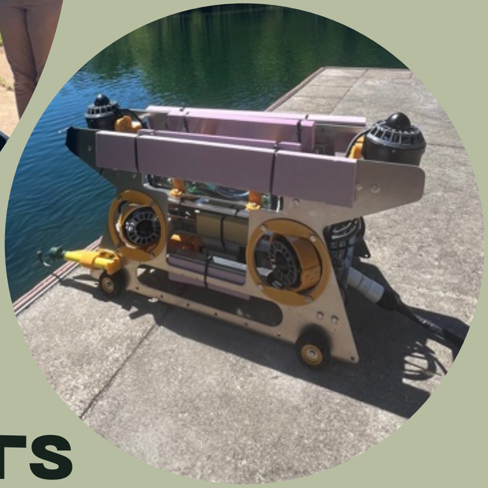
Crubotics

Pensacola Catholic High School
Pensacola, FL 32505
USA



Company Members

Brandon Hoppe | 12 | CEO, Pilot, 3rd yr**
Nicole Peterson | 12 | Safety Officer, 2nd yr**
Carsyn Neff | 11 | Marketing, 1st year*
Aloysius London| 11 | COO, 2nd Yr**
Mac McKinley | 11 | Lead Engineer, 3rd yr**
Grant Robertson | 12 | BGC Float, Lead, 3rd yr**
Caleb Bobe | 10 | Lead Programmer, 2nd yr**
Dylan Nguyen | 10 | Programmer, 1st yr*
Lucas Kasianov | 11 | Electrician, 1st yr*
Nate Flores | 12 | BGC Float, 2nd yr*
Frederick Strawitch | 12 | BGC Float, 1st yr*
Luke Foster | 11 | Float Engineer, 3rd yr**
*New Member **Returning Team member

Team Mentors

Dana Lupton, Science Teacher

Eric Requet, Math Teacher

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Abstract

The Pensacola Catholic High School Crubotics Team (***Figure 1***) contains 12 members that specialize in the building, programming, piloting, and marketing tasks required for the construction and promotion of remotely operated vehicles. These skills were used to create the Compact Aquatic Tool version Five (CAT-5) for the 2024 MATE Competition. CAT-5 features six motors (four horizontal, two vertical). Since the horizontal motors are oriented at a 45-degree angle, the ROV uses omnidirectional movement and changes in pitch to suit many tasks and currents.

CAT-5 contains a tilt-mount camera to provide wide-range views; this feature proves especially useful in collecting visual data during Task 3.3, for 3D coral modeling. This camera sits inside a 100 mm watertight enclosure at the front of the ROV. The decision for optimal placement was fixed on both the mechanical and stationary claws. Additionally, the enclosure contains the computing software: a raspberry pi, servo motors, wiring, and a terminal. One of these servo motors controls CAT-5's 3D-printed mechanical claw, used for gripping items. Contrarily, the ROV's stationary claw, resembling a hook, does not use a servo motor and instead dislodges items.

To ensure safety for wildlife and operators, the ROV is equipped with pressure-relief valves, prop shrouds, tether relief, and motor shields among others. All of the aforementioned features allow CAT-5 to complete the tasks in the MATE Competition; however, Crubotics strove to design an ROV that would also function well in real-world missions like examining ecosystem health, connecting power lines, and removing harmful environmental factors.

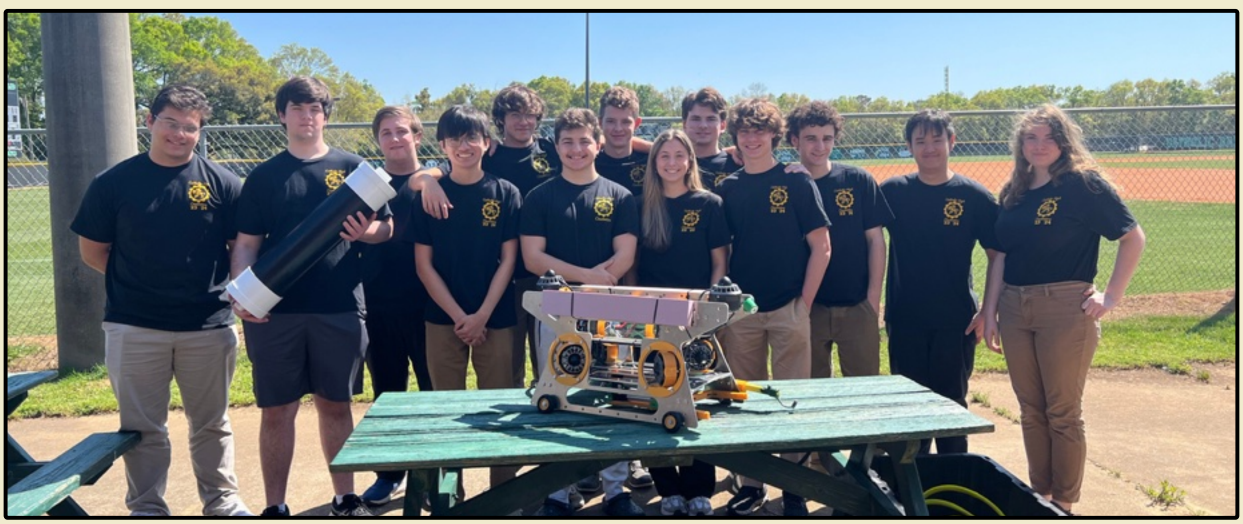


Figure 1. The 2023-24 Crubotics Ranger Team (left to right):
First Row: Grant Robertson, Nate Flores, Mac McKinley, Carsyn Neff, Caleb Bobe
Second Row: Lucas Kasinov, Fredrick Strawitch, Brandon Hoppe, Aloysius London, Luke Foster, Dylan Nguyen, Nicole Peterson

Project Management

Company Overview

The Pensacola Catholic High School Crubotics team, established in 2015, consists of 14 members: two teachers, three seniors, six juniors, and three sophomores. Each student utilizes their own skillset to help progress the team. (*Figure* 1) For more information see ***Appendix A.***

Scheduling

Starting in August, Crubotics held a meeting two times a week (Tuesdays and Thursdays, two hours a day). During this time, the team assigned specific jobs, groups, and task leaders **(*Figure* 2)**. Continuing into the new year, the team decided to add extra meetings on weekdays to ensure consistent work. To practice effective communication the team used email, group chats and whiteboard with a dated checklist and tasks assigned to each team member. A Gantt Chart **(*Appendix* B)** was also used to ensure team productivity and completion of tasks on due dates.

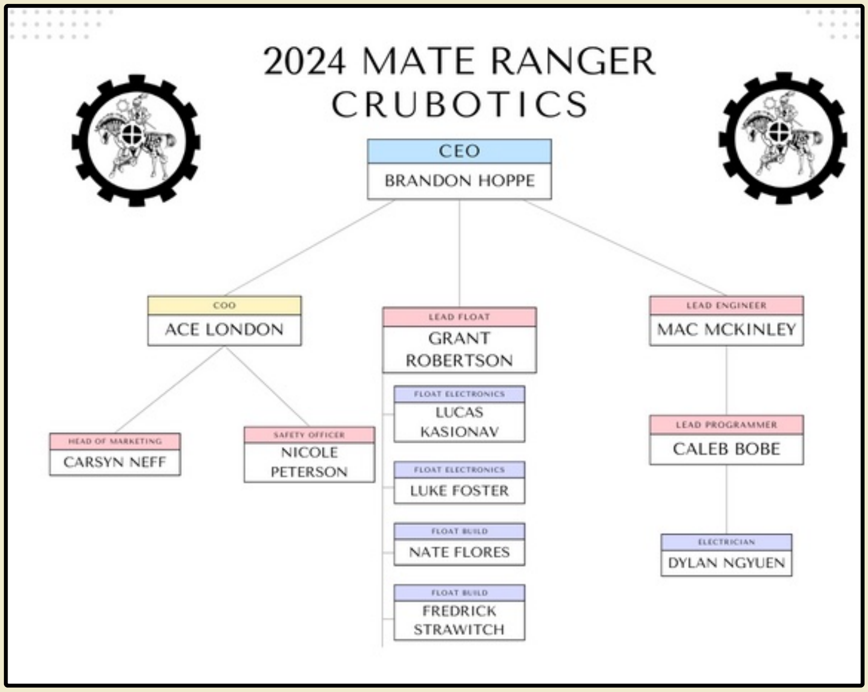


***Figure* 2.** Team Organizational chart depicting defined groups lead by students.

In terms of problem-solving, Crubotics follows the mantra: "Don't bring me a problem, bring me a solution." When problems arose, team members
1) identified the root cause of the issue,
2) developed multiple solutions, and
3) picked the most effective and financially feasible option.

For example, a specific detail which was crucial to the frame (the connecting brackets) was not given extra metal in the machine process to account for the needed bend in the metal. After this was realized, the engineering team listed a solution; re-designing, cutting, and fitting. However the plan was too time consuming and expensive. The team opted to quickly design a new part that could be 3D printed in-house, reducing the time and cost associated with the new parts that were needed.

Design Rationale

Engineering Process

The Crubotics team started brainstorming early in the 2023-24 school year. It was important that there was ample enough time to design, build, test, and modify the ROV in later months.

August – September 2023, Brainstorming:
During this period, the Crubotics team discussed the previous year's ROV used in the 2023 MATE competition and how it could be improved. The team utilized previous documentation and experience to effectively create drawings, proposals, and parameters for CAT-5. ***(Figure 3)***

November - December 2023, Modeling Phase:
Using the application Fusion360, the Crubotics team brought their ideas to life using computer aided design. This helped solidify general design ideas and begin buoyancy considerations. ***(Figure 4)***

December 2023, Finalizing Models
CAD models were finalized in this stage. The team created a list, sectioned by departments, of all necessary materials and costs to make the design a reality.

Crubotics Design Decisions			
Maneuverability			
Thruster Type		**Number of Thrusters**	
T200	Diamond Dynamics	4	6
• Produces 1.13 kgf per thruster • $236/thruster with ESC	• Produces 1.0 kgf per thruster • $64.00 per thruster with ESC • Failure in last year's ROV	• Provide more current to run with more thrust • Lateral motion and turning is limited and not as controlled. • Horizontal and vertical motion are dependent which can create listing.	• Provides less current making it slightly slower • Allows for lateral motion and more controlled turning radius. • Vertical motion is completely independent.
Power/Tether			
Separate Cat 5 & Power		**Combined POE**	
• Cost of separate cables is minimal compared to custom cable • Weight and flexibility are a concern but can be managed through buoyancy devices		• Cost and wait time of customized cable is prohibitive. • Weight is not prohibitive when considering the insulation jacket allows for built in buoyancy • More flexible than stranded high gauge wire • Purchase of an extra POE interface and space within enclosure is prohibitive	
10AWG Voltage drop 3.30V is significant but still allows for enough current to pass through to thrusters.	12AWG Voltage drop of 5.24V is too significant to warrant use.	**VOLTAGE DROP CALCULATIONS** $Voltage\ Drop = 2 \cdot I(A) \cdot L(ft) \cdot R\frac{(\Omega)}{1000}$ $VD(10AWG) = 2 \cdot 22A \cdot 75ft \cdot \frac{1\Omega}{1000} = 3.3V$ $VD(12AWG) = 2 \cdot 22A \cdot 75ft \cdot \frac{1.59\Omega}{1000} = 5.24V$	

***Figure* 3.** A "Design Decision Chart" created during early brainstorming to collaborate ideas and consider each option.

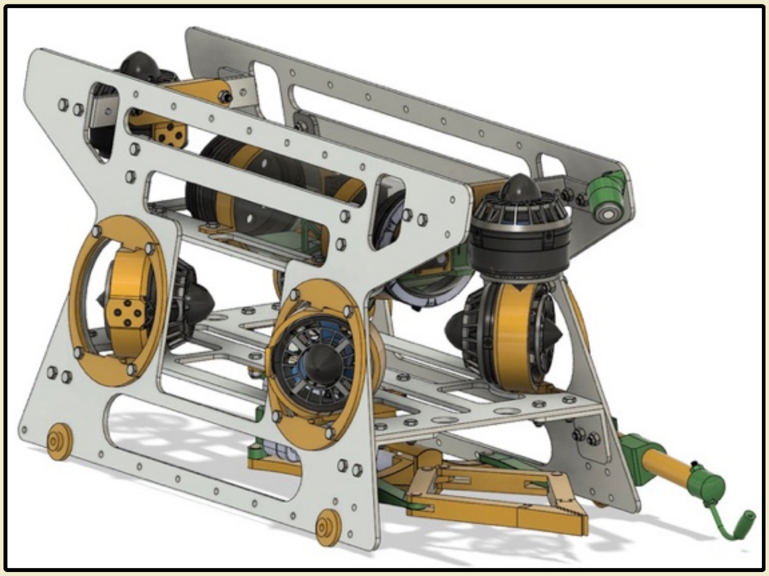


***Figure* 4.** An early CAD of CAT-5, created in Fusion360, to visualize the general structure and thruster placement.

January – March 2024, Building Phase
With the release of the mission tasks, the team's decision to switch to an aluminum frame was solidified. Other modifications were made from last years design, including new motors for better power and a redesign of the claw system to work more efficiently. Other minor adjustments include new landing gear, a cooling system connected to the Raspberry Pi to prevent overheating in the acrylic enclosure, as well as lights to better see in low light environments.

April 2024, Final Details and Testing
The team transitioned from heavy construction to heavy testing, focusing on only adding small modifications when necessary. This process included: dunk tests, buoyancy tests, pressure/leak tests, and motor tests.

Vehicle Structure

With intentions of innovative advancements beyond previous ROVs built by Crubotics, the team began the design of a non-PVC frame in the late summer after the 2023 International competition. After many design iterations with CAD models, Crubotics decided to use a 3/16" aluminum frame and contracted a metalworking company to water-jet our frame design. Aluminum was chosen over HDPE due to its non-corrosive and durable characteristics. All aspects of the robot were initially modeled into the frame to ensure perfect fit with the entirety of CAT-5.

Vehicle Systems

Propulsion

Positioned on team-designed motor mounts, six Blue Robotics T-200 thrusters were used **(*Figure 5*)**. Four of these thrusters were used at 45-degree angles to allow for strafing in any direction as well as a lower turning radius for easy yaw movement. The other two T-200s were utilized for vertical movement and pitch. The motor placement assists in Cat-5's incredible mobility in any direction necessary.

Figure 5. Two vertical and two angled, horizontal T200 thrusters. Two thrusters not depicted.

The team assessed re-using four Diamond Dynamics TD 1.2 motors. However, the cons outweighed the lower price. Although the T-200s were expensive and high on amperage draw, Crubotics decided to utilize generous donors to allocate the funds needed to resolve the high amperage draw. Built into CAT-5's software is a system to limit the throttle amount given to each thruster depending on how much power is demanded by other systems.

Control and Electrical System

Centered within the frame is a 100 mm watertight acrylic enclosure that houses all electrical components. CAT-5's thrusters are controlled by electronic speed controllers (ESCs) connected to a Blue Robotics Navigator Flight Controller paired with a Raspberry Pi 4 Model B. The Raspberry Pi communicates with ground control software via MavLink over Ethernet to control various vehicle functions ***(Figure 6)***. This design allows for a thinner tether (containing only one 10 AWG stranded copper wire for power and a UTP cable for communication); this both increases maneuverability and decreases the amount of expensive wire required. The H.264 video output of the low-light camera mounted near the front of the enclosure is streamed over UDP to the topside laptop computer. With the use of an H-bridge our Raspberry Pi can communicate with our claw and control its movement.

Within the enclosure, Crubotics placed leak sensors in ideal locations that connect to the flight controller. If a leak is detected, the ROV provides a warning or automatically disarms itself. This maximizes safety for people and marine life near the ROV and helps to prevent costly damage to electronics.

In addition to leak sensors, the flight controller has one six-axis IMU and two six-axis magnetometers for redundancy which enable the ROV to operate semi-autonomously.

Another addition to the enclosure is underwater lights which will be helpful in navigating darker areas such as underwater sturgeon breeding grounds such as Task 3.4. These lights will make certain objectives much easier while navigating underwater in the shadows of the reefs.

Figure 6. A topside view of CAT-5's electrical enclosure; the Raspberry Pi is covered with a black navigator shield and connected to an Ethernet and UTP cable.

Tether System

The 25-meter tether ***(Figure 7)*** consists of two cables (one carrying power and one carrying Ethernet signal). The tether brings power and communication from the on-shore station to CAT-5’s 100 mm acrylic enclosure where its electronics are housed. A tether relief bridle is connected at the stern of the ROV through a U-bolt on the frame. This transfers the strain off of the enclosure when the ROV is lifted by the tether, or gets snagged on obstacles underwater. To prevent damage to the tether, its full length is covered by a sheath to protect against abrasions.

Crubotics developed a tether management protocol to aid in product demonstration. If the pilot wishes for the ROV to be pulled in tighter or less tether to be left slack, they yell “Tether in!” to the tether manager. Conversely, if the pilot wishes for more slack or freedom, they yell “Tether out!” The tether is typically managed by Electrician Lucas Kasianov.

***Figure* 7.** Safety officer, Nicole Peterson, managing the tether at testing performed at Morrison Springs, Walton County, FL USA

Payload and Tools

Camera

CAT 5 utilizes one USB low-light HD camera. **(*Figure* 8)** It is positioned in the front of the enclosure dome. With the camera being on a tilt frame with a servo it is capable of capturing a wide view without needing a second system, therefore cost effective. Video compression is done on board with an H.264 chip, sent to the Raspberry Pi for transmission to the surface.

Although the camera’s primary purpose is for navigation, all tasks benefit from having a highly versatile viewing system. The following list are examples of why the specific camera was chosen: Task 1.1 releasing the multi-function node and visually determining the failure of the recovery float; 2.1 deploying the SMART Cable through the waypoints; 3.3 Coral 3D modeling; 3.4 Determine the location of the sturgeon spawning grounds.

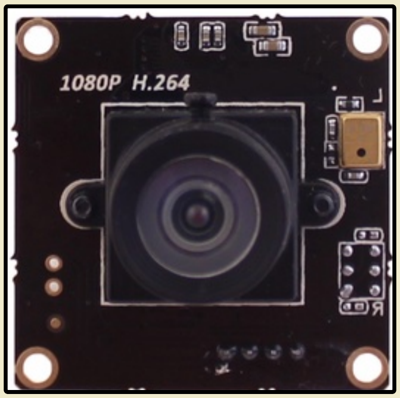
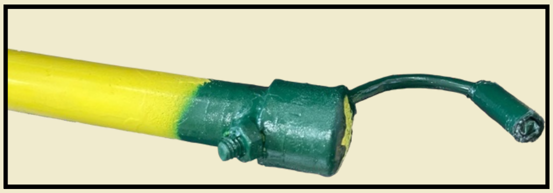


***Figure* 8.** USB HD Video Camera

Manipulators – Mechanical and Stationary Claws

CAT-5 houses two claws **(*Figure* 9)**. The main manipulator utilizes an IP68-rated linear actuator to provide mechanical movement to open and close the claw. The rest of this main claw is made of custom 3D-printed parts designed to give Crubotics the best opportunity to complete all assigned tasks. Crubotics has high aspirations for this claw due to problems fixed that have arisen in previous attempts at mechanically actuating claws. The Crubotics brought in innovation into the unique blending of the 3d printed manipulator and linear actuator housing. The claw will be found especially helpful in Tasks 1, 2, and 3 where CAT-5 will be expected to pulls pins, grasp cables, and place items designated locations.

Additionally, to maintain tradition, CAT-5 contains the static claw that was used on all the previous A.R.R.E. lineage of ROVs along with ROVs before COVID-19. This claw has become a symbol of Crubotic's problem-solving skills and our long-standing goal of reusability for parts. The static claw will allow for easy moving and transport.



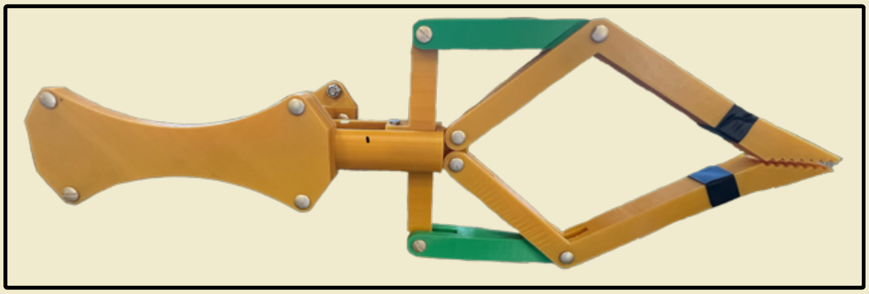


***Figure* 9.** The stationary claw (left) and mechanical gripper (right).

Buoyancy and Ballast

After performing buoyancy calculations through Fusion 360, Crubotics predicted that CAT-5 would be negatively buoyant. Further testing in April confirmed this assumption. The team decided that neutral buoyancy would operate most effectively with the motion required to complete mission tasks including the maneuvering of the BGC Float into position (Task 4.1). Buoyancy calculations **(*Figure* 10)** were made to ensure neutral buoyancy.

Additional ballast is not needed due to the weight distribution of the ROV frame and linear actuator and other components are in balance with each other

Crubotics Buoyancy Chart			
Volume Displaced (cm^3)-calculated from CAD model (*Figure 5*)	Mass of water Displaced (g)	Mass of ROV (g)	Net Buoyancy (g)
5870	5870	13, 181	-7311
Tested adjustments with combined Foam *Foamular (Density = 0.021 g/cm^3) **Subsea Buoyancy Foam (0.192g/cm^3)		7311	0

***Figure* 10.** Crubotics Buoyancy calculations

Consequently, Crubotics experimented with different types of positively buoyant materials such as pool noodles (polyethylene foam) **(*Figure* 11)** and Owens Corning® Foamular® (250 Extruded Polystyrene- XPS) **(*Figure* 12)** to add to CAT-5. This ensured that the ROV would be neutrally buoyant while also minimizing extra weight or bulkiness.

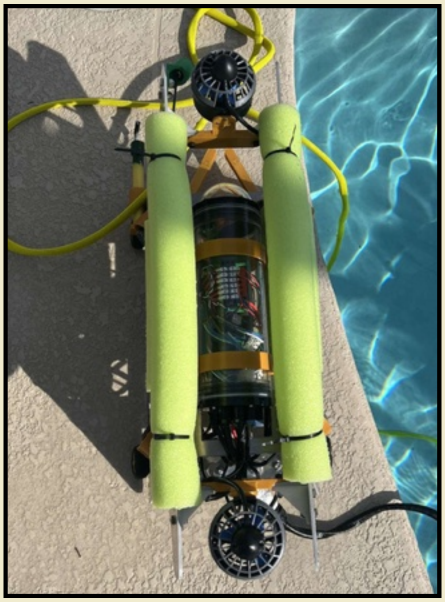


***Figure* 11.** First iteration of buoyancy testing with polyethylene foam.

***Figure* 12.** Second iteration of buoyancy testing with 250 Extruded Polystyrene- XPS.

Build vs. Buy

Crubotics utilized in-house 3D printers to customize specific elements of the ROV; this additionally increased cost-effectiveness. 3D-printed, customized features include the mechanical claw, the motor mounts, the thruster shrouds, the electronics housing within the enclosure, enclosure support rings and the camera mount.

Motor mounts were made specifically to be placed on a 45 degree angle to ensure proper directional movement needed for all underwater tasks. Similarly, a specifically designed claw was made to manipulate objects easily in situations similar to Task 1.1, 2.1, 3.1, 3.2 and 4.1. Along with these customized parts, Crubotics utilized previously purchased parts to help make CAT-5 as cost-effective as possible.

However, Crubotics wanted to improve from last year's model significantly and required new purchases to accomplish its goals. Firstly, to ensure a truly waterproof mechanical claw, Crubotics invested in an IP68-rated linear actuator. Secondly, Crubotics wanted to have more power in horizontal movement, so four more Blue Robotics T-200 thrusters were purchased. Lastly, Crubotics invested in a higher gauge tether to support more significant power draw from the new motors.

New vs. Reused

During the Brainstorming Phase, team members considered which features of the 2023-24 ROV should be included this year and which should be scrapped. The transition to a trapezoidal frame was a new decision; as well as the 3/16" Aluminum Steel 5052 framing to create this higher strength, more durable, corrosion resistant structure.

Similarly, the previous year's stationary claw remained on the ROV, but the hydraulic claw was traded for a new 3D-printed mechanical gripper operated by a linear actuator. The reused parts were two Blue Robotics T-200 thrusts, a HD tilt mount camera, the Blue Robotics watertight enclosure, as well as the Raspberry Pi, BlueRobotics Navigator Flight Controller, and the static claw. The combination of the reuse of these items will help in all attempted tasks.

Non-ROV – Float Rationale

To accomplish Task 4, design and construct an operational vertical profiling float, Crubotics developed a BGC Float dubbed the "Ecumenical Ensign." The float is designed using a buoyancy engine and "water bladder" system in order to achieve the vertical profiling through the water column. The float is also designed to collect and transmit data to an on-shore receiving unit.

The float exoskeleton is a 6" ABS cylinder that is to hold the internal electronics and provide enough volume to control the buoyancy. PVC endcaps are used to protect the electronics from water leakage into the internal systems. Ballast is controlled with diving weights in order to maintain an upright position.

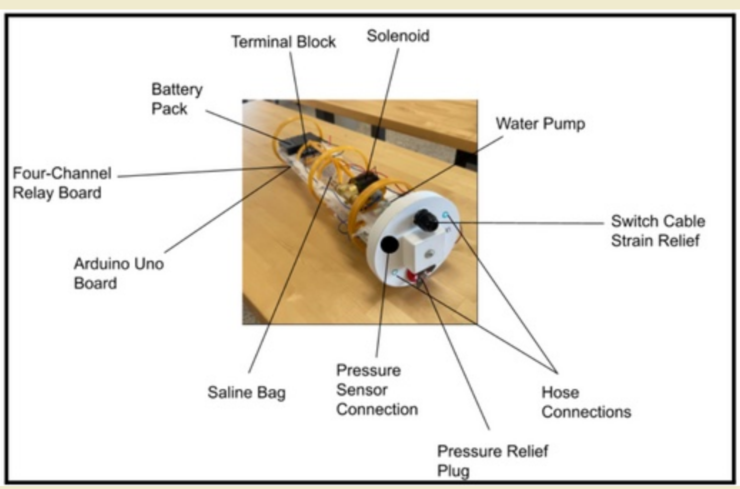


***Figure* 13.** Labeled diagram of BGC Float

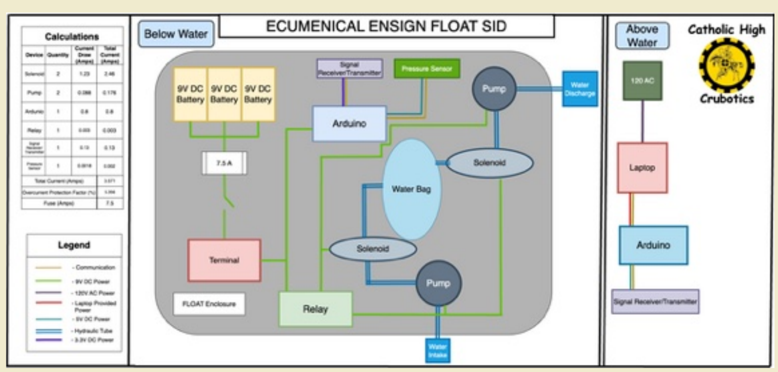


***Figure* 14.** The System Integration Diagram for the BGC Float.

The float endoskeleton **(*Figure 13*)** gives a frame for the electrical and mechanical systems. A robust electrical system exists within the Crubotics float in order to power the buoyancy engine, as well as collect and transmit pressure and time data. A battery pack consisting of three 9V batteries connected in parallel powers the circuit. A 7.5A mini-blade fuse lies within 5cm of the battery pack, followed by a IP68 waterproof switch to ensure a safe method of cutting power if needed. Power is distributed to a 4-channel relay, an Arduino Uno board, two self-priming diaphragm water pumps, and two electric solenoid valves. Additionally, a bluetooth transmitter device and a pressure sensor are both connected to and receive power from the Arduino Uno. A SID is provided in **(*Figure 14*)**. The Arduino Uno is programmed to communicate with the relay device to switch corresponding water pumps and solenoid valves off and on in order to either fill or empty the internal water bladder. The circuit design centers around the idea of giving the programming control over whether or not a pump or solenoid is on or off, and basing this condition off of the readings of the pressure sensor.

Safety

Safety Rationale

Crubotics places safety at the forefront of its operations through a comprehensive approach rooted in innovation and diligence. Recognizing the inherent risks associated with underwater robotics, Crubotics implements stringent safety protocols across all stages of development, deployment, and operation. This includes thorough risk assessments, regular safety audits, and continuous refinement of safety features embedded within its robotic systems. By prioritizing safety, Crubotics ensures not only the protection of its personnel but also the safeguarding of the environments in which its ROVs operate.

Safety Philosophy

At Crubotics, safety is not just a priority; it's an integral part of our DNA. As a company, Crubotics believes that every member of our team deserves to work in an environment where their well-being is paramount. Our safety philosophy revolves around three core principles: prevention, education, and continuous improvement.

First and foremost, prevention is key to ensuring a safe workplace. Teammates proactively identify potential hazards and implement robust safety measures to mitigate risks. The goal is to prevent accidents before they occur by promoting a culture of vigilance and accountability among all employees.

Education is another cornerstone of the Crubotics safety philosophy. From proper tool handling and ROV operations, Crubotics empowers members to make informed decisions and take proactive measures to safeguard themselves and their colleagues.

Safety Protocols

In our STEM Innovation lab, workshop, and poolside areas, safety is paramount to ensure the well-being of our employees and the integrity of our operations. We have developed a safety protocol encompassing two key areas: equipment maintenance and operation and personal protective equipment (PPE) usage.

Firstly, equipment maintenance and operation are critical aspects of ensuring a safe working environment. All machinery and tools must undergo regular inspections and maintenance to identify and address any potential hazards promptly. Employees are required to undergo thorough training on the safe operation of equipment and adhere strictly to manufacturer guidelines. Additionally, clear signage and labeling are implemented to indicate potential risks and proper usage instructions, minimizing the likelihood of accidents due to improper handling.

Secondly, the proper usage of personal protective equipment (PPE) is non-negotiable in our facilities. Employees are provided with appropriate PPE, including safety goggles, gloves, hair ties, and protective clothing, depending on the nature of their tasks. It is mandatory for all personnel to wear the designated PPE at all times while in the lab, workshop, or poolside areas, even when conducting routine activities. Regular inspections are conducted to ensure the adequacy and functionality of PPE, with immediate replacement or repair of any damaged or defective gear.

In the lab, members are required to keep long hair tied back, wear closed-toed shoes, and remove any jewelry. Members work consistently to keep the vehicle safe for the environment, ensuring that the pool interior will not be damaged nor any living organisms be harmed.

Prior to ROV use, members review a safety checklist prior to product demonstration, which is located in ***Appendix C.***

Safety - CAT-5

The Electrical components of CAT 5 are protected by a 100 mm waterproof, acrylic enclosure from Blue Robotics. This enclosure features a pressure relief valve rated up to a 950 m depth. Additionally, wetlink penetrators are used to ensure no leaks occur. Any electrical connections outside of the enclosure are rated waterproof beyond a depth of 4 m.

The Anderson Powerpole and its 25A blade fuse are within 30 cm of the DC power supply running through the control box, and AC power is also used in the box to power the computer. The control box is also waterproof for transport. The sheathed tether, which stretches from the box to the ROV, is equipped with a strain- relief system to prevent damage to CAT 5's waterproof enclosure; in event of an emergency, the tether can also quick-disconnect from the control box.

Calculations of amperage were performed based on the electronics used; the Fuse Overall Percentage falls within the range of the 25 amp fuse used. ***(Figure 15)*** An overall Systems Integrations Diagram is in ***Appendix D.***

The ROV's thrusters are Blue Robotics T200's, running on 3.3 Amps each. To protect wildlife (Task 3) and handlers, each thruster is covered on the front and back with shrouds. 3D printed mounts support the motors. (***Figure 16)***

All edges and surfaces are smooth within acceptable safe standards.The laptop, Ethernet cable and adapter, and controller are all located in the waterproof control box.

Calculations

Device	Quantity	Current Draw (Amps)	Total Current (Amps)
Rasp Pi w/Shield	1	0.323	0.323
T200 Motors	6	3.3	19.8
Linear Actuator	1	1.5	1.5
Servos	2	0.015	0.03
Camera	1	0.14	0.14
Total Current (Amps)			21.793
Overcurrent Protection Factor (%)			32.690
Fuse (Amps)			25

Figure 15. Fuse calculations used for confirming electrical safety.

Figure 16. 3D-printed shrouds are used to protect wildlife and operators from thruster motion.

Critical Analysis
Prototyping

Computer-aided designs of CAT-5's overall structure were created using Fusion360; the application allowed modelers to calculate buoyancy and test hydrodynamics. Computer-aided designs of CAT-5's overall structure were created using Fusion360, which allowed buoyancy and hydrodynamics testing.

The chosen trapezoidal prism design was seen to be negatively buoyant due to the aluminum frame, however, the robotics team opted for Foamular® (made of Extruded Polystyrene), to achieve neutral buoyancy. Additionally, more CAD parts were created to model any 3D-printed aspects of the ROV, including motor mounts, shouds, and claw mounts.

Testing

Crubotics follows the following methodology: test, assess, modify, test. First, an aspect of the ROV, such as buoyancy, was selected for testing. Team members used another member's pool to observe the nature of CAT-5 at rest in water. Then, team members would assess the results of the test; as predicted in Fusion360, CAT-5 was negatively buoyant.

The team concluded that neutral buoyancy would most effectively cooperate with the control system. Consequently, the ROV was modified by adding polyethylene foam (pool noodles) to make it more buoyant. Then, the buoyancy test was run again in the pool. It was later found that Foamular (Extruded Polystyrene) gave the most efficient and aesthetically pleasing outcome.

Crubotics performed as many iterations including those in freshwater as needed to obtain the desired result. (*Figure 17*)

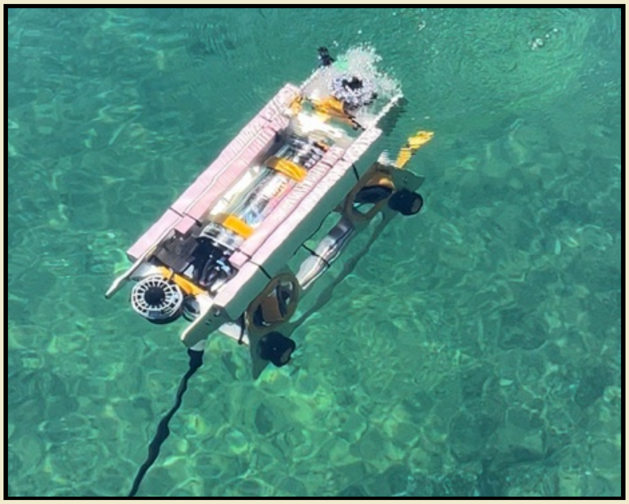


Figure 17. Real environment testing in Morrison Springs Walton County, FL.

Similarly, Crubotics had iteration testing for control operations and underwater claw manipulation, where the machine was dunked and tested in a small pool of water to ensure safety and proper behavior underwater. **(*Figure* 18)**

The aforementioned methodology was used to test propulsion, wiring, waterproofing, and pressure-resistance.

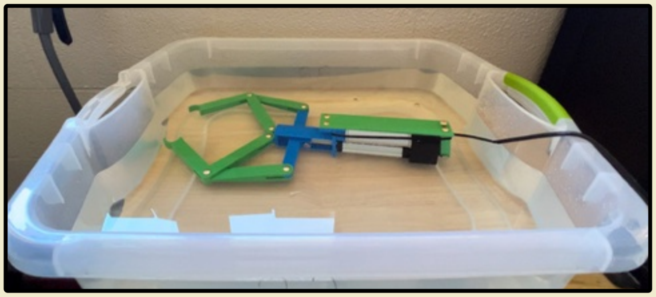


***Figure* 18** Iteration testing with the Mechanical Gripper. Instrument was placed into a tub of water to ensure safety of equipment.

Troubleshooting

Troubleshooting served as part of the "modify" phase of Crubotics's testing methodology. Upon encountering a problem during testing, team members first composed a list of possible sources of the issue. After ranking the sources from least to most likely, members went through each source to see if the corresponding feature of the ROV was working as intended. **(*Figure* 19)**

Once team members discovered an area that needed improvement, the lab whiteboard was used to consider possible solutions (unless there was a quick fix to the issue, such as a coding error). These solutions were then evaluated based on cost-effectiveness, likelihood of success, and time constraints.

Continuing with a previous example, Crubotics used the troubleshooting methodology when it became apparent the original design for the horizontal motor mounts was too complex to be made out of aluminum 5052 like the frame. Consequently, the engineers and CAD modelers convened to make necessary modifications to the previous design so that the mounts retained the important aspects of their design while also gaining the ability to be manufactured out of PLA in-house on the 3D printer.

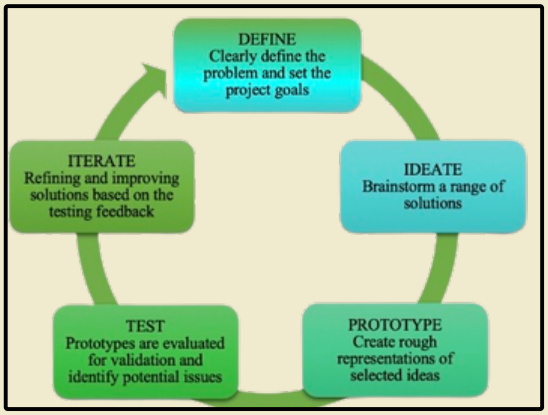


***Figure* 19.** Flow Chart of Crubotics Troubleshooting Ideology

Accounting

Budget

Crubotics budget consists of a variety of sources to keep individual team member costs in the form of dues to a minimum. Crubotics gave outreach speeches to the Rotary Club and IEEE that provided sponsorship opportunities. We also received other community sponsorships and donations. Fundraising opportunities were also created. **(*Appendix* E)**

Cost Accounting

Crubotics used decisions made from Design Rationale, Buy or Reuse, as well as, cost effects of Build vs Buy to ration the budget effectively. All cost accounting is documented accordingly **(*Appendix* E).**

Acknowledgements

First and foremost, Crubotics would like to thank MATE II for holding the 2024 ROV Competition; our team is grateful for the exposure to engineering innovations, product presentations, and company management duties. Additionally, we appreciate Dauphin Island Sea Lab for hosting the North Gulf Coast Regional Competition and providing a positive educational environment.

Secondly, we would like to thank the following sponsors and benefactors, without whom none of this would have been possible: Bear General Contractors, Blackwater River Tools, Perdido Key Rotary Club, Main Street Construction, IEEE, Pensacola Rubber and Gasket, D&D Welding and Fabrication, the Hoppe Family, and the Neff Family.

Lastly, we would like to give a big thank you to Mrs. Dana Lupton and Mr. Eric Requet for being incredible mentors. We always appreciate the time and effort you put into overseeing this team alongside your full-time jobs as teachers. None of this would be possible without you!

References

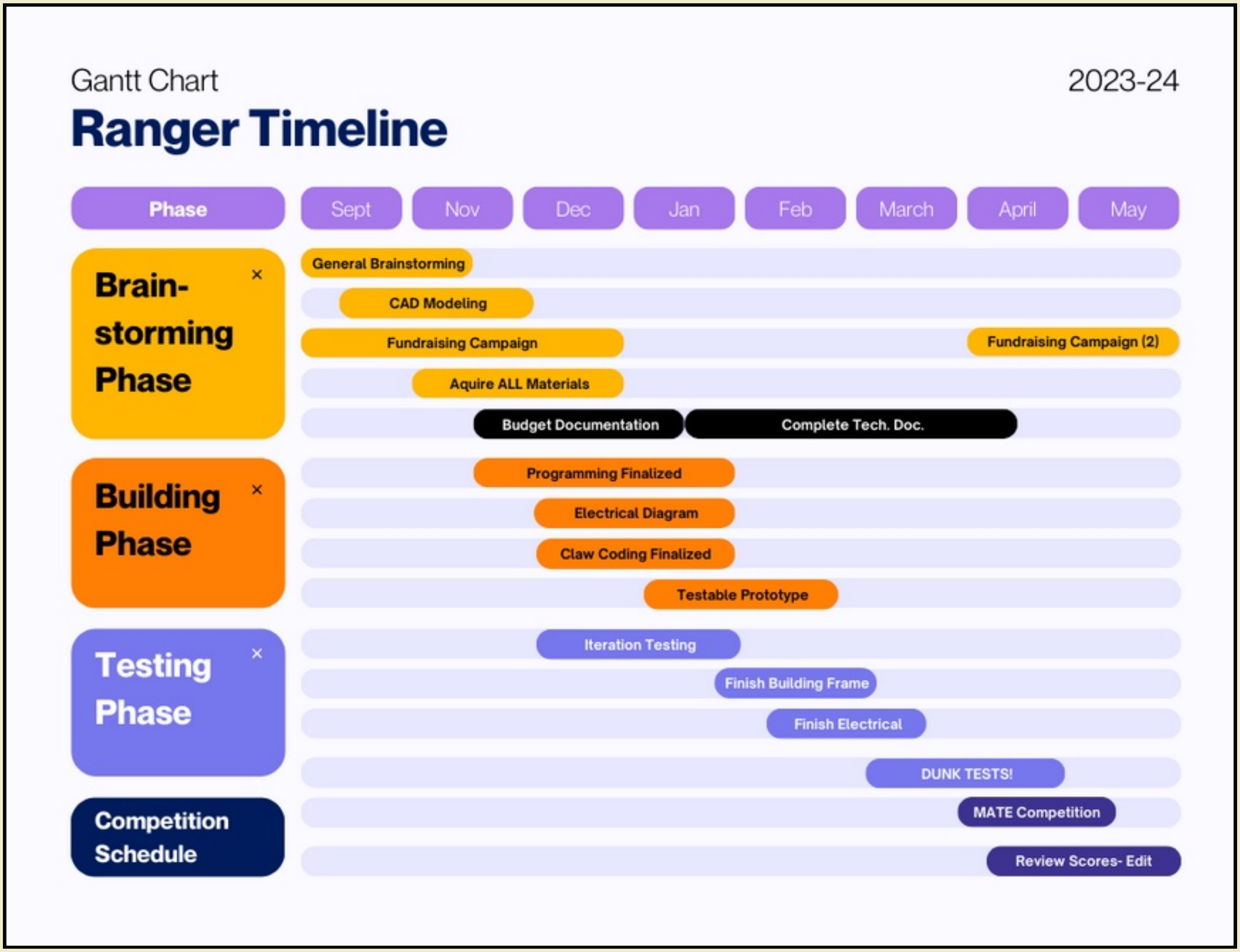
1. Blue Robotics T200 Motors
2. Foamular density
3. Wire Resistance
4. QGroundControl User Guide
5. Linear Actuator
6. Subsea Buoyancy Foam: R-3312

Appendix A
Job Descriptions

Brandon Hoppe '24 CEO/Pilot	Leads team meetings and presentations; oversees all modifications; pilots CAT-5 *3rd year in Crubotics*
Mac McKinley '24 Lead Design Engineer	Design 3D models in fusion 360 application; test said models via simulations; propose build modifications *2nd year in Crubotics*
Aloysius London '25 COO	Oversees day-to-day and minor operations in the lab; ensures safety of all members *3rd year in Crubotics*
Grant Robertson '24 BGC Float Lead Engineer	Leads Float team; constructs and handles frame of non-ROV devices *2nd year in Crubotics*
Nicole Peterson '24 Safety Officer	Preforms regular safety checks during construction and demonstration *2nd year in Crubotics*
Fredrick Strawitch '24 BGC CAD Modeler	Design non-ROV 3d models in fusion 360 application; test said models via simulations; propose build modifications *1st year on Crubotics*
Nate Flores '24 BGC Float Design	Contributes to discussion and modification of Float; proposes adaptations to mission tasks *2nd year in Crubotics*
Carsyn Neff '25 Head of Marketing	Composes all technical documentation; controls social media accounts *1st year on Crubotics*
Luke Foster '25 BGC Float Engineer	Contributes to discussion and modification of Float; proposes adaptation to mission tasks *3rd year in Crubotics*
Dylan Nguyen '25 BGC Float Programmer	Writes code for non-ROV control; oversees electronics installation *1st year in Crubotics*
Lucas Kasinov '25 Electrician	Manages wiring and troubleshooting on ROV and non-ROV devices *1st year in Crubotics*
Caleb Bobe '26 Lead Programmer	Writes code for ROV control; oversees installation of electronics *2nd year in Crubotics*

Appendix B

Crubotics Project Management Timeline



Appendix C
Safety Checklist

Pre-Power (Pilot, Co-Pilot, and Deck Crew)
- Area is clear and safe (no tripping hazards or obstructions)
- All team members are wearing safety glasses
- Verify control box power switches are off
- Tether laid out on the deck and is free of damage
- Tether is connected and secured to the control box
- Tether is connected to strain relief and secured to ROV
- Power source connected to control box
- Verify electronics housing is properly sealed and fasteners are tightened
- Visual inspection of electronics for damaged wires or loose connections
- Vacuum test electronics housing (see Enclosure Pressure Test below)
- Vacuum port is securely capped
- Thrusters are free from obstructions

Enclosure Pressure Test (Deck Crew)
- Verify electronics housing is properly sealed
- Connect vacuum pump to electronics housing
- Vacuum down the electronics housing to 5psi and verify they hold this pressure for 5 minutes
- Remove vacuum pump and securely cap vacuum port
- Return vacuum hand pump to case

Power-Up (Pilot, Co-Pilot, and Deck Crew)
- Verify control box is receiving 12V nominal
- Control computers up and running
- Ensure deck crew members are attentive
- Co-pilot calls out, "power on"
- Power on control box
- Co-pilot calls out, "performing thruster test"
- Test thrusters and verify thrusters are working properly
- Verify video feed from camera

ROV Launch (Pilot, Co-Pilot, and Deck Crew)
- Deck crew members handling ROV call out, "hands on"
- Carefully place ROV in the water
- Check for bubbles
- Visually inspect for water leaks
- It there are large bubbles, pull to surface immediately and proceed with Leak Detection Protocol
- If no issues are detected, call out, "prepare to launch"
- Deck crew members handling ROV remove their hands from the vehicle and call out, "hands off"
- Co-pilot calls out "thrusters engaged" and pilot begins mission

ROV Retrieval (Pilot, Co-Pilot, and Deck Crew)
- Pilot calls out, "ROV surfacing"
- Deck crew calls out, "ROV on surface. Disable thrusters"
- Co-pilot calls out, "thrusters disabled"
- Deck crew call out, "hands on," and remove ROV from water
- Co-pilot calls out, "safe to remove ROV"
- After securing the ROV on deck, deck crew calls out, "ROV secured on deck"
- Co-pilot powers from control box

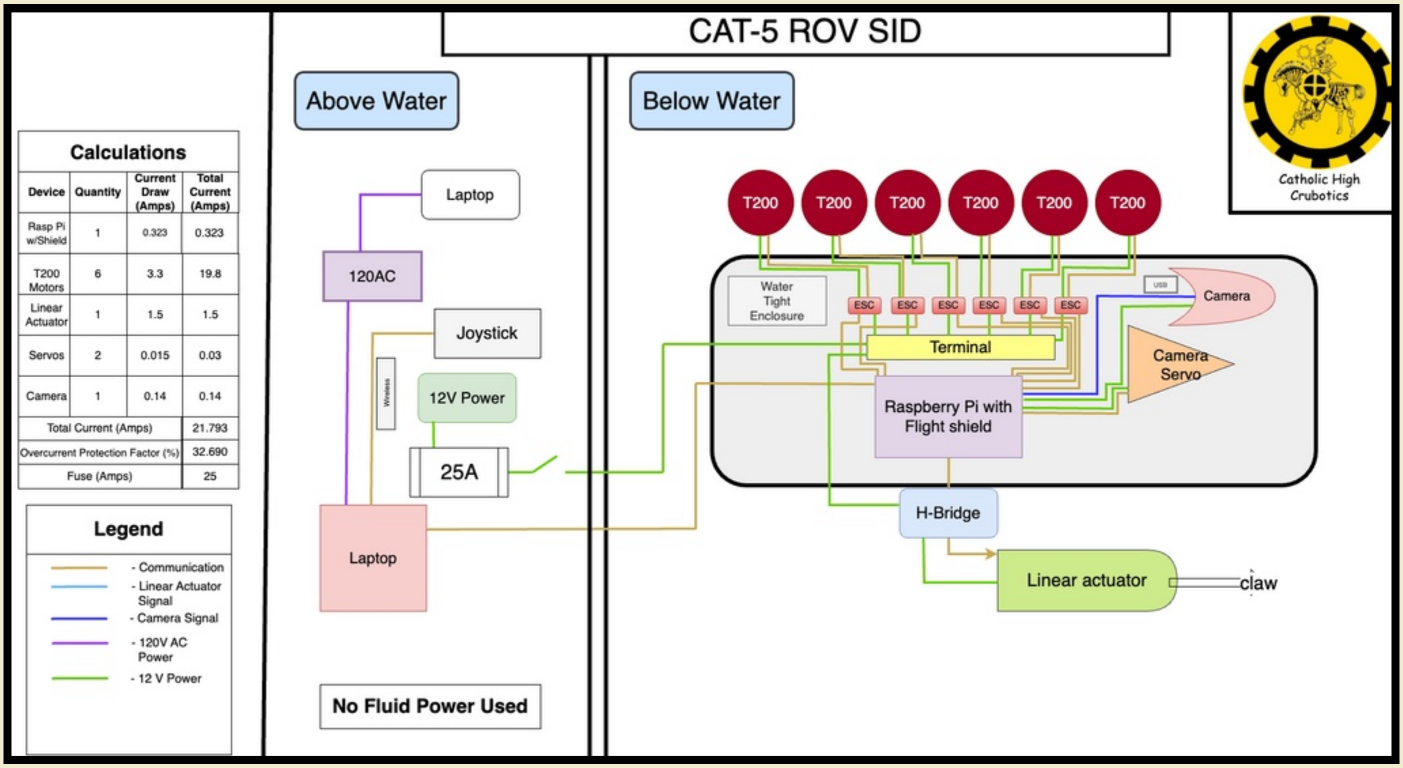
Leak Detection (Pilot, Co-Pilot, and Deck Crew)
- Immediately power down the ROV and control box systems and remove ROV from the water if a mission is occurring
- Visually inspect ROV to identify the source of the leak. Do not disassemble any part of the ROV until the source of leak is detected.
- Install pressure testing equipment and use soapy ater to verify source of leak.
- Create a plan and repair leak
- Check all systems for damage and verify proper operation
- Document the source and cause of the leak and detail the corrective actions and design changes made

Loss of Communication (Pilot, Co-Pilot, and Deck Crew)
- Cycle power on control box to reboot ROV
- If no communication, power down ROV, retrieve via tether
- If communication restored, confirm there are no leaks, resume operations
- If communication has not been restored, begin troubleshooting procedures and isolate the issue. Determine if the issue is with hardware or software.
- Document the problem and detail the corrective actions made to solve the problem

Pit Maintenance (All Team Members)
- Pit is well organized and free of debris
- All tools, cables, and equipment are safely stored in their designated spaces and there are no tripping hazards
- Check electrical cords and correct any electrical hazards
- Check supplies and organize a shopping list if anything is needed for repairs or upkeep
- Verify control box, ROV, and tether are clean, dry, and stored
- Protective caps for electrical connectors are in pace
- ROV, control box, and tether have been readied for use on the next mission run

Appendix D

System Integration Diagram



Appendix E

Project Costing

BUDGET				
School Name: Pensacola Catholic High School			Crubotics	
Mentor: Mrs. Dana Lupton and Mr. Eric Requet				
Reporting Period: September 1, 2023 - 4/26/2024				
INCOME		EXPENSES		
SOURCE	AMOUNT		PROJECTED	ACTUAL
Dues	$260.00	Vehicle Structure	$1,600.00	$510.85
Sponsorships	$8,000.00	Controls/Electronics	$3,380.00	$2,645.87
Donations	$680.00	Buoyancy	$50.00	$27.00
Fundraising	$1,610.00	Propulsion	$1,000.00	$984.00
Employee Paid	$742.00	BGC Float	$500.00	$423.46
Total Income	**$11,292.00**	Marketing	$750.00	$741.58
		Travel-Regionals	$900.00	$842.00
		TOTAL Expenses	$8,180.00	**$6,174.76**
			Net Profit/Loss	**$5,117.24**

				COST ACCOUNTING			
	School Name: Pensacola Catholic High School			Crubotics			
	Mentor: Mrs. Dana Lupton and Mr. Eric Requet						
	Reporting Period: September 1, 2023 - 4/26/2024					Rollover '22-'23	$527.73
Date	Category	Type	Qty	Item	Price / unit	Price	Running Total
9/1/2023	Controls/Electronics	Reused	1	Raspberry Pi 8 Model B Quad Core	$125.00	$125.00	$402.73
9/1/2023	Controls/Electronics	Reused	1	Cat 5 cable	$22.00	$22.00	$380.73
9/1/2023	Controls/Electronics	Reused	1	RJ45 quick release	$8.00	$8.00	$372.73
9/1/2023	Controls/Electronics	Reused	1	2 pin quick connect	$10.88	$10.88	$361.85
9/1/2023	Controls/Electronics	Reused	1	in-line fuse holder	$1.30	$1.30	$360.55
9/1/2023	Controls/Electronics	Reused	1	BlueRobotics Navigator Flight Controller w/cam	$524.00	$524.00	-$163.45
9/1/2023	Controls/Electronics	Reused	1	Fuse (multipack)	$12.99	$12.99	-$176.44
9/1/2023	Vehicle Structure	Reused	1	Blue Robotics 4in Enclosure	$402.00	$402.00	-$578.44
9/1/2023	Vehicle Structure	Reused	1	Blue Robotics Wetlink Penetrators, 5 pack	$50.00	$50.00	-$628.44
9/1/2023	Vehicle Structure	Reused	1	Vacuum Plug kit	$8.00	$8.00	-$636.44
9/1/2023	Vehicle Structure	Reused	1	M10 Vent and Plug	$9.00	$9.00	-$645.44
9/1/2023	Vehicle Structure	Donated	2	PLA (.75kg)	$32.00	$64.00	-$709.44
9/1/2023	BGC Float	Reused	1	Arduino Uno	$30.00	$30.00	-$739.44
9/15/2023	Controls/Electronics	Purchased	1	WASP 12V H bridge	$52.17	$52.17	-$791.61
9/15/2023	Controls/Electronics	Purchased	2	USB to PH2.0	$8.85	$17.70	-$809.31
9/15/2023	Controls/Electronics	Purchased	1	10-2 AWG cable and sleeve	$176.00	$176.00	-$985.31
10/23/2023	Controls/Electronics	Donated	1	Standalone Laptop	$2,400.00	$2,400.00	-$3,385.31
10/23/2023	Controls/Electronics	Donated	1	Xbox controller	$30.00	$30.00	-$3,415.31
1/15/2024	Vehicle Structure	Purchased	1	BR Wetlink Penetrators, 1 pack	$12.00	$12.00	-$3,427.31
1/15/2024	Vehicle Structure	Purchased	1	BR Wetlink Penetrators, 1 pack	$12.00	$12.00	-$3,439.31
1/15/2024	Propulsion	Donated	4	BlueRobotics T200 Motors w/ ESC and penetrator	$246.00	$984.00	-$4,423.31
1/23/2024	Vehicle Structure	Purchased	1	Aluminum Steel 5052 3/8"	$360.00	$360.00	-$4,783.31
1/24/2024	Vehicle Structure	Donated	1	Water Jet Service	$500.00	$500.00	-$5,283.31
2/1/2024	Vehicle Structure	Purchased	1	Hardware	$39.57	$39.57	-$5,322.88
2/1/2024	Vehicle Structure	Purchased	1	LED light	$15.79	$15.79	-$5,338.67
2/1/2024	BGC Float	Purchased	3	Battery holder	$2.67	$8.01	-$5,346.68
2/1/2024	BGC Float	Purchased	1	In-line fuse holder & Fuse (multipack)	$10.49	$10.49	-$5,357.17
2/1/2024	BGC Float	Purchased	1	Switch	$13.06	$13.06	-$5,370.23
2/1/2024	BGC Float	Purchased	1	Wireless transmitter/receiver	$9.69	$9.69	-$5,379.92
2/1/2024	BGC Float	Purchased	1	Hose Clamps & tubing	$23.98	$23.98	-$5,403.90
2/1/2024	BGC Float	Purchased	2	Jt-180a-12 Water Pump	$12.90	$25.80	-$5,429.70
2/1/2024	BGC Float	Purchased	2	Electric Solenoid Valve	$22.00	$44.00	-$5,473.70
2/1/2024	BGC Float	Purchased	4	Brass Hose Fitting	$5.91	$23.64	-$5,497.34
2/1/2024	BGC Float	Purchased	2	6" ABS Pipe & fittings	$48.92	$97.84	-$5,595.18
2/1/2024	BGC Float	Purchased	1	Water-resistant Pressure Sensor	$28.18	$28.18	-$5,623.36
2/1/2024	BGC Float	Purchased	2	12V 4 channel Relays	$7.39	$14.78	-$5,638.14
2/1/2024	BGC Float	Purchased	1	Cable Gland & 1.5" Gripper (Pressure Relief)	15.44	$15.44	-$5,653.58
2/1/2024	BGC Float	Purchased	1	5v 8 Channel Relay Board	$17.38	$17.38	-$5,670.96
2/1/2024	BGC Float	Purchased	2	Arduino Uno Screw Shields	$8.99	$17.98	-$5,688.94
2/15/2024	Vehicle Structure	Donated	1	Aluminum bending service	$50.00	$50.00	-$5,738.94
3/15/2024	Buoyancy	Purchased	3	Foam	$9.00	$27.00	-$5,765.94
3/15/2024	Marketing	Purchased		Shirts and Hats		$448.00	-$6,213.94
4/8/2024	Marketing	Purchased	1	stickers (150)	$25.00	$25.00	-$6,238.94
4/8/2024	Marketing	Purchased	1	Pens (250)	$140.00	$140.00	-$6,378.94
4/15/2024	Marketing	Purchased	1	Printing Marketing Info	$80.00	$80.00	-$6,458.94
4/15/2024	Marketing	Purchased	1	Laser Cut Tokens	$18.00	$18.00	-$6,476.94
4/15/2024	Travel	Purchased		Regional - Room and Board		$742.00	-$7,218.94
4/26/2024	Travel	Donated		Regional - Travel		$100.00	-$7,318.94
					Donated	$4,028.00	-$3,290.94
					Reused	$1,203.17	-$2,087.77
					Fundraised	$1,610.00	-$477.77
					Employee Paid	$742.00	$264.23