter, physical failure	drone cannot fly	10	signal from drive shafts does not come through	2	visual confirmation of propeller movement	8	160	check for residence and vibration, implement carbon fiber components	TBD @ MEE 489	Design next semester	10	1	8	80
2	Motors	Converts electrical energy to mechanical energy	power failure	drone cannot fly, power can't get to the propellers	10	improper housing, physical damage, corrosion, material build up, rotor failure,	2	visual and audio confirmation of motor running and turning the components	8	160	research and select ideal component for design	TBD @ MEE 489	research and select ideal component for design	10	1	8	80
3	Motors	Converts electrical energy to mechanical energy	overheating	drone cannot fly, low power	8	imsufficient power supply, excess load, bad manufacturing	5	visual of smoke shows signs of failure	5	200	double check loads, specify correct motors	TBD @ MEE 489	research and select ideal component for design	10	2	5	100
4	Controller	Maneuver the drone; sends out signals to drone	signals from controller do not get to the drone	drone will not move	9	radio signal lost, individual component failure	4	visual confirmation of drone movement	10	360	research and select ideal component for design	TBD @ MEE 489	research and select ideal component for design	9	2	10	180
5	Receiver	Receive signals	signals from controller do not get to the drone	drone will not move	9	radio signal lost, individual component failure	4	visual confirmation of drone movement	10	360	employ GSM2 point to point, use redundant 900MHz radio	TBD @ MEE 489	research and select ideal component for design	9	2	10	180
6	Power Supply	Power the drone so the components work	electrical components will not turn on	dronce will not turn on, functions will not operate	10	low charge, battery failure	3	visual confirmation of components working	10	300	specify correct battery for loads to minimize failure	TBD @ MEE 489	research and select ideal component for design	10	1	10	100
7	Disturbance Rejection	balances the drone when it is forced off track	cannot balance drone when it is thrown off balance	drone will not regain balance, could fall out of sky or be hard to control properly	8	malfunction of rejection's coding, ESC failure	4	visual confirmation of drone movement	8	256	research and select ideal component for design	TBD @ MEE 489	research and select ideal component for design	8	2	8	128
8	Camera	Allow user to see the area	screen does not display properly or clearly enough	cannot control drone with ease or accuracy	8	lense is not focused correctly, connections within camera are damaged or not set up correctly	3	visual confirmation of visuals	4	96	research and select ideal component for design, encourrage end users to regularly check	TBD @ MEE 489	research and select ideal component for design	8	2	4	64

Table 6.4.1b FMEA for ATS project part 1

													Action Results				
Find No.	**Part Name**	**Function**	**Potential Failure Mode**	**Potential Failure Effect**	**SEV**	**Potential Causes/Mechanisms of Failure**	**OCCUR**	**Current design Controls**	**DETECT**	**RPN**	**Recommended Actions**	**Responsibility & Target Completion Date**	**Action taken**	***pS***	***pO***	***pD***	***prpn***
1	Propellers	Transmits power by converting rotational motion into thrust. Makes the drone move	vibrational stress causes propellers to shatter, physical failure	drone cannot fly	10	signal from drive shafts does not come through	2	visual confirmation of propeller movement	8	160	check for residence and vibration, implement carbon fiber components	TBD @ MEE 489	Design next semester	10	1	8	80
2	Motors	Converts electrical energy to mechanical energy	power failure	drone cannot fly, power can't get to the propellers	10	improper housing, physical damage, corrosion, material build up, rotor failure,	2	visual and audio confirmation of motor running and turning the components	8	160	research and select ideal component for design	TBD @ MEE 489	research and select ideal component for design	10	1	8	80
3	Motors	Converts electrical energy to mechanical energy	overheating	drone cannot fly, low power	8	insufficient power supply, excess load, bad manufacturing	5	visual of smoke shows signs of failure	5	200	double check loads, specify correct motors	TBD @ MEE 489	research and select ideal component for design	10	2	5	100
4	Controller	Maneuver the drone; sends out signals to drone	signals from controller do not get to the drone	drone will not move	9	radio signal lost, individual component failure	4	visual confirmation of drone movement	10	360	research and select ideal component for design	TBD @ MEE 489	research and select ideal component for design	9	2	10	180
5	Receiver	Receive signals	signals from controller do not get to the drone	drone will not move	9	radio signal lost, individual component failure	4	visual confirmation of drone movement	10	360	employ GSM2 point to point, use redundant 900MHz radio	TBD @ MEE 489	research and select ideal component for design	9	2	10	180
6	Power Supply	Power the drone so the components work	electrical components will not turn on	dronce will not turn on, functions will not operate	10	low charge, battery failure	3	visual confirmation of components working	10	300	specify correct battery for loads to minimize failure	TBD @ MEE 489	research and select ideal component for design	10	1	10	100
7	Disturbance Rejection	balances the drone when it is forced off track	cannot balance drone when it is thrown off balance	drone will not regain balance, could fall out of sky or be hard to control properly	8	malfunction of rejection's coding, ESC failure	4	visual confirmation of drone movement	8	256	research and select ideal component for design	TBD @ MEE 489	research and select ideal component for design	8	2	8	128
8	Camera	Allow user to see the area	screen does not display properly or clearly enough	cannot control drone with ease or accuracy	8	lense is not focused correctly, connections within camera are damaged or not set up correctly	3	visual confirmation of visuals	4	96	research and select ideal component for design, encourrage end users to regularly check	TBD @ MEE 489	research and select ideal component for design	8	2	4	64

6.5 System Optimization

Optimization of our system is important because it keeps our product within reasonable specifications. There is much room for optimization within our product, and each component requires its own bit of optimization. The following sections 6.5.1 through 6.5.4 outline the optimization process for some of the key components in our system. Please note that the order of listed optimization analyses does not reflect the actual order in which the team performed these studies.

As the design process continues out of the preliminary design phase, further design changes and optimization will occur. Although these are definitive optimizations to our systems, they may not be included in this section.

6.5.1 Shaft and Locking Block Optimization

The shaft-block actuation system within the system reservoir is a key component to our project. Successful optimization of this component is key to ensure manufacturability, as well as minimize the overall material weight and cost to operate. Once the analysis was completed, optimization is performed on this component (for complete analysis see Section 6.6.4).

The components to be optimized are the safety factor, the overall component weight, dimensions, and material properties. The most important for our system are the component weight and dimensions since they directly impact the configuration of the system. The goal of this optimizations to find the most optimal design configuration and material that will be both cost effective and easy to manufacture in our design.

Since an excel sheet was created that performs the calculations based on the various input variables, the results of this optimization can be shown in a table. These outputs were iteratively updated through a process of changing the physical dimensions until desirable results were found for each material. Table 6.5.1.1 outlines the results of this optimization study.

Table 6.5.1.1: Results of Optimization for Shaft and Locking Block

USER INPUTS:												
reservoir internal height	0.06	m	0.06	m	0.06	m	0.06	m	0.06	m	0.06	m
reservoir internal diameter	0.207	m	0.207	m	0.207	m	0.207	m	0.207	m	0.207	m
fluid density	1000	kg/m^3	1000	kg/m^3	1000	kg/m^3	1000	kg/m^3	1000	kg/m^3	1000	kg/m^3
gravitational constant	10	m/s^2	10	m/s^2	10	m/s^2	10	m/s^2	10	m/s^2	10	m/s^2
door material	**ABS Plastic**		**ABS Plastic**		**ABS Plastic**		**ABS Plastic**		**ABS Plastic**		**ABS Plastic**	
thickness of door	0.003	m	0.003	m	0.003	m	0.003	m	0.003	m	0.003	m
density of door material	1060	kg/m^3	1060	kg/m^3	1060	kg/m^3	1060	kg/m^3	1060	kg/m^3	1060	kg/m^3
shaft material	**ABS Plastic**		**PVC Plastic (molded)**		**PLA Plastic**		**Aluminum 6061-T6**		**PVC Plastic (molded)**		**Aluminum 6061-T6**	
length of shaft	0.054	m	0.057	m	0.057	m	0.057	m	0.057	m	0.057	m
diameter of shaft	0.005	m	0.01	m	0.01	m	0.01	m	0.01	m	0.01	m
density of shaft material	1060	kg/m^3	1300	kg/m^3	1290	kg/m^3	2700	kg/m^3	1300	kg/m^3	2700	kg/m^3
modulus of elasticity shaft	2300000000	Pa	2160000000	Pa	2790000000	Pa	68900000000	Pa	2160000000	Pa	68900000000	Pa
Yield Strength Shaft	44100000	Pa	14000000	Pa	36300000	Pa	276000000	Pa	14000000	Pa	276000000	Pa
Average Melting Temp	219	C	179	C	156	C	616	C	179	C	616	C
Average Water Absorption	0.409	%	0.26	%					0.26	%		
Corrosive	NO		NO		YES		YES		NO		YES	
Brinell Hardness			15				95		15		95	
block material	**ABS Plastic**		**PVC Plastic (molded)**		**PLA Plastic**		**Aluminum 6061-T6**		**ABS Plastic**		**ABS Plastic**	
length of block	0.04	m	0.02	m	0.02	m	0.02	m	0.02	m	0.02	m
width of block	0.01	m	0.005	m	0.005	m	0.005	m	0.005	m	0.005	m
thickness of block	0.005	m	0.003	m	0.003	m	0.003	m	0.003	m	0.003	m
density of block material	1060	kg/m^3	1300	kg/m^3	1290	kg/m^3	2700	kg/m^3	1060	kg/m^3	1060	kg/m^3
modulus of elasticity block	2300000000	Pa	2160000000	Pa	2790000000	Pa	68900000000	Pa	2300000000	Pa	2300000000	Pa
Yield strength block	44100000	Pa	14000000	Pa	36300000	Pa	276000000	Pa	44100000	Pa	44100000	Pa
coefficient of friction between block and door-hooks	0.4		0.4		0.4		0.9		0.4		0.4	
Average Melting Temp	219	C	179	C	156	C	616	C	219	C	219	C
Average Water Absorption	0.409	%	0.26	%					0.409	%	0.409	%
Corrosive	NO		NO		YES		YES		NO		NO	
Brinell hardness			15				95					
CALCULATED VALUES:												
pressure of fluid	600	Pa	600	Pa	600	Pa	600	Pa	600	Pa	600	Pa
total force on bomb doors	20.192	N	20.192	N	20.192	N	20.192	N	20.192	N	20.192	N
Force on Door from fluid	11.622	N	11.622	N	11.622	N	11.622	N	11.622	N	11.622	N
Force on hinge from fluid	8.570	N	8.570	N	8.570	N	8.570	N	8.570	N	8.570	N
Force on door from material weight	0.291	N	0.291	N	0.291	N	0.291	N	0.291	N	0.291	N
Force on hinge from material weight	0.214	N	0.214	N	0.214	N	0.214	N	0.214	N	0.214	N
Total Force on door	11.913	N	11.913	N	11.913	N	11.913	N	11.913	N	11.913	N
Total Force on hinge	8.784	N	8.784	N	8.784	N	8.784	N	8.784	N	8.784	N
Total Force in Shaft	26.095	N	29.649	N	29.605	N	35.921	N	29.649	N	35.916	N
Normal Stress in Shaft	1328995.031	Pa	377508.487	Pa	376938.105	Pa	457361.963	Pa	377499.320	Pa	457299.320	Pa
Maximum Moment in Block	0.209	Pa	0.060	Pa	0.060	Pa	0.060	Pa	0.060	Pa	0.060	Pa
Maximum Shear Force in Block	11.918	N	11.913	N	11.913	N	11.914	N	11.913	N	11.913	N
Moment of Inertia of Block	1.04167E-10	m^4	1.125E-11	m^4	1.125E-11	m^4	1.125E-11	m^4	1.125E-11	m^4	1.125E-11	m^4
Maximum Bending Stress in Block	5005354.591	Pa	7942240.62	Pa	7942238.12	Pa	7942590.62	Pa	7942180.62	Pa	7942180.62	Pa
Maximum Shear Stress in Block	357525.3279	Pa	1191336.093	Pa	1191335.718	Pa	1191388.593	Pa	1191327.093	Pa	1191327.093	Pa
Torque required in Shaft	0.048	N*m	0.024	N*m	0.024	N*m	0.054	N*m	0.024	N*m	0.024	N*m
Max Shear Stress in Shaft	1063196024	Pa	151003394.9	Pa	150775242.1	Pa	182944785.3	Pa	150999728	Pa	182919728	Pa
Safety Factor Shaft	781		657		1706		11776		658		11777	
Deflection of Shaft	-0.031	mm	-0.010	m	-0.008	m	0.000	m	-0.010	mm	0.000	m
mass of Shaft	0.001	kg	0.006	kg	0.006	kg	0.012	kg	0.006	kg	0.012	kg
weight of shaft	0.011	N	0.058	N	0.058	N	0.121	N	0.058	N	0.121	N
safety factor block	17888		4125		10697		81329		12995		12995	
Deflection of Block ends	-0.120	mm	-0.030	m	-0.024	m	-0.001	m	-0.029	mm	-0.020	m
mass of block	0.0021	kg	0.0004	kg	0.0004	kg	0.0008	kg	0.0003	kg	0.0003	kg
weight of block	0.021	N	0.004	N	0.004	N	0.008	N	0.003	N	0.003	N
total mass of shaft and block	0.0032	kg	0.0062	kg	0.0062	kg	0.0129	kg	0.0061	kg	0.0124	kg
Material Property Source:	MatWeb.com											

Table 6.5.1.1 shows the results of deflection and weight for each of the considered materials. Based on these results, it seems most optimal to have a shaft diameter of 10mm, length of 570mm, block width length and thickness of 5mm, 20mm, 3mm respectively. As we can see, the deflection and total mass of the system are quite optimal for the uses we need them for. Ultimately, the pure ABS option was chosen, more information on this is in the Trade Study section of this report.

6.5.2 Reservoir Container and Trap Door Thickness Optimization

To ensure that the system remains lightweight while still maintaining its structural integrity with a high safety factor, the thickness of the container and trap doors were optimized to achieve an optimum thickness. This analysis was carried out in ANSYS and it was confirmed that it would be ideal to use a container wall thickness of 2mm and trap door thickness of 3mm. To see the analysis carried out to achieve this please refer Appendix A1.

It was seen that it was enough for the trap door to be reduced to 2mm as well however, to ensure that the product will not fail the team decided to give an extra factor of safety to the trap doors. In addition, the trap doors will also need to be able to withstand forces from the actuation shaft as well as the repellant. Not only that, the locking mechanism for the actuation block will also be a part of the trap doors so the extra thickness will help strengthen the structure.

6.5.3 Pin Optimization

To optimize the pin's diameter, hand calculations and MATLAB were used. In addition, an online calculator was used to confirm the results of the hand calculations. For these calculations, Newton's second law was applied to derive the internal shear stress and bending moment of the pin. For this case, the pin was simplified as a circular beam with uniformly distributed loads where the hinges would put pressure on the pin. Looking at the internal forces by parts, the maximum bending stress was found. This was used in an optimization analysis in MATLAB which used a modified endurance limit and distortion energy-Goodman equation shown below in equation (6.1). The results were iterated 3 times and did not differ within .1% so the result was confirmed to be .2 inches or 5mm. This is appropriate when compared to the other dimensions of the product. Using this new diameter, the factor of safety is approximately 2, which is what was desired. It is recommended to use 5-10mm for the diameter of the pin. Anything larger would be too heavy and potentially wouldn't fit in the hinge. A smaller pin would not keep the factor of safety at 2, so it would fail earlier than desired.

The simplified free body diagram and internal shear and moment diagrams created by the online calculator can be seen below in Figure 6.5.3.1.

The MATLAB script in Appendix A2 used to calculate and iterate the equation used to optimize the diameter of the pin can be found in the appendix along with the hand calculations used to determine the maximum stress.

$$d=\left(\frac{16n}{\pi}\left\{\frac{1}{S_e}\left[4\left(K_f M_a\right)^2+3\left(K_{fs}T_a\right)^2\right]^{\frac{1}{2}}+\frac{1}{S_{ut}}\left[4\left(K_f M_m\right)^2+3\left(K_{fs}T_m\right)^2\right]^{\frac{1}{2}}\right\}\right)^{\frac{1}{3}} \qquad (6.1)$$

Where,
d= Diameter of the pin
n= Factor of safety
S_e= Corrected endurance limit of the pin's material
K_f= Stress concentration factor
M_a= Alternating bending moment
K_{fs}= Shear stress concentration factor
T_a= Alternating Torque
S_{ut}= Ultimate tensile strength of pin's material
M_m= Midrange bending moment

T_m= Midrange torque

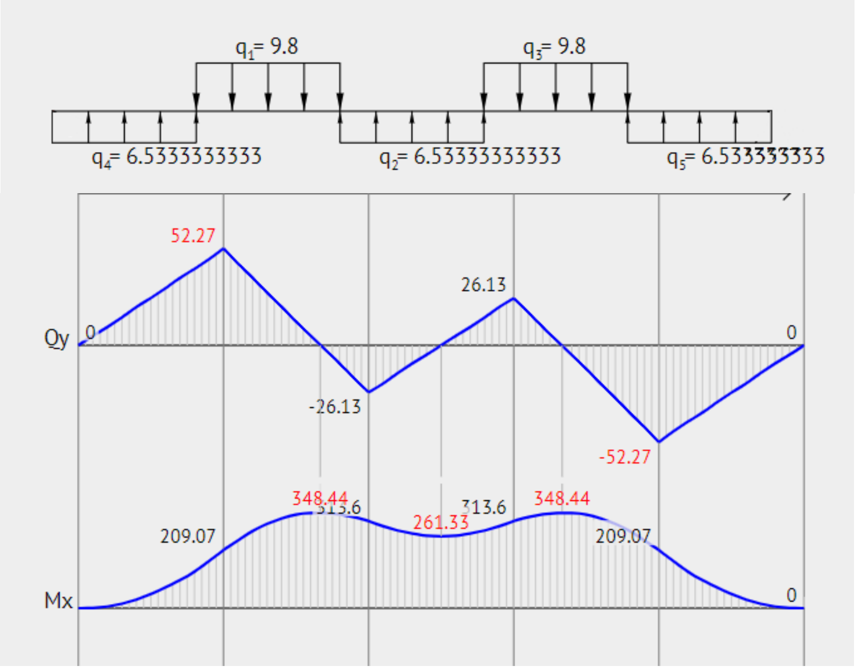


Figure 6.5.3.1: Online calculator generated simplified free body diagram and internal shear and moment diagrams

6.5.4 Slider Attachment Optimization

Table 6.5.4.1: Optimization for slider attachment design results.

	Max Deformation	Max Stress	Mass	Volume
Design #1	2.9154 E-4 mm	0.024975 MPa	60.84 g	58500 mm^3
Design #2	2.8690 E-4 mm	0.003319 MPa	55.97 g	53820 mm^3
Design #3	1.3960 E-4 mm	0.002265 MPa	65.01 g	62595 mm^3
% Optimized	**52.11% reduction in deflection**	**90.93% decrease in max stress**	6.85% increase in mass	14.85% increase in volume

Although the optimization of design causes an overall increase in the mass and volume the selection requires, the maximum deformation was decreased by 52.11% and the maximum stress was decreased by 90.93%. Since this component is required to support the entirety of the repellent reservoir structure the team is willing to yield to a slightly larger mass in exchange for increased rigidity and strength – overall reducing the failure potential of the component and the system.

6.6 Analyses

This section includes a compilation of the key analyses performed during the preliminary design phase. These simple analyses represent the team's efforts to run more in-depth calculations and confirm quantifiable design parameters for the project. Section 6.6.1 shows the analysis plan which outlines the timeline of some of the basic analyses performed in this phase. Sections 6.6.2 through 6.6.9 are summaries of the analysis performed. For the complete analysis calculations in more detail, refer to Appendix A: Full Analysis Reports. The preliminary analysis plan is outlined in Section 6.3.

6.6.1 Reservoir System Analysis

Problem Statement:

Depending on the structural loads applied to the container, decide on a suitable material and thickness for the fluid repellant container.

Approach:

Conduct hand calculations to get expected material properties and dimensions and then conduct a finite element analysis on ANSYS to verify that the system performs as expected.

Defining Equations:

$$\sigma = \frac{F}{A} \tag{6.2}$$

$$\sigma = \frac{My}{I} \tag{6.3}$$

$$\tau = \frac{VQ}{It} \tag{6.4}$$

$$\delta = \frac{PL}{EA} \tag{6.5}$$

For the above equations:

$\sigma = Stress$
$F = Force$
$A = Area$
$M = Moment$
$y = Distance\ from\ Neutral\ Axis$
$I = Moment\ of\ Inertia$
$\tau = Shear\ Stress$
$V = Shear\ Force$
$Q = Moment\ of\ Area$
$t = thickness$
$\delta = deformation$
$P = Force$
$L = Length$
$E = Young'sModulus$

Results:

Table 6.6.1.1: Comparing Structural Integrity

	Total Deformation (m)	Von-Mises Stress (Pa)	Normal Stress (Pa)	Yield Strength	Safety Factor
ABS	0.00034306	778550	775300	13000000	16.69770728
Aluminum	0.00001236	746010	741798.1	55000000	73.72555328
PLA	0.00026016	774630	771230	14000000	18.0731446

As seen in table 6.6.1.1, ABS provided the structural integrity required for our product with ease of manufacture at the budget available. So, Team ATS decided to use ABS for the manufacturing of the Container.

$$P_{max} = 1.18\,kPa$$
$$\delta_{max} = 0.34306\,mm$$
$$\sigma_{max} = 77.8\,kPa$$

Refer Appendix A1 to see complete analysis.

Conclusions:

It was concluded that ABS will be used in the prototype and the final product to manufacture the repellant container as it provides sufficient resistance to elements (as it will be used in a beach environment) and is capable of withstand the expected loads on the container.

Recommendations:

As proven by the results obtained above, use ABS for the container and trap doors as it suffices all necessary requirements with a high factor of safety.

6.6.2 Hinge Analysis

Problem Statement:

For the distribution system of the repellant, it is important to have hinges and pins that do not fail under the typical payload and operation conditions. As a result, proper analysis of the pin and hinges of our system are required. For the analysis of the hinge, the team wanted to test whether it would fail under the given stress.

Approach:

To simulate this, ANSYS was utilized. To simplify the model, the top part of the assembly was suppressed. This was done to lessen the amount of numerical problem size that ANSYS must calculate. A support was added where the hinge will be attached to the cylindrical chamber. This was done because the hinge will be 3D printed to the chamber so the main support of the hinge will be located at the surface where the two meet. The force of the fluid inside was added to gage its effect on the hinge. With a medium mesh, a deformation analysis was performed on the hinge without the pin.

Defining Equations:

The equations used were the same as those used above in section 6.6.1.

Results:

This analysis shows that the hinge deforms a mere .14 millimeters or .005 inches under this weight when the ABS plastic material is used. By using the results from stress analysis, the factor of safety was calculated to be 12.33.

Figure 6.6.2.1 below shows the mesh and deformation of the selected part of the system. The ANSYS deformation and stress results can be seen in Figure 6.6.2.2 and 6.6.2.3 respectively.

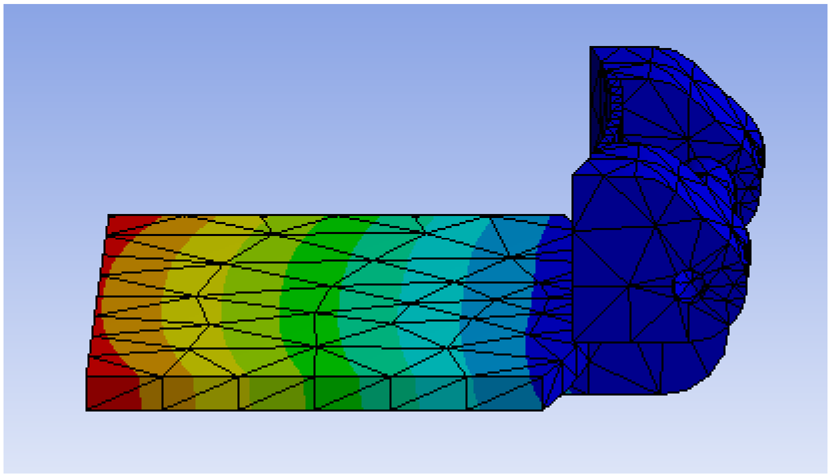
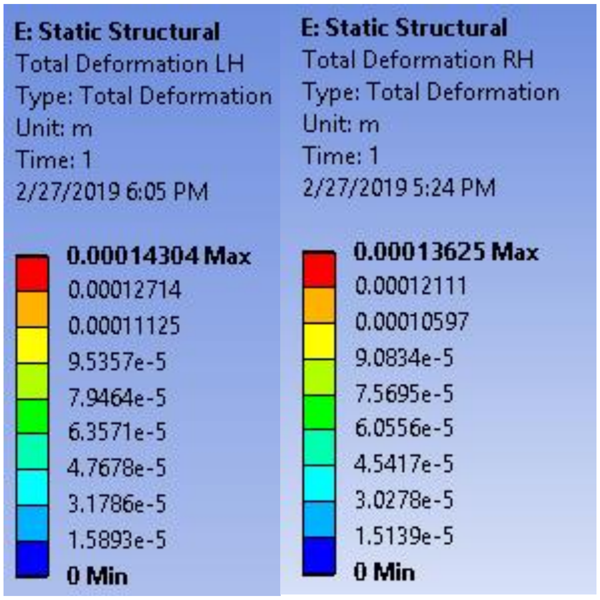


Figure 6.6.2.1 Mesh and deformation pattern of hinge



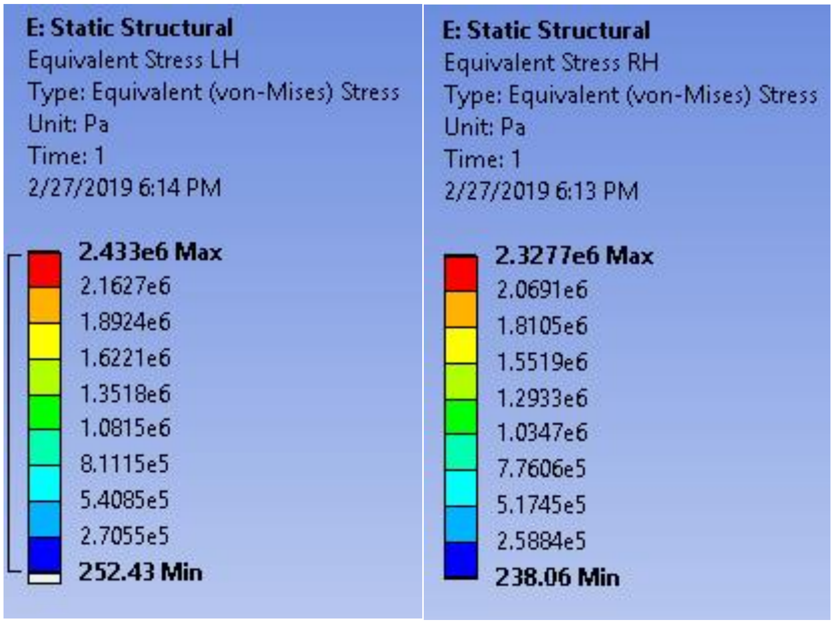
E: Static Structural
Total Deformation LH
Type: Total Deformation
Unit: m
Time: 1
2/27/2019 6:05 PM

0.00014304 Max
0.00012714
0.00011125
9.5357e-5
7.9464e-5
6.3571e-5
4.7678e-5
3.1786e-5
1.5893e-5
0 Min

E: Static Structural
Total Deformation RH
Type: Total Deformation
Unit: m
Time: 1
2/27/2019 5:24 PM

0.00013625 Max
0.00012111
0.00010597
9.0834e-5
7.5695e-5
6.0556e-5
4.5417e-5
3.0278e-5
1.5139e-5
0 Min

Figure 6.6.2.2 The deformation analysis results of the left and right hinge, respectively with the material selection of ABS plastic.


E: Static Structural
Equivalent Stress LH
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
2/27/2019 6:14 PM

2.433e6 Max
2.1627e6
1.8924e6
1.6221e6
1.3518e6
1.0815e6
8.1115e5
5.4085e5
2.7055e5
252.43 Min

E: Static Structural
Equivalent Stress RH
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
2/27/2019 6:13 PM

2.3277e6 Max
2.0691e6
1.8105e6
1.5519e6
1.2933e6
1.0347e6
7.7606e5
5.1745e5
2.5884e5
238.06 Min

Figure 6.6.2.3 The stress analysis results of the left and right hinge, respectively with the material selection of ABS plastic.

Conclusions:

When using the ABS material, the calculated factor of safety was significantly higher than the desired FOS of 2. This suggests that ABS can handle the required load.

Recommendations:

Due to the requirements and constraints of the class, the prototype hinges will be made out of ABS plastic. It is lightweight and less costly than the other materials. Additionally, since the device will be exposed to moisture, it is better to choose a material that will not rust. The deformation seen in Figure 6.6.2.2 is allowable for the purposes of this project. Additionally, since the main component is made of ABS plastic, it is recommended to make the hinge in the same material as the rest for this prototype.

6.6.3 Slider Attachment Analysis

Problem Statement:

The mounting attachment plays a critical role for the ATS system. It allows the repellent rig to be secured to the underside of the UAV and remain in place until the payload is delivered to its target. Multiple factors are cause for concern at different design points of this single component. The design itself must withstand the stresses experienced by the system and must remain un-deformed over time. Should the design begin to deform, the attachment could risk losing the payload mid-operation rendering the device useless. Also, necessary analysis must consider the material chosen for this particular part. Since the team has set elevated expectations for the weight of the repellent system, it is important to refine the design to save on weight and cost while still ensuring that the material is strong enough to withstand yielding and fracturing effects.

Approach:

First, the team will set a specific parameter for the surface area of the ridge that the pressure will sit on that is supported by the slider attachment. Those dimensions will allow a specific exerted force to be calculated and will be used as the constant in the analysis and optimization of the component design. Hand calculations will be conducted to determine the preliminary dimensions to calculate the resulting stress and deformation values at critical locations along the attachment.

Since the attachment is such a critical design component to the overall function of the drone, the team deems it necessary to perform extensive FEA on each design before moving forward with a particular option. This will allow for initial Proof-of-Concept (P.O.C.) design testing to be conducted at this stage prior to having a prototype or product.

<u>Defining</u>

$$A_s = l \times w \tag{6.7}$$

Where,

$$A_s = Surface\ area\ of\ contact$$
$$l = length\ of\ contact\ surface$$
$$w = width\ of\ contact\ surface$$

$$F = ma \tag{6.8}$$

Where,

$$F = force$$
$$m = mass$$
$$a = acceleration$$

$$P_{1-edge} = \frac{F/2}{A} \tag{6.9}$$

Where,

$$P_{1-edge} = resultant\ pressure\ of\ one\ slider\ edge$$

$$\sigma = \frac{My}{I} \tag{6.10}$$

Where,

$$\sigma = stress$$
$$M = moment$$
$$y = perpindicular\ distance\ to\ the\ neutral\ axis$$
$$I = moment\ of\ inertia$$

$$\varepsilon = \frac{\sigma}{E} \quad and \quad \delta = \frac{PL}{EA} \tag{6.11 \& 6.12}$$

Where,

$$\varepsilon = strain$$
$$E = Material\ Young's\ Modulus$$
$$\delta = deformation$$

<u>Results</u>:

From previous analysis, it was determined that the weight of 2 liters of repellent fluid would be approximately 2.2 kg. The team set a goal of 3.3 kg for the rig and repellent container that would be attached to the bottom of the UAV system. This means that the UAV would be supporting a total of 4.5 kg of total weight during flight operations.

Shown below is the initial analysis (Design #1) to support the team's previous trade studies.

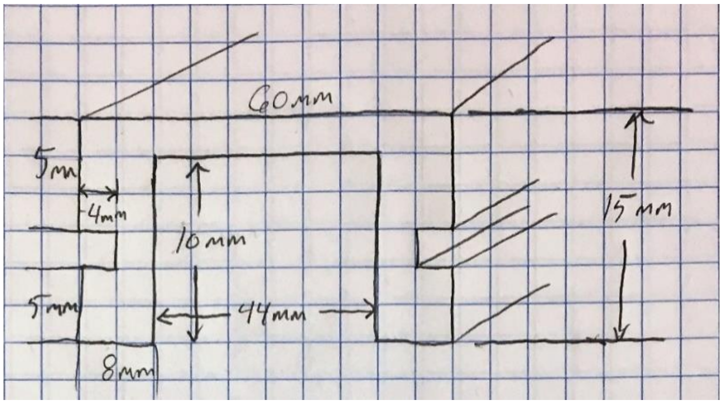


Figure 6.6.3.1. Initial design concept for slider attachment for UAV body.

Pressure calculations:

$$A = 8\,mm * 100\,mm = 8000\,mm^2 \qquad F = 5.5\,kg$$

$$P_{1-edge} = \frac{F/2}{A} = \frac{(5.5\,kg)}{2*(8000\,mm^2)}\frac{(9.81\,N)}{(1\,kg)}\frac{(1\,mm^2)}{(10^{-6}\,m^2)} = \frac{26.978\,N}{0.008\,m^2} = 3372.2\,Pa$$

Alternative options as design after pressure calculations:

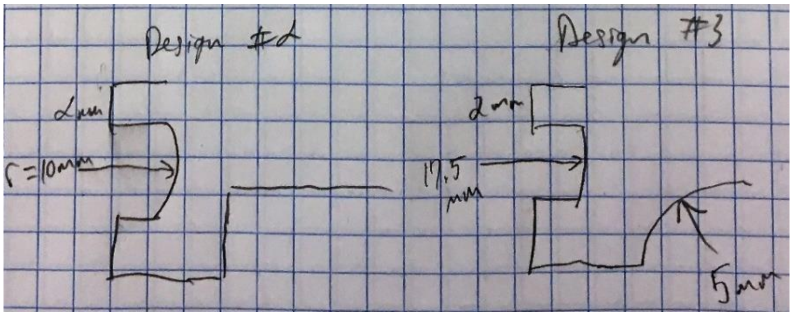


Figure 6.6.3.2: Alternative design ideas for slider attachment to redirect stress concentrations and add support.

In the FEA analysis shown in the following section, solid models were created for each of the three design options and tested using ANSYS static structural analysis. The constraints and forces explained in the original analysis are shown for each design as well, as previously derived in the analysis performed above. Each design is tested using the same parameters with two materials: Aluminum and ABS. This is to further assess the need for stronger versus lighter material for this specific component.

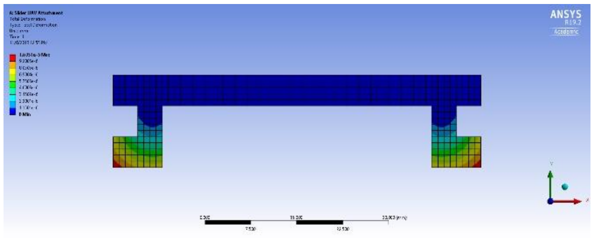


Figure 6.6.3.3: Design 1 (AL) deformation.

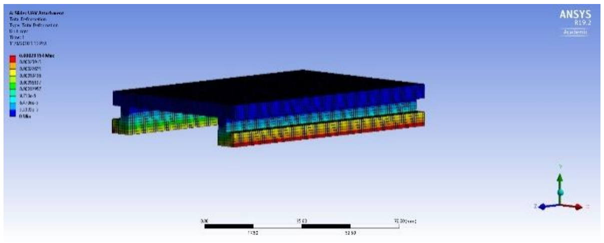


Figure 6.6.3.4: Design 1 (ABS) deformation.

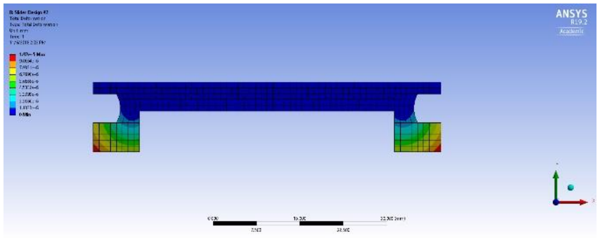


Figure 6.6.3.5: Design 2 (AL) deformation.

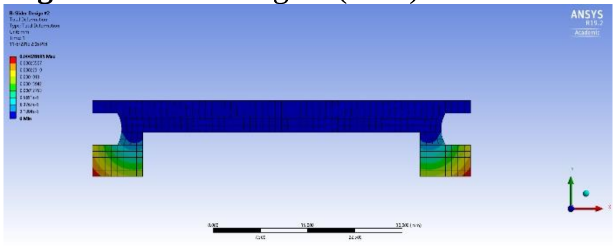


Figure 6.6.3.6: Design 2 (ABS) deformation.

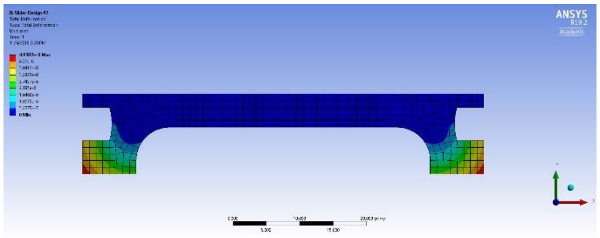


Figure 6.6.3.7: Design 3 (AL) deformation.

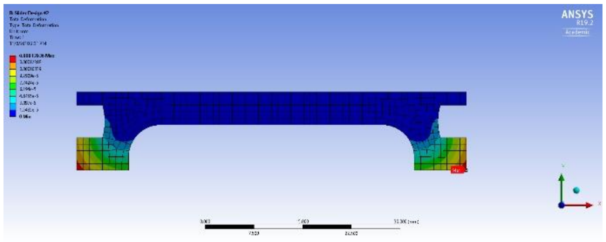


Figure 6.6.3.8: Design 3 (ABS) deformation.

Conclusions:

Table 6.6.3.1. Deformation and Stress results for initial design of slider attachment component.

Design #1		
Material	Max Deformation	Max Stress
Aluminum Alloy	1.0351 E-5 mm	0.025053 MPa
ABS	2.9154 E-4 mm	0.024975 MPa

Table 6.6.3.2. Deformation and Stress results for secondary design of slider component.

Design #2		
Material	Max Deformation	Max Stress
Aluminum Alloy	1.020 E-5 mm	0.0033626 MPa
ABS	2.869 E-4 mm	0.0033187 MPa

Table 6.6.3.3. Deformation and Stress results for final design of slider attachment component.

Design #3		
Material	Max Deformation	Max Stress
Aluminum Alloy	4.8397 E-6 mm	2.242 kPa
ABS	1.3960 E-4 mm	2.265 kPa

Recommendations:

The team has concluded that it that design #3 made with an aluminum alloy material would be used for the final product. Largely because of its rigidity and strength to prevent deformation while remaining light and affordable. However, for the prototype to be developed in the MEE 489 course, the team will use an ABS plastic material with design #3 due to its cost effectiveness and ease of manufacturing. This will allow for quick manufacturing times and ultimately additional time for testing validation.

6.6.4 Distribution Internal Mechanism Analysis

Problem Statement:

The shaft-block mechanism is likely the most critical component of our system since if it were to fail, the device might misfire and not fulfill its purpose. This is considered a critical failure by the team, and as a result, the device must be critically analyzed for stress failure and max deflection.

Approach:

This problem was approached from a structural mechanics standpoint where an analysis on the deformation, internal stresses, and deflection were performed. The locking-block mechanism was approximated to be a simple cantilevered beam with both sides of the block being perfectly equivalent to the other. The primary analysis was done through a Microsoft excel spreadsheet, but the defining system equations and relationships were worked out by hand. The excel spreadsheet was chosen to allow for ease of calculation for multiple material properties and dimensions. To account for factor of safety, the Von-Mises Stress equation was utilized.

Defining Equations:

This analysis had quite a few defining equations, but the primary ones are listed below:

Max Deflection of Cantilevered Beam from Point Load at End:

$$-\frac{PL^3}{3EI} \tag{6.13}$$

P= point load force, L=length of beam, E=Modulus of Elasticity of material, I=Moment of inertia of beam

Max Deflection of Cantilevered Beam from Distributed Load (weight of material):

$$-\frac{wL^4}{8EI} \tag{6.14}$$

w= distributed load on beam, L=length of beam, E=Modulus of Elasticity of material, I=Moment of inertia of beam

Deformation of Shaft:

$$\delta_s = -\frac{PL}{EA} \tag{6.15}$$

δ_s= deflection in shaft, P= Axial load in shaft, L= shaft length, E= Modulus of elasticity, A= Area of shaft cross section.

Results:

The results of this analysis are shown in Table 6.6.4.1 below. For the completed analysis, refer to Appendix A.4.

Table 6.6.4.1: Calculated Results of Shaft and Block Analysis

Parameter	Result
Material	ABS Plastic
Shaft Diameter	10.0 mm
Shaft Length	570.0 mm
Shaft Safety Factor	1336
Block Width	5.0 mm
Block Length	20.0 mm
Block Thickness	3.0 mm
Block Safety Factor	12995
Maximum Deflection at Ends	-0.244 mm
Total Mass	47.8 g

Additional Ansys Analysis was also performed, and the results of that simulation is shown in Figures 6.6.4.1 and 6.6.4.2 below.

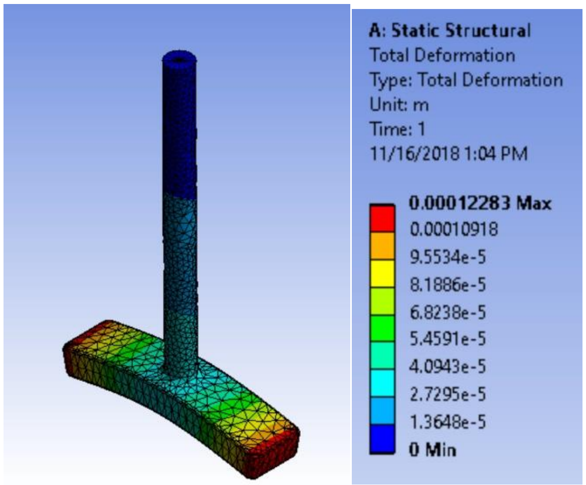


Figure 6.6.4.1. ANSYS Simulation of Total Deflection in Shaft-Block System

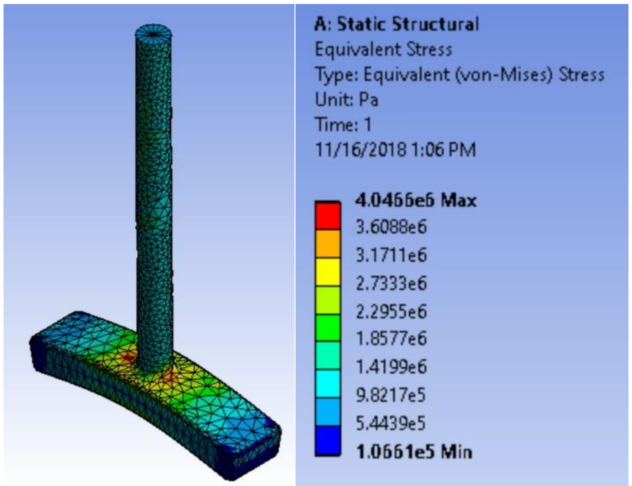


Figure 6.6.4.2. Ansys Simulation of Total Equivalent Stress in Shaft-Block System

Conclusions:

The two most important results of this are the safety factor and max deflection. The team determined that a safety factor of at least 2 is required for each of our components. The results show us that for both the shaft and the block, this expectation was far exceeded. This shows us that the system is overengineered significantly for safety, which is undesirable, until we consider the deflection. Post-optimization of our system yields minimal deflections that are less than the desired 0.5 mm. This is exactly how we want our system to be, considering if any deflection were to occur that exceeds this value significantly, there is the potential for fluid losses in our system. Since this is satisfied, we are happy with the results. This is likely the cause for such a large safety factor. Our design is satisfactory for the device.

Recommendations:

Based on this analysis, we can go forward with the design. Based solely on a stress and deformation standpoint the requirements are satisfied. I recommend that the team should adopt this as our preliminary design and go forward with optimization. Further improvements and design modifications may be made as further design changes are implemented.

6.6.5 Thrust and Lift Analysis

Problem Statement:

The lift force generated by the system must be twice that of the force of gravity on the system to allow for adequate course correction and maneuverability

Approach:

Approximate system mass of 7 kg will experience minimum gravitational force of approximately 70 N and a factor of 3 for safety would dictate 210 N of total lift for the system is required

Defining Equations:

$$T = \rho_{air} * \frac{\pi(0.0254 * d)^2}{4} * \left(rpm * p * 0.0254 * \frac{1}{60}\right)^2 * \left(\frac{d}{3.3 * p}\right)^{1.5} \tag{6.16}$$

$$d = rotor\ diameter\ , p = rotor\ pitch\ , rpm = motor\ rpm\ , \rho_{air} = density\ of\ air\ @\ sea\ level$$

Results:

$$T\ = \rho_{air} * \frac{\pi(0.0254 * d)^2}{4} * \left(rpm * p * 0.0254 * \frac{1}{60}\right)^2 * \left(\frac{d}{3.3 * p}\right)^{1.5}$$

$$d = rotor\ diameter\ , p = rotor\ pitch\ , rpm = motor\ rpm\ , \rho_{air} = density\ of\ air\ @\ sea\ level$$

Conclusions:
This rotor/motor configuration will provide enough lift for effective system operation

Recommendations:
Monitor design evolution closely tracking changes in mass and aerodynamics for effects on this analysis

6.6.6 Chassis Deflection, Chassis Stress and Power Analysis

Problem Statement:

The UAV will operate over sea shore when the shark attack occurred. The effect of environment plays major role in this case. Since the salt can be easily affect most metals, our group concern the choose of material for every part. For our optimal performance, durability and corrosion, we decided to choose carbon fiber for the frame construction and propeller.

Carbon fiber is a polymer and is sometimes knows as graphite fiber. Carbon fiber is several advantageous making for aircraft. The material is strong and very light weight. Which is five times stronger than steel and twice as stiff. Therefore, carbon fiber is stronger, stiffer and lighter than steel.

Our target flight time is 30 minutes minimum continuously. The li-po battery will be used for the system in this case because it has many advantageous compares to other type of battery for flying devices. Li-po batteries are lighter in weight, can be made any size or shape which is very useful especially in the quadcopter, which can store higher capacities and hold much more power, much more discharge rates which mean they can pack more punch.

Approach:

Once the material for chassis was defined, the stress analysis for each beam and the chassis. Then shear and bending force were calculated. From the shear and bending diagram, we can calculate shear stress and bending stress. To calculate the shear stress, the maximum shear force of each component will be divided over its cross sessional area. For the bending stress, first the distant from natural axis and surface of the beam had to be defined. Then moment of inertia was calculated by multiplying (1/12) times base of its cross-sectional area and its height cube. Finally, the bending stress can be calculated by using the formula below. As a result, the shear stress for front arm and rear arm were the same and which is -245.250 kPa. But for the chassis the shear stress is 301.19048 kPa. Therefore, the maximum shear stress for UAV can be assumed at the chassis. For the bending stress, the front arm is 84.614 Mpa, the rear arm is 158.188 Mpa and for the chassis is 63.2503 Mpa. By comparing those answers, the maximum shear stress is at rear arm. After defining all necessary stress, the safety factor of each parts would be defined by using the ratio of theoretical material yield strength and calculated maximum stress values. The value for the safety factors is 11.82, 6.32, 15.81 respectively for front arm, rear arm and chassis.

Flight time, the weight of the UAV, and the power consumption are directly related to each other. Therefore, for the battery calculation, the flight time and the weight of the UAV has to be defined first. The assumption for the flight time is 30 minutes and the mass of the whole system is around 7 kg. From that assumption, the power need for the UAV could be calculated by multiplying its current usage and the voltage of battery. Then the size (capacity) of the battery can be calculated by multiplying the target flight time and the system total current. According to the result, the UAV system should use 500 mAh for the optimal performance. The results for each calculation are shown in the result section.

Defining Equations:

In this part, shear stress, bending stress and safety factor will be defined. Maximum shear force is divided over cross-sectional area of the beam to calculate the shear stress. Similarly, for the bending stress, the maximum bending force will be divided over moment of inertia of cross-sectional area of the beam.

$$\tau = \frac{V_{max}}{A_{cross}} \tag{6.17}$$

$$\sigma = \frac{M_{max} * c}{I} \tag{6.18}$$

For the safety factor, which is the ratio of the theoretical yield strength and maximum strength calculated.

Where,

τ = Shear Stress,

A_{cross} = Cross-sectional Area

σ = Bending Stress,

I = moment of inertia

$$n = \frac{Sy}{\sigma} \tag{6.19}$$

Where,

n = safety of factor

S_y = Yield Strength

Multiplying the supply voltage from the battery with the current usage of the motor to calculate the power of the UAV. To calculate the flight time, the capacity of the battery is divided over current usage of the motor. In this case, our target flight time is 30 minutes and from there, the capacity of battery can be derived from the flight time and current. The result for the battery needs is shown in the result section.

$$P = V * I \tag{6.20}$$

$$V = I * R \tag{6.21}$$

$$t = \frac{C}{I} \tag{6.22}$$

Where,

P = Power

V = Voltage

I = Current
C = Capacity of Battery
t = time

<u>Results</u>:

Yield Strength for Carbon Fiber = 1Gpa

Front Arm:

Maximum Shear Force = -17.1675 N
Maximum Bending Force = 1.9743 N*m
Shear Stress = -245.250 kPa
Bending Stress = 84.614 Mpa
Safety Factor = 11.82

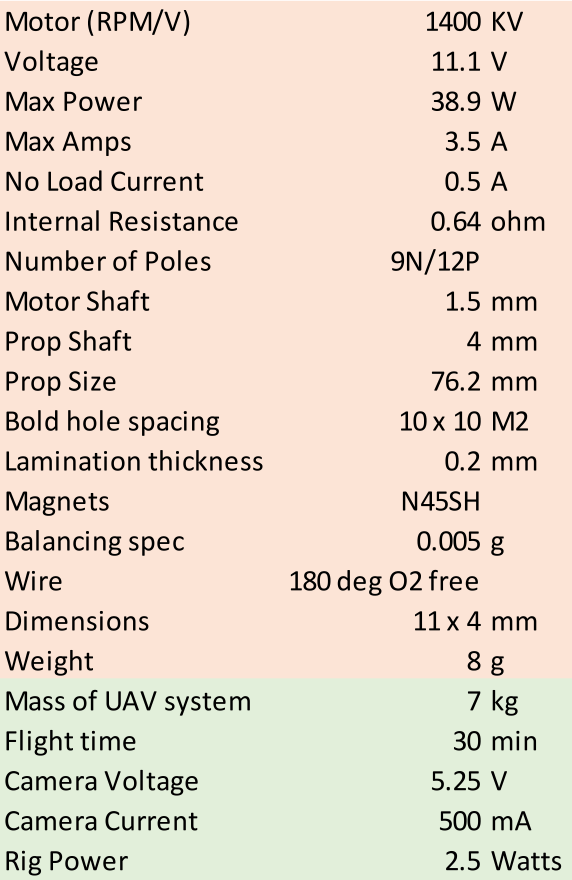
Rear Arm:

Maximum Shear Force = -17.1675 N
Maximum Bending Force = 3.6910 N*m
Shear Stress = -245.250 kPa
Bending Stress = 158.188 Mpa
Safety Factor = 6.32

UAV Frame:

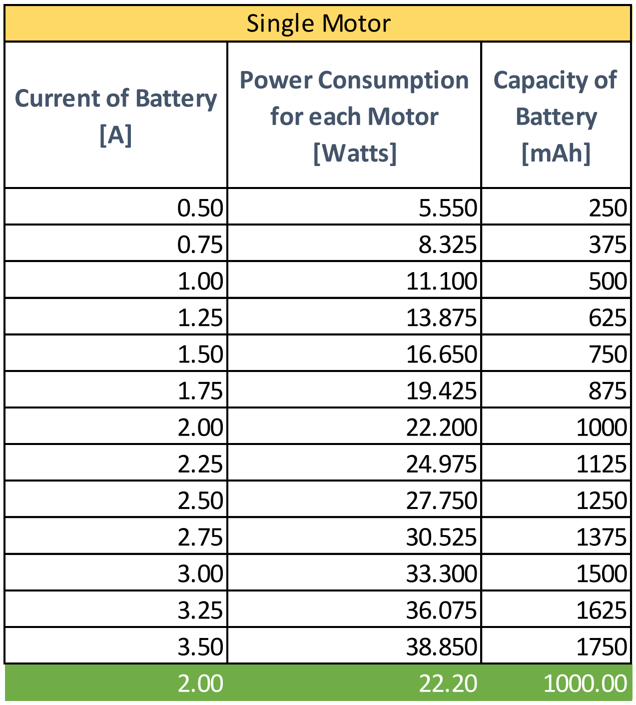
Maximum Shear Force = 42.1677 N
Maximum Bending Force = 2.9517 N*m
Shear Stress = 301.19048 kPa
Bending Stress = 63.2503 Mpa
Safety Factor = 15.81

Battery:



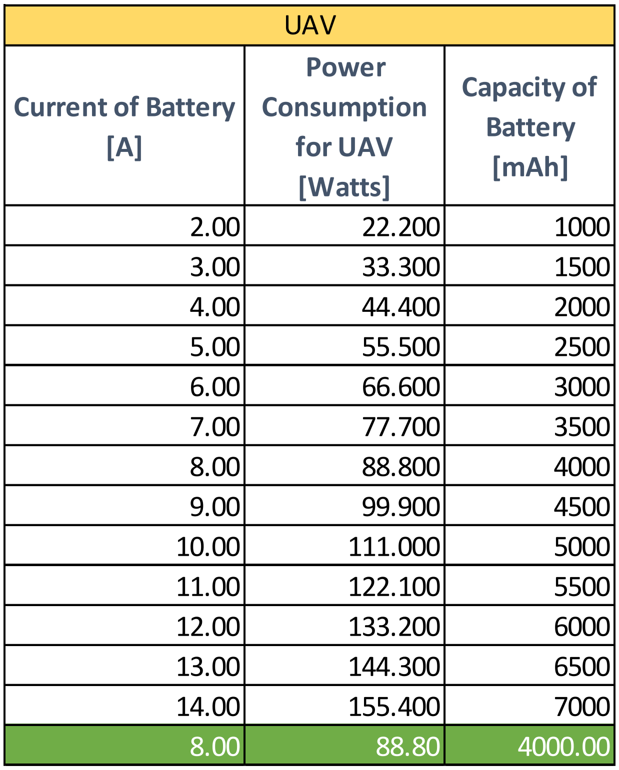
Motor (RPM/V)	1400	KV
Voltage	11.1	V
Max Power	38.9	W
Max Amps	3.5	A
No Load Current	0.5	A
Internal Resistance	0.64	ohm
Number of Poles	9N/12P	
Motor Shaft	1.5	mm
Prop Shaft	4	mm
Prop Size	76.2	mm
Bold hole spacing	10 x 10	M2
Lamination thickness	0.2	mm
Magnets	N45SH	
Balancing spec	0.005	g
Wire	180 deg O2 free	
Dimensions	11 x 4	mm
Weight	8	g
Mass of UAV system	7	kg
Flight time	30	min
Camera Voltage	5.25	V
Camera Current	500	mA
Rig Power	2.5	Watts

Figure 6.6.6.1: Specification of Motor for quadcopter.



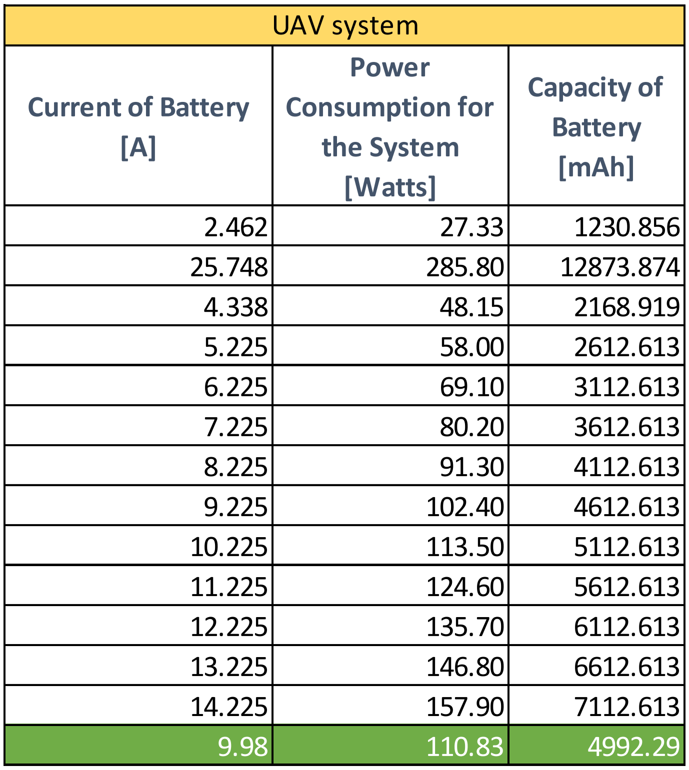
Single Motor		
Current of Battery [A]	Power Consumption for each Motor [Watts]	Capacity of Battery [mAh]
0.50	5.550	250
0.75	8.325	375
1.00	11.100	500
1.25	13.875	625
1.50	16.650	750
1.75	19.425	875
2.00	22.200	1000
2.25	24.975	1125
2.50	27.750	1250
2.75	30.525	1375
3.00	33.300	1500
3.25	36.075	1625
3.50	38.850	1750
2.00	22.20	1000.00

Figure 6.6.6.2: Require Battery for each Motor.



UAV		
Current of Battery [A]	Power Consumption for UAV [Watts]	Capacity of Battery [mAh]
2.00	22.200	1000
3.00	33.300	1500
4.00	44.400	2000
5.00	55.500	2500
6.00	66.600	3000
7.00	77.700	3500
8.00	88.800	4000
9.00	99.900	4500
10.00	111.000	5000
11.00	122.100	5500
12.00	133.200	6000
13.00	144.300	6500
14.00	155.400	7000
8.00	88.80	4000.00

Figure 6.6.6.3: Require Battery for the Quadcopter.



UAV system		
Current of Battery [A]	Power Consumption for the System [Watts]	Capacity of Battery [mAh]
2.462	27.33	1230.856
25.748	285.80	12873.874
4.338	48.15	2168.919
5.225	58.00	2612.613
6.225	69.10	3112.613
7.225	80.20	3612.613
8.225	91.30	4112.613
9.225	102.40	4612.613
10.225	113.50	5112.613
11.225	124.60	5612.613
12.225	135.70	6112.613
13.225	146.80	6612.613
14.225	157.90	7112.613
9.98	110.83	4992.29

Figure 6.6.6.4: Require Battery for the whole UAV system.

Conclusion/Recommendations:

In conclusion, the material and design chose for ATS project is that quadcopter with carbon fiber chassis. Since quadcopter has several advantageous among other type of air craft design, our project best fit with quadcopter because the aircraft needs hover above the see without drafting. The quadcopter is the most stable flying object for nowadays. For the material, it must be light, strong and corrosion resistant, the carbon fiber is the best fit in this case. For the battery usage, we chose li-po battery for our system because which is lighter than other type of battery. Which also can be built any shape as required, better discharge rate and can hold much more charge.

6.6.7 Concentration Analysis for Repellent Distribution

The shark repellent in consideration for the project is important because it determines the overall impact radius need during distribution to ensure the concentration is potent enough to have a deterring effect on the shark. The industry repellent chosen is rated for diving safety radius of approximately one quarter for instantaneous effect (roughly 0.4 km).

The corresponding concentration is rated below:

$$Instant\ potency\ rating = \frac{1\ mg}{200\ L} = 0.005\ ppm$$

Due to sharks' high sensory capabilities for odor, predators located nearly within 3 miles of impact would instantly detect the repellent for a one part per 200 million rating, with deterrence from impact occurring out to a 1.5-mile radius.

To ensure that the fluid repellent fell within a concentrated amount when it impacted the ocean surface, the team estimated the target radius to be within 1.5 meters from a 10-meter drop height. This would mitigate any diluting effects that could impede the repellent such as wind or sea currents, thus reducing the effectiveness of the deterrence. An amount of 1 liter (see Section 5.6.2 for derivation of volume) would guarantee a safeguard radius of approximately 150 meters regardless of ocean conditions, per listed specs of diving and submersible maritime guidelines.

$$V = 1\ L \qquad r_{target} = 1.5\ m$$

Where,

$$V = volume\ of\ repellent$$

$$r_{target} = target\ radius\ of\ repellent\ disbursement$$

Following the interview with the lifeguard organizations of Carlsbad and San Clemente, California, it was mutually decided that the ideal range would be within 100 m offshore. Therefore, the aforementioned amount of 1-liter disbursed within a 1.5-meter target radius would provide a virtually "guaranteed" shark-free water vicinity for the lifeguard to perform the rescue attempt without any increased risk for secondary attack.

6.6.8 Pin Analysis

Problem Statement:

For the analysis of the pin in the hinge, it was necessary to test whether it would fail under the given stress.

Approach:

To simulate this, Solidworks and ANSYS were utilized. To simplify the model, the top part of the distribution assembly was suppressed. This was done to lessen the numerical problem size that ANSYS must calculate. A support was added where the hinge will be attached to the cylindrical chamber. This was done because the hinge will be 3D printed to the chamber so the main support of the hinge will be located at the surface where the two meet. The force of the fluid inside was added to gage its effect on the hinge. With a medium mesh, a deformation analysis was performed on the pin located inside of both hinges separately.

<u>Defining Equations</u>:

The equations used were the same as those used above in section 6.6.1.

<u>Results</u>:

This analysis shows that the pin deforms a miniscule .006 millimeters or .0002 inches under the weight of the assembly when it is filled. By using the results from stress analysis, the factor of safety was calculated to be 2.7.

Figure 6.6.3.1 below shows the mesh and deformation of the selected part of the system. The ANSYS deformation and stress results can be seen in Figure 6.6.3.2 and 6.6.3.3 respectively.

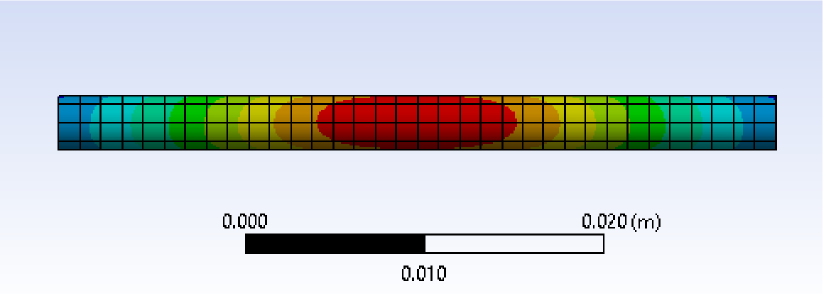
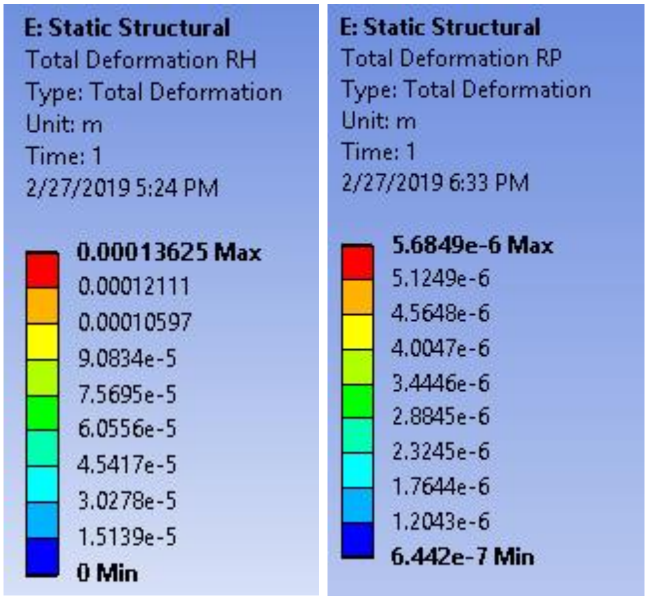


Figure 6.6.8.1 Mesh and deformation pattern of the pin used in the hinge.



E: Static Structural
Total Deformation RH
Type: Total Deformation
Unit: m
Time: 1
2/27/2019 5:24 PM

0.00013625 Max
0.00012111
0.00010597
9.0834e-5
7.5695e-5
6.0556e-5
4.5417e-5
3.0278e-5
1.5139e-5
0 Min

E: Static Structural
Total Deformation RP
Type: Total Deformation
Unit: m
Time: 1
2/27/2019 6:33 PM

5.6849e-6 Max
5.1249e-6
4.5648e-6
4.0047e-6
3.4446e-6
2.8845e-6
2.3245e-6
1.7644e-6
1.2043e-6
6.442e-7 Min

Figure 6.6.8.2 The deformation analysis results of the left and right pin, respectively.

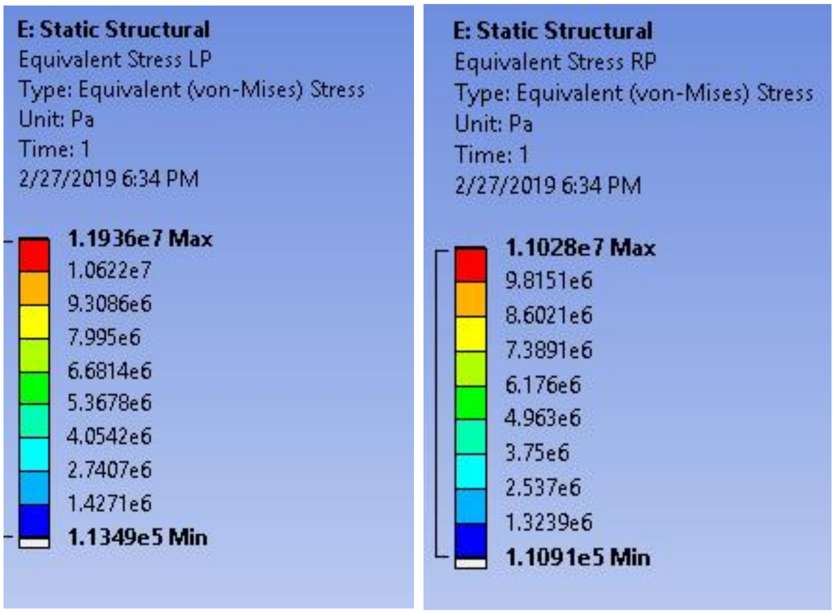


Figure 6.6.3.3 The stress analysis results of the left and right pin, respectively.

Conclusions:

When using the aluminum material, the calculated factor of safety was higher than the desired FOS of 2. This suggests that aluminum can handle the required load.

Recommendations:

Due to the requirements and constraints of the class, the prototype pins will be made from aluminum. It is lightweight and less costly than the other materials. The deformation seen in Figure 6.6.3.2 is allowable for the purposes of this project.

6.7 Proof of Concept Testing

This section describes the testing plan that Team 22 has designed for the ATS system. This process will consist of individual component testing for the UAV and repellent disbursement systems independently of one another. After each component has passed all individual criteria, the two systems will be joined to carry out prototype testing as a singular device.

UAV:

The testing will for the UAV will be based on flight capabilities with the payload, response time effectiveness flying with the payload, and ease of use for the user. As previously designated, the UAV needs to be able to carry two liters of shark repellent, in addition to the disbursement rig that will be attached to its frame. The UAV needs to be able to fly 100 meters (from takeoff to target) in less than 45 seconds, thus averaging a speed of 2.22 m/s. The drone must remain level during the flight, yielding no more than 15 degrees variation from planar. Finally, the drone test will be repeated by each team member to prove its ease of use capability. If each of these criteria are not met, the drone component will not pass testing and will need to be modified accordingly. Please see below for UAV test plan procedure.

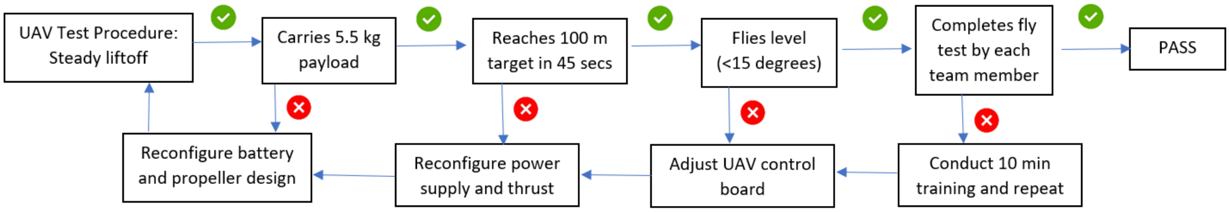


Figure 6.7.1: Test plan for UAV component involving lift, air speed, and stability characteristics.

Repellent Disbursement Container:

The testing completed for disbursement and actuation system will be focused primarily on reliability in the actuation capability and the corresponding target precision. The requirements for this device are that the dropping of the repellent is accurate, precise, and instantaneous as desired by the user. The container needs to be able to hold 1 liter of shark repellent throughout the duration of the flight without losing any of the fluid. At moment of reaching the location of target, actuation needs, and the corresponding payload drop, needs to satisfy a confidence interval of 99%. The fluid must drop from a height of 10 meters and reach the surface of impact under 3 seconds. Payload must disburse over target within a 1.5 m radius 98% of trials. Please see below for the container test plan procedure.

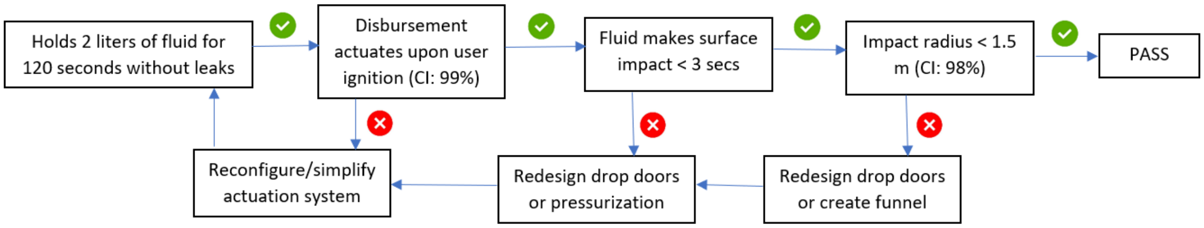


Figure 6.7.2 Test plan for repellent container involving reliability, accuracy, and precision.

6.7.1 Test Plan for Preliminary Design

Testing during the Preliminary Design was conducted via the mathematical analysis (see sections 6.6). The Proof of Concept test plan included above is for the testing of individual components and subsystem functionality during the post-fabrication and assembly process. To see results of test plan execution, Chapter 9.

6.8 Prototype Final Preliminary Design

The final preliminary design for the ATS system is shown below in Figures 6.8.1 and 6.8.2. The key components of the product are outlined in the figures.

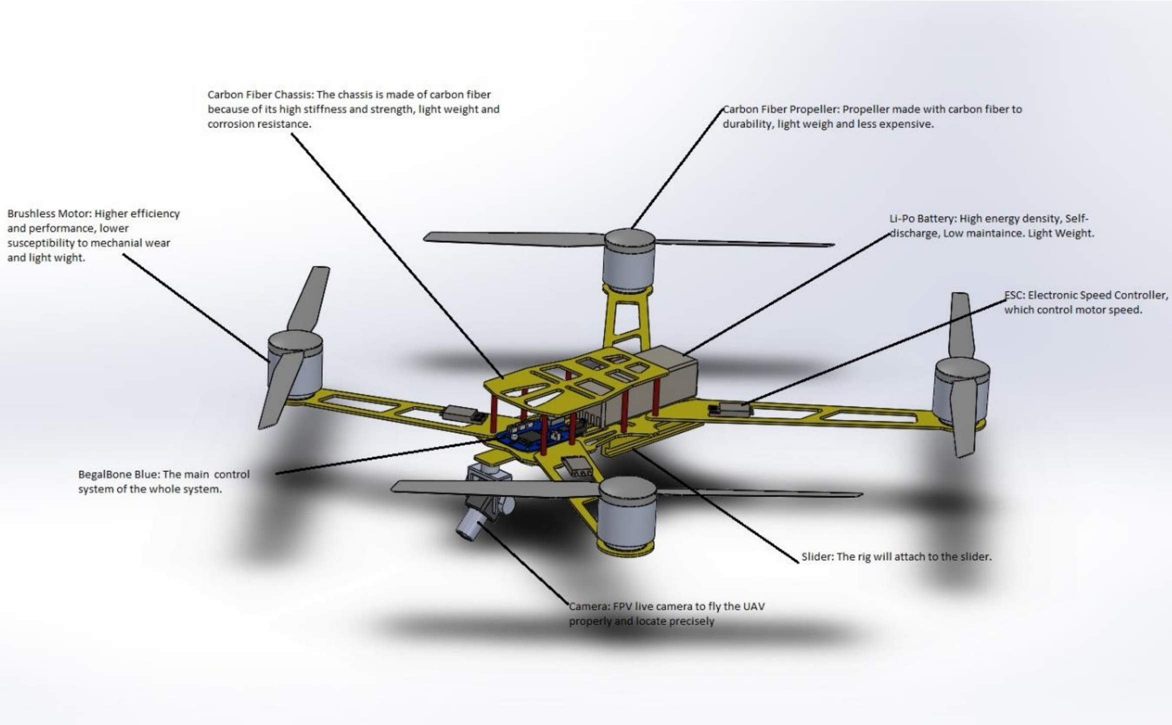


Figure 6.8.1: Preliminary Design for ATS System UAV, as of the conclusion of the Preliminary Design phase.

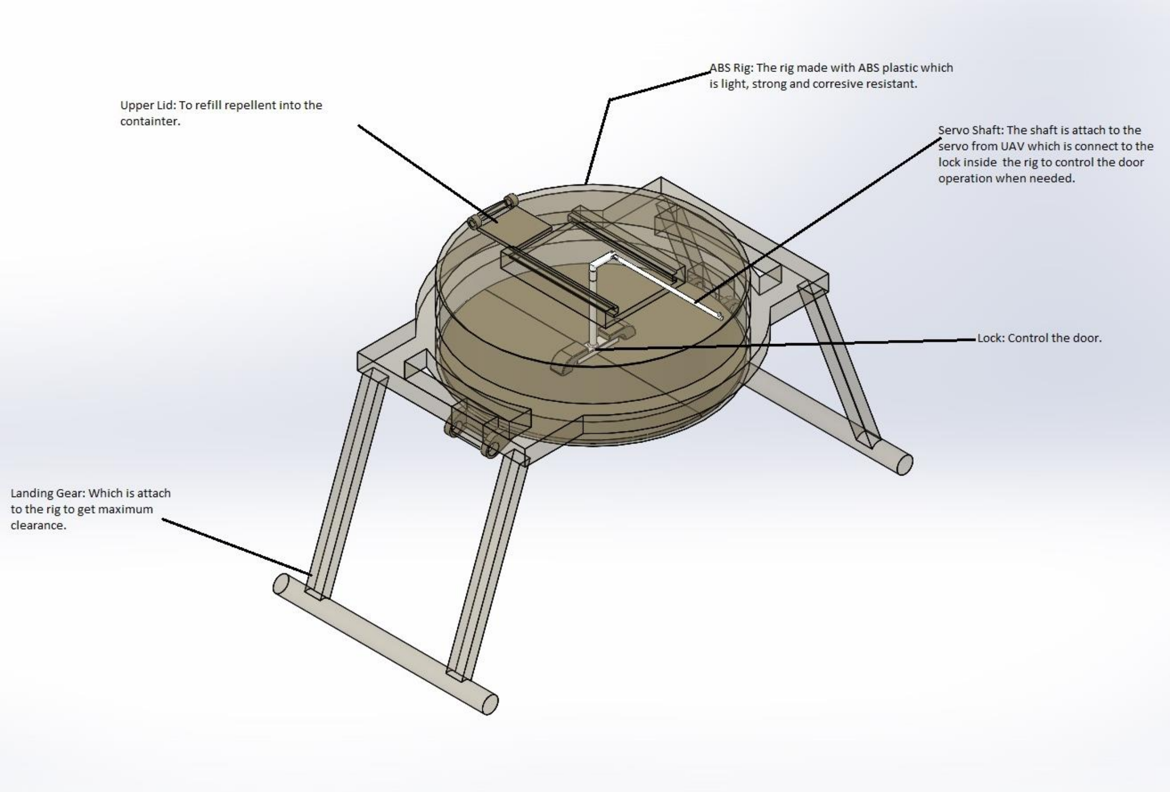


Figure 6.8.2: Preliminary Design for ATS System UAV Detachable Distribution Device, as of the conclusion of the Preliminary Design phase.

6.9 Commercialization

As discussed in 5.9, Commercialization will involve ruggedization of the system, hardware/technology upgrades, and cosmetic additions.

6.10 Long-Lead Hardware

At this point in time Air-to-Shark does not have any long lead items. The only potential long lead items will pieces associated with the ABS dispenser and the ABS mounting that will be 3D printed in the ASU machine shop. These lead times are undetermined as we have no functional machine shop availability schedule.

7. Detailed Design

The detail design phase primarily pertains to the finalization of our design as well as the creation of the detailed drawing packages. Within this phase, our team has expanded and detailed up on the preliminary design. This section reflects our final product design and specifications for manufacturing.

7.1 Detailed Design Analyses

After meeting with Dr. Abdelrahman Shuaib, Leonard Bucholz and Andre Magdelano the team was advised to make some design changes to make the manufacturing of the prototype easier and better. Table 7.1 provides a summary of the design changes made. Most of these design changes are also discussed in section 8.4: First article inspection and rework.

Table 7.1: Summary of Design Changes made in the Detailed Design Phase

Original Design	Recommendation	Go Forward Design
Container sides, hinges and top printed as one part, doors printed as another part	Buy stock material and combine to make the container	3D printing sides of container, hinges and doors as separate components, using clear polycarbonate for top
Military spec fasteners used	Use less serious and less bulky fasteners	Flat top fasteners used
Sleeve for arms fully cover arm of drone	Use 2 plastic plates instead	3D printing plates to use as dampeners instead of sleeves
Actuation system completely 3D printed as a single component	Split into 3 components to make assembly easier	Actuation system is in 3 pieces now and the rod is Aluminum instead of ABS for more rigidity
Use ABS for all 3D printed components	Consider polycarbonate for 3D print material as it is easier to work with and has more flexibility	Complete all 3D printing in polycarbonate
Actuation block was a simple diamond shaped piece that locks into place with slots in the container doors	Have an angle to get a better friction fit to improve locking of the actuation system	Make edits in the actuation block to contain required angle to lock system into place better
Some clearances of the slider attachment were not specified	Add clearances to the slider attachment	Add clearances to the slider attachment
Smooth edge on the top of the container submitted for 3D printing	Add a rib to make the mating of the 3D printed part to the polycarbonate sheet better	Add a rib to the top edge of the container part
Smooth edge on bottom of container that contacts the container doors	Add a countersink to make a better water seal at the bottom of the container	Add a countersink to the container doors
Purchase readymade gasket and O-rings	Can make gasket and O-rings using molds and polyurethane	Purchase stock O-rings and custom order gasket made of

		Buna-N to fit the thickness requirements of the system
Flight controller used for the system was the Beaglebone Blue	Didn’t have a method to facilitate firmware updates in Beaglebone Blue. Requires recompiling which took over 12 hours. Hence decided to change to Pixhawk Cube 2.1. PixhawkCube 2.1 is able to use mission command software that allows for better security and can change code from laptop instead of disassembling the entire component to change the code like the Beaglebone Blue requires.	Pixhawk Cube 2.1 used as the controller for the system

The following pages will discuss in depth of the changes conducted in the Detailed Design Process. The analyses in this section are quite limited, and simply reflect a few of the design changes.

7.1.1 Container Analysis

Team decided to reduce the volume of shark repellant carried by the container as the repellent was very strong and required much less than the originally planned 2L of shark repellant. Halved the volume of shark repellant to 1L and made the adjustments in the container to reflect this change. This also helped with weight reaction to allow the system to perform much better as the system would then be more responsive to the user input as there is less inertia in the system.

While the team understood that there is no possibility of the container failing as the forces acting on the container were now reduced and the moment arms on any surface of the container were reduced, the team decided to perform some simple ANSYS analysis to ensure that there were no unexpected forces that were generated on the container.

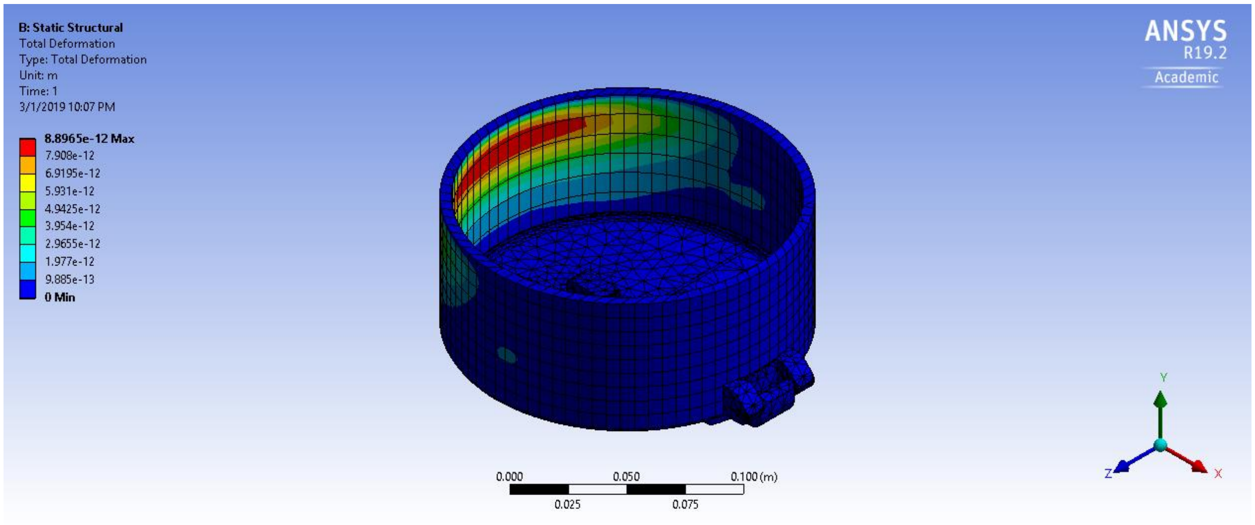


Figure 7.1.1.1: Total Deformation for Container and Doors

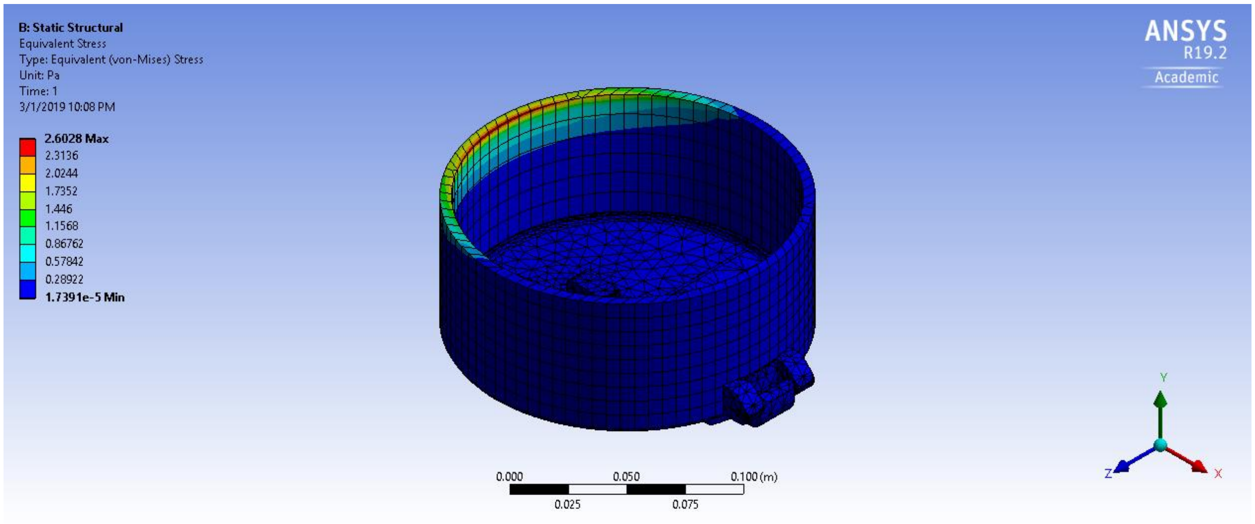


Figure7.1.1.2: Equivalent Stress for Container and Doors

As it can be seen above, the maximum stresses that are now acting on the container are much less in comparison to the analysis carried out in the preliminary design phase due to the reduction in the forces now acting on the container. So, it was concluded that ABS would still be a good choice to go with for the prototype as well as the final product. However, after further consulting with Leonard Bucholz and Andre Magdelano, it was decided that the team would instead go ahead with polycarbonate as it provides a better finish and has a bit of flex to it.

7.1.2 Hinge Analysis

For the analysis of the hinge, the team wanted to test whether it would fail under the given stress. To simulate this, ANSYS was utilized. To simplify the model, the top part of the assembly was suppressed. This was done to lessen the amount of numerical problem size that ANSYS must calculate. A support was added where the hinge will be attached to the cylindrical chamber. This was done because the hinge will be 3D printed to the chamber so the main support of the hinge will be located at the surface where the two meet. The force of the fluid inside was added to gage its effect on the hinge. With a medium mesh, a deformation analysis was performed on the hinge without the pin. This analysis shows that the hinge deforms a mere .14 millimeters or .005 inches under this weight when the ABS plastic material is used. By using the results from stress analysis, the factor of safety was calculated to be 12.33. This is significantly higher than the desired FOS of 2. Due to the requirements and constraints of the class, the prototype hinges will be made out of ABS plastic. It is lightweight and less costly than the other materials. Additionally, since the device will be exposed to moisture, it is better to choose a material that will not rust. The deformation seen in Figure 7.1.2.2 is allowable for the purposes of this project. Additionally, since the main component is made of ABS plastic, it is recommended to make the hinge in the same material as the rest for this prototype.

Figure 7.1.2.1 below shows the mesh and deformation of the selected part of the system. The ANSYS deformation and stress results can be seen in Figure 7.1.2.2 and Figure 7.1.2.3 respectively.

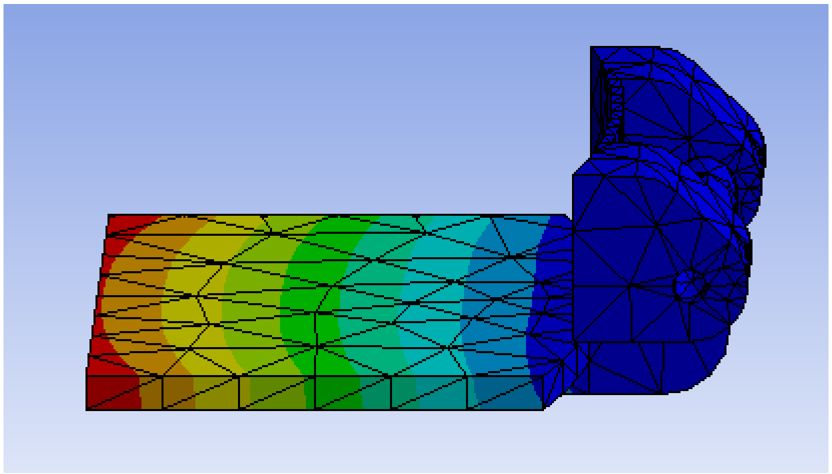
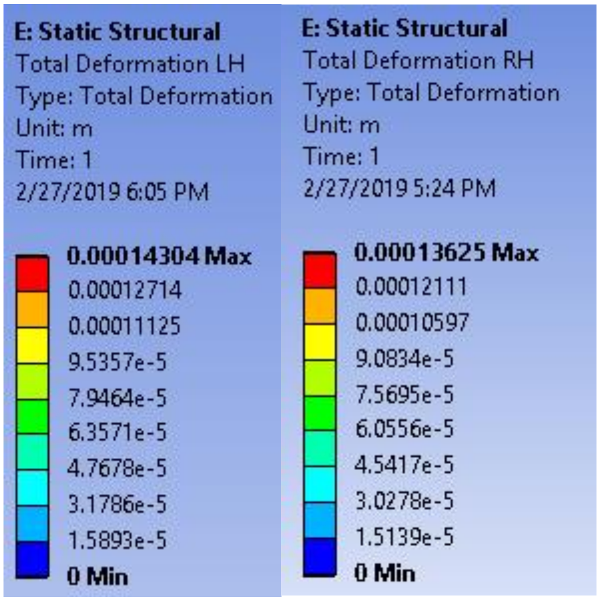


Figure 7.1.2.1: Mesh and deformation pattern of hinge



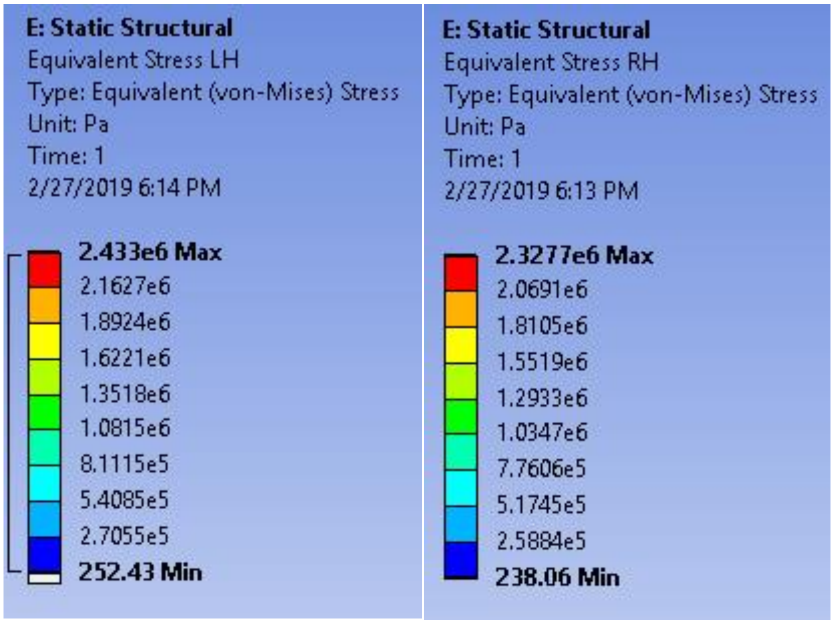
E: Static Structural
Total Deformation LH
Type: Total Deformation
Unit: m
Time: 1
2/27/2019 6:05 PM

0.00014304 Max
0.00012714
0.00011125
9.5357e-5
7.9464e-5
6.3571e-5
4.7678e-5
3.1786e-5
1.5893e-5
0 Min

E: Static Structural
Total Deformation RH
Type: Total Deformation
Unit: m
Time: 1
2/27/2019 5:24 PM

0.00013625 Max
0.00012111
0.00010597
9.0834e-5
7.5695e-5
6.0556e-5
4.5417e-5
3.0278e-5
1.5139e-5
0 Min

Figure 7.1.2.2: The deformation analysis results of the left and right hinge, respectively with the material selection of ABS plastic.



E: Static Structural
Equivalent Stress LH
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
2/27/2019 6:14 PM

2.433e6 Max
2.1627e6
1.8924e6
1.6221e6
1.3518e6
1.0815e6
8.1115e5
5.4085e5
2.7055e5
252.43 Min

E: Static Structural
Equivalent Stress RH
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
2/27/2019 6:13 PM

2.3277e6 Max
2.0691e6
1.8105e6
1.5519e6
1.2933e6
1.0347e6
7.7606e5
5.1745e5
2.5884e5
238.06 Min

Figure 7.1.2.3: The stress analysis results of the left and right hinge, respectively with the material selection of ABS plastic.

7.1.3 Pin Analysis

For the analysis of the pin in the hinge, it was necessary to test whether it would fail under the given stress. To simulate this, Solidworks and ANSYS were utilized. To simplify the model, the top part of the distribution assembly was suppressed. This was done to lessen the numerical problem size that ANSYS must calculate. A support was added where the hinge will be attached to the cylindrical chamber. This was done because the hinge will be 3D printed to the chamber, so the main support of the hinge will be located at the surface where the two meet. The force of the fluid inside was added to gage its effect on the hinge. With a medium mesh, a deformation analysis was performed on the pin located inside of both hinges separately. This analysis shows that the pin deforms a miniscule .006 millimeters or .0002 inches under the weight of the assembly when it is filled. By using the results from stress analysis, the factor of safety was calculated to be 2.7 which is larger than the desired FOS of 2. Due to the requirements and constraints of the class, the prototype pins will be made from AISI 4340 annealed steel. It is lightweight and less costly than the other materials. The deformation seen in Figure 7.1.3.1 is allowable for the purposes of this project.

Figure 7.1.3.1 below shows the mesh and deformation of the selected part of the system. The ANSYS deformation and stress results can be seen in Figure 7.1.3.2 and Figure 7.1.3.3 respectively.

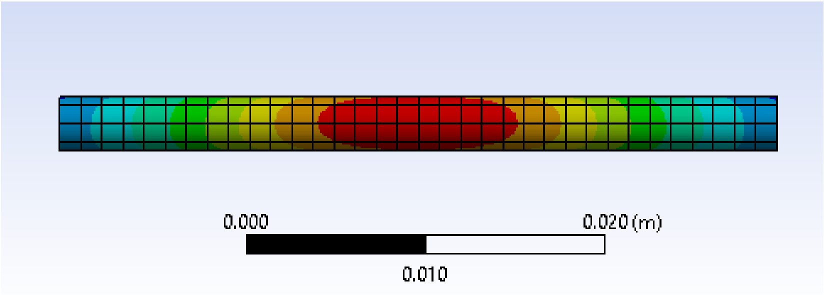
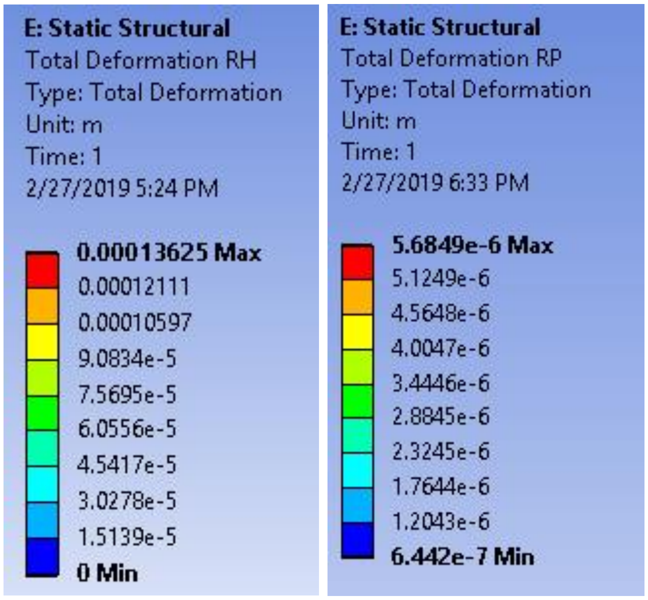


Figure 7.1.3.1: Mesh and deformation pattern of the pin used in the hinge.



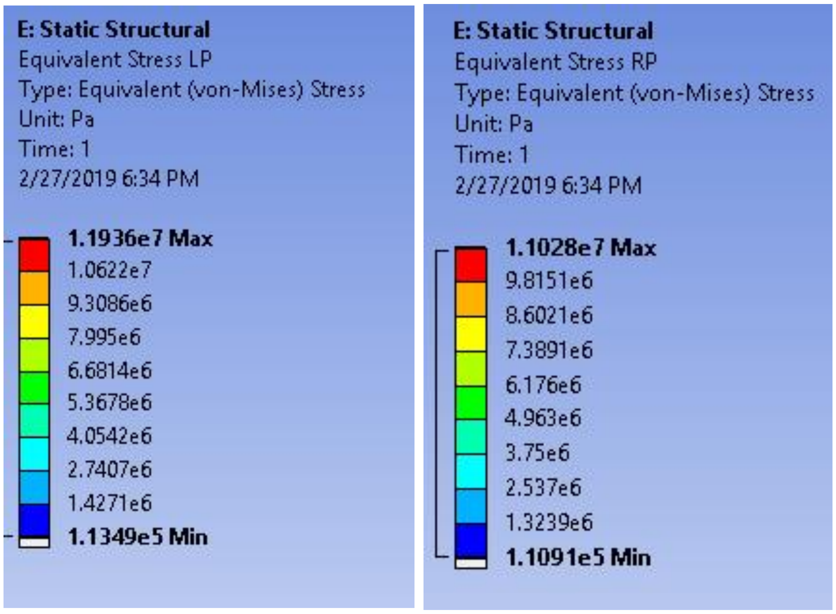
E: Static Structural
Total Deformation RH
Type: Total Deformation
Unit: m
Time: 1
2/27/2019 5:24 PM

0.00013625 Max
0.00012111
0.00010597
9.0834e-5
7.5695e-5
6.0556e-5
4.5417e-5
3.0278e-5
1.5139e-5
0 Min

E: Static Structural
Total Deformation RP
Type: Total Deformation
Unit: m
Time: 1
2/27/2019 6:33 PM

5.6849e-6 Max
5.1249e-6
4.5648e-6
4.0047e-6
3.4446e-6
2.8845e-6
2.3245e-6
1.7644e-6
1.2043e-6
6.442e-7 Min

Figure 7.1.3.2: The deformation analysis results of the left and right pin, respectively.



E: Static Structural
Equivalent Stress LP
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
2/27/2019 6:34 PM

1.1936e7 Max
1.0622e7
9.3086e6
7.995e6
6.6814e6
5.3678e6
4.0542e6
2.7407e6
1.4271e6
1.1349e5 Min

E: Static Structural
Equivalent Stress RP
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
2/27/2019 6:34 PM

1.1028e7 Max
9.8151e6
8.6021e6
7.3891e6
6.176e6
4.963e6
3.75e6
2.537e6
1.3239e6
1.1091e5 Min

Figure 7.1.3.3: The stress analysis results of the left and right pin, respectively.

7.1.4 Actuation Shaft and Locking Block Analysis

With our new locking block and actuation shaft design updated, further analysis needs to be performed to determine if the new design will not fail. The components were approximated as having a fixed support and a load of 10.405 kN representing the weight of the fluid and distribution system.

Through Ansys, the following information outlined in Table 7.1.4.1 was determined.

Table 7.1.4.1 Shaft and Locking Block FEA Summary

	Actuation Shaft	**Locking Block**
Assigned Material	6061-T6 Aluminum	Polycarbonate
Maximum Possible Stress	300.49 MPa	34.226 MPa
Max Deformation	0.08296 mm	0.46961mm
	Maximum Deformation of Assembly	0.55257 mm

Figures 7.1.4.1 and 7.1.4.2 below show a physical representation of these tabulated values.

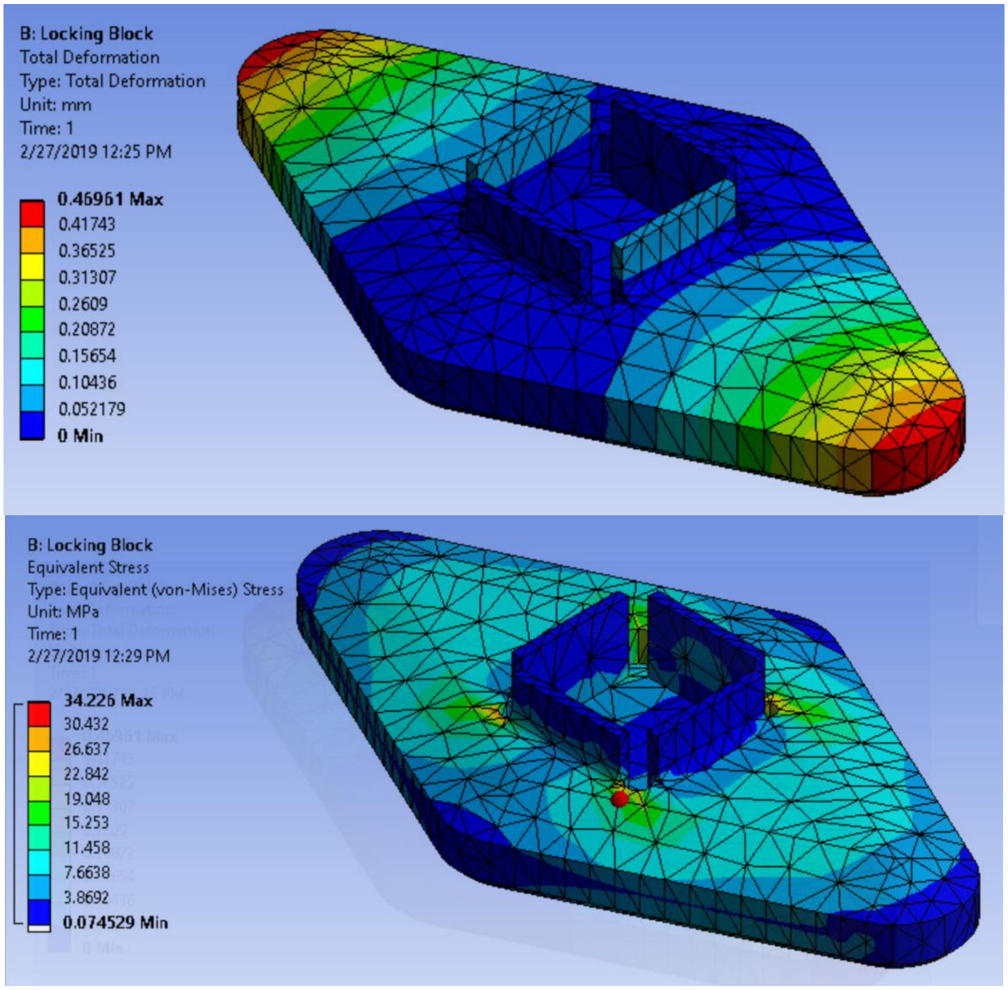


Figure 7.1.4.1 Locking Block Ansys Results

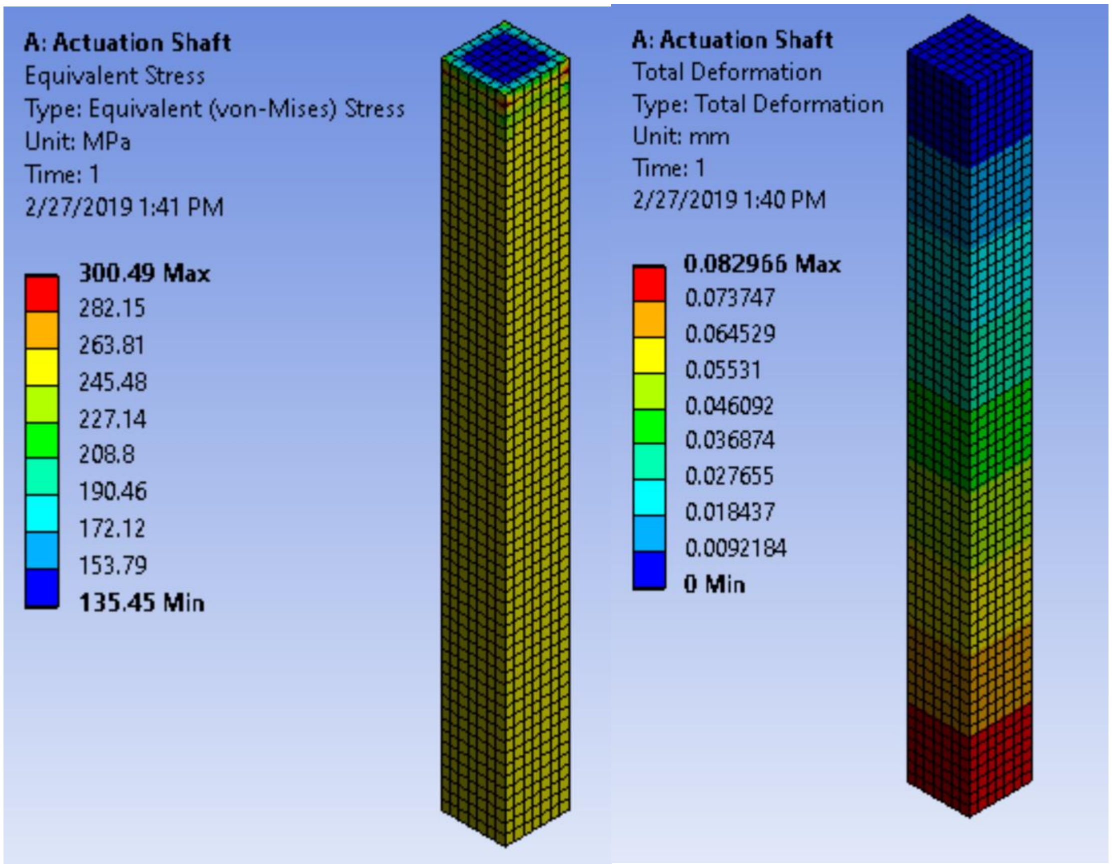


Figure 7.1.4.2 Aluminum Shaft Ansys Results

The results of our simple FEA yield adequate data. The team has determined that the total deformation is allowable for our product due to the gasketing system we have in place.

7.1.5 Gasket & O-Ring Analysis

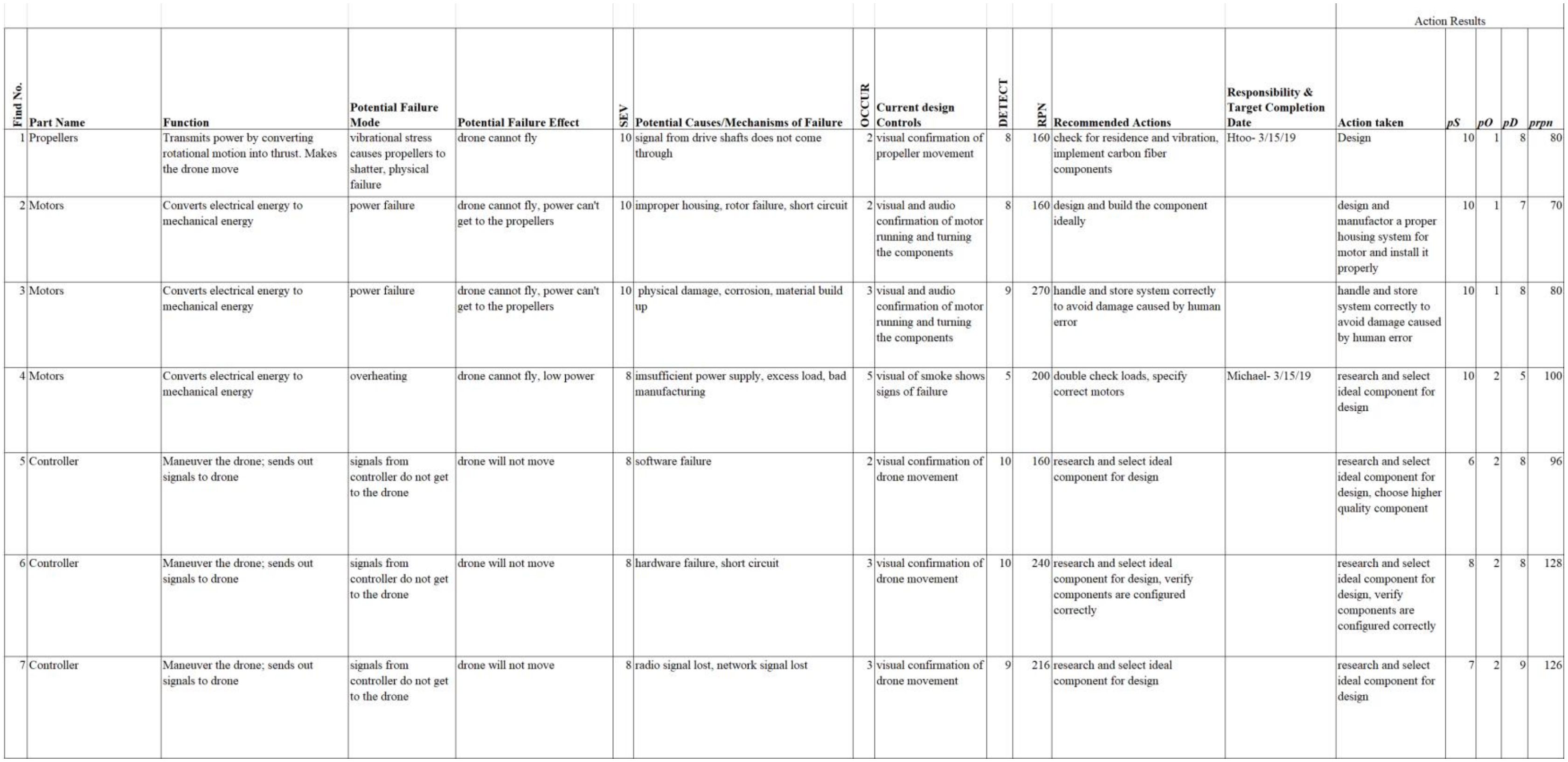
In the preliminary design team did a trade study for sealing ring material, team selected a Polyurethane material because it works in a big temperature range and can works for harsh fluids. After contacting Arizona Sealing Devices Inc to get a Polyurethane manufactured with a specific dimension will takes up to 13 weeks to get shipped. Team decided to change the material to Buna N which can works in a big temperature range too and strong enough for our prototype also, it can be manufactured and shipped in 1 week.

7.1.6 Updated FMEA

According to the Risk priority number (RPN), the most critical components in the SAVRRS project are the servo or actuator motor, the power supply battery, the flight controller, the GPS system and the total costs of the parts. The RPN represents how the part's failure will affect the design. Higher risk parts should be dealt with first to decrease the chances of failure.

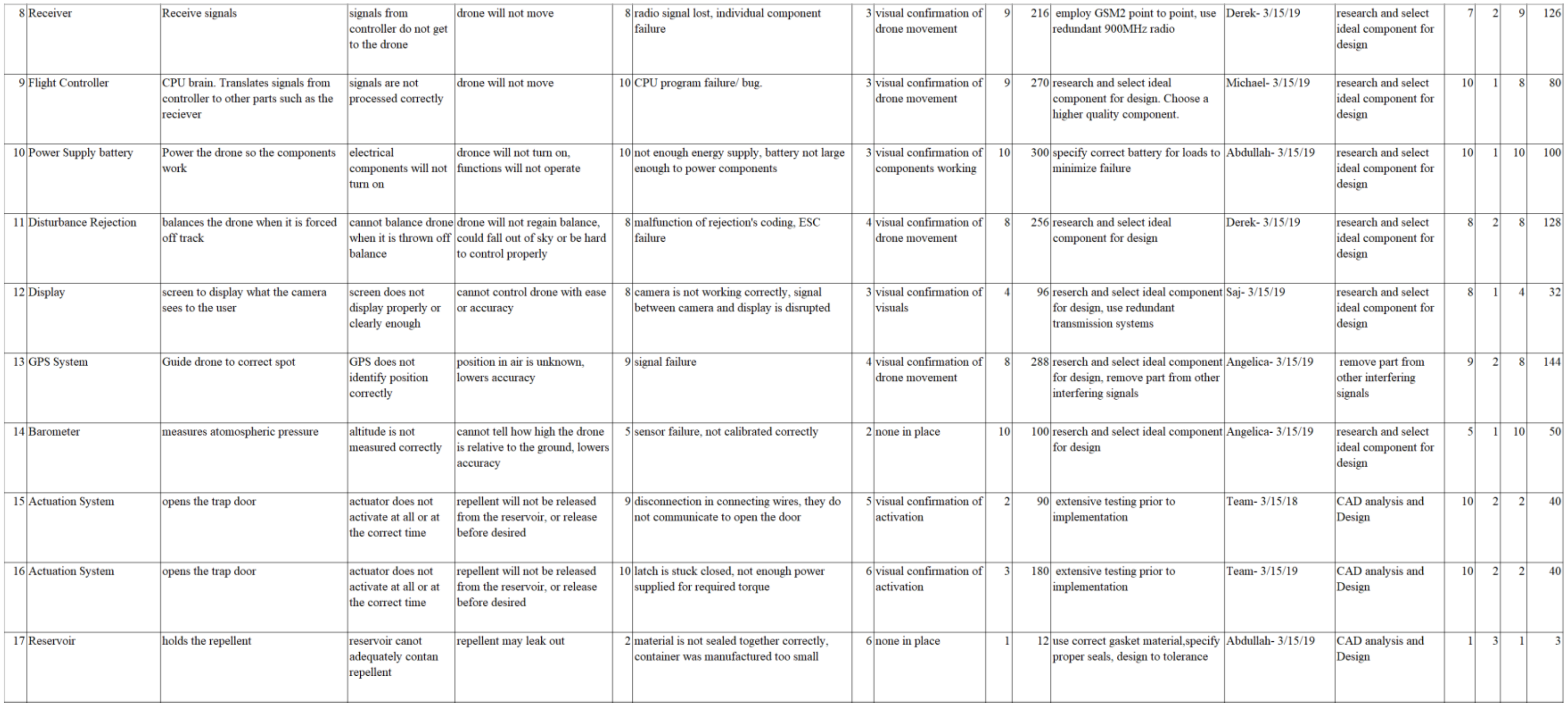
To lower the RPN of the servo, the team added a capacitor in the power feed to allow for enough power to be supplied during high demand operation and to minimize line noise. This lowered the failure rate drastically, by a factor of five. For the battery, the team carefully selected a large enough component to allow for enough energy supply to power the drone without being bulky and weighing it down. The flight controller's RPN was lowered by selecting a part with triple redundant IMU's to reduce vibration and increase stabilization of the drone during flight. To reduce the GPS' RPN, a stand was created to move it away from other signal sending electronics. This lowered the interference between the GPS' signals. Lastly, it was important for the team to keep all the parts under budget. If the parts are very efficient, but we cannot afford to purchase other key components because of their cost, then the project fails.

Figures 7.1.6.1 through 7.1.6.4 show the updated FMEA for the final design of our project. These RPN values are the lowest the team feels possible to attain given the resources available.



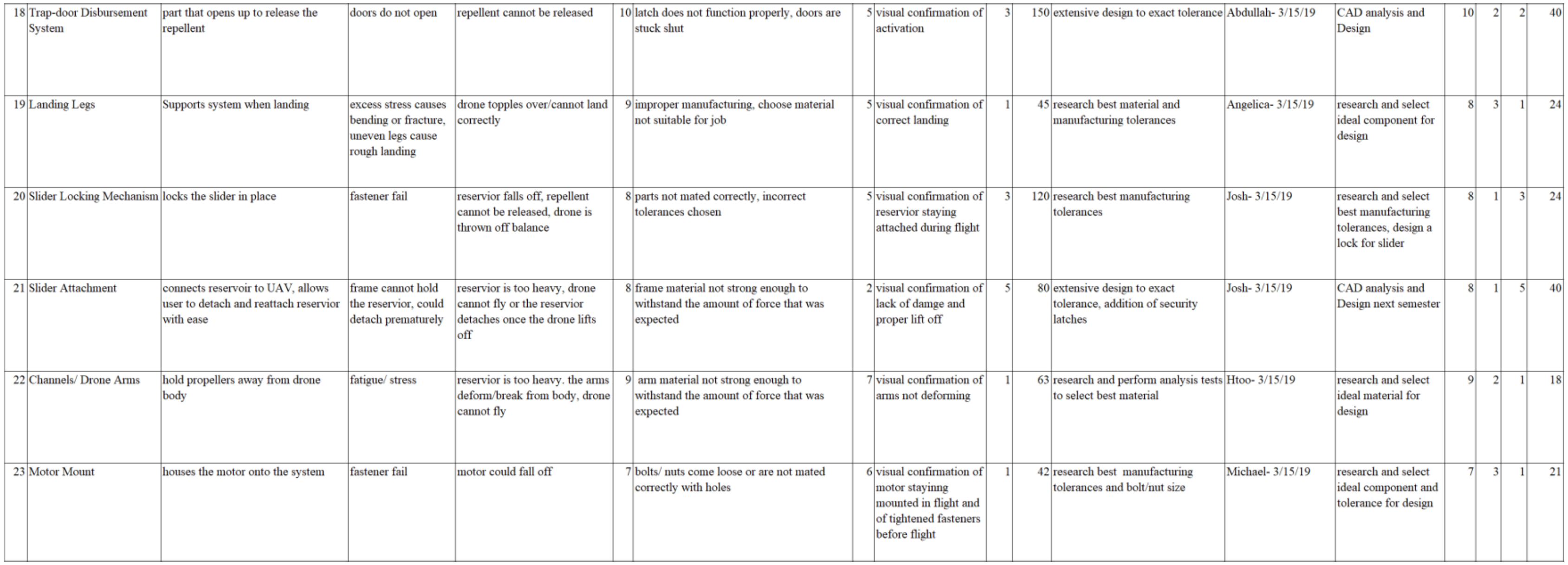
													Action Results				
Find No.	**Part Name**	**Function**	**Potential Failure Mode**	**Potential Failure Effect**	**SEV**	**Potential Causes/Mechanisms of Failure**	**OCCUR**	**Current design Controls**	**DETECT**	**RPN**	**Recommended Actions**	**Responsibility & Target Completion Date**	**Action taken**	***pS***	***pO***	***pD***	***prpn***
1	Propellers	Transmits power by converting rotational motion into thrust. Makes the drone move	vibrational stress causes propellers to shatter, physical failure	drone cannot fly	10	signal from drive shafts does not come through	2	visual confirmation of propeller movement	8	160	check for residence and vibration, implement carbon fiber components	Htoo- 3/15/19	Design	10	1	8	80
2	Motors	Converts electrical energy to mechanical energy	power failure	drone cannot fly, power can't get to the propellers	10	improper housing, rotor failure, short circuit	2	visual and audio confirmation of motor running and turning the components	8	160	design and build the component ideally		design and manufactor a proper housing system for motor and install it properly	10	1	7	70
3	Motors	Converts electrical energy to mechanical energy	power failure	drone cannot fly, power can't get to the propellers	10	physical damage, corrosion, material build up	3	visual and audio confirmation of motor running and turning the components	9	270	handle and store system correctly to avoid damage caused by human error		handle and store system correctly to avoid damage caused by human error	10	1	8	80
4	Motors	Converts electrical energy to mechanical energy	overheating	drone cannot fly, low power	8	imsufficient power supply, excess load, bad manufacturing	5	visual of smoke shows signs of failure	5	200	double check loads, specify correct motors	Michael- 3/15/19	research and select ideal component for design	10	2	5	100
5	Controller	Maneuver the drone; sends out signals to drone	signals from controller do not get to the drone	drone will not move	8	software failure	2	visual confirmation of drone movement	10	160	research and select ideal component for design		research and select ideal component for design, choose higher quality component	6	2	8	96
6	Controller	Maneuver the drone; sends out signals to drone	signals from controller do not get to the drone	drone will not move	8	hardware failure, short circuit	3	visual confirmation of drone movement	10	240	research and select ideal component for design, verify components are configured correctly		research and select ideal component for design, verify components are configured correctly	8	2	8	128
7	Controller	Maneuver the drone; sends out signals to drone	signals from controller do not get to the drone	drone will not move	8	radio signal lost, network signal lost	3	visual confirmation of drone movement	9	216	research and select ideal component for design		research and select ideal component for design	7	2	9	126

Figure 7.1.6.1: Updated FMEA Part 1



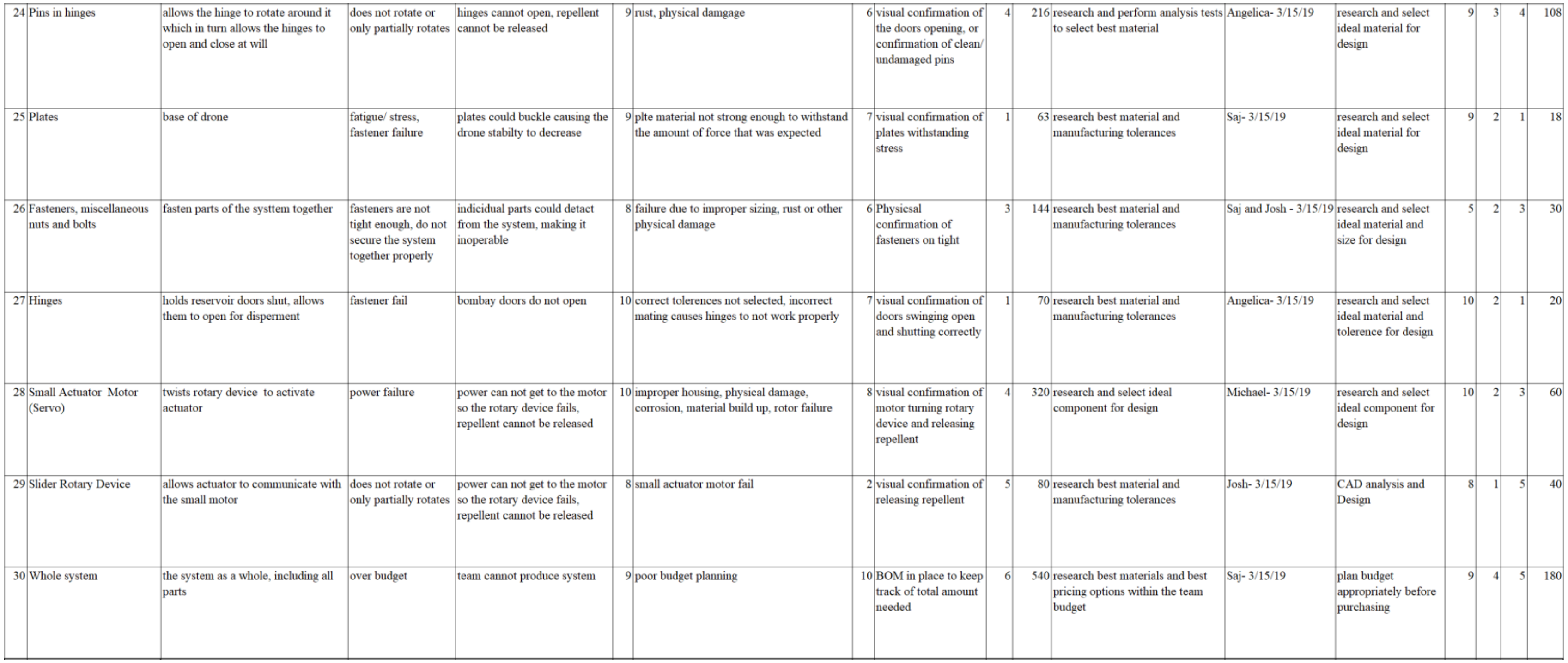
8	Receiver	Receive signals	signals from controller do not get to the drone	drone will not move	8	radio signal lost, individual component failure	3	visual confirmation of drone movement	9	216	employ GSM2 point to point, use redundant 900MHz radio	Derek- 3/15/19	research and select ideal component for design	7	2	9	126
9	Flight Controller	CPU brain. Translates signals from controller to other parts such as the reciever	signals are not processed correctly	drone will not move	10	CPU program failure/ bug.	3	visual confirmation of drone movement	9	270	research and select ideal component for design. Choose a higher quality component.	Michael- 3/15/19	research and select ideal component for design	10	1	8	80
10	Power Supply battery	Power the drone so the components work	electrical components will not turn on	dronce will not turn on, functions will not operate	10	not enough energy supply, battery not large enough to power components	3	visual confirmation of components working	10	300	specify correct battery for loads to minimize failure	Abdullah- 3/15/19	research and select ideal component for design	10	1	10	100
11	Disturbance Rejection	balances the drone when it is forced off track	cannot balance drone when it is thrown off balance	drone will not regain balance, could fall out of sky or be hard to control properly	8	malfunction of rejection's coding, ESC failure	4	visual confirmation of drone movement	8	256	research and select ideal component for design	Derek- 3/15/19	research and select ideal component for design	8	2	8	128
12	Display	screen to display what the camera sees to the user	screen does not display properly or clearly enough	cannot control drone with ease or accuracy	8	camera is not working correctly, signal between camera and display is disrupted	3	visual confirmation of visuals	4	96	reserch and select ideal component for design, use redundant transmission systems	Saj- 3/15/19	research and select ideal component for design	8	1	4	32
13	GPS System	Guide drone to correct spot	GPS does not identify position correctly	position in air is unknown, lowers accuracy	9	signal failure	4	visual confirmation of drone movement	8	288	reserch and select ideal component for design, remove part from other interfering signals	Angelica- 3/15/19	remove part from other interfering signals	9	2	8	144
14	Barometer	measures atomospheric pressure	altitude is not measured correctly	cannot tell how high the drone is relative to the ground, lowers accuracy	5	sensor failure, not calibrated correctly	2	none in place	10	100	reserch and select ideal component for design	Angelica- 3/15/19	research and select ideal component for design	5	1	10	50
15	Actuation System	opens the trap door	actuator does not activate at all or at the correct time	repellent will not be released from the reservoir, or release before desired	9	disconnection in connecting wires, they do not communicate to open the door	5	visual confirmation of activation	2	90	extensive testing prior to implementation	Team- 3/15/18	CAD analysis and Design	10	2	2	40
16	Actuation System	opens the trap door	actuator does not activate at all or at the correct time	repellent will not be released from the reservoir, or release before desired	10	latch is stuck closed, not enough power supplied for required torque	6	visual confirmation of activation	3	180	extensive testing prior to implementation	Team- 3/15/19	CAD analysis and Design	10	2	2	40
17	Reservoir	holds the repellent	reservoir canot adequately contan repellent	repellent may leak out	2	material is not sealed together correctly, container was manufactured too small	6	none in place	1	12	use correct gasket material,specify proper seals, design to tolerance	Abdullah- 3/15/19	CAD analysis and Design	1	3	1	3

Figure 7.1.6.2: Updated FMEA Part 2



18	Trap-door Disbursement System	part that opens up to release the repellent	doors do not open	repellent cannot be released	10	latch does not function properly, doors are stuck shut	5	visual confirmation of activation	3	150	extensive design to exact tolerance	Abdullah- 3/15/19	CAD analysis and Design	10	2	2	40
19	Landing Legs	Supports system when landing	excess stress causes bending or fracture, uneven legs cause rough landing	drone topples over/cannot land correctly	9	improper manufacturing, choose material not suitable for job	5	visual confirmation of correct landing	1	45	research best material and manufacturing tolerances	Angelica- 3/15/19	research and select ideal component for design	8	3	1	24
20	Slider Locking Mechanism	locks the slider in place	fastener fail	reservior falls off, repellent cannot be released, drone is thrown off balance	8	parts not mated correctly, incorrect tolerances chosen	5	visual confirmation of reservior staying attached during flight	3	120	research best manufacturing tolerances	Josh- 3/15/19	research and select best manufacturing tolerances, design a lock for slider	8	1	3	24
21	Slider Attachment	connects reservoir to UAV, allows user to detach and reattach reservior with ease	frame cannot hold the reservior, could detach prematurely	reservior is too heavy, drone cannot fly or the reservior detaches once the drone lifts off	8	frame material not strong enough to withstand the amount of force that was expected	2	visual confirmation of lack of damge and proper lift off	5	80	extensive design to exact tolerance, addition of security latches	Josh- 3/15/19	CAD analysis and Design next semester	8	1	5	40
22	Channels/ Drone Arms	hold propellers away from drone body	fatigue/ stress	reservior is too heavy. the arms deform/break from body, drone cannot fly	9	arm material not strong enough to withstand the amount of force that was expected	7	visual confirmation of arms not deforming	1	63	research and perform analysis tests to select best material	Htoo- 3/15/19	research and select ideal material for design	9	2	1	18
23	Motor Mount	houses the motor onto the system	fastener fail	motor could fall off	7	bolts/ nuts come loose or are not mated correctly with holes	6	visual confirmation of motor stayinng mounted in flight and of tightened fasteners before flight	1	42	research best manufacturing tolerances and bolt/nut size	Michael- 3/15/19	research and select ideal component and tolerance for design	7	3	1	21

Figure 7.1.6.3: Updated FMEA Part 3



24	Pins in hinges	allows the hinge to rotate around it which in turn allows the hinges to open and close at will	does not rotate or only partially rotates	hinges cannot open, repellent cannot be released	9	rust, physical damgage	6	visual confirmation of the doors opening, or confirmation of clean/ undamaged pins	4	216	research and perform analysis tests to select best material	Angelica- 3/15/19	research and select ideal material for design	9	3	4	108
25	Plates	base of drone	fatigue/ stress, fastener failure	plates could buckle causing the drone stabilty to decrease	9	plte material not strong enough to withstand the amount of force that was expected	7	visual confirmation of plates withstanding stress	1	63	research best material and manufacturing tolerances	Saj- 3/15/19	research and select ideal material for design	9	2	1	18
26	Fasteners, miscellaneous nuts and bolts	fasten parts of the systtem together	fasteners are not tight enough, do not secure the system together properly	indicidual parts could detact from the system, making it inoperable	8	failure due to improper sizing, rust or other physical damage	6	Physicsal confirmation of fasteners on tight	3	144	research best material and manufacturing tolerances	Saj and Josh - 3/15/19	research and select ideal material and size for design	5	2	3	30
27	Hinges	holds reservoir doors shut, allows them to open for disperment	fastener fail	bombay doors do not open	10	correct tolerences not selected, incorrect mating causes hinges to not work properly	7	visual confirmation of doors swinging open and shutting correctly	1	70	research best material and manufacturing tolerances	Angelica- 3/15/19	research and select ideal material and tolerence for design	10	2	1	20
28	Small Actuator Motor (Servo)	twists rotary device to activate actuator	power failure	power can not get to the motor so the rotary device fails, repellent cannot be released	10	improper housing, physical damage, corrosion, material build up, rotor failure	8	visual confirmation of motor turning rotary device and releasing repellent	4	320	research and select ideal component for design	Michael- 3/15/19	research and select ideal component for design	10	2	3	60
29	Slider Rotary Device	allows actuator to communicate with the small motor	does not rotate or only partially rotates	power can not get to the motor so the rotary device fails, repellent cannot be released	8	small actuator motor fail	2	visual confirmation of releasing repellent	5	80	research best material and manufacturing tolerances	Josh- 3/15/19	CAD analysis and Design	8	1	5	40
30	Whole system	the system as a whole, including all parts	over budget	team cannot produce system	9	poor budget planning	10	BOM in place to keep track of total amount needed	6	540	research best materials and best pricing options within the team budget	Saj- 3/15/19	plan budget appropriately before purchasing	9	4	5	180

Figure 7.1.6.4: Updated FMEA Part 4

7.1.7 Budget Update and Analysis

Attached below are updates for the current budget status as of February 27, 2019.

Table 7.1.7.1: Budget as of February 27, 2019

Component	Qty	Unit Price	Price	Status	Actual Price
Carbon Fiber Propeller 14*5.5	4	$7.00	$28.00	Purchased	$24.92
Pix-hawk 2 CUBE Flight Control Module	1		$0.00	Received	
SW0250MG - Waterproof Micro Digital Servo .11/69@6V	1	$30.00	$30.00	Purchased	$27.99
3510-350kV Carbon Case multi-rotor brushless motor	4	$45.00	$180.00	Purchased	$160.40
Multi-Star 30A Brushless ESC 32 bit 2-6s	4	$10.00	$40.00	Purchased	$39.96
6s 12c 6600 mAh Turnigy Lipo-pack w/ XT90	1	$85.00	$85.00	Purchased	$82.70
Pix-Hawk 2 900MHz Telemetry Antennae	1		$0.00	Received	
5.8GHz 200 mW Transmitter/Receiver & RC-FPV 800 TVL	1		$0.00	Pending	
LED Screen	1		$0.00	Received	
Remote Controller	1		$0.00	Received	
Gasket	1	$0.00	$0.00	Pending	
Camera	1		$0.00	Pending	
Passivated 18-8 Stainless Steel Pan Head Phillips Screw, 1/4"-20 Thread, 1" Long (91772A542)	50	$0.30	$15.00	Received	$17.52
Hex Nut (90762A112)	50	$0.55	$27.50	Received	$26.85
18-8 Stainless Steel Socket Head Screw, 1/4"-20 Thread Size, 2-1/2" Long, Fully Threaded (92196A821)	4	$1.25	$5.00	Pending	
Velcro Straps	12	$1.00	$12.00	Purchased	$9.18
Black UV Stabilized 12” Nylon Cable Ties	50	$0.20	$10.00	Purchased	$7.78
Polycarbonate Sheet	1	$20.00	$20.00	Received	$16.17
3D Print Cost	1	$70.00	$70.00	Pending	
Aluminum Rod (for hinge)	1	$10.00	$10.00	Received	$2.70
Square Rod for Actuation System			$0.00	Purchased	$1.16
Square Hollow Aluminum Rod	1	$20.00	$20.00	Pending	
Aluminum Sheet	1	$10.00	$10.00	Received	$31.56
Fiberglass Rod	1	$5.00	$5.00	Pending	
Tax			$50.00		$3.85
Shipping			$50.00		$56.16
Total Price			**$667.50**	**Total Spent**	**$508.90**
				Remaining Budget	**$191.10**

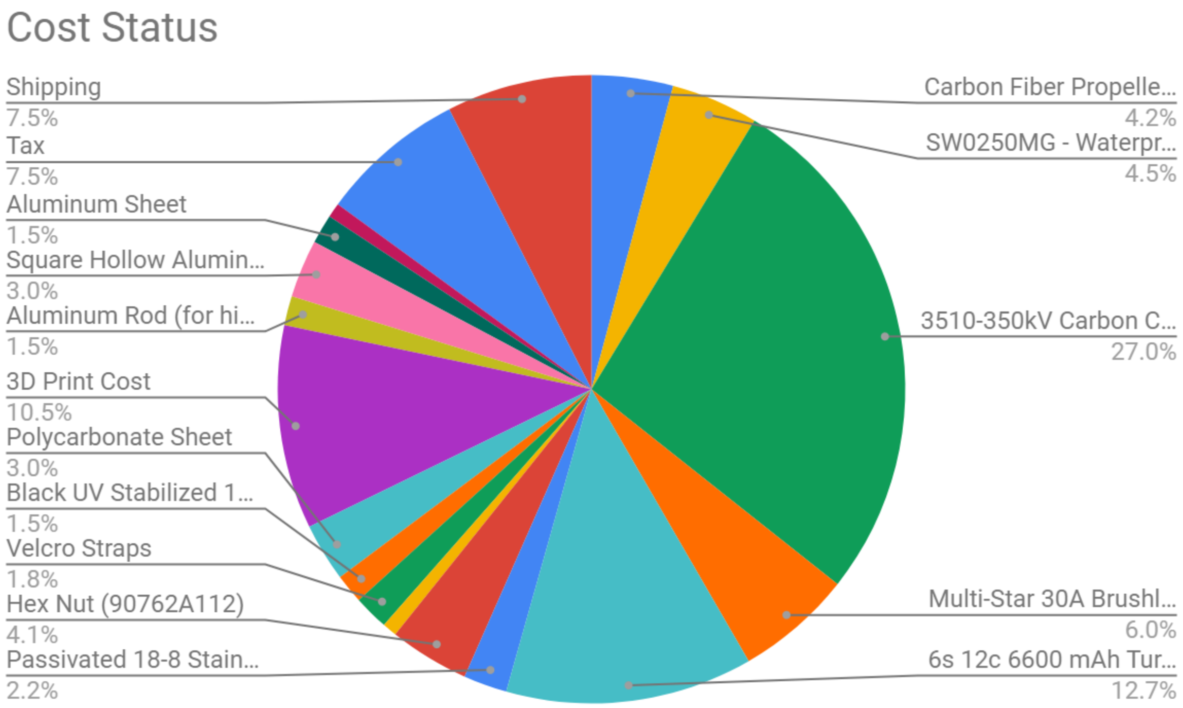


Figure 7.1.7.1: Current Cost Status as of February 27, 2019

As it can be seen from table 7.1.7.1 there are very few items left to order. All parts needed to complete manufacturing would be purchased by March 1st, 2019. The remaining items will be purchased by team members and submitted for reimbursement as they are only available in local stores as online stores and ordering required purchasing the items in bulk which leads to unnecessary costs.

In addition, it is important to note that we have approximately USD 190.00 left in our budget and have approximately USD 100.00 worth of material left to purchase. This allows us a leeway of approximately USD 90.00 which can be utilized to obtain reimbursement for some components that have been purchased by team members using their personal money and also to print the final poster and material for the ABET accreditation fair.

7.2 Design Package

This section outlines all the drawings required for manufacturing and fabrication of our product. All the drawings contained in this section are final and reflect the final design of our product.

Figure 7.2.1 below is an example of one of our detailed drawings for our product. This is a formal drawing which shows the dimensions, tolerances, and the specifications of the part. This example pertains specifically to the locking block component of our system. The entire drawings package is contained within Appendix B.

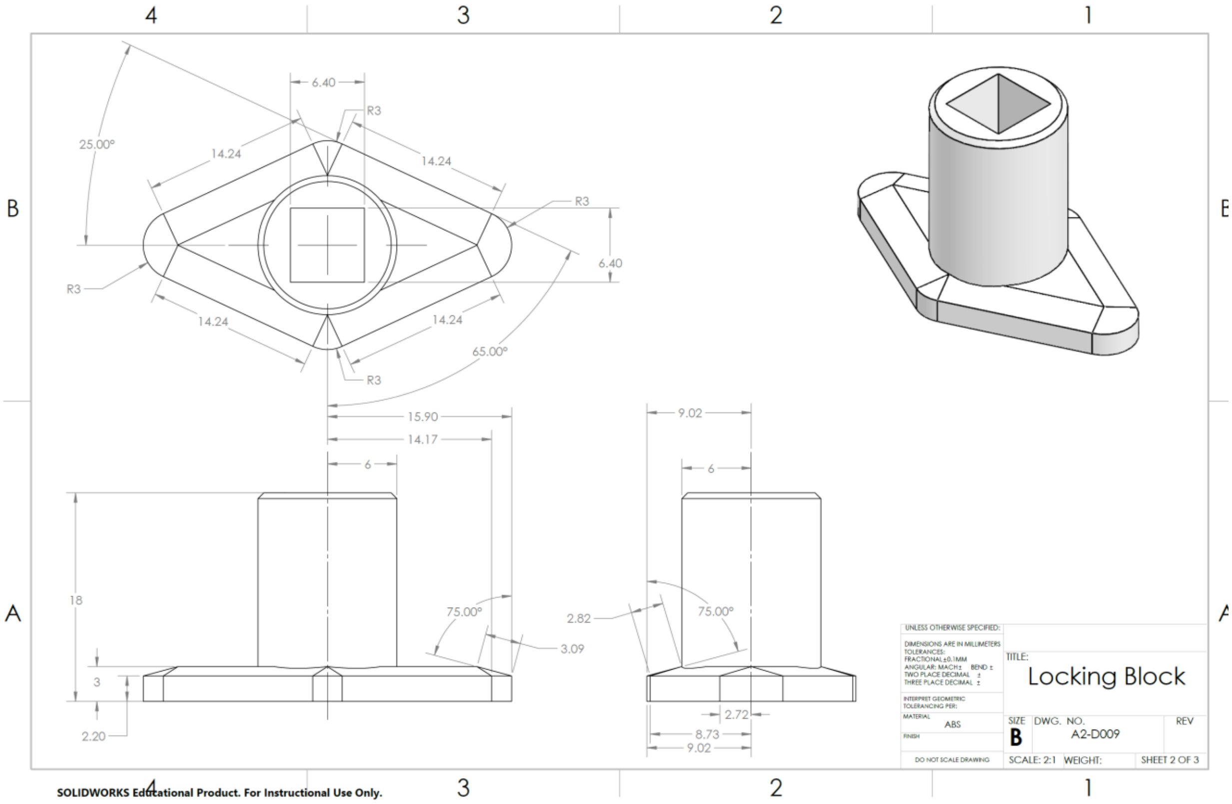


Figure 7.2.1: Example Formal Drawing

The drawing list for the complete drawing package outlined in Appendix B is as follows:

- Dwg A0-001 Full System Assembly
    - Dwg A1-D001 UAV Flight Subassembly
    - Dwg A1-D002 UAV Exploded View
        - Dwg A1-D003Aluminum Plate
        - Dwg A1-D004 Damping Bracket
        - Dwg A1-D005 Key Upper
        - Dwg A1-D006 Arm
        - Dwg A1-D007(a-b) Upper Slider
        - Dwg A1-D008(a-c) Motor Mount
        - Dwg A1-D009 Landing Leg
    - Dwg A2-D001 Distribution System Subassembly
    - Dwg A2-D002 Distribution System Exploded View
        - Dwg A2-D003 Bottom Slider
        - Dwg A2-D004 Door Gasket
        - Dwg A2-D005 Door Left
        - Dwg A2-D006 Door Right
        - Dwg A2-D007 Key
        - Dwg A2-D008 Lock Support Bar
        - Dwg A2-D009 Locking Block
        - Dwg A2-D010 Trapdoor Hinge
        - Dwg A2-D011 Reservoir Hinge
        - Dwg A2-D012 Reservoir Tube
        - Dwg A2-D013(a-b) Reservoir Lid
        - Dwg A2-D014 Hinge Pin
        - Dwg A2-D015 Actuation Shaft

8. Prototype Fabrication and Assembly

This section pertains to the fabrication and assembly of the Shark-Attack Victim Response & Repellent System. The following subsections will address the purchasing, fabrication, and assembly of product prototype. The physical components discussed are a direct result of the previous phases of the IPDS engineering process. Each individual subsection will go in to further detail about how the prototype came to be, as well as how it differs (if at all) from the final detailed design.

8.1 Purchased Parts

This section talks about the items purchased that will be utilized with minimum modification of the parts. The table below summarizes the parts that were purchased from manufacturers that will be implemented in the prototype with no further processing required.

Table 8.1.1: Table Containing All Items That Require No Additional Manufacturing

Component
Carbon Fiber Propeller 14*5.5
Pix-hawk 2 CUBE Flight Control Module
SW0250MG - Waterproof Micro Digital Servo .11/69@6V
3510-350kV Carbon Case multi-rotor brushless motor
Multi-Star 30A Brushless ESC 32 bit 2-6s
6s 12c 6600 mAh Turnigy Lipo-pack w/ XT90
Pix-Hawk 2 900MHz Telemetry Antennae
5.8GHz 200 mW Transmitter/Receiver & RC-FPV 800 TVL
LED Screen
Remote Controller
Passivated 18-8 Stainless Steel Pan Head Phillips Screw, 1/4"-20 Thread, 1" Long (91772A542)
Hex Nut (90762A112)
18-8 Stainless Steel Socket Head Screw, 1/4"-20 Thread Size, 2-1/2" Long, Fully Threaded (92196A821)
Velcro Straps
Black UV Stabilized 12” Nylon Cable Ties

The items mentioned above were either purchased from the budget allocated (see section 2.5: Cost Results for more information) or personal items of teammates that will be utilized for the prototype.

As it can be seen above, most of the items that were not manufactured by the team were electronic items and fixtures. This allowed for the team to get more experience by using equipment available on campus to manufacture the components using raw material and also resulted in more cost effectiveness which allowed the team to bring down the cost of the prototype. To get further information on the components purchased, refer section 6.2: Trade Studies.

The Carbon Fiber Propellers were purchased from Hobby King as the shape and dimensions of well performing propellers are hard and complex to manufacture by hand over a short amount of time. Also, manufacturing propellers will require a lot of research and analysis which will require a lot of time being put in for a single component which will put us behind schedule to complete the project on time.

The SW0250MG - Waterproof Micro Digital Servo .11/69@6V and Multi-Star 30A Brushless ESC 32 bit 2-6s require a lot of programming and coding and are all complex components. Hence, the team decided to purchase these components instead of deciding to manufacture these components as it requires a lot of expert knowledge and programming.

The 6s 12c 6600 mAh Turnigy Lipo-pack w/ XT90 was purchased as these are battery packs and are not capable of being manufactured on campus.

The 3510-350kV Carbon Case multi-rotor brushless motor was purchased as this is a vital component that again requires a lot of time and effort to make and program.

The Pix-hawk 2 CUBE Flight Control Module, Pix-Hawk 2 900MHz Telemetry Antennae, 5.8GHz 200 mW Transmitter/Receiver & RC-FPV 800 TVL, LED Screen and Remote Controller were already in hand with a teammate so the team decided to use the same components instead of purchasing new components to complete the prototype.

The Passivated 18-8 Stainless Steel Pan Head Phillips Screw, 1/4"-20 Thread, 1" Long (91772A542), Hex Nut (90762A112) and 18-8 Stainless Steel Socket Head Screw, 1/4"-20 Thread Size, 2-1/2" Long, Fully Threaded (92196A821) requires a lot of machining and already come in standard size from manufacturers and are readily available at the hardware stores, so the team decided to purchase these items instead of manufacturing these components.

Velcro Straps and Black UV Stabilized 12” Nylon Cable Ties are simply fixture components and hence were purchased.

8.2 Fabricated Parts

This section goes through the parts that were manufactured by the team and goes through the details of the processes used to complete manufacturing. For further information, refer to the manufacturing document compiled by the team.

One of the first components manufactured by the team were the rods for the hinges of the container. This process was very simple and only required the team to measure the length required of the pin using a caliper and then cutting the rod to length using a grinder. Then a polisher was used to smooth out the cut edges.

Figure 8.2.1: Grinder Used to Cut Pin to Size

Figure 8.2.2: Polisher Used to Polish Cut Material

Figure 8.2.3: Pins Used for the Hinge After Being Cut to Size

The next manufacturing that was also carried out was simple as this again required a single cut. This was to cut the actuating rod down to the required size. For this, a table saw was used. Then a polisher was used to smooth out the cut edges as discussed for the pins as well.

Figure 8.2.4: Table Saw Used to Cut Actuation Rod

Figure 8.2.5: Manufactured Actuation Rod

The next component that was being manufactured was the drone arms. For this, a band saw was first used to cut the aluminum tubes down to size. Then a milling machine was used to make the holes at the correct positions for the fixtures and legs. Finally, the arms were polished using a polisher to take out any rough edges left from the milling and sawing.

Figure 8.2.6: Band Saw Used to Cut Aluminum Tube

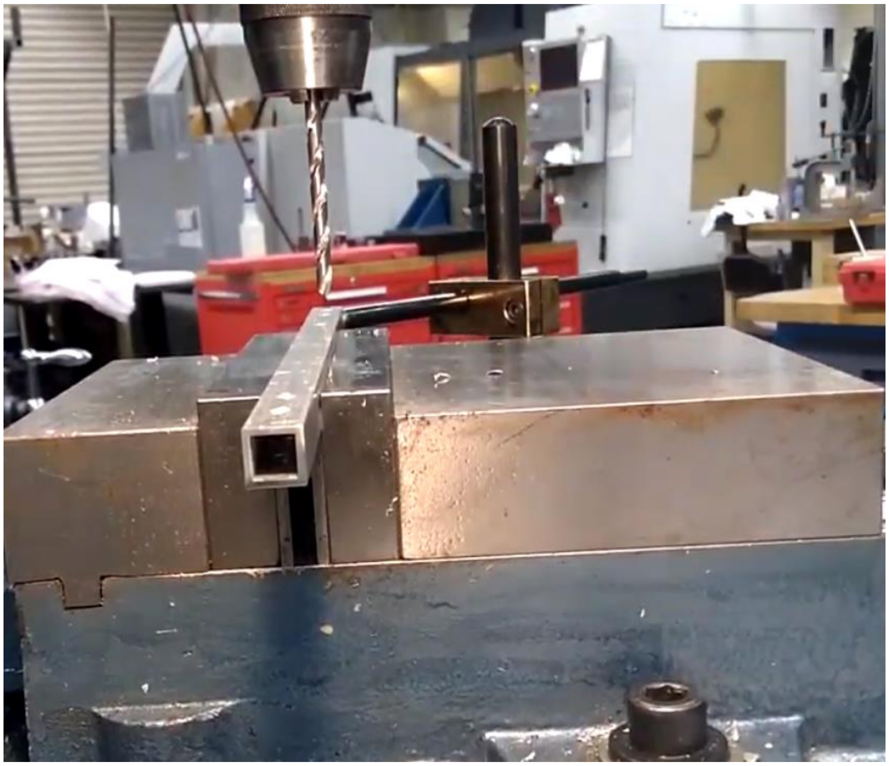


Figure 8.2.7: Using a Milling Machine to Drill Holes in the Arms of the Drone

Figure 8.2.8: Completed Drone Arms

While the team was manufacturing components by hand, staff at the machine shop were conducting 3D prints and CNC jobs the team had requested. The container, hinges, doors, actuation system components, slider attachments and locking mechanisms were 3D printed while the circular main body, motor mounts and container top were CNC'd.

Figure 8.2.9: Sample of 3D Printed Components Before Assembly

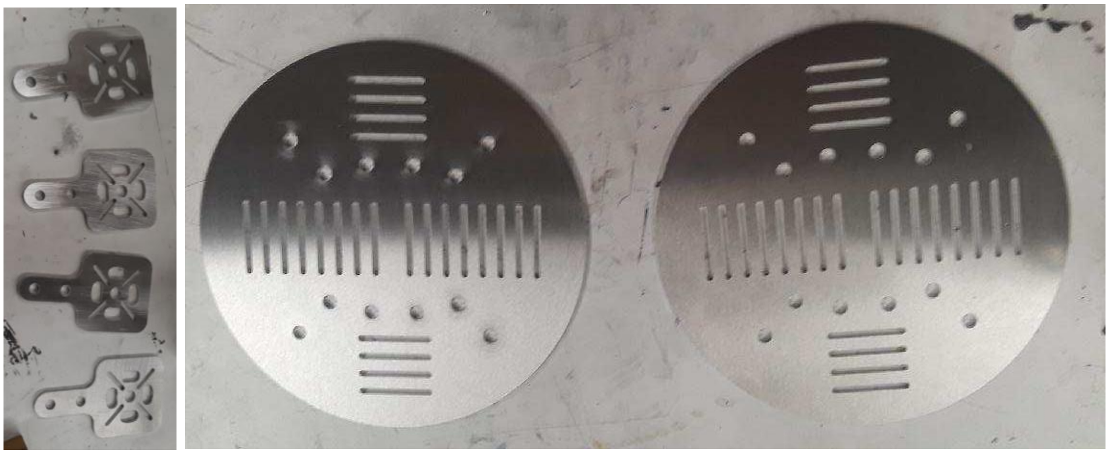


Figure 8.2.10: CNC'd Aluminum Components

8.3 Assembly

The assembly of the Shark-Attack Victim Response & Repellent System (SAVRRS) was divided into four main parts. The gaskets were placed followed by the bonding the of dispersion container parts, the sub assembly of the drone base and arms, and the wiring of the components. Before the dispersion chamber could be assembled, the gaskets needed to be placed to ensure that the chamber was watertight. For the lid, a strip of Buna-N was cut from a sheet using an x-acto knife. Ultra Black gasket maker was used to adhere the gasket materials seen in figure 8.3.1 to the 3D printed parts as seen below in figure 8.3.2. This was let dry over night to produce a firm bond between the two materials.

Figure 8.3.1 The materials needed for the gaskets. Pictured from left to right: Ultra Black gasket maker, Buna-N sheet, and U-ring material.

Figure 8.3.2 The chamber parts with sealants adhered.

Next, the smaller pieces were adhered together. The actuator had many different components to it that needed to be created in different materials. The rod and the locking block were bonded together using JB Plastic Weld epoxy. These parts can be seen below in figure 8.3.3. The epoxy was applied using a small popsicle stick and the excess was wiped away with a folded paper towel. The key and rod were also later bonded using this method.

Figure 8.3.3 Actuator rod and locking block along with the JB Plastic Weld epoxy adhesive

Figure 8.3.4 The actuator pieces joined together along with a small paper towel used to wipe any excess adhesive.

Plastic on plastic bonds were made using a SciGrip acrylic cement solvent shown below in figure 8.3.5. For better precision, a small amount was put into a drip bottle with a needle tip application. This was used for not only the small pieces like the lock support bars shown in figure 8.3.6, but the main parts of the reservoir as well.

Figure 8.3.5 SciGrip acrylic cement solvent used to bond the plastic pieces together in both its original can and in the drip bottle used for application.

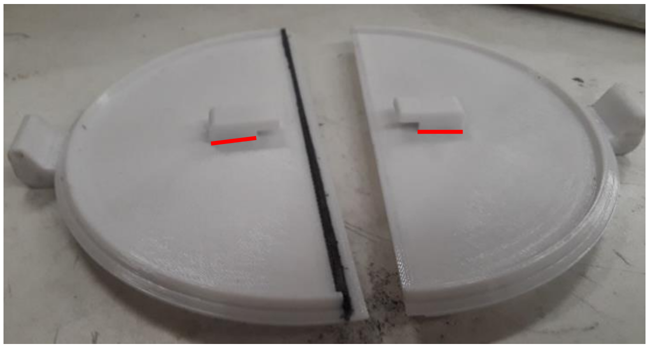


Figure 8.3.6 The lock support bars bonded to the reservoir lid.

To connect the reservoir’s lid, main body, hinge, and doors together the acrylic adhesive was used in the areas denoted below in figures 8.3.7, 8.3.8, and 8.3.9. It was important to apply the adhesive on the inside of the pieces as well as the outside to make the bond strong in every direction. Each piece was let dry for an hour before the next piece was bonded on. This was to avoid the cement from dripping onto the next part in an undesired place. After applying the adhesive, the system was elevated to avoid it bonding to the table.

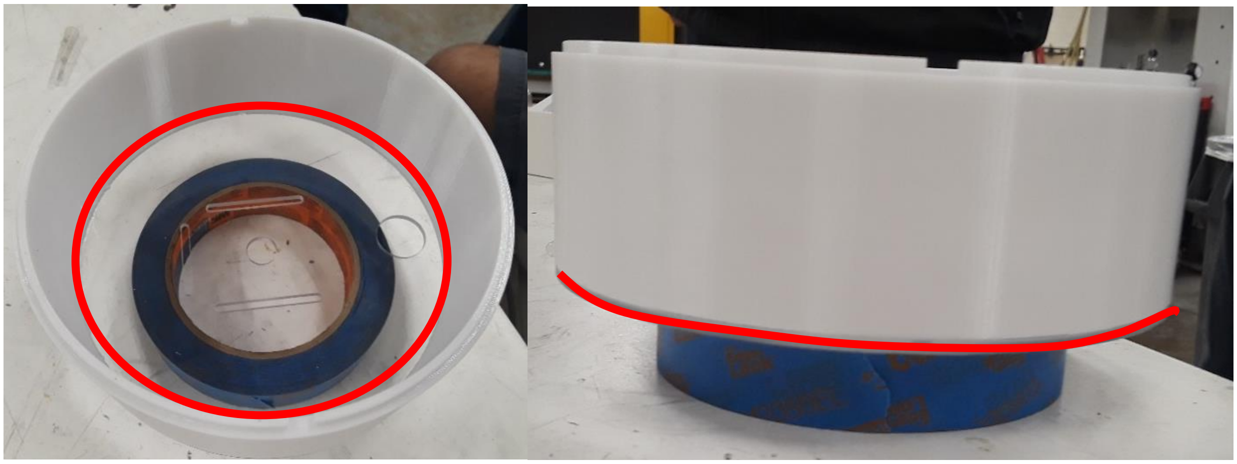


Figure 8.3.7 The reservoir lid and main body bonded together. Red highlights demonstrate where the adhesive was applied.

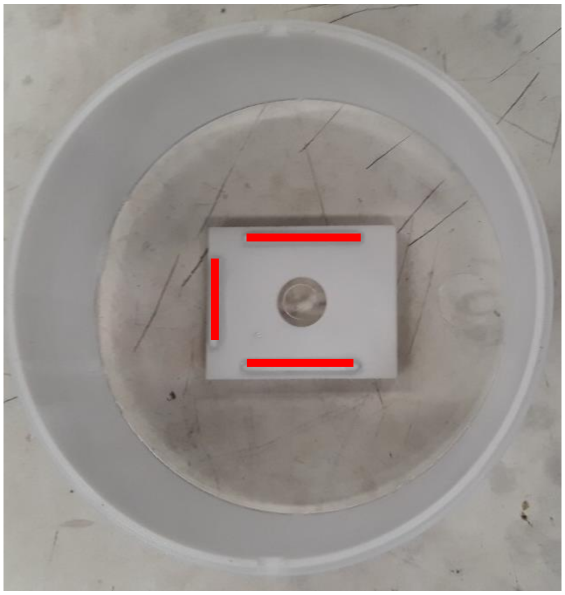


Figure 8.3.8 The bottom of the slider attachment bonded to the reservoir lid. Red highlights demonstrate where the adhesive was applied.

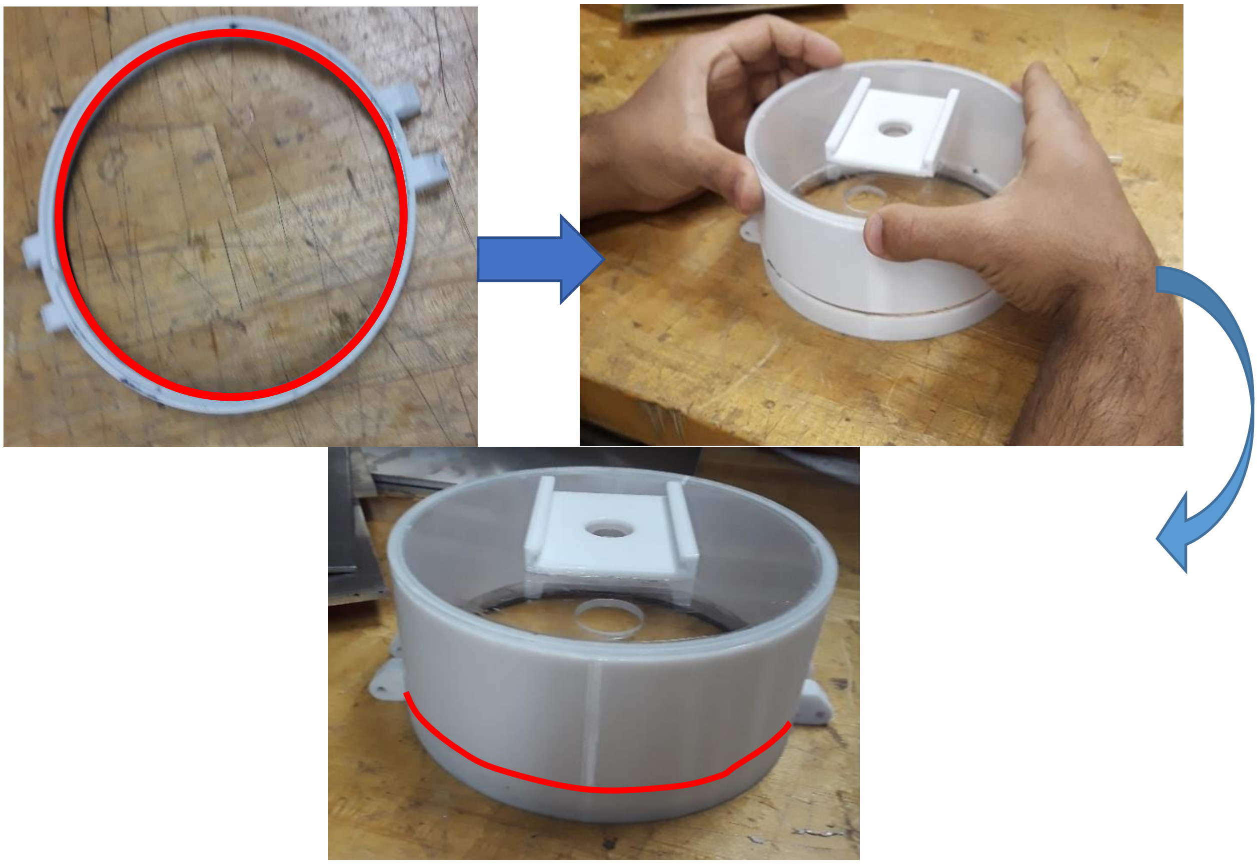


Figure 8.3.9 The order of adhesive application for the reservoir’s hinges.

After this dried the doors were placed. The pin was pushed through both the hole in the hinge and the hole in the door. Then the pin was trimmed, and the ends epoxied to keep it in place as shown below in figure 8.3.10.

Figure 8.10 Finalized pin placement.

With the plastics cementing, the aluminum pieces of the drone body, shown in figure 8.3.11, were prepared. First the rough side of the pieces were sanded down to avoid unnecessary cuts during assembly and use. This step can be seen below in figure 8.3.12.

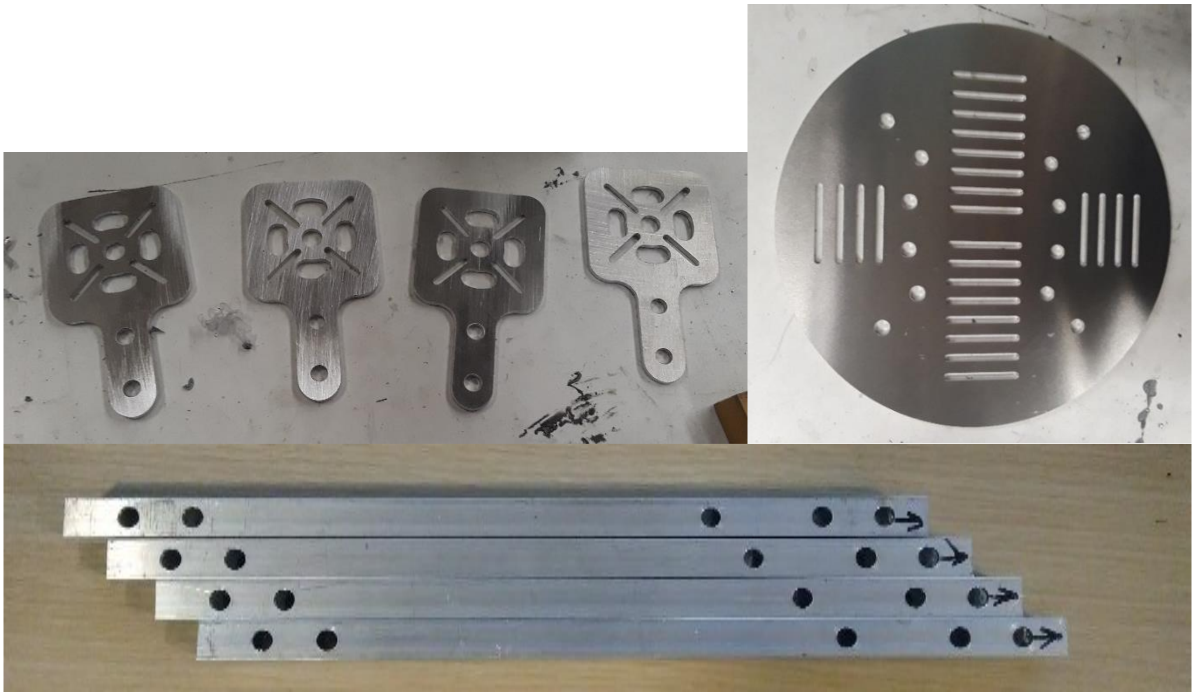


Figure 8.3.11 Parts used for the drone base sub-assembly. Top from left to right: motor mounts and base plates. Bottom: drone arms.

Figure 8.3.12 A plate on the sander used to smooth the freshly cut aluminum.

To begin with the assembly, the motor mounts were screwed onto the drone arms with a one-inch screw and a nut at the bottom holding them in place. This step can be seen below in figure 8.3.13.

Figure 8.3.13 A motor mount attached to the drone arm with a 1-inch screw with a ¼”- 20 thread and a ¼”-20 thread nut.

Next the arms were secured onto the top aluminum base plate with 3D printed brackets on each side of the arms for support. The 3-inch screws that secure the housing for the actuator’s motor were screwed through the bottom plate before it was attached to the top plate. All the screws were secured into place with nuts similarly to the motor mounts above. These steps can be seen below in figure 8.3.14 with the final sub-assembly production shown in figure 8.3.15.

Figure 8.3.14 The base plates of the drone with brackets and arms attached to it with 1 ½ inch hex bolts with a ¼”- 20 thread and the same ¼”-20 thread nut used on the motor mounts.

Figure 8.3.15 Complete sub-assembly as the drone base.

To finish the assembly, the distribution chamber sub-assembly needed to be completed. Before the doors could be placed, the actuation system was placed through the bottom. The key was epoxied to the actuation shaft through the hole in the slider using a drill press as shown below in figure 8.3.16. This was left to dry for 20 minutes before flipping it over to prevent the epoxy from dripping down in between the hole for the key and the key itself.

Figure 8.3.16 The reservoir and actuation system being held under the drill press (left) and a top view of the reservoir system after the epoxy dried (right). These photos demonstrate the actuation system assembly process.

Next, the actuator motor or servo was mounted to the slider and the slider was attached to the full assembly. M2.5x8 screws were used to attach the servo to the slider. The head size of this screw fit but they were too long and would drag along the bottom half of the slider, so they were trimmed as shown below in figure 8.3.17.

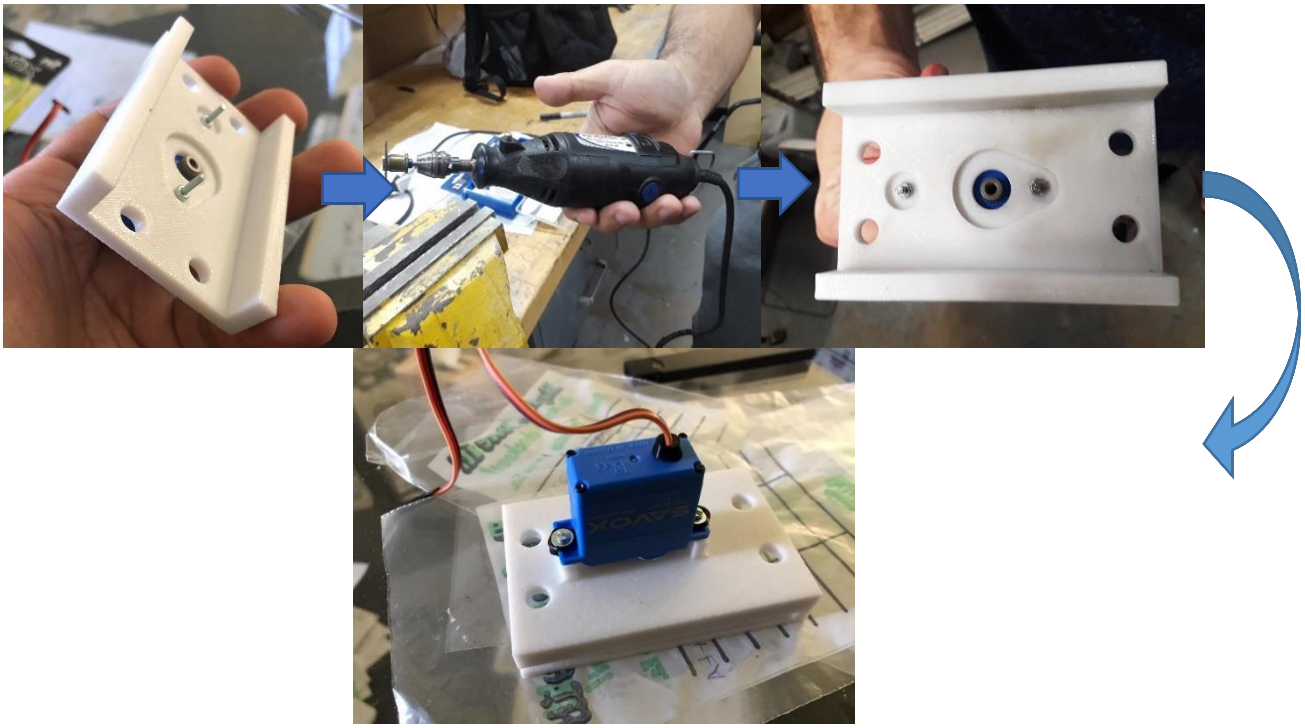


Figure 8.3.17 Servo mounting process.

To make legs for the SAVRRS device, fiberglass rods with rubber tips were taken and cut down to size and attached to the drone body using the holes machined for the landing legs as shown in figure 8.3.18.

Figure 8.3.18 Fiberglass landing legs attached to drone arms

Then, a GPS tower was created using 3 pieces of polycarbonate and solvent bonding (SciGrip acrylic cement) as shown below and fixed onto the body of the drone to prevent electrical and magnetic interference to the GPS by other electrical components as shown in figure 8.3.19. Section 8.4 discusses this further.

Figure 8.3.19 Polycarbonate GPS Mounting Tower

To finalize the drone body assembly, the propellers were added on using socket screws. They were attached to the motors which were attached to the body using manufacturer supplied machine capped screws. This process can be seen in Figures 8.3.20 and 8.3.21 below.

Figure 8.3.20 Propellers attached to motor and socket screw used to do so.

Figure 8.3.21 Motors attached to drone body and capped screws used to do so

Since the drone body assembly is completed, the electronics can be arranged in the way shown in figure 8.3.22.

Figure 8.3.22 A photograph displaying the electronics assembly

Lastly, the two sub-assemblies will be combined to complete the full assembly as shown below in figure 8.3.23

Figure 8.3.23 Final Assembled Design Prototype

8.4 First Article Inspection and Rework

This section will go into detail about the differences between the manufactured prototype hardware and the design drawings. There are six noteworthy differences between the drawings and the prototype hardware.

Reservoir Body and Hinges:

The reservoir body is a substantial component to the design of the SAVRRS system. For the prototyping development, it was decided that instead of manufacturing extruded tubing for this component, we would rather 3D print it for the sake of time and cost. Because of this, it was deemed convenient to print the body hinges and the reservoir tube simultaneously on the same structure. The product therefore has the hinges pre-attached to the reservoir body.

Here we have a situation where the only reason there is a difference between design and prototype is due to the convenience of 3D printing. In the final product design, the team still plans to use extruded plastic tubing for the reservoir body, so the convenience of the 3D printing is not a viable option. Hence, this difference is waived.

Reservoir Body Split for Printing:

Additionally, pertaining to the reservoir body, during the printing process around the hinge area, the component was split into two different cylinders with mating ribs for assembly. This change was only made since the additive manufacturing nature of 3D printing means that if the reservoir and hinges are printed together in one part, there would by necessity be extreme amounts of support structures and a lack of fine detail required where the reservoir tube mates with the O-ring. To combat this, a decision was made to split the reservoir where the hinges are attached. With the finer details facing upwards, there was no longer a need for extreme support structures nor would we compromise the fine detailing of the inner ridge of the reservoir.

Once again, this difference is waved due to it being a change necessitated by the method of prototype fabrication. We still do not plan to use Additive manufacturing processes in the final product, and therefore it would be of no use to adapt the design to reflect changes made during the prototyping phase. If the budget permitted, we would rather use extruded tubing with the hinges simply attached to the side.

Mating Ribs on Reservoir Body and Reservoir Lid:

One major oversight during the design phase was the ease of assembly for the product. One unintended result of this is the difficulty in aligning the reservoir body with the reservoir lid. To combat this difficulty, a simple rib and inverted rib was added to the reservoir body as well as the reservoir lid. This allows for the correct alignment of both components with respect to each other. This change has been implemented to the designs. Since it is easy to understand that manufacturing of our product should be easy, we deemed it necessary to include this change in the final product design.

Hinge Holes Tolerance Larger than Anticipated:

Byproduct of 3D printing the hinges and doors of our prototype resulted in an inability to tolerance the parts accordingly since the printer prints exactly what the 3D model shows. This means that when we created our hinges and doors, the size of the holes was exactly the same for both the hinge components, whereas it was intended that there would be an interference fit on the reservoir hinges, and a clearance fit on the door hinges. To combat this, the team had to drill the holes a bit to create that clearance fit on the hinges, however the hinge pins were still very tight on the pin.

This change has been reflected in the design since we now are aware of the tolerances required to achieve this effect.

Hinge Pin Diameter Reduced on Ends:

To again combat the difference in hinge tolerancing, the team had to get creative with the assembly of hinge pins with our prototype. To ensure the easy assembly, we decided to grind down the pins on either end in order to create a cone-shaped ramp which allows the pins to slide easier into the hinges. This is not an adequate design and is only implemented due to the necessity of the situation.

Since this is not an adequate design change, and is only reflected in the prototype, this change is waived and does not need to be modified in the drawings.

Door Gasket Less Intricate than Designed:

In our design, the door gasket is made to be quite intricate and flush with the distribution doors. However, during the prototyping, it was deemed unnecessary to have to include the amount of detail demanded by the design. Because of this, a simple rectangular strip of Buna-N rubber was used in place of the more intricate design. This was deemed appropriate due to time constraints and lack of tooling for the necessary intricacies.

We will once again waive this change since it will not be implemented in the final product. The sole purpose of this difference is to save time manufacturing the prototype. Similar results will yield regardless of how the gasket is manufactured.

Landing Legs Additional Support:

The landing legs shown in the design for our model are simply supported fiberglass rods which support the drone body and reservoir system. The legs were manufactured according to design, and work well to support and hold the system, however due to the extremely flexible nature of the fiberglass material, landing on the legs is extremely difficult. To combat this, simple wired supports have been implemented to allow the rods to bow outwards, making it easier to land and support the drone system. This design alteration will not be reflected in the detailed drawings since it is a last-minute adjustment made during the final week of testing. A more suitable solution must be researched prior to commercialization and final design for production is completed.

GPS Tower:

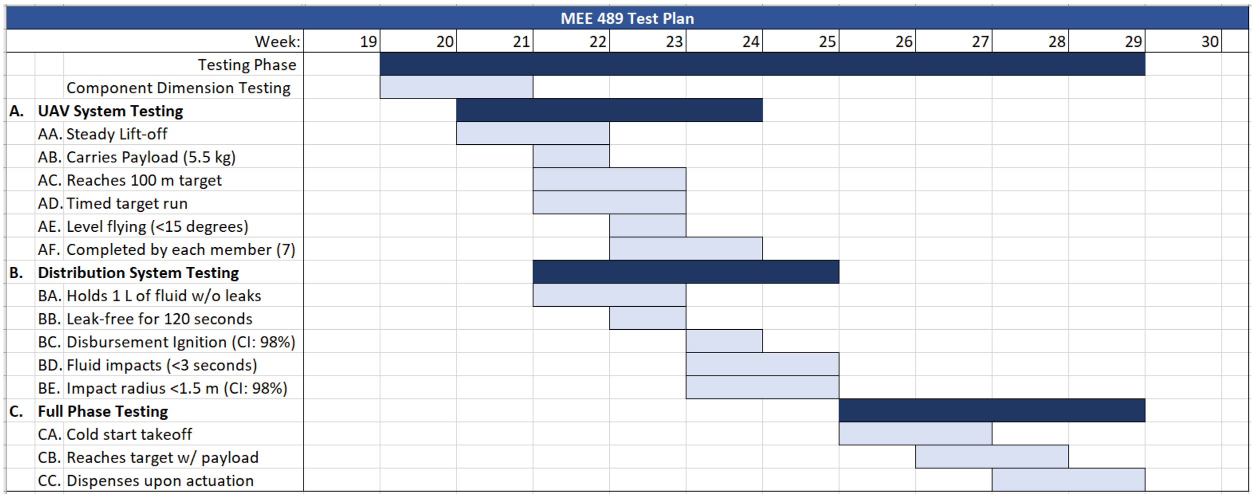
One prominent feature that was added to the SAVRRS system is the GPS tower which supports and raises the GPS system above the drone to eliminate any controller interference. This part was manufactured without any formal design or instructions, and therefore will not be included in the detailed design. More information on this fabrication process is found in section 8.3. The final production model of the system will certainly include some kind of solution to the issue of GPS interference, but due to time constraints, no formal research or design will be put into this problem for the current prototype.

9. Prototype Development

In prototype development, the team tested the SAVRRS prototype parts since the assembly. The team tested each part carefully to guarantee that each part would meet the requirement, while testing the parts the team did a small change and some reworks to meet the prototype requirements. Furthermore, the team started to compile the prototype parts after verified all the parts. Then compiled and assembly all the part as planed the team going to test the device to make sure it meets all the requirements, changes and reworks will be happened if the prototype did not meet one of the requirements. When the team guarantee that the prototype meets all the requirements the drawing package will be updated according to the changes.

9.1 Development Plan

The following chart depicts the developmental plan establish by the team in the early stages of Phase 4: Detailed Design preparatory to the commencement of manufacturing and assembly. The development plan was an overall guideline for testing and validation of customer/engineering requirements, while allowing for subsequent rework and correctional adjustments as needed. The chart represents the tests (listed on the left) with the corresponding weeks for the test to take place (listed at the top). Please see section 9.2.1 for the actual development plan carried out by the team.



MEE 489 Test Plan

	Week:	19	20	21	22	23	24	25	26	27	28	29	30
	Testing Phase		■	■	■	■	■	■	■	■	■	■	
	Component Dimension Testing		▨	▨									
A.	**UAV System Testing**			■	■	■	■						
	AA. Steady Lift-off			▨	▨								
	AB. Carries Payload (5.5 kg)				▨								
	AC. Reaches 100 m target				▨	▨							
	AD. Timed target run				▨	▨							
	AE. Level flying (<15 degrees)					▨							
	AF. Completed by each member (7)					▨	▨						
B.	**Distribution System Testing**				■	■	■	■					
	BA. Holds 1 L of fluid w/o leaks				▨	▨							
	BB. Leak-free for 120 seconds					▨							
	BC. Disbursement Ignition (CI: 98%)						▨						
	BD. Fluid impacts (<3 seconds)						▨	▨					
	BE. Impact radius <1.5 m (CI: 98%)						▨	▨					
C.	**Full Phase Testing**								■	■	■	■	
	CA. Cold start takeoff								▨	▨			
	CB. Reaches target w/ payload									▨	▨		
	CC. Dispenses upon actuation										▨	▨	

Figure 9.1.1: Project Development Plan and subsequent testing schedule for SAVRRS device

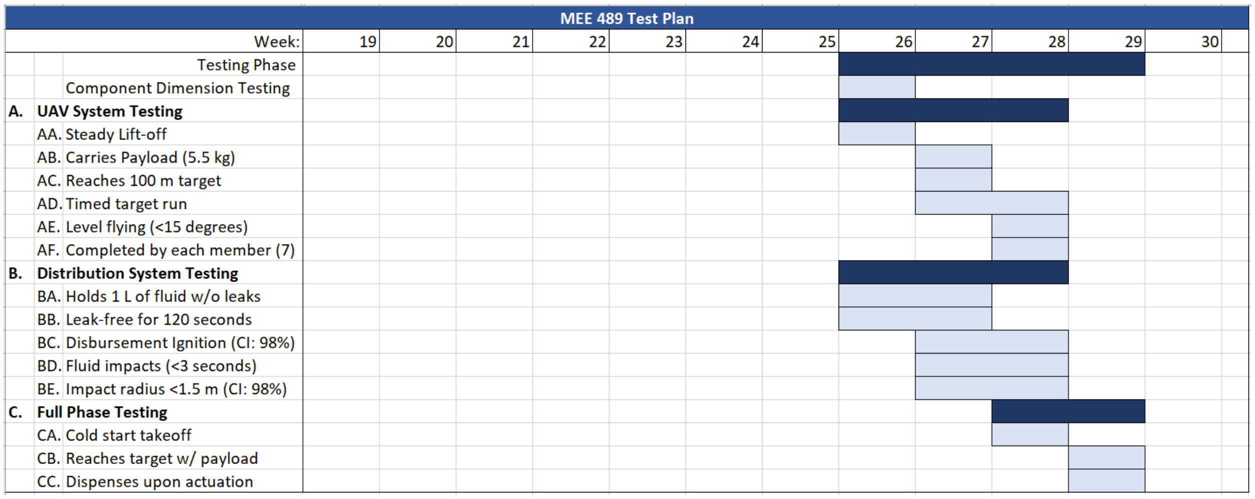
9.2 Development Phase Results

The testing will be delayed due to manufacturing delays, the team separated the testing to three parts which are UAV system, distributions system, and then the full phase testing in order to maximize the team qualifications of the time. Both the UAV system and the distributions system will be tested at the same days, while the testing the team will start testing the full phase. This plan will avoid other delays.

9.2.1 Actual Schedule and Overall Results

The chart shown below is the actual development schedule carried out by team member for the testing stages of the SAVRRS device and the overall results. The schedule was delayed and condensed due to unforeseen manufacturing delays in the fabrication and assembly stages of the project. A modified schedule was constructed based on the available time and required testing.

Subsequent results are shown in the following subsections detailing the procedural followings and resulting data.



MEE 489 Test Plan

	Week:	19	20	21	22	23	24	25	26	27	28	29	30
	Testing Phase								■	■	■	■	
	Component Dimension Testing								▨				
A.	**UAV System Testing**								■	■	■		
	AA. Steady Lift-off								▨				
	AB. Carries Payload (5.5 kg)									▨			
	AC. Reaches 100 m target									▨			
	AD. Timed target run									▨	▨		
	AE. Level flying (<15 degrees)										▨		
	AF. Completed by each member (7)										▨		
B.	**Distribution System Testing**								■	■	■		
	BA. Holds 1 L of fluid w/o leaks								▨	▨			
	BB. Leak-free for 120 seconds								▨	▨			
	BC. Disbursement Ignition (CI: 98%)									▨	▨		
	BD. Fluid impacts (<3 seconds)									▨	▨		
	BE. Impact radius <1.5 m (CI: 98%)									▨	▨		
C.	**Full Phase Testing**										■	■	
	CA. Cold start takeoff										▨		
	CB. Reaches target w/ payload											▨	
	CC. Dispenses upon actuation											▨	

Figure 9.2.1.1: Actual Development and Test Phase as completed by the team during Phase 5

9.2.2 Test 1

This section describes the testing plan, procedure, and results for test 1: Fluid Retention Test. For the complete testing plan and report, refer to appendix C.1 and D.1 respectively.

9.2.2.1 Actual Schedule and Overall Results

This test was conducted during the 27th week of the project, in accordance to the testing plan outlined in section 9.2.1. For a complete testing plan, refer to Appendix C part a.

9.2.2.2 Test Procedures

This section describes the formatted test procedure for validation of the distribution vessel subsystem reservoir fluid retention abilities.

Title:

Reservoir Fluid Retention Test

Purpose:

The purpose of this test is to validate if the reservoir, in its current state, can meet the pre-determined requirement of holding 1 Liter of fluid without any leaks for at minimum 120 seconds. If this is not the case, then rework and development of this feature must ensue.

Approach:

We will approach this test as a simple validation of the requirements set fourth by the team in our initial planning stages. This test may either pass or fail based on how it performs. Failure will result in immediate rework.

Description of Test Article:

This test will pertain to the prototype subassembly of the SAVRRS Distribution system. Figure 1 below shows the CAD model, and the prototype model of what will be tested. This test will use the current prototype in its entire assembled condition.

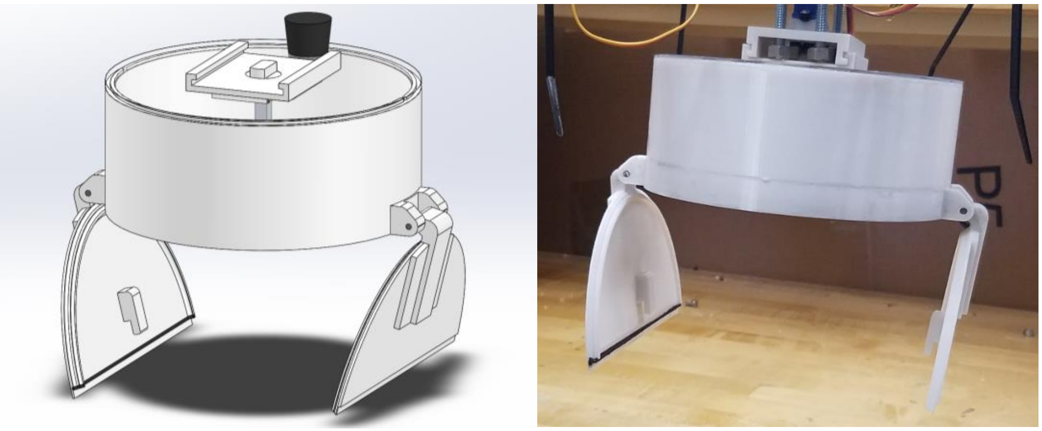


Figure 9.2.2.2.1 CAD Model and Prototype Model of Test Article

Description of Test Set-Up:

The testing setup will involve a member of the team holding the Distribution subassembly by its top slider attachment over a single bucket for containing any leaked water. This is a very simple setup, but it will effectively get the team the data required for next steps. Figure 2 below shows a simple schematic of the test assembly.

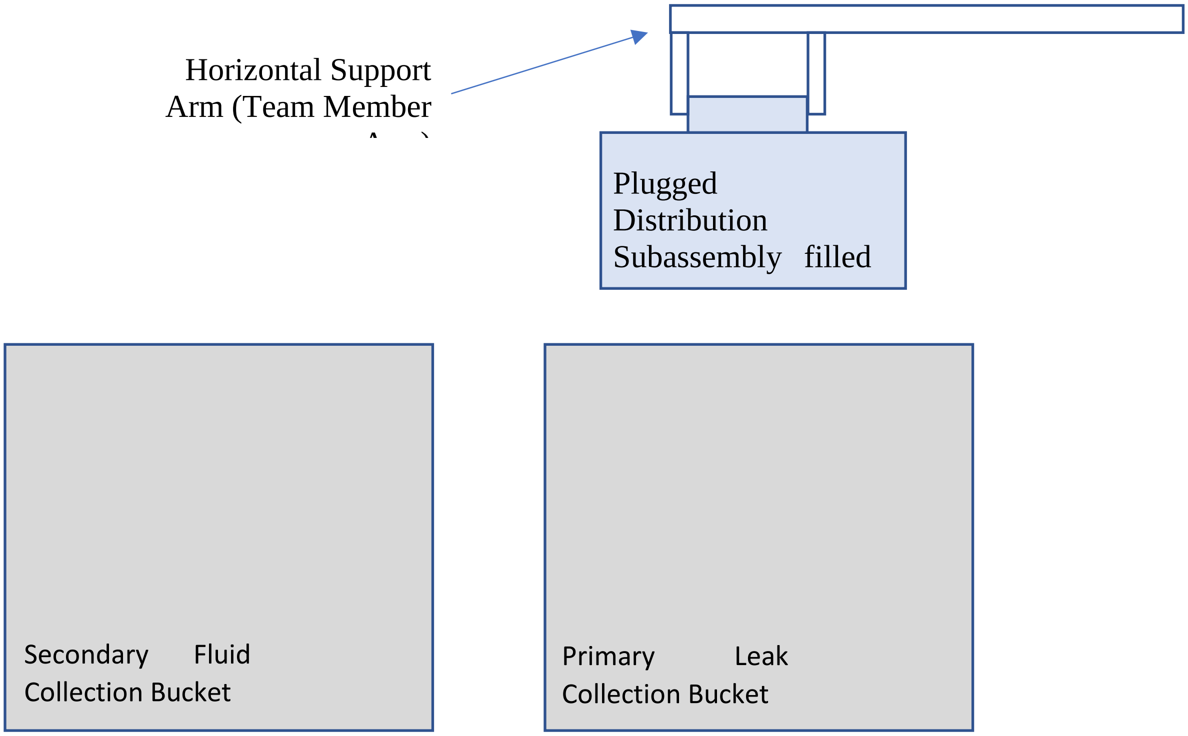


Figure 9.2.2.2.2 Schematic of Test Setup

Environment and Test Conditions:

The environment and conditions for testing are negligible for this test. Since the typical setting in which this product is to be used will be outdoors in a beach environment, the team plans to conduct this plan outdoors under the sun to simulate this, to some degree. Our team does not expect environmental factors to play too big in the retention rate of fluid for our product.

Safety and Provisions:

To ensure a safe testing environment, the team needs to perform the test outdoors and away from busy areas to ensure no leaked fluid will cause a slipping hazard to any passersby. The team needs to also make sure that majority of the fluid is caught by the buckets to similarly avoid any tripping hazards. Additionally, the member holding the distribution system should make sure they are not holding it in a way to cause any strain or unwanted pain in their arms, back, or legs. Since we will be testing this outdoors, it is also important to take normal precautions when dealing with heat and sun rays.

Data Collection Sheet:

The data will be collected in the format outlined in Table 9.2.2.2.1. A series of three trials will be performed, and after the three trials are completed, the average of the three will be taken. Each individual trial, as well as the average, will be judged on a pass/fail basis based on retention of fluid.

Table 9.2.2.2.1 Data Collection Sheet for Fluid Retention Test

	Trial 1	**Trial 2**	**Trial 3**	**Average**
Height of Leaked Water (mm)				
Volume of Leaked Water (m^3)				
Volume of Leaked Water (L)				
Height of Retained Water (mm)				
Volume of Retained Water (m^3)				
Volume of Leaked Water (L)				
Pass/Fail?				

To calculate the total volume of the fluid in either of the cylindrical buckets, use the height of the fluid, and the diameter of the cylindrical bucket. Equation 1 below will allow the use of these two measured parameters to determine the volume of the fluid in m^3.

$$V = \frac{\pi}{4} d^2 * H$$

Equation 9.2.2.2.1

In this equation, V is volume of fluid, d is the diameter of the cylindrical bucket, and H is the height of the fluid sitting at the bottom of the bucket.

Step-by-Step Test Instructions:

1. Close the doors on the distribution subassembly and use the locking block to secure the doors and gasket material.
2. Measure the diameter of the base of the bucket.
3. Holding on to the top of the slider, position the distribution system above a cylindrical bucket so that any potential leaks will fall in the bucket.
4. Set a timer for 120s and begin filling the reservoir with water. Once the reservoir has reached its maximum capacity, plug the fill hole and begin the countdown.
5. After the 120s is passed, quickly and carefully move the distribution system above the second empty bucket.
6. Open the doors of the reservoir and dump all the remaining water into the new bucket.
7. Using a measuring tape, measure the height of both buckets, and record them accordingly in the data table.
8. Safely empty both buckets and perform this experiment two additional times.

9.2.2.3 Test Results

Table 9.2.2.3.1 Completed Data Collection Sheet for Fluid Retention Test

	Trial 1	**Trial 2**	**Trial 3**	**Average**
Height of Leaked Water (mm)	(0 ± 1) mm	(0 ± 1) mm	(0 ± 1) mm	(0 ± 1) mm
Volume of Leaked Water (m^3)	(0 ± 0.00) m^3	(0 ± 0.00) m^3	(0 ± 0.00) m^3	(0 ± 0.00) m^3
Volume of Retained Water (L)	(0 ± 0.05) L	(0 ± 0.05) L	(0 ± 0.05) L	(0 ± 0.05) L
Height of Retained Water (mm)	(20 ± 1) mm	(20 ± 1) mm	(19 ± 1) mm	(19.7 ± 1) mm
Volume of Retained Water (m^3)	(0.001 ±0.00) m^3	(0.001 ±0.00) m^3	(0.001 ±0.00) m^3	(0.001 ±0.00) m^3
Volume of Retained Water (L)	(1.01 ± 0.05) L	(1.01 ± 0.05) L	(0.963 ± 0.05) L	(0.994 ± 0.05) L
Pass/Fail?	PASS	PASS	PASS	PASS

The outcome of this test is that the reservoir in the distribution subsystem can successfully hold roughly 1L of water without any major leaking. Since all our values, as well as the average demonstrated the ability to hold 1L of fluid within one uncertainty level, the overall test is successful. We can reasonably conclude that the reservoir can hold 1L of fluid during a mission for distribution.

For the full report and analysis, refer to appendix D, part a.

9.2.3 Test 2

This section describes the testing plan, procedure, and results for test 2: Actuation Reliability Test. For the complete testing plan and report, refer to appendix C.2 and D.2 respectively.

9.2.3.1 Test Procedures

This section describes the formatted test procedure for validation of the distribution vessel subsystem accuracy.

- Title of the Test: Actuation Reliability Test
- Purpose: Ensure the actuation system works as expected under mechanical actuation (by hand) with no failure or irregularities
- Approach Actuate the actuation system mechanically (by hand) with a normally loaded container (approximately 1L of liquid and stoppered on top filler) and make sure the system functions optimally with no errors.
- Description of Test Article: The subsystem being tested in this test is the actuation system of the container. This includes the actuation system and container.
- Description of Test Set-Up (Diagrams and Schematics):
    - Container was locked using the actuation system and filled with approximately 1L of fluid (water for testing purposes)
    - Container was stoppered to make system watertight
    - Actuation system was actuated mechanically and observed to see if there were any irregularities during actuation or if the actuation system was too tight or starting to fail due to forces acting on it

Figure 9.2.3.1.1 Loading of Container with Fluid for Actuation Reliability Test

- Environment and Test Conditions: There were no special needs for this test. The container was filled to the top using water as the liquid inside and actuated manually and thus required no electrical or physical measurement recording. However, the experiment was carried out outdoors to ensure that the actuation didn't create any spills indoors. Container was loaded to standard operating conditions (1L of fluid)

- Safety Provisions:
    - Water was released into a bucket, so no spills were made
    - Hands were kept clear of hinges and door to prevent any injury

Table 9.2.3.1.1 Data Collection Sheet

Run Number	**Status**

- Step-by-Step Test Instructions:
    - Close the container doors and lock the actuation system
    - Fill liquid to normal conditions and stopper the container
    - Actuate the system mechanically (by hand) and ensure the doors open successfully and follow a smooth motion with no interference
    - Repeat steps 1-3 as needed

9.2.3.2 Test Results

Table 9.2.3.2.1 below shows the completed data collection for the manual Actuation Reliability Test.

Table 9.2.3.2.1 Completed Data Collection Sheet

Run Number	**Status**
1	Pass
2	Pass
3	Pass
4	Pass
5	Pass
6	Pass
7	Pass
8	Pass
9	Pass
10	Pass

As it can be seen from the table above, the mechanical aspect of the actuation system performed very well with no failures. This concluded that the actuation system works as expected and does not need any additional designing or improvements as the system works as expected.

System works well, so don't need to modify the system any further. Would be better to conduct the experiment for a higher number of times with a final product to ensure no fatigue failure occurs in the actuation system.

9.2.4 Test 3

This section describes the testing plan, procedure, and results for test 3: Fluid Impact Time Test. For the complete testing plan and report, refer to appendix C.3 and D.3 respectively.

When considering the reliability of the system, the reservoir played a huge part. An important aspect of the reservoir and actuator system was the ability to disperse the repellent quickly. If the system works and can disperse the repellent, but not within a timely manner, then it fails. For this reason, this test was designed to ensure that the system takes no longer than three seconds to make impact following actuation from a ten-meter height.

9.2.4.1 Test Procedures

The procedure to carry out the Fluid Impact Time Test is as follows:

1. Fill a 3-gallon buck with water for a supply source.
2. Two persons go up to the 10-meter height with the reservoir, 3-gallon bucket of water, and a smaller container to transfer the water from the bucket to the reservoir.
3. A third person stays on the ground level with a timer. Two or three additional persons may stay on the ground floor to clear the premises of passerby.
4. Once at the 10-meter height, lock the doors on the reservoir shut using the actuator system
5. With the reservoir fully closed, transfer water from the bucket to the reservoir. Fill the reservoir completely and close the hole using the rubber stopper.
6. Steadily hold the reservoir by its body over the edge of the 10-meter height, being sure that the doors are not held closed.
7. As one person holds the reservoir as described in step 7, the second person shall count down to verbally alert the person on the ground floor when they are going to release the water.
8. At the count of three, the second person will actuate the system and release the water. At the same time, the person at the bottom starts the timer.
9. The person on the ground level stops the timer when all the water hits the surface.
10. Repeat steps 4 through 9 for nine additional test runs.

9.2.4.2 Test Results

Below is a tabulation of the data collected during the testing phase for the Fluid Impact Time Test.

Table 9.2.4.2.1 Results of the Fluid Impact Time Test

Test Number	**Time (s)**	**Pass/ Fail**
1	2	Pass
2	1.22	Pass
3	1.39	Pass
4	1.98	Pass
5	2.11	Pass
6	1.77	Pass
7	1.83	Pass
8	2.1	Pass
9	1.97	Pass
10	2.22	Pass
Average	1.86	

The reservoir sub-system passed the test for each run. This factor is a bit difficult to measure accurately by hand, so the recorded times had a range of a second in between the shortest and longest recorded time. Nevertheless, every run was under three seconds signifying that the actuation system was quick enough to be implemented in the final design.

9.2.5 Test 4

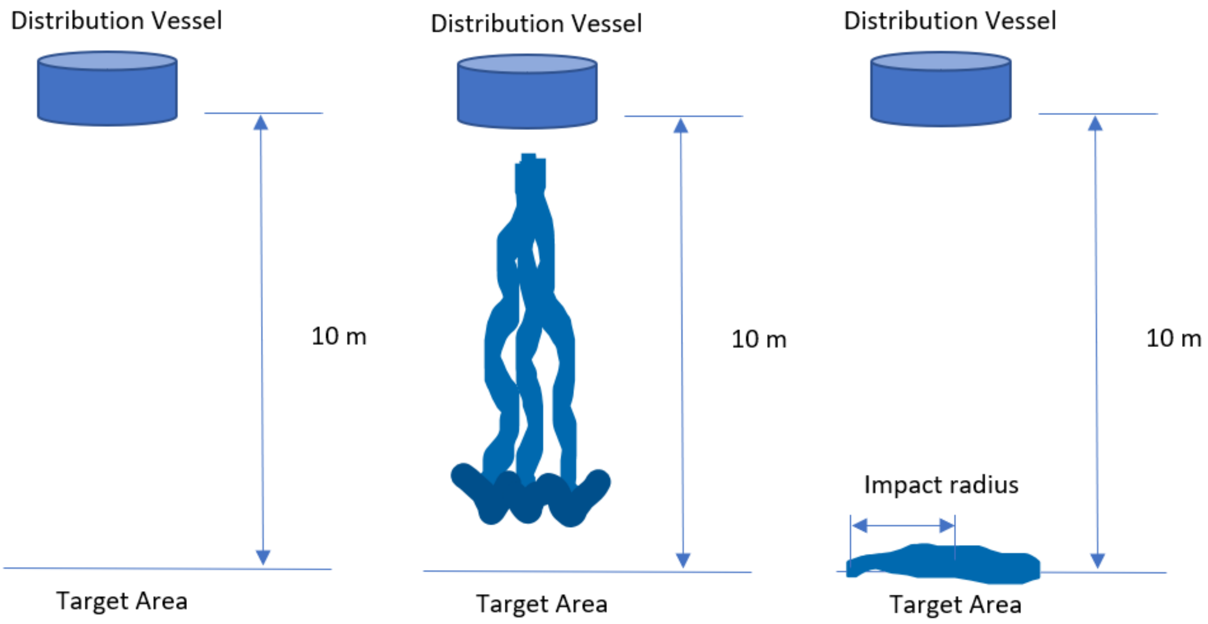
This section describes the testing plan, procedure, and results for test 4: Distribution Accuracy Test. For complete testing plan and report, refer to appendix C.4 and D.4 respectively.

9.2.5.1 Actual Schedule and Overall Results

9.2.5.2 Test Procedures

This section describes the formatted test procedure for validation of the distribution vessel subsystem accuracy.

- Title of the Test: Distribution Vessel & Repellent Impact Radius
- Purpose: The purpose of this test is to validate the accuracy of the distribution vessel from a 10-meter drop height, ensuring that it will be able to impact the water in the area of the shark attack victim.
- Approach: The approach was to conduct a series of tests that would validate the vessel requirement of being able to generate a 1.5-meter target radius from a height of 10 meters. The team would select a location that would provide a 10-meter height and replicate a series of 10 full vessel actuation runs and measure the resulting radius of the distribution impact. Then, the data would be analyzed to validate the customer and engineering requirements for accuracy as outlined in the team Project Plan.
- Description of Test Article: The article to be tested will be the distribution vessel. This does not include the top or bottom slider attachments, nor any UAV component. The subsystem is tested independent of other subsystems to validate individual capability.
- Description of Test Set-Up (Diagrams and Schematics):



Step 1. Set vessel at 10 m. **Step 2.** Open vessel doors. **Step 3.** Measure radius.

Figure 9.2.5.2.1 Distribution Vessel Accuracy Test Schematic

- Environment and Test Conditions: The team researched a drop area on Arizona State University—Tempe campus that would provide a 10-meter drop location below a concrete target area that would be sufficient to test liquid impact. The team would test this under "ideal" conditions, in an area that is blocked from wind or other environmental factors that could skew the data.
- Safety and Provisions: A perimeter around the drop zone will be monitored and secured during testing, with 5 team members observing the area to ensure safe drops are executed. The change from repellent to water, for testing purposes, is also for safety and corrosive protection.
- Data Collection Sheet:

Table 9.2.5.2.1 Data Collection Sheet for Vessel Accuracy Test

Run Number	Diameter 1 (m)	Diameter 2 (m)	Avg. Diameter (m)	Impact Radius (m)	Notes
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
Average					

- Step-by-Step Test Instructions:
    - First, secure and clear drop zone. Secure the trap doors of the vessel by engaging the locking block mechanism at the bottom of the vessel by rotating the actuation rod 90-degrees with the doors shut.
    - Next, open rubber stopper on top polycarbonate lid of distribution vessel and fill container with 1 liter of water. Then, replace the stopper.
    - After container is filled, have spotter (team member at the target zone) do final check to ensure target zone is clear.
    - Team member with distribution vessel then engages actuation rod via actuator for electronic testing, or by rotating the actuation key 90-degrees counterclockwise to open trap doors.
    - After impact, the spotter will then measure the impact radius by measuring the diameter two different directions, averaging those two values, and dividing the resulting average in half for that run's radius value in meters.

Then repeat by re-engaging the trap doors and refilling for the following 9 trial runs.

9.2.5.3 Test Results

Table 9.2.5.3.1 Completed Data Collection Sheet for Vessel Accuracy Test

Run Number	Diameter 1 (m)	Diameter 2 (m)	Avg. Diameter (m)	Impact Radius (m)	Notes
1	1.60	1.55	1.575	0.7875	**Pass**
2	1.50	1.40	1.450	0.7250	**Pass**
3	1.22	1.20	1.210	0.6050	**Pass**
4	1.40	1.44	1.420	0.7100	**Pass**
5	1.47	1.29	1.380	0.6900	**Pass**
6	1.26	1.30	1.280	0.6400	**Pass**
7	1.60	1.40	1.500	0.7500	**Pass**
8	1.47	1.50	1.485	0.7425	**Pass**
9	1.53	1.40	1.465	0.7325	**Pass**
10	1.35	1.35	1.350	0.6750	**Pass**
Average			**1.4115 m**	**0.70575 m**	

The distribution vessel subsystem was manufactured to requirement and has adequate performance measures to validate the team's prototype. The prototype performed up to standards meeting both the quantitative and qualitative requirements set forth by the customer, as well as the team members.

No rework modifications are recommended at this time due to the subsystem's successful performance during the testing and validation phase. The only recommendation is further testing in different environment conditions (i.e. wind and temperature) that would imitate applicational environments in the ocean. These tests were conducted under ideal conditions to primitively validate the overall functionality of the device but are not sufficient for real world application. With additional time and budget, the team recommends further testing and development to advance the prototype's credibility for final product.

9.2.6 Test 5

This section describes the testing plan, procedure, and results for test 5: Take-off Capability Test. For complete testing plan and report, refer to appendix C.5 and D.5 respectively.

9.2.6.1 Test Procedures

The following is the step-by-step test procedures for the Take-off Capability Test.

- *Test Number*: UAV1
- *Features to be tested*: Take-off capability, & in-flight stability during take-off.
- *Acceptance Criteria*: 1m/s > maximum vertical flight speed, and 15 degrees > of deviation in pitch, roll, & yaw relative to the plane of flight (parallel with the ground for roll and pitch, and initial facing direction perpendicular to flight plane in line with the axis running front to back on the UAV for yaw)
- *Expected Results*: Successful and stable take-off within desired parameters
- *Test Conditions*: 5-40 degrees C, 10 m/s < wind speeds
- *Test set ups and test rigs*: (4) 0.5 kg mass drums to simulate fully loaded UAV
- *Summary of Test Procedures*:
    1. Using the nylon zip-ties and the Velcro straps purchased for the project fix the mass weights to the bottom of the UAV on the available slots of the Aluminum bottom plate.
    2. Power on Lap-top and load Ardu-Pilot Mission Planner software.
    3. Connect battery power to UAV and power on the flight board and radio receiver.
    4. Establish connection to radio receiver and telemetry from hand held radio. Confirmation will display on hand held radio and Mission Planner software.
    5. Confirm GPS and Mav-link connections in software and on hand held radio.
    6. Clear area of unnecessary people and double check surrounding area for and potential hazards.
    7. Perform test by initiating take-off with the hand held radio toggles and achieve and altitude of 3 m inside of the previously mentioned constraints.
    8. Record results from the Mission Planner software flight monitoring.

Repeat test for a total of 10 instances.

9.2.6.2 Test Results

Table 9.2.6.2.1 below shows the results of the takeoff capability testing during our testing and validation phase.

Table 9.2.6.2.1 Test Results for Takeoff Capability Test

Test Name	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
Max Pitch	< 10 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg
Max Roll	< 10 deg	< 10 deg	< 10 deg	22 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg
Max Inst. Accent	1.9 m/s	1.5 m/s	2.3 m/s	3.2 m/s	1.4 m/s	1.7 m/s	1.8 m/s	1.6 m/s	1.8 m/s	1.7 m/s
Max Inst. Descent	3.7 m/s	3 m/s	3.6 m/s	4.1 m/s	4.3 m/s	3.7 m/s	3.2 m/s	2.9 m/s	3.5 m/s	3 m/s
Altitude	8m	8m	8m	8m	8m	8m	8m	8m	8m	8m
Pass/Fail	**PASS**	**PASS**	**PASS**	**PASS**	**PASS**	**PASS**	**PASS**	**PASS**	**PASS**	**PASS**

*****The isolated 22-degree deviation was caused by a snag on the grass in the take-off area, not actual equipment difficulty.

Description of Data Reduction Analysis: Data was collected straight from Mission Planner software

Results: Test was successful. There was an instance of out of bounds values being recorded, but it was due to environmental influence and not device capability

Conclusions: Test Successful

Recommendations: Make sure take off area is free of long grass and potential horizontal impairments to the landing legs during take-off

9.2.7 Test 6

This section describes the testing plan, procedure, and results for test 6: Sustain Payload Test. For the complete testing plan and report, refer to appendix C.6 and D.6 respectively.

9.2.7.1 Test Procedures

The following are the procedures to be completed during this test:

1. Find an empty area for safety purposes.
2. Weight the UAV without vessel and fly it to check the motors.
3. Add the empty vessel to the UAV and weight it, then fly the UAV to check it with the additional weight.
4. Add a little of liquid to the vessel and weight the UAV, then fly the UAV to check if it is able to carry that additional weight.
5. Fill the vessel with water and weight it, then fly the UAV with the max weight for 10 m height and check if the UAV able to carry this weight.
6. Repeat step 5 for nine additional runs.

9.2.7.2 Test Results

Table 9.2.7.2.1 shows the simple pass vs fail data collected from the testing of our payload sustainability test.

Table 9.2.7.2.1 Sustain Payload Test Data Table

Run	UAV Weight	Status
1	4.5 kg	PASS
2	4.5 kg	PASS
3	4.5 kg	PASS
4	4.5 kg	PASS
5	4.5 kg	PASS
6	4.5 kg	PASS
7	4.5 kg	PASS
8	4.5 kg	PASS
9	4.5 kg	PASS
10	4.5 kg	PASS

- Description of Data Reduction Analysis: Simple pass/fail of flight capability

- Results: Test was successful.
- Conclusions: Test Successful, no recommendations for improvement

9.2.8 Test 7

This section describes the testing plan, procedure, and results for test 7: General Distribution Vessel and UAV Test. For complete testing report, refer to appendix D.7.

9.2.8.1 Test Procedures

Testing procedure for UAV

- Choose the suitable testing ground for UAV testing. Where is at least 5 miles away from airport. Also keeping away from emergency responders, near stadiums, sports events or groups of people.
- Make sure all wire connection is correct before attaching battery to UAV.
- Turn on the radio first. Then turn on the UAV to make sure it connects to radio correctly.
- Once it connects to radio correctly, spin the motor (not including propeller). Make sure all the radio signals and channels work correctly. In this process, the rotation of front two motors has to be rotate opposite direction each other. The rotation of diagonal motors has to match the direction. For SAVRRS default setting that front right motor and rear left motor would be rotate counter clockwise direction. Front left motor and rear right motor would be rotate clockwise direction.
- Once all the rotation tests are done, attach the propeller on each corresponding motor.
- For stability testing, the team will fly the UAV 1 meter above the ground and landing back for 5 trial. In each process, the team will observe if the UAV is drifting.
- Once the stability test is done, the flight time test will be performed. The goal of the project is to fly the UAV 30 minutes continuously. Charge the battery until 100% complete. Then team will fly UAV for about 10 minutes above 3 meters and will measure the battery to calculate maximum flight time.
- Set two points A and B on the ground. The distance between two points will be 500 meters. The pilot will start from the point A and the team member(s) will wait at point B. The UAV will start from point A to B and return to point A. Repeat 5 times for this testing.
- During the range testing, the team will record the time taken between each points and form that, velocity of the UAV will be calculated.
- Connect the container fill with water (which is 1.459 kg by measured during testing) to the UAV. The total weight is approximately 3.5 kg. The team will fly the whole system for about 3 minutes to test the SAVRRS's payload.
- Expected results of the UAV will be list in the following
    - Flight time = 10 minutes.
    - Range = 500 meter.
    - Elevation = 10 meter.
    - Payload = 3.5 kg.

Testing procedure for Repellent Container

- Collect the empty bucket which is going to use in leaking test.
- Close the trap door of the repellent container and lock by turning the key by hand.
- Fill the water and put the rubber stopper. Make sure everything is sealed correctly.
- Hold the repellent container from the body without touching the trap door. Wait until 2 minutes to observe the any dripping from the trap door. Repeat this process for 5 times.
- Measure the height from where the repellent container will release water. The expectation height of the team is around 10 meters.
- One team member will hold the container from 10 meters height and another team member will release the water by turning the key my hand.
- Record the time taken the water to reach the ground.
- Measure the water splash from the ground in x and y direction. Then calculate the diameter of water splash. (Concrete ground will be better suitable for this testing).
- Repeat this testing for 10 trials. Then calculate the average diameter of water splash.

9.2.8.2 Test Results

There are two separate tests for our project, which include UAV test and repellent container test. Pairing between radio controller and UAV system, flight stability, flight time, flight range, flight payload tests were performed in UAV test. The following table is shown the results of the UAV system under various features.

Table 9.2.8.2.1 The Data of UAV Testing.

Features to be tested	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Status
Radio Control Connection	Pair	Pair	Pari	Pair	Pair	Pair	Pass
Flight Stability [drifting in meters within a minute]	2.8	3.2	3.3	2.7	2.4	2.88	Acceptable
Flight Time [minutes]	8.8	8.7	9.1	9.4	9.3	9.06	Acceptable (Scaled)
Flight Range [m]	200	200	200	200	200	200	Pass
Flight Speed	8.2	8.3	8.0	8.1	8.3	8.18	Pass
Flight Payload	4.5	4.5	4.5	4.5	4.5	4.5	Pass

Conclusion

During the flight test, the UAV was a little drifting to the right about 2.8 meters within a minute. It can cause from the cross wind during flight test. But we can fix that by calibrating GPS auto stability module. The connection between radio controller and UAV pair perfectly in each run. Since the UAV was flying acceptable stability and balance, all the motor rotation and synchronizing between each motor were working correctly. With 6600 mAh battery with full payload, the UAV could fly about 9 minutes which is acceptable for scaled battery requirement. That can be solved by upgrading the higher capacity battery. Flight range, flight speed and flight payload qualified as the team goal.

10. Requirements Validation

When the prototype manufacturing was completed, our team have put together a validation matrix to illustrate each requirement fulfilment. Each prototype requirement is listed in table 10.1 in the validation matrix that shows the status whether it has been completed or still in progress. Also, it will conduct the method of validation for each requirement.

Table 10.1 Requirements Validation Matrix

No.	Prototype Requirement	Method of Validation	Status
1	Storable in 2.5 m x 2.5 m x 2.5 m lifeguard tower	Analysis	Complete
2	UAV capable of flying with 4.5 kg of additional weight	Analysis and Testing	A: Complete T: Complete
3	Repellent reservoir can hold 1 liters of liquid	Analysis	Complete
4	Flight time to be less than 45 seconds. Flight time is equal to cold start, fly 100 meters offshore, and drop payload	Analysis and Testing	A: Complete T: Complete
5	Time from actuating drop-sequence to surface impact of full payload less than 3 seconds	Demonstration	Complete
6	Drop payload within 1.5 m radius	Analysis and Testing	A: Complete T: Complete
7	Drops payload within 1.5 m of designated target 98% of trials	Analysis and Testing	A: Complete T: Complete
8	Material and manufacturing costs less than $700	Calculations	Complete
9	Operate and carry payload using a 6600 mAh power supply, and minimize the power needed to actuate disbursement	Analysis	Complete
10	Maintain 25 km/hr with payload to satisfy response time requirement	Analysis and Testing	A: Complete T: Complete

11	Hover 10 m above drop zone	Demonstration and Testing	D: Complete T: Complete
12	Fly with payload 15 m above sea level	Analysis and Testing	A: Complete T: Complete
13	Operate between 10º C and 40º C	Demonstration	Complete
14	Operate above sea level	Demonstration	Complete
15	Withstand sand and saltwater corrosion, to operate without repair for 6-months	Inspection	Complete
16	Someone can be trained to use device within 8 hours of training and is intuitive operation	Testing	Complete
17	UAV allows for guards on the outer 90º of blades to be protected from contact	Demonstration	Complete
18	Design and production must be accomplished within 6 months with 7-team members	Demonstration	Complete
19	Power supply can allow for 20 minutes of flight without recharging	Analysis and Testing	A: Complete T: Complete
20	Disbursement system comprised of less than 5 components, to reduce failure probability	Demonstration	Complete

10.1 Requirements Validation Plan

For each requirement listed in table 10.1, a test has been performed. Based on the results of that test, it may pass of fail. If the test has passed and the requirements was met, the team will move on. On the other hand, if it fails, our team will reconsider the situation and try to meet the requirement.

10.2 Validation Results

A more detailed information is being described in the two sections below. Section 10.2.1 will explain requirement 1: Storage Box along with section 10.2.2 that covers requirement 2: Capability of flying with weight and so on.

10.2.1 Requirement 1 Validation

Requirement: Storable in a $2.5m^3$ storage area.

For this to be validated, the team have designed a box with specific dimension to store the UAV while not in use. The box size is designed to be 2.5m x 2.5m x 2.5m.

10.2.2 Requirement 2 Validation

Requirement: UAV capable of flying with 4.5 kg of total weight.

This requirement is very important, we have validated this through our analysis that this UAV will be capable of flying when we add the additional weight of the shark repellant liquid. The analysis show that the motors are powerful enough to lift the UAV.

10.2.3 Requirement 3 Validation

Requirement: Repellent reservoir can hold 1 liter of fluid without any leaks.

This requirement was validated via testing an analysis. Experiment number DS1 tested the ability for the distribution system assembly to hold one liter of fluid without any leaks for two minutes. The result of our testing is that the fluid reservoir is sufficient for holding almost exactly one liter of fluid. More information on this experiment and its results is found in section 9.2.2.

10.2.4 Requirement 4 Validation

Requirement: Total mission time of less than 45 seconds.

From VOC data received from interviews, it was determined that the UAV would need to reach a victim located 100 meters offshore within 45 seconds of initiating operation. Giving 5 seconds of cold start up from the UAV, and another 5 seconds for deceleration at the location of the victim, that resulted in a total of 35 seconds to reach the 100-meter target. This meant that the UAV would need to sustain an average velocity of at least 2.85 meters per second to reach the victim’s location within the allotted time.

This requirement was initially met from the power analysis conducted supplied from the battery source during the early stages of Preliminary Design, with considerations made of the additional payload. Physical testing was conducted and this requirement was met very well, with speeds of greater than 8 m/s

10.2.5 Requirement 5 Validation

Requirement: Three second or less drop sequence from start of actuation to surface impact.

This requirement was set by the team to ensure that the system was quick and efficient enough to disperse repellent to a person in need. To properly assist the patron, the system must take a minimal amount of time to make impact following actuation. The requirement was met during validation testing of the reservoir prototype. Based on the data from the Fluid Impact Time test seen in section 9.2.4, this requirement was fulfilled by the SAVrRS system. For each test run, the fluid made surface impact in under three seconds when released from a 10-meter height.

10.2.6 Requirement 6 Validation

Requirement: Payload spread at least 1.5m radius from UAV center.

This requirement was intended to validate the overall accuracy of the distribution vessel from a 10-meter drop height. The team set a standard of disbursing the repellent over an impact radius of no more than 1.5 meters to ensure a concentrated amount of repellent would land near the victim’s location.

The team conducted a series of 10 trial runs of the distribution vessel accuracy from a height of 10 meters during test number DS4. The test resulted in all 10 trial runs passing the validation requirement with an average impact radius of 0.7358 meters, well below the target radius of 1.5 meters.

10.2.7 Requirement 7 Validation

Requirement: Drop payload within a 1.5m radius of the victim.

In addition to the distribution accuracy and impact radius, an additional related requirement was the precision of the accuracy. Therefore a 98% confidence interval was assigned to the 1.5-meter impact radius. From the data that was collected, it was determined that the prototype returned an impact radius of 0.706 ± 0.048 meters for a 98% confidence interval (2-tailed). These results were well within the desired dimension of accuracy requirements. Thus, this data analysis from the validation testing resulted in a completed requisite of the prototype precision.

10.2.8 Requirement 8 Validation

Requirement: Material and manufacturing cost less than $700.00.'

As it can be seen from Table 10.2.8.1 below, the team managed to stay under a budget of $700 for prototyping purposes. While some parts were purchased from the personal budget of team members and some components were already purchased items from team members, the team was able to stay under $700.

For more information on this requirement, refer to section 11.4

10.2.9 Requirement 9 Validation

Requirement: Operate and carry a payload using a 6600mAh power supply.

The design of the UAV is to carry the total of 3.5 kg payload and reach to destination. The possible maximum distance between the lifeguard tower and the victim is about 100 meters. The expected average velocity of the UAV is around 7 m/s and the average targeted flight time is less than 30 minutes. The main power usage of UAV is its four motors which are 355W each.

Testing was conducted, and the average speed was 8.2 m/s, greater than the anticipated 7 m/s. The flight time was anywhere between 8-9 minutes on the 6600 mAh which when scaled up to a 16000 mAh, or 20000 mAh battery will stay airborne for approximately 30 minutes.

10.2.10 Requirement 10 Validation

Requirement: Maintain a 25 km/hr flight speed.

Nowadays, the average velocity of most aerial photography quadcopters is around 70 km/h. However, the design of SAVRRS is to carry repellent container in which there is liquid shark repellent. Since speed and stability are inversely proportional, the team considered the velocity of SAVRRS around 25 km/h for the best ratio between velocity, payload and stability. The expected range between lifeguard tower and victim is around 100 meters. Therefore, the SAVRRS can reach to the victim within 14.3 seconds theoretically.

Average velocity during range test was 8.2 m/s which is well beyond the stated need of approximately 7 m/s.

10.2.11 Requirement 11 Validation

Requirement: Hover about 10m above drop target.

The capability to hover above the target is crucial to the delivery of the repellent to the intended area. The UAV must stay within the general 3 m area to properly loiter and dispense repellent. This test was conducted and the UAV was able to drift less than 3 m (average 2.88) and maintain a constant altitude of 10m +/- 1 m. This test was successful.

10.2.12 Requirement 12 Validation

Requirement: Fly with payload 15m above sea level.

Testing has been concluded and the UAV can fly at a constant altitude anywhere between 3m to 125m above surface level.

10.2.13 Requirement 13 Validation

Requirement: Device can operate within the temperature range of 10°C and 40°C

Although this requirement was not explicitly tested on, given the thermal properties of the selected materials, as well as the outdoor tests performed, we can conclude that our device does indeed work within this range. Further extensive testing may be required to fully validate this condition at its extremes. We do know that the device can operate in a comfortable level between these extrema.

10.2.14 Requirement 14 Validation

Requirement: Operate above sea level.

The operational capabilities were originally suggested by the voice of customer interviews for the anti-corrosion and overall longevity of the device during its operation at sea level conditions. At this time the prototype is believed to be able to operate at sea level conditions without environment impedance. Although some component materials have changed over the course of the design process prototype, it has been built to sufficiently validate the functionality of the device before fatigue or corrosion begins to affect the capabilities of the subsystems. Therefore, no specific/independent testing was needed to validate this requirement.

It should be noted that the anti-corrosive material would be implemented for final production devices to ensure longevity at sea level conditions.

10.2.15 Requirement 15 Validation

Requirement: Withstand corrosive environment of the beach atmosphere.

During the designing phases of the SAVRRS device, the team made sure to select materials resistant to corrosion from beach environments. For example, ABS and Polycarbonate are both resistant to humidity, abrasion from sand and are inert to salts present in coastal areas. In addition, the metals used, stainless steel and aluminum, are capable of resisting corrosion. For the final device going into customer availability will be more resistant to elements by coating the metals with a corrosion resistant layer and finishing the polycarbonate and ABS to have a more refined surface.

As the materials used for the prototype are enough to resist against the elements and the final product has more capability of resisting the elements, requirement 15 has been validated and the SAVRRS device is resistant to sand and saltwater corrosion.

10.2.16 Requirement 16 Validation

Requirement: Ease of use, allowing ease of training and pick up and go flight ability.

This validation is straight forward, each team member will be able to operate, fly and land the UAV. This is because how simple the controls are. The simplicity of this device is meant to be easy to satisfy our customer requirement.

10.2.17 Requirement 17 Validation

Requirement: UAV allows for the placement of guards around propellers for safety.

The original requirements called for at least 90-degree blade protection from the propellers mounted on top of the UAV system. Due to budget and time constraints that the design process presented, this requirement was not met by the prototype manufactured. To meet more critical components incorporated in the project, this non-functional enhancement was left out of the final prototype design. The team has outlined plans for blade protection to be implemented in the final production model in this report.

10.2.18 Requirement 18 Validation

Requirement: The product design must be completed within 8 months of the start of the project.

As MEE 488 started in August 2018 and MEE 489 ends in April 2019, it can be concluded that a team of 7 mechanical engineers successfully concluded the design and production of the SAVRRS device within the allocated 6-month time frame provided to the team.

Within this time, the team was able to research the problem at hand, analyze viable solutions, conduct trade studies to select the best option, develop the device, improve the device and manufacture the device with future recommendations for final manufacturing. This successfully concluded requirement 18 as Team ATS was able to complete the project at hand within the timeframe provided, with the budget and resources available and 7 members in the team.

10.2.19 Requirement 19 Validation

Requirement: Power supply can allow for 20 minutes of continuous flight without recharge.

The power supply that we currently are operating with (6,600 mAh) will not meet the twenty-minute flight time requirement. It was only due to budgetary constraints that a larger, (>10,000 mAh) power supply could not be implemented. In any commercial production the larger battery power supply would be used and would be successful in this requirement.

10.2.20 Requirement 20 Validation

Requirement: Disbursement system composed of a maximum of 5 parts to prevent critical failure.

This requirement was fulfilled by the team during the design phase. The disbursement system was designed to be composed of three parts: the actuation shaft, locking block, and key. With only three parts, the team lessened the probability of the system’s failure by lessening the amount of parts that could fail.

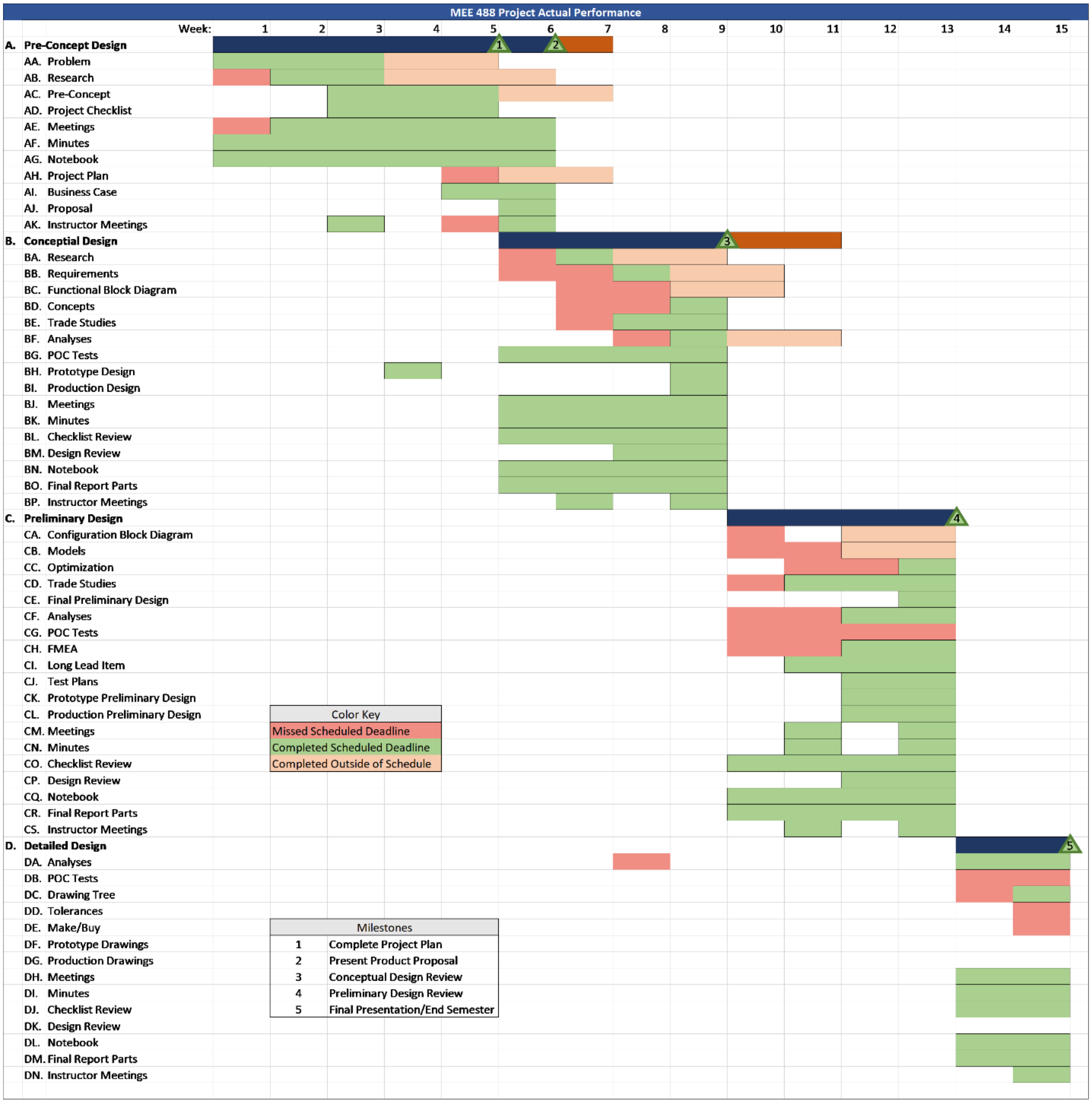
11. Project Performance

In the pre-concept phase of the IPDS process, the team made an approximate team schedule, labor budget, and a series of deadlines and goals to be met over the course of the entire project. Since the team has completed the project, it is a good idea to look back at the original planning documents and compare them to the actual team performance. This section will take the opportunity to look back at the pre-conceptual design planning documents and compare and discuss the variation from the actual team performance.

11.1 Final Program Schedule

Gantt charts are effective tools for determining and visualizing the timeframe and tasks to be completed over the course of an entire project. During the first phase of our project, we created a Gantt chart to outline the timeframe for the various necessary project tasks. As is typically the case, our team was unable to strictly follow the idealized Gantt chart schedule. Figures 11.1.1 and 11.1.2 show the actual completed Gantt chart timeline. For the pre-conceptual idealized Gantt charts, refer to figures 3.2.8.1 and 3.2.8.2 in section 3.

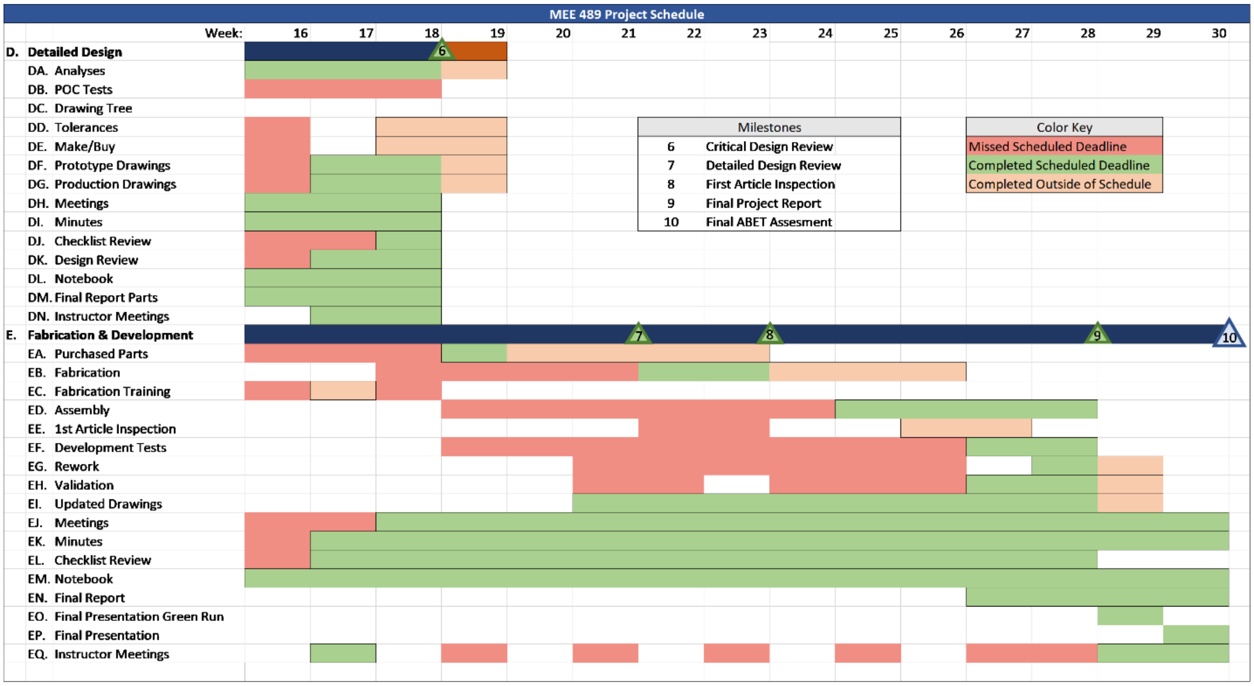
A note when interpreting figures 11.1.1 and 11.1.2 is that the completed tasks are color coded based on completion. The tasks indicated by red are missed tasks that were not completed according to schedule. Tasks indicated by green are tasks completed on time and according to the schedule. Tasks indicated by orange are tasks that were completed beyond the allotted schedule. This is essential in understanding the actual team performance.



Color Key
🟥 Missed Scheduled Deadline
🟩 Completed Scheduled Deadline
🟧 Completed Outside of Schedule

Milestones	
1	Complete Project Plan
2	Present Product Proposal
3	Conceptual Design Review
4	Preliminary Design Review
5	Final Presentation/End Semester

Figure 11.1.1 Completed Gantt Chart for MEE 488



MEE 489 Project Schedule

Week: 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

D. Detailed Design
- DA. Analyses
- DB. POC Tests
- DC. Drawing Tree
- DD. Tolerances
- DE. Make/Buy
- DF. Prototype Drawings
- DG. Production Drawings
- DH. Meetings
- DI. Minutes
- DJ. Checklist Review
- DK. Design Review
- DL. Notebook
- DM. Final Report Parts
- DN. Instructor Meetings

E. Fabrication & Development
- EA. Purchased Parts
- EB. Fabrication
- EC. Fabrication Training
- ED. Assembly
- EE. 1st Article Inspection
- EF. Development Tests
- EG. Rework
- EH. Validation
- EI. Updated Drawings
- EJ. Meetings
- EK. Minutes
- EL. Checklist Review
- EM. Notebook
- EN. Final Report
- EO. Final Presentation Green Run
- EP. Final Presentation
- EQ. Instructor Meetings

Milestones	
6	Critical Design Review
7	Detailed Design Review
8	First Article Inspection
9	Final Project Report
10	Final ABET Assesment

Color Key
🟥 Missed Scheduled Deadline
🟩 Completed Scheduled Deadline
🟧 Completed Outside of Schedule

Figure 11.1.2 Completed Gantt Chart for MEE 489

The Gantt charts shown in figures 11.1.1 and 11.1.2 indicate that the team had some difficulties staying on schedule, despite the planning. Many of the discrepancies between the scheduled and actual completion can be largely credited to the team's lack of experience with the IPDS process going in to the project. Additional obstacles and performance issues do also exist. Further discussion on variance and discrepancies is found in section 11.3 below.

11.2 Actual vs. Budgeted Labor

During the pre-concept phase of the project, the team determined an approximate labor budget for how many hours the entire project should take. Throughout the course of the project, the team also recorded the actual hours spent towards the project throughout each week. The result of these two data sets is the Actual vs Approximated labor chart found in figure 11.2.1.

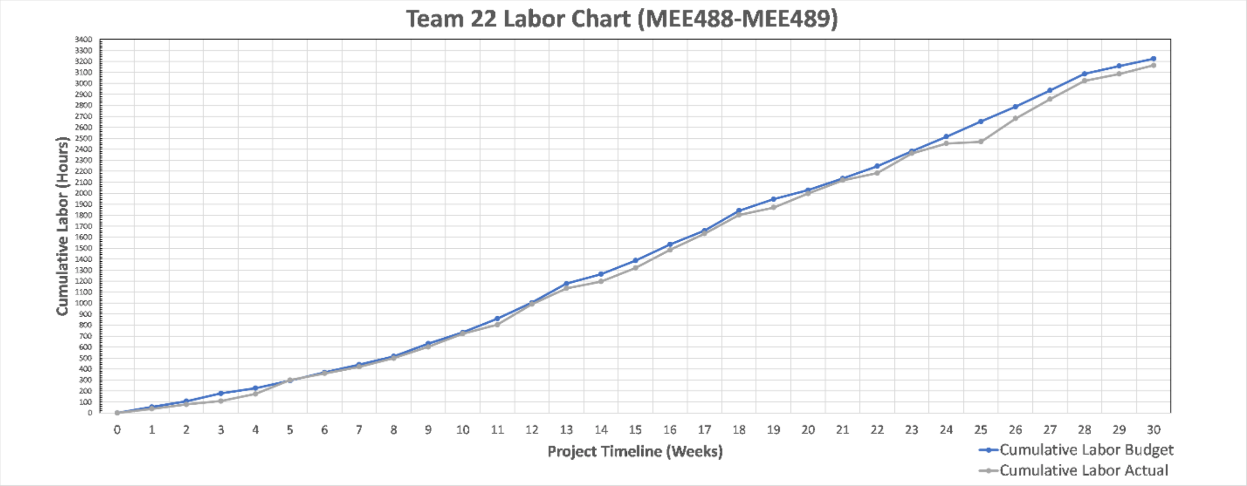


Figure 11.2.1 Final Labor Chart for MEE 488/489

Figure 11.2.1 shows that there is variation between the budgeted and actual labor spent towards the project. The curves show that the team generally followed the expected labor each week, but ultimately fell a bit short of the actual expected labor output. For a bit of reference, the team anticipated that for 100% completion, 3224 labor hours were required in total. Ultimately, the team put in 3164 total labor hours, which is 98.1% of the budgeted hours. Further discussion on variance between actual and budgeted labor is found in section 11.3.

11.3 Variance Discussion

Sections 11.1 and 11.2 both discuss the team's effort in scheduling and planning in the pre-conceptual phase of the project. This was done using Gantt charts and approximate labor loading diagrams (more info on this in sections 3.2.8 and 3.2.9). As is shown in figures 11.1.1, 11.1.2, and 11.2.1, the team did not perfectly follow the planned schedule and labor requirements. This discrepancy did not result in a failed project; however, it implies that there were obstacles and team issues encountered during the process which resulted in missed deadlines and loss of anticipated labor.

Referring specifically to the Gantt charts in figures 11.1.1 and 11.1.2, there is a trend seen that the team did not put as much effort into certain tasks on the front end, and as a result either completed the task on time with additional required efforts or missed the deadline entirely and had to compensate behind schedule. This trend occurred regularly throughout the entire project. A couple of specific examples of this is in the pre-conceptual phase of the project. Initially, the team had difficulty determining the exact problem that we wanted to tackle, and as a result we spent more time than expected in the problem and research phase. A few ideas that the team considered tackling were deemed unreasonable and scrapped on the front end due to perceived difficulties by the team. This is the primary reason for the discrepancies found in the pre-conceptual phase shown in figure 11.1.1. Additionally, in figure 11.1.2, the team encountered issues in the fabrication and development phase which resulted in many missed tasks and deadlines. Specifically, the manufacturing of some parts took much longer than anticipated, this resulted in team drawbacks due to inability to assemble, test, and develop our prototype. Part of this problem was due to poor planning on ordering parts and materials, but a greater part is due to machine shop difficulties resulting in delays. Although this problem could have been fixed by better panning and anticipation of issues, the team did not take the necessary precautions.

The overall project schedule shows that although the team did miss some critical opportunities and scheduled tasks, the project was still completed on time and to the best ability of the team given the constraints and resources. One thing to notice about the project plan is how consistently the team met for team meetings, minutes, and notebook compilation. This was one strong spot of A.T.S. systems. We regularly met, discussed tasks, assigned roles, and planed for deadlines due dates etc. The result of this was a greater sense of team unity, increased team mood, and higher level of accountability.

For the labor chart, there is minor discrepancy between predicted vs actual labor hours spent on the project. Figure 11.2.1 shows the variation between budgeted and actual labor. In general, the team spent less labor hours towards the final project than expected. This can be seen as both a good and a bad thing for the project completion. It is good, in the sense that the team over budgeted, and did not expend our labor to complete the project. It can be perceived as bad, on the other hand, since the team expected to put more work into the project, but did not in some areas, resulting in project aspects that may be lacking, or seem incomplete to the best of our ability.

One area on the labor chart that can be discussed are weeks 24 and 25. Notice how the actual labor spent between these two weeks is quite insignificant in comparison to the rest of the chart. This is primarily due to the manufacturing drawbacks discussed earlier. The team hit a wall that week, which prevented us from progressing significantly as we moved forward. Notice, however, that the following week the team spent almost double the expected additional labor in order to catch up to the budget. This extra push to complete the tasks before the deadline truly helped the team stay close to the expectations set in the pre-concept design phase.

Even with the discrepancies in both the labor and Gantt charts, the team was still able to overcome and complete the project to the best of our ability by the assigned due date. Variation found between the budgeted and actual schedules are accounted for. The team has overcome despite these sources of variation.

11.4 List of Material Expenses and Funding

Table 11.4.1 shows a list of all items purchased for the SAVRRS project.

Table 11.4.1 Bill of Purchased Materials

Component	**Actual Price**
Carbon Fiber Propeller 14*5.5	$24.92
Pix-hawk 2 CUBE Flight Control Module	-
SW0250MG - Waterproof Micro Digital Servo .11/69@6V	$27.99
3510-350kV Carbon Case multi-rotor brushless motor	$160.40
Multi-Star 30A Brushless ESC 32 bit 2-6s	$39.96
6s 12c 6600 mAh Turnigy Lipo-pack w/ XT90	$82.70
Pix-Hawk 2 900MHz Telemetry Antennae	-
5.8GHz 200 mW Transmitter/Receiver & RC-FPV 800 TVL	-
LED Screen	-
Remote Controller	-
Gasket	$15.09
Camera	$0.00
Passivated 18-8 Stainless Steel Pan Head Phillips Screw, 1/4"-20 Thread, 1" Long (91772A542)	$17.52
Hex Nut (90762A112)	$26.85
18-8 Stainless Steel Socket Head Screw, 1/4"-20 Thread Size, 2-1/2" Long, Fully Threaded (92196A821)	$10.00
Velcro Straps	$9.18
Black UV Stabilized 12" Nylon Cable Ties	$7.78
Polycarbonate Sheet	$16.17
3D Print Cost	$100.00
ABS Filament	$20.00
Stainless Steel Rod (for hinge)	$2.70
Square Rod for Actuation System	$1.16
Square Hollow Aluminum Rod	$7.77
Aluminum Sheet	$31.56
Fiberglass Rod	$5.00
Additional Screws	$4.00
Tax	$3.85
Shipping	$56.16
Total Price	**$670.76**

Most of the budget came from Arizona State University for the SAVRRS project. ASU gave Team ATS $700 to put towards the project and almost all this money was utilized by the team to manufacture the prototype. As it can be seen, some of the items were already in the possession of Team ATS Systems (denoted by – in the table) and there wasn’t any monetary funding required for the prototyping phase of the device. In addition, some of the monetary prices listed above were also by individual team members and were not reimbursed in order to save more money for final report printing and team poster printing purposes.

Overall, the team was able to stay on track with budget and the team was prepared to put in funds by hand to complete the SAVRRS device. To reiterate, most of the budget came from Arizona State University with a few purchases by team members personal funds and items the team already had in possession.

11.5 Key Lessons Learned

The MEE 488/489 capstone project resulted in many lessons learned for the individual team members as well as the group as a whole. After completion of the project and validation, the team conversed and decided on four main lessons that will be beneficial to our future careers as professional engineers: organization, budget and time allocation, IPDS process, and hands-on experience.

First and foremost, the organizational focus of the project was a keystone in the operational success during the project completion. Every aspect required organized communication and verification between team members to ensure that each responsibility was fulfilled to the standard of the team. The numerous steps, processes and procedures followed dictated success or failure of the team requiring organized efforts from the initial design phases to the final execution of the project.

Budget and time allocation were essential due to the condensed resources the team was allotted. Given the short time and small budget the team was given to complete the project requirements, each member was required to be resourceful and clever in their individual efforts for maximum output. The team’s overall ambitions to create an entire UAV device from scratch, in addition to manufacturing a separate distribution subsystem required strict adherence to deadlines and finite budget limits. The overall success of the project was largely attributed to the lessons learned from this particular aspect of project completion.

Experiencing the IPDS process was also key in the development of the team members over the course of the two semesters. Completion of each of the five individual phases also contributed to the aforementioned lesson of deadline assurance. The layered phases facilitated quick turn around in between project milestones and encouraged team members to avoid delays at all compensation. The sum of the diverse skills set contributed from each team member led to a greater overall result than would have been otherwise expected from a group of team members from a similar background. This led to the understanding of the importance of diversity in skill sets for each project team.

Lastly, the hand-on experience was incomparable in worth for engineers preparing to enter the workforce. The manufacturing and fabrication processes that were carried out during the final phase of the capstone project provided the opportunity to take analytical understand from previous course and apply them in a real-world situation. The team benefitted from the construction and assembly from both subsystems; requiring hand-operated tools (i.e. drill press, bandsaw) as well as automated machinery (i.e. 3D printing, CNC). These functional skills can be utilized for both personal and professional betterment in future opportunities.

12. Project Conclusion

Team ATS started to design and manufacture the SAVRRS device to respond to shark attacks to give life guards a safe environment to extract a victim from the water by giving them a safe window to work with without the lifeguards getting attacked by the shark during the process. Team ATS was able to successfully address the voice of the customer and create a prototype this working device that shows that the device is feasible and capable of meeting the customer requirements while staying within a reasonable budget.

As described and shown in section 10.2, all the customer needs were met during the final prototype stage of SAVRRS. The prototype already meets all the of the customer requirements, but recommendations have been provided to manufacture a better final design which will be available to the customer.

As shown in section 10.2, all the requirements and constraints for the device to be successful have already been met with the prototype manufactured by Team ATS. The main requirements that have been proven to be met include the structural integrity of the system, the flight capability and actuation reliability of the system and the flight time of the system. SAVRRS has been a successful device during the prototype stage and is very capable of becoming a device available to our customers.

The problem statement for Team 22 ATS was regarding the issue of shark attack victims on beaches and coastlines monitored by lifeguards. At current a lifeguard cannot enter the water to effect immediate rescue to a shark attack victim without confirmation that the area is free of sharks. Our mission was to design a device that could clear the area of shark presence and create and environment for safe rescue.

This environment demanded its own set of constraints as well as performance constraints set by the team. Each of these constraints consisted of quantifiable and measurable limits or goals. The design and prototyping reflected these constraints to culminate in a design and prototype that would satisfy all environmental and performance requirements within acceptable tolerances. Certain systems were scaled or omitted due to budgetary constraints but were ultimately designed and planned for in any commercial outcome.

The current prototype can perform all mechanical functions of the design and the requirements. Testing has been conducted for part of the device with flight testing designed and scheduled. All tests (three tests completed) that have been conducted have been passed.

The team worked very hard and covered a wide array of engineering skills i.e.

- Planning and Organization (IPDS)
- FMEA
- Finite Element Analysis
- Circuit Design and Programming
- Trade Studies and Voice of the Customer
- Solid Mechanics
- Manufacturing Techniques
- Engineering Testing
- Adapt and Overcome the Unavoidable and Unexpected

Team ATS successfully designed and manufactured a prototype for the aid and facilitation of safe rescue to shark attack victims. The prototype meets all system requirements with clear paths forward for a total commercial solution. We collectively take with us a host of lessons learned and real engineering experience that will make us all better engineers in our careers.

13. Recommendations

Team 22 ATS was successful in the IPDS process by creating a system from conception to design and ultimately to fabrication. The resulting prototype meets all customer needs that have been tested for or measured, and clear indicators of successful testing to continue. The work completed by Team 22 ATS meets and exceeds the ABET requirements for analysis and engineering. A successful prototype was created and is ready to move forward in the commercial environment for final redesign and finishing work. With augmented financial and duration capacities, the research and development of the SAVRRS device could be improved for qualified implementation in real-world application. Further recommendations to complete the full-phase manufacturing process are outlined in this report for improved rigidity, longevity and overall performance in commercialized production models.

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Appendices

Appendix A: Full Analysis Reports

A.1) Reservoir System Analysis

Container and Trap Door Material Analysis

This section contains ANSYS simulations that were conducted to verify what material to use for the container and trap doors. The following figures show the deformation and stresses experienced by the container and trap doors.

ABS:

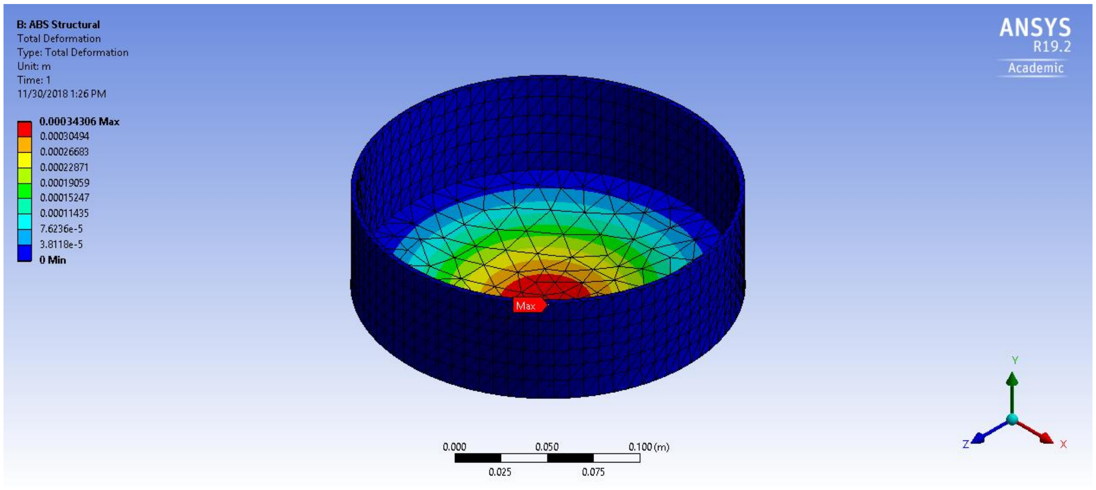


Figure A.1.1 Total Deformation for Container and Trap Door When Using ABS

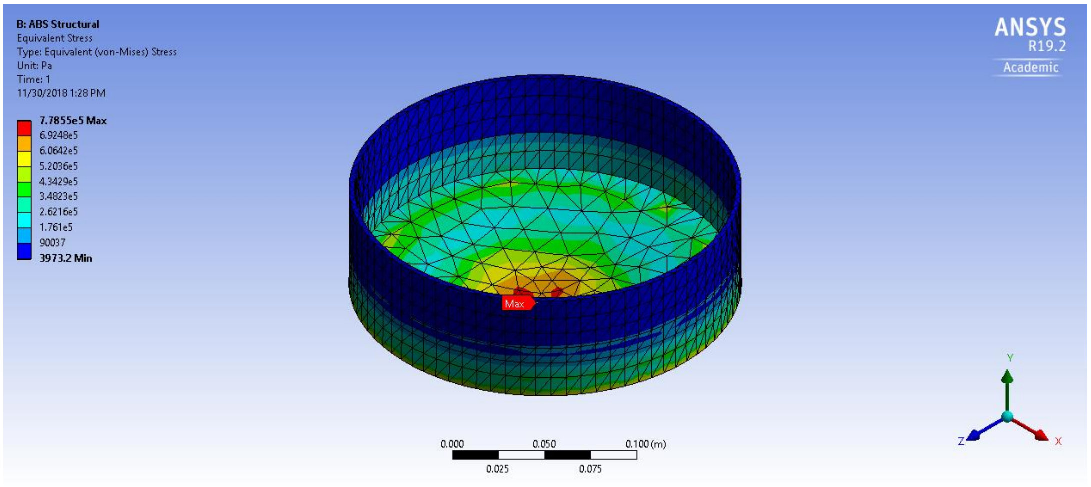


Figure A.1.2 Von-Mises Stress for Container and Trap Door When Using ABS

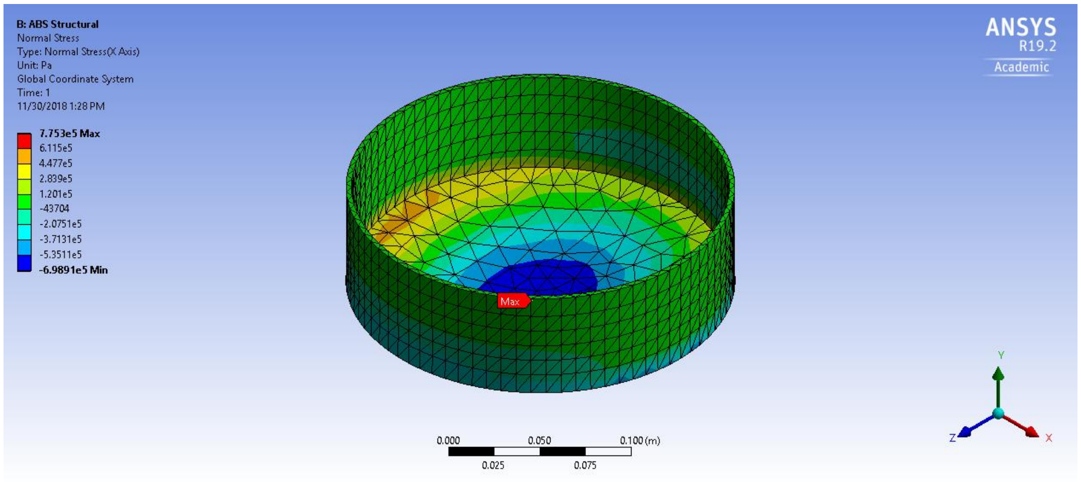


Figure A.1.3 Normal Stress for Container and Trap Door When Using ABS

Aluminum:

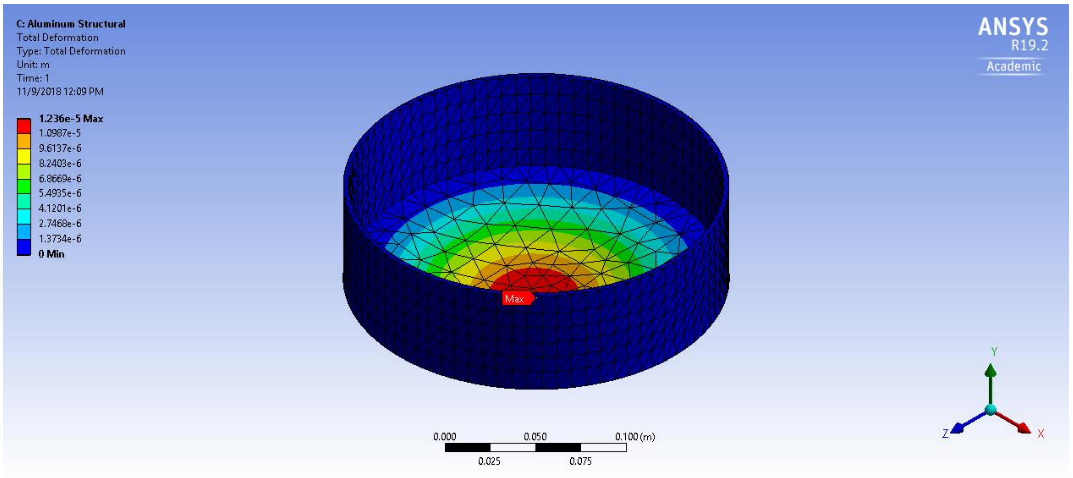


Figure A.1.4 Total Deformation for Container and Trap Door When Using Aluminum

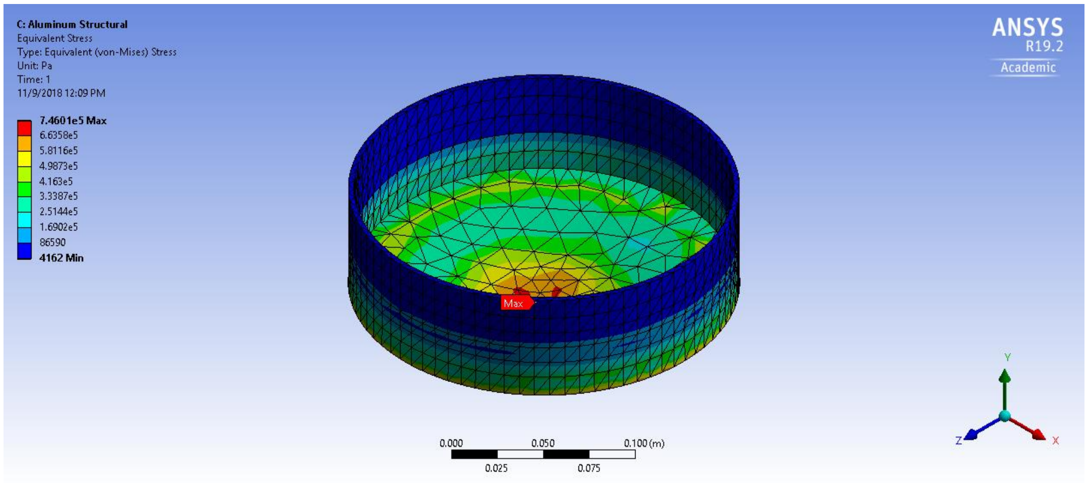


Figure A.1.5 Von-Mises Stress for Container and Trap Door When Using Aluminum

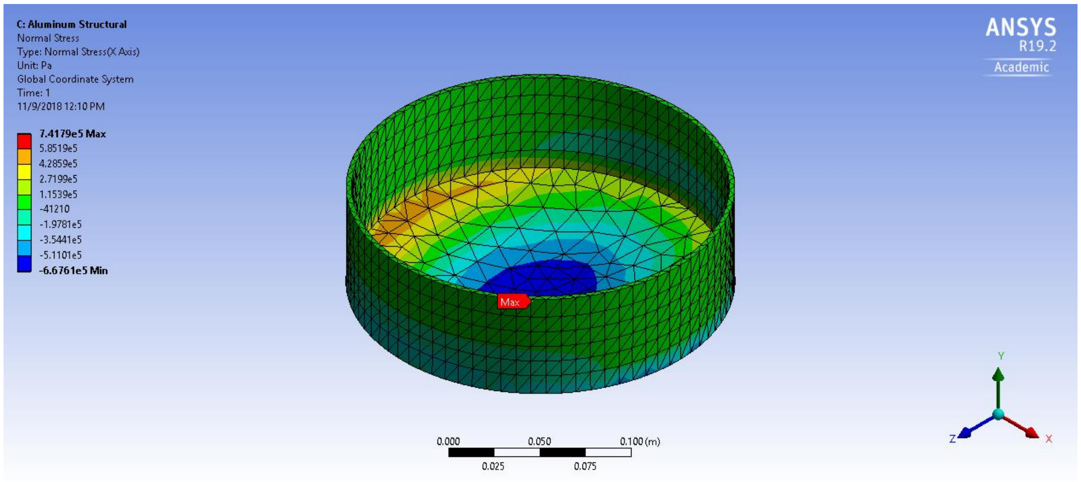


Figure A.1.6 Normal Stress for Container and Trap Door When Using Aluminum

PLA:

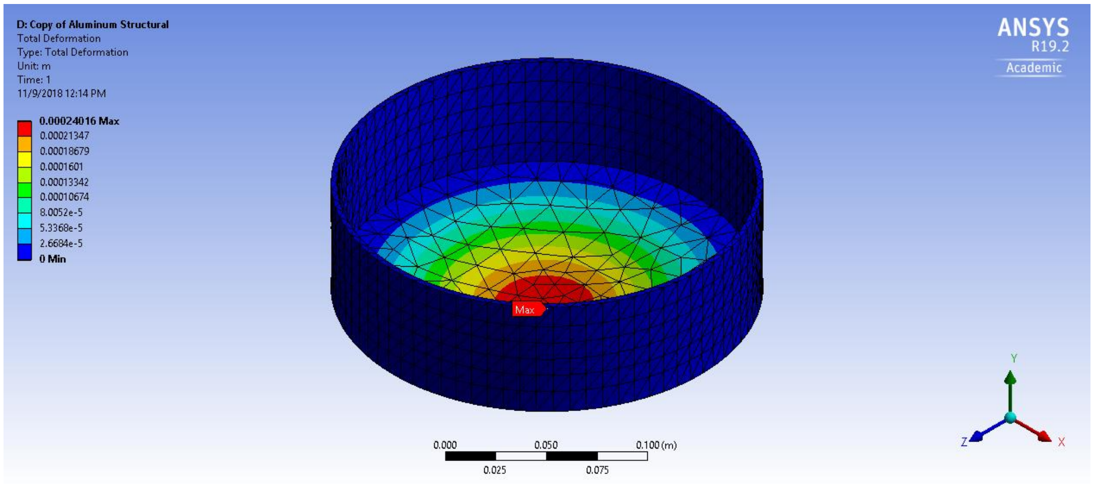


Figure A.1.7 Total Deformation for Container and Trap Door When Using PLA

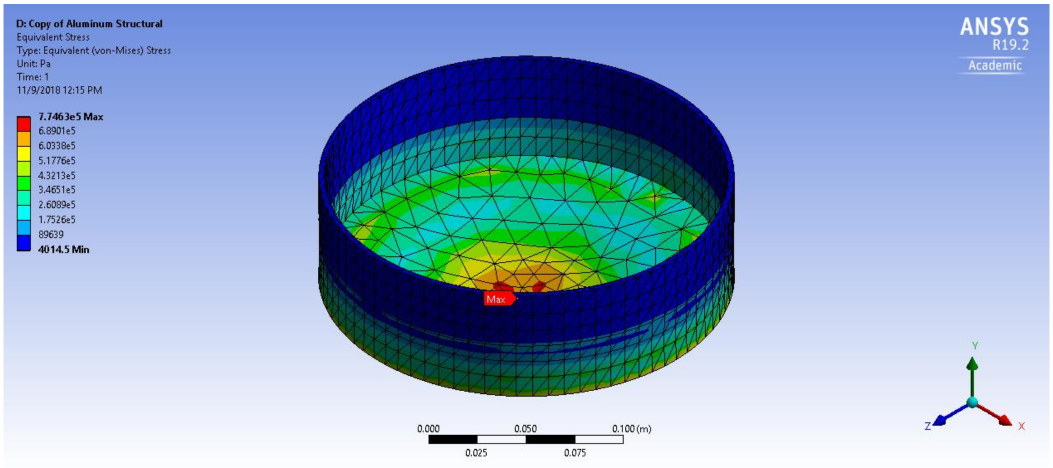


Figure A.1.8 Von-Mises Stress for Container and Trap Door When Using PLA

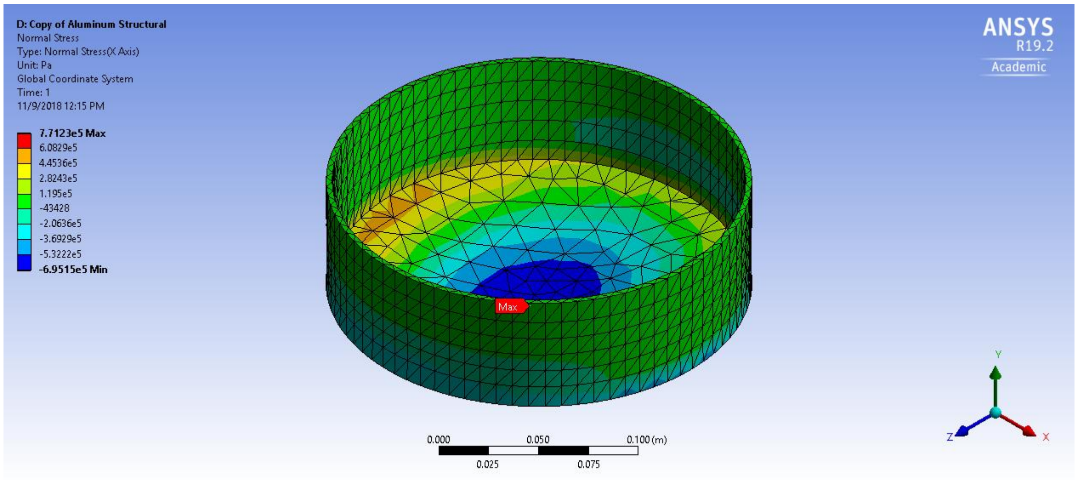


Figure A.1.9 Normal Stress for Container and Trap Door When Using PLA

Table A.1.1 Comparing Structural Integrity

	Total Deformation (m)	Von-Mises Stress (Pa)	Normal Stress (Pa)	Yield Strength	Safety Factor
ABS	0.00034306	778550	775300	13000000	16.69770728
Aluminum	0.00001236	746010	741798.1	55000000	73.72555328
PLA	0.00026016	774630	771230	14000000	18.0731446

Table A.1.2 Container Material Trade Study

		ABS		Aluminum		PLA	
Criteria	**Weighting**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Resistance to Elements	10	9	90	5	50	6	60
Structural Integrity	10	8	80	10	100	6	60
Ease of Manufacture	7	8	56	5	35	10	70
Cost	7	8	56	5	35	10	70
Weighted Totals			282		220		260

The FEA conducted yielded similar stress values to that obtained when hand calculations were carried out. This As seen in the table above, ABS gave us the structural integrity required for our product with ease of manufacture at the budget available. So, Team ATS decided to use ABS for the manufacturing of the Container.

$$P_{max} = 1.18\ kPa$$
$$\delta_{max} = \ 0.34306\ mm$$
$$\sigma_{max} = 77.8\ kPa$$

Optimizing Container Thickness and Trap Door Thickness:

To reduce the weight of the system to get a better performance as a reduction in weight will require lesser thrust from the motors to provide the same lift. Upon conducting analysis, it was concluded that a thickness of 2mm will suffice for both the container walls and the trap doors. However, the trap door of the container will have other loads that will be constantly acting on the trap door and there might be abrasion occurring during actuation of the trap door. So, it was decided to not reduce the thickness of the trap door to ensure failure shall not occur from this component.

It was noticed that the thickness of the container walls can be reduced further. However, for safety reasons further optimization of the container thickness was paused until winter break to ensure that further optimization of the container will not lead to failure of the system.

Table A.1.3 Deformation of Container Wall and Trap Door

Thickness (mm)	Container Wall Deformation (mm)	Trap Door Deformation (mm)
3	0.005	0.34306
2	0.006	0.45073

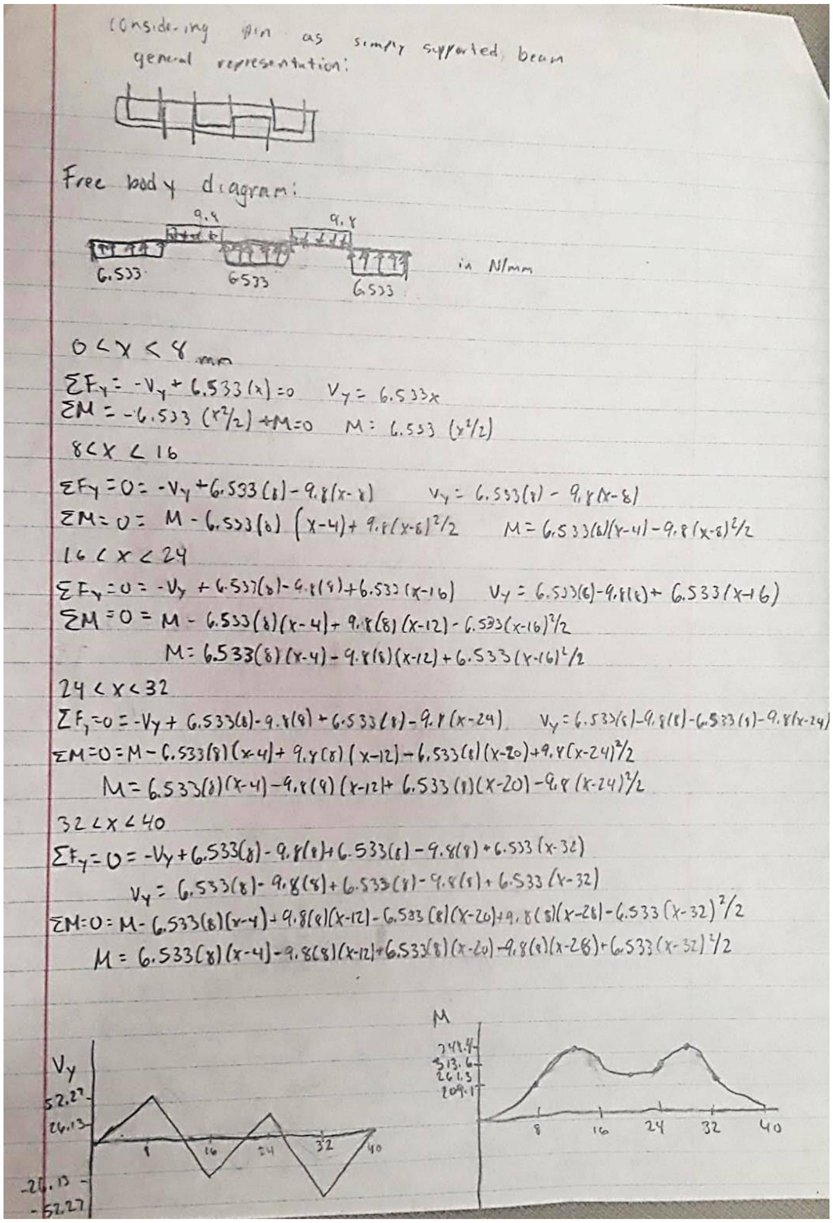
A.2) Hinge and Pin Analysis

MATLAB code for optimization process:

```
Sut= 45000; %Aluminium 6061-T6 %45000psi %310MPa
Sy=40000;%40000psi, 276MPa
seprime= .5*Sut; %for sut<200ksi

ka=2.7*Sut^(-.265);

Dg1=10/25.4; %D guess 10 mm, the initial guess for D, convert to in
de=.37*Dg1; %bc nonrotating
kb= .879*de^(-.107); %kb based on first guess, de~.146in >.11

kc= 1 ; %for combined (assumed combination)

kd= 1; %no temp stuff

ke= .753; %reliability of 99.9%

n=2; %factor of safety

Ma=557.51*10^-3;
Mm=0;
Ta=0;
Tm=0;
Kfs=1;
Kf=1;

Se= ka*kb*kc*kd*ke*seprime;

D= ((16*n/pi)*(1/Se)*(4*(Ma)^2)^(1/2))^(1/3);

skb= .879*D^(-.107);
Se= ka*skb*kc*kd*ke*seprime;

sD=((16*n/pi)*((1/Se)*(4*(Kf*Ma)^2+3*(Kfs*Ta)^2)^(1/2)+(1/Sut)*(4*(Kf*Mm)^2+3*(Kfs*Tm)^2)))^(1/3);

tkb= .879*sD^(-.107);
Se= ka*tkb*kc*kd*ke*seprime;

tD=((16*n/pi)*((1/Se)*(4*(Kf*Ma)^2+3*(Kfs*Ta)^2)^(1/2)+(1/Sut)*(4*(Kf*Mm)^2+3*(Kfs*Tm)^2)))^(1/3)
D=.2;

n_newD = ((16/(pi*(D)^3))*((1/Se)*(4*(Kf*Ma)^2)^(1/2)))^(-1); %factor of safety using 5mm D

sstressD= ((32*Ma)/(pi*D^3));
```

```
ns_D= Sy/sstressD; %static factor of safety


stressD= ((32*Ma)/(pi*D^3))*Kf; %max  stress
tD = 0.2001
```

Hand Calculations:


Considering pin as simply supported beam

general representation:

Free body diagram:

$0 < x < 8$ mm

$\Sigma F_y = -V_y + 6.533(x) = 0 \quad V_y = 6.533x$

$\Sigma M = -6.533(x^2/2) + M = 0 \quad M = 6.533(x^2/2)$

$8 < x < 16$

$\Sigma F_y = 0 = -V_y + 6.533(8) - 9.8(x-8) \quad V_y = 6.533(8) - 9.8(x-8)$

$\Sigma M = 0 = M - 6.533(8)(x-4) + 9.8(x-8)^2/2 \quad M = 6.533(8)(x-4) - 9.8(x-8)^2/2$

$16 < x < 24$

$\Sigma F_y = 0 = -V_y + 6.533(8) - 9.8(8) + 6.533(x-16) \quad V_y = 6.533(8) - 9.8(8) + 6.533(x-16)$

$\Sigma M = 0 = M - 6.533(8)(x-4) + 9.8(8)(x-12) - 6.533(x-16)^2/2$

$M = 6.533(8)(x-4) - 9.8(8)(x-12) + 6.533(x-16)^2/2$

$24 < x < 32$

$\Sigma F_y = 0 = -V_y + 6.533(8) - 9.8(8) + 6.533(8) - 9.8(x-24) \quad V_y = 6.533(8) - 9.8(8) - 6.533(8) - 9.8(x-24)$

$\Sigma M = 0 = M - 6.533(8)(x-4) + 9.8(8)(x-12) - 6.533(8)(x-20) + 9.8(x-24)^2/2$

$M = 6.533(8)(x-4) - 9.8(8)(x-12) + 6.533(8)(x-20) - 9.8(x-24)^2/2$

$32 < x < 40$

$\Sigma F_y = 0 = -V_y + 6.533(8) - 9.8(8) + 6.533(8) - 9.8(8) + 6.533(x-32)$

$V_y = 6.533(8) - 9.8(8) + 6.533(8) - 9.8(8) + 6.533(x-32)$

$\Sigma M = 0 = M - 6.533(8)(x-4) + 9.8(8)(x-12) - 6.533(8)(x-20) + 9.8(8)(x-28) - 6.533(x-32)^2/2$

$M = 6.533(8)(x-4) - 9.8(8)(x-12) + 6.533(8)(x-20) - 9.8(8)(x-28) + 6.533(x-32)^2/2$

Figure A.2.1 hand Calculations for Pin Stress

A.3) Slider Attachment Analysis

Analysis to support Trade Studies – UAV slider attachment design requirements

From previous analysis, it was determined that the weight of 2 liters of repellent fluid would be approximately 2.2 kg. The team set a goal of 3.3 kg for the rig and repellent container that would be attached to the bottom of the UAV system. This means that the UAV would be supporting a total of 4.5 kg of total weight during flight operations.

The repellent rig and container need to be fastened to the bottom under-tray of the UAV body. Therefore, there is a need for an attachment device that will allow for easy securing to the drone. The team created a slider design that would allow for the repellent vessel to slide and lock onto its mounting fixture located on the underside of the UAV. The mounting fixture would be responsible for being safely secure to the drone body, as well as supporting the weight of the repellent container during all of its missions. Shown below is the initial analysis (Design #1) to support the team's previous trade studies.

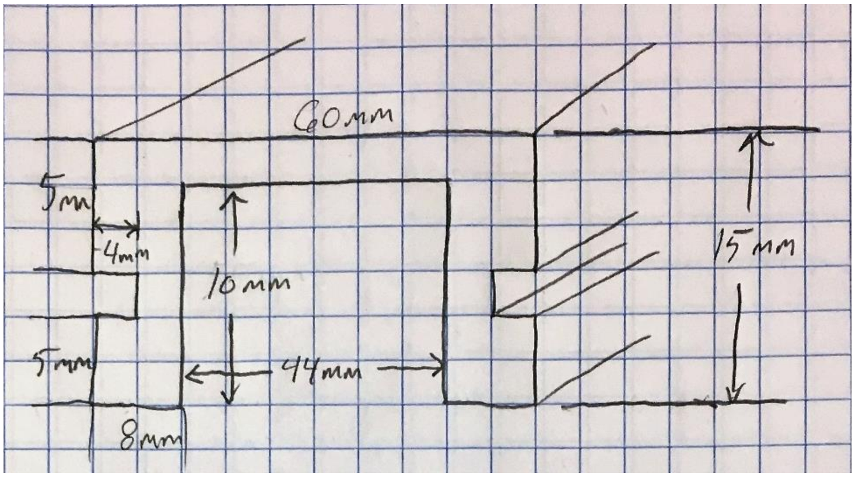


Figure A.3.1 Initial design concept for slider attachment for UAV body.

Pressure calculations:

$$A = 8\,mm * 100\,mm = 8000\,mm^2 \qquad F = 5.5\,kg$$

$$P_{1-edge} = \frac{F/2}{A} = \frac{(5.5\,kg)}{2*(8000\,mm^2)}\frac{(9.81\,N)}{(1\,kg)}\frac{(1\,mm^2)}{(10^{-6}\,m^2)} = \frac{26.978\,N}{0.008\,m^2} = 3372.2\,Pa$$

Alternative options as design after pressure calculations:

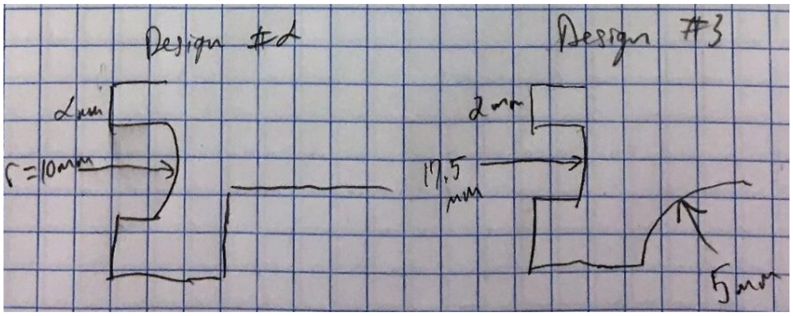


Figure A.3.2 Alternative Design Option Ideas

Component Trade Studies for Slider Design Attachment

Table A.3.1 Slider Component Design Trade Study Matrix

	Positives	Concerns
Design #1	• Simplistic design • Easy to manufacture	• Design could cause significant stress concentrations • Needs to be optimized for weight
Design #2	• Improved stress distribution at points of concern • Reduced material	• Could require additional structure support at fixed edge • Potential for undesirable stress concentrations
Design #3	• Potential improvement for reinforcement at stress loading • Least likely for system failure in use	• Design could require more material and add weight to structure • Difficult to manufacture

There are numerous positives and concerns with each design – most of which have been unsupported claims and assumptions up to this point in the design considerations for the attachment device. The mounting attachment plays a critical role for the ATS system. It allows the repellent rig to be secured to the underside of the UAV and remain in place until the payload is delivered to its target.

Multiple factors are cause for concern at different design points of this single component. The design itself must withstand the stresses experienced by the system as a whole, and must remain un-deformed over time. Should the design begin to deform, the attachment could risk losing the payload mid-operation rendering the device useless. Also, necessary analysis must consider the material chosen for this part. Since the team has set high expectations for the weight of the repellent system, it is important to refine the design to save on weight and cost while still ensuring that the material is strong enough to withstand yielding and fracturing effects.

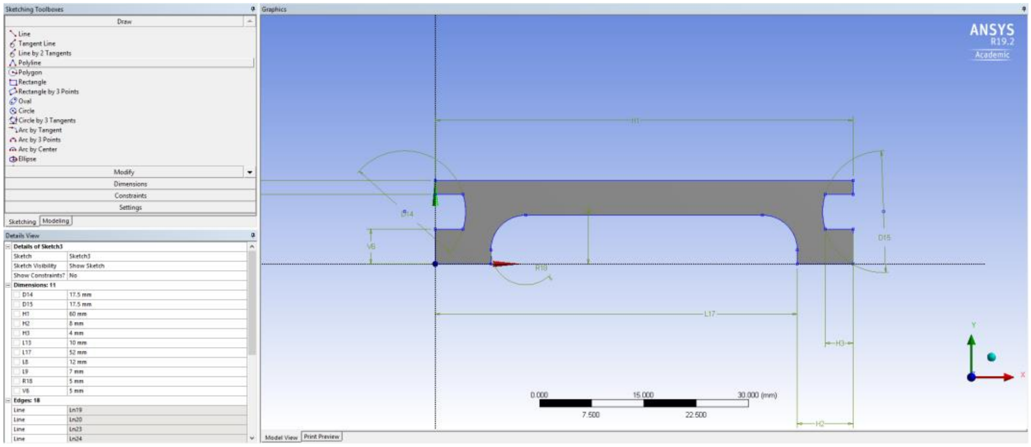
Since the attachment is such a critical design component to the overall function of the drone, the team deems it necessary to perform extensive FEA on each design before moving forward with an option. This will allow for initial Proof-of-Concept (P.O.C.) design testing to be conducted at this stage prior to having a prototype or product.

In the FEA analysis shown in the following section, solid models were created for each of the three design options and tested using ANSYS static structural analysis. The constraints and forces explained in the original analysis are shown for each design as well, as previously derived in the analysis performed above. Each design is tested using the same parameters with two materials: Aluminum and ABS. This is to further assess the need for stronger versus lighter material for this specific component.

FEA Analysis to support component Trade Studies – Slider Attachment Design

Design #3: Filleted bottom supports for stress distribution:

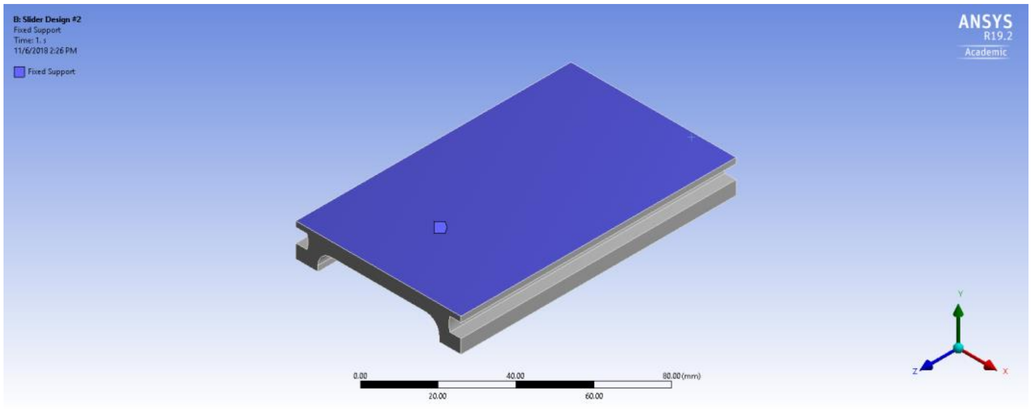
The following figures shows the design option number three for the slider attachment.



Details View

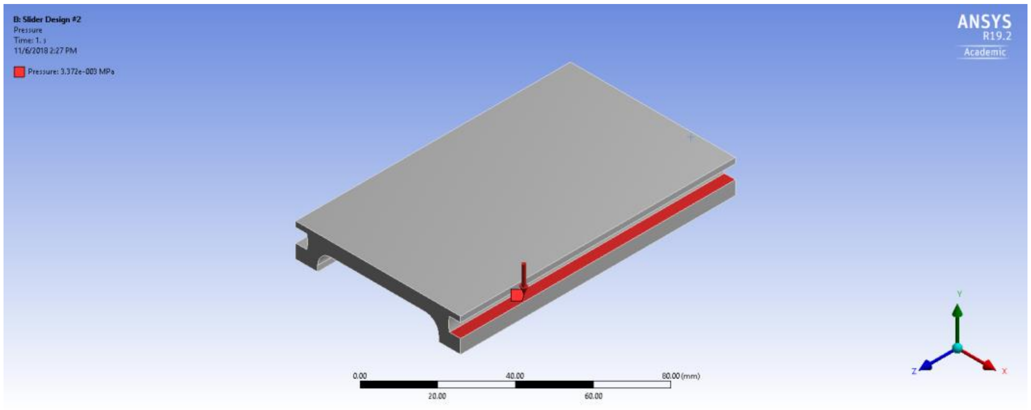
Details of Sketch3	
Sketch	Sketch3
Sketch Visibility	Show Sketch
Show Constraints?	No
Dimensions: 11	
☐ D14	17.5 mm
☐ D15	17.5 mm
☐ H1	60 mm
☐ H2	8 mm
☐ H3	4 mm
☐ L13	10 mm
☐ L17	52 mm
☐ L8	12 mm
☐ L9	7 mm
☐ R18	5 mm
☐ V6	5 mm
Edges: 18	
Line	Ln19
Line	Ln20
Line	Ln23
Line	Ln24

Figure A.3.3 Design 3 in Ansys (a)


B: Slider Design #2
Fixed Support
Time: 1. s
11/6/2018 2:26 PM

🟦 Fixed Support

Figure A.3.4 Design 3 in Ansys (b)


B: Slider Design #2
Pressure
Time: 1. s
11/6/2018 2:27 PM

🟥 Pressure: 3.372e-003 MPa

Figure A.3.5 Design 3 in Ansys (c)

Design #3: Aluminum Alloy

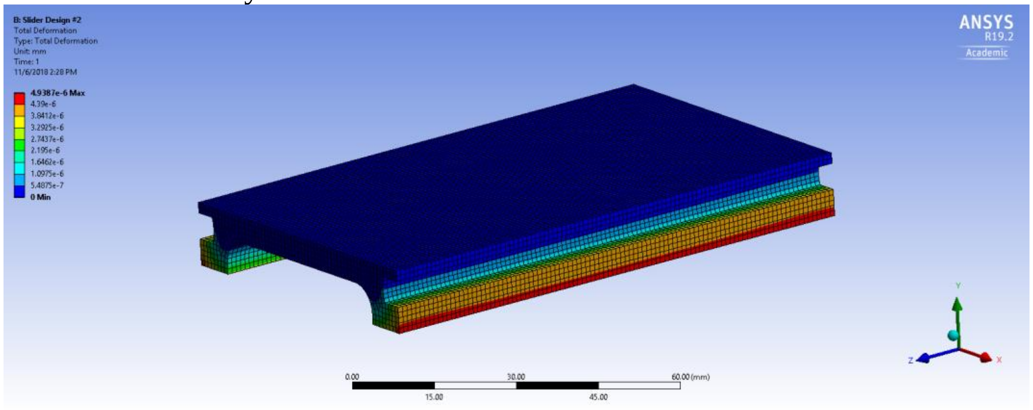


Figure A.3.6 Design 3 in Ansys (d)

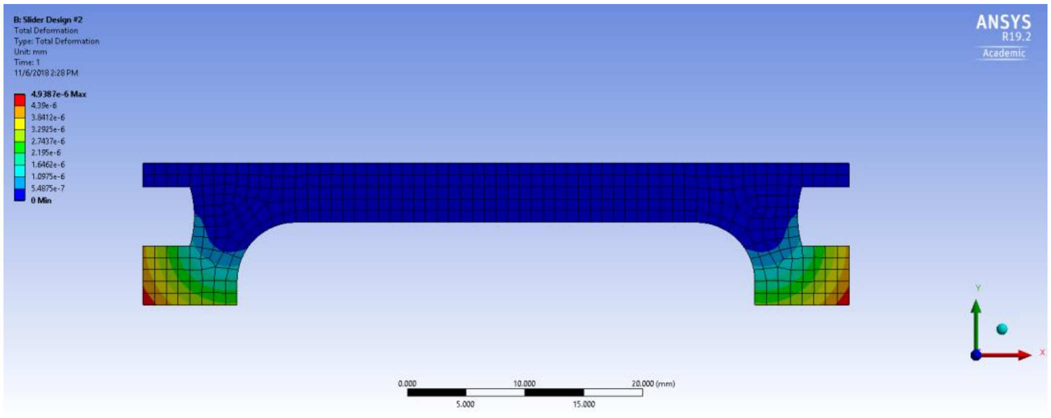


Figure A.3.7 Design 3 in Ansys (e)

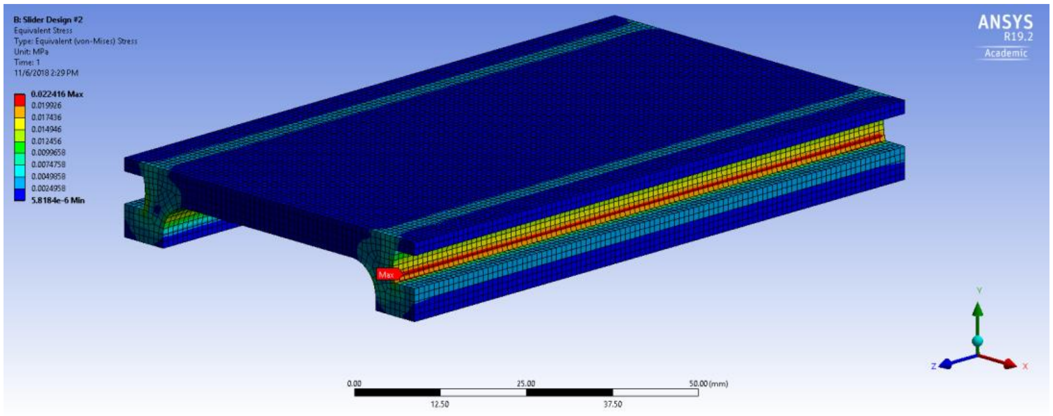


Figure A.3.8 Design 3 in Ansys (f)

ABS: Design #3

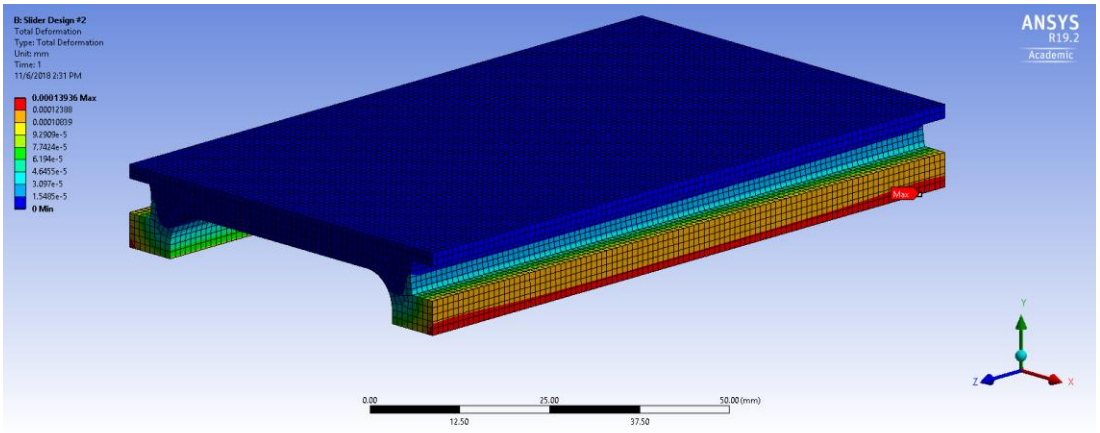


Figure A.3.9 Design 3 in Ansys (g)

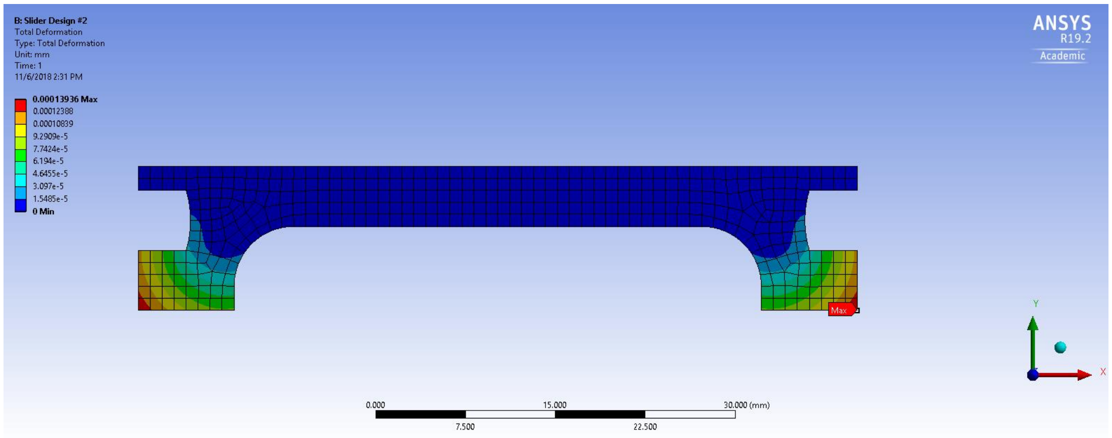


Figure A.3.10 Design 3 in Ansys (h)

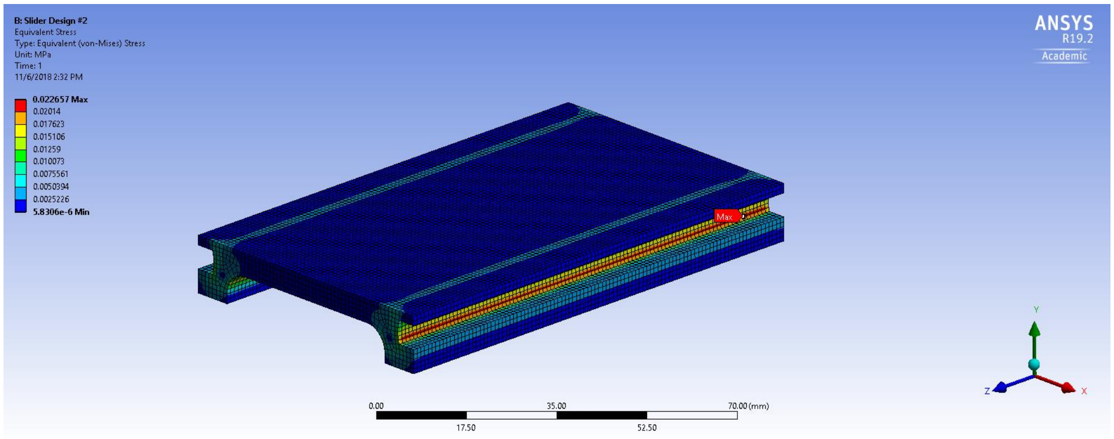


Figure A.3.11 Design 3 in Ansys (i)

Proof-of-Concept (P.O.C.) to support Trade Studies – Slider Attachment Design

Table A.3.2 Design 1 Proof of Concept Data

Design #1		
Material	Max Deformation	Max Stress
Aluminum Alloy	1.0351 E-5 mm	0.025053 MPa
ABS	2.9154 E-4 mm	0.024975 MPa

Table A.3.3 Design 2 Proof of Concept Data

Design #2		
Material	Max Deformation	Max Stress
Aluminum Alloy	1.020 E-5 mm	0.0033626 MPa
ABS	2.869 E-4 mm	0.0033187 MPa

Table A.3.4 Design 3 Proof of Concept Data

Design #3		
Material	Max Deformation	Max Stress
Aluminum Alloy	4.8397 E-6 mm	2.242 kPa
ABS	1.3960 E-4 mm	2.265 kPa

$$P_{max} = 3372.2\ Pa$$
$$\delta_y = 1.396\ \times 10^{-4}\ mm$$
$$\sigma_{max} = 2.265\ kPa$$

Table A.3.5 Decision Summary

System	Summary	Option Selected
Slider Attachment Mount	Calcs and FEA results. Matrix formed to select design/material.	Refined Design (v3) additional supports. Made w/ ABS plastic.

A.4) Distribution Internal Mechanism Analysis

Problem Statement:

One of the most critical components of our design is the dispensing door actuation system. The system consists of a shaft and locking block which will support the door panels pre-disbursement and will rotate to release the panels when disbursement is required. Figure A.4.1 below shows a Cad model of the system being analyzed, and how it will function.

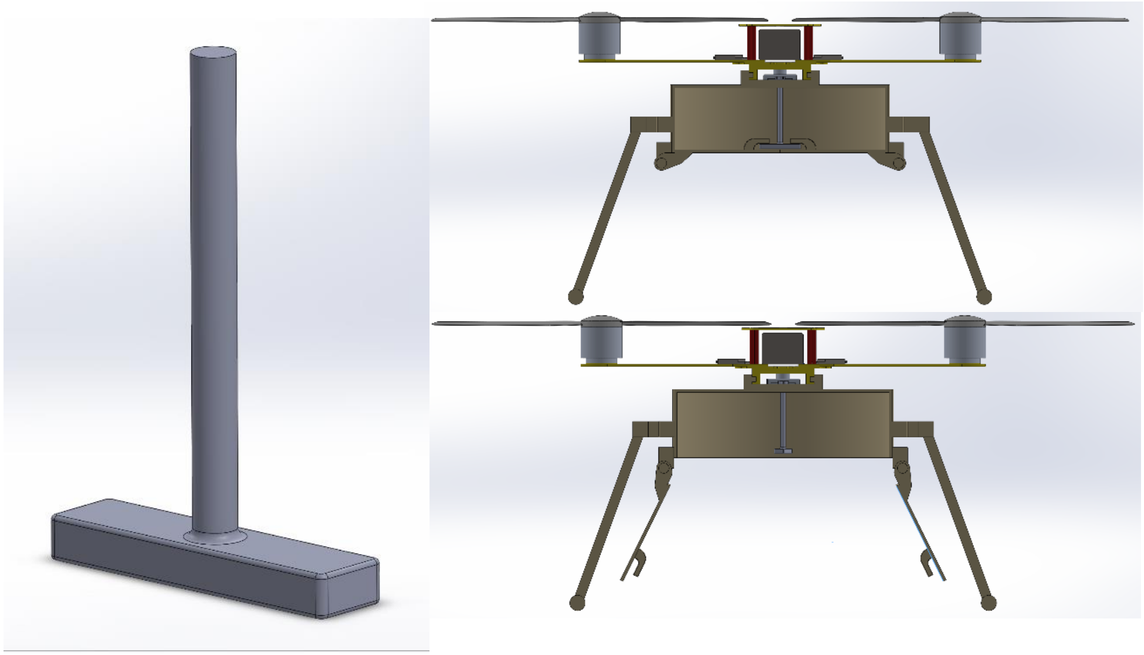


Figure A.4.1: Shaft and Locking Block CAD Configuration and Function

The shaft-block mechanism is likely the most critical component of our system since if it were to fail, the device might misfire and not fulfill its purpose. This is considered a critical failure by the team, and as a result, the device must be critically analyzed for stress failure and max deflection.

Approach:

We approached this problem by first determining the forces acting on the block face. This requires a bit of analysis toward the total pressure of fluid within the system, and how it correlates to a point load on either side of the block. Since the pressure on each of the bomb doors is effectively a distributed load over a semicircle, we need to find the center of mass of our semicircle door to pin the point where the equivalent point load rests. Once we know the exact distance from the door hinge that the point load is resting, we ca determine the magnitude of the load.

Now that we have the load on the block determined, we consider the shaft-block system and the load translated throughout. We can assume that the total magnitude of the force on either side of the block is equivalent to the total point load on each of the doors. Using this assumption, we determine that the total force going through the shaft is equal to the force of gravity acting on the shaft-block device, added to two times the force acting on a single door. We can use this value to determine the stresses in the shaft. As for the bending and deflection of the block, we conservatively assume that the force acting on the block is exactly resting on the end of the block as a point load. This is not accurate to the real world but will provide us with a more conservative safety factor and higher stress values, making our device safer than it actually would need to be. Since either side of the block is effectively the same as the other end, we can model one side as a cantilevered bream with a point load applied at the end. The maximum bending moment and transverse shear stresses were determined within the block due to the loading applied. A safety factor was then formulated by using the Distortion Energy or Von-Mises criterion.

Maximum deflection was found at the block ends by using the deflection equations found in a structural mechanics textbook. Inputting the values would result in the max deflection of one side of the block, not including the shaft deformation at all.

Now that the analysis was completed for the block mechanism, the shaft needs to be evaluated as well for max stress and deflection. Since this shaft will be experiencing torsion during normal operation, the maximum torque, and resulting shear stress was found, as well as the total axial stress from the load. Deflection of the shaft was likewise calculated. A safety factor for the shaft was also calculated, using the same method as earlier.

Once the deflection in the shaft was found, the total deflection of the block ends could be determined by summing the shaft and block deflection values.

We determined that any type of yielding is considered failure, and we do not want deformation at the end of the blocks to exceed 0.5 mm in order that no misfires may occur.

If the total deflection of this system is deemed negligible for operation, and none of the components experience any yielding failure during typical conditions, then the device is successful.

Since a material and dimensions were not yet selected at this point, the approach was to use variables to reflect parameters, and then create an excel spreadsheet which would use the assigned material properties and dimensions to these variable to calculate the critical values.

Defining Equations:
The defining equations for this analysis are the following:

Fluid pressure:

$$P = h\rho g$$

P= pressure, h= height of fluid, ρ = density of fluid, g= gravity constant for earth.

Total force on door:

$$F = P * A$$

F= force, P= pressure on single semicircle door, A= Area of single semicircle door.

Center of Mass of Semicircle:

$$\bar{Y}' = \frac{2d}{3\pi}$$

$\bar{Y}'$= Y location of center of mass, d= diameter of semicircle.

Bending Stress:

$$\sigma_b = \frac{My}{I}$$

σ_b= Bending Stress, M= Maximum bending moment, y= distance from neutral axis, I= Moment of inertia of bar.

Moment of Inertia of Rectangular Cross Section:

$$I = \frac{1}{12} wt^3$$

I= Moment of inertia, w= width of cross section, t= thickness of cross section (height)

Max shear stress:

$$\tau_{max} = \frac{3R}{2wt}$$

τ_{max}= max shear, R= shear force at beam end, w= width of cross section, t= thickness of cross section (height)

Von-Mises Stress:

$$n = \frac{S_y}{\sigma_s + 3\tau_s}$$

n= safety factor, Sy= yield strength of material, σ_s= equivalent max normal stress, τ_s= equivalent max shear stress.

Max Deflection of Cantilevered Beam from Point Load at End:

$$-\frac{PL^3}{3EI}$$

P= point load force, L=length of beam, E=Modulus of Elasticity of material, I=Moment of inertia of beam

Max Deflection of Cantilevered Beam from Distributed Load (weight of material):

$$-\frac{wL^4}{8EI}$$

w= distributed load on beam, L=length of beam, E=Modulus of Elasticity of material, I=Moment of inertia of beam

Normal Stress in Shaft:

$$\sigma_s = \frac{4P}{\pi d^2}$$

σ_s= stress in shaft, P= loading in axial direction, d= diameter of shaft

Max Shear Stress in Shaft:

$$\tau_{max} = \frac{16T_s}{\pi d^3}$$

τ_{max}= max shear stress, Ts= max torque on shaft, d= diameter of shaft.

Deformation of Shaft:

$$\delta_s = -\frac{PL}{EA}$$

δ_s= deflection in shaft, P= Axial load in shaft, L= shaft length, E= Modulus of elasticity, A= Area of shaft cross section.

Results:

After compiling all the equations and relationships into a single excel spreadsheet, the results of the analysis were determined. The free variables in this situation are the material properties and the shaft and block dimensions. After performing an iterative optimization process, the final material and dimensions were determined, and as a result the max deflection, internal stresses and safety factor was found. Table A.4.1 below shows the results for our selected material.

Table A.4.1: Calculated Results of Shaft and Block Analysis

Parameter	Result
Material	ABS Plastic
Shaft Diameter	10.0 mm
Shaft Length	570.0 mm
Shaft Safety Factor	1336
Block Width	5.0 mm
Block Length	20.0 mm
Block Thickness	3.0 mm
Block Safety Factor	12995
Maximum Deflection at Ends	-0.244 mm
Total Mass	47.8 g

Additionally, an ANSYS simulation was prepared for this component system, and the results are displayed in the following figures A.4.2 and A.4.3.

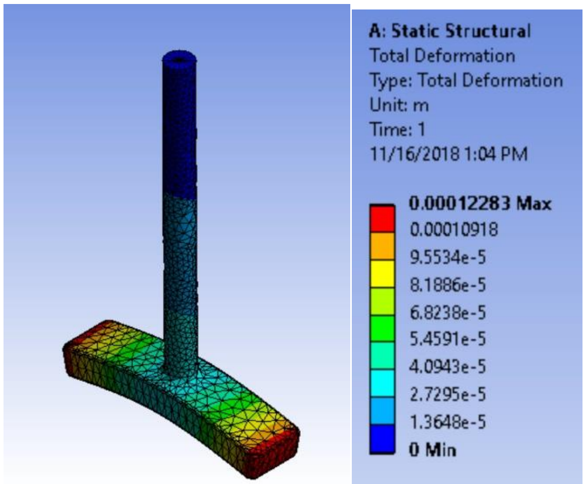


Figure A.4.2: ANSYS Simulation of Total Deflection in Shaft-Block System

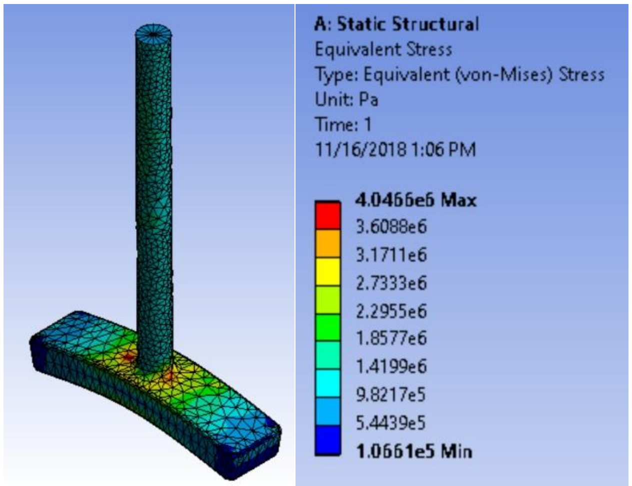


Figure A.4.3: Ansys Simulation of Total Equivalent Stress in Shaft-Block System

The results of the ANSYS simulation are likely more accurate to the actual system due to the loading conditions being more realistic and the finite element analysis capabilities of the software. Rather than point loads, distributed loads were assigned over the face of the block to accurately represent the system. Despite this, the results of this simulation seem to compliment the hand-calculations performed earlier.

The complete hand-calculations are shown in the appendix at the end of this report.

Conclusions:

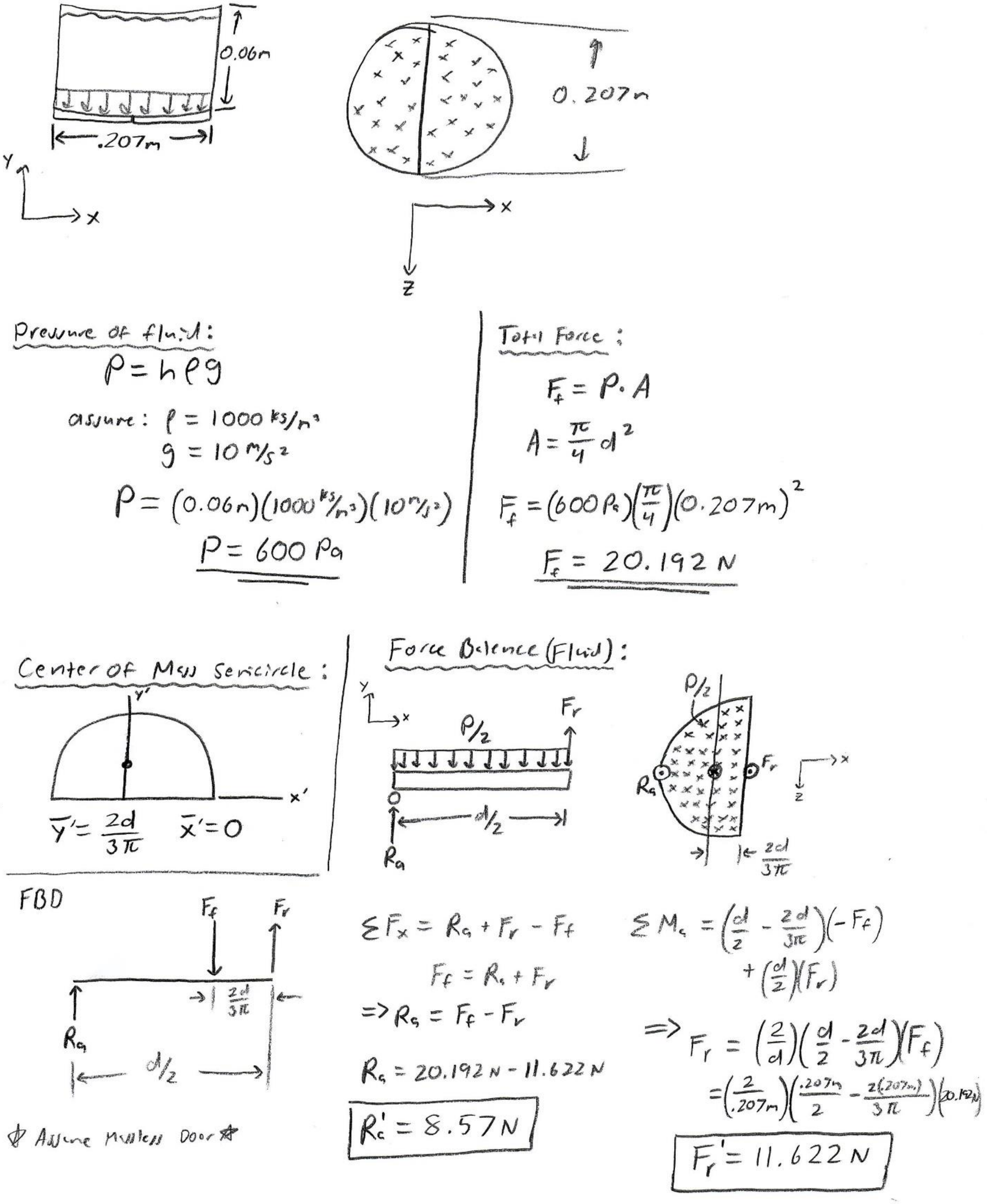
The two most important results of this are the safety factor and max deflection. The team determined that a safety factor of at least 2 is required for each of our components. The results show us that for both the shaft and the block, this expectation was far exceeded. This shows us that the system is overengineered significantly for safety, which is undesirable, until we consider the deflection. Post-optimization of our system yields minimal deflections that are less than the desired 0.5 mm. This is exactly how we want our system to be, considering if any deflection were to occur that exceeds this value significantly, there is the potential for fluid losses in our system. Since this is satisfied, we are happy with the results. This is likely the cause for such a large safety factor. Our design is satisfactory for the device.

Recommendations:

Based on this analysis, we can go forward with the design. Based solely on a stress and deformation standpoint the requirements are satisfied.

I recommend that the team should adopt this as our preliminary design and go forward with optimization. Further improvements and design modifications may be made as further design changes are implemented.

Hand-Calculations and Equation Derivations



Pressure of fluid:

$P = h\rho g$

assume: $\rho = 1000\ \mathrm{kg/m^3}$

$g = 10\ \mathrm{m/s^2}$

$P = (0.06\mathrm{m})(1000\ \mathrm{kg/m^3})(10\ \mathrm{m/s^2})$

$\underline{\underline{P = 600\ \mathrm{Pa}}}$

Total Force:

$F_f = P \cdot A$

$A = \frac{\pi}{4} d^2$

$F_f = (600\ \mathrm{Pa})\left(\frac{\pi}{4}\right)(0.207\mathrm{m})^2$

$\underline{\underline{F_f = 20.192\ \mathrm{N}}}$

Center of Mass Semicircle:

$\bar{y}' = \frac{2d}{3\pi}$ $\quad \bar{x}' = 0$

Force Balance (Fluid):

FBD

$\Sigma F_x = R_a + F_r - F_f$

$F_f = R_a + F_r$

$\Rightarrow R_a = F_f - F_r$

$R_a = 20.192\mathrm{N} - 11.622\mathrm{N}$

$\boxed{R_c' = 8.57\mathrm{N}}$

$\Sigma M_a = \left(\frac{d}{2} - \frac{2d}{3\pi}\right)(-F_f) + \left(\frac{d}{2}\right)(F_r)$

$\Rightarrow F_r = \left(\frac{2}{d}\right)\left(\frac{d}{2} - \frac{2d}{3\pi}\right)(F_f)$

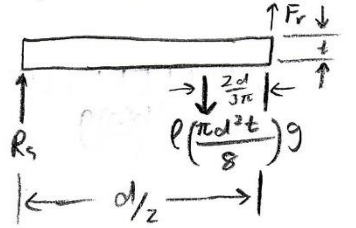
$= \left(\frac{2}{.207\mathrm{m}}\right)\left(\frac{.207\mathrm{m}}{2} - \frac{2(.207\mathrm{m})}{3\pi}\right)(20.192\mathrm{N})$

$\boxed{F_r' = 11.622\mathrm{N}}$

* Assume Massless Door *

Figure A.4.4 Handwritten Analysis Calculations (a)

Force Balence (weight of door):



$\sum M_a$

$$0=\left(\frac{d}{2}\right)F_r-\left(\frac{d}{2}-\frac{2d}{3\pi}\right)\left(\rho\,\frac{\pi d^2 t}{8}\right)g$$

$$\Rightarrow F_r=\left(\frac{2}{d}\right)\left(\frac{d}{2}-\frac{2d}{3\pi}\right)\left(\rho\,\frac{\pi d^2 t}{8}\right)g$$

$$F_r=\left(\frac{2}{0.207m}\right)\left(\frac{.207m}{2}-\frac{2(.207m)}{3\pi}\right)\left(\rho\,\frac{\pi(.207m)^2 t}{8}\right)(10\,m/s^2)$$

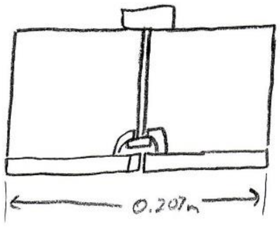
$$\boxed{F_r''=0.029\rho t}$$

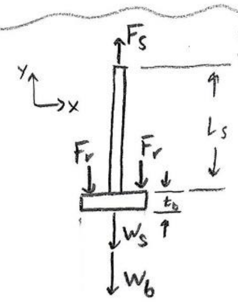
$$\sum F=R_a+F_r-\rho\left(\frac{\pi d^2 t}{8}\right)g$$

$$\Rightarrow R_a=(0.029-0.017)\rho t \Rightarrow \boxed{R_a''=0.012\rho t}$$

Total sum:

$$\boxed{F_r=\left[11.622+0.029\rho t\right]N},\quad \boxed{R_a=\left[8.57+0.012\rho t\right]N}$$



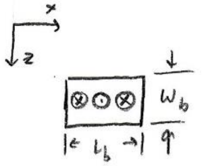


Weight of shaft:

$$W_s=\rho_s g\left(\frac{\pi d_s^2 L_s}{4}\right)$$

Weight of block:

$$W_s=\rho_b g w_b L_b t_b$$

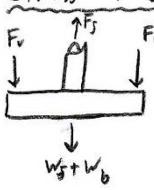


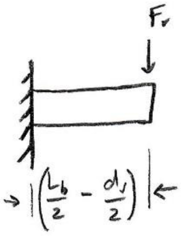
$$\boxed{F_s=2\left[11.622+0.029\rho_d t_d\right]+\rho_s g\left(\frac{\pi d_s L_s}{4}\right)+\rho_b g w_b L_b t_b}$$

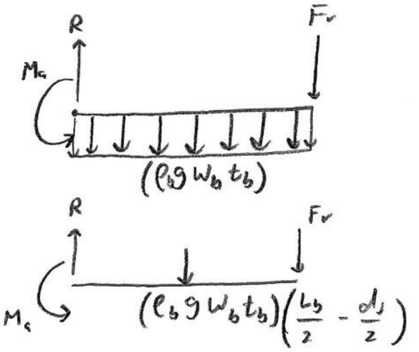
$$\boxed{\sigma_s=\frac{4F_s}{\pi d^2}}$$

Figure A.4.5 Handwritten Analysis Calculations (b)

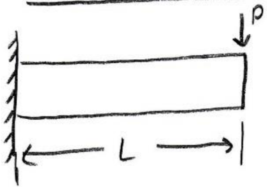
Stress in block!





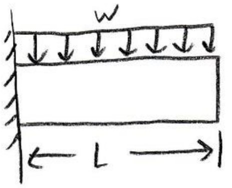


Beam Deflections



Max Deflection

$$\frac{-PL^3}{3EI}$$



Max Deflection

$$-\frac{wL^4}{8EI}$$

ΣM_c:

$$F_r\left(\frac{L_b-d_s}{2}\right) = M_a - \left(\frac{L_b-d_s}{4}\right)\left(\rho_b g w_b t_b\right)\left(\frac{L_b-d_s}{2}\right)$$

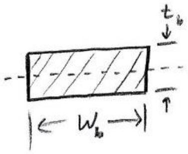
$$\boxed{M_a = \left[F_r + \left(\frac{L_b-d_s}{4}\right)\rho_b g W_b t_b\right]\left(\frac{L_b-d_s}{2}\right)}$$

ΣF_y:

$$\boxed{R = F_r + \rho_b g W_b t_b\left(\frac{L_b-d_s}{2}\right)}$$

$\underline{V_{max} = R, \quad M_{max} = M_a}$

$$\sigma_b = \frac{My}{I}, \quad \tau = \frac{QV}{IW}$$



$I = \frac{1}{12} W_b t_b^3$

$$\boxed{\sigma_{b_{max}} = \frac{6M_a}{W_b t_b^2}}$$

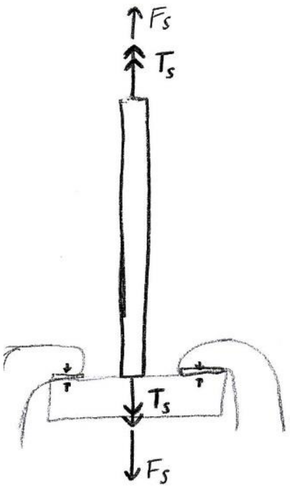
$$\boxed{\tau_{max} = \frac{3R}{2W_b t_b}}$$

Max deflection = deflection of beam + deflection of shaft

Von-Mises Stress:

$$\sigma' = \frac{S_y}{n} = \left(\sigma_{b_{max}} + 3\tau_{max}\right)^{1/2} \Rightarrow \boxed{n = \frac{S_y}{\left(\sigma_s + 3\tau_s\right)^{1/2}}}$$

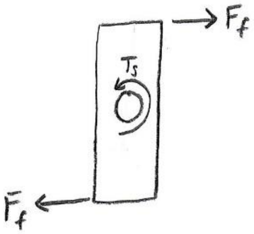
Figure A.4.6 Handwritten Analysis Calculations (c)



F_s = Norm force in the shaft from weight

T_s = Torque required to rotate shaft 90°

T_s = function of friction forces between rectangular bar and hooks on doors



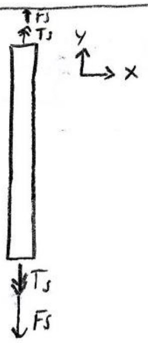
$$F_f = \mu F_r$$

$$\boxed{T_s = \mu F_r w_b}$$

$$\boxed{\tau_{max_s} = \frac{16 T_s}{\pi d_s^3}}$$

$$\boxed{\sigma_s = \frac{4 F_s}{\pi d_s^2}}$$

Von-Mises Stress:



$$\sigma' = \frac{S_y}{n} = (\sigma_s + 3\tau_s)^{1/2}$$

$$\boxed{n = \frac{S_y}{(\sigma_s + 3\tau_s)^{1/2}}}$$

Deformation in the shaft:

$$\delta_s = \frac{-PL}{EA} \Rightarrow \boxed{\frac{4 F_s L_s}{E_s \pi d_s^2} = \delta_s}$$

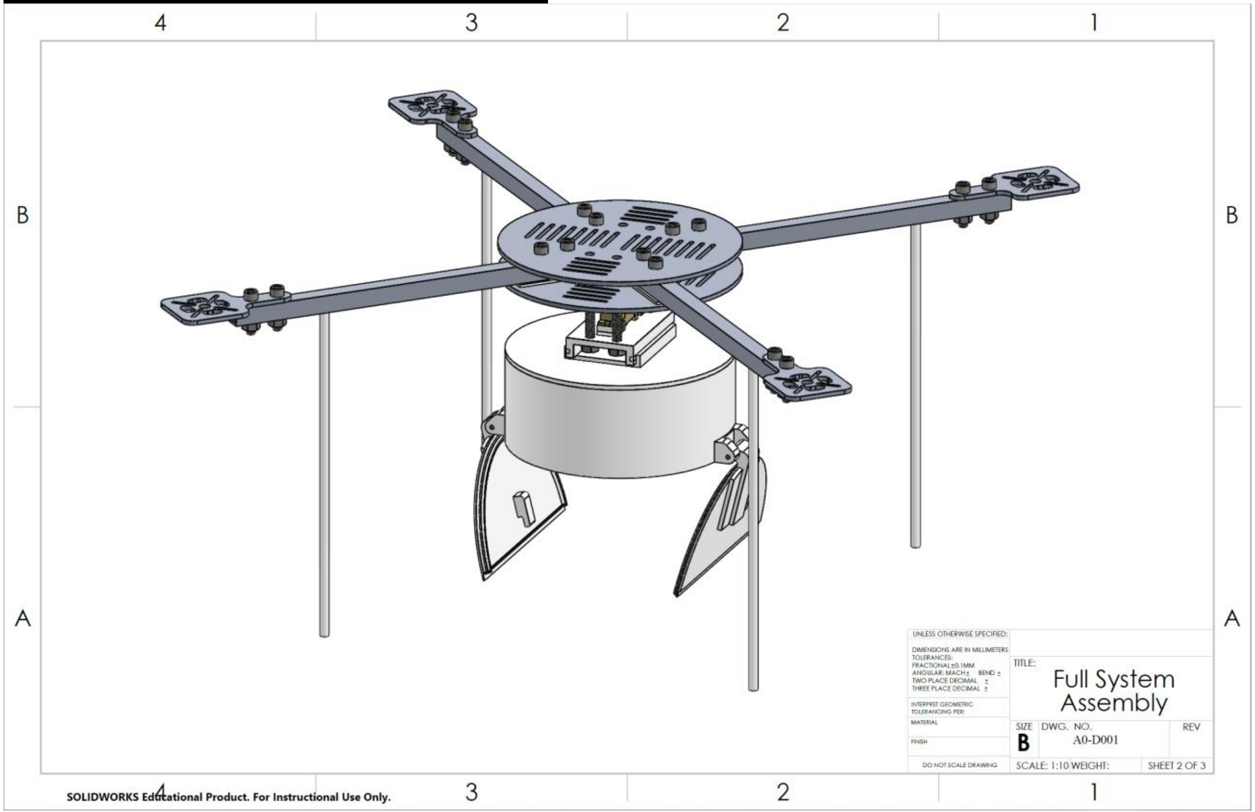
Figure A.4.7 Handwritten Analysis Calculations (d)

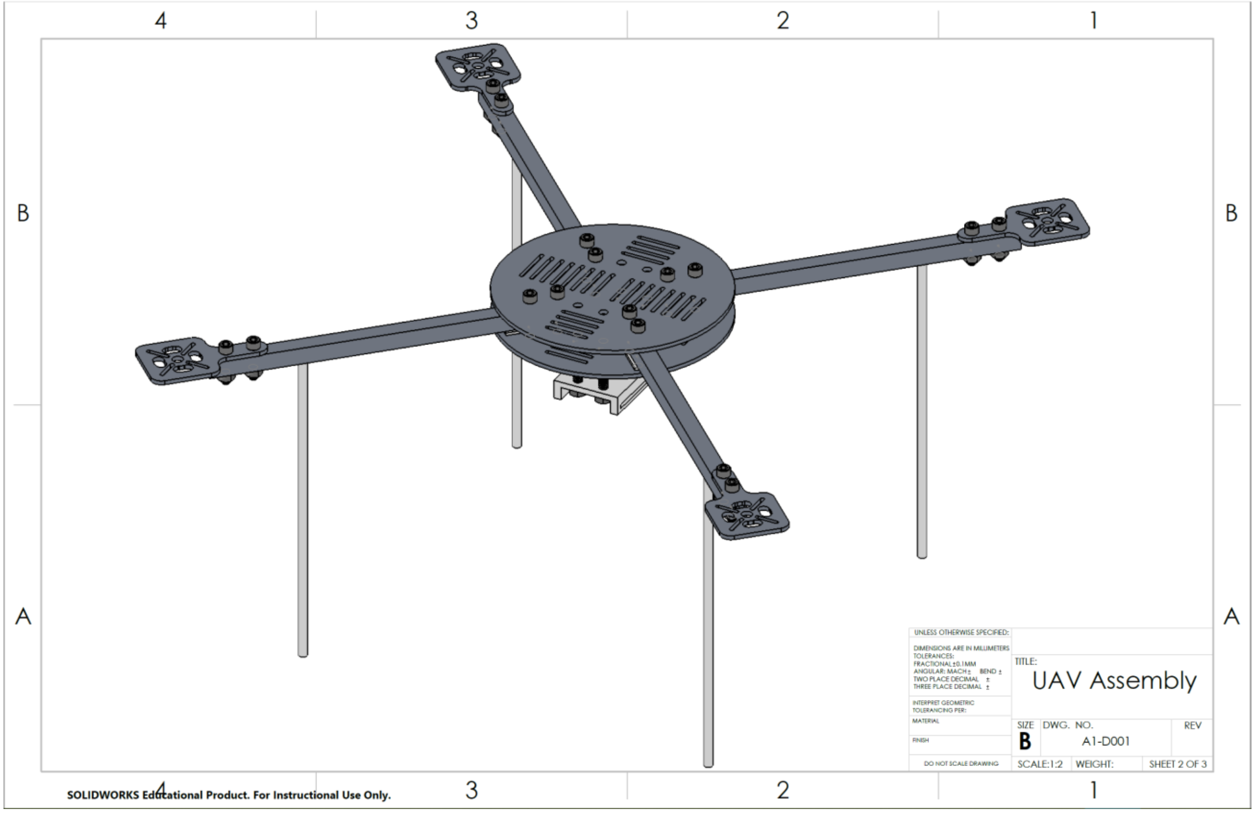
Deformation in block:

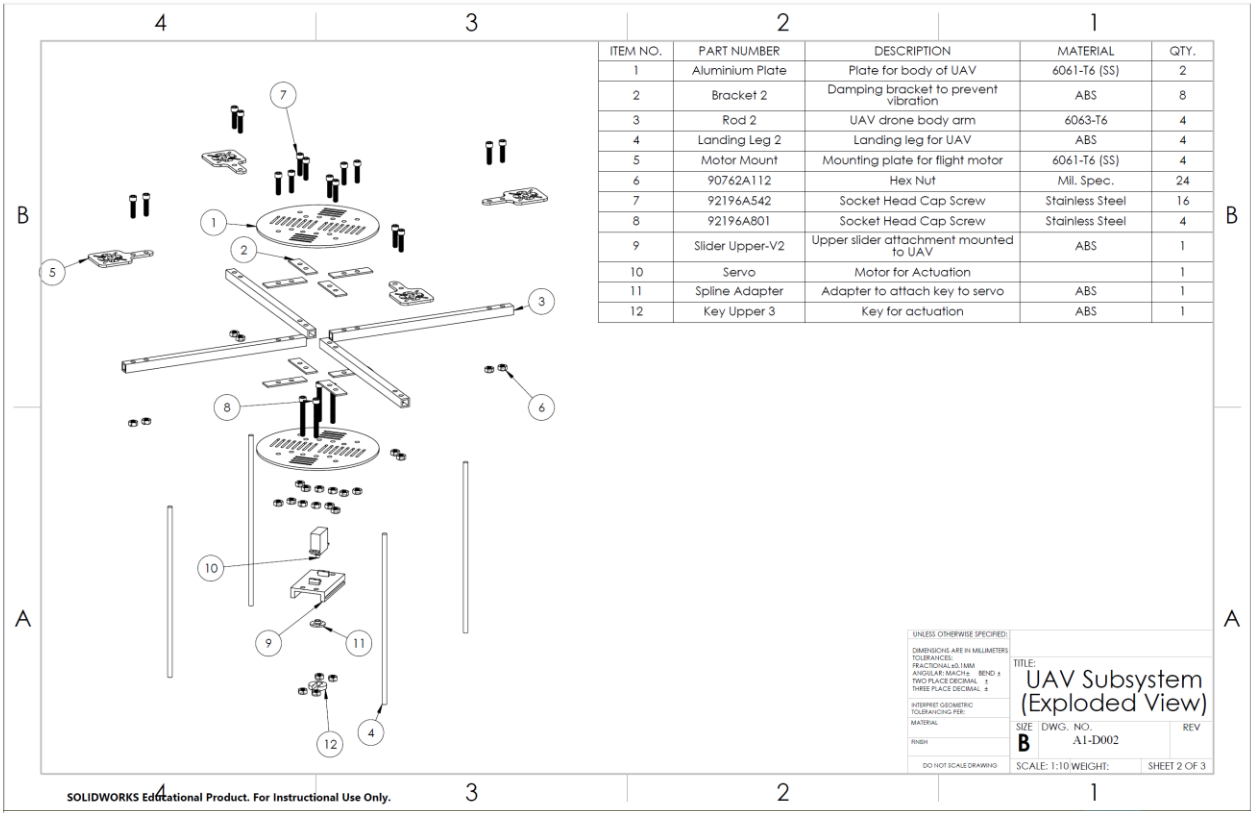
$$\delta_b = \frac{-F_r\left(\frac{L_b}{2} - \frac{d_s}{2}\right)^3}{3\,E_B\left(\frac{1}{12}\right)w_b\,t_b^{\,3}} - \frac{\left(\ell_b\, g\, w_b\, t_b\right)\left(\frac{L_b}{2} - \frac{d_s}{2}\right)^4}{8\,E\left(\frac{1}{12}\right)w_b\,t_b^{\,3}} - \delta_s$$

Figure A.4.8 Handwritten Analysis Calculations (e)

Appendix B: Detailed Drawing Package







ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	QTY.
1	Aluminium Plate	Plate for body of UAV	6061-T6 (SS)	2
2	Bracket 2	Damping bracket to prevent vibration	ABS	8
3	Rod 2	UAV drone body arm	6063-T6	4
4	Landing Leg 2	Landing leg for UAV	ABS	4
5	Motor Mount	Mounting plate for flight motor	6061-T6 (SS)	4
6	90762A112	Hex Nut	Mil. Spec.	24
7	92196A542	Socket Head Cap Screw	Stainless Steel	16
8	92196A801	Socket Head Cap Screw	Stainless Steel	4
9	Slider Upper-V2	Upper slider attachment mounted to UAV	ABS	1
10	Servo	Motor for Actuation		1
11	Spline Adapter	Adapter to attach key to servo	ABS	1
12	Key Upper 3	Key for actuation	ABS	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±0.1MM
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

TITLE: UAV Subsystem (Exploded View)

SIZE B DWG. NO. A1-D002 REV

SCALE: 1:10 WEIGHT: SHEET 2 OF 3

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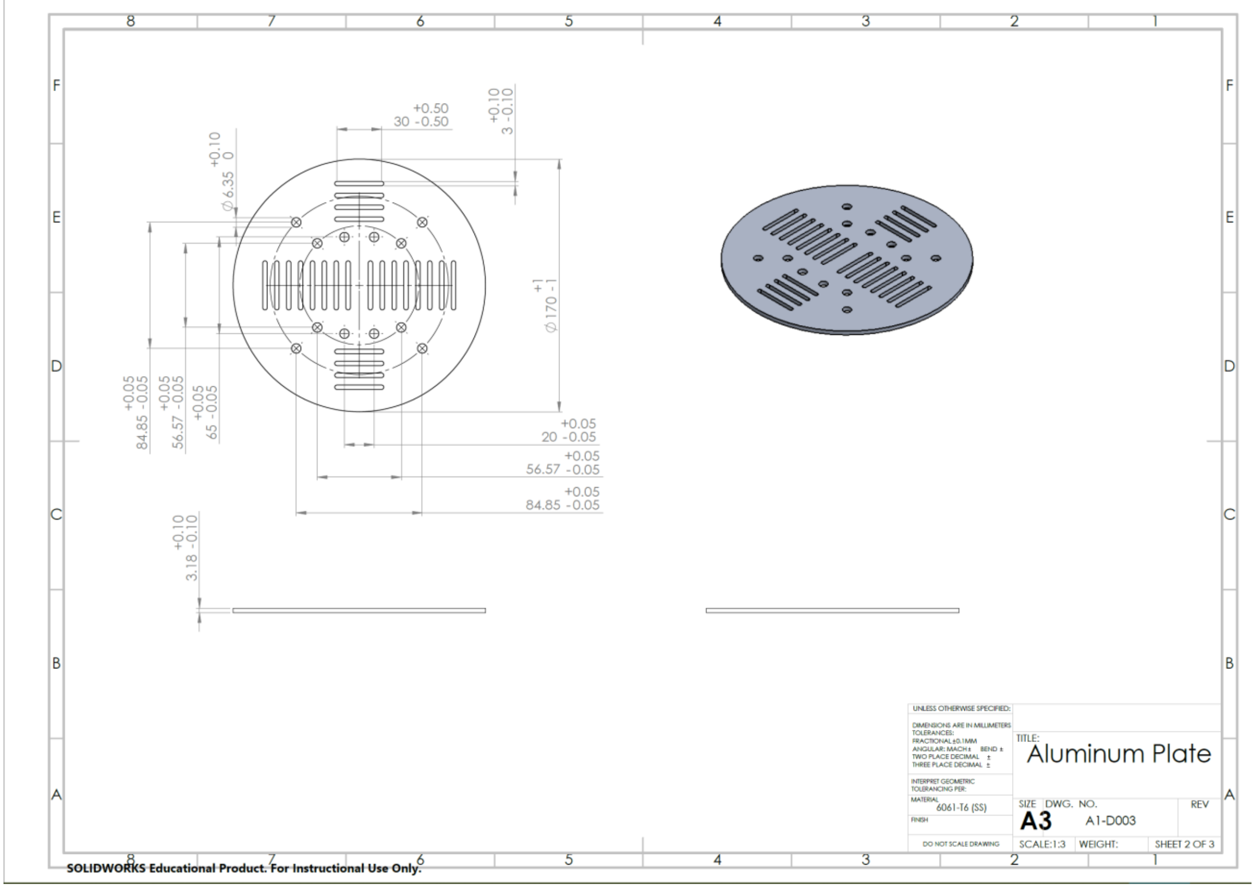

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±0.1MM
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL 6061-T6 (SS)
FINISH
DO NOT SCALE DRAWING

TITLE: Aluminum Plate

SIZE A3 DWG. NO. A1-D003 REV

SCALE:1:3 WEIGHT: SHEET 2 OF 3

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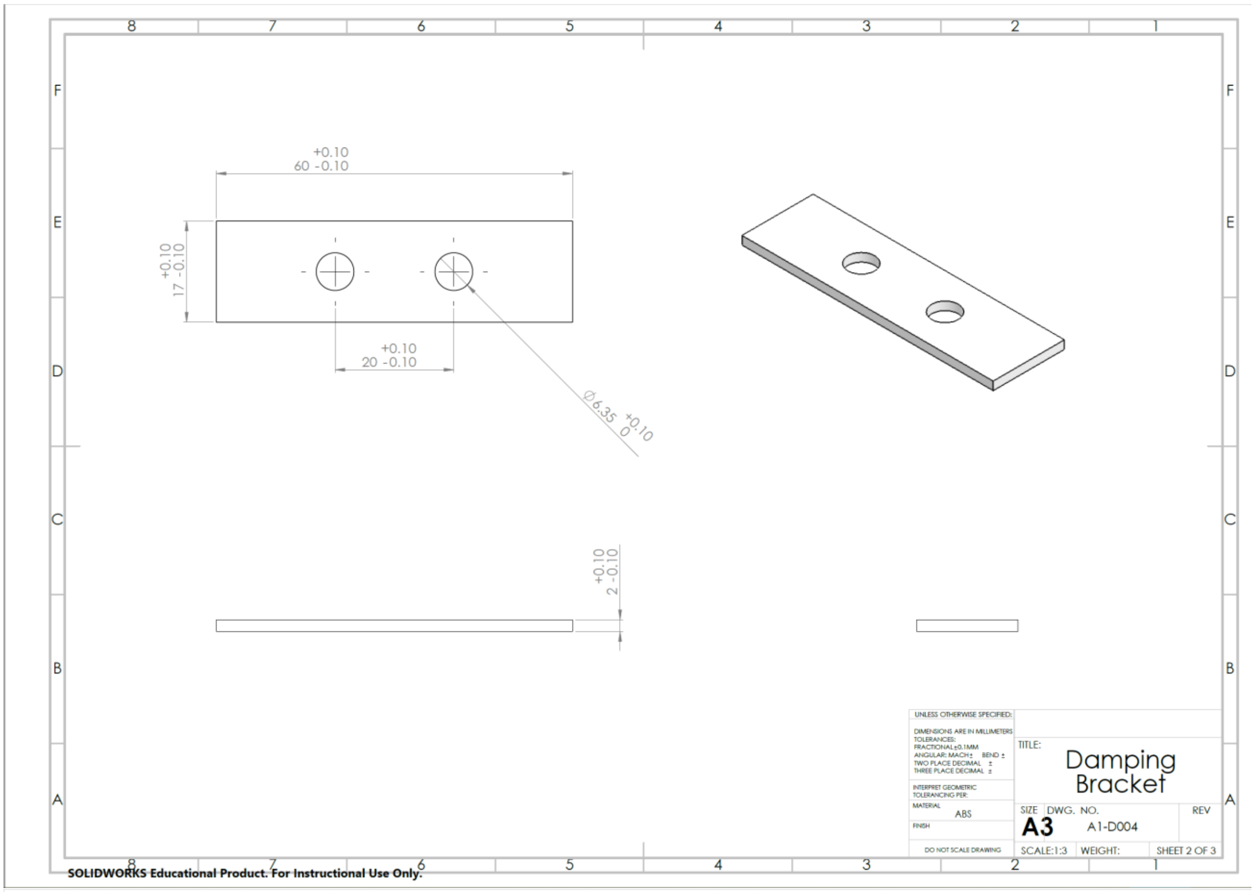
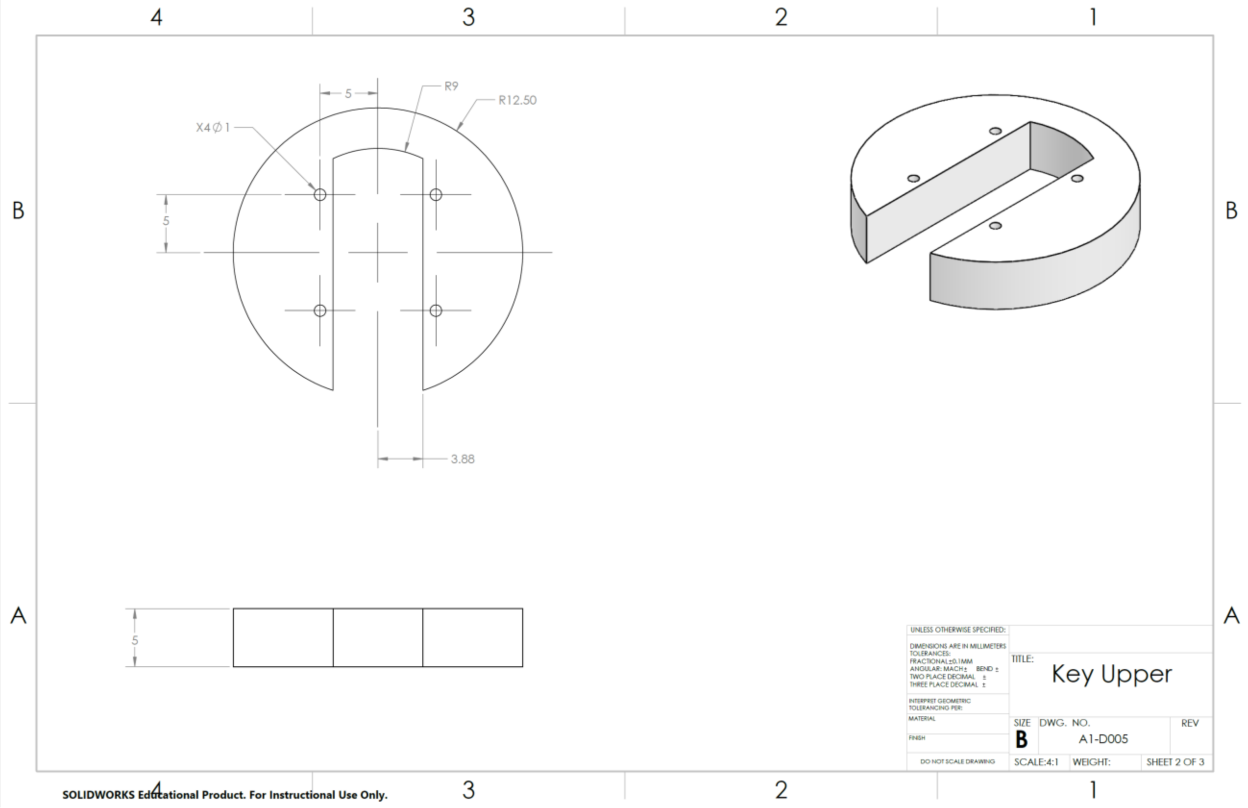
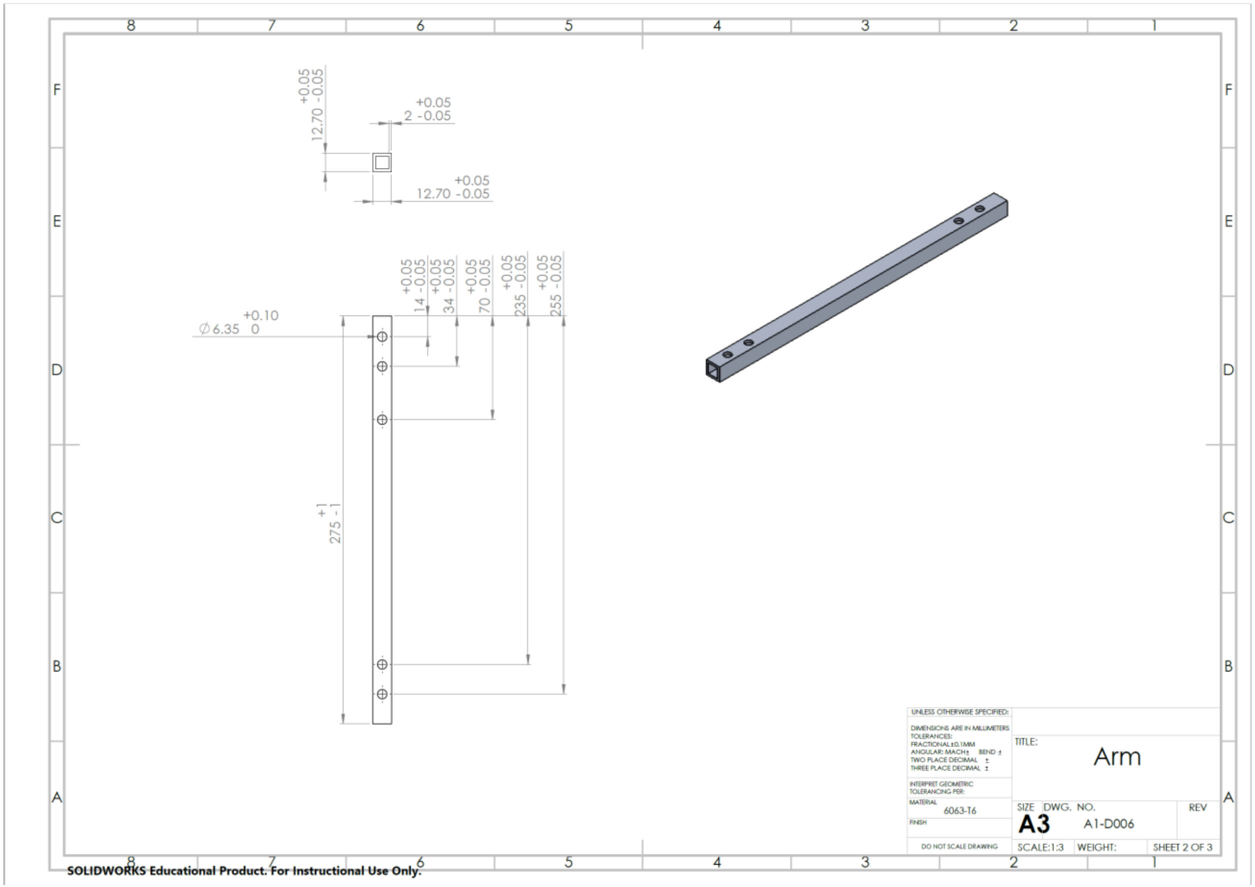


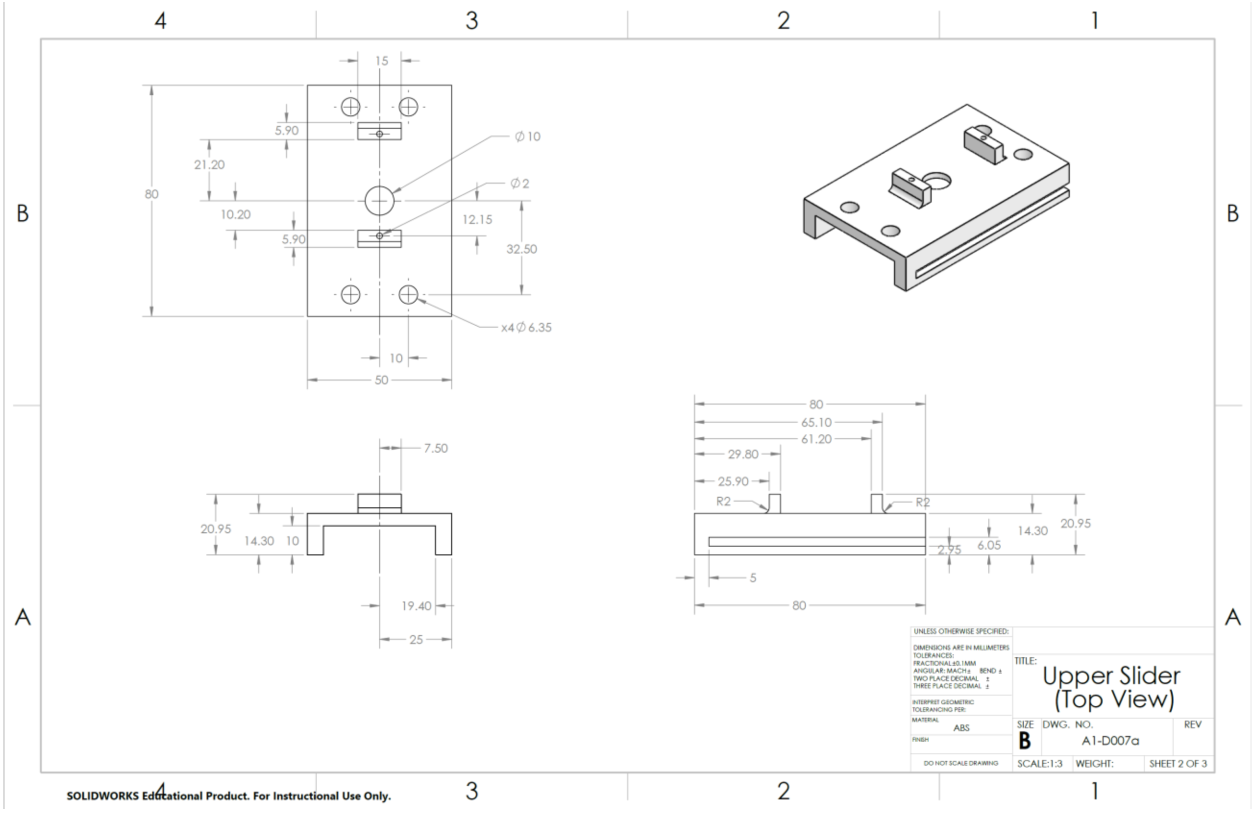
60 +0.10 -0.10
17 +0.10 -0.10
20 +0.10 -0.10
∅6.35 +0.10 0
2 +0.10 -0.10
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL±0.1MM
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ABS
FINISH
DO NOT SCALE DRAWING
TITLE:
Damping Bracket
SIZE
A3
DWG. NO.
A1-D004
REV
SCALE:1:3
WEIGHT:
SHEET 2 OF 3
SOLIDWORKS Educational Product. For Instructional Use Only.



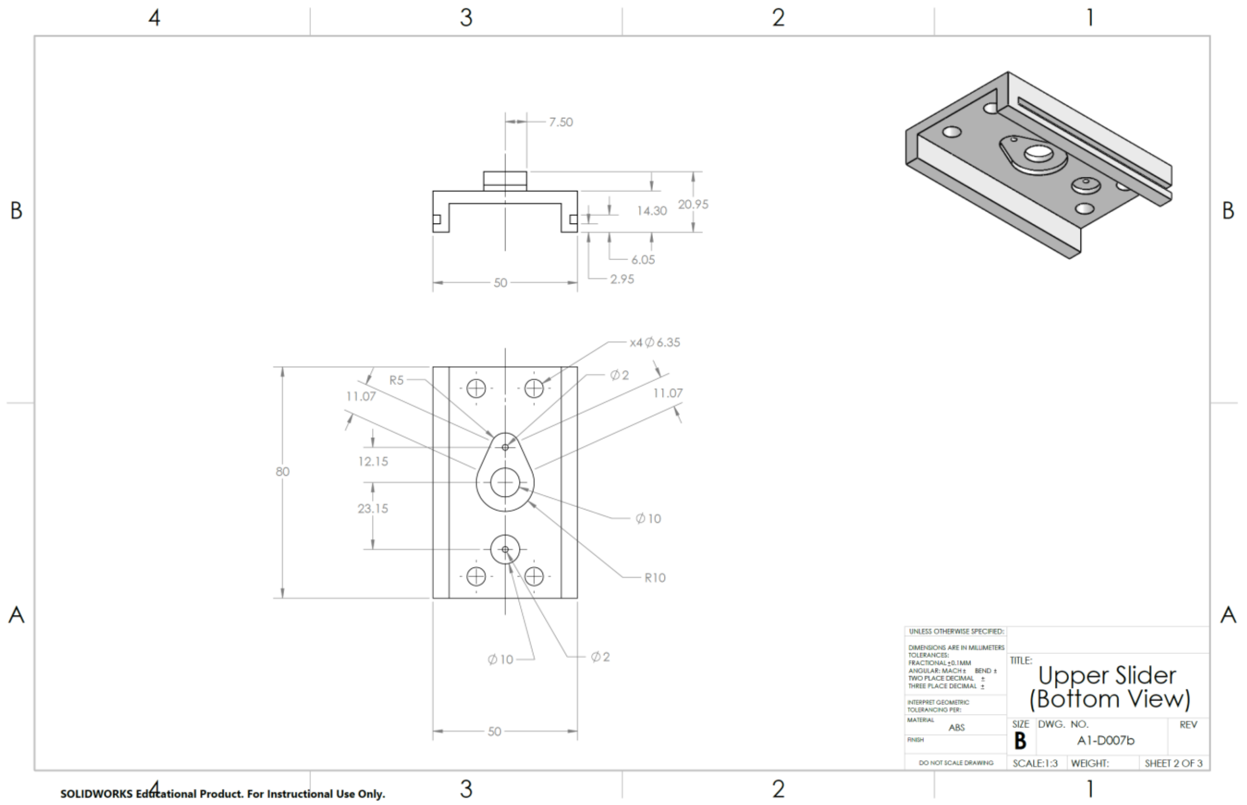
5
R9
R12.50
X4 ∅ 1
5
3.88
5
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL±0.1MM
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
TITLE:
Key Upper
SIZE
B
DWG. NO.
A1-D005
REV
SCALE:4:1
WEIGHT:
SHEET 2 OF 3
SOLIDWORKS Educational Product. For Instructional Use Only.

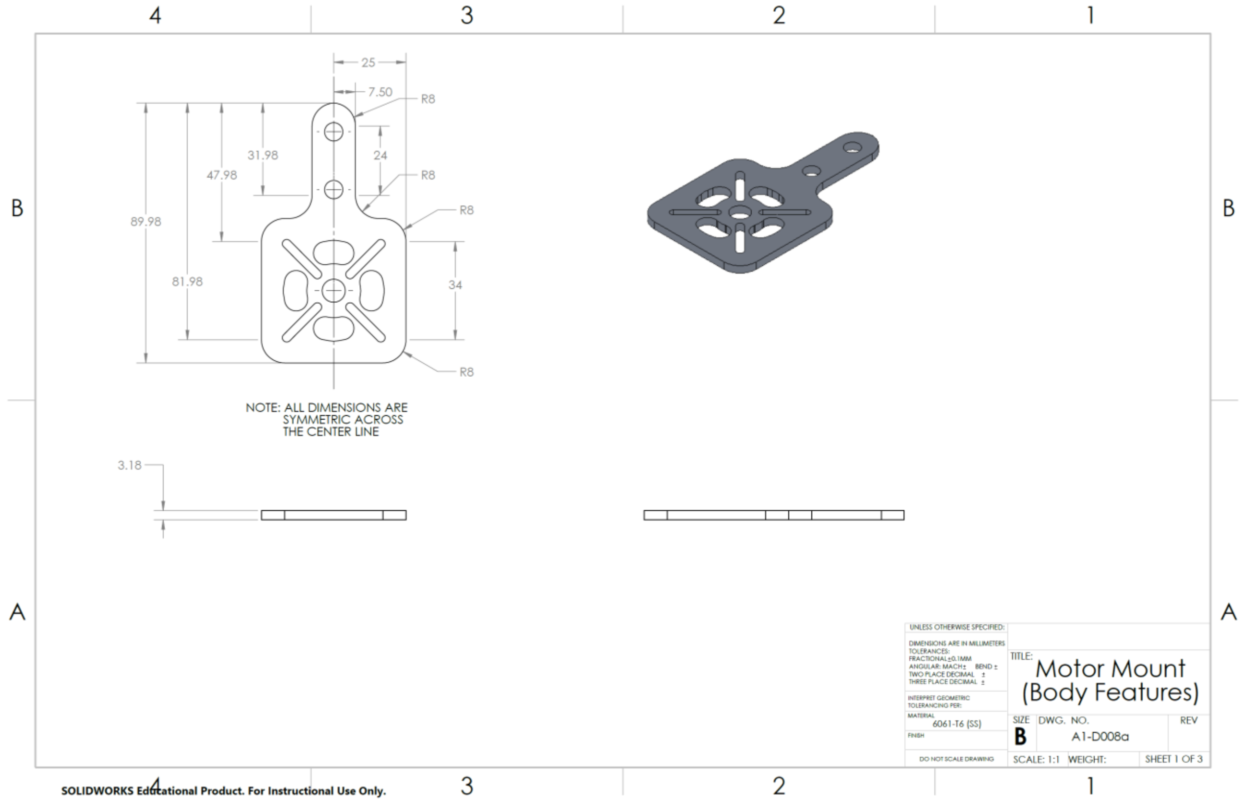


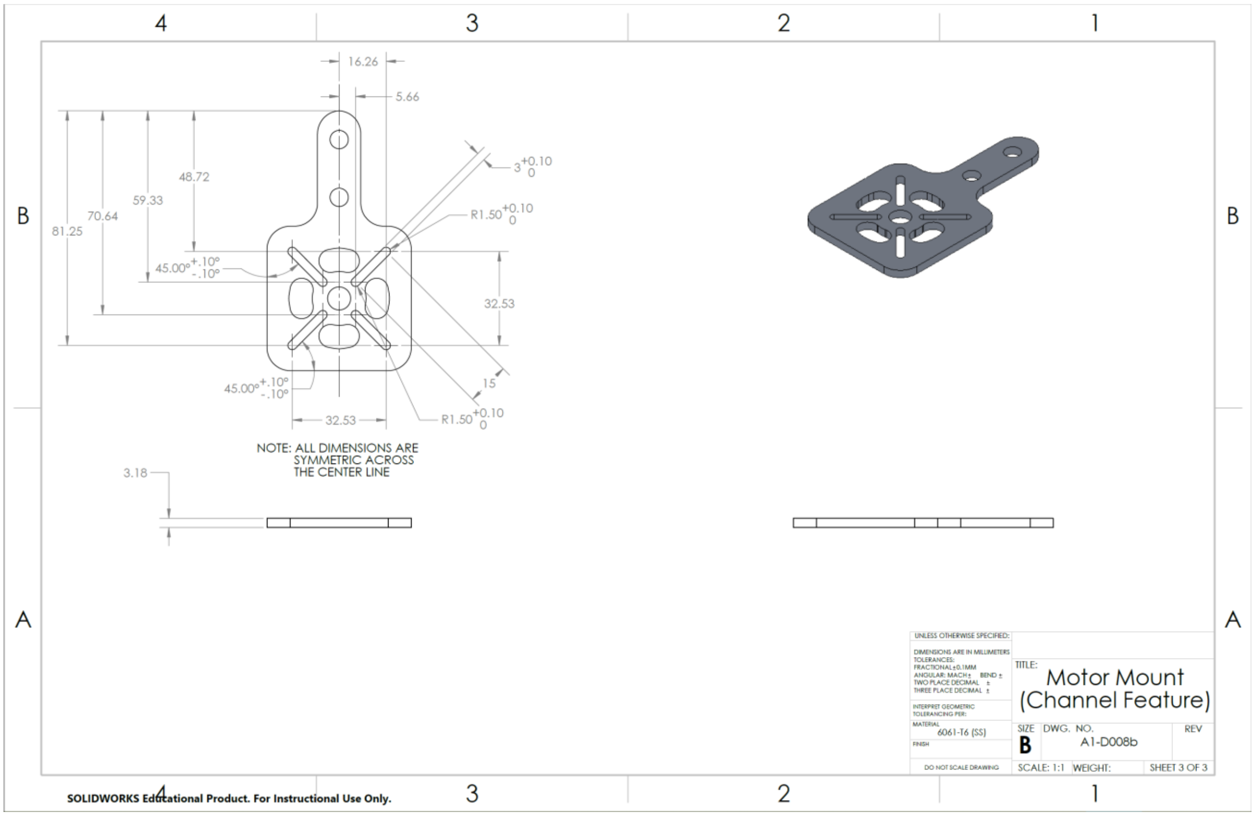
+0.05 12.70 -0.05
+0.05 2 -0.05
+0.05 12.70 -0.05
+0.10 ∅6.35 0
+0.05 14 -0.05
+0.05 34 -0.05
+0.05 70 -0.05
+0.05 235 -0.05
+0.05 255 -0.05
+1 275 -1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL±0.1MM
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL 6063-T6
FINISH
DO NOT SCALE DRAWING
TITLE:
Arm
SIZE A3
DWG. NO. A1-D006
REV
SCALE:1:3
WEIGHT:
SHEET 2 OF 3
SOLIDWORKS Educational Product. For Instructional Use Only.



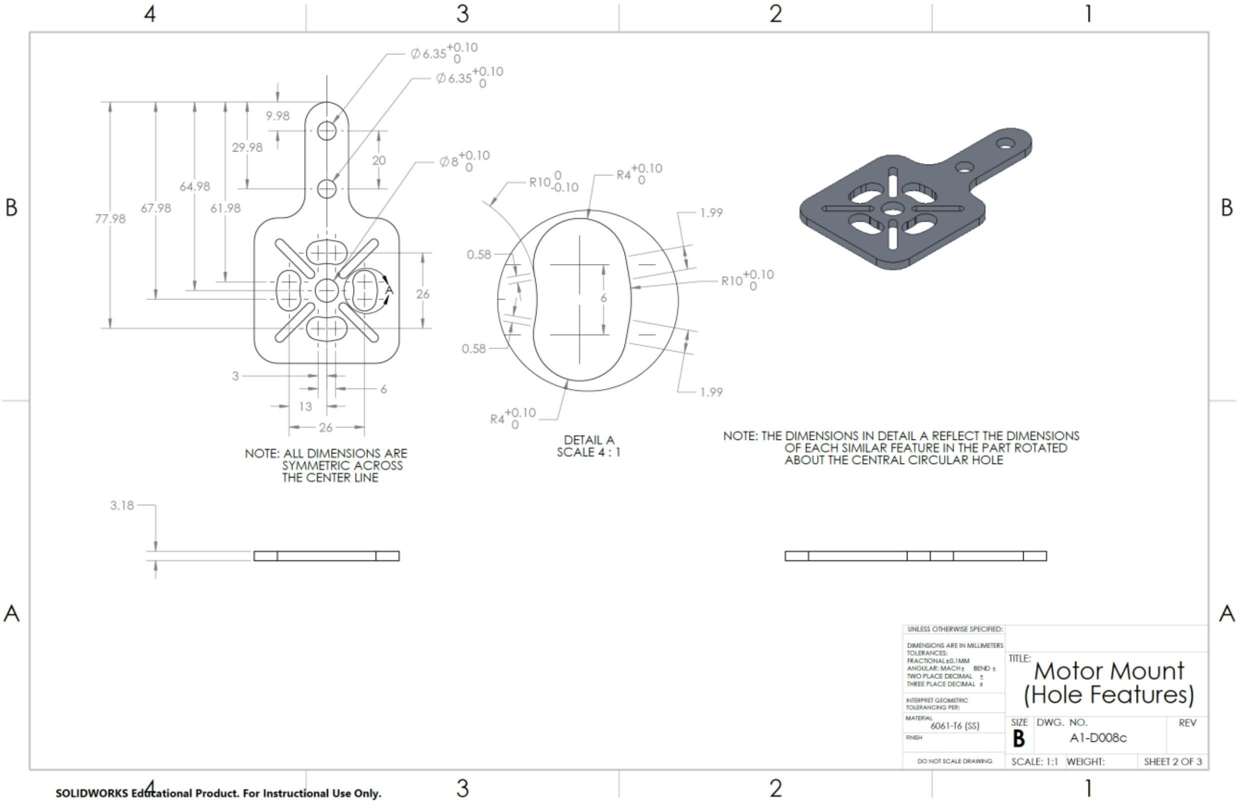
15
5.90
21.20
80
10.20
5.90
∅10
∅2
12.15
32.50
x4∅6.35
10
50
7.50
20.95
14.30
10
19.40
25
80
65.10
61.20
29.80
25.90
R2
R2
14.30
20.95
2.95
6.05
5
80
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL±0.1MM
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL ABS
FINISH
DO NOT SCALE DRAWING
TITLE:
Upper Slider (Top View)
SIZE B
DWG. NO. A1-D007a
REV
SCALE:1:3
WEIGHT:
SHEET 2 OF 3
SOLIDWORKS Educational Product. For Instructional Use Only.


4
3
2
1
B
A
7.50
14.30
20.95
6.05
2.95
50
x4 ∅6.35
R5
∅2
11.07
11.07
12.15
80
23.15
∅10
R10
∅10
∅2
50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±0.1MM
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ABS
FINISH
DO NOT SCALE DRAWING
TITLE:
Upper Slider (Bottom View)
SIZE
B
DWG. NO.
A1-D007b
REV
SCALE:1:3
WEIGHT:
SHEET 2 OF 3
SOLIDWORKS Educational Product. For Instructional Use Only.

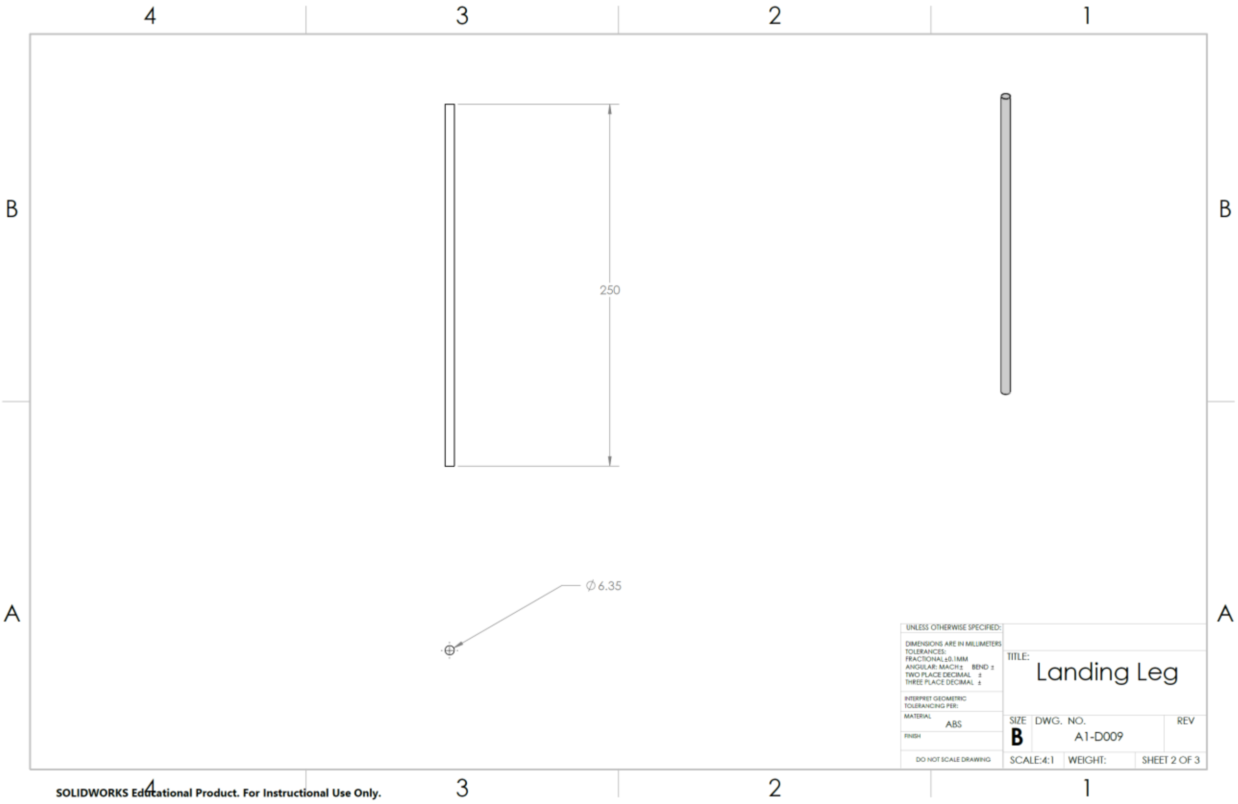

4
3
2
1
B
A
25
7.50
R8
24
R8
R8
31.98
47.98
89.98
81.98
34
R8
NOTE: ALL DIMENSIONS ARE SYMMETRIC ACROSS THE CENTER LINE
3.18
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±0.1MM
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061-T6 (SS)
FINISH
DO NOT SCALE DRAWING
TITLE:
Motor Mount (Body Features)
SIZE
B
DWG. NO.
A1-D008a
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 3
SOLIDWORKS Educational Product. For Instructional Use Only.

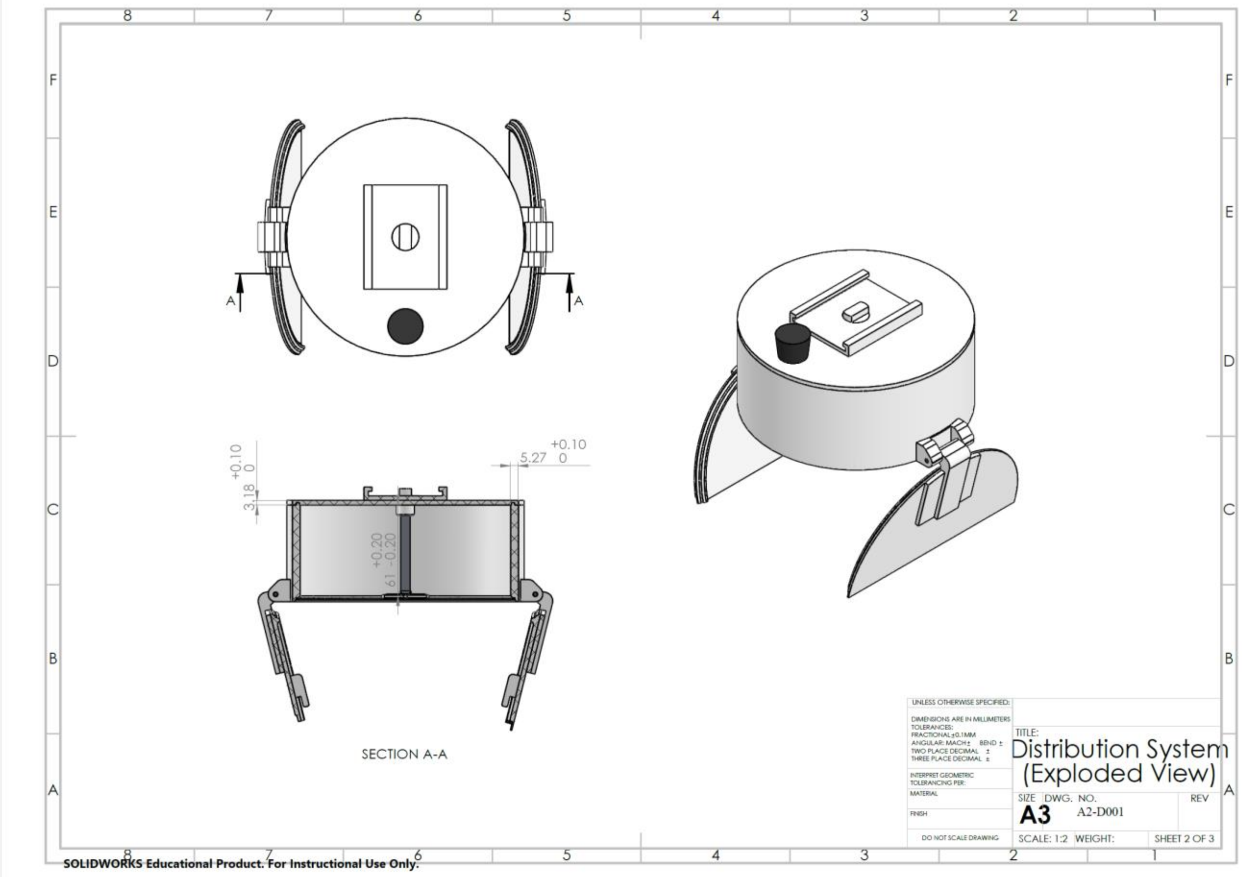


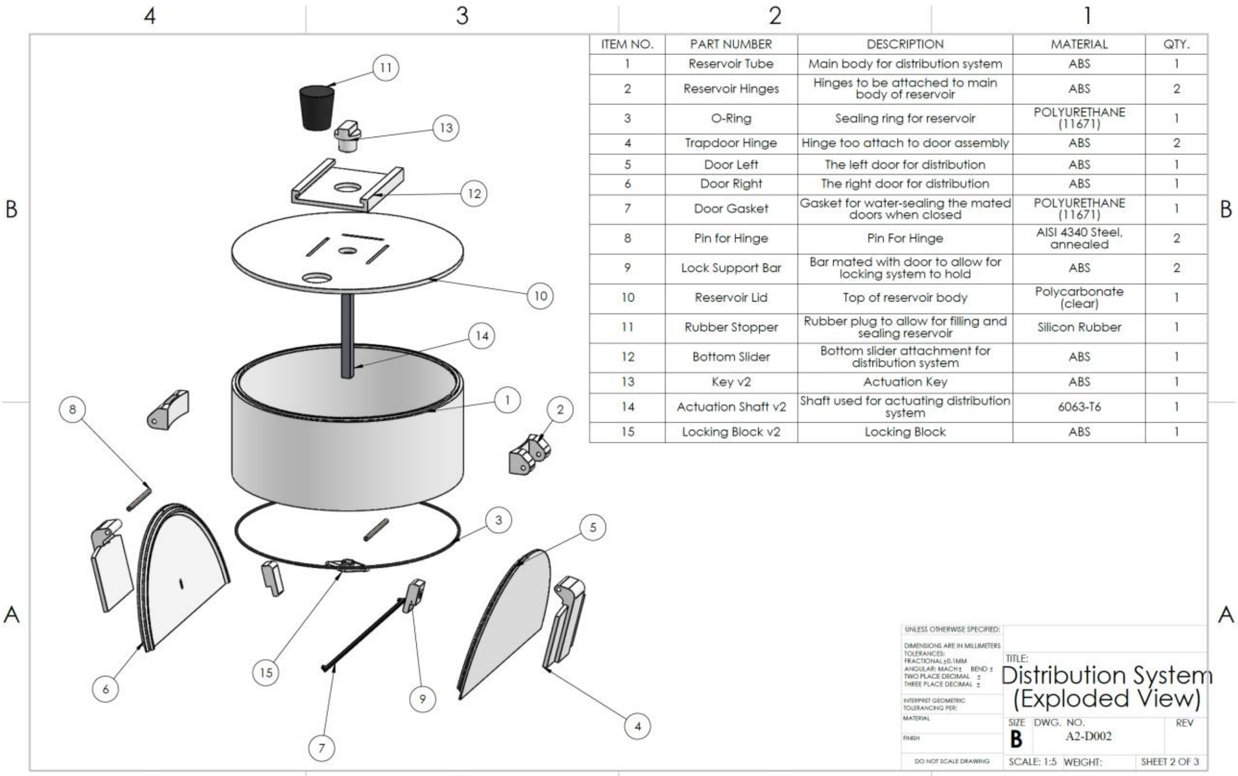
16.26
5.66
48.72
59.33
70.64
81.25
3 +0.10 0
R1.50 +0.10 0
45.00° +.10° -.10°
32.53
15
NOTE: ALL DIMENSIONS ARE SYMMETRIC ACROSS THE CENTER LINE
3.18
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: FRACTIONAL±0.1MM
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL 6061-T6 (SS)
FINISH
DO NOT SCALE DRAWING
TITLE: Motor Mount (Channel Feature)
SIZE B
DWG. NO. A1-D008b
REV
SCALE: 1:1
WEIGHT:
SHEET 3 OF 3
SOLIDWORKS Educational Product. For Instructional Use Only.



Ø6.35 +0.10 0
Ø6.35 +0.10 0
Ø8 +0.10 0
9.98
29.98
20
64.98
67.98
61.98
77.98
26
3
13
6
R10 0 -0.10
R4 +0.10 0
R10 +0.10 0
0.58
1.99
DETAIL A SCALE 4 : 1
NOTE: ALL DIMENSIONS ARE SYMMETRIC ACROSS THE CENTER LINE
NOTE: THE DIMENSIONS IN DETAIL A REFLECT THE DIMENSIONS OF EACH SIMILAR FEATURE IN THE PART ROTATED ABOUT THE CENTRAL CIRCULAR HOLE
3.18
UNLESS OTHERWISE SPECIFIED:
MATERIAL 6061-T6 (SS)
TITLE: Motor Mount (Hole Features)
SIZE B
DWG. NO. A1-D008c
SCALE: 1:1
WEIGHT:
SHEET 2 OF 3
SOLIDWORKS Educational Product. For Instructional Use Only.


4
3
2
1
B
A
250
Ø 6.35
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL±0.1MM
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ABS
FINISH
DO NOT SCALE DRAWING
TITLE:
Landing Leg
SIZE
B
DWG. NO.
A1-D009
REV
SCALE:4:1
WEIGHT:
SHEET 2 OF 3
SOLIDWORKS Educational Product. For Instructional Use Only.


8
7
6
5
4
3
2
1
F
E
D
C
B
A
A
A
+0.10
0
3.18
5.27
+0.10
0
61
+0.20
-0.20
SECTION A-A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL±0.1MM
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
TITLE:
Distribution System (Exploded View)
SIZE
A3
DWG. NO.
A2-D001
REV
SCALE: 1:2
WEIGHT:
SHEET 2 OF 3
SOLIDWORKS Educational Product. For Instructional Use Only.

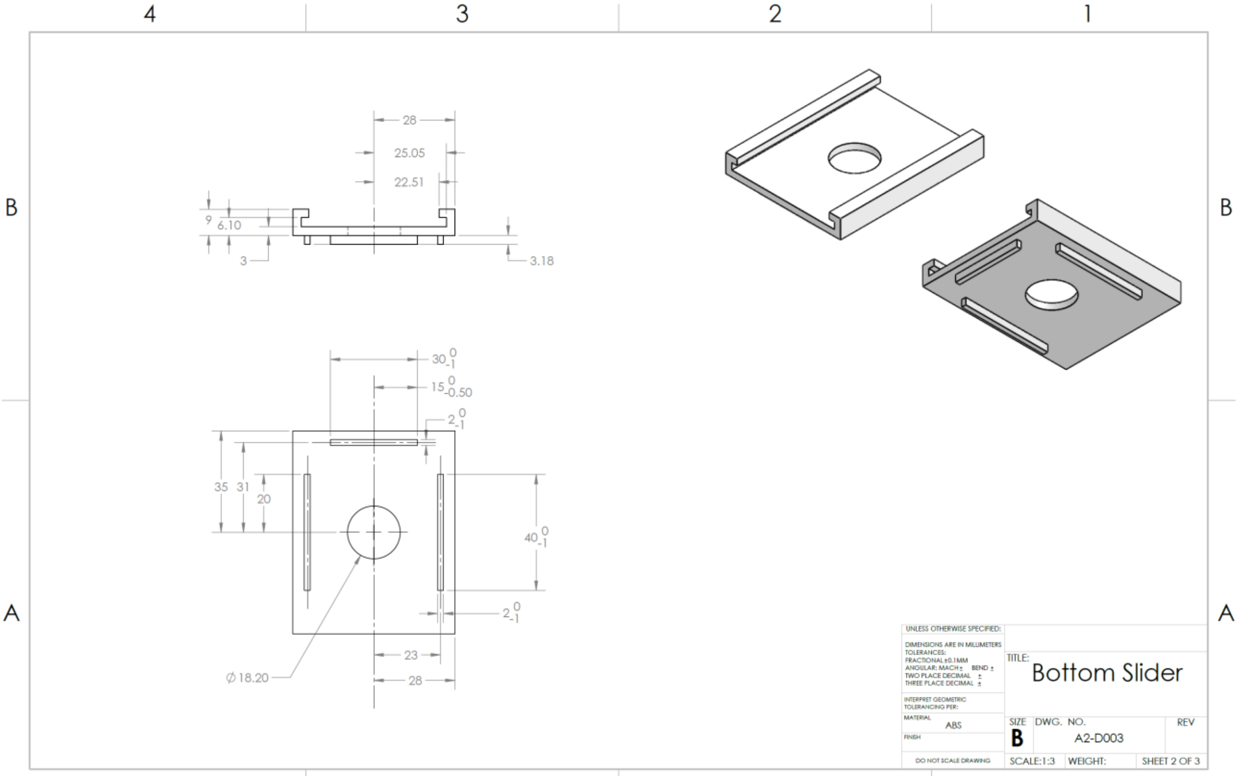


ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	QTY.
1	Reservoir Tube	Main body for distribution system	ABS	1
2	Reservoir Hinges	Hinges to be attached to main body of reservoir	ABS	2
3	O-Ring	Sealing ring for reservoir	POLYURETHANE (11671)	1
4	Trapdoor Hinge	Hinge too attach to door assembly	ABS	2
5	Door Left	The left door for distribution	ABS	1
6	Door Right	The right door for distribution	ABS	1
7	Door Gasket	Gasket for water-sealing the mated doors when closed	POLYURETHANE (11671)	1
8	Pin for Hinge	Pin For Hinge	AISI 4340 Steel, annealed	2
9	Lock Support Bar	Bar mated with door to allow for locking system to hold	ABS	2
10	Reservoir Lid	Top of reservoir body	Polycarbonate (clear)	1
11	Rubber Stopper	Rubber plug to allow for filling and sealing reservoir	Silicon Rubber	1
12	Bottom Slider	Bottom slider attachment for distribution system	ABS	1
13	Key v2	Actuation Key	ABS	1
14	Actuation Shaft v2	Shaft used for actuating distribution system	6063-T6	1
15	Locking Block v2	Locking Block	ABS	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±0.1MM
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

TITLE:
Distribution System (Exploded View)

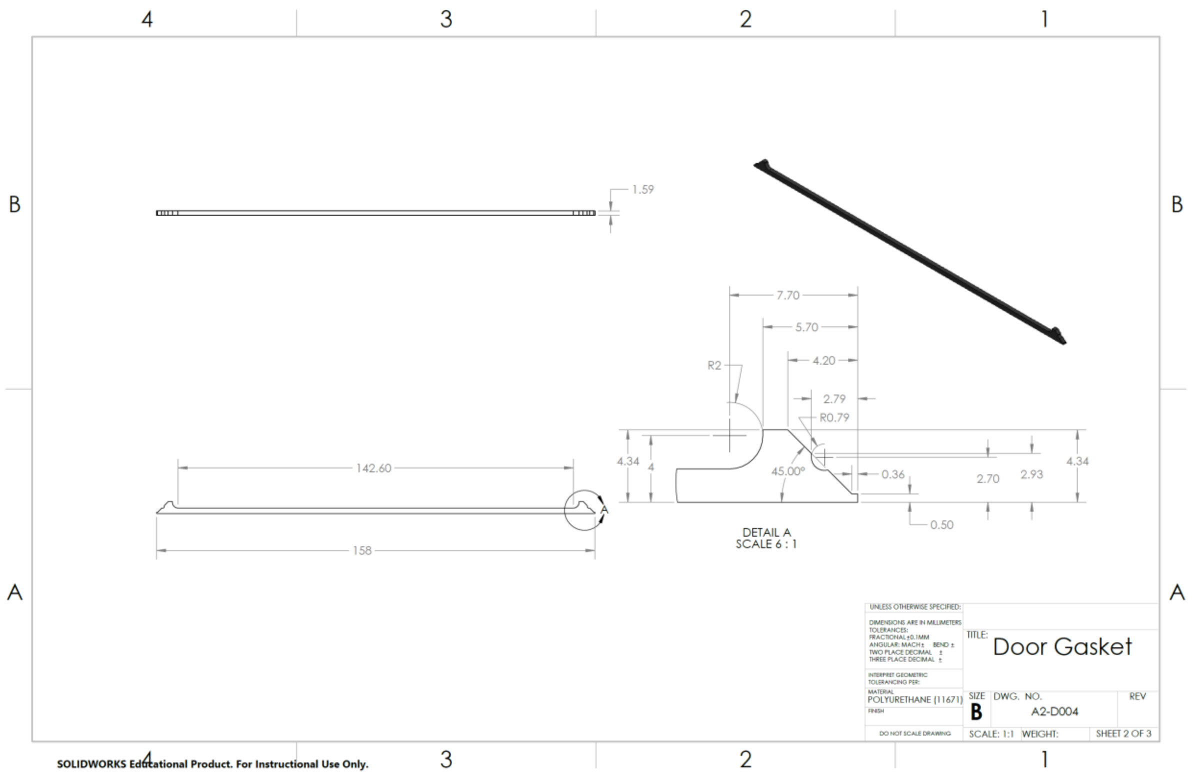
SIZE B
DWG. NO. A2-D002
REV
SCALE: 1:5
WEIGHT:
SHEET 2 OF 3



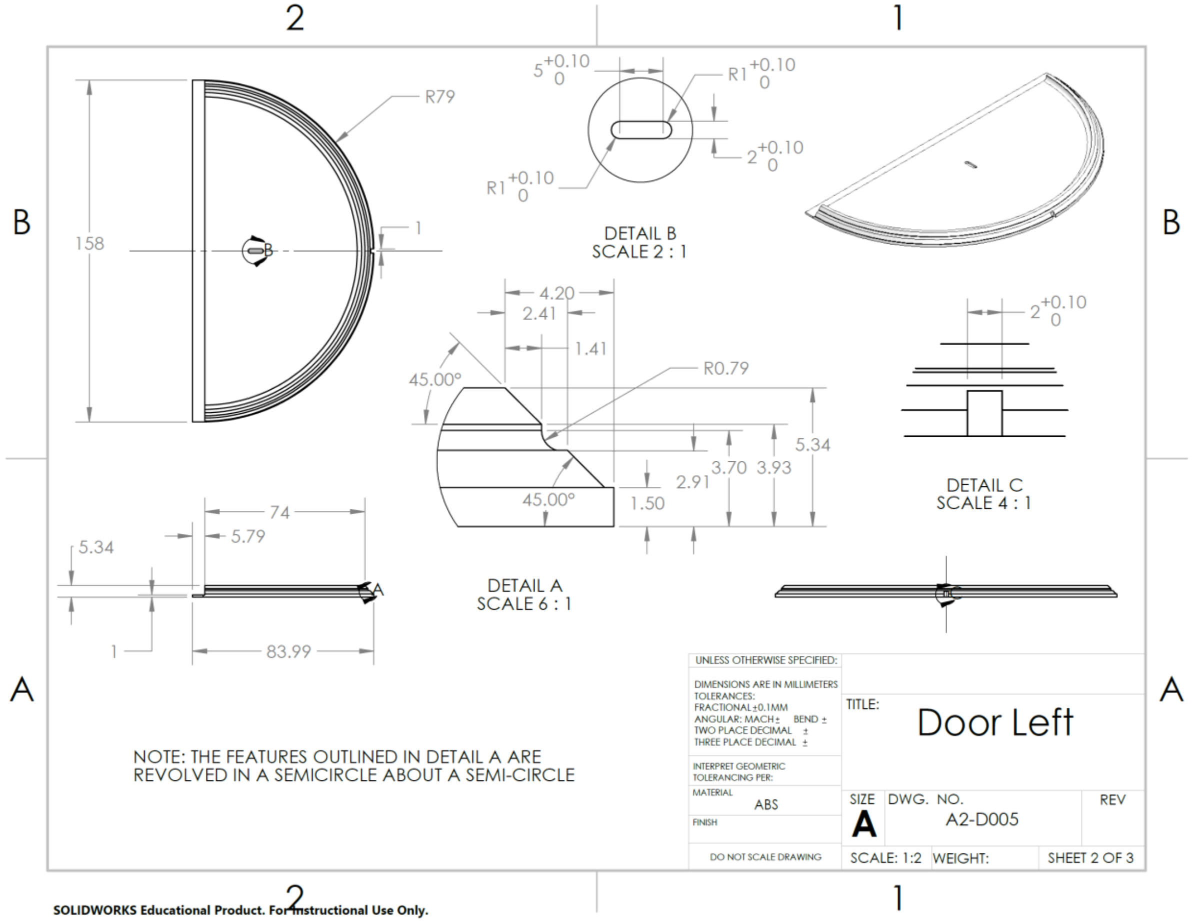
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±0.1MM
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL ABS
FINISH
DO NOT SCALE DRAWING

TITLE:
Bottom Slider

SIZE B
DWG. NO. A2-D003
REV
SCALE:1:3
WEIGHT:
SHEET 2 OF 3

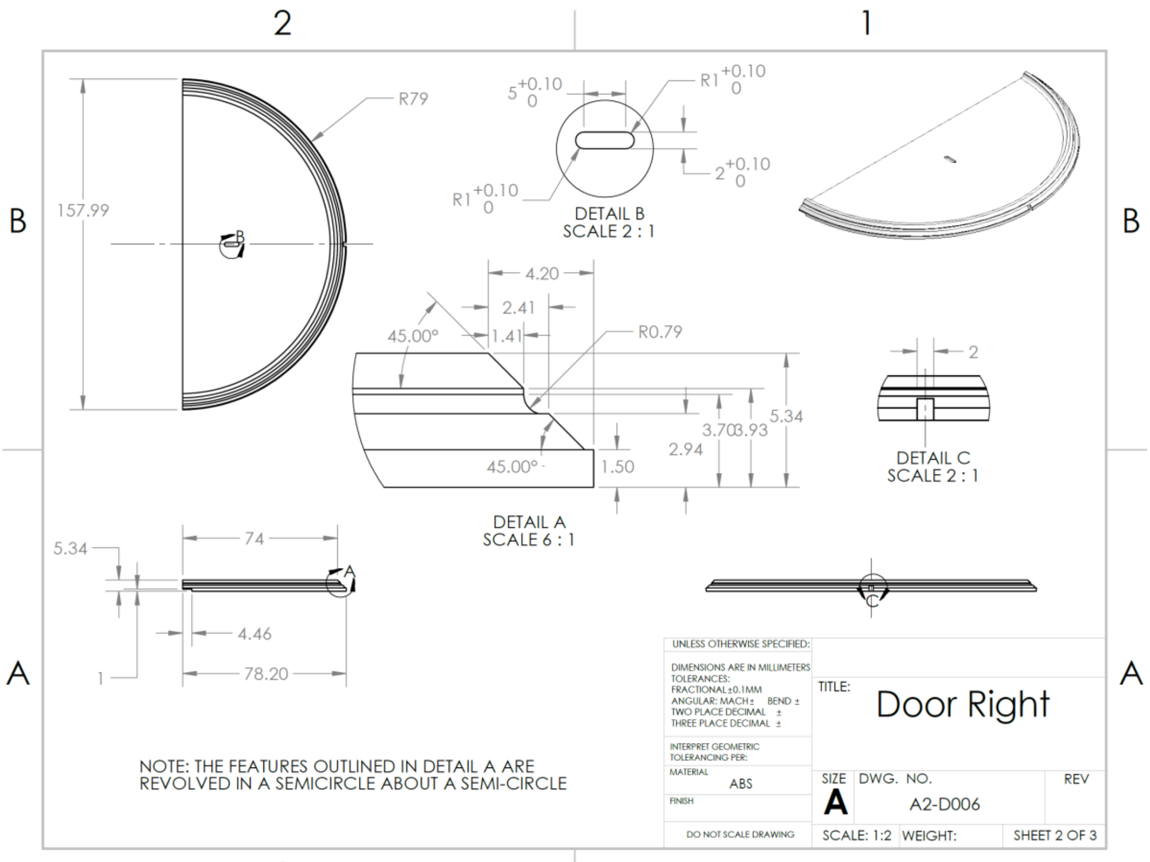


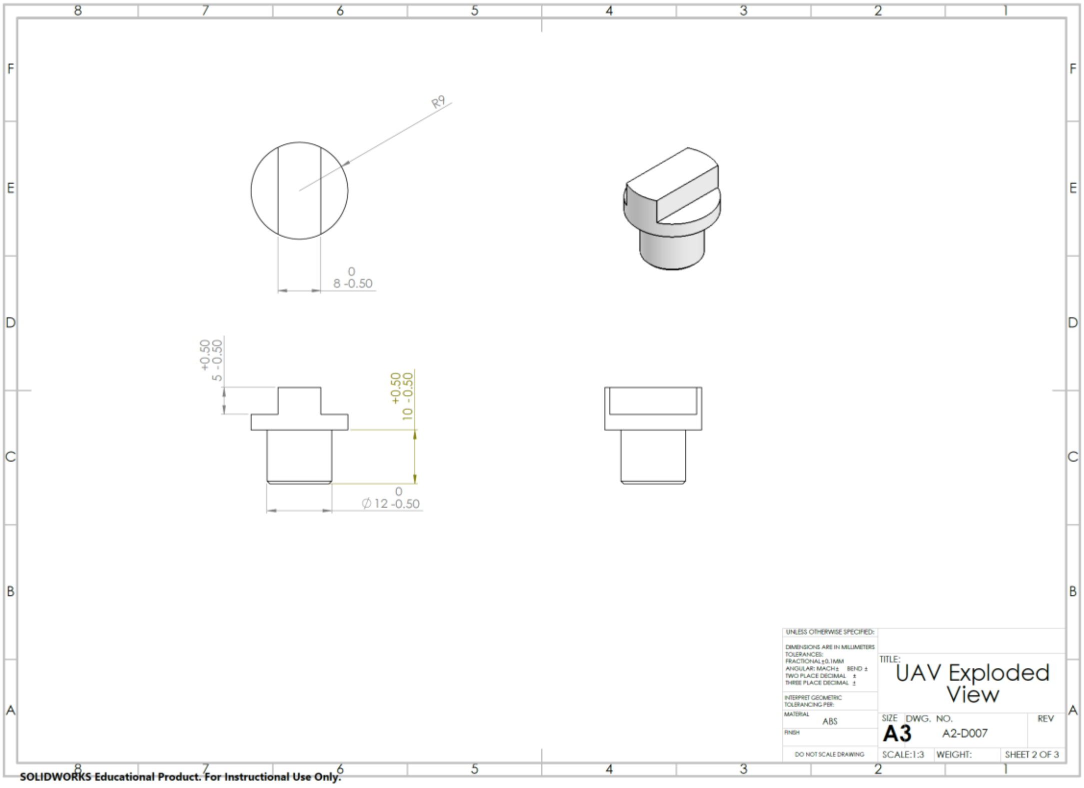
SOLIDWORKS Educational Product. For Instructional Use Only.

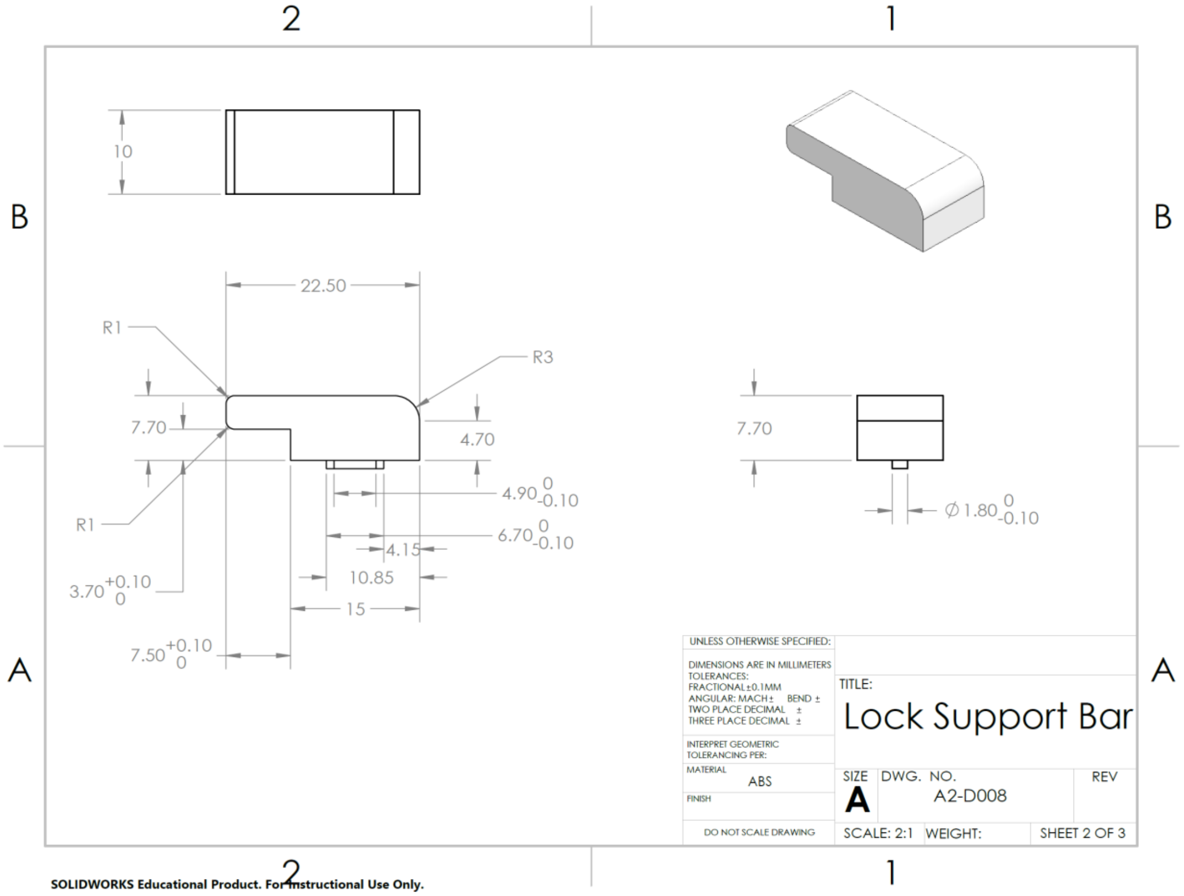


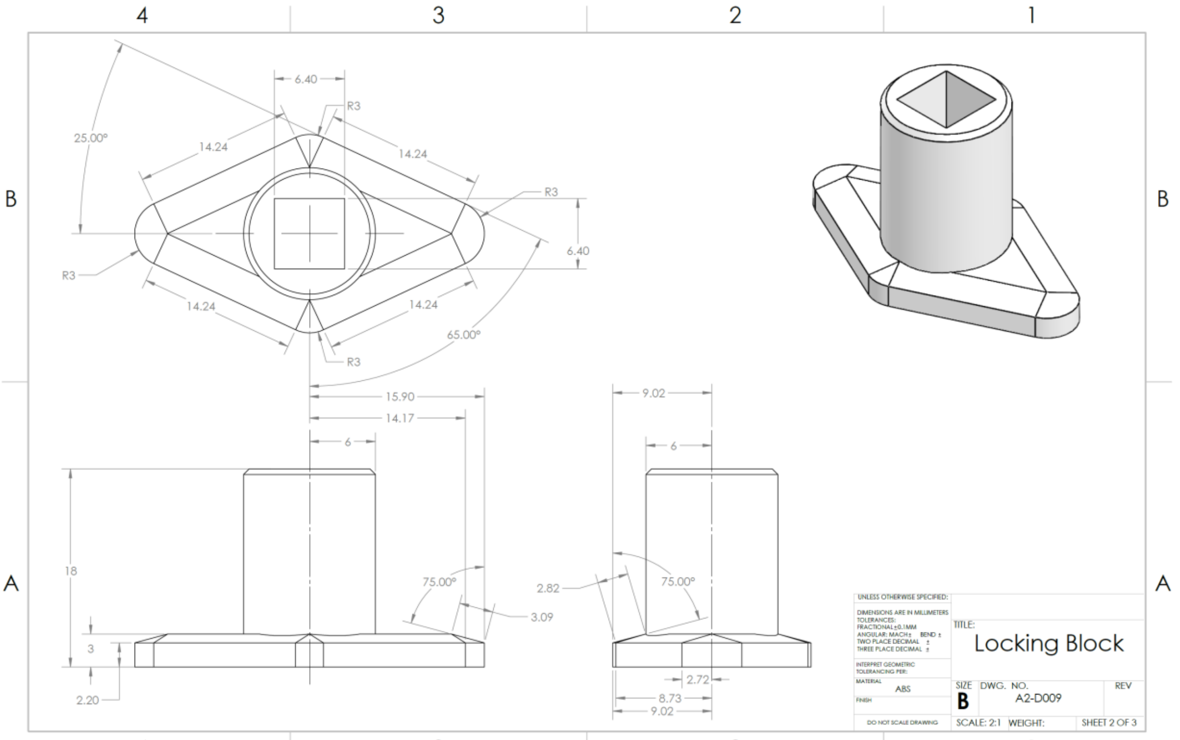
NOTE: THE FEATURES OUTLINED IN DETAIL A ARE
REVOLVED IN A SEMICIRCLE ABOUT A SEMI-CIRCLE

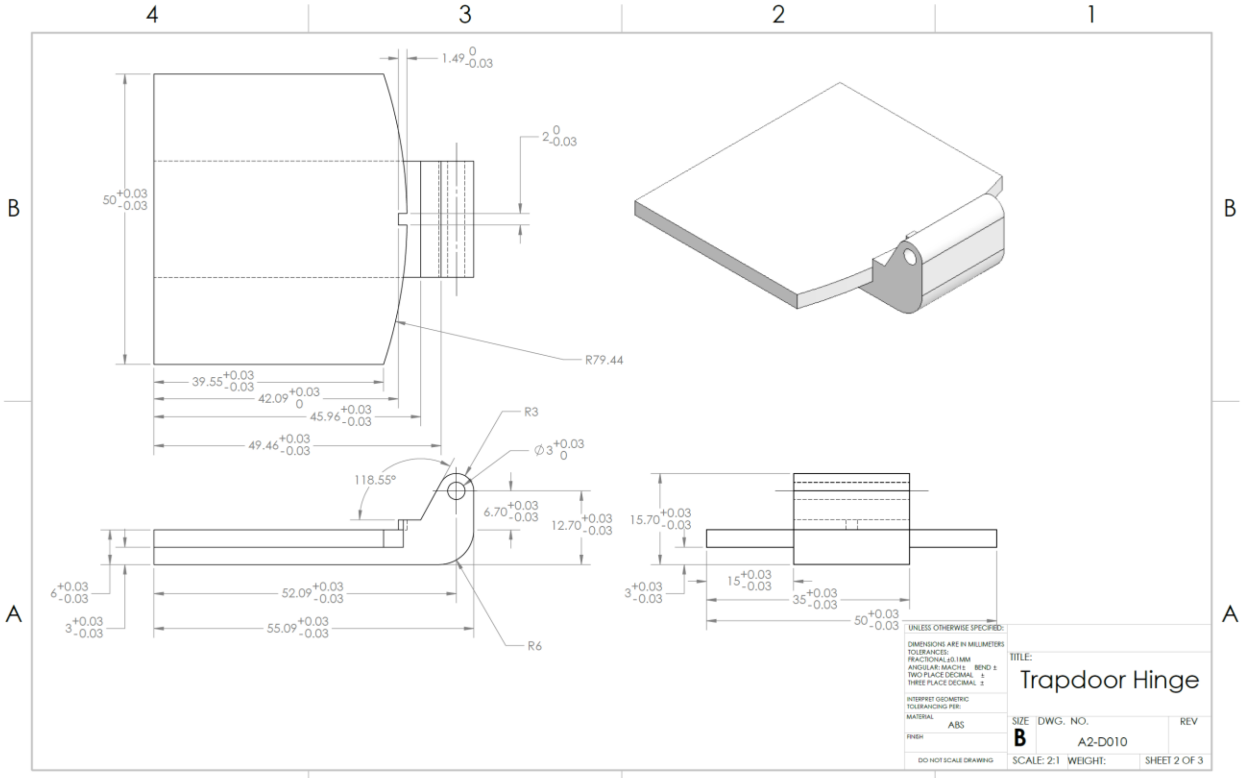
SOLIDWORKS Educational Product. For Instructional Use Only.

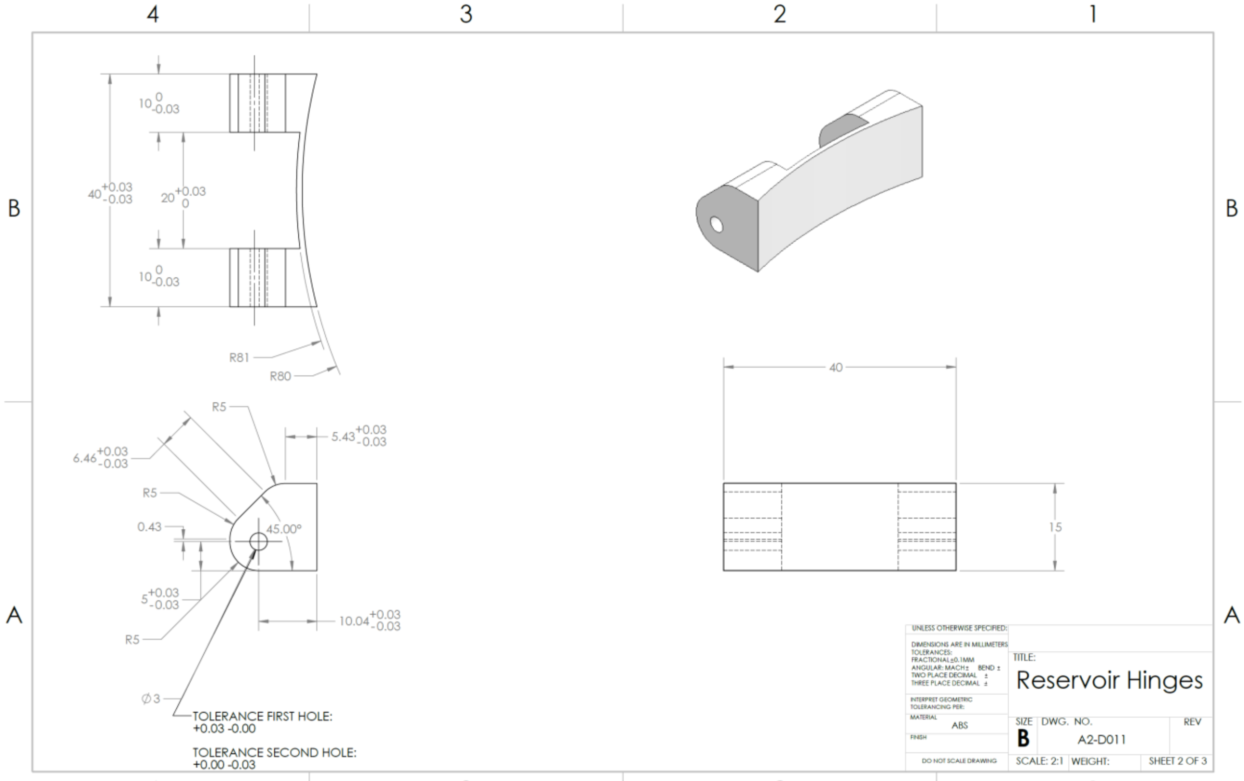

2
1
B
A
R79
157.99
5 +0.10 0
R1 +0.10 0
2 +0.10 0
DETAIL B
SCALE 2 : 1
4.20
2.41
1.41
45.00°
R0.79
5.34
3.70
3.93
2.94
1.50
45.00°
DETAIL A
SCALE 6 : 1
2
DETAIL C
SCALE 2 : 1
5.34
74
4.46
1
78.20
NOTE: THE FEATURES OUTLINED IN DETAIL A ARE REVOLVED IN A SEMICIRCLE ABOUT A SEMI-CIRCLE
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL±0.1MM
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ABS
FINISH
DO NOT SCALE DRAWING
TITLE:
Door Right
SIZE
A
DWG. NO.
A2-D006
REV
SCALE: 1:2
WEIGHT:
SHEET 2 OF 3

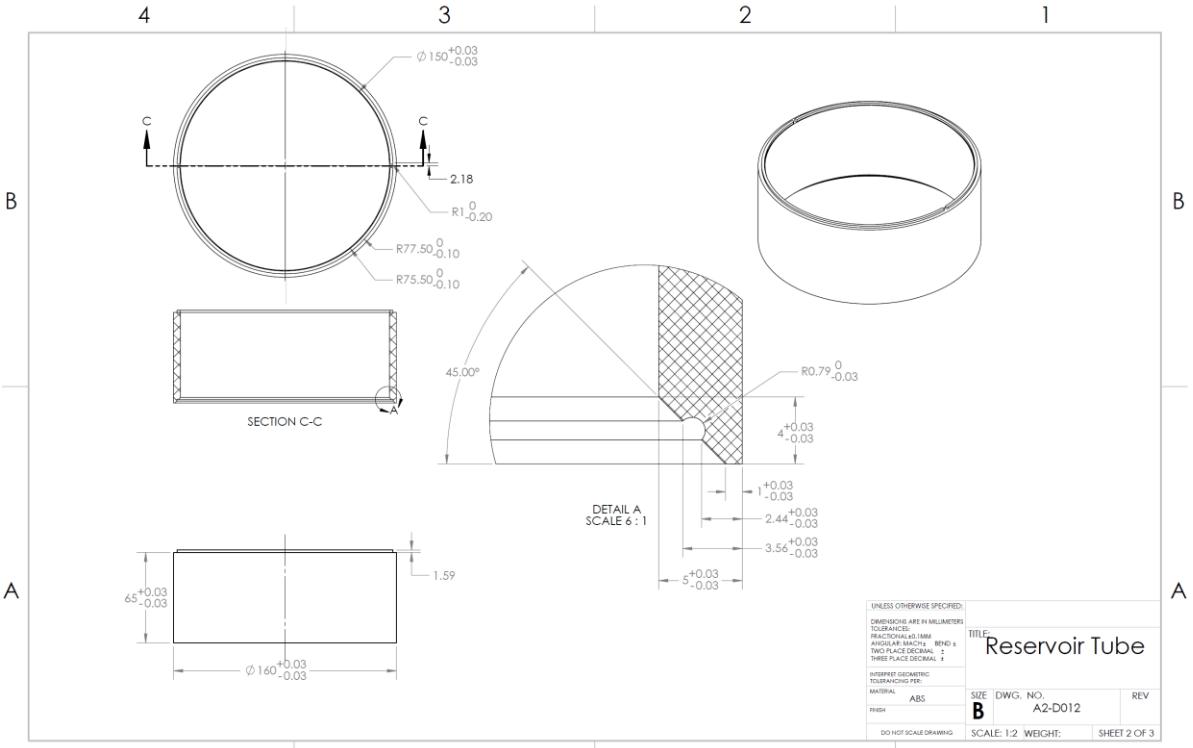

8
7
6
5
4
3
2
1
F
E
D
C
B
A
R9
8 0 -0.50
5 +0.50 -0.50
10 +0.50 -0.50
∅12 0 -0.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL±0.1MM
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ABS
FINISH
DO NOT SCALE DRAWING
TITLE:
UAV Exploded View
SIZE
A3
DWG. NO.
A2-D007
REV
SCALE:1:3
WEIGHT:
SHEET 2 OF 3

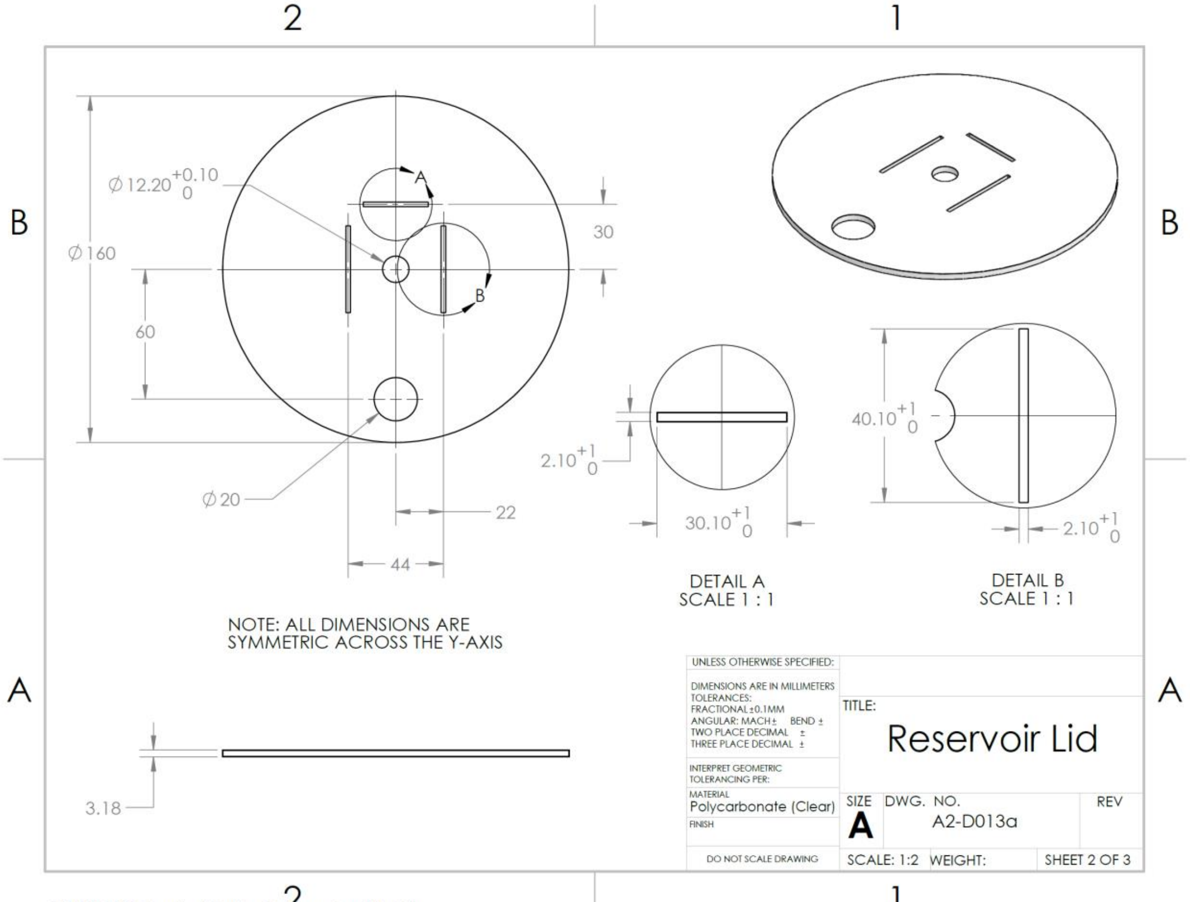

10
22.50
R1
R3
7.70
4.70
4.90 0 -0.10
R1
6.70 0 -0.10
4.15
10.85
3.70 +0.10 0
15
7.50 +0.10 0
7.70
Ø 1.80 0 -0.10
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL±0.1MM
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL ABS
FINISH
DO NOT SCALE DRAWING
TITLE:
Lock Support Bar
SIZE A
DWG. NO. A2-D008
REV
SCALE: 2:1
WEIGHT:
SHEET 2 OF 3

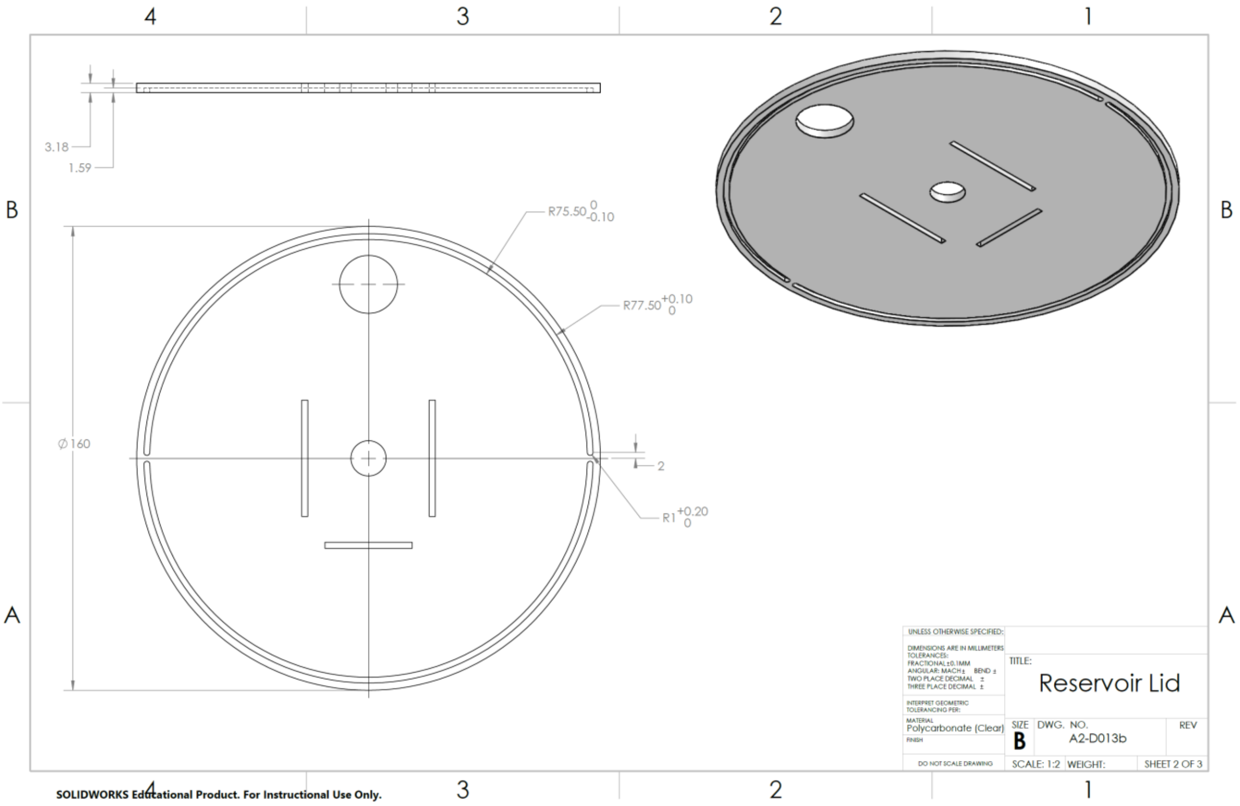

6.40
R3
25.00°
14.24
14.24
R3
R3
6.40
14.24
14.24
65.00°
R3
15.90
14.17
6
9.02
6
18
75.00°
2.82
75.00°
3.09
3
2.20
2.72
8.73
9.02
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL±0.1MM
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL ABS
FINISH
DO NOT SCALE DRAWING
TITLE:
Locking Block
SIZE B
DWG. NO. A2-D009
REV
SCALE: 2:1
WEIGHT:
SHEET 2 OF 3

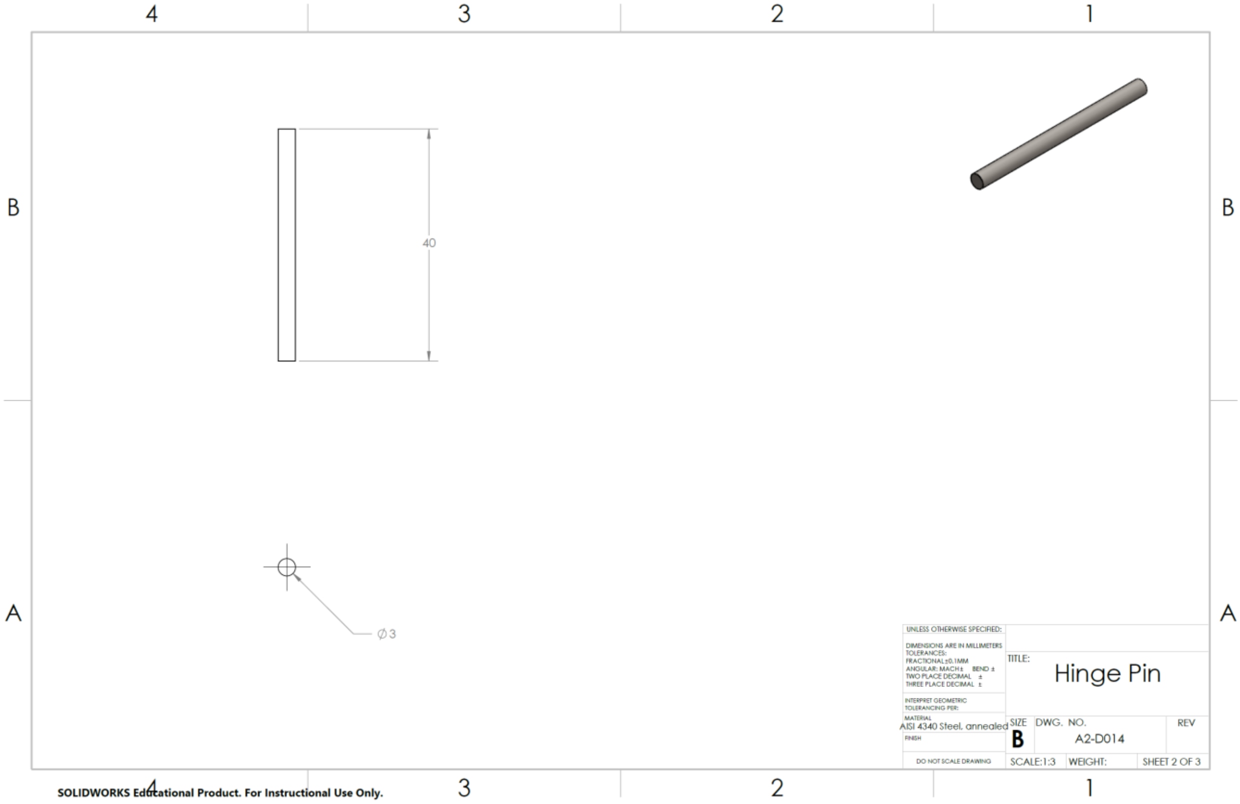

4
3
2
1
B
A
1.49 0 -0.03
2 0 -0.03
50 +0.03 -0.03
R79.44
39.55 +0.03 -0.03
42.09 +0.03 0
45.96 +0.03 -0.03
49.46 +0.03 -0.03
R3
∅3 +0.03 0
118.55°
6.70 +0.03 -0.03
12.70 +0.03 -0.03
15.70 +0.03 -0.03
6 +0.03 -0.03
3 +0.03 -0.03
52.09 +0.03 -0.03
55.09 +0.03 -0.03
R6
3 +0.03 -0.03
15 +0.03 -0.03
35 +0.03 -0.03
50 +0.03 -0.03
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±0.1MM
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ABS
FINISH
DO NOT SCALE DRAWING
TITLE:
Trapdoor Hinge
SIZE DWG. NO. REV
B
A2-D010
SCALE: 2:1 WEIGHT:
SHEET 2 OF 3

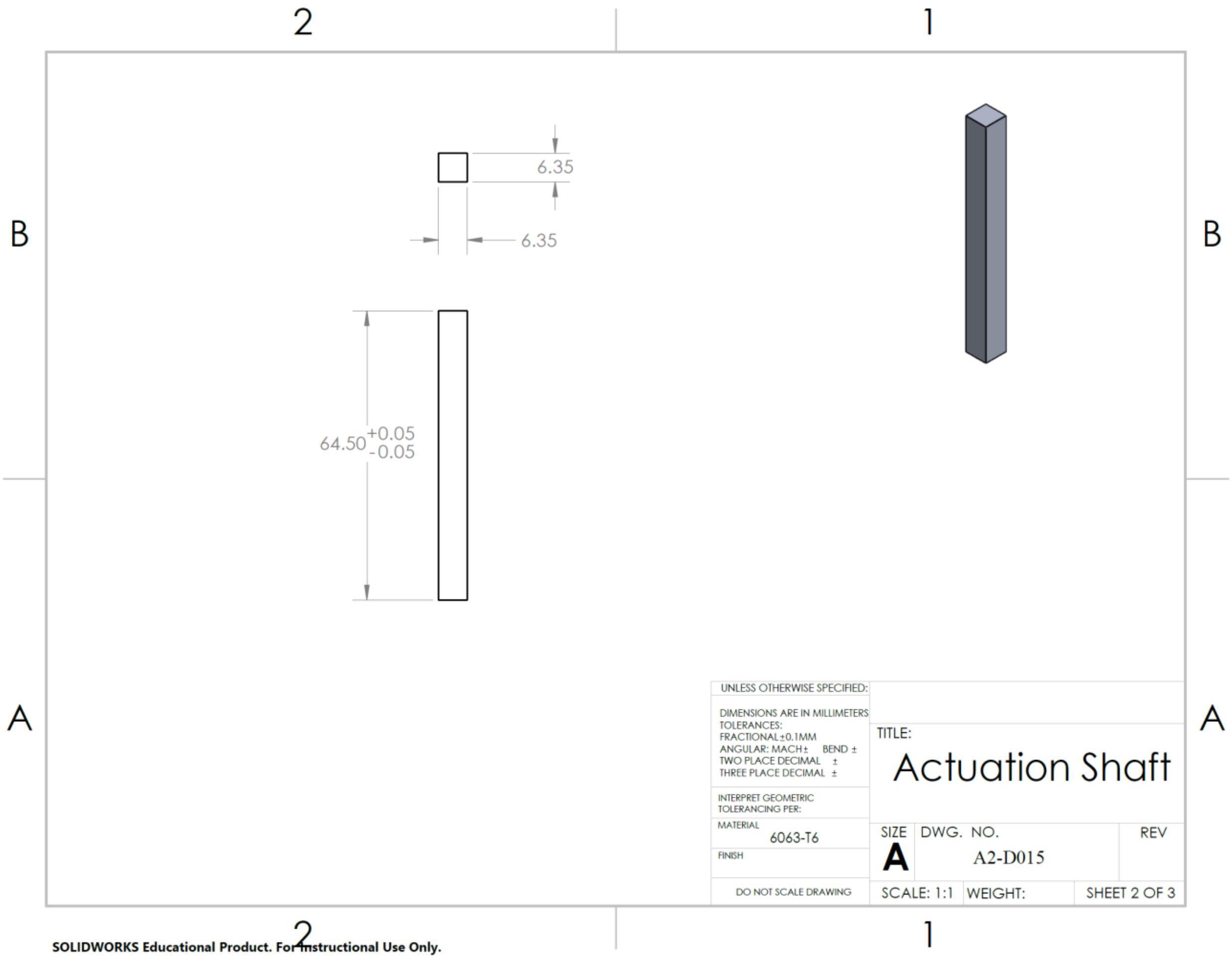

4
3
2
1
B
A
10 0 -0.03
40 +0.03 -0.03
20 +0.03 0
10 0 -0.03
R81
R80
R5
6.46 +0.03 -0.03
5.43 +0.03 -0.03
R5
0.43
45.00°
5 +0.03 -0.03
R5
10.04 +0.03 -0.03
∅3
TOLERANCE FIRST HOLE:
+0.03 -0.00
TOLERANCE SECOND HOLE:
+0.00 -0.03
40
15
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±0.1MM
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ABS
FINISH
DO NOT SCALE DRAWING
TITLE:
Reservoir Hinges
SIZE DWG. NO. REV
B
A2-D011
SCALE: 2:1 WEIGHT:
SHEET 2 OF 3


4
3
2
1
B
A
Ø 150 +0.03 -0.03
C
C
2.18
R1 0 -0.20
R77.50 0 -0.10
R75.50 0 -0.10
SECTION C-C
A
45.00°
R0.79 0 -0.03
4 +0.03 -0.03
1 +0.03 -0.03
2.44 +0.03 -0.03
3.56 +0.03 -0.03
5 +0.03 -0.03
DETAIL A
SCALE 6 : 1
1.59
65 +0.03 -0.03
Ø 160 +0.03 -0.03
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL±0.1MM
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ABS
FINISH
DO NOT SCALE DRAWING
TITLE:
Reservoir Tube
SIZE
B
DWG. NO.
A2-D012
REV
SCALE: 1:2
WEIGHT:
SHEET 2 OF 3


2
1
B
A
Ø 12.20 +0.10 0
Ø 160
A
B
30
60
Ø 20
22
44
2.10 +1 0
30.10 +1 0
40.10 +1 0
2.10 +1 0
DETAIL A
SCALE 1 : 1
DETAIL B
SCALE 1 : 1
NOTE: ALL DIMENSIONS ARE SYMMETRIC ACROSS THE Y-AXIS
3.18
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL±0.1MM
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Polycarbonate (Clear)
FINISH
DO NOT SCALE DRAWING
TITLE:
Reservoir Lid
SIZE
A
DWG. NO.
A2-D013a
REV
SCALE: 1:2
WEIGHT:
SHEET 2 OF 3


3.18
1.59
R75.50 0 -0.10
R77.50 +0.10 0
⌀160
2
R1 +0.20 0
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±0.1MM
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Polycarbonate (Clear)
FINISH
DO NOT SCALE DRAWING
TITLE:
Reservoir Lid
SIZE B
DWG. NO. A2-D013b
REV
SCALE: 1:2
WEIGHT:
SHEET 2 OF 3
SOLIDWORKS Educational Product. For Instructional Use Only.


40
⌀3
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±0.1MM
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
AISI 4340 Steel, annealed
FINISH
DO NOT SCALE DRAWING
TITLE:
Hinge Pin
SIZE B
DWG. NO. A2-D014
REV
SCALE:1:3
WEIGHT:
SHEET 2 OF 3
SOLIDWORKS Educational Product. For Instructional Use Only.


2
1
B
A
6.35
6.35
64.50 +0.05 -0.05
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±0.1MM
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6063-T6
FINISH
DO NOT SCALE DRAWING
TITLE:
Actuation Shaft
SIZE
A
DWG. NO.
A2-D015
REV
SCALE: 1:1
WEIGHT:
SHEET 2 OF 3

Appendix C: Test Plans for Validation Testing

C.1) Reservoir Fluid Retention Test Plan

1. Purpose

This document describes the reservoir fluid retention test to be conducted for the SAVRRS device during the development and validation phases of the program.

2. Approach

We perform this test with the goal of verifying that the reservoir can hold and retain at least 1 liter of fluid for 120 seconds without any leaking. This will help the team to identify any necessary rework required towards our final product.

3. Requirements and Tests

Table C.1.1: Requirements and Tests for Reservoir Fluid Retention Test

Test Number	DS1
Features to be Tested	This test will involve the distribution subassembly, which will investigate the effectiveness of the design of the reservoir body, doors, gasket, o-ring, rubber stopper, and reservoir lid.
Acceptance Criteria	We will accept the test if we are sure that 1 liter of water can be held within the reservoir for 120 seconds without any major leakage or malfunction in any way.
Expected Results	We expect that the design in its current state will satisfy the test requirements.
Test Conditions	The conditions of the test shall be typical outdoor conditions during the spring at ASU. We will also not test this while the drone is in flight, but rather with a stationary test rig which will support the distribution system body.
Test Setup and Test Rigs	The setup will involve the distribution system mounted to a horizontal support above a bucket. In this case, the horizontal support will be a team member holding the subsystem over the bucket. Fluid is to be poured into the reservoir of the distribution system while it is mounted to the horizontal support. A device which can measure volume of water will also be required.
Summary of Test Procedures	Begin the test by first closing and locking the reservoir doors on the distribution assembly. Once the doors are closed, hang the distribution assembly on a horizontal support directly above a bucket to catch any potential leakage. Once the distribution assembly is secured, begin filling the reservoir with water until it reaches maximum capacity. As soon as all the fluid is in the reservoir body, stop filling, and use the rubber stopper to plug the refill hole. Immediately start a stopwatch for 120 seconds. At the end of the 120 seconds, remove the distribution system from the first bucket. With a second bucket, empty all the fluid from the reservoir, and measure to see how much fluid remained. Repeat this procedure two additional times, and determine the average fluid retained.

4. Environmental Considerations and Test Rig Needs

For testing this feature of the SAVRRS device, the optimal environment will be outdoors on a typical warm day. Since the device will be used on a beach, it is optimal to have conditions that mimic a typical summer day. These conditions do not need to be perfect and will be deemed appropriate by the team while performing the test.

The testing rig only required a couple of buckets and a horizontal support. For simplicity sake, this support will be a team member holding up the assembly with his or her arms. Nothing too fancy, since the conditions of this test do not need to be perfect.

5. Schedule and Personnel Assignments

The plan for this test is to have the initial test completed by Wednesday, 4/3/2019. Based on how the test performs, any follow-ups and additional design modifications or development changes must be completed prior to Monday, 4/8/19. These will be completed to the best of the team ability. Figure 9.2.1.1 shows the overall testing plan for this phase and may be referred to for further information on scheduling.

C.2) Actuation Reliability Test Plan

1. Purpose

This document describes one of the individual quantitative tests to be conducted for the Actuation Reliability System of the SAVRRS device.

2. Approach

The approach for this development test was to actuate the servo motor ten times mechanically without the use of the actuation servo motor and give a result of pass or fail depending on if the actuation system worked smoothly and deployed the liquid in the container. The results were then analyzed to ensure to ensure there is a 99% confidence interval to make sure failure of this system is minimal to none.

If the confidence interval is less than 99%, the team will develop the design to ensure the team has an operating actuation system. Then the test will be repeated with the new design.

3. Requirements and Tests

- *Test Number*: DS2
- *Features to be tested*: Reliability of the Actuation System (Mechanical)
- *Acceptance Criteria*: Servo motor actuates successfully and opens the container doors resulting in the liquid to flow out.
- *Expected Results*: Servo motor actuates as expected with no errors and opens container doors successfully, releasing the liquid in the container.
- *Test Conditions*: Standard loading conditions (1L of fluid in container with stopper plugged in on top), hinge in locked position as start of the experiment.
- *Test set ups and test rigs*: No special test rig was required. System was actuated mechanically when container was loaded to normal conditions.
- *Summary of Test Procedures*:
    - Close the container doors and lock the actuation system
    - Fill liquid to normal conditions and stopper the container
    - Actuate the system mechanically (by hand) and ensure the doors open successfully and follow a smooth motion with no interference
    - Repeat steps 1-3 as needed

4. Environmental Considerations and Test Rig Needs

There were no special needs for this test. The container was filled to the top using water as the liquid inside and actuated manually and thus required no electrical or physical measurement recording. However, the experiment was carried out outdoors to ensure that the actuation didn’t create any spills indoors.

5. Schedule and Personnel Assignments

This experiment was conducted on Wednesday April 3rd, 2019 and only required two members (Sajana Ratnayake and Joshua Morton) to be present as no extra measurements were recorded as only a pass/fail assignment was given and there was one person who filled and held the container (Joshua Morton) while the other (Sajana Ratnayake) actuated the system by

C.3) Fluid Impact Time Test Planning Document

1. Purpose

This document describes the one of the individual quantitative tests to be conducted for the Fluid Impact Time test of the SAVRRS device. This is to ensure that the system is quick and efficient enough to disperse the repellent on a shark attack scene.

2. Approach

The approach for this development test was to disperse the liquid from the container from a ten-meter height. The fluid was to make impact with the surface below within the three second threshold. For the purposes of this test, soapy water was used to represent the actual repellent. A team member held the reservoir at a ten-meter height. Another member stands at surface level with a timer. The team member with the reservoir verbally confirms when the liquid has been initially dispersed so the member at surface level can start the timer. The reservoir was then refilled. This test was conducted for ten trials.

3. Requirements and Tests

- *Test Number*: DS3
- *Features to be tested*: Actuator and reservoir
- *Acceptance Criteria*: The liquid makes surface impact in three seconds or less after actuation.
- *Expected Results*: The liquid will make surface impact in three seconds or less after actuation.
- *Test Conditions*: The bottom of the reservoir should be at a ten-meter height at all times with a tolerance of .1 meters or less. The actuation is to be manually operated each time.

- *Test set ups and test rigs*: A timer, a solid place 10 meters high to steadily hold the reservoir. A 3 gallon bucket and a smaller container for water transfer.
- *Summary of Test Procedures*: One person holds the reservoir at a ten-meter height. Another stands at surface level with a timer. The person with the reservoir verbally confirms when the liquid has been initially dispersed so the person at surface level can start the timer. Dispel the liquid either manually or via the actuator. Record the elapsed time from release to impact. Refill the reservoir. Repeat steps ten times.

4. Environmental Considerations and Test Rig Needs

Since there is no indoor space large enough to perform this test, it was imperative that the tests were run on a clear day without rain or clouds in order to accurately record the data for this test. It was also important to locate a space that was clear of any passersby or debris to minimize disruption and optimize the surface impact.

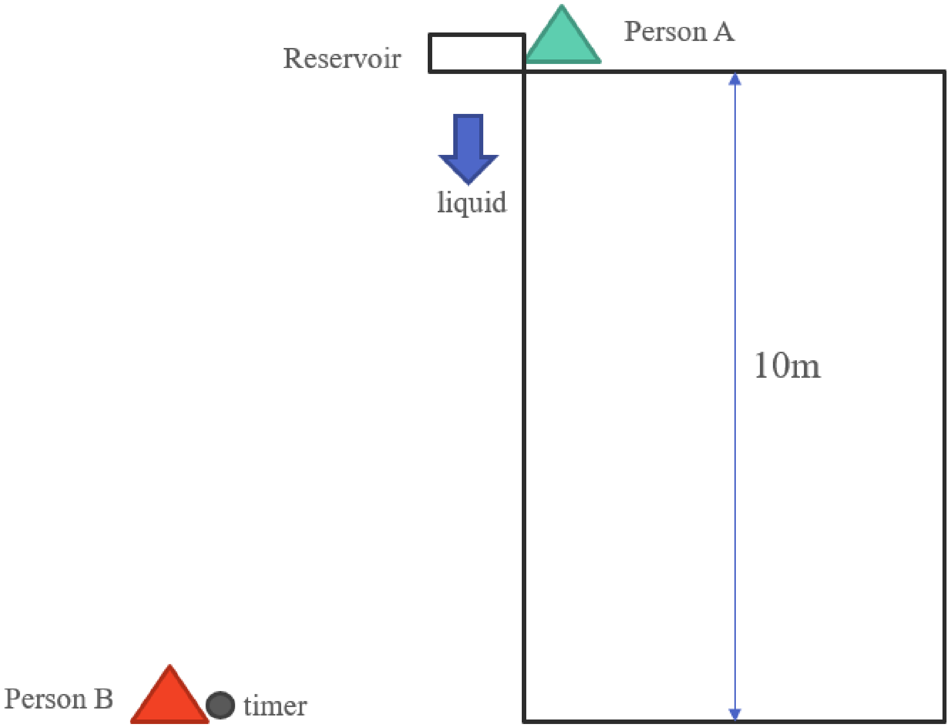
5. Schedule and Personnel Assignments

The schedule for the test was to execute it on Wednesday, April 3rd from noon until 2 pm that day. The personnel assignments for this test were Angelica Guzman, Derek Jensen, Josh Morton, and Saj Ratnayake.

This section describes the formatted test procedure for validation of the distribution vessel subsystem accuracy.

- Title of the Test: Fluid Impact Time
- Purpose: Ensure that fluid makes surface impact in less than 3 seconds following actuation from 10m drop
- Approach: Held reservoir from a rigid site at a ten meter height. One person released the liquid via actuation device or manually. Another person at the bottom of the ten meter height recorded the elapsed time from actuation to surface impact. The reservoir was then refilled. The steps were repeated ten times.
- Description of Test Article: A one liter cylindrical container made of ABS that is designed to hold liquid shark repellent. The lid is made of clear polycarbonate to allow the user to see when the container is full. A rubber stopper is used to plug the opening. Bombay doors on the bottom open up when the dowel and lock system is twisted a ninety-degree angle by the actuator.

- Description of Test Set-Up (Diagrams and Schematics):



- Environment and Test Conditions: The bottom of the reservoir should be at a ten-meter height at all times with a tolerance of .1 meters or less. The actuation is to be manually operated each time.
- Safety and Provisions: No persons should be standing directly under the reservoir as the liquid is released. The person holding the reservoir should not overextend their arms to avoid falling or dropping the reservoir.
- Data Collection Sheet:

Test Number	**Time (s)**	**Pass/ Fail**
1		
2		
3		

4		
5		
6		
7		
8		
9		
10		
Average		

- Step-by-Step Test Instructions:

  Firstly, fill a 3-gallon bucket with water. Then two persons go up the 10-meter height with the reservoir, 3-gallon bucket of water, and a smaller container to transfer the water from the bucket to the reservoir. Another person stays on the ground level with a timer. Two or three other persons may stay on the ground floor to clear the premises of passerby. Once at the 10-meter height, lock the doors on the reservoir shut using the actuator system. With the reservoir fully closed, transfer water from the bucket to the reservoir. Fill the reservoir completely and close the hole using the rubber stopper. Steadily hold the reservoir by its body, being sure that the doors are not held closed. One person holds the reservoir over the edge of the 10-meter height. The other counts down to verbally alert the person on the ground floor when they are going to release the water. At the count of three, the second person will actuate the system and release the water. At the same time, the person at the bottom starts the timer and stops it when all of the water hits the surface.

C.4) Distribution Accuracy Test Plan

1. Purpose

This document describes the one of the individual quantitative tests to be conducted for the distribution vessel target accuracy of the SAVRRS device during both the development and validation phases of the project.

2. Approach

The quantitative testing for the distribution accuracy and the subsequent procedural steps are outlined in this document. The approach was to conduct a series of tests that would validate the vessel requirement of being able to generate a 1.5-meter target radius from a height of 10 meters. The team would select a location that would provide a 10-meter height and replicate a series of 10 full vessel actuation runs and measure the resulting radius of the distribution impact. Then, the data would be analyzed to validate the customer and engineering requirements for accuracy as outlined in the team Project Plan.

3. Requirements and Tests

- *Test Number*: DS4
- *Features to be tested*: The accuracy of the distribution vessel from a 10-meter drop height
- *Acceptance Criteria*: Average impact radius equals $1.5 \pm 0.1\ m$ (7% error acceptable)
- *Expected Results*: The team will conduct 10 test runs. Each test will result in a target distribution radius of where the liquid makes impact. The average impact radius of each run will be measured. This data will undergo observational and uncertainty analysis to determine if the impact radius meets the customer requirements.
- *Test Conditions*: The team researched a drop area on Arizona State University—Tempe campus that would provide a 10-meter drop location below a concrete target area that

would be sufficient to test liquid impact. The team would test this under "ideal" conditions, in an area that is blocked from wind or other environmental factors that could skew the data.

- *Test set ups and test rigs*: The test set-up would be to have one of the team members located at the top of the drop location with a filled distribution vessel and another team member at the target location to measure the resulting impact radius.
- *Summary of Test Procedures*: The first team member would fill the distribution vessel with water. (Note: Water is being used for the development testing phase because it has a similar viscosity and density as the repellent to be used in real-world application). The member would then take the filled vessel to the top of the drop location (height of 10m). The vessel would then be actuated, rotating the actuation rod and opening the trap doors, releasing the fluid toward to the target location below. After impact, the team member at the target location would measure the average radius of the fluid distribution and record the data for analysis.

4. Environmental Considerations and Test Rig Needs

As mentioned previously, the testing location was located on ASU's Tempe campus under "ideal" conditions (i.e. no noticeable external effects). The repellent was substituted for distilled water during testing for sustainability purposes, with water having a valid physical make-up that would be similar to the repellent used in application. No additional test rigs are needed for completion of testing.

5. Schedule and Personnel Assignments

This test is scheduled to be conducted on April 3rd, 2019 at approximately 12:00pm. During the 10 trials, a number of other parameters will be being tested as well. That data is independent of the impact radius, so it will not effect the overall results of each independent test. Since a multitude of parameter data must be collected for each run trial, all team members will be present for the testing.

C.5) Take-off Capability Test Plan

1. Purpose

This document describes the one of the individual quantitative tests to be conducted for the Take-Off Capability test of the SAVRRS device.

2. Approach

The approach for this development test was to physically initiate and monitor the first 3 meters of vertical flight simulating the take-off portion of full mission flight with the SAVRRS device. Mass weights to simulate the full payload will be fixed to the UAV frame so as to not risk the integrity of the distribution vessel unnecessarily.

3. Requirements and Tests

- *Test Number*: UAV1
- *Features to be tested*: Take-off capability, & in-flight stability during take-off.
- *Acceptance Criteria*: 1m/s > maximum vertical flight speed, and 15 degrees > of deviation in pitch, roll, & yaw relative to the plane of flight (parallel with the ground for roll and pitch, and initial facing direction perpendicular to flight plane in line with the axis running front to back on the UAV for yaw)
- *Expected Results*: Successful and stable take-off within desired parameters
- *Test Conditions*: 5-40 degrees C, 10 m/s < wind speeds
- *Test set ups and test rigs*: (4) 0.5 kg mass drums to simulate fully loaded UAV
- *Summary of Test Procedures*:
    9. Using the nylon zip-ties and the Velcro straps purchased for the project fix the mass weights to the bottom of the UAV on the available slots of the Aluminum bottom plate.

10. Power on Lap-top and load Ardu-Pilot Mission Planner software.
11. Connect battery power to UAV and power on the flight board and radio receiver.
12. Establish connection to radio receiver and telemetry from hand held radio. Confirmation will display on hand held radio and Mission Planner software.
13. Confirm GPS and Mav-link connections in software and on hand held radio.
14. Clear area of unnecessary people and double check surrounding area for and potential hazards.
15. Perform test by initiating take-off with the hand held radio toggles and achieve and altitude of 3 m inside of the previously mentioned constraints.
16. Record results from the Mission Planner software flight monitoring.
17. Repeat test for a total of 10 instances.

4. Environmental Considerations and Test Rig Needs

This section explains the environment in which conditions were tested and possible effects, as well as any additional resources the team used to complete the testing.

5. Schedule and Personnel Assignments

The schedule for the test is the week of 04-06-19 through 04-06-19 and the personnel requirement is Michael Davis, and Kjaw Htoo for assistance and monitoring.

C.6) Sustain Payload Test

Purpose

The purpose of this test is to check if the UAV able to carry around 4.5 kg total weight. By this test the team will insure that SAVRRS device followed the requirement, since one of the requirements is able to carry additional weight from repellent and vessel approx. 4.5 kg.

Approach

The approach for this development test was to carry 4.5 kg. First, we will fly the UAV without the vessel to check the motors, after checking the motors team will fly the drone with the vessel and start to add the liquid progressively to ensure the UAV able to carry the weight and to not have big damage.

Requirements and Tests

- *Test Number*:
- UAV2
- *Features to be tested*:
- The motors will be able to carry 4.5 kg.
- *Acceptance Criteria*:
- The UAV have to carry 4.5 kg weight and able to fly with 10 m height.
- *Expected Results*:
- The team expect the UAV will able to carry the weight.
- *Test Conditions*:
- Test the UAV without the vessel to check the motors, then add the vessel and ad the liquid progressively to not have a damage and ensure it is able to catty that weight.
- *Test set ups and test rigs*:
  Finding an empty area to test the UAV, weight the UAV every time before flying it since, we will add the weight progressively. Finally, fly the drone to 10 m height after adding all the weight around 4.5 kg.
- *Summary of Test Procedures*:
- Ensure that the device will follow the requirements, team will do changes if the UAV not able to carry the weight.

Environmental Considerations and Test Rig Needs

This test will be outdoor, and we just need a scale for this test to weight the UAV before we fly it. There were no special needs for this test.

Schedule and Personnel Assignments

This test is scheduled to be conducted on April 3, 2019, but there was a delay since we had some issues with the controller.

Test Procedure

The procedure to sustain payload test:

1. Find an empty area for safety purposes.
2. Weight the UAV without vessel and fly it to check the motors.

3. Add the empty vessel to the UAV and weight it, then fly the UAV to check it with the additional weight.
4. Add a little of liquid to the vessel and weight the UAV, then fly the UAV to check if it is able to carry that additional weight.
5. Fill the vessel with water and weight it, then fly the UAV with the max weight for 10 m height and check if the UAV able to carry this weight.

Repeat step 5 for nine additional runs.

Data Collection Sheet

The first five runs in the bellow table is to check the motors by adding the weight progressively. Then from run 6 to 15 the weight will be around 4.5 kg to check if the UAV able to carry the weight.

Table 1

Run	UAV Weight	Status
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		

Appendix D: Full Phase 5 Test Reports and Analyses

D.1) Fluid Retention Test

Title of Test:

Reservoir Fluid Retention Test

Purpose:

The purpose of this test is to validate if the reservoir, in its current state, can meet the pre-determined requirement of holding 1 Liter of fluid without any leaks for at minimum 120 seconds. If this is not the case, then rework and development of this feature must ensue.

Approach:

We will approach this test as a simple validation of the requirements set forth by the team in our initial planning stages. This test may either pass or fail based on how it performs. Failure will result in immediate rework.

Test Procedures:

1. Close the doors on the distribution subassembly and use the locking block to secure the doors and gasket material.
2. Measure the diameter of the base of the bucket.
3. Holding on to the top of the slider, position the distribution system above a cylindrical bucket so that any potential leaks will fall in the bucket.
4. Set a timer for 120s and begin filling the reservoir with water. Once the reservoir has reached its maximum capacity, begin the countdown.
5. After the 120s is passed, quickly and carefully move the distribution system above the second empty bucket.
6. Open the doors of the reservoir and dump all the remaining water into the new bucket.

7. Using a ruler, measure the height of both buckets, and record them accordingly in the data table.
8. Safely empty both buckets and perform this experiment two additional times.

Data Collection Sheets:

Table 3: Data Collection Sheet for Fluid Retention Test

	Trial 1	**Trial 2**	**Trial 3**	**Average**
Height of Leaked Water (mm)	(0 ± 1) mm	(0 ± 1) mm	(0 ± 1) mm	(0 ± 1) mm
Volume of Leaked Water (m^3)	(0 ± 0.00) m^3	(0 ± 0.00) m^3	(0 ± 0.00) m^3	(0 ± 0.00) m^3
Volume of Retained Water (L)	(0 ± 0.05) L	(0 ± 0.05) L	(0 ± 0.05) L	(0 ± 0.05) L
Height of Retained Water (mm)	(20 ± 1) mm	(20 ± 1) mm	(19 ± 1) mm	(19.7 ± 1) mm
Volume of Retained Water (m^3)	(0.001 ±0.00) m^3	(0.001 ±0.00) m^3	(0.001 ±0.00) m^3	(0.001 ±0.00) m^3
Volume of Retained Water (L)	(1.01 ± 0.05) L	(1.01 ± 0.05) L	(0.963 ± 0.05) L	(0.994 ± 0.05) L
Pass/Fail?	PASS	PASS	PASS	PASS

Results:

The diameter of the measuring bucket was determined to be approximately: **10 in, or 0.254 m**. Using this, and the equation for calculating area of a circle, the area of the base of the bucket is determined to be: **0.0506 m^3**.

Following the test, each of the trials passed within their margin of error. The average retained volume of water is found to be: **(0.994 ± 0.05) L**. This is the appropriate value that the team deemed necessary for passing the test.

Since we were measuring the water height using a measuring tape, there is room for human error in the measurements. To compensate for this, the error of ± 1mm was added to each of the height measurements. This error simply propagated through the calculates.

Conclusions:

The outcome of this test is that the reservoir in the distribution subsystem can successfully hold roughly 1L of water without any major leaking. Since all our values, as well as the average demonstrated the ability to hold 1L of fluid within one uncertainty level, the overall test is successful. We can reasonably conclude that the reservoir can hold 1L of fluid during a mission for distribution.

Recommendations:

It is recommended that during the filling process for the reservoir that a firm grip is used when holding the doors. Doing this prevents any leakage due to the lack of rubber stopper on top of the system.

If further, more accurate data and analysis is desired, it may be appropriate to conduct further experiments using the weight of the fluid rather than the visual height for calculation of volume. This will have a lesser margin of error, and more accurate results for determining volume capacity of the reservoir. For our purposes, however, it is reasonable to use the methods described above.

Appendix:

- Sample Analysis:

The measurements for the first trial are given as follows:

Leaked Water Height: (0 ± 1) mm

Retained Water Height: (20 ± 1) mm

Using Equation 1 and the fact that the inner diameter of the bucket is found to be 0.254m, we can approximate the volume of water in each bucket in terms of m^3:

$$V_{leak} = \frac{\pi}{4}(0.254m)^2 * 0m$$
$$V_{leak} = 0m^3$$

$$V_{retain} = \frac{\pi}{4}(0.254m)^2 * 0.02m$$
$$V_{retain} = 0.00101m^3$$

The uncertainty was calculated similarly for each:

$$\sigma_{leak} = \frac{\pi}{4}(0.254m)^2 * 0.001m$$
$$\sigma_{leak} = 5.067 * 10^{-5}m^3$$

$$\sigma_{retain} = \frac{\pi}{4}(0.254m)^2 * 0.001m$$
$$\sigma_{retain} = 5.067 * 10^{-5}m^3$$

Then the simple conversion factor of 1 m^3 = 1000 L is used to convert the values from cubic meters to liters.

V_{leak} =(0 ± 0.05) L

$$V_{retain} = (1.01 \pm 0.05)\text{ L}$$

In this case, the test has passed.

D.2) Actuation Reliability Test Report

This section describes the formatted test procedure for validation of the distribution vessel subsystem accuracy.

- Title of the Test: Actuation Reliability Test
- Purpose: Ensure the actuation system works as expected under mechanical actuation (by hand) with no failure or irregularities
- Approach Actuate the actuation system mechanically (by hand) with a normally loaded container (approximately 1L of liquid and stoppered on top filler) and make sure the system functions optimally with no errors.
- Description of Test Article: The subsystem being tested in this test is the actuation system of the container. This includes the actuation system and container.
- Description of Test Set-Up (Diagrams and Schematics):
  - Container was locked using the actuation system and filled with approximately 1L of fluid (water for testing purposes)
  - Container was stoppered to make system watertight
  - Actuation system was actuated mechanically and observed to see if there were any irregularities during actuation or if the actuation system was too tight or starting to fail due to forces acting on it

Figure 1: Loading of Container with Fluid for Actuation Reliability Test

- Environment and Test Conditions: There were no special needs for this test. The container was filled to the top using water as the liquid inside and actuated manually and thus required no electrical or physical measurement recording. However, the experiment was carried out outdoors to ensure that the actuation didn't create any spills indoors. Container was loaded to standard operating conditions (1L of fluid)
- Safety Provisions:
  - Water was released into a bucket, so no spills were made
  - Hands were kept clear of hinges and door to prevent any injury

- Data Collection Sheet:

Run Number	**Status**

1	Pass
2	Pass
3	Pass
4	Pass
5	Pass
6	Pass
7	Pass
8	Pass
9	Pass
10	Pass

- Step-by-Step Test Instructions:
    - Close the container doors and lock the actuation system
    - Fill liquid to normal conditions and stopper the container
    - Actuate the system mechanically (by hand) and ensure the doors open successfully and follow a smooth motion with no interference
    - Repeat steps 1-3 as needed

6.2 Test Reports

- Title of Test: Actuation Reliability Test
- Purpose: Ensure the actuation system works as expected with no failure or irregularities
- Approach: Actuate the actuation system mechanically (by hand) with a normally loaded container (approximately 1L of liquid and stoppered on top filler) and make sure the system functions optimally with no errors.
- Refer to Test Procedures in Appendix:
- Data Collection Sheets:

Run Number	**Status**
1	Pass
2	Pass
3	Pass
4	Pass
5	Pass
6	Pass
7	Pass
8	Pass
9	Pass
10	Pass

- Description of Data Reduction Analysis: N/A
- Results: The test was a success as we had no failures in the actuation of the actuation system mechanically and there weren't any fail results.

  (Note this test does not contain any graphs or further analysis as it is a simple pass-fail test)
- Conclusions: As it can be seen from the table above, the mechanical aspect of the actuation system performed very well with no failures. This concluded that the actuation system

works as expected and does not need any additional designing or improvements as the system works as expected.

- Recommendations: None. System works well, so don’t need to modify the system any further. Would be better to conduct the experiment for a higher number of times with a final product to ensure no fatigue failure occurs in the actuation system.
- Appendix
  - Copy of Test Procedures
    - Close the container doors and lock the actuation system
    - Fill liquid to normal conditions and stopper the container
    - Actuate the system mechanically (by hand) and ensure the doors open successfully and follow a smooth motion with no interference
    - Repeat steps 1-3 as needed
  - Sample Analysis Calculations
    - N/A

D.3)

Test Reports

- Title of Test: Fluid Impact (time)
- Purpose: Ensure that fluid makes surface impact in less than 3 seconds following actuation from 10m drop
- Approach: Held reservoir from a rigid site at a ten meter height. One person released the liquid via actuation device or manually. Another person at the bottom of the ten meter height recorded the elapsed time from actuation to surface impact. The reservoir was then refilled. The steps were repeated ten times.
- Refer to Test Procedures in Appendix:
- Data Collection Sheets: Data Collection Sheet:

Test Number	**Time (s)**	**Pass/ Fail**
1	2	Pass
2	1.22	Pass
3	1.39	Pass
4	1.98	Pass
5	2.11	Pass
6	1.77	Pass
7	1.83	Pass
8	2.1	Pass
9	1.97	Pass
10	2.22	Pass
Average	1.86	

- Description of Data Reduction Analysis: Since all of the tests passed with no outliers, there will be no reduction in the data. All the tests accurately prove that the actuation is swift enough for the given requirements.
- Results: The reservoir has passed the Fluid Impact (time) test each time it was conducted.

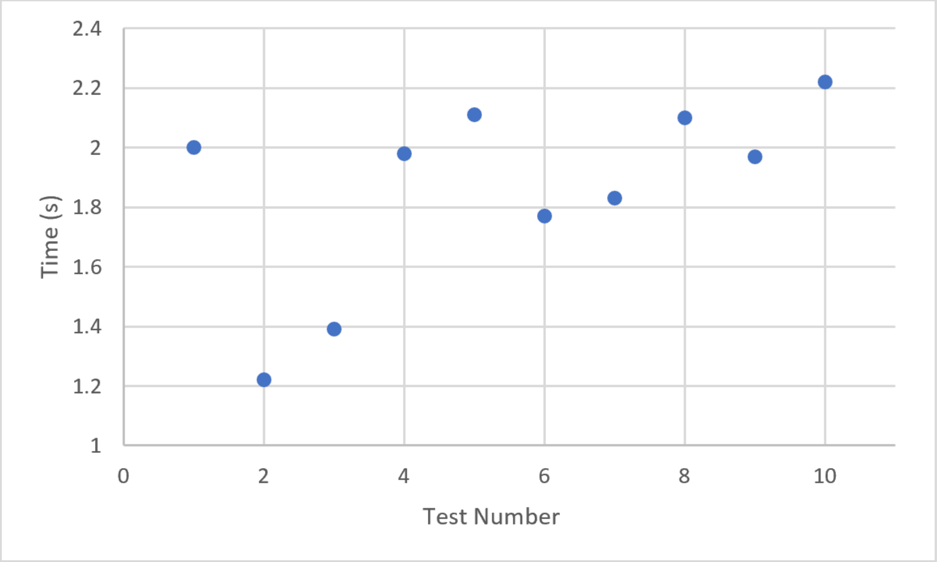


Figure 1: A plot displaying the elapsed time recorded for each test.

Using kinematic equations, the approximate time for a 10 meter fall should be 1.43 seconds. The average time recorded was 1.83 seconds.

- Conclusions: All the tests accurately prove that the actuation is swift enough for the given requirements. The time is recorded as a bit longer than calculated. This may come from errors in human measurement in both the recording of elapsed time and the height that the water was released from. Considering a slightly larger height of 10.1 meters yields a elapsed time of 1.86 which is a 2% difference from the average time obtained. Using this information, it can be concluded that the actuation is working properly and the repellent will have enough time to reach the victim.
- Recommendations: Have a better way to measure time. Human error plays a big role in the variation of elapsed time. To be more accurate, a slow motion camera could be used in future tests. Use the exact height to get more accurate predictions in the calculations.
- Appendix.
    - Sample Analysis Calculations

Using kinematics, an approximation of the expected elapsed time was calculated.

$$\Delta x = v_0 + \frac{1}{2} a\, t^2 \tag{1}$$

In this case, Δx is the change in height, which is 10m, v_0 is the initial velocity which is 0m/s since the reservoir is at rest, a is the acceleration which would solely be due to gravity, and t is the time.

Rearrange equation (1) for time to calculate the time the water should take to hit the surface following actuation.

$$t = \sqrt{\frac{2(\Delta x - v_0)}{a}} \tag{2}$$

Finally plug in the known values for height, initial velocity and acceleration.

$$t = \sqrt{\frac{2(10 - 0)}{9.8}} = 1.43s$$

D.4) Distribution Accuracy Test

- Title of Test: Distribution Vessel & Repellent Impact Radius
- Purpose: The purpose of this test is to validate the accuracy of the distribution vessel from a 10-meter drop height, ensuring that it will be able to impact the water in the area of the shark attack victim.
- Approach: The approach was to conduct a series of tests that would validate the vessel requirement of being able to generate a 1.5-meter target radius from a height of 10 meters. The team would select a location that would provide a 10-meter height and replicate a series of 10 full vessel actuation runs and measure the resulting radius of the distribution impact. Then, the data would be analyzed to validate the customer and engineering requirements for accuracy as outlined in the team Project Plan.
- Test Procedures:
    - First, secure and clear drop zone. Secure the trap doors of the vessel by engaging the locking block mechanism at the bottom of the vessel by rotating the actuation rod 90-degrees with the doors shut.
    - Next, open rubber stopper on top polycarbonate lid of distribution vessel and fill container with 1 liter of water. Then, replace the stopper.
    - After container is filled, have spotter (team member at the target zone) do final check to ensure target zone is clear.
    - Team member with distribution vessel then engages actuation rod via actuator for electronic testing, or by rotating the actuation key 90-degrees counterclockwise to open trap doors.
    - After impact, the spotter will then measure the impact radius by measuring the diameter of liquid distribution in two different directions, averaging those two

values, and dividing the resulting average in half for that run's radius value in meters.

- Then repeat by re-engaging the trap doors and refilling for the following 9 trial runs.

- Data Collection Sheets:

Run Number	Diameter 1 (m)	Diameter 2 (m)	Avg. Diameter (m)	Impact Radius (m)	Notes
1	1.60	1.55	1.575	0.7875	**Pass**
2	1.50	1.40	1.450	0.7250	**Pass**
3	1.22	1.20	1.210	0.6050	**Pass**
4	1.40	1.44	1.420	0.7100	**Pass**
5	1.47	1.29	1.380	0.6900	**Pass**
6	1.26	1.30	1.280	0.6400	**Pass**
7	1.60	1.40	1.500	0.7500	**Pass**
8	1.47	1.50	1.485	0.7425	**Pass**
9	1.53	1.40	1.465	0.7325	**Pass**
10	1.35	1.35	1.350	0.6750	**Pass**
Average			**1.4115 m**	**0.70575 m**	

- Description of Data Reduction Analysis: Once all 10 impact radii have been measured, the average impact radius will be calculated, along with the corresponding variance and standard deviation. The bias error will also be calculated to consider the experimental uncertainty of the resulting data.

- Results: The result of this test was an overall PASS of the distribution subsystem accuracy. The customer and engineering requirement of the vessel was that it would create a repellent impact radius of less than 1.5 meters, when dropped from a height of 10 meters, to ensure that there would be a concentrated amount of repellent disbursed near the victim's location. The testing phase resulted in an average impact of 0.70575 meters when dropped from a height of 10 meters, with every individual trial meeting the performance requirement.

- Conclusions: The distribution vessel subsystem was manufactured to requirement and has adequate performance measures to validate the team's prototype. The prototype performed up to standards meeting both the quantitative and qualitative requirements set forth by the customer, as well as the team members.
- Recommendations: No rework modifications are recommended at this time due to the subsystem's successful performance during the testing and validation phase. The only recommendation is further testing in different environment conditions (i.e. wind and temperature) that would imitate applicational environments in the ocean. These tests were conducted under ideal conditions to primitively validate the overall functionality of the device but are not sufficient for real world application. With additional time and budget, the team recommends further testing and development to advance the prototype's credibility for final product.
- Appendix
    - Copy of Test Procedures:

    1. First, secure and clear drop zone. Secure the trap doors of the vessel by engaging the locking block mechanism at the bottom of the vessel by rotating the actuation rod 90-degrees with the doors shut.
    2. Next, open rubber stopper on top polycarbonate lid of distribution vessel and fill container with 1 liter of water. Then, replace the stopper.
    3. After container is filled, have spotter (team member at the target zone) do final check to ensure target zone is clear.

4. Team member with distribution vessel then engages actuation rod via actuator for electronic testing, or by rotating the actuation key 90-degrees counterclockwise to open trap doors.
5. After impact, the spotter will then measure the impact radius by measuring the diameter of liquid distribution in two different directions, averaging those two values, and dividing the resulting average in half for that run’s radius value in meters.
6. Then repeat by re-engaging the trap doors and refilling for the following 9 trial runs.

PICTURES FOR EACH STEP ARE SHOWN BELOW

Step 1: Secure the trap doors of the vessel by engaging the locking block mechanism at the bottom of the vessel by rotating the actuation rod 90-degrees with the doors shut.

Step 2: Open rubber stopper on top polycarbonate lid of distribution vessel and fill container with 1 liter of water.

Step 3: Replace the stopper.

Step 4: After container is filled, have spotter (team member at the target zone) do final check to ensure target zone is clear.

Step 5: Team member with distribution vessel then engages actuation rod via actuator for electronic testing, or by rotating the actuation key 90-degrees counterclockwise to open trap doors.

Step 6: Measure impact dimension and repeat.

- Sample Analysis Calculations

$$Impact\ Radius\ (m) = \left(\frac{D_1 + D_2}{2}\right) * 0.5 = \left(\frac{(1.6) + (1.55)}{2}\right) * 0.5 = 0.7875m$$

$$Confidence\ Interval: \mu = \bar{x} \pm t_{\frac{\alpha}{2}}\left(\frac{S}{\sqrt{n}}\right)$$

$$Average: \bar{x} = 0.70575\ meters$$

$$T - value\ (CI\ @\ 98\%): t_{\frac{\alpha}{2}} = 2.822$$

$$Standard\ Deviation: S = 0.05453$$

$$Number\ of\ data\ points: n = 10$$

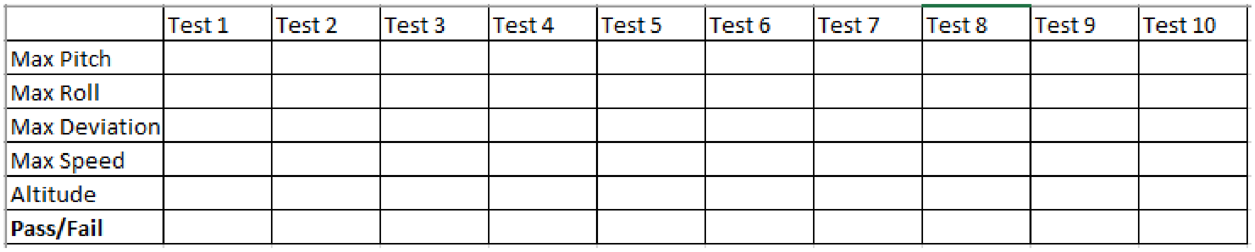
$$\mu = (0.7057) \pm (2.882)\left(\frac{(0.05453)}{\sqrt{10}}\right) = \pm 0.04866\ m$$

$$CI\ of\ 98\%: 0.70575\ \pm 0.04866\ m$$

D.5) Take-off Capability Test

This section describes the formatted test procedure for validation of the distribution vessel subsystem accuracy.

- Title of the Test: Take-Off Capability (Test# UAV1)
- Purpose: Establish flight take-off capability under full load
- Approach: Initiate take-off and achieve and altitude of 3 meters, while not deviating more than 15 degrees from initial course, or in pitch or roll
- Description of Test Article: The UAV with fixed weights to simulate full payload and not jeopardize the actual distribution vessel. Flight lap-top for test monitoring and hand held radio for UAV control.
- Description of Test Set-Up (Diagrams and Schematics): UAV will start standing on the ground in a level clear area (preferably park or designated air field) in this case a park. Take-off will be initiated and monitored through the first 3 meters of flight and then data will be recorded from the Mission Planner software.
- Environment and Test Conditions: 5-40 degrees C, 10 m/s > wind speeds (actual conditions will be recorded)
- Safety and Provisions: Heavy construction grade hard-hats, and protective safety glasses
- Data Collection Sheet:



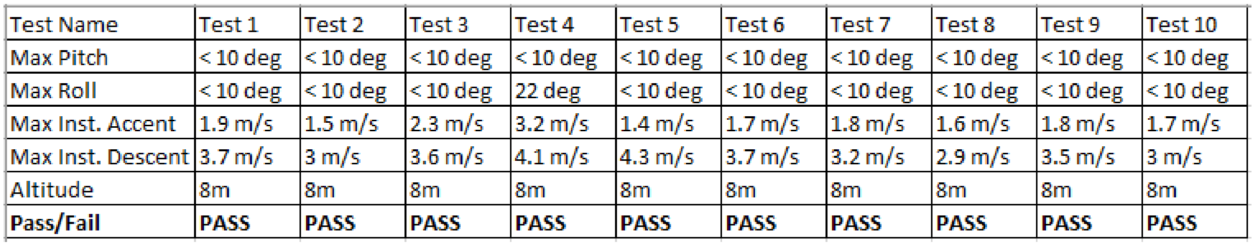
	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
Max Pitch										
Max Roll										
Max Deviation										
Max Speed										
Altitude										
Pass/Fail										

- Step-by-Step Test Instructions:

1. Using the nylon zip-ties and the Velcro straps purchased for the project fix the mass weights to the bottom of the UAV on the available slots of the Aluminum bottom plate.
2. Power on Lap-top and load Ardu-Pilot Mission Planner software.
3. Connect battery power to UAV and power on the flight board and radio receiver.
4. Establish connection to radio receiver and telemetry from hand held radio. Confirmation will display on hand held radio and Mission Planner software.
5. Confirm GPS and Mav-link connections in software and on hand held radio.
6. Clear area of unnecessary people and double check surrounding area for and potential hazards.
7. Perform test by initiating take-off with the hand held radio toggles and achieve and altitude of 3 m inside of the previously mentioned constraints.
8. Record results from the Mission Planner software flight monitoring into Excel file.
9. Repeat test for a total of 10 instances.

6.2 Test Reports

- Title of Test: Take-Off Capability Test (Test #UAV1)
- Purpose: Establish flight take-off capability under full load
- Approach: Initiate take-off and achieve and altitude of 3 meters, while not deviating more than 15 degrees from initial course, or in pitch or roll
- Refer to Test Procedures in Appendix: 6.1
- Data Collection Sheets: Tests unconducted to date, premade table below



Test Name	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
Max Pitch	< 10 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg
Max Roll	< 10 deg	< 10 deg	< 10 deg	22 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg	< 10 deg
Max Inst. Accent	1.9 m/s	1.5 m/s	2.3 m/s	3.2 m/s	1.4 m/s	1.7 m/s	1.8 m/s	1.6 m/s	1.8 m/s	1.7 m/s
Max Inst. Descent	3.7 m/s	3 m/s	3.6 m/s	4.1 m/s	4.3 m/s	3.7 m/s	3.2 m/s	2.9 m/s	3.5 m/s	3 m/s
Altitude	8m	8m	8m	8m	8m	8m	8m	8m	8m	8m
Pass/Fail	**PASS**	**PASS**	**PASS**	**PASS**	**PASS**	**PASS**	**PASS**	**PASS**	**PASS**	**PASS**

*****The isolated 22 degree deviation was caused by a snag on the grass in the take-off area, not actual equipment difficulty.

- Description of Data Reduction Analysis: Data was collected straight from Mission Planner software
- Results: Test was successful. There was an instance of out of bounds values being recorded, but it was due to environmental influence and not device capability
- Conclusions: Test Successful
- Recommendations: Make sure take off area is free of long grass and potential horizontal impairments to the landing legs during take-off

D.6) Test 6 Sustain Payload Test

The following are the procedures were completed during the reservoir load sustainability test:

1. Find an empty area for safety purposes.
2. Weight the UAV without vessel and fly it to check the motors.
3. Add the empty vessel to the UAV and weight it, then fly the UAV to check it with the additional weight.
4. Add a little of liquid to the vessel and weight the UAV, then fly the UAV to check if it is able to carry that additional weight.
5. Fill the vessel with water and weight it, then fly the UAV with the max weight for 10 m height and check if the UAV able to carry this weight.
6. Repeat step 5 for nine additional runs.

Test Results

Table D.6.1 Sustain Payload Test Data Table

Run	UAV Weight	Status
1	4.5 kg	PASS
2	4.5 kg	PASS
3	4.5 kg	PASS
4	4.5 kg	PASS
5	4.5 kg	PASS
6	4.5 kg	PASS
7	4.5 kg	PASS
8	4.5 kg	PASS
9	4.5 kg	PASS
10	4.5 kg	PASS

- Description of Data Reduction Analysis: Simple pass/fail of flight capability
- Results: Test was successful.
- Conclusions: Test Successful, no recommendations for improvement

D.7) General UAV and Distribution Testing

Purpose

The design need dictates an unmanned aerial vehicle which could stop the shark from remaining in the vicinity without causing more harm to the victim and puts the lifeguards in the best scenario to have a successful rescue as quickly as possible. Since the repellent is one of the most effective way to deterring sharks from an area. By developing a UAV that could reach to the victim and disperse the potent repellent quickly, the goal of the team is to decrease the response time, as well as increase the success rate for all future shark-attack rescue attempts. Therefore, reliability of the system plays major role in this project. Our project has two major separate components, UAV itself and repellent container. Therefore, the purpose of this tests to determine if our requirement has been met and to determine the effect of our goal outcomes.

Approach

For the safety reason, the team will find the location where is less crowded and at least 5 miles away from any airport. The team will be looking the softer landing ground, for example over grass area to less damage if the UAV crash accidently. We are going check all necessary wire connection of the UAV before start flying. Turn on the radio and check to pair between UAV and radio correctly. After checking all components is correctly setup, the team will start fly the UAV just above the ground about 2 feet. Once the UAV could flawlessly fly under control, the team will start perform the flight stability, flight time, flight range, flight speed and flight payload which are described in detail.

For the repellent container testing, the team will find the height of 10 meters and less crowded area. The team found 2nd floor of PSYN building at ASU Tempe is the best fit for this testing. Where is exactly 10 meters height and less crowded. The team collected two buckets for refilling water as necessary. One bucket will be used for container seals to prevent the water spill. From the 2nd floor, one team member will hold the container from the body and another team member will release the trap door and measure the diameter of the splash. The team will also record the time take when water to reach the ground.

Requirement and Tests

There will also be two separate tests in this project for both UAV and repellent container which include power of UAV, radio control, motors, flight stability, flight range, flight time, flight speed and flight payload for UAV testing. For the repellent container, the servo trap-door, dispersing the repellent, seals. For the acceptance criteria and the team's expected outcomes are shown in the following tables.

Table 01: *Acceptance Criteria and Expected Results for UAV Testing.*

	Acceptance Criteria	Expected Results
Power	All electronic work correctly	All electronic work correctly
Radio Control	Pair UAV with controller correctly	Pair UAV with controller correctly

Servo motor	Turn between 85 degrees and 95 degrees then return to home position	Turn 90 degrees and return to home position
Flight Stability	Maximum 3.5 meters drifting within a minute of flight time	Maximum 3 meters drifting within a minute of flight time
Flight Range	100 meters	120 meters
Flight Time	8 minutes	10 minutes
Flight Speed	7 m/s	8 m/s
Flight Payload	4.0 kg	4.3 kg

Table 02: *Acceptance Criteria and Expected Results for Repellent Container Testing.*

	Acceptance Criteria	Expected Results
Weight of the container	.35 kg to .45 kg	.4 kg
Weight of the container + water	1.40 kg to 1.60 kg	1.5 kg
Seal	50 cm^3 of water leak within 5 minutes	Less than 25 cm^3 of water leaking within 5 minutes
Dispersing Radius	Between 1 meter and 2 meters of diameter spread out from releasing from 10 meters height	1.5 meters of diameter spread out releasing from 10 meters height
Time	Less than 2.5 second to reach the ground	2 seconds to reach the ground

Environmental Considerations and Test Rig Needs

For UAV test, the team will need safer and legal location. According to the FAA rules and regulation of unmanned aerial vehicle, the team will choose 5 miles away from airport, away from emergency responders, not too closed to stadiums, sports events or group of people and have to be lower than 400 feet. The 6-channel radio will need for SAVRRS flight test. To measure the altitude of the SAVRRS, protractor will be need to measure the angle of the SAVRRS when flying and calculated by using trigonometry or we could use electronic barometer that will attach to SAVRRS and record the altitude. For the speed test, the team will need a stop watch and measuring tape.

For the repellent container test, the team will be looking the building of 10 meters height and less crowded area. The two empty buckets will be required to prevent spilling the water. Measuring tape and stop watch will be also required for this test to record time take the water to reach the ground and to measure the diameter of water splash.

Schedule and Personnel Assignments

Schedule for repellent container test would at noon on 04/03/19 at PSYN building south. Because of the unexpected delay of last piece of electronics for UAV (but which arrived on 04/05/19), the team have to move this test to 04/10/19.

Testing Procedures

Testing procedure for UAV

- Choose the suitable testing ground for UAV testing. Where is at least 5 miles away from airport. Also keeping away from emergency responders, near stadiums, sports events or groups of people.
- Make sure all wire connection is correct before attaching battery to UAV.
- Turn on the radio first. Then turn on the UAV to make sure it connects to radio correctly.
- Once it connects to radio correctly, spin the motor (not including propeller). Make sure all the radio signals and channels work correctly. In this process, the rotation of front two motors has to be rotate opposite direction each other. The rotation of diagonal motors has to match the direction. For SAVRRS default setting that front right motor and rear left motor would be rotate counter clockwise direction. Front left motor and rear right motor would be rotate clockwise direction.
- Once all the rotation tests are done, attach the propeller on each corresponding motor.
- For stability testing, the team will fly the UAV 1 meter above the ground and landing back for 5 trial. In each process, the team will observe if the UAV is drifting.
- Once the stability test is done, the flight time test will be performed. The goal of the project is to fly the UAV 30 minutes continuously. Charge the battery until 100% complete. Then team will fly UAV for about 10 minutes above 3 meters and will measure the battery to calculate maximum flight time.
- Set two points A and B on the ground. The distance between two points will be 500 meters. The pilot will start from the point A and the team member(s) will wait at point B. The UAV will start from point A to B and return to point A. Repeat 5 times for this testing.
- During the range testing, the team will record the time taken between each points and form that, velocity of the UAV will be calculated.
- Connect the container fill with water (which is 1.459 kg by measured during testing) to the UAV. The total weight is approximately 3.5 kg. The team will fly the whole system for about 3 minutes to test the SAVRRS's payload.
- Expected results of the UAV will be list in the following
  - Flight time = 10 minutes.
  - Range = 500 meter.
  - Elevation = 10 meter.
  - Payload = 3.5 kg.

Testing procedure for Repellent Container

- Collect the empty bucket which is going to use in leaking test.
- Close the trap door of the repellent container and lock by turning the key by hand.
- Fill the water and put the rubber stopper. Make sure everything is sealed correctly.
- Hold the repellent container from the body without touching the trap door. Wait until 2 minutes to observe the any dripping from the trap door. Repeat this process for 5 times.

- Measure the height from where the repellent container will release water. The expectation height of the team is around 10 meters.
- One team member will hold the container from 10 meters height and another team member will release the water by turning the key my hand.
- Record the time taken the water to reach the ground.
- Measure the water splash from the ground in x and y direction. Then calculate the diameter of water splash. (Concrete ground will be better suitable for this testing).
- Repeat this testing for 10 trials. Then calculate the average diameter of water splash.

Testing Results

The results of the testing are shown in the following tables. Because of unexpected delay of the last peace of the electronic for UAV, the team could not reach the goal during this week. For this reason, the UAV testing data couldn't be done during this week. Although UAV testing couldn't perform in this week, the team could finish that test in coming week.

The testing process pictures and formulas use in this test will be shown in appendix section.

Table 03: *The Data of UAV Testing.*

Features to be tested	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
Radio Control Connection	Pair	Pair	Pari	Pair	Pair	Pair
Flight Stability [drifting in meters within a minute]	2.8	3.2	3.3	2.7	2.4	2.88
Flight Time [minutes]	8.8	8.7	9.1	9.4	9.3	9.06
Flight Range [m]	200	200	200	200	200	200
Flight Speed	8.2	8.3	8.0	8.1	8.3	8.18
Flight Payload	4.5	4.5	4.5	4.5	4.5	4.5
Features to be tested	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
Radio Control Connection	Pair	Pair	Pari	Pair	Pair	Pair

End of Report