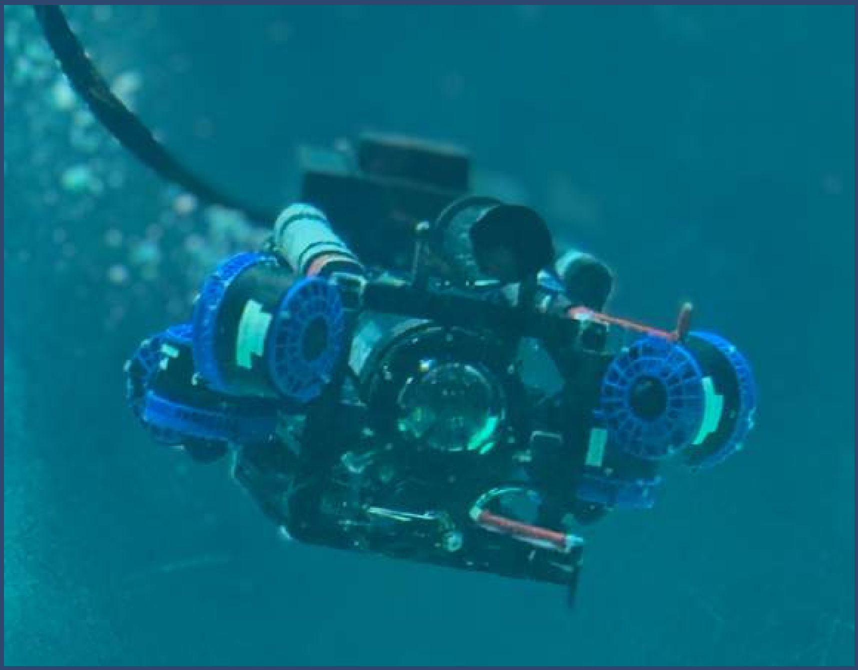
TECHNICAL DOCUMENTATION 2025

HEART INNOVATORS

Holy Heart of Mary High School
St. John's, NL Canada



CEO
Benjamin Evans '25

COO
Natalie Mitchell '25

Mentor
Mr. Cole Murphy

Software
Kenneth Le '25 (Director)
Peyton Cashin '25
Frank Chen '25
Noah MacDonald '26
Junjie Mou '26

Graphic Design
Saige Navarro '26
Waffa Zahralyn '25

Design & Fabrication
Sophia Zhang '26 (Director)
Madison Drover '27
Michael Osborne '27
Abbey Janes '26 (Safety)

Marketing
Vidya Chedella '27

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1. Abstract

HEART Innovators is a dynamic underwater robotics organization based on the East Coast of Canada. Composed of fourteen skilled and passionate engineers and technicians, the team is committed to designing forward-thinking technologies that address pressing exploration issues while safeguarding shipwreck artifacts.

This year, our team proudly introduced our third-generation Remotely Operated Vehicle (ROV), purpose-built to tackle real-world challenges beneath the surface. Drawing on past experience and refined technical expertise, the ROV integrates a compact, durable frame with custom 3D-printed components, precision navigation tools, and an intuitive multi-camera control system to execute missions with accuracy and agility.

Rooted in Newfoundland and Labrador's deep history of ships and ocean navigation, HEART Innovators embraces its responsibility to protect history through shipwrecks. Through participation in the MATE ROV competition, the team will contribute to global initiatives such as preservation, mapping, and monitoring our shipwrecks and maritime artifacts—all while honouring the legacy of our ocean-bound home.

Figure 1. HEART Innovators Team Photo

2. Teamwork

A. Company Overview

HEART Innovators is a student-led underwater robotics company based in St. John's, Newfoundland and Labrador, Canada. Now in its third year of operation, the company focuses on engineering innovative submersible technologies that address the problems in shipwreck exploration, preservation, and navigation. Through the design and development of a Remotely Operated Vehicle (ROV), the company fosters ocean literacy and champions environmental sustainability. What sets HEART Innovators apart is its commitment to mentorship and accessibility. The team empowers high school students to explore diverse engineering fields, including mechanical design, electronics, and software development, and environmental science. By cultivating technical and leadership skills in an inclusive, real-world engineering environment, HEART Innovators aims not only to produce effective underwater technologies—but also to develop the next generation of STEM leaders.

B. Company Personnel

HEART Innovators operates through a collaborative leadership model, which supports clear communication across departments. The team is composed of 14 members and organized into five core departments: Design and Fabrication, Software, Marketing, Graphic Design and Safety. Each department is guided by a director or lead, with oversight from the company's two leadership officers: the Chief Executive Officer (CEO) and Chief Operating Officer (COO).

The CEO is responsible for overseeing the core technical functions—software and design & fabrication—ensuirng the ROV's construction, testing, and technical innovation remain on track. The COO manages internal logistics, visual identity, and administrative operations by leading the marketing, graphic design, and safety departments. Together, the CEO and COO provide strategic direction, facilitate cross-functional collaboration, and ensure alignment with project goals and values.

Additionally, a dedicated Senior Management Team (SMT) which is composed of the CEO, COO, and department directors—meets weekly to evaluate progress, resolve challenges, and coordinate resources effectively.

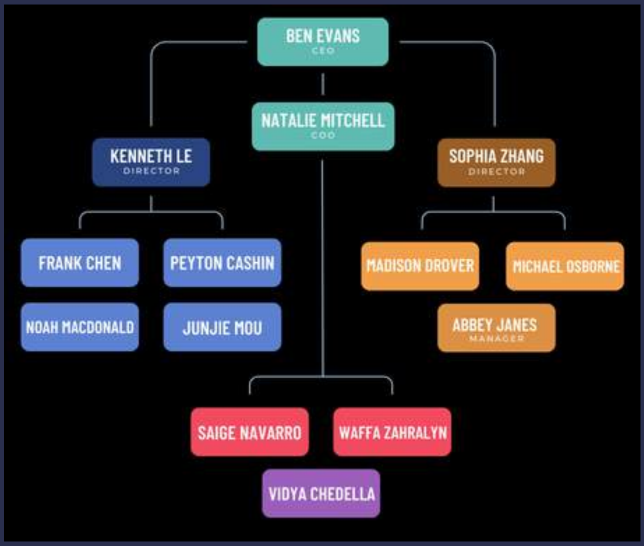

Figure 2. HEART Innovators Company Organization

Figure 3. HEART Innovators SMT Meeting

C. Planning & Scheduling

HEART Innovators follows a structured meeting schedule that balances productivity with members' academic and personal commitments. Full team meetings are held every Monday and Thursday, creating a consistent platform for design, fabrication, testing, and cross-departmental collaboration. Additionally, the Senior Management Team meets weekly on Wednesdays to evaluate progress, address challenges, and coordinate upcoming tasks. These leadership sessions ensure that department efforts remain aligned and that teams have the resources they need to meet project milestones. While the schedule is rigorous, the team places a strong emphasis on member well-being. A supportive onboarding process, regular check-ins, and mentorship opportunities help foster a positive, inclusive environment where members feel empowered and equipped to succeed.

D. Project Management

To ensure operational efficiency and project transparency, HEART Innovators adopted a comprehensive project management system this season. A key feature of this approach was the introduction of each department's Project Management Chart (PMC)—a centralized tool used to structure project timelines. The PMC includes a logistics timeline for major milestones, department-specific schedules, weekly meeting objectives, as well as deadlines and deliverables. This framework allowed the team to coordinate tasks, delegate responsibilities, and monitor progress with clarity. It also facilitated early identification of obstacles and informed adjustments in scheduling or resource allocation. For example, the Design & Fabrication PMC was critical in guiding the department towards a successful first pool test in March, ensuring ROV deployment was scheduled within a clear, achievable timeline. When used in tandem with weekly leadership meetings, the team's PMCs ensured that key technical goals were met on time and that all departments moved forward cohesively. This disciplined, process-driven approach to project management has not only enabled the team to deliver a reliable, competition-ready ROV, but also laid the groundwork for scalability and improvement in future seasons.

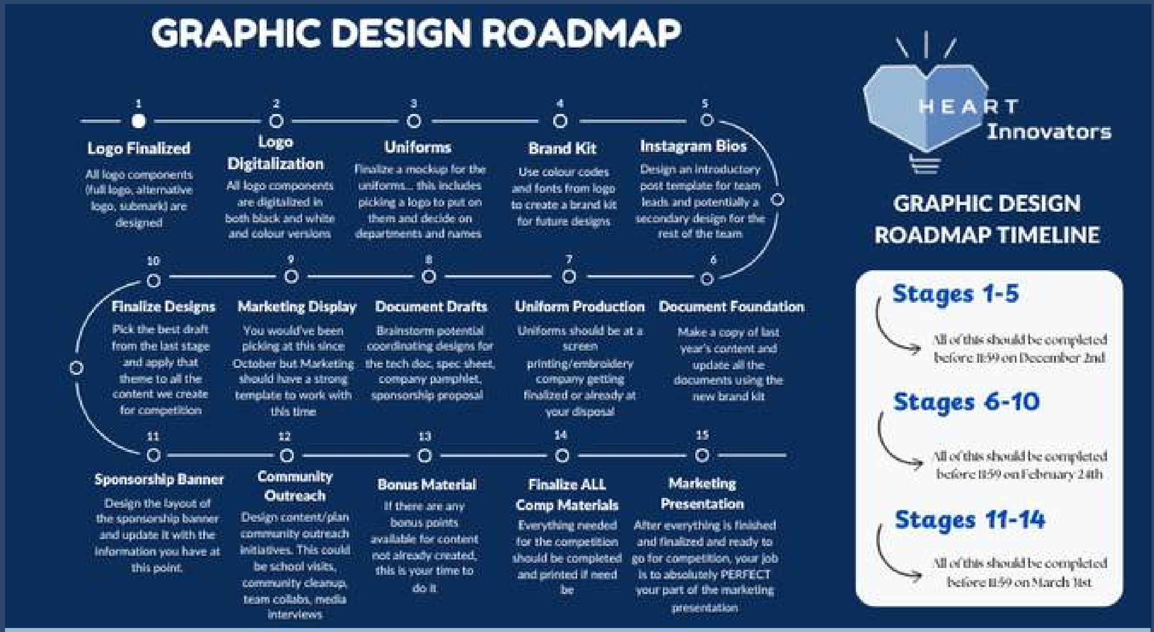

Figure 4. HEART Innovators Project Management Chart

3. Design Rationale

At HEART Innovators, we're driven by more than technical excellence. What sets us apart is our emphasis on collaboration and inclusivity. Our team members actively contribute their unique skills and perspectives, creating an environment where creativity thrives. Together, we aim to make a measurable impact—both locally and globally—by combining cutting-edge technology with a deep commitment to historical conservation. Our submersible ROV isn't just advanced technology; it's a tool for tackling critical issues like shipwreck preservation, exploration and mapping .

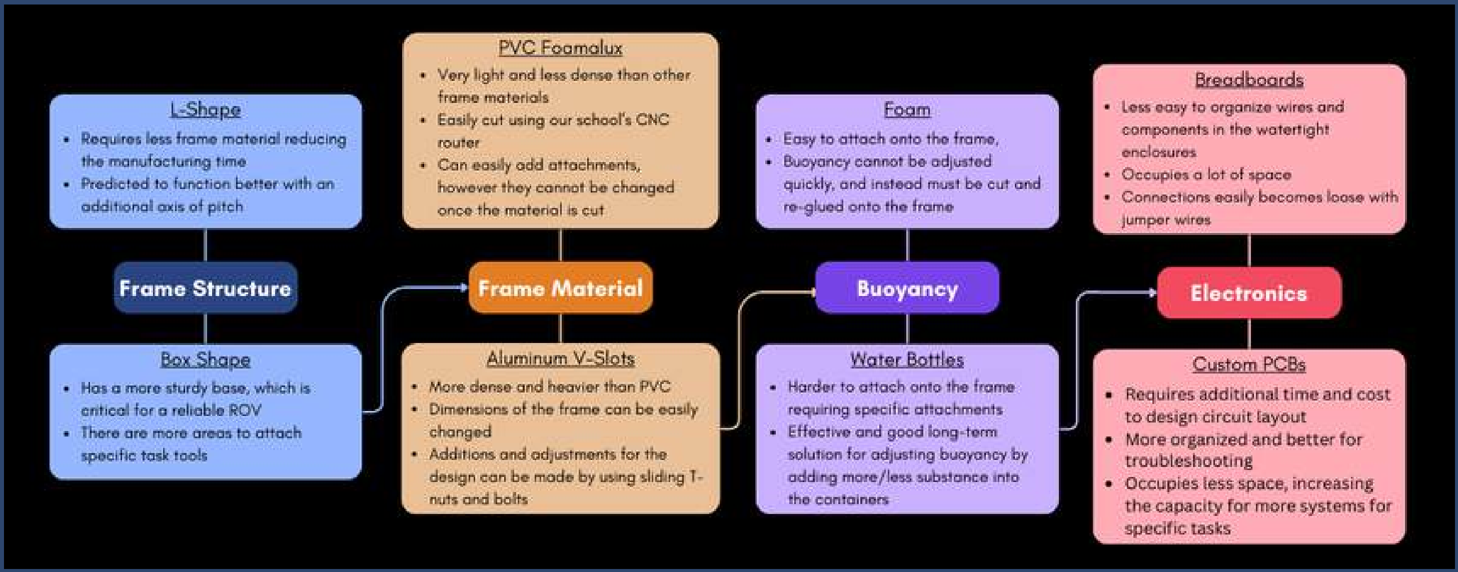

Figure 5. 2025 Design Decision Matrix

3.1 Design Overview

Figure 6. HEART Innovators' ROV, CAPTAIN

Figure 7. HEART Innovators' Float, SAILOR

At HEART Innovators, innovation is not just a feature—it's a philosophy embedded into every phase of our design, from initial concept to final deployment. Throughout the 2025 season, we focused on creating cost-effective, high-functioning systems by iterating on past designs, engineering new solutions, and maximizing in-house resources.

A. Vehicle Design

HEART Innovators' 2025 ROV, CAPTAIN, was engineered through a deliberate, iterative design process rooted in functionality, safety, modularity, and mission alignment. The overall design integrates mechanical, electrical, and software systems in a compact, lightweight frame capable of executing complex tasks in dynamic underwater environments.

Our design journey began with a critical analysis of last year's vehicle, identifying key limitations in buoyancy balance, maneuverability, and frame adaptability. These findings shaped our design priorities and informed a structured development plan that included CAD modeling, in-house prototyping, and repeated pool testing at the Marine Institute.

The vehicle's modular frame is built from anodized aluminum V-slot extrusions, providing a durable yet adaptable platform that supports mission-specific tools such as a pneumatic claw, dual-syringe sampler, and a wide variety of high-resolution cameras. These tools are complemented by an electronics enclosure optimized for waterproofing, onboard sensors for real-time monitoring, and a powerful propulsion system composed of six Blue Robotics T200 thrusters. Our Raspberry Pi-based control system powers CAPTAIN, utilizing sensors and cameras through a custom PCB and newly developed GUI.

Each design decision was made with thoughtful trade-offs, balancing performance, cost-efficiency, sustainability, and ease of repair. The result is a robust, mission-ready ROV that reflects our team's commitment to engineering excellence and environmental responsibility.

B. Innovation

HEART Innovators prioritized practical innovation to enhance CAPTAIN's performance while minimizing costs. A major improvement includes the shift to a modular V-slot aluminum frame, replacing last year's PVC-based structure. This allowed for rapid prototyping, easier integration of tools, and reduced material waste. Custom 3D-printed mounts enabled the seamless addition of mission-specific tools like our dual-syringe water sampler and IP20-compliant thruster shrouds—boosting safety and task performance at minimal cost.

We also developed a pneumatic claw composed of six 3D-printed components, engineered for precision and compactness in high-dexterity tasks. On the software side, our in-house Graphical User Interface unified control of both the ROV and our float, SAILOR, streamlining mission execution and removing reliance on third-party tools.

By leveraging open-source hardware, additive manufacturing, and internal software development, HEART Innovators delivered a high-performance, modular system that's adaptable, cost-efficient, and competition-ready.

Figure 8. Innovative Solution
(Water Bottle Bouyancy System)

C. Problem Solving

At HEART Innovators, problem-solving is an iterative and data-driven process rooted in collaboration. At the start of the season, our company initiated structured brainstorming sessions where members from all departments contributed ideas to address challenges from the previous year—particularly buoyancy issues, component modularity, and maneuverability. Using a shared whiteboard system and department-based task logs, we generated a list of potential improvements and solutions. To evaluate design alternatives, we conducted trade studies comparing materials like our PVC derivative, Fomalux, (used in our 2024 ROV) with anodized aluminum extrusions. We tested these materials for weight, ease of modification, strength, and environmental resistance. Data from submersion tests and performance simulations informed our decision to transition to a V-slot aluminum frame. This frame provided the necessary rigidity while remaining lightweight and allowed for flexible mounting options using standardized connectors. Throughout the process, all decisions were guided by performance metrics, team experience, and the mission requirements. By fostering an open forum for ideas and evaluating each alternative with logic and evidence, HEART Innovators developed a high-functioning ROV tailored for both the competition and real-world underwater tasks.

Figure 9. Problem Solving

D. Sourcing Decisions

HEART Innovators approached sourcing with a focus on functionality, sustainability, and cost-effectiveness. Our team made strategic decisions about which components to build in-house and which to purchase, balancing mission requirements with available resources and time constraints. We reused several high-performing components from previous seasons, including the Blue Robotics watertight electronics tube, thrusters, and control units. This decision reflects our sustainability philosophy of reducing waste and ensuring reliability with proven parts. However, we also upgraded where necessary. For example, integrating new 14-gauge power cables and developing a custom PCB to streamline wiring and reduce the risk of disconnections. Our tooling strategy also reflected this balance. Mounting brackets, thruster shrouds, and the claw mechanism were designed and 3D-printed in-house to maintain precision while minimizing external expenses. Prefabricated joints and structural sliders were sourced commercially to save labor and ensure durability. These sourcing decisions allowed us to meet mission objectives, control costs, reduce environmental impact, and maintain a high level of customization and performance in our ROV—all while building our technical skills and taking ownership of the engineering process from concept to deployment.

Figure 10. HEART Sourcing Decisions

3.2 Vehicle Structure and Systems

A. Systems Approach

Our team employed a systems-based approach to ensure all subsystems functioned seamlessly together. The frame, sensors, tether, and claw were co-developed with a focus on functionality, accessibility, and mission effectiveness. Close collaboration across departments ensured that each component complemented the others, resulting in a cohesive, high-performing ROV design.

B. Vehicle Systems

Both of CAPTAIN's physical and electronic systems were chosen specifically to meet the needs of this year's competition requirements and tasks. For instance, we decided to improve our camera systems, as we realized there were many precise movements and actions required. Cameras were specifically placed to give our pilots the best views to complete the tasks required; the FPS and resolution of the cameras were also improved for more effective piloting and viewing of the surrounding environment. Our physical systems, primarily our frame, were also specifically improved; constructing our frame out of V slot aluminum allows for easier mounting of tools used for mission tasks, all with a common mounting apparatus. The purchase of the aluminum is also an investment for future years, as the extra aluminum can be used in the construction of future ROVs.

C. Vehicle Structure (Frame)

The frame is designed as a rectangular prism supported by four 10 cm legs, creating space beneath it for a downward-facing camera to focus on specific tasks. Constructed from aluminum, the frame benefits from a higher density compared to alternative materials. This allowed us to calibrate buoyancy more effectively by increasing flotation at the top rather than adding weight below, resulting in greater underwater stability and improved control of CAPTAIN's movements. The anodized aluminum provides excellent durability and corrosion resistance, protecting the frame from rust and long-term wear. Additionally, the use of V-slot bars enables easy attachment of thrusters, mounts, tools, and custom 3D-printed components, allowing for efficient upgrades and modifications.

Figure 11. Picture of Frame

D. Propulsion

CAPTAIN is equipped with six T200 thrusters from Blue Robotics, each capable of delivering approximately 3.7 kilograms of forward thrust. These thrusters were selected for their high reliability, robust performance, and precise control capabilities. Their power output is seamlessly controlled through an advance vectorized configuration and is then displayed on our custom-developed Graphical User Interface (GUI). This acts as a bridge between the user and the control code—enabling real-time adjustments to speed and voltage. The thrusters are strategically positioned to give CAPTAIN smooth, responsive movement in all six degrees of freedom, including control in all axes of movement.

Figure 12. Thruster Diagram (1.)

E. ROV Software

CAPTAIN's software is divided into two main codebases: topside and ROV-side. The topside code handles the primary graphical user interface (GUI) and overall control of the ROV. It displays real-time sensor data, camera feeds, thruster outputs, and includes interactive buttons for managing various subsystems. Key features of the topside software include an automatic balancing system, advanced vector-based thruster control, sensor integration, a software management system, and a float manager. These components are all integrated into the GUI, streamlining both development and debugging. On the ROV side, the software primarily uses a UDP socket to transmit and receive sensor data between the vehicle and the topside controller. The entire software stack is written in Python and leverages PySide6, including its built-in Designer tool, to efficiently build and update the user interface.

Figure 13. ROV Graphical User Interface

Figure 14. Float Graphical User Interface

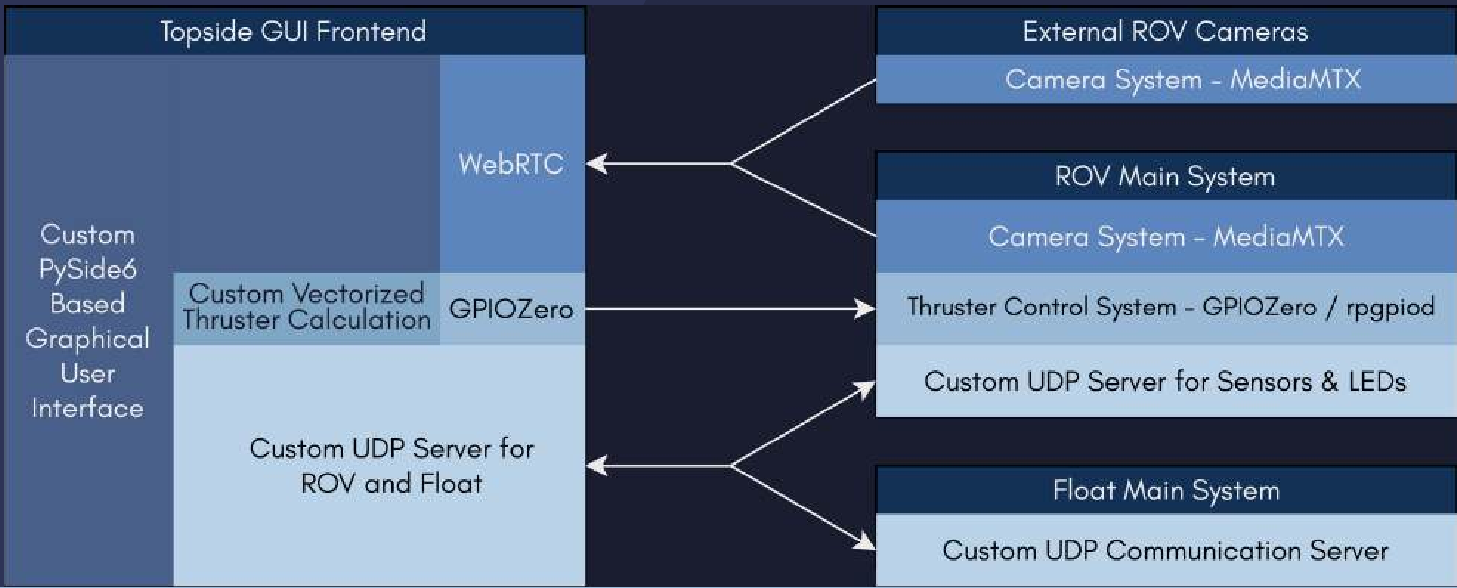

Figure 15. Software Flowchart

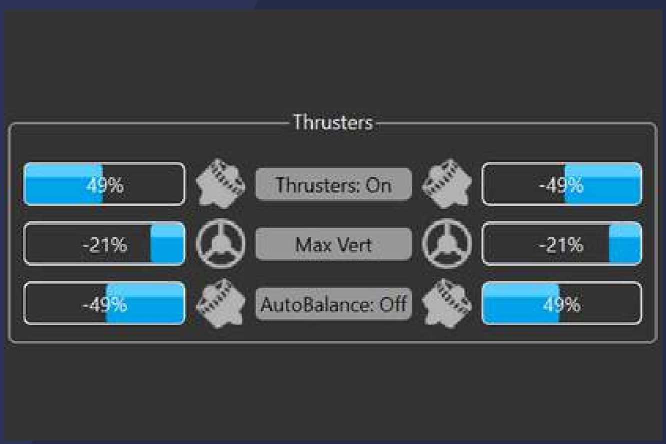

Figure 16. Thuster Values

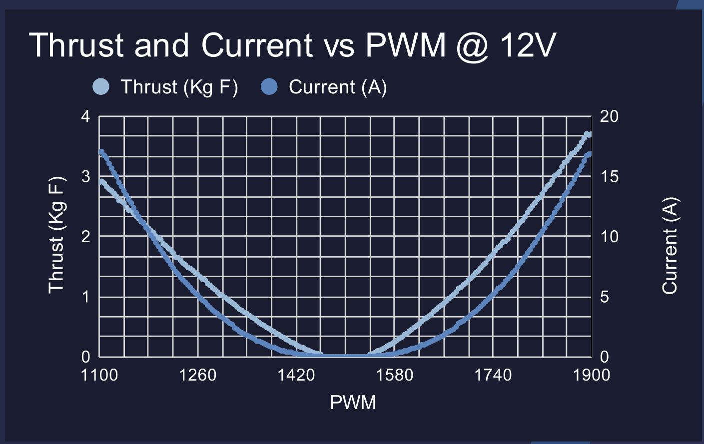

Figure 17. Thruster Thrust vs Current (2.)

F. Buoyancy and Ballast

We recently upgraded CAPTAIN's buoyancy and ballast system from basic foam blocks and frame-mounted weights to a more adaptable setup using multiple balast tanks mounted to the frame. These tanks can be filled with varying amounts of air or water, allowing us to fine-tune buoyancy with greater precision. This system enables quick, on-the-fly adjustments—especially useful when adding tools or payloads during task execution. By calculating the required water volume for neutral buoyancy in advance, we can prepare the exact ballast needed and make rapid adjustments on deck, ensuring CAPTAIN remains stable and easy to pilot at all times.

$$F_{net} = F_g - F_b = m_{bottle} a_{max}$$
$$m_{bottle} g - \rho_{water} V_{bottle} = m_{bottle} a_{max}$$
$$a_{max} = \frac{\rho_{water} V_{bottle} g - m_{bottle} g}{m_{bottle}}$$
$$a_{max} = \frac{1000kg/m^3 \times 0.00591m^3 \times 9.81N/kg - 0.3kg \times 9.81N/kg}{0.3kg}$$
$$a_{max} = 9.5157 m/s^2 \text{ per bottle}$$
$$F_{ROV} + (\#bottle)F_{bottle} = 0$$
$$F_{ROV} =- (\#bottle)F_{bottle}$$
$$F_{ROV} =- (\#bottle)m_{bottle} a_{max}$$
$$F_{ROV} =- 9.5157(\#bottle)m_{bottle}$$

Figure 18. Buoyancy Calculations

3.3 Electrical and Control Systems

A. ROV Electronics

CAPTAIN's electronics system was designed with functionality, modularity, expandability, and ease of maintenance in mind. At its core is a Raspberry Pi 4B, which manages communication between the ROV and the topside controller, primarily handling the transfer of sensor data. To support multiple components, we developed a custom PCB specifically tailored to our ROV's requirements. The board includes i2C ports for sensor connections, eight PWM outputs for thrusters or servos, dedicated power ports, and a GPIO breakout section to support future expansion. For ease of use, we incorporated a printed reference table and added our team's logo for branding. All electronics are housed within a watertight enclosure using Blue Robotics tubes, with cable entries sealed using epoxy-potted penetrators to ensure waterproofing and a clean, professional internal layout.

CAPTAIN's electronics are distributed across three acrylic tubes: two 150 mm tubes with 2-inch diameters, and one 300 mm tube with a 4-inch diameter. The larger tube contains the main components, including the Raspberry Pi 4B, electronic speed controllers (ESCs), network switch, main camera, power distribution system, and custom PCB. The smaller tubes house a modular camera system built on a Raspberry Pi Zero 2W paired with a Raspberry Pi Camera V3 Wide, providing significantly enhanced visual coverage for task execution.

Figure 19. 3D Render of CAPTAIN's Custom PCB

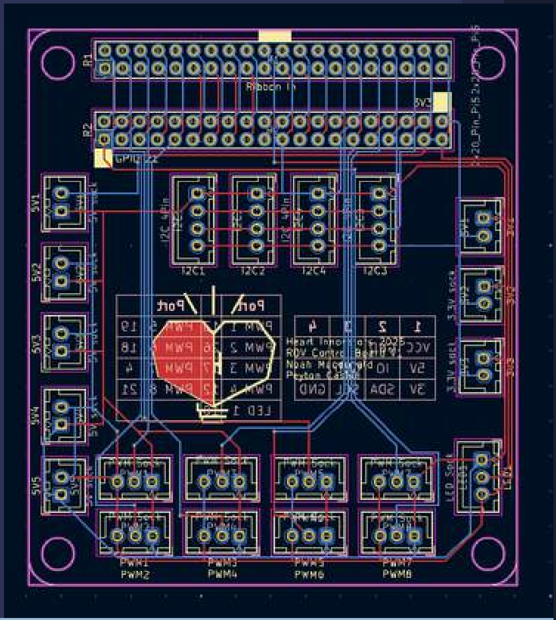

Figure 20. Custom PCB Layer View

With CAPTAIN's transition from USB based cameras to a multi-Raspberry Pi design we also reevaluated not just the cameras themselves but also their topside connection, this led us to choosing standard Gigabit Ethernet as it provided the best speed with minimal costs and no extra required hardware. With this transition we also added a Gigabit Ethernet switch to facilitate the 3 required Ethernet connections, this also allows us to further expand our ROV without adding extra cables within our tether.

	Max Speed	Required Twisted Pairs	Extra Hardware	Cost
Gigabit Ethernet	1000 Mbps	4	None	> $50
Fast Ethernet	100 Mbps	2	None	> $50
BR Fathom-X	60-80 Mbps	1	Media Converters	$300-350
Automotive Ethernet	1000 Mbps	1	Media Converters	$150-250

Figure 21. Networking Spec Comparison

B. Tether

CAPTAIN's tether consists of three main components: a waterproof CAT6 Ethernet cable, two 14-gauge power wires, and three pneumatic tubes. The Ethernet cable establishes a reliable data connection between the ROV's onboard electronics and the topside router, ensuring efficient communication and video streaming. The 14-gauge wires deliver power from a 12V power supply to the ROV's electrical systems, while two of the pneumatic tubes provide pressurized air to operate the pneumatic claw. The third pneumatic tube feeds air to the water sampler, allowing the syringes to retract. To maintain organization, reduce drag, and minimize the risk of entanglement or tripping hazards, the entire tether is enclosed in a durable mesh sheathing.

Figure 22. CAPTAIN's Tether

C. Controller

For the CAPTAIN control system, we selected the 8Bitdo Pro 2 wired controller due to its enhanced functionality, reliable wired communication, and long-term durability. Unlike many standard controllers, the 8Bitdo Pro 2 offers extended hardware support through readily available replacement parts, aligning with our commitment to reducing electronic waste and increasing system longevity.

	Voltage Drop
I = 25A	V = IRL
R = 0.008286Ω/m	V = (25)(0.008286)(16)
L = 16m	V = 3.31V Drop

Figure 23. Voltage Drop Calculations

Figure 24. ROV Controller

3.4 Payload and Tools

A. Camera System

CAPTAIN's scalable digital camera system was completely redesigned to improve performance, efficiency and cost-effectiveness. This new system delivers industry-leading performance of 1080p at 30 FPS live video with less than 40 milliseconds of latency, achieving more than 20x latency reduction compared our previous system.

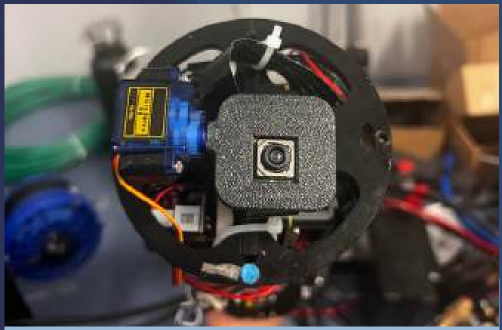

Figure 25. CAPTAIN's Front Camera.

HEART Innovators developed two innovative camera systems to meet the contract requirements. One design incorporates a traditional primary camera, housed within the acrylic dome of a Blue Robotics tube. The other is our groundbreaking independent camera module system.

CAPTAIN's primary camera is based around the Raspberry Pi Camera Module V3 Wide, powered by the onboard Raspberry PI 4B, this setup allows for a 120 degree field of view and it includes a servo motor allowing for CAPTAIN's pilot to adjust the camera for an enhanced view of the ROV's surroundings.

Figure 26. CAPTAIN's independent camera module.

CAPTAIN's auxiliary cameras are built using the same Raspberry Pi Camera Modules as our primary camera paired with an independent Raspberry Pi Zero 2W. These cameras are housed within Blue Robotics 2-inch Acrylic tubes, offering enhanced expandability. Unlike traditional USB or legacy IP based solutions our auxiliary cameras provide the same 1080p resolution at 30 FPS with less than 40ms of latency as CAPTAIN's primary camera.

CAPTAIN's camera layout was chosen to help provide a level of depth-perception not traditionally possible with 2D camera systems, allowing for more precise navigation and manipulation.

The independent and modular nature of the camera modules provides an adaptable camera system that can be tailored to the exact contract requirements, allowing CAPTAIN to be used in a variety of diverse environments and situations.

B. Manipulator

The manipulator is composed of 6 3D-printed components, and has 6 joints held together with M3 bolts. The claws interlace, allowing them to hold cylindrical objects of varying sizes as well as narrow objects such as ropes. Rotation of the manipulator to a vertical position may be achieved via the rolling of the ROV using the middle thrusters. The mount is angled slightly downwards to allow reach below the frame.

CAPTAIN's manipulator is powered by pneumatics, which allows us to move and adjust props during the company product demonstration. It is also easily interchangeable with other modifications to be a better fit for other tasks. We decided to keep the same manipulator as last year as it performed well, working with adequate force and reliability.

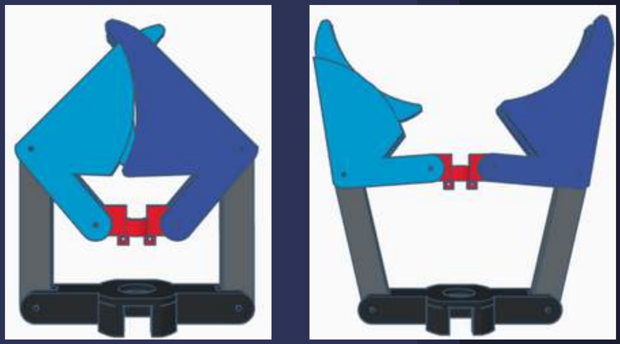

Figure 27. Manipulator CAD

C. Tools

i. Water Sampler System

CAPTAIN is outfitted with a custom-designed water sampling mechanism used to collect data for environmental monitoring, including pH levels, dissolved carbon dioxide, and environmental DNA (eDNA) for tracking invasive species. The system consists of a dual-syringe apparatus mounted on the ROV, connected to the surface via a pneumatic line. Initially, both syringes remain in the closed position. When compressed air is introduced from the surface, it drives the syringes to retract, drawing in a water sample. Upon surfacing, the syringes are manually compressed to expel the collected sample for laboratory analysis—offering a simple, low-impact method to assess water quality and ecosystem health.

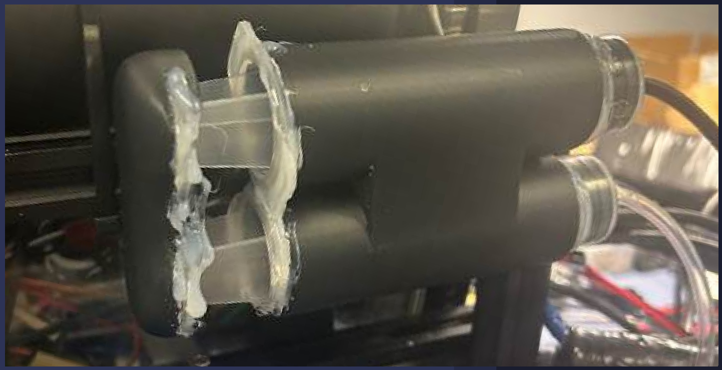

Figure 28. Water sampler

Figure 29. Analyzing eDNA

ii. Sacrificial Anode Replacement Mechanism

To streamline the process of removing and replacing the sacrificial anode on the offshore wind farm's base structure, we engineered a specialized tool that eliminates the need for complex ROV maneuvering. This device allows the anode to be rotated into and out of position without requiring CAPTAIN to twist or reposition itself—reducing task completion time and improving precision. The mechanism, which mounts securely to CAPTAIN using custom 3D printed components, incorporates a 70kg/N waterproof servo motor, enabling remote actuation of the rotational motion required to disengage and secure the anode with ease.

Figure 30. Sacrificial Anode Mechanism

D. Onboard Sensors

CAPTAIN is equipped with 5 onboard sensors for monitoring the aquatic environments and monitoring the ROV itself, these sensors include an accelerometer, gyroscope, voltmeter, ammeter and thermometer. CAPTAIN's accelerometer and gyroscope allow us to get the real-time motion and rotation information which we use for our custom auto-balancing system. The balancing system uses the accelerometer's raw values combined with simple trigonometry, the rotation of the ROV can be found. This value is then feed into the system to power the thrusters. CAPTAIN's power measurement module, which includes the voltmeter and ammeter, allows us to calibrate and optimize the per-thruster power usage to dynamically provide different power limits to achieve greater speeds and improve navigation. CAPTAIN's temperature sensor lets us do real-time monitoring of the aquatic environments around the ROV.

To send the sensor data from CAPTAIN to our topside GUI we developed a custom UDP based server protocol to help simply sending and receiving data with the ROV.

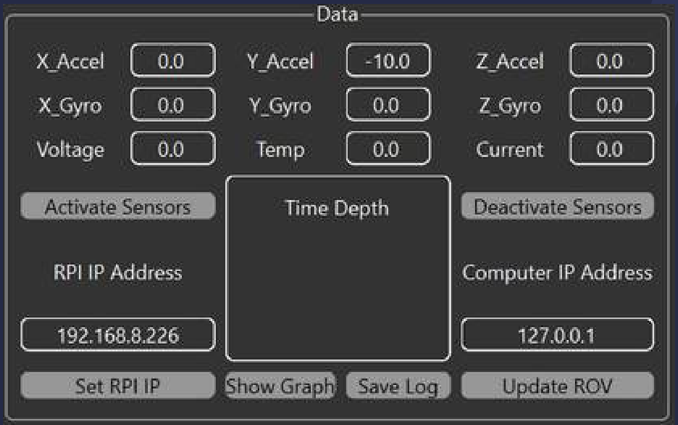

Figure 31. CAPTAIN's Sensors

	UDP	MQTT	TCP	REST API
Complexity	Low	Medium	Medium	High
Software Complexity	Very Low	High	Medium	High
Reliability	Medium	Medium	High	High
Scalability	Medium	Very High	Medium	High

Figure 32. Network Protocol Comparison

E. Vertical Profiling Float

SAILOR (Sea Assistance Instrument for Logistics and Oceanic Research), Heart Innovators' Vertical Profiling Float was redesigned from the ground up to improve performance, maintenance and reliability.

SAILOR is equipped with a buoyancy engine driven by a NEMA 17 stepper motor and is controlled by a Seeed Studio Xiao ESP32-S3 Microcontroller. This setup allows us to complete the vertical profile, collect the depth data and communicate with our topside software to meet the contract requirements

SAILOR communicates over 2.4 GHz Wi-FI as it provides the most seamless integration with our existing systems and is a much more mature protocol compared to LoRA, BLE, Thread or Wi-FI HaLow.

	Wi-FI	BLE	Thread	LoRA	Wi-Fi HaLow
Frequency	2.4 GHz	2.4 GHz	2.4 GHz	433 / 900 MHz	900 MHz
Power Use	High	Medium	Low	Low	Low
Preformance	High	Low	Medium	Medium	Unknown
Range	Low	Medium	Medium	Very High	Very High
Complexity	Low	Medium	High	Medium	Unknown
Reliability	Medium	Low	Medium	High	Unknown
Cost	Low	Low	Medium	Medium	High
Hardware Requirements	Low	Low	Medium	Medium	High

Figure 34. Wireless Protocol Comparison

Figure 33. SAILOR

To integrate support for the Blue Robotics Pressure sensor Heart Innovators has developed a custom port of Blue Robotic's i2C driver for use with CircuitPython. This allows for greater alignment across internal codebases and improves long-term maintainability. The driver along with our firmware code have been publicly released on our GitLab to support and contribute to the broader hobbyist robotics community.

SAILOR's battery pack consists of 8 AA nickel-metal hydride (NiMH) batteries wired in series, delivering a max voltage of 9.6 volts. This battery pack is then protected by the onboard, user-serviceable 5 amp fuse.

SAILOR's onboard RGBW light system was inspired by the lighthouses present in both Alpena, Michigan and Newfoundland, such as the Alpena light and the Cape Spear Lighthouse. The onboard lighting system not only provides a visual indication of its presence but also diagnostic information, allowing for SAILOR to communicate even when traditional radio options aren't possible.

4. Safety

A. Safety Philosophy & Protocols

At HEART Innovators, safety is a foundational pillar of our company culture and engineering practice. From design to deployment, we prioritize the well-being of our team members and the integrity of our work environment. Our approach to safety includes stringent on-deck protocols, built-in safety design features, proactive hazard mitigation, and formal training procedures.

On-deck safety is essential to daily operations, particularly when working with power tools and electrical systems. All team members adhere to established safety protocols, including but not limited to:

- Tying back long hair
- Wearing closed-toed, slip-resistant footwear
- Keeping work areas free from tripping hazards

Our Safety Officer is responsible for enforcing these protocols and ensuring the use of appropriate personal protective equipment (PPE). Every member is trained to safely handle equipment and operate within the designated workshop environment.

Our team also conducts a standardized pre-deployment safety checklist **(see Appendix A)** which includes system checks, tether management, and waterproofing confirmation.

B. Vehicle Safety Features

Safety extends into our vehicle design, where we implement multiple layers of protection to minimize risk. Key examples include:

- Sanded Edges: All sharp edges on the ROV frame are either sanded smooth or covered to reduce the risk of cuts and abrasions during handling and transport.
- Watertight Electronics Housing: CAPTAIN's electronics are securely contained within a Blue Robotics tube, sealed with multiple O-rings and locking flanges. To further protect against leaks, all cable pass-throughs are potted with epoxy.
- Thruster Protection: All thrusters are enclosed in custom 3D-printed shrouds that meet IP20 safety standards, reducing the risk of contact with moving parts. High-visibility caution labels serve as visual reminders around these areas.

C. Emergency Preparedness and First Aid

To further enhance workplace safety, five members of HEART Innovators are certified in Standard First Aid, Aquatic Emergency Care, and Mental Health First Aid. These individuals are identifiable by green crosses on their team name tags. Their training ensures that we are prepared to respond swiftly and effectively in the event of an injury or emergency during both pool tests and competition activities.

5. Accounting

A. Build vs Buy, New vs Reused

When designing this year's ROV, CAPTAIN, our team conducted a comprehensive evaluation of all available components with the goal of balancing performance, cost-effectiveness, and environmental responsibility. A key part of this process involved weighing the advantages of reusing existing parts versus sourcing entirely new materials. Reused components, such as our T200 thrusters, offered proven reliability from past seasons, significantly reducing both financial costs and material waste. This decision also aligned with our core sustainability philosophy, which emphasizes upcycling: extending the life of components by repurposing them for new, mission-specific roles.

This approach allowed us to make the most of our available resources while promoting circular engineering practices, reducing the demand for new raw materials and lowering our overall environmental footprint. For components that no longer met performance standards or where enhanced capabilities were necessary, such as the USB extender, we made targeted investments in high-efficiency, precision-manufactured alternatives. These upgrades were chosen not only for their improved performance, but also for their potential to be reused in future builds, supporting long-term sustainability and reducing waste.

Throughout the design and build process, each decision to reuse or replace was informed by rigorous testing, reliability assessments, and an eye toward longevity. By prioritizing thoughtful resource allocation and intentional design, HEART Innovators was able to deliver a high-performing ROV that embodies our values of innovation, reliability, and environmental stewardship—demonstrating that high-quality engineering can also be sustainable.

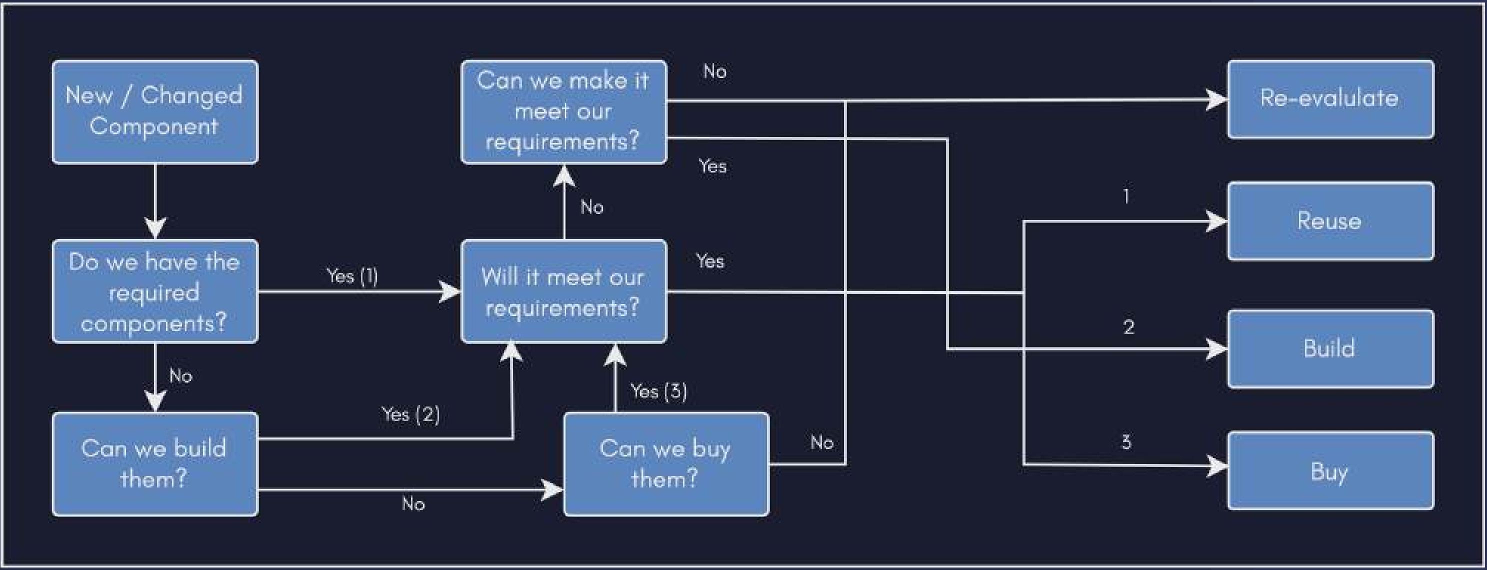

Figure 35. Build vs. Reuse vs. Buy Decision Matrix

B. Budget

HEART Innovators maintains a carefully planned and responsibly managed budget to support the development, outreach, and travel for our project. Our funding comes from regional event support, local sponsorships, community donations, and team-led fundraising efforts. One of our ongoing initiatives is a school-wide recycling program, which not only promotes environmental conservation but also generates profits that directly support our company. For the 2024-2025 season, our total operating budget is $40,000.00. This amount covers materials and components, travel expenses, marketing assets, and outreach activities. We allocate funds strategically to ensure that each department—from software to marketing—has access to the resources they need to succeed.

Our Chief Operating Officer (COO) collaborates closely with our teacher mentor and the marketing department to oversee expenditures, assess cost-efficiency, and ensure that all funds are being used effectively. This partnership enables us to make informed financial decisions that align with both our technical requirements and experimental learning goals.

C. Project Costs

To build and maintain our ROV, CAPTAIN, HEART Innovators tracks all expenses carefully across departments to ensure transparency and sustainability. We categorize our spending by system and function, ensuring each component of the ROV meets our performance goals while remaining cost-effective. Below is a breakdown of the expenses involved in the construction, operation, and promotion of our ROV and related projects.

To remain economically responsible, we aim to reuse components from past builds wherever possible, and we actively seek out cost-effective suppliers to avoid compromising on quality or safety. These strategies allow us to stay within budget while continuing to innovate.

Please refer to Appendix B for a detailed breakdown of all project-related expenses this year.

Category	Cost
Electronics	$269.88
Frame	$107.39
Custom Components	$93.27
Pneumatics	$104.82
Float	$514.57
Travel & Competition Fees	$32,000
Marketing & Branding	$1,540

Figure 36. Project Costs Among Project Systems and Categories

6. Critical Analysis

Throughout the 2024-2025 season, HEART Innovators engaged in an intensive cycle of testing and troubleshooting to prepare our ROV, CAPTAIN, for real-world mission performance. From initial prototypes to final deployment, we conducted thorough evaluations focused on buoyancy, maneuverability, tool function, and systems integration under simulated competition conditions.
A core component of this process involved repeated trials at the Marine Institute's aquatic testing chamber. These sessions allowed us to fine-tune both hardware and software in a controlled, yet realistic environment. One of the most significant obstacles we faced during this phase was a persistent leak in the watertight electronics enclosure—a failure that demanded detailed, methodical problem-solving.

Our team initially suspected material compatibility and reverted from a high-density polyethylene (HDPE) backplate to the original aluminum one, hoping to isolate the source of the leak. When this proved ineffective, we proceeded to re-grease and reseal all O-rings, re-tighten all mounting bolts, and rework the front plate assembly. After eliminating several possibilities, we identified the root cause: a failure in the epoxy potting compound used to seal our cable penetrations. Over time, the epoxy had degraded, compromising the enclosure's watertight integrity.

Resolving this issue not only restored system reliability but also gave us deeper insight into long-term sealing solutions and material behavior under pressure. Rather than discard the HDPE component, we creatively repurposed it in the construction of our float module, SAILOR, where its lightweight strength and customizability were ideally suited.

This pivot underscores our team's adaptability and commitment to resourceful, sustainable engineering. More broadly, the experience highlighted the value of cross-departmental collaboration, systematic diagnostics, and iterative testing. These lessons strengthened our ability to deliver a mission-ready ROV that aligns with the technical precision and environmental focus central to the 2025 MATE ROV Competition.

Figure 36. Troubleshooting in the Marine Institute

Figure 37. SAILOR's HDPE Backplate

7. Conclusion

A. Acknowledgements

HEART Innovators respectfully acknowledges the island of Newfoundland as the traditional unceded homeland of the Mi'kmaq and the Beothuk. HEART Innovators is appreciative of MATE, along with MATE II, the National Science Foundation, Oceaneering International, Ocean Infinity, and Reach the World for their continued support of the MATE competition and for providing this incredible educational opportunity. Finally, we thank the Marine Institute for giving testing opportunities as well as Holy Heart for providing an environment for STEM learning. We'd also like to send our appreciation to Harvey's Home Heating, MATE II, and the Schmidt Ocean Coalition for their generous stipends to aid our travel to the World Championships.

We would like to acknowledge the following for contributing to the success of our company:

- Holy Heart of Mary High School, thank you for providing us with the meeting and laboratory space we needed to turn our ideas into reality. Your encouragement and resources have been invaluable.
- Our incredible HEART Innovators Mentor, Cole Murphy, your time, experience, dedication, and knowledge have been transformative for our team. Your patience and commitment fostered an environment where learning and fun go hand in hand, and we are so grateful for your guidance.
- Our families, we extend our heartfelt gratitude for your unwavering support, encouragement, and understanding. Your belief in us and guidance helped us stay motivated and focused on our goals.
- We would also like to thank our sponsors for their generous contributions, which made it possible for us to participate in competitions, acquire materials, and take on exciting challenges. Your support fuels our growth and innovation.
- The teachers and staff of Holy Heart for sharing your expertise and cheering us on every step of the way.
- Our community and everyone who has encouraged us along the way, thank you for believing in the potential of young minds to make a difference. Your support reminds us of the power of teamwork and perseverance.

We are so proud to represent our school and community, and we look forward to continuing to grow and innovate together.

B. References

1. Figure 12: https://discuss.bluerobotics.com/t/better-vectored-thruster-assembly-configuration/4001
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8. Appendices

Appendix A: Operations and Safety Checklist

1. Pre-Deployment Safety & Systems Checklist

	Task	Details	Member Responsible
☐	**Visual ROV Inspection**	Check frame for cracks, stress points, and loose components	Team Lead (Ben Evans)
☐	**Tether Inspection**	Untangle tether; check for frays, exposed wires, and secure strain relief	Tether Manager (Frank Chen)
☐	**Thruster Check**	Ensure thrusters are secure and free from obstruction; test rotation	Pilot (Kenneth Le)
☐	**Electronics Dry Run**	Power off system; inspect control box for damage, corrosion, or moisture	Co-Pilot (Noah MacDonald)
☐	**Camera & Sensor Test**	Power on, verify video feed, lights, and sensor feedback	Pilot (Kenneth Le)
☐	**Buoyancy Check**	Confirm floatation is intact and balanced per mission specs	Pilot (Kenneth Le)
☐	**Safety Equipment Readiness**	Confirm fire extinguisher, first aid kit, and emergency plan are on site	Safety Lead (Abbey Janes)
☐	**Cable Management**	Route cables safely; verify all connectors are secure	Tether Manager (Frank Chen)
☐	**Role Assignment & Briefing**	Brief entirety of deck crew on safety/emergency protocols	Team Lead (Ben Evans)

2. Operational Protocol (During Mission)

	Task	Details	Member Responsible
☐	**Area Clearance**	Ensure deck is free from tripping hazards or unnecessary tools	Safety Lead (Abbey Janes)
☐	**No Wet Hands on Electronics**	All handling of control box must be with dry hands	ALL
☐	**Clear Launch Communication**	Call out "HANDS OFF, POWER ON" before submersion	Pilot (Kenneth Le)
☐	**Tether Monitoring**	Keep tether slack controlled, untangled, and visible	Tether Manager (Frank Chen)
☐	**No Contact Rule**	No hands in water or contact with ROV when powered on	ALL
☐	**Thermal Monitoring**	Observe control box for signs of overheating	Co-Pilot (Noah MacDonald)
☐	**Continuous Feedback**	Maintain verbal updates from Pilot to Co-Pilot and Team Lead	Pilot & Co-Pilot (Kenneth Le & Noah MacDonald)
☐	**Real-Time Logging**	Record mission malfunctions, or incidents	ALL

3. Post-Deployment & Maintenance Checklist

	Task	Details	Member Responsible
☐	**Power Down**	Disconnect battery and power supply safely	Co-Pilot (Noah MacDonald)
☐	**ROV Cleaning & Drying**	Towel dry all components; check for trapped water or sediment	Team Lead (Ben Evans)
☐	**Component Inspection**	Look for damage to thrusters, frame, sensors, tether	ALL
☐	**Debriefing Session**	Review mission outcomes, safety concerns, team feedback	Team Lead (Ben Evans)
☐	**Incident Reporting (if needed)**	Complete incident form and log any injuries or safety risks	Safety Lead (Abbey Janes)

4. Emergency Protocols

Electrical Hazard / Short Circuit

Action: Immediately shut off the power source.
Response Team: Co-Pilot (Noah MacDonald), Safety Lead (Abbey Janes)
Equipment Used: Insulated gloves, fire extinguisher

Water Intrusion or Submersion of Control Unit

Action: Power off system; remove unit from water; dry thoroughly.
Do NOT attempt to power on until cleared by Team Lead (Ben Evans).

Injury / First Aid Incident

Action: Contact certified first aid employee (Abbey Janes, Frank Chen) and alert an adult supervisor immediately.
Use: First Aid Kit; document using Incident Report Form.
Response Team: First Aid Certified Employees (Frank Chen, Abbey Janes)
Equipment Used: First Aid Kit

Drowning

Action: Call for certified lifeguard on deck (Frank Chen) by yelling "DROWNING EMERGENCY", ensuring the nearest adult supervisor is notified.
Response Team: Certified Lifeguard (Frank Chen), Safety Lead (Abbey Janes)
Equipment Used: First Aid Kit, AED

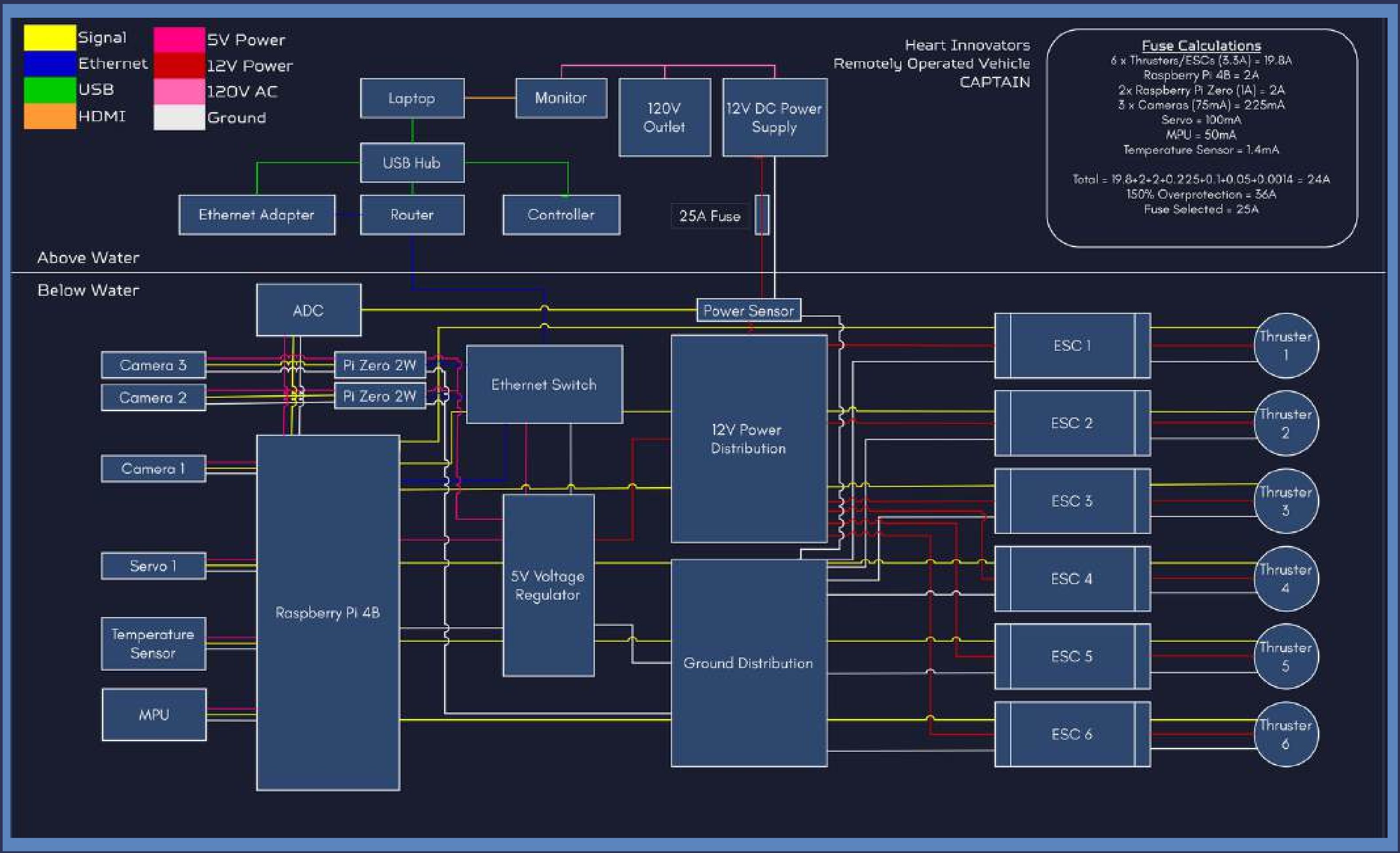
Appendix B: Project Costs

Item	Unit Cost (USD)	2025 Cost (USD)
Blue Robotics 100mm Enclosure	$300.01	Reused
2 x 50mm Blue Robotics Enclosure	$104.32	$104.32
6 x T200 Thrusters	$1,108.39	Reused
6 x Blue Robotics ESC	$163.25	Reused
V Slot Aluminum Extrusions	$107.39	$107.39
8BitDo Pro 2 wired controller	$26.34	$26.34
5 port ethernet switch	$12.17	$12.17
2 x Raspberry Pi Zero 2	$45.09	$45.09
Ethernet/USB Hub Hat for Pi Zero	$37.22	$37.22
Raspberry Pi 4B (8gb)	$98.77	Reused
100ft 14 gauge wire	$21.40	$21.40
DC Motor Driver Board	$18.60	$18.60
8 x Rechargable NIMH Batteries	$21.18	$21.18
4 x 355ml Stainless Steel Bottles	$26.41	$26.41
2 x 130ml Stainless Steel Bottles	$21.39	$21.39
70kg 360° IP68 Brushless Servo	$45.41	$45.41

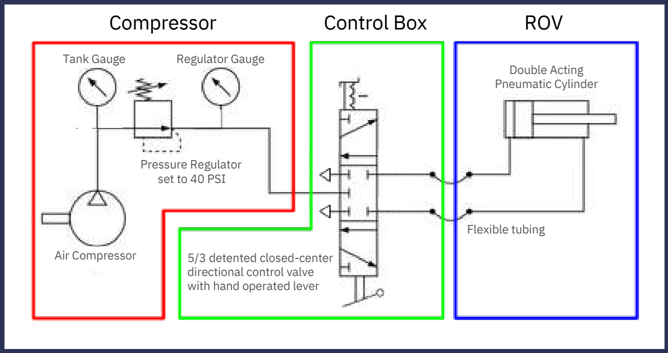
Appendix C: Travel Budget

Travel Expenses	Cost (USD)
Hotel (6 nights x 6 rooms)	$3,959.76
Car Rental (2 minivans)	$1,982.30
Flights (YYT-YYZ + return x 12)	$9,199.14
Gas (Estimated)	~$1,000
Total:	$15,141.20

Appendix D: ROV SID



Appendix E: Pneumatics SID



Appendix F: Float SID