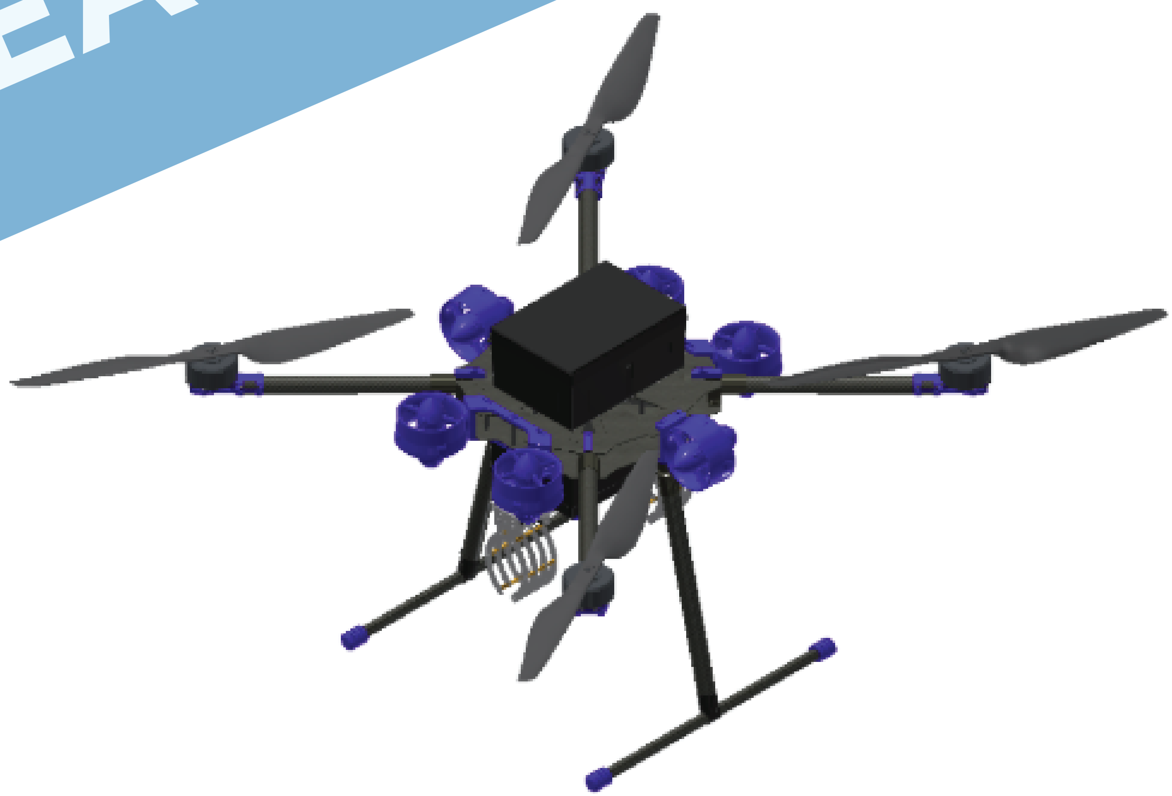
IDEAS WORTH HEARING

ECHO TECHNOLOGIES



PROOF OF CONCEPT

"It's not about ideas. It's about making ideas happen."

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COMPANY PROFILE

EXECUTIVE SUMMARY

ECHO Technologies is currently developing recovery vehicle technology that will allow salvage operations to be done in the safest manner with minimal damage. We have designed and are in the process of testing a hybrid multi-purpose Unmanned Aerial Vehicle/Unmanned Underwater Vehicle system (codenamed Megalodon) that is capable of flight in multiple fluid mediums. In addition, company interns will design and develop a Remotely Operated Vehicle (codenamed Remora), capable of locating the wreckage site and signaling the Megalodon. In this simulated mission "Project Azorian", the Megalodon and Remora will work collaboratively to locate and recover the remains of a Russian K-129 nuclear capable submarine as well as various objects of interest scattered along the ocean floor.

ECHO Technologies has spent around $9,000 on "Project Azorian" thus far accounting for the prototypes themselves, outreach events, and formal presentations. ECHO Technologies has taken much care to ensure that progress is being made with the money used.

The Megalodon has already demonstrated the ability to fly while carrying heavy payloads as seen in testing with an impressive flying weight of 15.9 kg. This is more than 3 kg over the expected final design flying weight. In addition, the Megalodon has also proven to be a completely waterproof design when tested at depths of 7 feet.

The Remora, with an expected weight of approximately 3 kilograms on land, is able to provide 5.624 kilograms of thrust underwater. The passive intake for the Remora was tested with the "warheads" facing different directions. This allowed us to note the improvements needed for the intake to work properly, including thicker walls.

The next steps for the Megalodon are to attach the claw, demonstrate underwater maneuvering, and test autonomous features. For Remora, the interns plan to purchase a control box to control the Remora, purchase a watertight enclosure to protect electrical components, and finish assembling and testing the Remora. With 46 days until the mission, ECHO Technologies is continuing to make improvements to both the Megalodon and Remora in order to successfully execute the mission.

MISSION OVERVIEW

CAMS Advanced Research Projects Agency (CARPA) Initiative has tasked ECHO Technologies to design and build a UAV/UUV vehicle named Megalodon that can recover the items of interest from the K-129 crash site after pinpointing a signal from an Unmanned Underwater Vehicle (UUV) named Remora that located those items of interest and recovered the radioactive items.

This mission is an attempt to recover the leftover parts from a nuclear capable K-129 crash that the CIA failed to completely recover the ocean floor. As a ship was raising the K-129 from the ocean floor, it broke apart and part of the submarine was lost.

The mission will begin with the Megalodon picking up and placing Remora into the water to locate the crash site. Once the crash site is located, Remora will recover the radioactive items after inspecting the crash site with a UV light and then rise to the surface to signal for the Megalodon. The Megalodon will then transition to underwater, and swim to the crash site to recover the remainder of the K-129. The Megalodon will deposit the parts it collects before coming back for Remora where it picks Remora up and travels back to land.

CONSTRAINTS:

- Funding **(under $10,000)**
- Time **(263 days as of 9/6/18, 46 days as of 3/26/19)**
- Weather **(wind, temperature)**
- FAA Regulations
- Need pool for testing
- Megalodon cannot use a tether

DELIVERABLES:

- **The Megalodon mechanism must:**
  - Be completely waterproof
  - Be capable of flight, in dual fluid mediums
  - Fly 201.9 feet in the air to the pool, locate the pool, and dive into the pool, swimming to the wreckage
  - Manipulate recovery articulation
  - Be able to detect the beacon of the Remora, and retrieve it, once the salvage operation is complete
- **The Remora mechanism must:**
  - Be completely waterproof
  - Be able to locate the wreckage site through a live video feed
  - Provide a beacon for the Megalodon device

    - Recover the radioactive items of interests
    - Be able to detect radioactive activity, with UV light
- **Additional Deliverables:**
    - Development of a communication method that will work between 100-3000Hz

MISSION CHANGES:

- **Megalodon:**
    - Must land on a "helicopter pad" floating in a random location of the pool
- **Mission:**
    - Alteration #1:
        - Remora must locate a submarine with missiles, communicate with Megalodon
        - Megalodon must be able to pick up a submarine with missiles placed loosely inside
            - Missiles can fall out very easily, must be very balanced
        - IF completed successfully, Remora will have no further job
        - Megalodon lifts Remora out of the pool

- Megalodon completes mission by landing on helicopter pad

- IF NOT
    - Resume normal mission

CORPORATE RISKS AND ASSUMPTIONS

RISK SCALES

	SEVERITY (S)			
LIKELIHOOD (L)	1 - Inconsequential	2 - Insignificant	3 - Noteworthy	4 - Dangerous
1 - Anticipated	Moderate	High	Undesirable	Undesirable
2 - Possible	Acceptable	Moderate	High	Undesirable
3 - Improbable	Acceptable	Acceptable	Moderate	High
4 - Unrealistic	Acceptable	Acceptable	Moderate	High

CORPORATE RISK MANAGEMENT				
RISK	**CONSEQUENCE**	**RATING (S/L)**	**RISK FACTOR**	**ACTION**
Shipping Times	Parts arrive late	1/2	Acceptable	Ensure we have the best times and know when deliveries should be coming and have work that can be done without said materials
Poor Group Dynamics	Conflicts, less cooperation, inability to properly contribute to the project	2/3	Acceptable	Have team building events to ensure members get to know one another and can cooperate, if members show they cannot cooperate with one another attempt to separate those members from one another and act through an intermediary
Cost Overruns	Echo Tech are forced to take loans or go bankrupt	3/3	Moderate	Evaluate costs and cut anything unnecessary and ensure we never spend more than we can afford to
Schedule Overruns	The project will be behind schedule and we may not be able to perform the mission by when we need to	3/3	Moderate	Organize our schedules and enforce these schedules to ensure we are following or ahead of them
Possible Injuries	Personnel may need medical attention which may affect the timeline	3/2	High	Personnel are required to follow many procedures for safety, using protective equipment, and being well informed
Little Outside Investments	Echo Tech will be unable to pay for anything we require	3/1	Undesirable	Assure investors that the project is very well thought out and prove our claims through presentations

EXECUTIVE MANAGEMENT PROCEDURE

Throughout the course of the project, ECHO Technologies is subject to the following performance reviews set by the CARPA Initiative:

IN PROCESS REVIEW (IPR)

Informal weekly reports within the company to assess the progress of the project. This is done in order to ensure that the company stays on schedule to complete the project by the projected mission date.

PERIODIC DESIGN REVIEW (PDR)

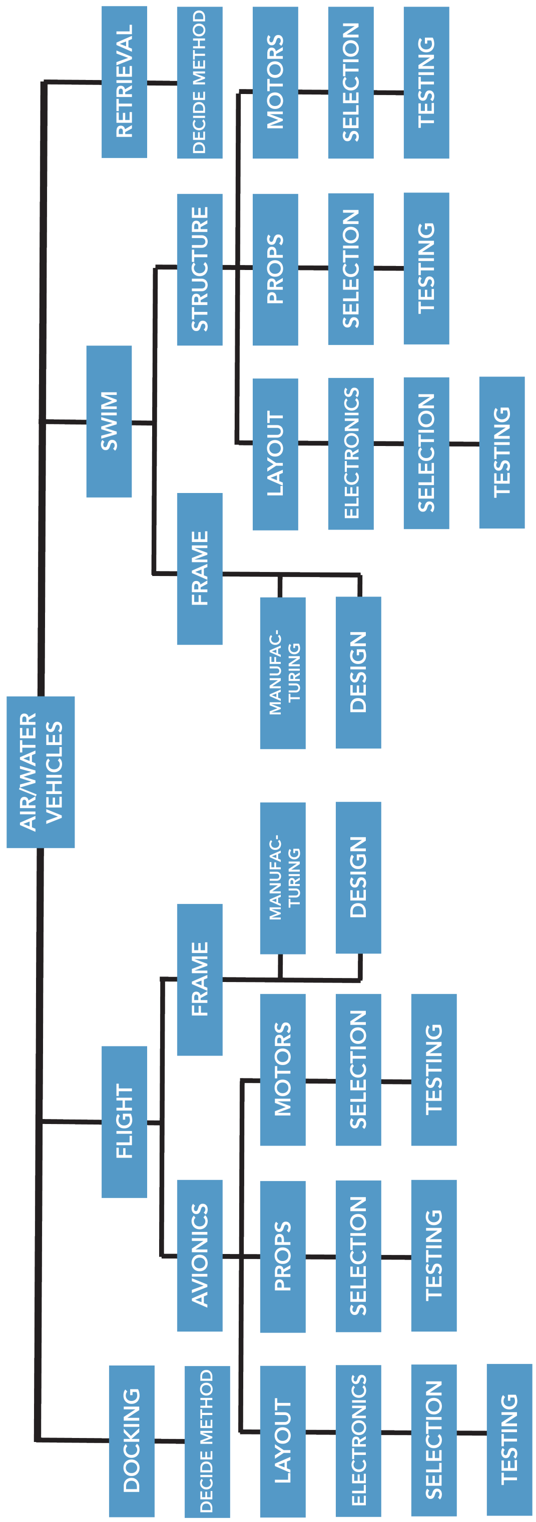
Formal monthly meetings held with the customer to demonstrate the progress of individual subsections within the company. Management is responsible for reviewing all work done by the subteams in order to ensure it meets company standards.

CRITICAL DESIGN REVIEW (CDR)

Major design review period occurring a total of five times throughout the course of the project. These reviews are the times in which deliverables will be graded, and a panel of 3rd party representatives evaluate the solution proposed. The five CDRs that will take place are:

- Systems Performance Specification **(SPS)** and Presentation
- Proof of Concept **(POC)** Presentation and Demonstration
- First Article and Technical Data Package **(TDP)**
- Mission Performance
- Engineering Design & Development **(EDD)** Expo and Presentation

WORK BREAKDOWN SCHEDULE



APPROACH

MISSION APPROACH

1. **Objects of interest include (all items are cylindrical):**

- Coding machines
- A missing torpedo
- R-21 ballistic missiles, possibly tipped with nuclear warheads **(3)**
- any possible remainder of the hull.

Part of this new mission is to discover whether the K-129 was armed with nuclear tipped R-21 ballistic missiles, in violation of the 1971 Strategic Arms Limitation Treaty (SALT).

2. **On-board UV light**

MISSION APPROACH

To complete this mission two robots will be made. The design of the first Unmanned Aerial Vehicle (UAV) the Megalodon, will be a combination of both a quadcopter and an underwater ROV. It will consist of two seperate systems: an aerial system and an underwater system. The second Remotely Operated Vehicle (ROV) , the Remora, will only need to be mobile while underwater and will only consist of an underwater system.

The Remora will act as a third-person camera during the Megalodon's time underwater. A communication system will be developed such that simple open-looped commands (forwards, backwards, turning) can be sent from mission control to the Megalodon during underwater operation. The pilots will control the Megalodon to reach the general vicinity of the objects of interest. Because of challenges with real-time communication, human-piloted control will be limited. An underwater vision system to autonomously orient the Megalodon to pick up the objects of interest will then activate.

The Aerial system will be responsible for the flight of the UAV. Using this system, and an attachment to the remora the megalodon will transport the the remora from the dock into the water. The Megalodon will fly over 200 feet to the Remora with a pre-calculated trajectory. Crash prediction from our sensor suite, as well as crash prevention failsafes, will be integrated into pre-programmed flight. The Megalodon will line up with and pick up the Remora using automatic vision targeting and proceed to drop the Remora in the pool with another pre-calculated trajectory.

From here, the Megalodon will return to the dock to conserve battery, while the remora locates the wreckage. Once the Remora locates the wreckage it will become a beacon for the Megalodon. However, the distance from the wreckage to the dock can be large and it may be hard for the Megalodon to see the beacon from the distance. To help with this, in the process of finding the wreckage, the Remora will record relative position from it to the dock. The dock will be considered the home point and once the Remora finds the wreckage it will record relative position. The Megalodon will then use these relative positions to determine a rough area to where the wreckage is located. Once the Megalodon reaches that area it will be much easier for the Megalodon to see the beacon since its looking in a more limited area. Once here the Megalodon will dive and begin recovering items. Starting here the underwater system for the Megalodon will be used.

The Megalodon will recover the coding machines, missiles, and torpedoes. All of these items will be placed in the remainder of the hull at the beginning of the mission. The Megalodon will first attempt to recover the hull with all of its contents. If the Megalodon fails and some or all items fall out, then the Megalodon will locate each item and grab onto the item using our articulation system. The Megalodon will then resurface and fly to the dock and place that item/items down. The Megalodon will then dive back into the water and begin looking for the next item.

The Remora has the task to recover ballistic missiles and determine if they are radioactive. In order to limit the possibility of collisions and because the Remora is also being used a third person camera, the Remora will only conduct this part of the mission while the Megalodon is a far distance away, mostly while the Megalodon is in the air. The Remora will have to recover and analyze three missiles and will be able to hold all of them at the same time.

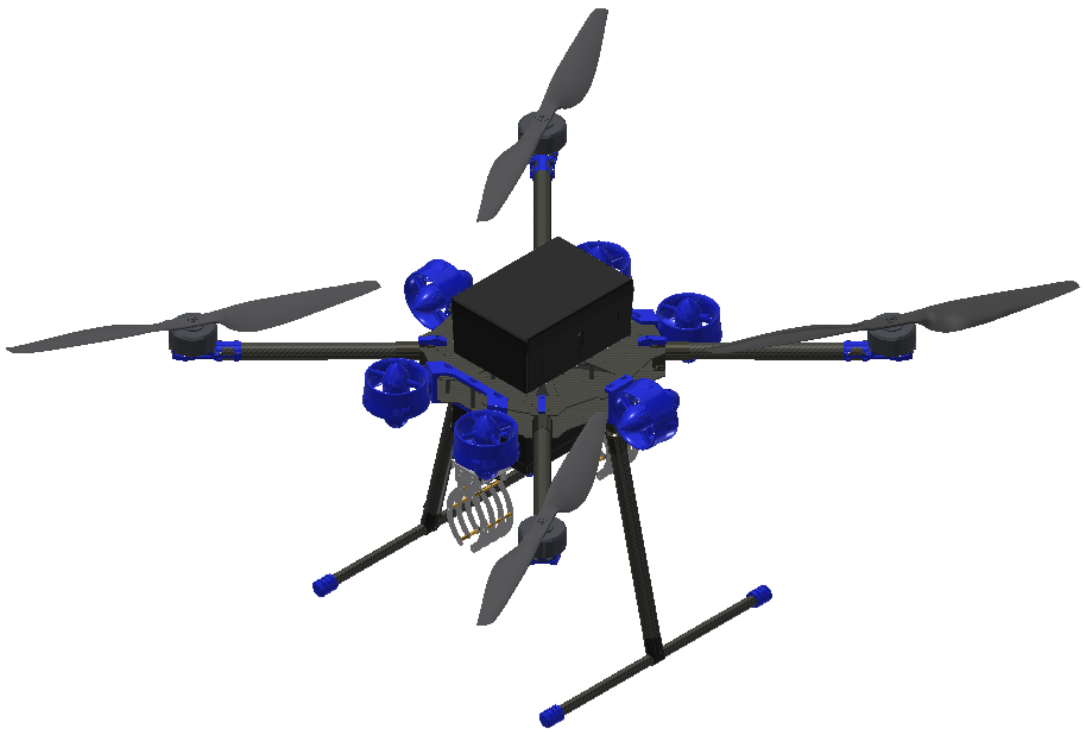
Once the Megalodon finishes recovering all the items and the Remora has recovered all the missiles the Remora will once again attach to the Megalodon and the Megalodon will fly to the landing site.

STRATEGY

The Megalodon will fly over 200 feet to the Remora with a pre-calculated trajectory. Crash prediction from our sensor suite, as well as crash prevention failsafes, will be integrated into pre-programmed flight. The Megalodon will line up with and pick up the Remora using automatic vision targeting and proceed to drop the Remora in the pool with another pre-calculated trajectory.

The Remora will be equipped with the necessary sensors to perform localization relative to its starting position. Once the Remora successfully locates the wreckage and drops the beacon, it will send its coordinates to Mission Control, which will then send the coordinates to the Megalodon. The Megalodon will fly over to the wreckage and perform a controlled diving sequence. The Remora will act as a third-person camera during the Megalodon's time underwater. A communication system will be developed such that simple open-looped commands (forwards, backwards, turning) can be sent from mission control to the Megalodon during underwater operation. The pilots will control the Megalodon to reach the general vicinity of the objects of interest. Because of challenges with real-time communication, human-piloted control will be limited. An underwater vision system to autonomously orient the Megalodon to pick up the objects of interest will then activate. Once all objects of interest are collected the Megalodon will fly to a floating landing site. Since this will be done out of the water radio control will most likely be used to fly the Megalodon to the landing site, however an autonomous program may also be developed to land the Megalodon.

DESIGN OVERVIEW: MEGALODON

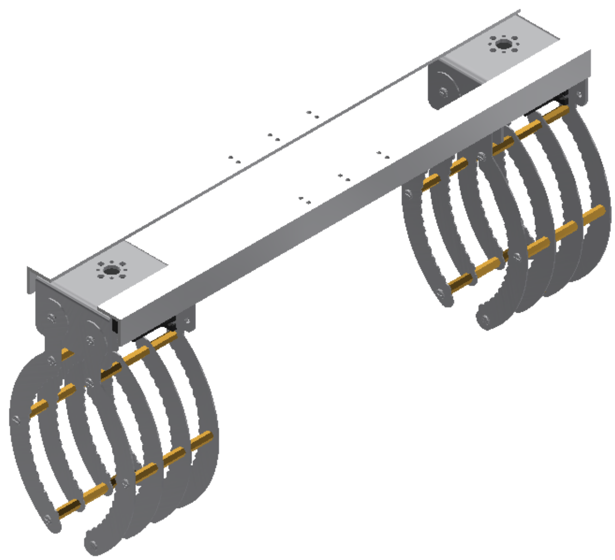


[**Figure 1**: Finalized Megalodon design]

(FIGURE 1) Echo Technologies's approach for the Megalodon is to use a carbon fiber frame that serves as a durable, large, and lightweight platform to mount four aerial motors, six underwater motors, two ABS watertight enclosure, as well as an articulated mechanism to recover the objects of interest. This design gives us the performance and size we will need to meet the mission deliverables. The mission will be completely autonomous through use of environmental sensors as opposed to constant communication, given that today's technology limits communication with the Megalodon deep on the ocean floor.

The Megalodon will implement an aerial quadcopter drone and a six-motor underwater UUV system. The quadcopter design consists of four motors with a low center of gravity which is proven to be a stable and maneuverable platform while carrying significant payloads. The six motor UUV system takes advantage of a neutrally buoyant design, with four motors controlling up and down and two forward mounted motors with differential thrust for control on the horizontal plane. Both of these subsystems, aerial and underwater, will provide sufficient power for a lightweight vehicle that can carry a large payload and transition from aerial flight to underwater travel.

The two watertight electronics enclosures serve as the heart of the Megalodon. The bottom mounted ABS enclosure will hold the batteries to power the Megalodon while the top mounted ABS enclosure will hold various Raspberry Pi processors, aerial and underwater electronic speed controllers, orientation sensors for the air and underwater, a programmable flight controller. The programmable flight controller allows the Megalodon to be operated autonomously with a pilot in a position to override the system in case there is loss of control. In addition, the electronics enclosure will provide an appropriate amount of buoyant force, making it just under the weight requirements of our vehicle, meaning our engineers will have the ability to adjust the buoyancy of the Megalodon.



[**Figure 2**: Megalodon recovery mechanism]

The objects of interest are of unknown sizes but it is predicted the hull of the K-129 is about 15 inches long with a diameter of 3 inches. As seen in **FIGURE 2**, the Megalodon will be using two claws positioned about 12 inches apart (subject to change if we receive any more intelligence about the size of the K-129). The distance separating the claws is important because it provides the stability needed when recovering the K-129 so no part of the submarine is lost. In addition, the Megalodon will be equipped with a camera providing vision to identify the parts on the ocean floor allowing the Megalodon to approach and collect the submarine.

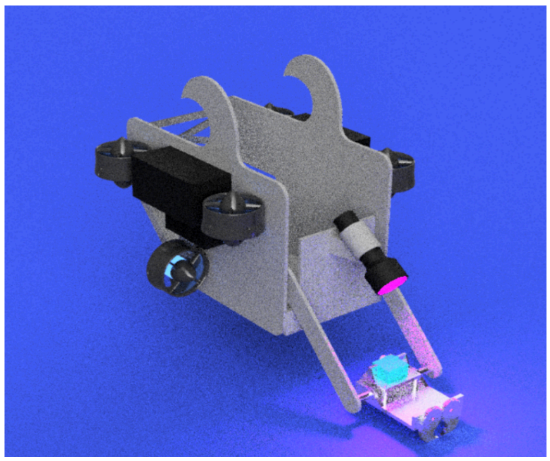
The Megalodon has undergone multiple design revisions since Echo Technologies' Systems Performance Specification. The most significant change was the decision to abandon the ballast system because Echo Technologies has confidence in the Megalodon to perform all aspects of the mission without the added complexity of a ballast system. In addition, the claw was significantly changed from the previous "dustpan" design to two claws that will recover the K-129. Other changes include a bigger battery, more powerful brushless motors, and bigger propellers to give the Megalodon the required thrust as well as flight and underwater time.

[**Figure 3**: Megalodon Prototype]

The current Megalodon prototype is evidently different than the final design as seen in **FIGURE 3**. Because Echo Technologies is still in the developing and testing stages, the current prototype is lacking the two, horizontal mounted UUV thrusters and the actual claw to recover the K-129. Less obvious from the outside appearance is the fact that the current prototype is not yet autonomous and instead relies on manual control. Using the current prototype, Echo Technologies has gathered much valuable information necessary for the further progression of completing all mission deliverables.

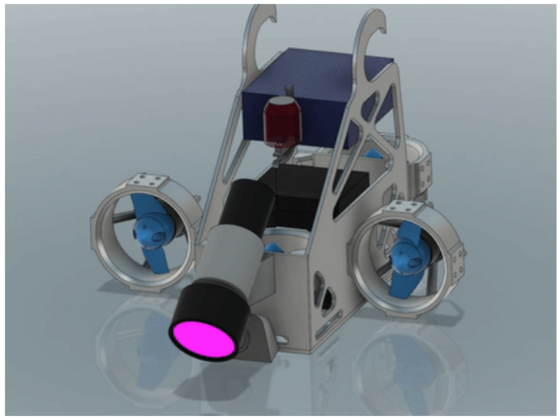
DESIGN OVERVIEW: REMORA

FRAME



[**Figure 4**: Remora Design from SPS]

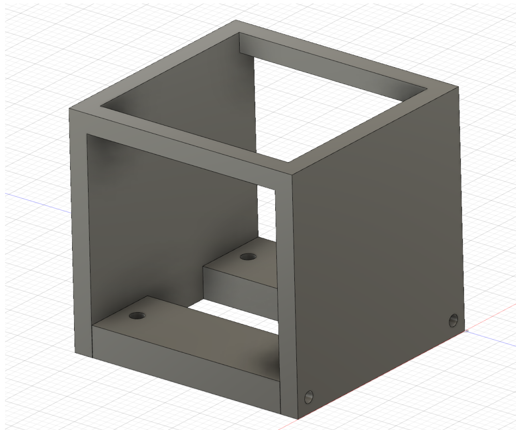
(FIGURE 4) The previous design consisted of: a claw mechanism for the intake system, a ballast system for buoyancy, and six motors for movement. However, ECHO technologies found that the combination of these three systems not only increased the weight - making the ROV surpass the projected weight limit - but also decreased the feasibility of completing the mission. For instance, the claw mechanism was inconvenient due to the pressure that the claw would be experiencing as it moved up. Similarly, the ballast system and the motors added unnecessary weight. Buoyancy could be achieved by making the ROV neutrally buoyant. The two extra motors were intended for diagonal movement, but we realized that the mission did not require this type of movement, so we would only need four motors total.



[**Figure 5**: Remora Design from SPS]

Taking these issues into consideration, we made some improvements to our design **(FIGURE 5)**. To achieve neutral buoyancy, there will be holes in the frame for the water to flow through. Also, instead of using a claw mechanism to retrieve the nuclear warheads, we will use a passive intake to cut down on weight.

INTAKE



[**Figure 6**: Remora Recovery Mechanism]

(FIGURE 6) The current prototype for the passive intake uses two doors to hold the warheads. The intake is shaped like a box and would sit at the bottom of the Remora. There are two doors that are limited to only open in one direction. The ideal action would be for the Remora to sit on the warheads and intake them. As it "sits" on the warheads, the doors would open inwards and as the warhead passes through, the doors would close.

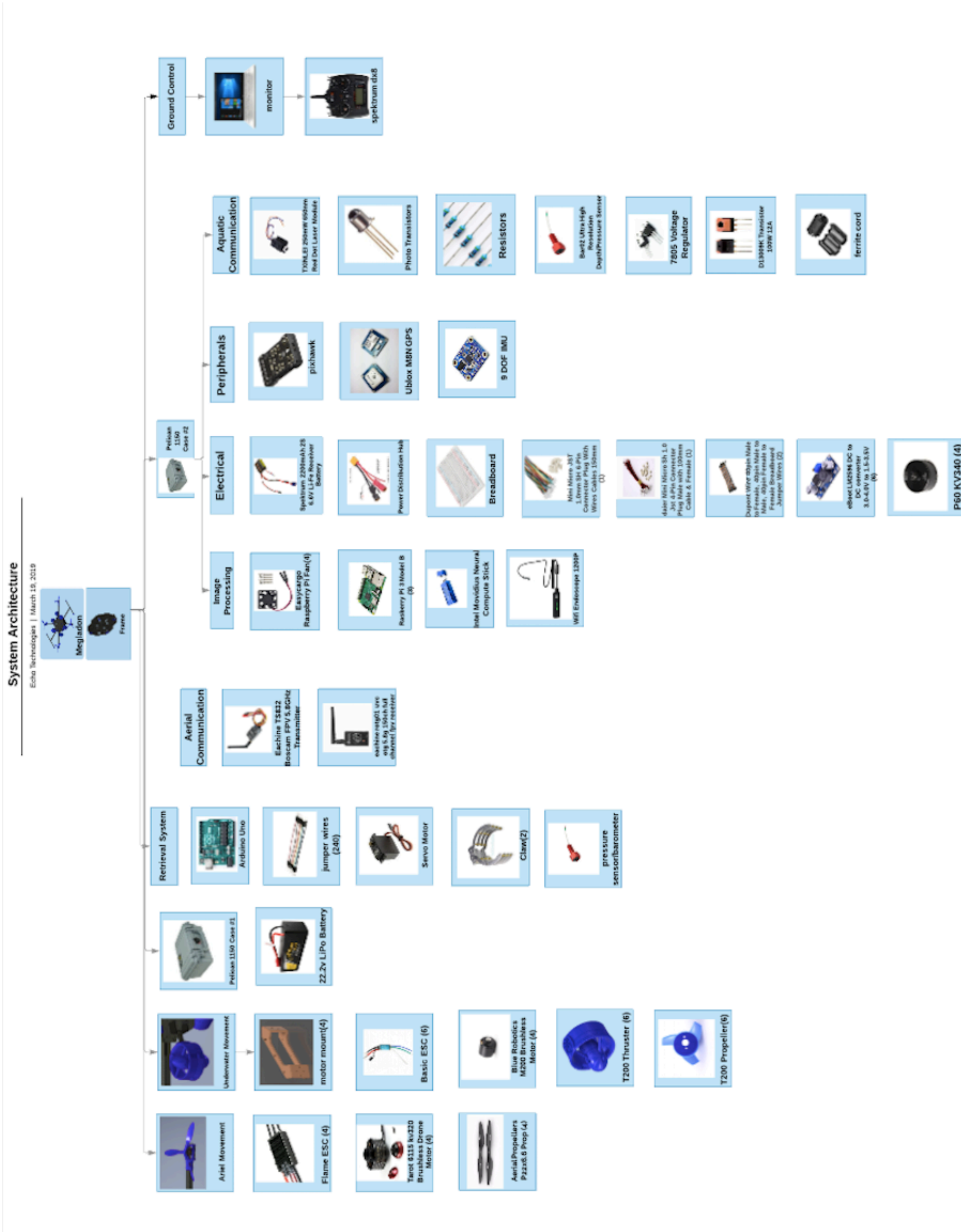
The result of the experimental testing showed otherwise. Through much forceful trial and error, the doors would not open wide enough for the warheads to pass through entirely nor would flush with the bottom of the frame. The force and location of the rubber bands pulling the doors inward hindered them from fully picking up the warhead. Thus, only one configuration of the warhead was able to be intaken. The gripping force was not great enough for the warhead to be entirely gripped when the warhead was laying on its side, so when the intake was shaken the capsule would fall out.

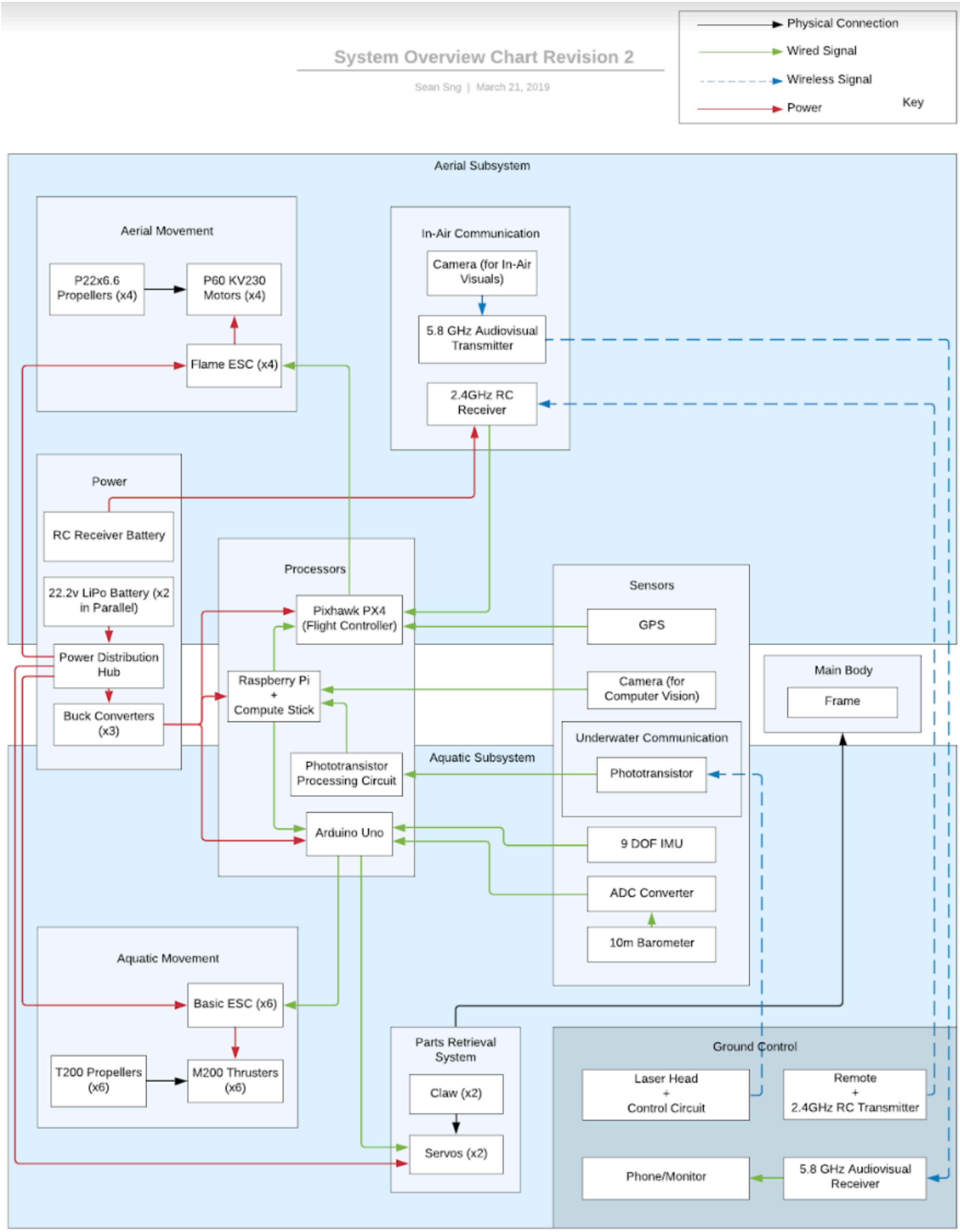
For future improvements, the location of the hooks should be modified. The current position of the hooks is forcing the doors to rest in a partially open state. By moving them closer together, the team is hoping that the doors will sit normally, as planned originally. Another change to the intake would be rounding the inside edges of the doors. This would hopefully ease the process of the warheads passing through, no matter the orientation of the warhead.

SYSTEM

ARCHITECTURE

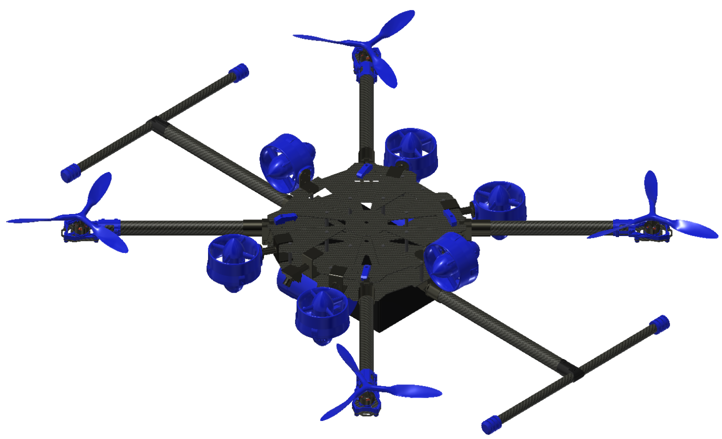
SYSTEM ARCHITECTURE CHARTS




System Overview Chart Revision 2
Sean Sng | March 21, 2019
Physical Connection
Wired Signal
Wireless Signal
Power
Key
Aerial Subsystem
Aerial Movement
P22x6.6 Propellers (x4)
P60 KV230 Motors (x4)
Flame ESC (x4)
In-Air Communication
Camera (for In-Air Visuals)
5.8 GHz Audiovisual Transmitter
2.4GHz RC Receiver
Power
RC Receiver Battery
22.2v LiPo Battery (x2 in Parallel)
Power Distribution Hub
Buck Converters (x3)
Processors
Pixhawk PX4 (Flight Controller)
Raspberry Pi + Compute Stick
Phototransistor Processing Circuit
Arduino Uno
Sensors
GPS
Camera (for Computer Vision)
Underwater Communication
Phototransistor
9 DOF IMU
ADC Converter
10m Barometer
Main Body
Frame
Aquatic Subsystem
Aquatic Movement
Basic ESC (x6)
T200 Propellers (x6)
M200 Thrusters (x6)
Parts Retrieval System
Claw (x2)
Servos (x2)
Ground Control
Laser Head + Control Circuit
Remote + 2.4GHz RC Transmitter
Phone/Monitor
5.8 GHz Audiovisual Receiver

FRAME

Since the Systems Performance Specifications, the main frame of the Megalodon has not been altered, as the original frame design provides stability and efficiency when moving from one fluid to the other.



[**Figure 7**: Frame of Megalodon]

The Megalodon drone frame is constructed of eight, hollow, carbon fiber tubes which are connected to two central carbon fiber plates. There are two pairs of carbon fiber tubes on either side of the of the drone frame – both in the shape of a T – that function as the "legs" and "feet" of the drone **(FIGURE 7)**. The "legs" are connected to an actuator system which allows them to rotate with 90 degrees of freedom, allowing them to stay parallel to the drone during flight (for improved aerodynamics) and perpendicular when the drone is on the ground.

Every carbon fiber tube on the drone is waterproofed on the ends and joints with Flex Seal (a rubber cement). By applying the Flex Seal to the ends of each tube, the drone becomes positively buoyant underwater because air is trapped inside the tubes and can't escape. The drone also has a fixed density since water can't collect in the tubes, causing the drone to be weighed down and more difficult to pilot.

The other four tubes on the drone are connected diagonally with respect to the legs, and are connected to the P60 aerial motors. These arms are rigid and are connected on fixed joints to the central frame.

CLAW

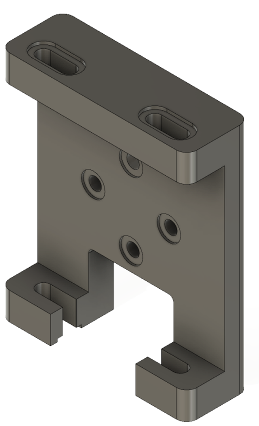
The claw is composed of two mechanical standard gripper claws that each uses two aluminum stiff arms with gears as joints attached to a servo box. These two claws are placed at the end of two 12-inch chassis rails which holes are drilled to attach the claw which is then mounted onto the electrical box as two points of connection are important in stabilizing holding the submarines. The length of this chassis rail will change as we are unsure of the length and weight of the submarines. Two waterproof servos are placed within each of the claw's respective servo box, being attached to one of the gear joints, controlling the opening and closing sequence of the claw. These motors are synced through programming and through long bars that attach two both claws to mechanically ensure the synchronization of both claws.

Although this method of obtaining and securing the objects of interest is slow because the Megalodon would have to align itself, it is accurate and will always hold the object to grab. In our previous designs, we had a stiff giant mesh box as a storage point for these submarines and we would collect these submarines using a spinning intake. This idea soon evolved into the two claws with two points of contact as it was much more reliable and efficient.

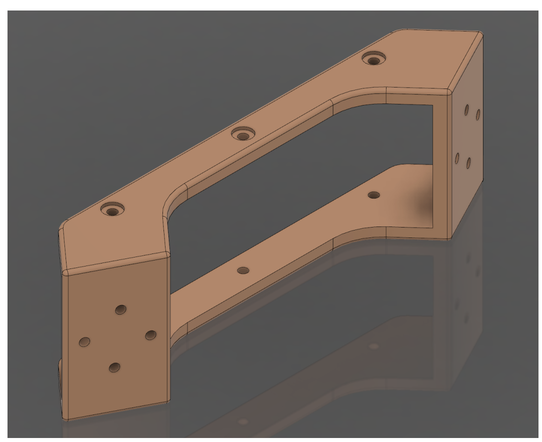
MOTOR MOUNTS

Motor mounts were constructed specifically for underwater motors, to maximize stable attachment to the frame **(FIGURE 8, FIGURE 9)**. The motor mounts our fairly flush against the carbon fiber frame, and holes were constructed to match up with the frame's holes, making the motor mounts easy to screw on and take off for testing purposes.

After constructing a motor mount based on the main frame, we determined the material using a decision matrix **(FIGURE 10)**, ultimately deciding to 3D print the motor mounts out of ABS Plastic, as 3D printing allows specific customization, while ABS Plastic is durable, waterproof, light, and easily molded.



[**Figure 8**: Motor Mounts for Horizontal T200 Underwater Motors]



[**Figure 9**: Motor Mounts for Vertical T200 Underwater Motors]

KEY	
PROS	+
NEUTRAL	0
CONS	-

Potential Materials for Underwater Motor Mount	Waterproof Ability	Weight	Durability	Ease of Molding	Cost	Total
Aluminum	+	0	+	+	0	**3**
ABS Plastic	+	+	+	+	0	**4**
Wood	-	-	-	+	0	**-2**

[**Figure 10**: Motor Mount Decision Matrix and Key]

MEGALODON ELECTRICAL

Our aerial subsystem is supplied with four P60 KV340 motors which are each controlled by FLAME 70A LV Aerial ESCs. As for the aquatic subsystem, there are six T200 Thrusters that are connected to six Basic ESCs from BlueRobotics. Two 16000mAh Turnigy LiPo Batteries will be used in parallel to provide power to all ESCs and to their respective motors through a power distribution hub. The power distribution hub will distribute power to the ESC's which will control the motors and then connected from the PDH are the ESC's. Four of the ESC's for the underwater subsystem are directly connected to one Raspberry Pi. As for the remaining six ESC's for the aerial subsystem, they are connected to a flight controller, which is then connected to the same Pi. An operating voltage of 5 V will be supplied to the smaller components and programming boards by way of eBoot Buck Converters. The parts that are also connected to the voltage transformer are the 3 Pi's. One of the two remaining Pi's are linked to a radio, pressure sensor and an IMU, while the other Pi is connected to cameras and two servos. In order to save vertical room inside the robot's electrical housing, the Raspberry Pi's will be modified. By desoldering and removing the ethernet ports and reducing the number of USB type A jacks on the board from 4 to 2, the width of the

Pi can be cut almost in half. This saves a lot of room when arranging Pi's, which will be stacked on top of each other using aluminum standoffs. The aerial ESCs will also be mounted against the wall of the control box.

CHANGES FROM SPS

After SPS, all of the components in the electrical system relatively stayed the same. The fan for the Raspberry Pi boards has been removed from the system after it was brought up during the presentation that it would not be much help to circulate the air within the control box. With wires directly going in and out of both boxes that contain electrical components, the process of waterproofing connections is placing cable penetrators and epoxy in each hole.

COMMUNICATIONS

UNDERWATER COMMUNICATION

Though we are striving to make the entire system of the Megalodon autonomous, underwater communication is still a vital part to the project. If anything goes wrong during the mission or even during testing underwater communication will be utilized.

PIEZOELECTRIC TRANSDUCERS

Shortly after SPS the piezoelectric transducers were tested as a possibility for our underwater communications. We decided to first test them in the air because if it does not work in the air then it would not work in the water since, dB levels drop underwater. Placing the piezoelectric transducer, a ½ foot away from a speaker we attached a voltmeter to the piezoelectric transducer and the varied the volume of the speaker. The results of the test were not promising. Though the volume of the speaker changed the voltmeter, about only half the time, had a different output. The other half of the time the voltmeter readings were very inconsistent. It changed randomly or did not even change at all. In order to remedy all of these problems we would need to have a much larger speaker and buy another piezoelectric transducer with a higher sensitivity. We ruled against doing this because the financial investment was very large for something we did not even know for sure would work.

LASER AND PHOTOTRANSISTORS

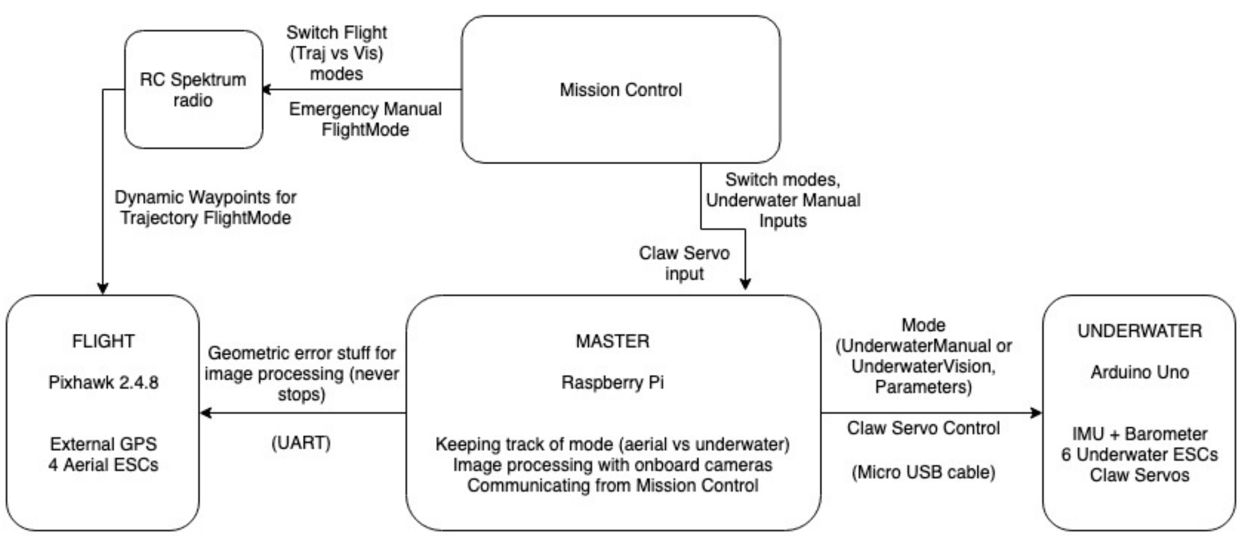
After ruling out piezoelectric transducers, we continued to research and decided to explore the use of lasers and photodiodes. In this system, the lasers would transmit information through light signals, similar to fiber optics, to the photodiodes

An optical transmitter will be used to convert the electrical signals into a light signal for the laser to transmit. The optical transmitter controls the laser and would, based on the electric signal, rapidly turn on/off the laser. This would create a light binary signal. The transmitted signal will be received by phototransistors, which we are using as our transducer to convert the light signal to an electrical signal. This system would be solely sending simple moving commands: Forward, backward, left, and right. Since we are only trying to control movement the only inputs for the laser would be from the joystick.

The laser would be positioned just below the surface of the water, but would also be connected to the control box to receive the commands from the joysticks. An obstacle that would be encountered in this design is the accuracy of the laser. In order for this system to work the laser would have to be aimed so that it is in continuous contact with the photoresistors. A slight miss would result in an incomplete signal and a failed command. To give us the best control of the laser a servo gimbal and a linear motion structure will be constructed. The laser will be hooked up to the servo gimbal which will allow it to move on the yaw and pitch axis, and the servo gimbal will be hooked up to the linear motion structure, giving it movement in the x-direction. This amount of maneuverability for the laser would give us great control however, an extra camera will also have to be added to the entire system. This camera would be used by the person operating the laser so that they have an obstructed view to aim the laser.

AUTONOMOUS CONTROL SYSTEM

The control system has changed from three Raspberry Pi 3 Model B programming boards to three different processors. In order to achieve real-time control, the Megalodon will use the PixHawk 2.4.6 flight controller and an Arduino Uno microcontroller in addition to a Raspberry Pi 3 Model B programming board. The Raspberry Pi will serve as the main processor for vision and will give high-level commands to these two new pieces of hardware. The overview of the system architecture with communication **(FIGURE 11)** is shown below.



[**Figure 11**: Autonomous Communication System Architecture]

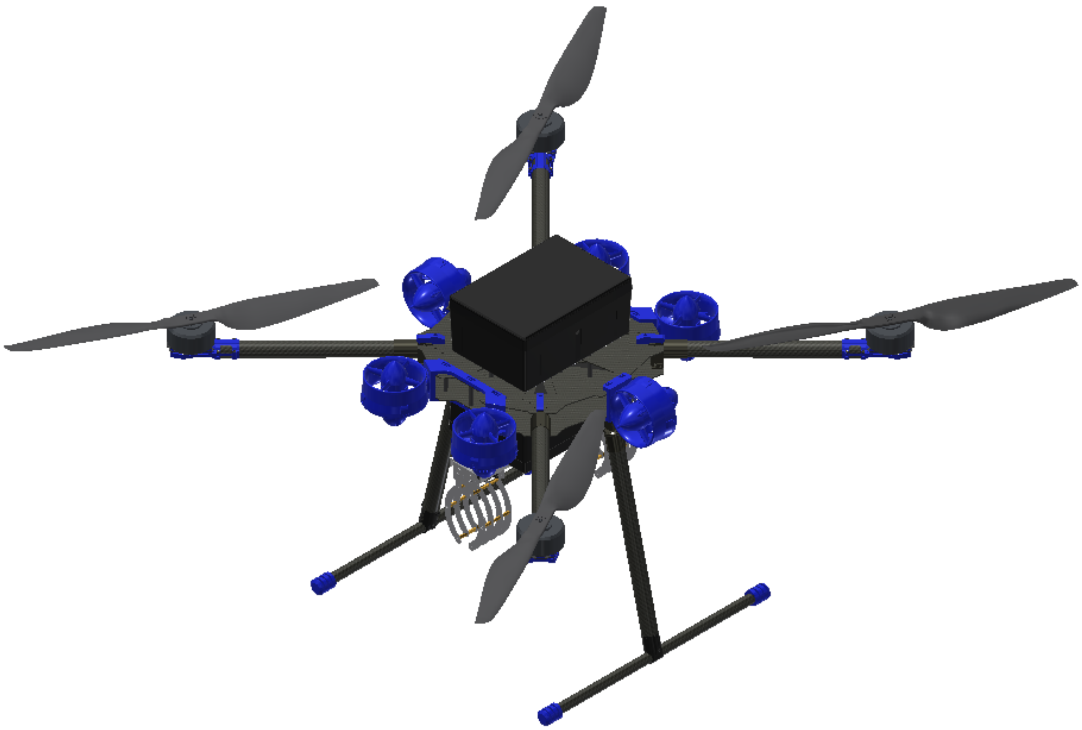
TESTING & DATA ON PROTOTYPE

MEGALODON FLIGHT TESTING

The total weight of the Megalodon UUV and UAV vehicle is predicted to be 12.401 kg takeoff weight and 8.371 kg without the battery. The chosen brushless motors will have 27 kg of thrust giving the drone a better than two to one thrust to weight ratio. This amount of thrust will also allow for an easy transition from water to air and the ability to carry a significant payload like Remora which is expected to weigh 3kg. Our prototype is on track to meet this estimated weight as the prototype weighs 7.39 kg without the battery. The reason it weighs less is because the claw is yet to be mounted and we currently have four UUV motors instead of six. The weight breakdown is shown in **FIGURE 12.**

ITEM	QUANTITY	UNIT WEIGHT	TOTAL WEIGHT
Frame (Tarot x4)	1	1.32 kg	1.32 kg
Pelican Case Protector 1150 Case	2	0.7 kg	1.40 kg
Aerial Motors	4	0.375 kg	1.50 kg
UUV Thrusters (Blue Robotics T200)	6	0.344 kg	2.06 kg
Aerial Propellers 4	4	0.051 kg	0.24 kg
Claw	2	0.115 kg	0.23 kg
Batteries 6s 1600mah *(subject to change)*	2	2.015 kg	4.03 kg
Electrical Wiring	1	1.123 kg	1.12 kg
ESC's Underwater (Blue Robotics Basic ESC)	6	.027 kg	0.16 kg
ESC's Aerial	4	.0735 kg	0.29 kg
UUV Motor Mounts	6	.05 kg	0.20 kg

[**Figure 12**: Megalodon Weight Breakdown]



[**Figure 13**: Full Assembly of Megalodon Design]

Using computer aided drawings as seen in **FIGURE 13**, we calculated the volume of the frame, the two Pelican cases, the aerial power system, and the UUV motors. This estimation suggests that the Megalodon will displace 11 kg of water when fully submerged. The objective is to have a neutrally buoyant design meaning we still have to displace an estimated 1.401 kg of water. However, it is better to have this problem as opposed to needing to add ballast, because displacing the required amount of water will not have a significant weight penalty on the Megalodon. In order to displace the required amount of water to have a neutrally buoyant design, ECHO Technologies will add ballast foam under each aerial motor mount of the Megalodon.

[**Figure 14**: Megalodon Flight Test]

TESTING METHOD

Before each flight, the battery voltage was recorded with the use of a lipo voltage checker. The drone would then be thoroughly inspected including motor mounts, propellers, propeller clearance, electrical connections, center of gravity, and the overall structural integrity before each flight regardless if a flight was performed minutes earlier. Weights would be added onto the drone by placing them inside the drone's legs (for the first flight, no weights would be added). Weights would be added in increments after the first flight depending on the pilot's controllability of the drone. Each flight was video recorded so that flight time can be later determined, and the video can provide us a source of post-review. After the flight, the Megalodon's ESC's would have their temperature checked through feel and the battery's voltage would again be recorded with a lipo voltage checker.

FINDINGS

The purpose of flight testing was to validate our claim that the Megalodon is capable of carrying significant payloads, and ECHO Technologies tested the Megalodon lifting ability up to 15.9 kg of flying weight. In addition, we wanted to demonstrate the maneuverability and safety of these flying operations. In all flights the Megalodon had sufficient power to climb even while carrying the heavy payloads. The Megalodon also demonstrated impressive stability even in the windy conditions. The Megalodon was capable of simple pattern flying maneuvers including different sizes of figure eight circuits showing it can cover the required 201.9 feet of distance to the pool. During each test flight, the before and after battery voltage was recorded as seen in **FIGURE 15.**

DATE	FLIGHT #	MEGALODON WEIGHT (kg)	DURATION ALOFT (sec)	BATTERY VOLTAGE BEFORE (V)	BATTERY VOLTAGE AFTER (V)
2/8/19	1	5.8967	13	25.1	24.9
	2	5.8967	38	25.1	24.9
	3	5.8967	83	25.1	24.5
	4	5.8967	146	25.1	24.1
2/24/19	1	5.8967	77	23.7	23.1
	2	8.16466	52	24.7	23.9
	3	10.4326	24	25.1	24.7
	4	12.7006	32	25.1	24.3
3/1/19	1	8.19185	272	25.2	22.7
3/16/19	1	9.07185	28	25.1	24.7
	2	13.6078	35	24.7	23.7
	3	15.8757	16	25.1	24.6

[**Figure 15**: Megalodon Flight Testing Data]

The voltage drop compared to the flight time looks concerning considering Echo Technologies is intending to use a 6 cell, 22.2-volt battery. However, the battery being used in all test flights was only a 22.2 volt, 5-amp battery which is considerably smaller than the 22.2 volt 32-amp battery Echo Technologies plans on using. In addition, the bulk of the mission time will be completed underwater with flying taking much less time. Battery comparison pictures between the test battery and final design battery are shown in **FIGURE 16**. The final design battery consists of two 22.2 V, 16 amp batteries connected in parallel.

[**Figure 16**: Design Batteries for Megalodon]

On the first day of test flying (2/24/19), it was noted that the ESC's of motors one and three were significantly warmer than the other ESC's although it was not a temperature that discouraged further testing. After an inspection of the motor mounts, it was apparent that some motor mounts were slightly tilted suggesting that motors one and three had to spin at higher RPM than motors two and four to counteract the yaw caused by the mounts being off-center. As seen in **FIGURE 17**, the motor mounts are friction fit without any guides so each mount must be attached with extra care so the mount is level with the rest of the frame. The slight yaw effect was also apparent when flying although it was corrected using the trim feature on the transmitter. After correcting the angles on the motor mounts, all ESC's were at the same temperature and the Megalodon required no yaw correction.

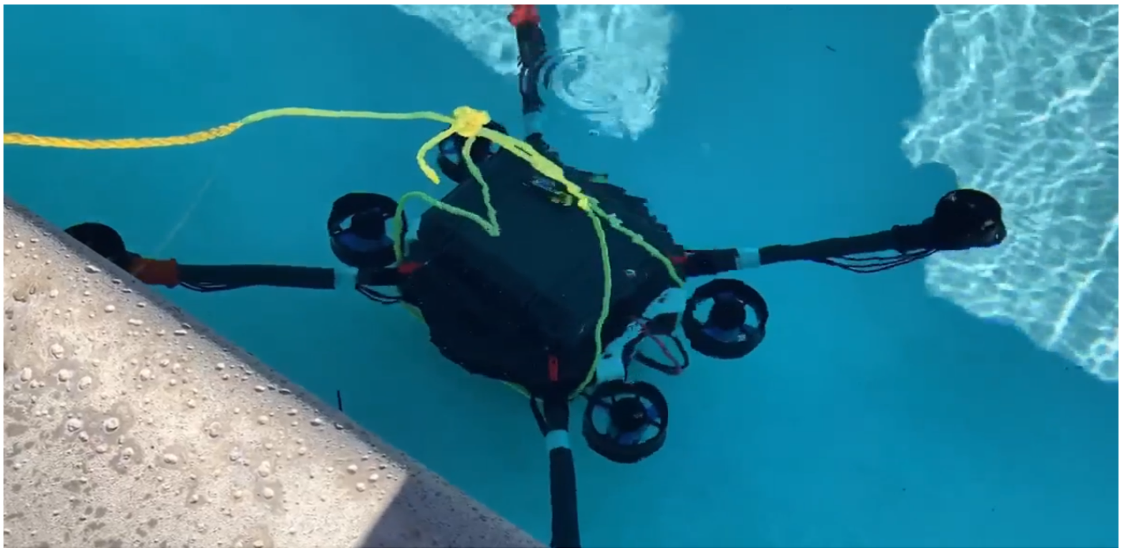
[**Figure 17**: Aerial Motor Mount]

On the last test flight recorded in the flight test data table, the Megalodon experienced an unexpected crash while testing the climb capabilities at full power for the first time. The cause of the crash was partially attributed to the friction-fit motor mounts as seen in **FIGURE 17**. However, it was not an issue with the mount being inadequately tightened. Instead, the chief scientist and test engineer, who were present at the accident and reviewed the flight video, suspect a harmonic vibration caused by the motors operating at full power which allowed the motor three mount to slip in flight resulting in the propeller of motor three striking the UUV motor causing an overload cut-off of the motor by the ESC leading to the crash. Inspection of the motor mount seemed to confirm this theory as the mount was still too tight to physically rotate but under the circumstances of a harmonic vibration, this is very possible. Furthermore, there are spacers separating the motor from the motor mount meaning a vibration originating in the motor has more leverage to rotate the mount as seen in the accident.

To address this issue, Echo Technologies has reinforced the motor mounts by adding a mechanical constraint on the rotation of the mount so friction is not the only force fighting the vibration and torque of the motors. By using a screw running through the plastic motor mount and carbon fiber arm, as seen in **FIGURE 18**, the harmonic vibration will no longer be able to rotate the motor mounts even at full power.

[**Figure 18**: Motor Mount Securer]

MEGALODON WATER TESTING



[**Figure 19**: Megalodon Water Test]

TESTING METHOD

In order to test the waterproofing done to the Megalodon, we submerged the drone to depths of 3, 5 and 7 feet. Before each trial, Echo Technologies placed paper towels around different wires running through the walls on the Pelican 1150 Protector Cases to determine the source of the leak, if any. The drone would then be lowered into the pool by use of a rope while the test engineer would record observations and time. After recovering the Megalodon from the pool floor, the paper towels would be inspected and replaced.

FINDINGS

The purpose of the underwater tests was to determine if the changes we made to the Pelican 1150 protector case were in fact waterproof. Before making changes to the Pelican case, Echo Technologies had determined the Pelican case itself could remain underwater at a depth of seven feet for at least ten minutes on multiple trials. Our goal was to demonstrate this same capability with multiple wires running through the plastic walls of the Pelican case. As seen in **FIGURE 20**, the first tests resulted in failure as a small amount of water leaked into the Pelican enclosure. Because we used paper towels around each wire penetrator, we were able to attribute the small amount of water to a UUV motor wire penetrator running through the Pelican 1150 Protector case. For the next week, Echo Technologies addressed the issue and continued testing. Using a combination of O-rings, flex seal, and epoxy, the Pelican case remained waterproof at that same depth of seven feet. For the mission, the cases will be lowered to a maximum depth of four feet meaning there is a level of confidence in the successfulness of the waterproofing done to the Megalodon.

In addition, we observed the tendencies of the drone as it sank to the pool floor noting it never rolled over on itself but instead descended vertically at a constant rate in a very stable manner which will be to our benefit for underwater control.

The aerial motors are brushless outrunners meaning they are a capable of operating exposed to water. The real concern is corrosion due to the water and minerals but not short circuiting of the electronics. For that reason, the Megalodon uses brushless motors with a corrosion resistant coating. Echo Technologies has gone even a step further by adding another layer of corrosion resistant spray. As a result, the motors have continued to turn freely and with the same amount of rpm after being exposed to water.

DATE	TRIAL #	DEPTH (ft)	DURATION (sec)	PASS/FAIL
3/10/19	1	3	20	FAIL
	2	3	15	FAIL
	3	3	30	FAIL
3/17/19	1	3	30	PASS
	2	3	60	PASS
	3	3	120	PASS
	4	3	600	PASS
	5	5	60	PASS
	6	7	120	PASS

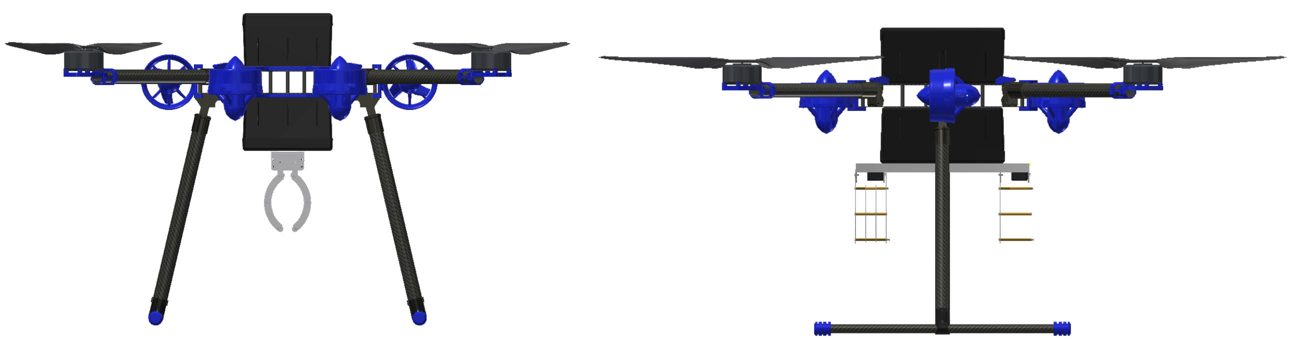
[**Figure 20**: Megalodon Water Testing Data]

TRANSITIONING FROM WATER TO AIR

While carrying out these waterproof tests, Echo Technologies used a fishing scale to record the weight of the Megalodon when it was pulled out of the water as seen in **FIGURE 21**. The reason for this was to see if suction or drag created by the water would add to the weight of the drone as it transitioned from underwater operations back to the air. From these tests, we found that the water added no weight during this process. This test was done three times for each of two Megalodon weights of 13.6 kg and 11.4kg. In all six tests, there was no recordable difference between the dry weight of the Megalodon and the maximum weight in transition from underwater to the air. Both the dry weight and the weight in transition was measured using the fishing scale to keep all factors consistent. The fact that there was no recordable difference could be due to the precision of the fishing scale being to the nearest pound. Based on the data, the aerial power system would need to output thrust equal to the weight of the Megalodon on land to transition from underwater operations to aerial flight. The Megalodon has already easily demonstrated the ability to fly under these weight conditions.

[**Figure 21**: Megalodon Thrust Test]

However, the aerial motors are only making enough thrust in the air to lift the drone. The aerial motors are not designed to work efficiently underwater and therefore do not produce the torque necessary to lift themselves out of the water. As a result, the UUV motors have to be strong enough to lift the aerial motors into the air where they can take over the heavy lifting. The Megalodon uses four vertically facing UUV motors to control vertical position. At 12 volts, each UUV thruster provides a maximum of 3.55kg of thrust. The total thrust of these four motors is therefore 14.2kg meaning these motors are more than capable of lifting the top half of the Megalodon out of the water as seen in **FIGURE 22** which includes the aerial motors.

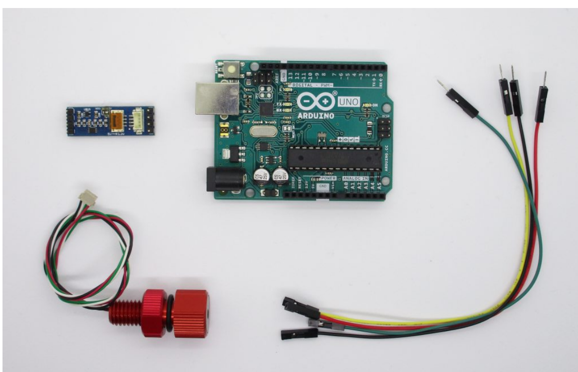


[**Figure 22**: Front and Side Views of Megalodon]

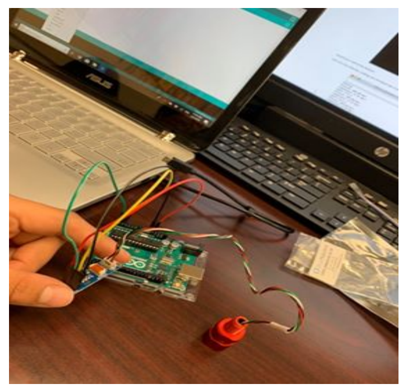
PROGRAMMING TESTS

BAROMETER TESTING – BAR02 DEPTH/PRESSURE SENSOR

Using an I2C level converter, we connected the Bar02 barometer to the Arduino **(FIGURE 23, FIGURE 24)**. A sample program **(FIGURE 25)** was used to run tests on the sensor to measure the air pressure and height. The barometer was accurate and worked well outdoors.



[**Figure 23**: Arduino, I2C Converter, Bar 02 Sensor, Jumper Wires]



[**Figure 24**: Testing of Barometer with Arduino Programming Board]

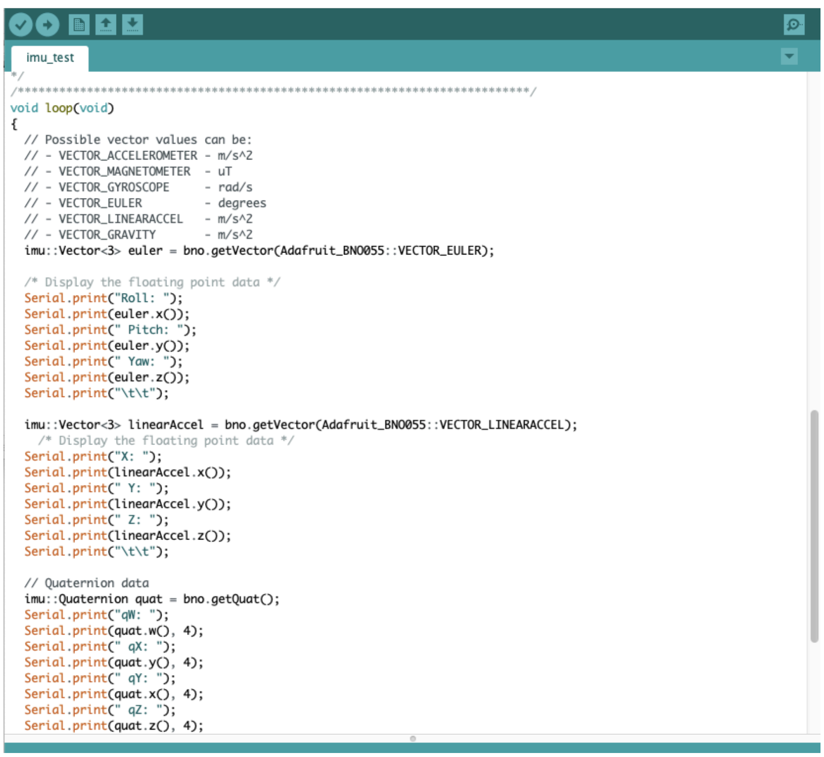
sensortest.ino

```
#include <MS5837.h>

#include <Wire.h>

MS5837 sensor;

void setup() {

  Serial.begin(9600);

  Serial.println("Starting");

  Wire.begin();

  sensor.setModel(MS5837::MS5837_02BA);
  sensor.init();

  sensor.setFluidDensity(997); // kg/m^3 (997 freshwater, 1029 for seawater)
}

void loop() {

  sensor.read();

  Serial.print("Altitude: ");
  Serial.print(sensor.altitude());
  Serial.println(" m above mean sea level");
```

[**Figure 25**: Sample Barometer Testing Code]

IMU TESTING – ADAFRUIT BNO055 ABSOLUTE ORIENTATION SENSOR

We also ran tests on the BNO055 IMU with the Arduino **(FIGURE 26)**. Our results showed accurate orientation readings, but could not keep a very accurate estimate of translational movements over time. This was expected because the position estimation algorithm uses double integration on acceleration, introducing chances for noise to grow into large accumulations of error.

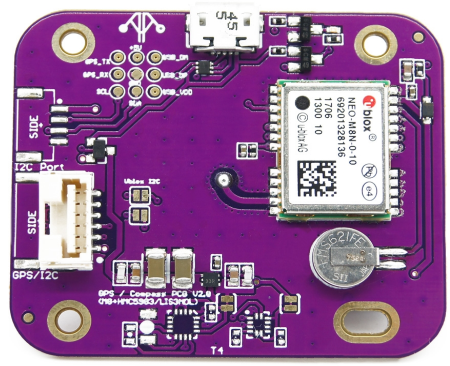


```
imu_test
*/
/**************************************************************************/
void loop(void)
{
  // Possible vector values can be:
  // - VECTOR_ACCELEROMETER - m/s^2
  // - VECTOR_MAGNETOMETER  - uT
  // - VECTOR_GYROSCOPE     - rad/s
  // - VECTOR_EULER         - degrees
  // - VECTOR_LINEARACCEL   - m/s^2
  // - VECTOR_GRAVITY       - m/s^2
  imu::Vector<3> euler = bno.getVector(Adafruit_BNO055::VECTOR_EULER);

  /* Display the floating point data */
  Serial.print("Roll: ");
  Serial.print(euler.x());
  Serial.print(" Pitch: ");
  Serial.print(euler.y());
  Serial.print(" Yaw: ");
  Serial.print(euler.z());
  Serial.print("\t\t");

  imu::Vector<3> linearAccel = bno.getVector(Adafruit_BNO055::VECTOR_LINEARACCEL);
    /* Display the floating point data */
  Serial.print("X: ");
  Serial.print(linearAccel.x());
  Serial.print(" Y: ");
  Serial.print(linearAccel.y());
  Serial.print(" Z: ");
  Serial.print(linearAccel.z());
  Serial.print("\t\t");

  // Quaternion data
  imu::Quaternion quat = bno.getQuat();
  Serial.print("qW: ");
  Serial.print(quat.w(), 4);
  Serial.print(" qX: ");
  Serial.print(quat.y(), 4);
  Serial.print(" qY: ");
  Serial.print(quat.x(), 4);
  Serial.print(" qZ: ");
  Serial.print(quat.z(), 4);
```

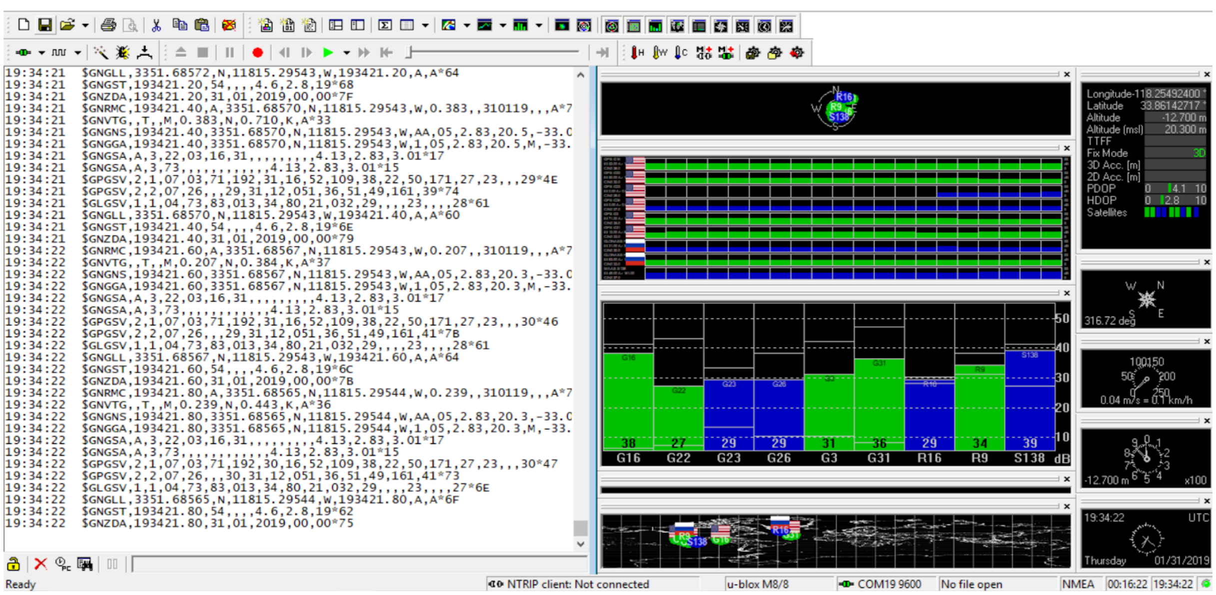
[**Figure 26**: Sample IMU Testing Code]

GPS TESTING – MRO GPS UBLOX NEOM8N

In order to test the Ublox M8N GPS **(FIGURE 27)**, Ucenter, which is provided by Ublox, was downloaded. The GPS was connected to the computer through USB and UCenter was able to receive data about the location, signal, and more which is shown below **(FIGURE 28)**.



[**Figure 27**: uBlox GPS Model BGP]



[**Figure 28**: GPS Data Testing Results]

PIXHAWK 2.4.6

The Megalodon will use the mRo Pixhawk 2.4.6 **(FIGURE 29)** as its flight controller. The Pixhawk 2.4.6 is an adaptable, high-quality, and lightweight flight controller that is made specifically to work in hand with the PX4 or Ardupilot library. It comes with peripherals including a GPS and radio that are advantageous for things such as aerial localization and communication. Also, the Pixhawk I2C port can be used to connect to the Raspberry Pi.

The Pixhawk 2.4.6 includes the features:

- 32-bit Cortex® M4 core with FPU
- 168 MHz/256 KB RAM
- 32-bit failsafe co-processor
- Micro 3-axis 16-bit gyroscope
- Micro 3-axis 14-bit accelerometer/magnetometer
- Invensense® MPU 6000 3-axis accelerometer/gyroscope
- MEAS barometer

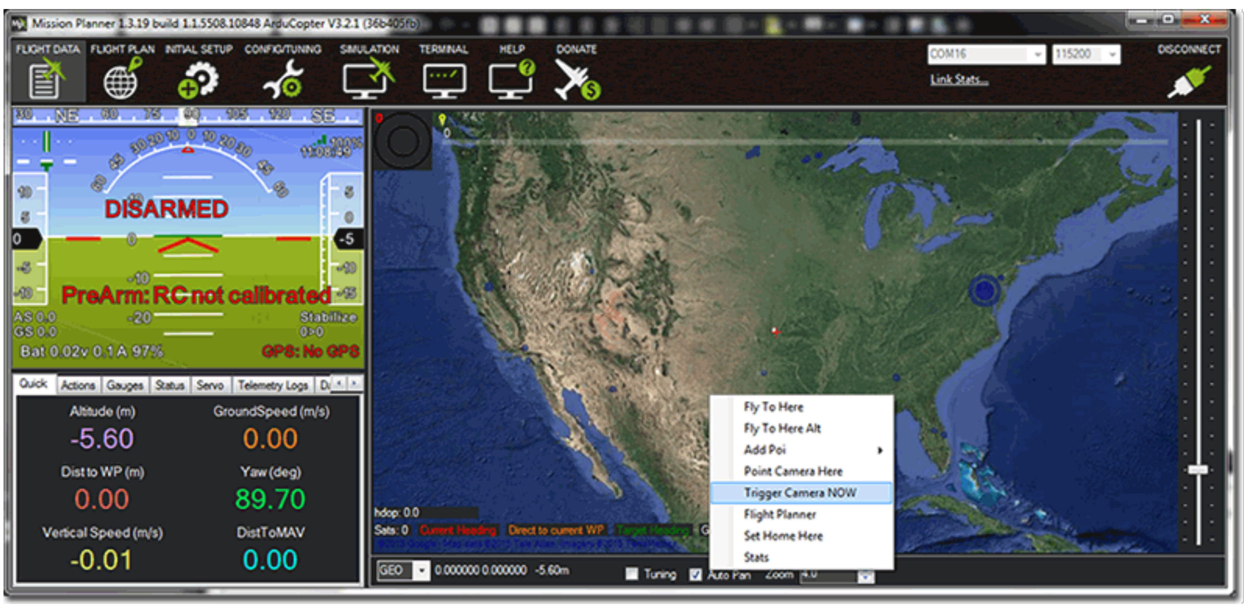
[**Figure 29**: mRo Pixhawk 2.4.6]

ARDUPILOT

The Pixhawk flight controller is compatible with ArduPilot which is an open source autopilot software with advanced data-logging, analysis and simulation tools. Ardupilot offers different programs depending on the vehicles, and for the Megalodon we will be using ArduCopter. It offers a variety of flight software from manual to autonomous. ArduCopter has auto-level and altitude hold modes that allow the Megalodon to fly straight with ease without the pilot having to worry about keeping of the vehicle's heading. It also has Loiter and PosHold modes which the vehicle will keep the position it's in by using its GPS, accelerometers and barometer.

MISSION PLANNING

ArduPilot software platform works seamlessly with a variety of Ground Control Station **(FIGURE 30)** programs that are used to setup the vehicle, monitor the vehicle's flight in real-time and perform powerful mission planning activities. ArduCopter assists in autonomous missions by allowing us to use the ground station to define complex missions with up to hundreds of GPS waypoints. Then switch the vehicle to "AUTO" and watch it take-off, execute the mission, then return home, land and disarm all without any human intervention. In order to plan the autonomous mission, we first load the the software into the Pixhawk board. We then setup, configure, and tune the flight controller for the mission. Finally, we are able to plan, save and load autonomous missions into autopilot with simple point-and-click waypoint entry on Google or other maps. Some nice features about ground control station are the ability to download and analyze mission logs created, record telemetry logs, and the ability to view and analyze the telemetry logs.



[**Figure 30**: Mission Planning – Ground Control Station]

MOTOR TESTING

To control each individual underwater motor, we send a Pulse-Width Modulation (PWM) signal to a BlueRobotics ESC through the Arduino. We use the Arduino servo library to send this signal. Through testing, we determined that the effective range of applicable values to send to the motor controller was from 1100 to 1900, which 1500 serving as the "stop" value. To make setting individual motor speeds more intuitive, we scaled [1100 to 1900] to [-1.0 to 1.0], where -1.0 represents full reverse throttle and 1.0 represents full forward throttle.

The motors successfully ran with the simple test script shown in **FIGURE 31**, so we adopted the -1.0 to 1.0 throttle scheme in the rest of our control scheme.

single_motor_test

```
#include <Servo.h>

byte servoPin = 9;
float throttle = 0;
Servo motor1;

// set power from -1.0 to 1.0
void setThrottle(float motorThrottle) {
  float input = motorThrottle * 400 + 1500;
  motor1.writeMicroseconds(input);
  Serial.print("Motor 1 Throttle: ");
  Serial.print(motorThrottle);
  Serial.print(" || Motor 1 input: ");
  Serial.print(input);
  Serial.println();
}

void setup() {
  Serial.begin(9600);

  motor1.attach(servoPin);
  setThrottle(0);
  delay(7000);
}

void loop() {
  setThrottle(0.3);


}
```

[**Figure 31**: Script to run Motors at a Specified Throttle from -1.0 to 1.0]

CONTROL SCHEME

Our underwater control scheme relies on the IMU and barometer to give us position and orientation feedback. The entire system is under closed-loop control. We are able to theoretically send a translation or rotation command and have the Megalodon reach that desired pose.

Currently, we have 6 proportional controllers that act on translations and rotations about each of the 3 major axes. We will add integral and derivative terms to these controllers as necessary. Our overall control scheme adds the outputs of these controllers in different ways to find the exact throttle we need to send to each motor to reach our desired pose.

VISION

COLOR DETECTION

A crucial part of the mission is detecting the underwater components we need to pick up. In order to do so, we have brainstormed different strategies including OpenCV color detection with Python. We ran a sample program **(FIGURE 32)** that allows us to use the camera on a laptop in order to detect masks of designated colors. We plan on running this same program on a Raspberry Pi connected to a waterproof camera.

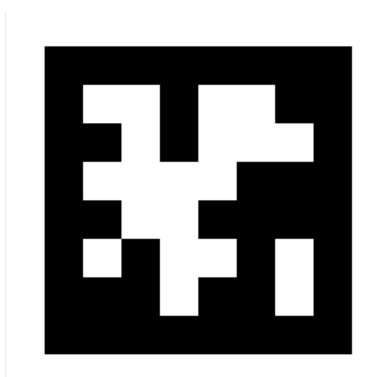
```python
# Python program for Detection of a
# specific color(blue here) using OpenCV with Python
import cv2
import numpy as np

# Webcamera no 0 is used to capture the frames
cap = cv2.VideoCapture(0)

# This drives the program into an infinite loop.
while(1):
    # Captures the live stream frame-by-frame
    _, frame = cap.read()
    # Converts images from BGR to HSV
    hsv = cv2.cvtColor(frame, cv2.COLOR_BGR2HSV)
    lower_red = np.array([110,50,50])
    upper_red = np.array([130,255,255])

    # Here we are defining range of bluecolor in HSV
    # This creates a mask of blue coloured
    # objects found in the frame.
    mask = cv2.inRange(hsv, lower_red, upper_red)

    # The bitwise and of the frame and mask is done so
    # that only the blue coloured objects are highlighted
    # and stored in res
    res = cv2.bitwise_and(frame,frame, mask= mask)
    cv2.imshow('frame',frame)
    cv2.imshow('mask',mask)
```

```python
    lower_red = np.array([110,50,50])
    upper_red = np.array([130,255,255])

    # Here we are defining range of bluecolor in HSV
    # This creates a mask of blue coloured
    # objects found in the frame.
    mask = cv2.inRange(hsv, lower_red, upper_red)

    # The bitwise and of the frame and mask is done so
    # that only the blue coloured objects are highlighted
    # and stored in res
    res = cv2.bitwise_and(frame,frame, mask= mask)
    cv2.imshow('frame',frame)
    cv2.imshow('mask',mask)
    cv2.imshow('res',res)

    # This displays the frame, mask
    # and res which we created in 3 separate windows.
    k = cv2.waitKey(5) & 0xFF
    if k == 27:
        break

# Destroys all of the HighGUI windows.
cv2.destroyAllWindows()

# release the captured frame
cap.release()
```

[**Figure 32:** Color Detection Sample Program]

APRILTAGS

Tasks in the mission such as picking up the Remora require precise alignment. To help achieve this, we've decided to use QR code-like fiducial markers known as AprilTags **(FIGURE 33)**. Advantages of AprilTags include robust and accurate corner detection. With this level of corner detection, we can estimate the full 3D pose (position and orientation) of a target relative to a camera on the robot by solving the Perspective-N-Point problem.

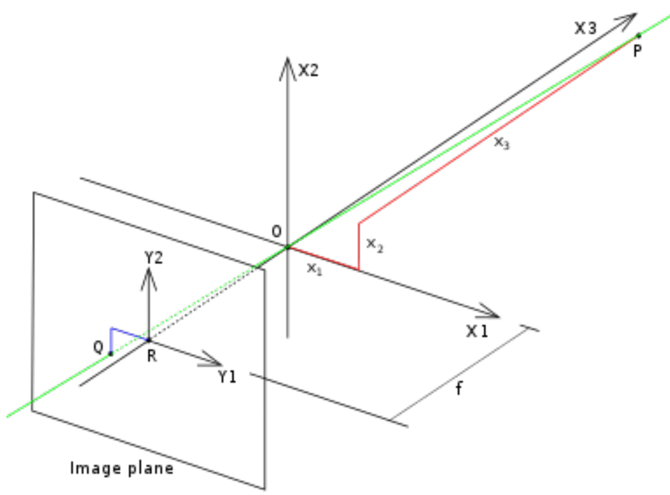


[**Figure 33:** AprilTag "tag36_11_00001"]

CAMERA CALIBRATION

To convert information, we learn from an image, which is represented in pixels, to real world units, we need to know the camera intrinsic parameters.

In the pinhole camera model **(FIGURE 34)**, all projection lines from a real-world point to its corresponding point on the image sensor pass through a single point, which is what we call the optical center O. The focal length f is the distance between the optical center and the image sensor.



[**Figure 34:** Pinhole Camera Model]

A camera's intrinsic parameters can be represented by the intrinsics matrix K **(FIGURE 35)**. Here, f_x and f_y represent the focal length, and x_0 and y_0 represent the optical center. s represents axis skew, but we can safely ignore that as it has little effect on accuracy of pose estimation.

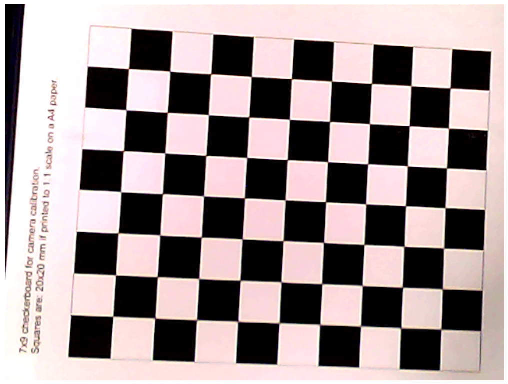
Note: for the rest of the image processing section, we may also use c_x and c_y to represent optical center.

$$K = \begin{pmatrix} f_x & s & x_0 \\ 0 & f_y & y_0 \\ 0 & 0 & 1 \end{pmatrix}$$

[**Figure 35:** Intrinsics Matrix K]

To find these intrinsic parameters for our camera, we perform the common chessboard calibration process. The chessboard is widely used for camera calibration because of its highly structured geometry. Passing all corners of a printed-out chessboard in an image taken from the camera **(FIGURE 36)** we want to calibrate into the OpenCV function "calibrateCamera" gives us the camera intrinsics matrix K in pixels:

- $f_x = 782.4328288970378$
- $f_y = 775.4785896345137$
- $c_x = 348.44041423071474$
- $c_y = 192.40481442590067$



[**Figure 36:** Image of Printed Chessboard taked with USB Camera]

PERSPECTIVE-N-POINT PROBLEM

In the Perspective-N-Point (PNP) problem, the givens are as follows: the camera intrinsics matrix, the real-world 3D locations of n points on the object of interest, and the corresponding coordinates of those points in the image taken by the camera. To reiterate, our goal is to calculate the 3D pose (position and orientation) of a target relative to a camera on the robot.

We will represent the coordinates of the camera in 3D space with X, Y, and Z. We will also represent the coordinates of a point on the target in 3D space with U, V, and W. We can represent the transformation from (U, V, W) to (X, Y, Z) we can use Equation 1 **(FIGURE 37)**. This gives us a rotation matrix R and translation vector t, which is the solution to the PNP problem.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \mathbf{R} \begin{bmatrix} U \\ V \\ W \end{bmatrix} + \mathbf{t}$$

$$\Rightarrow \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = [\mathbf{R} \mid \mathbf{t}] \begin{bmatrix} U \\ V \\ W \\ 1 \end{bmatrix}$$

[**Figure 37:** Equation 1]

However, although we know instances of real-world points on the target (U, V, W), we don't know (X, Y, Z). We need to use the coordinates of points in the image taken by the camera to estimate (X, Y, Z). This can be done with the intrinsics matrix K obtained from camera calibration. Equation 2 **(FIGURE 38)** shows the relationship of image coordinates (x, y) and (X, Y, Z). s is an unknown scale factor.

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = s \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

[**Figure 38:** Equation 2]

Now that we have something to represent (X, Y, Z), we can put it all together in an expanded form of Equation 1 **(FIGURE 39)**. This will be the equation we solve to obtain the transformation matrix that can be used to calculate the pose of the target relative to camera.

$$s \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} r_{00} & r_{01} & r_{02} & t_x \\ r_{10} & r_{11} & r_{12} & t_y \\ r_{20} & r_{21} & r_{22} & t_z \end{bmatrix} \begin{bmatrix} U \\ V \\ W \\ 1 \end{bmatrix}$$

[**Figure 39:** Expanded Form of Equation 1]

To estimate an initial solution to this equation, we can apply the Direct Linear Transform (DLT) algorithm. However, the solution given by the DLT algorithm always has a substantial amount of error. To minimize the error in the solution, we can use the Levenberg-Marquardt

Optimization algorithm, which iteratively guesses parameters that continually get closer to the true solution.

We use an implementation of this algorithm known as the SolvePnP function in OpenCV. With the size of the AprilTag and the coordinates of its corners in a live stream, we're able to estimate the full real-time 3D transformation of an AprilTag to a camera. Through extensive testing, we've determined that this is a robust method of pose estimation that we can use as feedback to physically align any two things we have control over in the mission.

REMORA TESTING

WATER TESTING

AUXILLARY BEACON

[**Figure 40:** Pelican Mini Flasher 2130 LED]

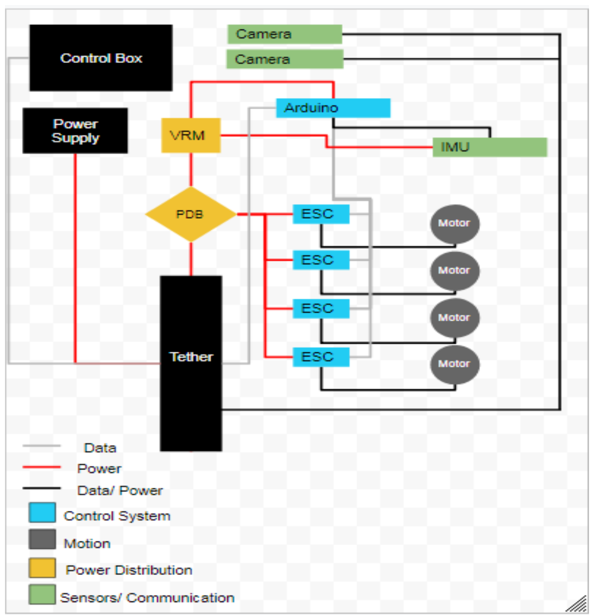
As a backup to our Apriltag OpenCV, we bought a Pelican Mini Flasher 2130 LED **(FIGURE 40)**. This would allow the Remora to effectively communicate with the Megalodon if our main communication system was rendered ineffective or malfunctioned. Our initial idea was to attach this small, 0.5 oz. flashing LED to constantly flash as the Remora moved, allowing the Megalodon to "see" where the Remora was, for a quick withdrawal.

In order to test the effectiveness of the beacon, it was placed in a pool at various depths. When placed in a clear pool at depths between 0-3 ft, the beacon was completely visible, so long as there were no disturbances in the water. When placed between 4-5.5 ft, the beacon became less visible (flashing "less often"). Most orientations (any orientation that didn't have the light directly pointed towards the viewer) allowed for some flashes to become visible, but it was inconsistent overall. Below 6 ft, the light was barely visible, its flashes only visible occasionally.

These trials all were conducted so that the water was completely still and void of any other obstructions. But, when surface disturbances did occur, the light was only visible at approximately 1 ft. When the Remora and Megalodon are in the water, there is likely to be some disturbances in the water. These disturbances in the water make it unlikely that the beacon will be visible at depths of 11 ft (the maximum depth of the real-life pool). Therefore, this beacon is not a viable option due to the lack of depth that it can be viewed at.

ELECTRICAL TESTING

The new electrical schematic **(FIGURE 41)** for the Remora is fairly similar to the one presented at SPS. As mentioned before, the Remora will be powered from an external power source, which will send power and data through a tether to the onboard electronics of the ROV. The power from the tether will be sent to an onboard power distribution panel (PDB) which will disperse the power through the system. The Remora has a set of 6 T100 motors which supply 5 pounds of thrust each. Each motor will be connected to an Electronic Speed Controller (ESC) which in turn is connected to the PDB. The ESC's will be connected directly to the PDB, while the onboard Arduino Uno Rev 3, and IMU will be powered from the PDB through a 5V voltage regulator module (VRM); lowering the output of the tether to their operating voltage of 5V. A camera will receive power directly through a USB extension connected to our tether, while our auxiliary beacon and UV light have built-in batteries.



[**Figure 41:** New Remora Electrical Schematic]

CONTROL SYSTEM

The robot is controlled by an external control box with a joystick and button system that will send data through the tether to the Arduino Uno which is connected to each of the 6 ESC's which drive the propulsion motors of the robot. Signals from the tether will go to the Arduino which can communicate with the ESC's through the PDB. The control box and computer on the surface will process the camera feed and send it to the operator who will be controlling the ROV. The IMU data will be sent to the control box and on towards Megalodon through the Arduino, which will use the data to pinpoint the location of the Remora, in order to pick it up.

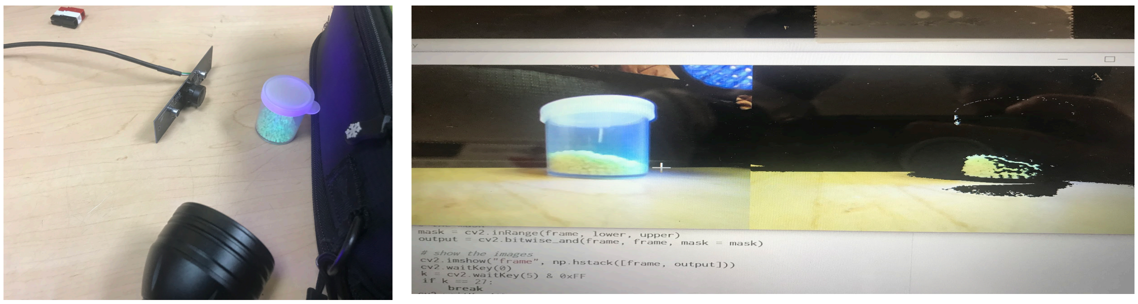
PROGRAMMING TESTING

VISION

Vision is an essential component of Remora's mission. Without any knowledge of its surroundings, the Remora will not be able to identify its location, or even locate any debris littered throughout the ocean floor. To be able to determine our current location, we implemented two (2) USB Standard ROV cameras from openROV.

Using openCV in python, we were able to establish a live stream video feed of what the camera was currently viewing. In addition to this, we also experimented around with a program that can identify the neon - yellow color of what the radioactive material will look like when exposed to UV light **(FIGURE 42)**. However, this testing was done out of the water, in a classroom.

In the future, we will work on refining the color identification program as the parameters for the program are different in different lighting conditions. We will also begin to test these same programs in water of varying lengths in order to tweak our parameters.



[**Figure 42:** Live Video Feed Testing]

QUALITY ASSURANCE REPORT

Along with the Systems Engineer, a tolerance sheet has been made (attached below) that both the interns and the manufacturing department must abide by. This sheet has been approved by the manufacturing department whom agree that working with this sheet is feasible. All tolerances from the table were based off of the tools Echo Technologies has as well as industry standards. As well as this, to ensure quality the technical drawings produced by the mechanical department and the interns, have been reviewed and sent back for revisions if needed.

In collaboration with the Test Engineer, a test bench is being developed to assist the programming department with attitude calibrations. The bench is designed to be practical to build but still be functional. The main issue that prolonged the building of the test bench was finding the proper wood that fit the unique dimensions that the Test Engineer required while still remaining durable. Eventually the decision was made to use beech wood that came in the exact dimensions required and would be strong enough to use.

A template for the technical data package, designed by the lead of the Mechanical Department has been made and will be used by the interns and mechanical department. Failure to use this template will result in the drawing being sent back by the Quality Assurance Officer. Through the Project Manager for the interns, it has been communicating with the interns about the format for the Technical Data Package and what is expected from them and their drawings.

FUTURE TESTS
& GOALS

FUTURE TESTS AND GOALS: MEGALODON

Much work is still required to complete the final design of the Megalodon prototype. The underwater subsystem is yet to be tested with the exception of waterproofing. Following POC, ECHO Technologies will continue to build and test the prototype to meet the mission day deadline.

The top priority is to connect the UUV motor ESCs to the battery allowing the underwater performance of the Megalodon to be tested with a pilot. At the same time, mechanical engineers of ECHO Technologies will finish building and testing the claw to ensure that it can attach to the Remora and carry the required payloads. Following the off the drone recovery tests, the claw will then be attached to the drone allowing for piloted recovery tests. With the completion of the test bench in the coming week after POC, the autonomous flight features of the drone will begin to be tested. In addition, underwater autonomous features and an alternative communication method will be tested before the mission day.

Lastly, ECHO Technologies plans to complete a simulation of the mission as a whole to not only test the prototype, but also test the procedures that need to be established as a team before mission day to ensure a fast and successful operation.

FUTURE TESTS AND GOALS: REMORA

In the future, Ripple Technologies plans to buy a control box that we can use to control the robot, rather than making one ourselves. Due to time constraints, Ripple Technologies believe that it will be more time efficient and more feasible spend time researching for the right controls.

As for the assembly of the Remora, the company plans on finishing the assembly and testing all of the systems in the Remora Ripple Technologies plans on testing the intake system underwater to ensure that it will work properly under the conditions set out in the mission. In addition, the company will begin testing our electrical system once the assembly is finished. The final test will be regarding the code underwater; it has only been tested on the surface, with this test the company aims to view how water distortion affects the program in order to modify it.

When this is completed, Ripple Technologies hopes to test the camera and the code along with the finished robot, to simulate any problems possible during the actual mission and fix them before going on the real mission. The tests will most likely consist of the robot completing tasks similar to those needed in the actual mission.

RISKS AND ASSUPTIONS CHARTS

RISK SCALES

	SEVERITY (S)			
LIKELIHOOD (L)	1 - Inconsequential	2 - Insignificant	3 - Noteworthy	4 - Dangerous
1 - Anticipated	Moderate	High	Undesirable	Undesirable
2 - Possible	Acceptable	Moderate	High	Undesirable
3 - Improbable	Acceptable	Acceptable	Moderate	High
4 - Unrealistic	Acceptable	Acceptable	Moderate	High

Mission Risk Management				
Risk	**Consequence**	**Rating (S/L)**	**Risk Factor**	**Action**
Landing on the Landing Pad	Megalodon does not successfully land and get retrieved	1/3	Acceptable	Use available software to identify the landing pad and slowly land atop it.
Docking	Inability to retrieve the submarine parts from the Megalodon	1/3	Acceptable	Resurface at a stable rate and test the ballast systems to ensure they work as intended
Retrieving the Remora	Damage to the Remora or if Echo Tech fails to retrieve it we fail a portion of the mission	2/3	Acceptable	Use all available knowledge to properly retrieve the Remora from the water
Retrieving the Parts of the Submarine	Takes more time to retrieve the individual parts	2/2	Moderate	Be as efficient and fast as possible without causing damage to the Megalodon due to the charge of the battery
Flight Section to Location	Crashing and inability to finish the mission	3/4	Moderate	Ensure all crash avoidance is functional, and that manual control is possible if autonomy is not
Collisions	Possible damage to components or a loss of direction	3/3	Moderate	Have both drones operating at different times when possible, collision detection systems will account
Water Damage	Internal systems may be compromised and mission will be failed	3/3	Moderate	Waterproof all systems and ensure their reliability via testing
Running Out of Battery	Systems will shut down and mission will be failed	3/3	Moderate	Complete the mission as fast as possible, and ensure the battery will last long enough for the mission with delays
Unfavorable Weather Conditions	Flight may be affected and pilots may need cover	3/3	Moderate	Reschedule or use canopies to stay out of the rain
Retrieving the Submarine and Missiles	Dropping the missiles and being unable to complete this mission this way	3/2	High	Take extreme care and caution when retrieving the portion with the missiles inside, ensure they do not get disturbed and they are stable.

Manufacturing Risk Management				
Risk	**Consequence**	**Rating (S/L)**	**Risk Factor**	**Action**
Manufacturing Errors	Material and time is wasted; the parts may malfunction	2/3	Acceptable	Account for possible error and have QA check all measurements twice
Outsourcing to Manufacture Parts	Deadlines may not be met and shipping may take longer than anticipated	2/3	Acceptable	Account for shipping times, vet all parts received, and make orders well before parts are needed
Wrong CAD/CAM	Material is wasted and a new part needs to inserted	2/3	Acceptable	Double check each program to lessen mistakes and watch the process so we can stop the procedure immediately
Tools are Damaged	Slows work and tools need to be replaced	2/3	Acceptable	Use all tools properly as to reduce the possibility of damages and replace damaged tools
Manufacturing Injuries	Timeline is delayed, personnel may need medical attention	3/3	Moderate	Practice safe procedures and follow the rules of the Annex

Electrical Risk Management				
Risk	**Consequence**	**Rating (S/L)**	**Risk Factor**	**Action**
Camera Malfunctions	Cannot detect object difficulty plotting	2/3	Acceptable	Check camera connections and test visuals
Low Battery Charge	Failure mid-flight, more time to charge	2/3	Acceptable	Always charge the craft prior to flight, have charging available
Lipo Battery Leaks/Damage	Fire, poisonous fumes, severe burns, explosion	3/3	Moderate	Use a salt water bath and dispose
Inhalation of Dust	Nose bleeds, issues breathing, harm to lungs	3/3	Moderate	Wear a face mask when dealing with dust
Inhalation of Lead Fumes	Cancer	3/3	Moderate	Have ventilation, use a fan while soldering, do not stay directly above fumes
Electronic Malfunction	Failure mid-flight, rewiring, timeline is delayed	3/3	Moderate	Check all cable connections, and test prior to flight multiple times
Water Damage	Timeline is delayed and systems may need to be rebuilt	3/2	High	Test containment and ensure no water leakage before testing

Testing Risk Management				
Risk	**Consequence**	**Rating (S/L)**	**Risk Factor**	**Action**
Detection Software Errors	Timeline is delayed	1/2	Acceptable	Use familiar code and heavily focus on properly testing and ensuring the software functions as intended
Using the Test Bench	Damage to important components or personnel	2/3	Acceptable	Make an area for the test bench to sit in with nets and proper padding beneath it in case of failure
Using Important Parts and Damaging them	Timeline is accounts for the replacement or repairing of parts	3/3	Moderate	Ensure qualified personnel are using the best materials available create normal back up, or replacement parts
Live Testing of Complete Mission	Damage to important components or personnel	3/2	High	Testing procedures using nets to protect personnel are in place and properly practiced in order to prevent injury or damage to project

System Risk Management				
Risk	**Consequence**	**Rating (S/L)**	**Risk Factor**	**Action**
Autonomously Completing the Mission	Errors will result in a failure without manual control	1/2	Acceptable	There are manual controls in place as well as numerous sensors which help account for everything during autonomy
Errors in Autonomy Program	Inability to complete the mission within the frame	2/2	Acceptable	We use a library established and made specifically for drone piloting decreasing possible errors
Flying Along a Path	Going off the path or crashing into something in the path	2/2	Moderate	Integrate object detection and avoidance, stabilizers, and dynamic path planning
Detection Systems Don't Work Underwater	The mission is greatly slowed and there is a chance we may not have enough charge	3/3	High	Ensure lots of testing is done of identifying objects both in and out of water so that we know during the mission we will not have difficulties finding the parts needed
Underwater Communication	Inability to communicate with the Megalodon	4/2	Undesirable	Ensure there are precautions in place in case communications are lost and that we have a few modes for communication underwater

Largest Risk Management				
Risk	**Consequence**	**Rating (S/L)**	**Risk Factor**	**Action**
(Testing/Corp.) Possible Injuries	Personnel may need medical attention which may affect the timeline	3/2	High	Personnel are required to follow many procedures for safety, using protective equipment, and being well informed
(Mission) Retrieving the Submarines and Missiles	Dropping the missiles and being unable to complete the mission this way	3/2	High	Tale extreme care and caution when retrieving the portion with the missiles inside, ensure they do not get disturbed and they are stable
(Electrical) Water Damage	Timeline is delayed and systems may need to be rebuilt	3/2	High	Test containment and ensure no water leakage before testing with the electronics
(Testing) Live Testing of Complete Mission	Damage to any important components or personnel	3/2	High	Testing procedures using nets to protect personnel are in place and properly practiced in order to prevent injury or damaging project
(System) Underwater Communication	Inability to communicate with the Megalodon	4/2	Undesirable	Ensue there are precautions in place in case communications are lost and that we have a few modes for communication underwater
(Corporate) Little Outside Investments	ECHO tech will be unable to pay for anything we require	3/1	Undesirable	Assure investors that the project is very well thought out and prove our claims through presentations

FINANCE

FINANCIAL REPORT

ECHO Technologies has been tasked with designing, building, and demonstrating a hybrid, multi-purpose Unmanned Aerial Vehicle/Unmanned Underwater Vehicle (UAV/UUV) systems, code-named "Megalodon", capable of flight in multiple fluid mediums (air and water) and "Remora" which is capable of recovering items of interest. These UAV/UUV systems will be operated no later than May 2019.

In order to successfully accomplish the task at hand, ECHO Technologies' financial team will maintain a formal budget. This budget will include a Bill of Materials, which is a proposed list of materials that serves as an estimate of the anticipated cost of the entire project. In addition to the cost of materials necessary for the building of the robot, the costs of multiple events will also require funding. The Bill of Materials includes essential information such as the vendor, the quantity, and the price of the materials. For clarity, the Bill of Materials is separated into two sections: Systems and Miscellaneous. The Systems section includes a list of parts needed to make the drone function and carry out the commands as dictated by its programming as well as a list of parts that give the UAV/UUV structure and shape. The Miscellaneous section includes materials needed to run and represent the organization as well as propagate STEM education through outreach programs.

FUNDRAISING

In order to produce the UAV/UUV, funding is essential to the project. The finance team intends to raise $10,000 through various fundraisers, donations from generous individuals and groups, and sponsorships from corporations as described in the Funding section. Through fundraising, we have successfully raised $170 from the school event Taste of CAMS, and have scheduled future fundraisers such as a Dippin Dots Fundraiser on November 14, 2018 and more that will take place before the end of this year. We are also in the process of using the crowdfunding site, GoFundMe, to acquire donations from the general public, are in discussion with LA Galaxy and are currently waiting for response for potential sponsorships.

BUSINESS CASE

1. COMMERCIAL APPLICATIONS

The systems and strategies being developed by ECHO Technologies have a broad range of applications in the modern market outside of its confines in the lab.

1.1 Search, Rescue, and Recovery

Recovery, inspection or observation tasks are often unscheduled and unpredictable. The Megalodon responds well under these conditions as it is built for these same principles. Having an ROV to assist in search and recovery operations without furthering human risk, will be a huge asset and a commodity that consumers will be highly interested in.

2. FINANCIAL APPRAISAL

2.1 Affordability

The entirety of the project is projected to cost around $10,000. Learning from the history under the CARPA Initiative, ECHO Technologies knows that projects like these cost more than what they seem, and $10,000 is reasonable when compared to its previous companies. This number includes extra funds to cover any mishaps, design changes throughout the process, and funds needed to sustain the company.

3. FUNDING

3.1 ECHO Technologies currently receives funding from a diverse range of sources. In the future it could be contracted to help work towards any of the plans described in the “Commercial Applications” section.

3.2 Independent and Partnered Fundraisers

Our company has set up and is planning to set up independent fundraisers selling food or at different events to raise small amounts of money to be used for our expenses such as purchasing parts or decorative pieces for events we host. Some of these fundraisers include the California Academy of Mathematics and Science’s annual Taste Of CAMS event on October 26, 2018 as well as a partnership with Dippin Dots to sell different flavored ice cream on November 14 2018.

During these fundraisers, either the Project Manager, Deputy Project Managers, or the CFO oversee the event, keep track of the money, and delegate the volunteers who are employees of ECHO Technologies.

3.3 Company Sponsorships

ECHO Technologies has asked a multitude of companies, those of which we are awaiting a response from such as L.A Galaxy and D.A.R.P.A. who many of our employees have had experience and connections with. In return of these sponsorship, many will be granted variety packages

3.4 Donations

At the start of the creation of ECHO Technologies, each member of the company donated money to a total of about $330. We have also set up a donation center using the crowdfunding site GoFundMe which will officially launch after the Media Team creates a promotional video for ECHO Technologies. We also plan to host events where we present our mission and our strategies in using the donated money to potential donees.

4. PURCHASING STRATEGY

Echo Technologies intends to utilize the formal budget and team research to purchase quality materials whilst being cost efficient through discussions with vendors for donations or discounts, ensuring the order procedure for departments are formal and taking into account tax, shipping, and other potential additional costs. All the funds that Echo Technologies raise and obtain through grants, donations, or sponsorships will be put into the checking account "EDD Blue Team 2019", which is supervised by Mrs. Jackie - the banker for the California Academy of Mathematics and Sciences (CAMS). In order to buy materials for our organization and our project, we will fill out the appropriate forms, such as the "Purchase Order" forms, and submit them to the staff of the CAMS office to legally withdraw money from our account directly to the company we are buying our parts from. Some companies we expect to buy materials from are McMaster-Carr, RobotShop, Blue robotics, Pelican, Polycase, and Amazon. To save money, we will also be requesting promotional deals -when applicable- from these companies. Parts in demand will be delegated by the financial team, and they will communicate with other employees of the company to organize what parts are needed by when, and will purchase them accordingly based on the level of necessity. Every order will go through the Project Manager, Ada Saing, and if it is approved, will be submitted in the "Purchase Order" form by the financial team. The financial team will ultimately make sure that all money earned is in the appropriate place, and that all money spent is properly exchanged.

BILL OF MATERIALS

SYSTEMS

Item No.	Vendor	Name	Part No.	Unit	QTY	Unit Price	Total Price	Additional Information
1	Amazon	Raspberry Pi Model B	RASPBERRYPI 3-MODB-1GB	each	3	$37.30	$111.90	DONATION
2	Fox Tech	Tarot X4 Quadcopter Frame	1946	each	1	$234.99	$234.99	DONATION
3	Amazon	CyclingDeal 20X Bike Bicycle Air Pump Inflator 16G Co2 Threaded Cartridges	CD-CO2-20	20	1	$24.00	$24.00	
4	Amazon	Black CO2 Inflator for Bikes Tire By BriskMore, Presta and Schrader Valve Compatible, Bike Tire Pump for Mountain and Road Bicycles, Insulated Sleeve	BT-003A	each	1	$14.90	$14.90	
5	Amazon	Revmega Tubeless Presta Valve Stem - Pair	VS02	each	1	$12.99	$12.99	
6	Amazon	FLY5D 3Pcs Pump Air Wedge Alignment Inflatable Shim Air Cushioned Powerful Hand Tools	FAW-02	each	2	$16.99	$33.98	
7	Blue Robotics	Bar02 Ultra High Resolution 10m Depth/Pressure Sensor	BAR02-SENSOR-R1-RP	each	1	$88.00	$88.00	DONATION

8	Amazon	Pelican 1150 Camera Case With Foam	1150-000-110	each	1	$54.68	$54.68	
9	Polycase	ML Series Outdoor NEMA Enclosures	ML-58F*1508	each	1	$42.34	$42.34	
10	Blue Robotics	Cast Acryllic Tube (6" Series)	WTE6-ASM-R1-VP	each	1	$90.00	$90.00	DONATION
11	Blue Robotics	O-Ring Flange	WTE6-ASM-R1-VP	each	2	$59.00	$118.00	DONATION
12	Blue Robotics	Aluminum End Cap with 15 Holes (6" Series)	WTE6-ASM-R1-VP	each	2	$44.00	$88.00	DONATION
13	Blue Robotics	Enclosure Vent and Plug	WTE6-ASM-R1-VP	each	1	$8.00	$8.00	DONATION
14	Blue Robotics	T200 Thruster	T200-THRUSTER-R1-RP	each	4	$169.00	$676.00	DONATION
15	Ebay	New 230mm Aluminum Robot Claw Arm Paw Gripper Clamp For Arduino	262593788091	each	2	$14.70	$29.40	
16	Amazon	Flex Glue Strong Rubberized Waterproof Adhesive, 10-oz Pro Formula	113-9964548-913/810	each	1	$14.99	$15.89	$0.90 tax
17	Amazon	eBoot Buck Converters	113-8444420-5435441	each	4	$10.98	$43.92	
18	Adafruit	USB Type A Converter	2225	each	15	$0.69	$21.08	$10.88 tax $0.15 discount
19	Amazon	210Pcs Assorted M3 M2.5 Nylon Screws Nut Standoffs	113-8444420-5435441	210	2	$9.99	$19.98	
20	Amazon	SanDisk 32GB Ultra microSDXC UHS-I	113-8444420-5435441	each	2	$7.98	$15.96	

		Memory Card with Adapter						
21	Amazon	Mudder Black Aluminum Heatsink Cooler Cooling Kit for Raspberry Pi 3, Pi 2, Pi Model B+, 10 Pieces	LYSB01LXWK626-ELECTRNCS	each	2	$7.99	$15.98	
22	Amazon	1 inch Diameter 24 inch Long Carbon Steel Shaft	113-7146049-0321012	each	1	$32.61	$35.71	$3.10 tax
23	VXB.com	1" Inch Sealed Linear Motion Ball Bushing	LBB16UU-LINEAR	each	2	$23.95	$66.09	$6.15 tax $12.04 shipping
24	T-Motors	Aerial Motors	P60 KV340	each	4	$107.90	$431.60	
25	T-Motors	Aerial Propellers	P22x6.6 Prop-2PCS/PAIR	2	2	$140.90	$281.80	
26	Newark Element14	BeagleBone Blue	BBONE-BLUE	each	1	$79.99	$79.99	
27	Amazon	Smallest Mini 50.0 Mega Pixel USB HD Video Camera Webcam	NCOREJNJIJKKM362	each	1	$6.29	$6.29	
28	McMaster Carr	Aluminum Plate Stock (6"X6"X.125")	89015K235	each	1	$8.87	$8.87	
29	McMaster Carr	Aluminum Square Stock (12inX2inX2in)	6546K23	each	1	$16.32	$16.32	
30	Amazon	Pelican 1150 Camera Case With Foam	1150-000-180	each	1	$39.95	$43.75	$3.80 tax

31	mRobotics	mRo GPS NEO-M8N	MRO-GPS004-MR	each	1	$69.90	$76.19	$6.29 tax
32	Arduino	Arduino Uno	B01N4LP86I	each	1	$22.00	$24.37	$2.37 shipping and handling
33	Blue Robotics	Basic ESC	BESC30-R3	each	6	$25.00	$170.26	$6.00 shipping $14.26 tax
34	T-Motors	ESC's for Aerial motors	FLAME 70A LV	each	4	$69.99	$279.96	
35	Banggood	20Pcs Mini Micro JST 1.0mm SH 6-Pin Connector Plug With Wires Cables 150mm	1170259	20	1	$3.66	$6.10	$2.44 shipping + tax
36	Amazon	daier 20 Sets Mini Micro Sh 1.0 Jst 4-Pin Connector Plug Male with 100mm Cable & Female	WD095*2	20	1	$7.99	$7.99	
37	Amazon	120pcs Multicolored Dupont Wire 40pin Male to Female, 40pin Male to Male, 40pin Female to Female Breadboard Jumper Wires Ribbon Cables Kit for arduino	EL-CP-004	120	2	$6.98	$13.96	
38	Amazon	BOESHIELD T-9 Rust & Corrosion Protection/Inhibitor and Waerproof Lubrication, 12 oz	122182	each	1	$18.99	$20.79	$1.80 tax

39	Horizon Hobby	DSMX Remote Receiver	SPM9745	each	1	$34.99	$41.58	$6.59 shipping + tax
40	Motion RC	Eagle X6 6-Axis Multi-Rotor Flight Controller	HEX6STND	each	1	$25.99	$25.99	
41	Motion RC	Spektrum DSMX Quad Race Serial Receiver with Diversity	SPM4648	each	1	$24.99	$32.28	$7.29 shipping
42	Amazon	Intel Movidius™ Neural Compute Stick	NCSM2450.DK1	each	1	$74.99	$82.07	$7.08 tax
43	Amazon	Black USB 3.0 Extension Adapter Cable	USB3EXT6INBK	each	1	$5.47	$7.22	$1.75 tax
44	McMaster Carr	135 Degree Point Long-Life Drill Bit	29045A754	each	1	$2.79	$10.06	$7.27 tax+shipping
45	McMaster Carr	Alloy Steel Low-Profile Socket Head Screw	93070A070	25	1	$6.15	$6.15	
46	Amazon	Banana Plug Male Female Bullet Connector Replacements for ESC Battery and Motors	Blulu-Bullet Connector-01	30	1	$6.99	$6.99	
47	Amazon	SanDisk 32GB Ultra microSDXC UHS-I Memory Card with Adapter	SDSQUAR-032G-GN6MA	each	3	$7.41	$22.23	
48	Amazon	250mW 650nm Red Dot Laser Module	715444672385	each	1	$19.99	$22.09	$2.10 tax
49	Home Depot	Douglas Fir Board	HCF-KDDF-PRIME-2x6x12	each	1	$6.86	$7.51	$0.65 tax
50	Amazon	Micro USB Cable	B07F9LWQTM	6	1	$8.99	$8.99	

51	Blue Robotics	Underwater enclosure	UE1293COE	each	1	$39.99	$39.99	DONATION
52	Ebay	Waterproof Servo Motor for Claw	HS646WP 646WP	each	1	$38.99	$44.98	$2.95 shipping +$3.04 tax
53	Blue Robotics	I2C Level Converter	LEVELCONVERTER-R1-RP	each	1	$14.00	$15.34	$1.34 tax
54	McMaster Carr	Alloy Steel Low-Profile Socket Head Screw	93070A061	50	1	$9.35	$9.35	
55	Amazon	Photo Transistors	03-01-0591	20	2	$4.99	$9.98	
56	Amazon	Radial Electrolytic Capacitor	B-0002-D01	5	2	$5.38	$10.76	
57	Amazon	Resistors	EL-CK-004	525	2	$10.86	$21.72	
58	Amazon	3.5mm Aux Cord to 1/4 Aux cord	10625	each	1	$8.99	$10.01	$1.02 tax
59	Amazon	Ferrite Core	B01E5E5IY4	20	1	$11.99	$11.99	
60	Amazon	13009 Transistor 10 pcs	B07K5BJFRD	1	1	$9.25	$9.25	
61	Amazon	Spektrum Receiver Battery	SPMB2200LFRX	1	1	$32.99	$42.68	$5.99 S/H + $3.70
62	Amazon	D13009 Transistor	B07FS73T9C	10	1	$6.58	$6.58	
63	Amazon	Digital Servo High Torque Full Metal Gear Waterproof for RC Model	DS3218MG	1	1	$17.89	$17.89	
64	Amazon	Door Hinge	N128-157	1	4	$5.99	$26.24	$2.28 sales tax
65	Banggood	Aerial Camera	1000TVL	1	1	$9.99	$12.60	$2.61 shipping fee
66	Blue Robotics	Waterproof Servo Motor for Claw	HS-646WP	1	1	$43.00	$47.09	$4.09 tax
67	Ebay	13009 Transistor	E13009L	2	1	$9.95	$9.95	

68	Banggood	5.8 GHz AV transmitter	5325-5945MHZ	1	1	$11.21	$11.21	
69	Banggood	5.8 GHz AV receiver	ROTG01	1	1	$17.99	$19.98	$1.41 shipping $0.58 tax
70	Home Depot	Scotchblue Tape	2090-48N	1	1	$5.97	$6.54	$0.57 tax
71	WoodCraft	Basswood 4" x 8" x 12"	50W77B4W80D	1	1	$35.99	$52.54	$11.99 shipping + $4.56 tax
72	Amazon	Proheader PS746	P52746D01	1	1	$24.99	$34.98	$9.99 shipping
73	Amazon	Wireless Endoscope, Waterproof USB Borescope 1200P HD Wifi Inspection Camera	EN008B	1	1	$22.99	$22.99	
74	Amazon	Arduino Uno	A000066	1	1	$23.00	$23.00	
75	AdaFruit	IMU	BNO055	1	1	$34.95	$34.95	
76	Mcmaster Carr	Alloy Steel Low-Profile Socket Head Screw	93070A070	1	1	$6.15	$12.88	$0.58 tax + $6.15 shipping
77	Blue Robotics	M10 Cable Penetrator for 6mm Cable	6MM-10-25-R2-RP	1	3	$4.00	$12.00	DONATION
78	Blue Robotics	M10 Cable Penetrator for 8mm Cable	8MM-10-25-R2-RP	1	3	$5.00	$15.00	DONATION
79	Blue Robotics	Loctite Marine Epoxy (USA ONLY)	LOCTITE-MARINE-EPOXY	1	1	$6.00	$9.15	**$3.15 tax**

80	Amazon	Pelican 1150 camera case with foam	B000N9PQEI	1	1	$39.95	$39.95	DONATION
81	T-motor	Aerial propellers P22x6.6 Prop 2pcs/pair	U7-KV280	2	2	$140.90	$281.80	DONATION
82	Defender USA	PheonixM2 Single Camera Digital Wireless Security System	B01GQEDV2C	1	1	$199.99	$199.99	DONATION
83	Home Depot	Aluminum Angle Piece (L CHANNEL)	800057	1	1	$10.53	$17.52	$5.99 shipping + $1.00 tax
84	Amazon	Readytosky Pixhawk PX4 Flight Controller	B07CHQ7SZ4	1	1	$71.79	$71.79	
85	Blue Robotics	Thruster Cable	CAB-A-3-18AWG-R1	1	1	$7.00	$7.67	DONATION $0.67 tax
86	Blue Robotics	T200 Thrusters	T200-THRUSTER-R1-RP	1	2	$169.00	$377.53	$25.53 tax + $14.00 shipping POFF DONATION
87	Hobby King	Turnigy High Capacity 16000mAh 6S 12C Multi-Rotor Lipo Pack w/XT90	9067000429-0	1	2	$192.07	$384.14	DONATION
88	Home Depot	Heat Shrink Tubing - Black	902-355	1	1	$10.39	$10.39	DONATION
89	Defender USA	PheonixM2 Single Camera Digital	B01GQEDV2C	1	1	$199.99	$218.99	$19.00 tax

		Wireless Security System						DONATION
90	IR-LOCK	Pixhawk2.1 Standard Set	HX4-06001	1	2	$238.00	$476.00	DONATION
91	Amazon	USB Endoscope Inspection Camera	FBA_4332023214	1	1	$17.99	$19.74	$1.75 tax DONATION
92	HeliPal	Auto Landing Gear	TL69A02	1	1	$56.90	$88.16	$31.26 shipping
93	Amazon	TXINLEI 250mW 650nm Red Dot Laser Module, DC 3-5V Focal Adjustable Laser	715444672385	1	1	19.99	$19.99	
Total							$6,418.47	

MISCILLANEOUS

Item No.	Vendor	Name	Part No.	Unit	QTY	Unit Price	Total Price	Additional Information
1	Amazon	BookFactory Black Engineering Notebook	LIRPE-168-SGR-A-LKT4	each	1	$29.99	$29.99	
2	Tie Mart	Blue Staff Tie	AC58NW-0014	each	50	$2.50	$136.95	DONATION $11.95 shipping
3	Signarama	Team Canvas Banner	N/A	each	1	$145.00	$154.80	DONATION $9.80 tax
4	FedEx	SPS Document	N/A	each	1	$180.00	$197.36	$17.36 tax
5	Name Cheap	Website Domain (echotechnologies.org)	40174168	each	1	$11.69	$11.69	
6	Costco	Cookies	43475	60	1	$15.99	$15.99	
	Food for Less	Jarritos	N/A	1	55	$0.79	$50.94	$2.75 CA Redem Val $4.74 tax
7	Sweet Embellishments	Cupcakes	37714	36	4	$13.00	$57.33	$5.33 tax
8	Dollar Tree	Decorations for Taste of CAMS	824401	each	11	$1.00	$12.50	$1.50 tax
9	Dippin' Dots	Dippin' Dots	1182-8366	each	3	$50.00	$144.85	$5.15 discount
10	Target	Photo paper	56071127	100	1	$16.29	$17.84	$1.55 tax
11	Michaels	Jumbo popsicle sticks (200 ct)	10334892	200	1	$4.24	$4.24	

12	Michaels	Normal popsicle sticks (1000ct)	10094698	1000	1	$3.50	$3.50	
13	Michaels	Mini pom pom balls (80ct)	10561030	80	2	$0.90	$1.80	
14	Amazon	Soda plastic bottle caps (50 ct)	SK50CAP	50	1	$7.90	$7.90	
15	Michaels	Rubber bands (100ct)	10150214	100	1	$1.74	$1.74	
16	Amazon	Small Sized Bean Bags (3.5" x 3.5") By Tailgate360 (Red and Blue)	BBAG-3	8	1	$12.99	$31.68	$17.94 shipping +$.74 tax
17	Home Depot	Plywood (¼ inch x 2 ft x 2 ft)	206804070	each	2	$6.42	$20.05	$7.21 shipping + tax
18	Target	Dawn Ultra Dishwashing Liquid Original - 75 fl oz Dawn	N/A	each	3	$8.99	$26.97	DONATION
19	Target	Corn Syrup - 32oz - Market Pantry™	N/A	each	4	$3.99	$15.96	DONATION
20	Michaels	Fabric	N/A	each	2	$6.89	$13.78	
21	Target	Dawn Ultra Dishwashing Liquid Original - 75 fl oz Dawn	N/A	each	3	$8.99	$26.97	
22	Aldi	20 oz Paper Bowl	B07BHTV9VQ	each	2	$1.95	$3.90	DONATION
23	Aldi	Clear Cutlery	B010RLC7P2	each	1	$2.75	$2.75	DONATION
24	Aldi	Sandwich Bags	B002A1SE5U	each	1	$1.99	$2.88	$0.89 tax DONATION
25	Michaels	1 Gallon School Glue	G10U18E15U	each	2	$15.00	$32.85	$2.85 tax

								DONATION
26	Dollar Tree	Trifold Display Board	730109	each	4	$1.00	$4.48	$0.48 tax
27	Costco	Frito Variety Pack	B00BIDU9JA	each	2	$12.89	$25.78	
28	Costco	Kirkland Signature FunHouse Treats	N/A	each	1	$13.99	$13.99	
29	Amazon	28mm Plastic Screw Caps for PET Bottle	SK50CAP	50	3	$7.90	$26.00	$2.30 tax DONATION
30	Coscto	renu Advanced Formula Multi-Purpose Solution	1225794	each	1	$15.99	$17.54	$1.55 tax DONATION
31	Michaels	Elmer's® Washable School Glue, 1 Gallon	10522755	each	3	$15.00	$57.32	$4.37 tax + $7.95 shipping DONATION
32	Target	Magic Tape	N/A	each	2	$3.49	$8.00	$1.02 tax
33	Target	Clips	N/A	each	2	$1.87	$3.74	
34	CVS	Salin Twin Pack	N/A	2	1	$6.99	$6.99	
35	General Discount	Foam Cups	N/A	each	5	$1.29	$6.45	
36	General Discount	Straight Straws	N/A	50	2	$0.99	$1.98	
37	General Discount	Straws	N/A	50	2	$0.99	$1.98	
Total							$1,201.46	

INTERNS

Item No.	Vendor	Name	Part No.	Unit	QTY	Unit Price	Total Price	Additional Information
1	Amazon	UV Light	40174168	each	1	$10.99	$10.99	DONATION
2	Amazon	MG Chemicals Silicone Modified Conformal Coating,	422B-55ML	each	1	$12.95	$12.95	
3	Amazon	Raspberry Pi 3 Model B Motherboard	RASPBERRYPI3-MODB-1GB	each	1	$34.99	$34.99	
4	Amazon	Loctite Epoxy Quick Set 0.85-Fluid Ounce Syringe	1395391	each	1	$5.30	$7.03	$1.73 tax
5	Amazon	Waterproof Servo	B01N0XZOZU	each	1	$17.87	$17.87	
6	Amazon	HOBBYMATE XT60 PDB Power Distribution Board	B078JBT2HQ	each	1	$9.99	$9.99	
7	Alibaba	OpenROV Camera	6951377-01	each	2	$55.00	$124.59	$14.59 tax +shipping
8	BlueRobotics	M100 Thrusters	M100-MOTOR-R1-RP	each	4	$70.00	$280.00	
9	BlueRobotics	M100 Propellers	M100-P-PROPELLER-REV-R1-VP	each	4	$12.00	$48.00	
10	Blue Robotics	Basic ESC	BESC30-R3	each	4	$24.00	$144.66	$8.00 + $40.66 tax + shipping
11	Monoprice	82 ft. USB Cable	26/22AWG	each	2	$37.12	$88.61	$14.37 tax + shippin

12	Markertek	Pelican Mini Flasher 2130 LED	PEL-2130	each	1	$13.54	$13.54	
13	McMaster Carr	Clear Polycarbonate Sheet, 12" x 24" x 1/8"	8574K41	each	1	$14.28	$22.42	$1.36 tax $6.78 shippin
14	Amazon	Arduino Uno	B01N4LP 86I	each	1	$16.99	$16.99	
15	Digikey	Assorted 22 AWG Wire	1528-174 3-ND	each	1	$15.95	$15.95	
16	Digikey	Female to Female Jumper Cable	1528-196 1-ND	each	1	$1.95	$1.95	
17	Digikey	Male to Male Jumper Cable	1528-196 7-ND	each	2	$1.95	$3.90	
18	Digikey	28 AWG Heat Shrink	3M15682 5-ND	35	1	$16.48	$16.48	
19	Digikey	22 AWG Heat Shrink	3M15682 5-ND	each	1	$1.79	$16.57	$9.99 shippin g + $4.79 tax
20	Digikey	Zip-Tie Mounts	A114092-ND	each	10	$0.45	$4.49	
21	Digikey	Zip ties	A112496-ND	each	50	$0.12	$5.85	
22	McMaster Carr	0-80 steel hex nut	90480A00 1	each	100	$0.05	$5.02	
23	McMaster Carr	0-80 steel socket head screw	92200A05 7	each	10	$0.72	$14.23	$1.16 tax +$5.83 shippin
24	Blue Robotics	Fathom ROV Tether	F12T02M 67	each	1	$162.0 0	$162.00	DONAT ION
25	SeaMate	SeaMATE Barracuda Control Box Kit	3-UDA-40 13-AB-01	each	1	$700.0 0	$750.75	$50.75 DONAT ION
Total							$1,829. 82	

DONATIONS

Item No.	Vendor	Name	Part No.	Unit	QTY	Unit Price	Total Price	Additional Information
1	Amazon	Raspberry Pi Model B	RASPBERRYPI 3-MODB-1GB	each	3	$37.30	$111.90	DONATION
2	Fox Tech	Tarot X4 Quadcopter Frame	1946	each	1	$234.99	$234.99	DONATION
3	Blue Robotics	Bar02 Ultra High Resolution 10m Depth/Pressure Sensor	BAR02-SENSOR-R1-RP	each	1	$88.00	$88.00	DONATION
4	Blue Robotics	Cast Acryllic Tube (6" Series)	WTE6-ASM-R1-VP	each	1	$90.00	$90.00	DONATION
5	Blue Robotics	O-Ring Flange	WTE6-ASM-R1-VP	each	2	$59.00	$118.00	DONATION
6	Blue Robotics	Aluminum End Cap with 15 Holes (6" Series)	WTE6-ASM-R1-VP	each	2	$44.00	$88.00	DONATION
7	Blue Robotics	Enclosure Vent and Plug	WTE6-ASM-R1-VP	each	1	$8.00	$8.00	DONATION
8	Blue Robotics	T200 Thruster	T200-THRUSTER-R1-RP	each	4	$169.00	$676.00	DONATION
9	Blue Robotics	Underwater enclosure	UE1293COE	each	1	$39.99	$39.99	DONATION
10	Blue Robotics	M10 Cable Penetrator for 6mm Cable	6MM-10-25-R2-RP	1	3	$4.00	$12.00	DONATION
11	Blue Robotics	M10 Cable Penetrator for 8mm Cable	8MM-10-25-R2-RP	1	3	$5.00	$15.00	DONATION
12	Blue Robotics	Loctite Marine Epoxy (USA ONLY)	LOCTITE-MARINE-EPOXY	1	1	$6.00	$9.15	$3.15 tax

13	Amazon	Pelican 1150 camera case with foam	B000N9PQEI	1	1	$39.95	$39.95	DONATION
14	T-motor	Aerial propellers P22x6.6 Prop 2pcs/pair	U7-KV280	2	2	$140.90	$281.80	DONATION
15	Defender USA	PheonixM2 Single Camera Digital Wireless Security System	B01GQEDV2C	1	1	$199.99	$199.99	DONATION
16	Blue Robotics	Thruster Cable	CAB-A-3-18AWG-R1	1	1	$7.00	$7.67	DONATION $0.67 tax
17	Tie Mart	Blue Staff Tie	AC58NW-0014	each	50	$2.50	$136.95	DONATION $11.95 shipping
18	Signarama	Team Canvas Banner	N/A	each	1	$145.00	$154.80	DONATION $9.80 tax
19	Target	Dawn Ultra Dishwashing Liquid Original - 75 fl oz Dawn	N/A	each	3	$8.99	$26.97	DONATION
20	Target	Corn Syrup - 32oz - Market Pantry™	N/A	each	4	$3.99	$15.96	DONATION
21	Target	Dawn Ultra Dishwashing Liquid Original - 75 fl oz Dawn	N/A	each	3	$8.99	$26.97	
22	Amazon	UV Light	40174168	each	1	$10.99	$10.99	DONATION
23	Blue Robotics	Fathom ROV Tether	F12T02M67	each	1	$162.00	$162.00	DONATION

24	Blue Robotics	T200 Thrusters	T200-THRUSTER-R1-RP	1	2	169	377.53	$25.53 tax + $14.00 shipping DONATION
25	Hobby King	Turnigy High Capacity 16000mAh 6S 12C Multi-Rotor Lipo Pack w/XT90	9067000429-0	1	2	192.07	384.14	DONATION
26	Home Depot	Heat Shrink Tubing - Black	902-355	1	1	10.39	10.39	DONATION
27	Defender USA	PheonixM2 Single Camera Digital Wireless Security System	B01GQEDV2C	1	1	199.99	218.99	$19.00 tax DONATION
28	IR-LOCK	Pixhawk2.1 Standard Set	HX4-06001	1	2	238	476	DONATION
29	Amazon	USB Endoscope Inspection Camera	FBA_4332023214	1	1	17.99	19.74	$1.75 tax DONATION
30	Amazon	28mm Plastic Screw Caps for PET Bottle	SK50CAP	50	3	7.9	26	$2.30 tax DONATION
31	Coscto	renu Advanced Formula Multi-Purpose Solution	1225794	each	1	15.99	17.54	$1.55 tax DONATION
32	Michaels	Elmer's® Washable School Glue, 1 Gallon	10522755	each	3	15	57.32	$4.37 tax + $7.95 shipping DONATION

33	SeaMate	SeaMATE Barracuda Control Box Kit	3-UDA-4013-AB-01	each	1	$700.00	$750.75	$50.75 DONATION
Total							$4,893.48	

TOTAL

SYSTEMS	$6,418.47
MISCELLANEOUS	$1,201.46
INTERNS	$1,829.82
Total Cost	$9,449.75
TOTAL PART DONATIONS	$4,893.48
PROJECTED ADDITIONAL COSTS	$3,000

OUTREACH REPORT

OUTREACH REPORT

Our Outreach department encourages the youth in pursuing a career in a science, technology, engineering, art, and mathematics (STEAM) field. Through various interactive activities, students discover the diversity within STEAM. We hope to give back to the community, by inspiring the children. We collaborate with Umizora Technologies' Outreach team for scheduling and executing all outreach events. Achieving our goal, we have had four events within the past few months, and have 6 upcoming events.

On February 14, we had our first official outreach event, aside from CAMS community day, at the Boy and Girls Club, Wilmington. Sponsored by shell, the Boys and Girls Club invited us to join them in providing a STEM fair for approximately 150 middle schoolers. We were one of two circuits held and our circuit had a total of 8 activities, each corresponding to a category under STEM. The activities consisted of the "Bubble Trap," "Jar of Densities," Non-Newtonian Fluid," and "Leak Proof Ziploc" under science, "Steady Hand Game" and "Let's Get This Bread(Board)" under technology, "Catapult Catastrophe" under engineering, and "Math Bean Bag Toss" under mathematics. We used a stamp card system that encouraged students to visit each activity in exchange for a prize. Prizes varied depending on the number of stamps (three stamps = candy; five stamps = chips; eight stamps = slime) As for the prize of slime, they get the opportunity to make it themselves alongside outreach team to stimulate creativity. For each activity, there was a poster board that informed the students of the concept, explanation, materials, and steps for each activity. For the "Bubble Trap" activity, the student would stand on a stool in the middle of a kid pool as we lift a hula hoop, creating a giant bubble that surrounds the participant. The concept taught under science was surface tension of water.

For the "Jar of Densities" activity with the concept of density, students will demonstrate how density affects its position in the jar. They create layers in a cup by first filling ⅓ of it with food colored water, the next ⅓ with maple syrup, and the last ⅓ with cooking oil. Lastly, they would drop a screw, a grape, a bottle cap, and a piece of sponge to observe which layer each object falls on. For the "Non-Newtonian Fluid" activity, students will create a mixture that behaves like a solid one instant and a liquid the next using only cornstarch and water. For the "Leak Proof

Ziploc" activity, students will learn how to poke holes in a plastic bag filled with water without spilling a drop under the concept of low-density polyethylene which is a polymer that Ziploc bags are made of. Under the category of technology, the "Steady Hand Game" gave students the opportunity to be educated on the concept of completing a complete or closed loop for the LED light to light up by following a curved wire path with a loop of wire without letting the two touch. The "Let's Get This Bread(Board)" activity had the children learn about open and closed circuits by creating a closed circuit alongside well-educated seniors using wires and breadboards. For engineering, we allowed students to use their basic engineering skills to build a mini catapult that launches mini pom-pom balls through the activity called "Catapult Catastrophe." Lastly, the "Math Bean Bag Toss" activity strengthen the student's fundamental skills in math by having them toss a bean bag into the hole with two factors that created the product given. The bean bag toss was in the form of a four by four grid, and we had two boards (first board had the rows and columns labeled two through five and the other six through nine.) For instance, we would give them the number 12, and they would find where column 4 meets with row 3 and toss the bean bag in that hole or column 3 row 4.

One of our most recent events took place at Benjamin F. Tucker Elementary School from 11 AM to approximately 1 PM on March 15. We were invited, along with Cabrillo high school, to observe one of their wheelchair soccer games. After observing for approximately an hour, there was a meeting held with complimentary food to discuss the issues of the game, mainly focusing on how the soccer ball gets stuck within the shield connected to the wheelchair. The movement of the wheelchair is being controlled by wingmen and the shield was connected by zip ties. Our observations consisted of the ball getting stuck within the shield of the wheelchair due to the wingman lifting the wheelchair further back whilst trying to maneuver, the difference in height regarding the shield and wheelie bars, and certain actions of the participant in the wheelchair that made it difficult for the wingman to control. Our consensus was to even out the heights of the wheelie bars (or add them for the ones who do not have them) and shield, restricting the movement of the wingman but not affecting its maneuvering abilities. They have invited us to their last wheelchair game as an opportunity to make this vision come to life.

Another outreach event was held on the same day at Grant Elementary School from 4:30 PM to 6 PM for the STEAM fair for their after-school Winners Reaching Amazing Potential (WRAP) program. There were approximately 145 elementary students present. This event involved 9 activities, two for every category under STEAM except for technology and art, which only have one activity each. For this event, there was no stamp card system, but some of the activities from the Boys & Girls Club STEM fair were reused. The activities included "Human Bubble," "Balloon Rocket," and "Oil Bet You Won't See It" under science, "Robotic Hand" under technology, "Marshmallow Tower" and "Mini Catapult" under engineering, “Fluffy Glitter Slime” under arts, and “How Many Skittles in the Jar” and “Cool Math Equation Activity” under mathematics. The “Human Bubble,” “Mini Catapult,” and “Fluffy Glitter Slime” activities were reused. As for the “Balloon Rocket,” students will observe a handmade balloon rocket being launched and learn about action and reaction. In the “Oil Bet You Won’t See It” activity, students will observe a beaker disappearing in another beaker when both are filled with oil due to the light rays slowing down when entering the oil. For the “Robotic Hand,” students will use cardboard and string to create an extension of a hand using basic robotic techniques. Through the concept of robotics, Creativity and technology intertwine within the robotics field, by its design and manufacturing. The “Marshmallow Tower” activity consists of the students learning basic engineering skills by building their own tower out of only marshmallows and toothpicks. The “How Many Skittles in the Jar” had the students guess the answer to the question and whoever guessed it correctly or had the closest number got to get the entire jar. Lastly, “Cool Math Equation Activity” had the students create a manual equation calculator out of Styrofoam cups to strengthen their fundamental skills in math. Due to the fact that there was an overflow of students on one activity, a system was set up where a batch of kids would go at a time and visit the other activities as they wait for their turn.

The very first event was held on November 11 at our school, California Academy of Mathematics and Science (CAMS), as a collaboration with the principal's event called "Community Day." The purpose was to inform any interested middle schoolers who plan to attend CAMS of what this school has to offer. The Engineering, Design, & Development (EDD) CAPSTONE class prepared a presentation for the families that visited and offered a slime activity to give a bit of exposure to the purpose of the Outreach Team within the EDD program. Our vice principal donated all the materials needed to execute this activity.

Upcoming events will occur on March 26 at Jane Addams Elementary, April 4 at Mann Elementary (approximately 400 plus elementary students), and April 11 at Dooley Elementary. We are currently in contact with Hickory elementary school and are planning to schedule three events, one on April 23 and two on April 30. We are also in contact with Magruder Middle school, in hopes of scheduling more events soon.

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ACRONYMS

ASB: Associated Student Body

BOM: Bill of Materials

CAD: Computer- Aided Design

CAMS: California Academy of Mathematics & Science

CARPA: CAMS Advanced Research Projects Agency

CIA: Central Intelligence Agency

CFO: Chief Financial Officer

CDR: Critical Design Review

CNC: Computer numerical control

CS: Chief Scientist

DARPA: Defense Advanced Research Projects Agency

DPM: Deputy Project Manager

FAA: Federal Aviation Administration

GD&T: Geometric Design & Tolerance

EDD: Engineering Design & Development

ESC: Electronic Speed Controller

IPR: In Process Review

LIPO: Lithium Polymer

NEMA: National Engineering Manufacturers Association

PDB: Power Distribution Board

PDR: Periodic Design Review

PM: Project Manager

POC: Proof Of Concept

ROV: Remotely Operated Vehicle

SALT: Strategic Arms Limitations Treaty

SPS: Systems Performance Specifications

TDP: Technical Data Package

IDP: Interdisciplinary Project

UV: UltraViolet

UAV: Unmanned Aerial Vehicle

UUV: Unmanned Underwater Vehicle

WIFI: Wireless Fidelity

2D: Two Dimensional

3D: Three Dimensional

CARPA APPROVAL

Rules, conditions, and requirements are subject to change by the CARPA authority. All changes will be discussed in class, and be presented to the company teams in writing. Changes are negotiable and deadline extensions must be agreed upon by all parties.

Project Manager Date

Deputy Project Manager Date

Deputy Project Manager Date

Chief Scientist Date

Director of Publications Date

CARPA Authority Date