MEMORIAL UNIVERSITY

eastern Edge

MI MARINE INSTITUTE

Memorial University St. John's
Newfoundland and Labrador

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Martha Snelgrove	COO
Jadzia Penney	CMO
Stefan Boon-Petersen	CTO - Electrical
Tim Squires	CTO - Mechanical
Russell Corbett	CTO - Software
Alex Kennedy	CSO
Zach Bennett	Electrical
Shane Tetford	Electrical
Logan Smith	Electrical
Winston Hoffman	Electrical
Cameron Shea	Electrical
Mark Johnson	Mechanical
Eric Goulding	Mechanical
Devon Tobin	Mechanical
Joshua Deering	Mechanical
Mike O'Connor	Mechanical
Bedir Acar	Mechanical
Sarthak Srivastava	Mechanical
Léo Gilbert	Software
Evan Vokey	Software
Aaron Oates	Software
Naomi Pierce	Software
Ethan Denny	Software
Jessie Ball	Software
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Abdul Turonov	Software
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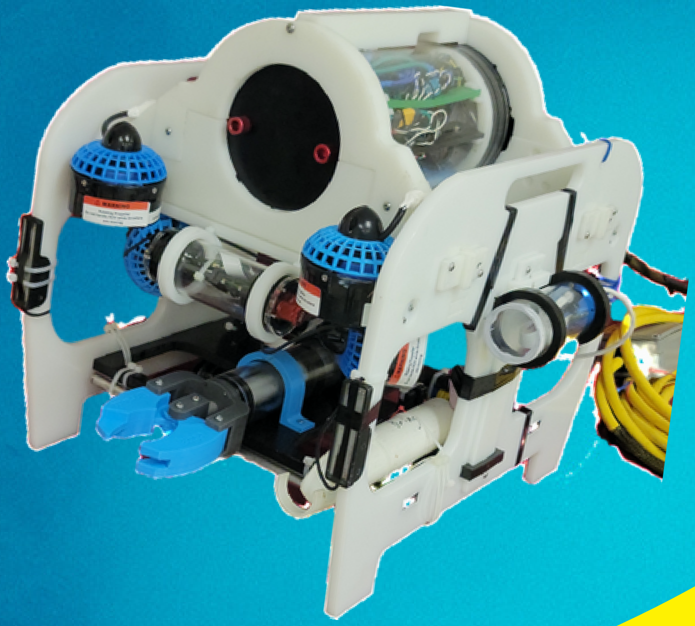


Abstract

Eastern Edge Robotics (EER) is a multi-disciplinary company based out of the Marine Institute in St. John's, NL. Twenty-seven employees concentrate on designing, manufacturing, and operating remotely operated vehicles (ROVs). With 21 years of experience and 19 requests for proposals (RFP), Eastern Edge has a foundation of knowledge built upon every year. For each new RFP, EER innovates a new ROV with a significant focus on sustainability and safety.

For the 2023 contract, Eastern Edge has developed a brand new ROV from the ground up.
ROV Caribou is designed to meet and exceed the requirements of the RFP. Caribou includes extensive safety features, a custom electrical system designed specifically for the ROV, multiple custom tools for the current RFP and more. Caribou is designed to operate in salt and freshwater environments and complete tasks such as maintenance of underwater renewable energy systems, surveillance of marine ecosystems and deployment of a vertical profiling float. Caribou weighs 21.65 kg and has a maximum size of 564 mm L x 405 mm W x 492 mm H. With a fair market value of $5,518.31, Caribou is a practical, low-cost solution to any underwater environmental needs.

Figure 1. Company Employees, Photos taken at the Marine Institute
(Back Row, L-R): Zach Bennet, Ethan Denny, Alex Kennedy, Léo Gilbert, Joshua Deering, Russell Corbett, Aaron Oates, Eric Goulding, Winston Hoffman, Mark Johnson
(Front Row, L-R): Abdul Turonov, Zaid Duraid, Shane Tetford, Logan Smith, Stephen Fudge, Jadzia Penney, Tim Squires, Jessie Ball, Martha Snelgrove
Missing: Stefan Boon-Petersen, Devon Tobin, Bedir Acar, Evan Vokey, Cameron Shea, Mike O'Connor, Naomi Pierce, Sarthak Srivastava, Gavin Hull

Table of Contents

I. Safety

A. *Safety Presentations*

At Eastern Edge, safety is our top priority. The company's Chief Safety Officer (CSO) gave multiple safety presentations to introduce new employees to the company's safety expectations and provide a refresher for returning employees. Topics covered in these presentations include: the use of Eastern Edge's custom safety documents; proper use of personal protective equipment (PPE); and emergency safety plans, such as instructions on handling an electrical fire. Our company cultivates an open safety culture, thus these presentations were also an opportunity for employees to participate in the creation of safety procedures and practices.

B. *Safety Passports*

A safety passport is a checklist of tools an individual is trained to use. Returning employees train new employees to use each tool, allowing the company to pass down continuous safety knowledge. The CSO then signs off on this training, adding the tool to the individual's safety passport.

C. *JSA's*

A Job safety analysis (JSA) is required to be completed before an employee begins a task that may be dangerous, such as soldering or computer numerical control (CNC) milling. They allow employees to determine a task's danger and encourage them to obtain proper safety equipment before the job begins. Each JSA is sent to the CSO directly so that they can review the data in case of a safety incident. In addition, an Operational Safety Checklist (OSC) outlined in Appendix A is required to be completed prior to starting any ROV operations by the deck crew. A Construction Procedure Checklist (CPC) can be found in Appendix B and is used to ensure correct assembly of the ROV following the completion of a JSA for the ROV assembly task.

D. *Incident Report Form*

Employees use the incident report form to report any incident that resulted in an injury (regardless of severity) or any "near-misses" if an injury was narrowly avoided. These forms contain:

- Information about the incident.
- Contact information for the injured employee and any witnesses (for investigation).
- Information on recovery time for the injury.

This information is intended only for the use of the CSO and is kept confidential to respect employees' privacy.

E. *Unsafe Work Refusal Form*

The unsafe work refusal form is a confidential form that employees can fill out if they are asked to complete a task they feel is unsafe. This form allows the CSO to investigate the job and determine if further action must be taken. In line with Eastern Edge's open safety culture, this ensures a safe working environment and a private way for employees to seek help if unsafe working conditions exist.

F. *Safety Procedures*

Caribou includes many safety features to ensure all employees can interact safely with the ROV. There are three different warning labels on the ROV itself: on the thrusters for moving propellers, the SubSeize for the pinch point, and the enclosure because it contains fibre. There are also labels for 120VAC on the topsides components, such as the laptop charger and the power supply cable. Caribou has thruster guards on the top and bottom of each thruster, designed to keep fingers and objects away from the blades and ensure that motion is not impeded. Employees thoroughly tested this design to ensure no employees could fit their fingers inside the gaps. The edges of Caribou have been dulled to ensure employees do not encounter any sharp edges when interacting with the ROV. Caribou has a strain relief system to ensure that when the ROV is lifted or moved there is no strain on the fibre optics tether. This system consists of a Carabiner attached to the tether and to ropes on either side that become tense when the tether is pulled on preventing tension on the tether. Within the software, emergency shut-offs have been implemented so the pilot can turn the ROV off immediately in the case of detected leaking or control issues. There is a button in the Graphical User Interface (GUI) and a button on the controller, both of which can be triggered by the pilot. There are automatic shut-offs when power or communication is lost written into the software.

Eastern Edge's top priority is employee safety. Therefore, two necessary protocols have been developed to ensure employees are safe when the ROV is in operation. One is the safety checklist; this exists within the GUI and must be completed to begin using the ROV. This checklist ensures:

- That the tether is neatly coiled in the figure-eight pattern for easy use and to protect the fibre.
- Those interacting with the ROV must ensure that the power switch starts in the OFF position.
- Deck crew must wear eye protection, a personal flotation device (PFD) and steel toe boots to use the ROV.
- Employees must check to ensure that the topside laptop is fully charged, and a charger is available.
- Employees shall identify any hazards that must be removed from the workspace and address these issues before work can begin.
- If an air compressor is being used, it must be checked to ensure that everything is connected correctly.

Once this list has been completed, the GUI can be accessed, and the ROV can be turned on. Once the ROV is in operation, the company uses a hands-on, hands-off procedure. When employees touch the ROV while it is powered, they say hands-on, and the pilot will let go of the controls; when employees finish with the ROV, they say hands-off so the pilot knows it is safe to begin flying the ROV.

II. Logistics

A. Company structure

For the 2023 contract, Eastern Edge has improved upon the dynamic structure used in the previous contract to maximize employee contribution and opportunities, as shown in Figure 2. Operations like scheduling, budgeting, and company management are performed by the Chief Executive Officer (CEO) with the assistance of the Chief Operations Officer (COO). The CSO oversees safe operations in the workshop environment and handles the safety training of all employees. The Chief Marketing Officer (CMO) handles marketing, outreach and fundraising. The three Chief Technical Officers (CTO) oversee the company's electrical, mechanical and software divisions. This allows for a smooth integration of Caribou's systems into one working design. Throughout the development of Caribou, the company held meetings called Edge Day roughly once a month. On Edge Day, the CTOs from each division of the company present the recent designs/work of the division's employees to the CEO, COO and the rest of the company. This provides an opportunity for design feedback, a chance to recognize which divisions may require more employees and ensures that everyone in the company is on the same page regarding the design.

Figure 2. Company Organizational Breakdown Structure. Photo Credit: Jadzia Penney

The company structure is then broken down into tasks. Depending on employees' disipline, they may complete jobs in one of the broader categories. These more general categories may also include employees from multiple disciplines. For example, mechanical and electrical employees worked together under the vertical profiler task to upgrade the profiler from the previous RFP. This allows the company to maintain an integrated work environment and gives employees many learning opportunities.

B. Schedule

Development of Caribou began in October of 2022 for the 2023 RFP. The CEO developed the project schedule using Smartsheet with collaboration from the COO and CTOs (Appendix C). The schedule is broken down into significant divisions and their tasks for project completion.

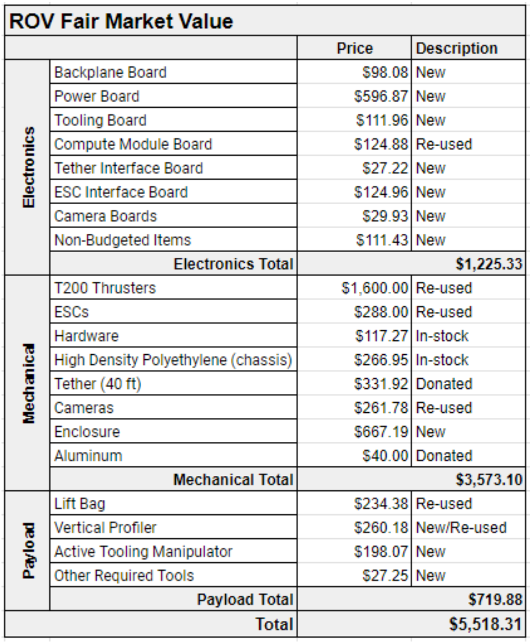
C. Budget

After the release of the RFP, a preliminary budget was developed by the CEO, COO, and CTOs for the required components and materials necessary to complete the contract. The initial proposed cost for the construction of Caribou with added contingency was estimated at $3,034.83 USD. The cost breakdown in Appendix D includes the budgeted and expensed amounts for planned items. Administrative costs for registration, printing, uniforms, and long-term non-ROV equipment were estimated at $2,374.70 USD. The initial cost for travel to Longmont was estimated at $42,843.34 USD (Appendix D).

D. Project Costing

After determining the budget for the 2023 RFP, Eastern Edge pursued an iterative design for this year's ROV while utilizing available spare components to minimize costs for the project. Eastern Edge remained within the allocated budget to produce Caribou, at a fair market value of $5,518.31 USD, as shown in Table 1.

Table 1
FAIR MARKET VALUE BREAKDOWN FOR CARIBOU.
PHOTO CREDIT: STEPHEN FUDGE



ROV Fair Market Value

		Price	Description
Electronics	Backplane Board	$98.08	New
	Power Board	$596.87	New
	Tooling Board	$111.96	New
	Compute Module Board	$124.88	Re-used
	Tether Interface Board	$27.22	New
	ESC Interface Board	$124.96	New
	Camera Boards	$29.93	New
	Non-Budgeted Items	$111.43	New
	Electronics Total		**$1,225.33**
Mechanical	T200 Thrusters	$1,600.00	Re-used
	ESCs	$288.00	Re-used
	Hardware	$117.27	In-stock
	High Density Polyethylene (chassis)	$266.95	In-stock
	Tether (40 ft)	$331.92	Donated
	Cameras	$261.78	Re-used
	Enclosure	$667.19	New
	Aluminum	$40.00	Donated
	Mechanical Total		**$3,573.10**
Payload	Lift Bag	$234.38	Re-used
	Vertical Profiler	$260.18	New/Re-used
	Active Tooling Manipulator	$198.07	New
	Other Required Tools	$27.25	New
	Payload Total		**$719.88**
	Total		**$5,518.31**

E. Resource Management

The company utilizes multiple open-source platforms to manage and ensure the flow of information among employees. A cloud storage system, Google Drive, manages all company files and document control. This allows employees to access data from this year and previous years easily. Eastern Edge has continuously improved over the years because the company has this knowledge base. Eastern Edge also utilizes GitHub, a code host platform, to store and manage Caribou's software and PCB designs. GitHub acts as a version control system, allowing employees to make design changes while saving previous versions as "commits". These "commits" can be retrieved at any time, which ensures that if any mistakes are made along the way, there won't be any lost work. OnShape was the primary computer aided design (CAD) software used by the company this year. This is a free cloud-based program that allows multiple users to access and work on a single design concurrently using any device. OnShape is also the CAD software taught in first-year engineering at Memorial University of Newfoundland, facilitating the introduction of new employees to the company's design process. Additionally, OnShape has a robust file management system, where versions of a model can be created, ensuring that any design changes will not be lost.

III. Design Rationale

For the 2023 RFP, Eastern Edge used a multi-step design process which ensured cross-system compatibility throughout the development of Caribou. This process began with brainstorming and prototyping initial designs. Over time, the company created the final working product through multiple design iterations.

Creating a stable, easy-to-use vehicle with intuitive piloting controls and reliable tooling was the main focus during system design and integration. Every design discussion began with whether to build, buy or re-use components following UN Sustainability Goal Number 12 responsible: consumption and production [1]. Using this methodology, Eastern Edge has produced a vehicle capable of completing all tasks in the 2023 contract. A render of Caribou's final design, with a weight of 21.65 kg and a maximum size of 564 mm L x 405 mm W x 492 mm H, can be seen in Figure 3.

Figure 3. Render of Caribou. Phot Credit Bedir Acar

Eastern Edge utilized an assessment-based approach to evaluate the benefits and improvements that could be achieved by upgrading the previous vehicle design, Happy Adventure, the 2022 ROV. The development of Caribou began with small multidisciplinary groups evaluating the effectiveness of Happy Adventure, and iterations that could be made. Then new innovative features and tooling designs were created based on this year's RFP and lessons learned from previous RFPs. The team leads presented these designs to the entire company during Edge Day, and the optimal solutions were selected based on feasibility in development, manufacturing, and implementation.

A. Chassis

E Eastern Edge designed the chassis of Caribou to maximize simplicity and modularity by drawing inspiration from wood joinery techniques [2]. By utilizing the joining techniques of slotting and friction fit, the design shown in Figure 4 limits the use of mounting hardware while distributing all load across the entire chassis. This method achieves a rigid and stable structure, limits possible failure points, and simplifies the disassembly and customization processes of the chassis for ease of modification if needed.

Figure 4. Caribou’s Frame Photo Credit: Bedir Acar

C Caribou's frame has five main components: two side panels, a mid-plate, a tooling skid, and an electronics enclosure mount. The mid-plate, tooling skid, and enclosure mount fit into slots on both side plates to hold the chassis together. For this year's RFP, the company took advantage of undercuts, a CNC machining technique that removes the radius that typically remains in the corners of a pocket by the endmill [3]. Incorporating undercuts significantly reduced the time spent filing the machined slots and facilitated the assembly of the chassis components. Figure 5 shows a diagram of a CNC undercut.

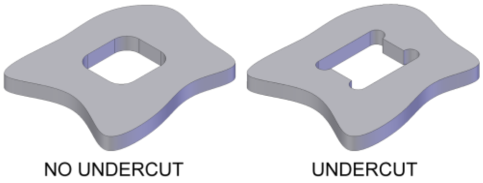


Figure 5. Holes Cut with and without Undercuts. Source: [3]

Once the pieces are pushed together, shims are fitted through cut-outs on the mid-plate, tooling skid, and enclosure mount to ensure the chassis is rigidly secured. The shims are screwed into both side panels using heat-set threaded inserts to ensure they remain secure during flight. The side panels of the chassis have integrated handles to allow for easy transport and deployment of the vehicle. Additionally, the side panels have space for mounting the four vertical thrusters and two camera mounts on the port and starboard sides of the chassis. The mid-plate of the chassis provides space to mount the four horizontal thrusters and two camera mounts on the fore and aft ends of the chassis. The tooling skid provides several attachment points to outfit Caribou with the tools and payload necessary to complete the contract. Finally, the enclosure mount incorporates channels for the end cap screws in its design. These slots ensure that the enclosure remains correctly aligned and allows for easy assembly and removal of the leading electronics enclosure as required. Figure 5 shows the design of the enclosure mount.

Figure 5. The Bottom of Caribou’s Enclosure Mount. Photo Credit: Tim Squires

Each chassis component is constructed from high-density polyethylene (HDPE), a marine-grade plastic. The company chose this material for its high strength, similar density to water, and ease of manufacturing. HDPE's density is 970 kg/m3, close to freshwater's 1000 kg/m3 density. The density similarity means the chassis is nearly neutrally buoyant, so it does not require significant buoyancy to compensate for its weight. By utilizing excess HDPE inventory from past contracts, the company minimized expenses related to chassis fabrication.

B. Propulsion

Caribou incorporates eight Blue Robotics T200 thrusters, chosen for their robust and reliable design.

These thrusters were repurposed from a previous contract, keeping in line with UN Sustainability Goal 12 while also reducing costs [1]. Four thrusters are used for lateral motion (surge, sway, and yaw directions), while the other four thrusters are used for vertical motion (heave, pitch, and roll directions). Figure 6 shows the thruster configuration on Caribou.

Figure 6. Thruster Configurations. Photo Credit: Eric Goulding

For this RFP, four vertical thrusters were used to increase overall vertical thrust capacity. For the 2022 RFP, only two vertical thrusters were used, and employees observed issues with how long it took the ROV to surface from depth, resulting in reduced performance. The four lateral thrusters are vectored at a 45° angle relative to the centreline of the ROV to simplify thrust calculations. Each thruster is placed in-plane and equidistant from the center of mass of the ROV to achieve the most efficient thrust transfer. The vectoring of the thrusters allows for a theoretical maximum thrust of approximately 116 N in both the surge and sway directions [4]. The four vertical thrusters are placed on the fore and aft sides of the ROV, equidistant from the center of mass, capable of supplying a theoretical maximum vertical thrust of approximately 130 N [5].

C. Buoyancy and Ballast

The volume of water displaced by the electronics enclosure provides more than the required buoyancy force to keep the ROV neutrally buoyant. The ROV achieves neutral buoyancy by placing ballast weights strategically on the chassis. This maintains the position of the center of gravity (COG) and center of buoyancy (COB).

To achieve stability when the ROV is submerged, the COB should be located as far as possible above the COG. When this condition is met, a sizeable restoring torque is created to return the object to equilibrium following any rotation or tilting [6]. This stable equilibrium is crucial for optimal ROV performance. Caribou considers this principle by placing the primary source of buoyancy as high up as possible on the chassis.

D. Cameras

Caribou's camera system for the 2023 contract incorporates six Raspberry Pi V2 cameras mounted inside five blue robotics two-inch watertight enclosures. These cameras stream 720p HD, 60 FPS video to Caribou's topsides control system, with a latency of only 80ms. Three modular assembly designs were integrated within the watertight enclosures for specific use cases. This included two "Active Cameras," two "Static Cameras," and one "Dual Camera." The company decided to create a new innovative six-camera system to give Caribou's pilots a better understanding of their working environment and how to keep the ROV safe during operation.

The company decided to reuse four Blue Robotics two-inch enclosures and six Raspberry PI V2 cameras from previous contracts. This gave the company the opportunity to put resources into integrating an improved six-camera system. This involved purchasing a new dual camera enclosure, and designing new camera adapter PCBs and 3D-printed mounts. These new design projects also helped company members to develop mechanical/electrical design and manufacturing skills.

Active Cameras

The active cameras are positioned at the fore and aft sides of the chassis as the pilot's main viewpoints. The assembly functions by mounting a Raspberry PI V2 camera onto a servo motor and a ball bearing with custom 3D parts, which can be seen in Figure 7 This allows the pilot to smoothly rotate the camera 180 degrees to an optimal viewpoint position during

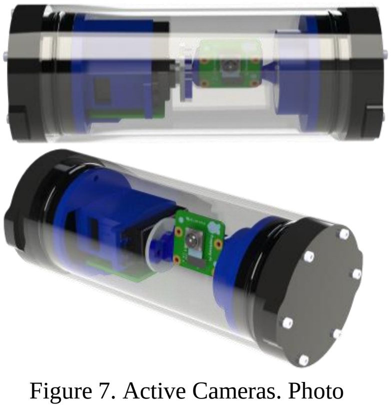


Figure 7. Active Cameras. Photo Credit: Bedir Acar

the completion of the contract's required tasks. The company has iterated on previous solutions from the 2019 and 2022 contracts for this design, enabling remote rotation of the cameras by sending power and camera signals over a standard Mini-DisplayPort cable. This is accomplished with a custom-designed camera board adapter PCB and modified 9.5 mm LC Wetlink Penetrators from Blue Robotics.

Static Cameras

The static cameras are positioned at the port and starboard of the chassis and hold its components with a two-piece custom 3D-printed assembly, which can be seen in Figure 8. The assembly connects through a friction fit between the mounting piece, which holds the camera adapter board PCB. The mounting piece, containing the Raspberry Pi V2 Camera is a static design. A static design means the viewing ability is less versatile than an active one, but is a more straightforward and cost effective alternative to integrate into Caribou without the requirement for servo motors. The positioning of the cameras was chosen not only to give the pilot a different viewing angle on the blindsides of the ROV, but to also allow for the implementation of Eastern Edge's brand-new 360-degree viewing mode.

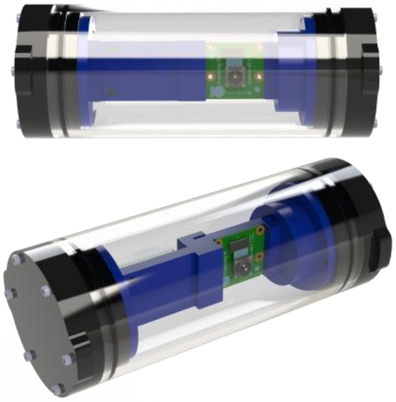


Figure 8. Static Cameras. Photo Credit: Bedir Acar

Dual Camera

The innovative dual camera is positioned on the underside of the tool skid. It contains two Raspberry Pi V2 cameras mounted via a three-piece 3D-printed assembly, shown in Figure 9. Eastern Edge has created this new solution for the 2023 contract, helping to view the bottom of the ROV during piloting and take overlapping images to complete the photogrammetry of underwater objects, such as coral heads. The cameras integrate through two Raspberry PI Zero PCB boards mounted in the enclosure and modified 9.5 mm LC Wetlink Penetrators from Blue Robotics. The camera's mount was designed collaboratively, combining multiple employees' initial assembly designs. The three-piece modular assembly was chosen due to 3D-printing manufacturing constraints and to enable the disassembly of the enclosure for testing and on-site repair.

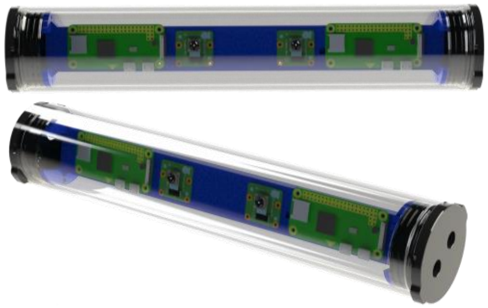


Figure 9. Dual Camera. Photo Credit: Bedir Acar

E. Tether

Caribou's tether was designed by Eastern Edge and donated by the manufacturer, Leoni-Elocab. This tether has been utilized in previous contracts and lowers the cost of development for Caribou by re-using this component for the 2023 contract. This tether has a length of 12m and contains two multimode fibre pairs for communication and two 14 American Wire Gauge (AWG) conductors for power. A cross-section of the tether's construction can be seen in Figure 10.

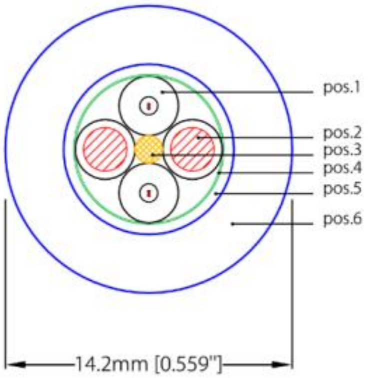


Figure 10. Tether Cross Section. Source [5].

The tether incorporates a neutrally buoyant jacket to aid in tether management. It is managed using company protocols by flaking the tether in a figure-eight shape, seen in Figure 11. This orientation minimizes the twists in the tether compared to a standard coil and is completed by two personnel.

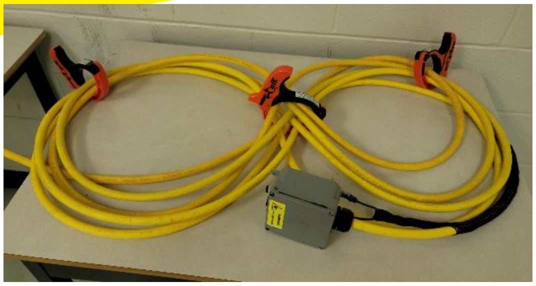


Figure 11. Flaked tether in figure eight shape. Photo Credit: Stephen Fudge

One person either increases or decreases the amount of tether in the pool based on the pilot’s needs, and a second person maintains the figure 8 pattern on deck. The tether is flaked and kept neatly organized with three cable cuffs when not in use.

F. Payload

SubSieze

The Eastern Edge *SubSieze*, shown in Figure 12, was designed to place, transport, and retrieve various objects during operation. This versatile custom-built tool features interlocking jaws which allow the pilot to complete multiple tasks, including removing biofouling from a floating solar panel array and installing Eco-Mooring systems to protect seagrass and seahorse habitats. This aligns with UN sustainability goal 14; life below water [1]. A PA-11-D30 Tubular Linear Actuator is used to power the SubSieze. This linear actuator was selected due to its small outer diameter and compact in-line motor design, enabling seamless placement inside its housing, a 2-inch Blue Robotics tube. The linear actuator can generate maximum static and dynamic forces of 33 lbs [7].

Figure 12. The SubSieze. Photo Credit: Bedir Acar

The company built a custom manipulator rather than procuring a standard industry product by implementing a cost-effective and learning-driven approach. By constructing the SubSieze in-house, significant cost savings were made as all components were manufactured using existing materials and hardware from previous contracts, except for the newly purchased linear actuator and Blue Robotics tube. Most importantly, building the SubSieze from scratch offered an unparalleled learning experience for the company. The acquired knowledge of the functionality of the active tooling system enhanced the company's ability to troubleshoot challenges that emerged during ROV trial runs.

Pneumatic pistons were briefly considered to power the SubSieze, but the actuator was chosen as its position can be easily controlled for tasks requiring specific jaw opening widths. A single X-ring creates a dynamic seal between the actuator rod and a custom-designed 3D-printed end cap, preventing water ingress in the tube.

Extractor

The *Extractor*, shown in Figure 13, was custom-made to extract saltwater samples and collect data on reef organisms. This aligns with UN sustainability goal 14; life below water [1]. The Extractor utilizes a bilge pump for water intake,

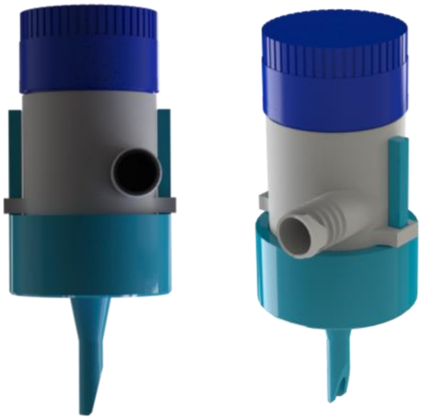


Figure 13. The Extractor. Photo Credit: Bedir Acar

while the water is stored in a removable bladder attached to the underside of Caribou. A bilge pump was chosen as it is cost-effective, waterproof, and provides the necessary power to extract the water samples. The needle is 3D-printed out of PLA, making it easily replaceable if it is damaged during operation. The Extractor is positioned such that the needle protrudes from the underside of the tooling skid, allowing the pilot to position themselves above the designated area and quickly retrieve the sample.

Dispenser

The *Dispenser* was designed to transport fish fry to a habitat where they can safely be released. This aligns with UN sustainability goal 14; life below water [1]. This passive tool, shown in Figure 14, consists primarily of custom 3D-printed parts, simplifying the manufacturing and iterative design processes. The tool features a handle that can be securely held in the *SubSieze* for easy transport. The bottom of the tool acts as a trapdoor, being held in place on one side by a ⅛" neodymium magnet that attaches to a metal bar. On the other side, it is held in place by a single screw serving as a hinge, allowing the trap door to rotate once disengaged from the magnets. After acclimating the fish into their new environment, the pilot will pitch Caribou forward, pressing down on the lever extending from the trapdoor. The trapdoor will be forced open, and the fish fry will be released.

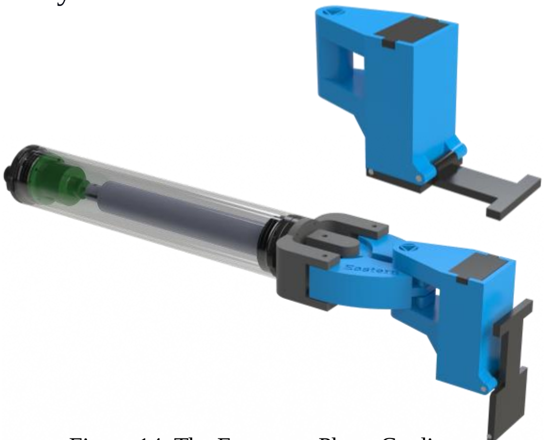


Figure 14. The Extractor. Photo Credit: Bedir Acar

Light Brites

Caribou has two front-mounted LED lights on the port and starboard side. These lights, as seen in Figure 15, are made from repurposed cabinet light strips potted to be waterproof. The tooling board controls the light's brightness, assuring maximum visibility for the pilot.

Figure 15. Light Brites. Photo Credit: Eric Goulding

Flashlight

The *Flashlight*, shown in Figure 16, uses the same repurposed cabinet lights that power the Light Brites. These lights were chosen as they are both cost-effective and bright, meaning they will supply plenty of light to irradiate the diseased area of coral. This aligns with UN sustainability goal 14; life below water [1]. The light source is affixed to the inside of a 3D-printed enclosure, which can block out external light before the illumination of the Flashlight.

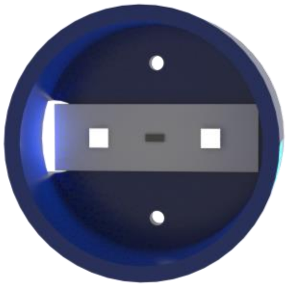


Figure 16. Flashlight. Photo Credit: Eric Goulding

Walrus

The *Walrus*, shown in Figure 17, is a stationary hook that provides robust and secure lifting capabilities while retrieving and transporting objects underwater. This hook is constructed from a carved PVC pipe that is secured to the tooling skid. The Walrus is primarily used for attaching mooring connectors to anchor points to secure the solar panel array in place. This aligns with UN sustainability goal 7; affordable and clean energy [1]. It provides support against bends from heavy objects compared to other manipulator designs due to its round shape, distributing applied forces across a greater cross-sectional area.

G. *Vertical Profiler*

For the 2023 RFP, Eastern Edge has upgraded the previous buoyancy engine vertical profiler. By

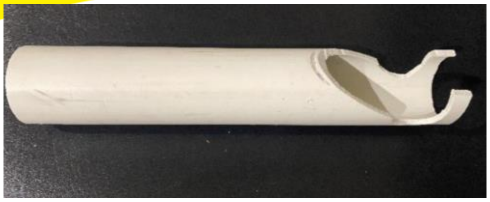


Figure 17. Walrus. Photo Credit: Bedir Acar

reusing this tool from the last RFP, the company could lower costs and align itself with UN sustainability goal 12, responsible consumption and production [1]. The profiler will be moved into place by Caribou using the SubSieze. Once in place, the profiler will receive a signal from the receiver to begin two profiles autonomously, sending a transmission of the current time and company name each time it surfaces.

A 2-inch diameter Blue Robotics tube is used for the electronics enclosure of the vertical profiler. This enclosure holds all components of the device. A syringe is used for water intake and outflow, modifying the overall density of the system and allowing the profiler to sink and float as required. Once the profiler receives the signal from the receiver box, it will draw the plunger from the syringe and take on water, causing it to sink. Figure XX shows the final profiler design.

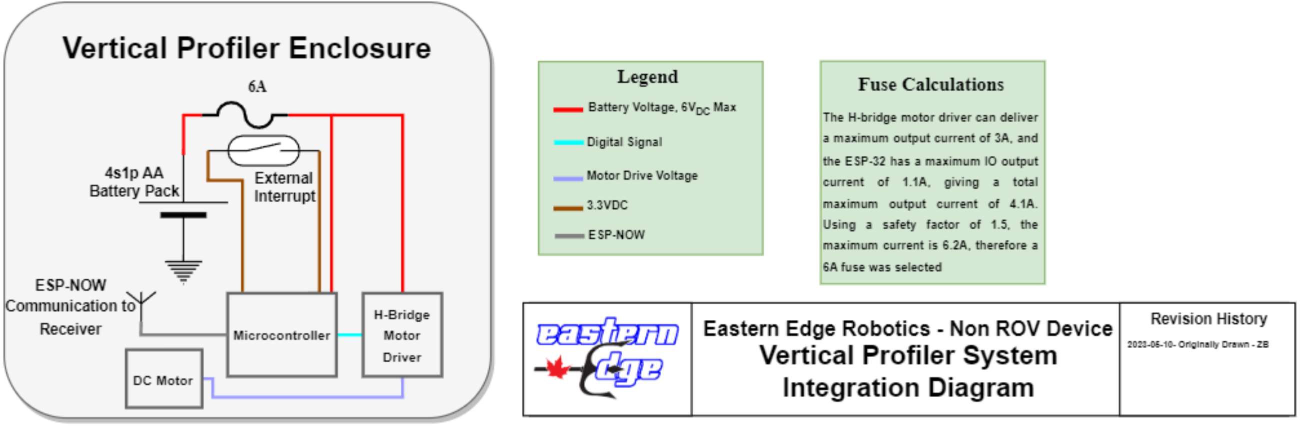
Eastern Edge upgraded last year's vertical profiler by swapping out the previous Arduino with an ESP32 WROVER dev kit. The ESP32 will be kept in a deep sleep state. A reed switch is used to wake up the profiler with a magnet, putting it into standby mode until a signal is sent from the receiver box. The ESP32 microcontroller has an onboard antenna to communicate with the topside system.

The end caps are non-locking to prevent any dangerous buildup of pressure. This way, if the internal pressure exceeds the external pressure, the end caps will disengage and prevent any potentially explosive pressures. This safety feature ensures that employees can safely interact with the device. The SID for the vertical profiler can be seen below in Figure 18.

H. Electrical Architecture Design

Caribou's electrical system was redesigned from the 2022 ROV to accommodate design improvements and a change to a smaller enclosure. The company found that a larger enclosure made the chassis design overly large, and the ROV required excess ballast to account for the added buoyancy of the tube. Therefore, the shift was made from an 8" enclosure to a 6" Blue Robotics enclosure. Caribou's electrical system is designed with thermal management and space efficiency in mind. Thermal management is achieved using the electronics enclosure's aluminum end cap as a heatsink for its DC-DC converters, allowing any heat produced to be dissipated into the surrounding water. Custom printed circuit boards (PCBs) were required to make the design feasible since off-the-shelf components would not fit within the end cap's space constraints. PCBs were re-used throughout the enclosure from the 2022 RFP where possible to minimize cost. The PCBs were secured to 3D-printed trays to limit manufacturing constraints and allow easy design modifications.

Caribou's electrical system is split into two subsystems: a high-power conversion and distribution system, and a low-power electronics and communications subsystem. The high-power subsystem comprises three custom-designed PCBs: one for power conversion and two for power distribution. The low-power subsystem shall consist of four custom PCB designs, one of which is re-used



Fuse Calculations

The H-bridge motor driver can deliver a maximum output current of 3A, and the ESP-32 has a maximum IO output current of 1.1A, giving a total maximum output current of 4.1A. Using a safety factor of 1.5, the maximum current is 6.2A, therefore a 6A fuse was selected

Figure 18. Vertical Profiler SID. Photo Credit: Winston Hoffman

from the company's 2022 ROV. A full System Integration Diagram (SID) of the electrical system is included in Appendix E.

Backplane Board Design

The Backplane is the center of Caribou's low-power subsystem and distributes power and communications to other subsystem components. It features a PCB edge connector to connect to the power board without requiring additional wires and distributes 11.19VDC, 5VDC, and 3.3VDC from the power board to other low-power components [8]. It also includes a 4.5W 3.3VDC to 1.8VDC converter to supply the compute module cards with 1.8V.

The Backplane includes two Peripheral Component Interconnect Express (PCIe) connectors to connect to the two compute module adapter cards and a 20-pin wired connection to connect to the tooling board. Additionally, the Backplane is also equipped with two ethernet connectors, four Mini Displayport connectors, three Inter-Integrated Circuit (I2C) connectors, and two Controller Area Network (CAN) connectors to connect with additional low-power peripherals. The ethernet connectors are used to connect the compute modules with the ethernet switch, the Mini Displayport connectors are reserved for use with the ROV's four main cameras, one I2C connector is used to connect to the PWM generation board, and one of the I2C connectors is reserved for Caribou's pressure sensor. The remaining I2C connector and two CAN connectors are not currently used and allow for new peripherals to be installed in the future if additional capabilities are required. A render of the backplane board can be found in Figure 19.

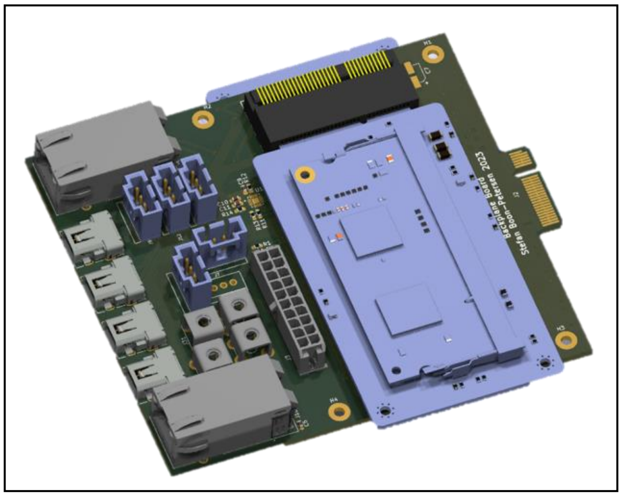


Figure 19. Backplane board for 2023. Photo Credit: Stephen Fudge

Compute Module Board Design

Caribou uses two Raspberry Pi Compute Module 3+ (CM3+) as the onboard computers to handle communications with the surface and control the electrical system's other aspects. The CM3+ provides similar functionality to a regular Raspberry Pi 3B+ (RP3B+) while using a smaller form factor that can be better integrated into Caribou's electrical system. Additionally, the CM3+ supports one additional Raspberry Pi Camera than the RP3B+. Two CM3+ are used to help four Raspberry Pi Cameras and to split the onboard computing load. Caribou's two CM3+ were re-used from the company's 2022 ROV to reduce cost. The reused compute module boards can be seen in Figure 20.

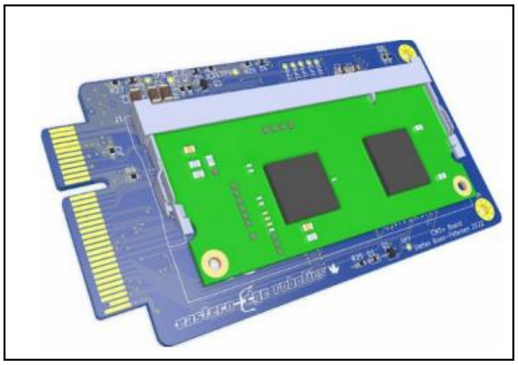


Figure 20. Reused compute module boards from 2022. Photo Credit: David Drover

ESC Interface Board

The ESC adapter board is a power distribution board that distributes 11.19VDC to Caribou's eight electronic speed controllers (ESCs). It connects to the power board using a board-to-board connector. This allows the panels to be connected without requiring any wires, which allows the end cap of the enclosure to be easily removed as necessary. A hall-effect current sensor is placed on each ESC power terminal to measure the current flowing to each thruster. These sensors produce analog signals sent to the power board's microcontroller for interpretation. A render of the ESC interface board is shown in Figure 21.

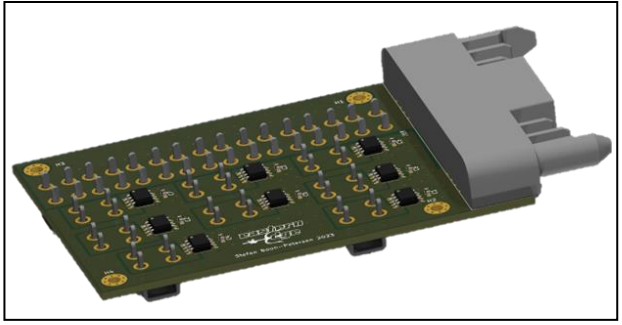


Figure 21. ESC Interface Board current sensor side. Photo Credit: Stephen Fudge

Tether Interface Board

The tether interface board was created to connect the power wires in the tether to a board-to-board connector that can connect to the power board. This allows the tether wires to remain fixed even if the power board is disconnected. The tether interface is shown in Figure 22.

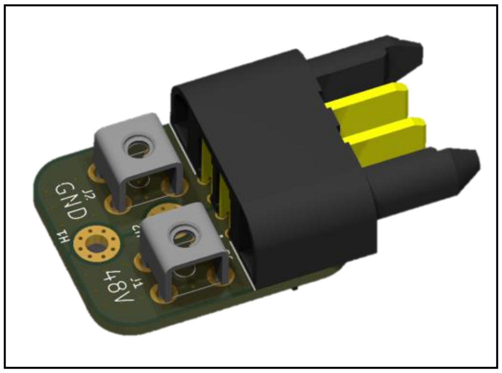


Figure 22. Render of Tether Interface Board. Photo Credit: Stephen Fudge

Power Board Design

The high-power PCB for Caribou, displayed in Figure 23, was designed to reduce wiring inside the enclosure and optimize thermal performance. The circular shape of the board allows for maximum usage of available space, leaving room for large conduction planes sufficient for high currents. The two Murata DC-DC convertors are mounted directly to the metal end cap, enhancing heat dissipation. These converters feature 95.5% efficiency, 600W output power each (1200W total), isolation between the 48V input and 11.19V output, and built-in over temperature and output over voltage and current protection. The design is made more robust by including a secondary layer of input protections using the Richtek RT1720 protection Integrated Circuit (IC). This provides similar protections to the DC-DC converters, a programmable fault-protection timer, and reverse input voltage blocking. The enclosure's assembly is facilitated by board-to-board connectors, allowing for seamless connections between the power board and the tether interface, ESC interface, and backplane boards. Additionally, the PCB features an STM32 microcontroller that enables and disables the DC-DC convertors through software and measures the power consumption of each of the eight Blue Robotics T200 thrusters.

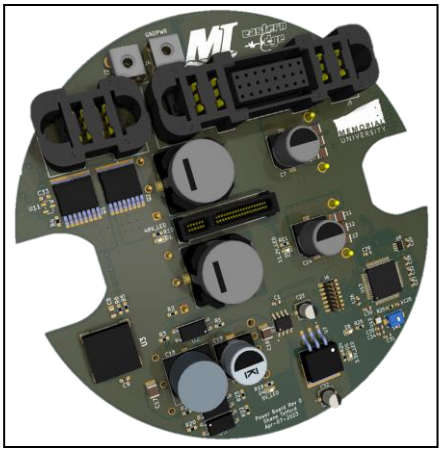


Figure 23. Power Board Render. Photo Credit: Stephen Fudge

Tooling Board Design

The Tooling Board, shown in Figure 24, was designed to control any active tools of the ROV using DC motor drivers and has functionality for leak detection, LED control, and an Inertial Measurement Unit. The Tooling Board utilizes three voltage connections from the Backplane, 3.3VDC, 5VDC, and 12VDC, to power the actuators, the microcontroller, and all other peripherals on the board. The tooling board has been integrated into the ROV's electrical system through MOLEX connectors and communicates with the system via universal asynchronous receiver / transmitter (UART) protocols. The Tooling Board also has functionality for a controller area network (CAN) bus and Inter-Integrated Circuit (I2C) communication. The Raspberry Pi Compute Modules communicate different messages to the Tooling board for various functionalities, such as deactivating the ROV's power if the leak sensor detects a leak, changing the brightness of LEDs on the ROV, changing the position of any active tools via the DC motor drivers, and monitoring their current via Analogue to Digital Converter (ADC) pins. There are five DC motor drivers on the tooling board, two for 12V motors and three for 5V motors, allowing for the future expandability of the product. These motor drivers allow motors to draw up to 3.7A of current. Four N-channel MOSFETs are used as LED drivers that will enable LEDs to be controlled via Pulse Width Modulation (PWM), connected to one of four ports on the Tooling Board. The maximum current draw of the N-Channel Metal Oxside Semiconductor (NMOS) is 4.2A, and the duty cycle (time that the circuit is one versus the time that the circuit is off) can be adjusted to change the brightness of the LEDs on the ROV by changing the output PWM signal. This is useful for different depths in a body of water where visibility will vary

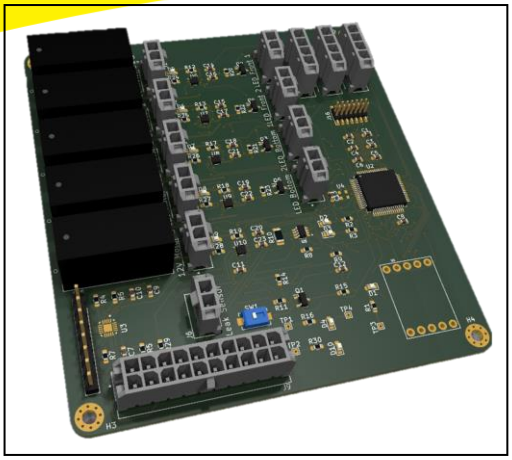


Figure 24. Power Board Render. Photo Credit: Stephen Fudge

depending on depth, warranting different LED brightness. The actuators, as well as the communication to the Raspberry Pi Compute Modules, are controlled by an STM32 microcontroller on the board. This board also contains the Inertial Measurement Unit (IMU) that is used within the GUI to aid with piloting the ROV.

I. Software (Communications)

There are six computing units used in the operation of Caribou. These are the topside control laptop, scientific laptop, onboard dual Raspberry Pi CM3+'s and dual Raspberry Pi Zero's. The control laptop takes in input from the pilot's joysticks and receives information from the Raspberry Pis, such as camera feeds and vehicle orientation. The compute modules receive input from topsides and manage all ROV functionality, such as thrusters and tooling. The Figure 25 flowchart shows the process used by the raspberry pi's to receive, execute, and send messages.

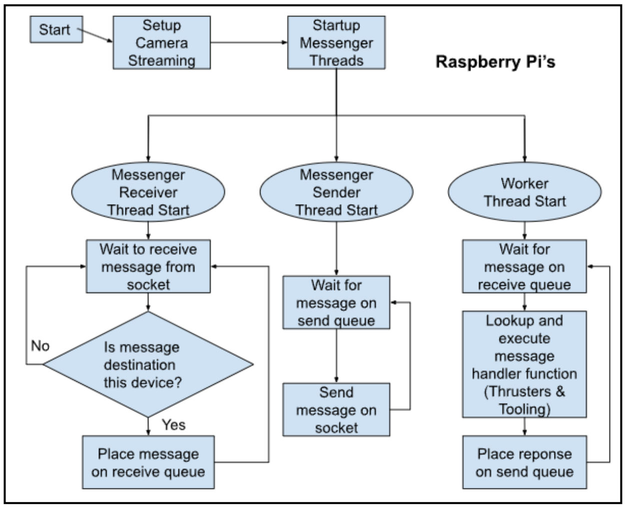


Figure 25. Raspberry Pi's Software Flowchart. Photo Credit: Evan Vokey

The topside and onboard software are connected using User Datagram Protocol (UDP). UDP was chosen as it provides lower latency when compared to other communications protocols, which is critically essential in real-time control systems. The six computing units are connected via ethernet and fibre using a five port ethernet switch, a fibre optic converter on the ROV, and a combined ethernet switch/fibre converter on topsides, as seen in Figure 26. The two Raspberry Pi Zeros are used for additional cameras on the ROV and are mounted in a separate enclosure.

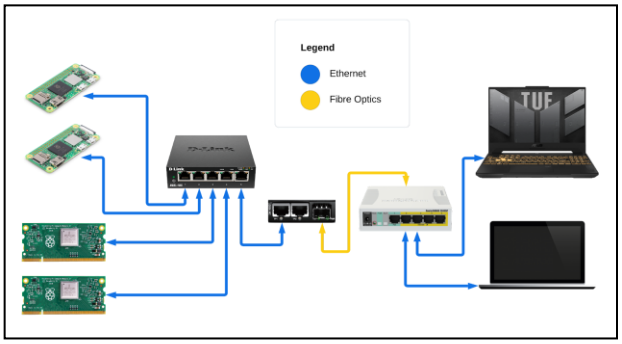


Figure 26. Network Diagram. Photo Credit: Russell Corbett

Software (Core)

Caribou's software was written in Python, chosen for ease of development and the many functionalities it offers through its various external libraries. The Company's software is an integral part of Caribou's operation. It takes user input, communicates with and within the ROV across many computing units, and returns output to the user, encapsulating everything they need to know in a straightforward interface. The software package is an extensive program, running dozens of threads and performing various functions simultaneously. A GUI application was developed in QT (an open-source software designed specifically for creating GUIs) to allow the pilot to control all aspects of the ROV's configuration easily. The GUI includes the following elements: main controls, science tasks, diagnostics and a profile editor. A secondary topside laptop manages, computes, and analyzes scientific tasks. This GUI includes the following elements: main calculations, AI, and image recognition and diagnostics. Both have individual error loggers, settings and pre-flight and safety checklists. In addition to the GUI applications, the software runs on each of the Raspberry Pis without a direct user interface.

Topsides Control Software

Figure 27 gives a practical overview of what the Software that the Controls Laptop performs and in what order. Caribou's topsides control software was created with safety in mind, as seen in Figure 19; no data will be sent or received by Controls Laptop unless the pre-flight safety checklist is checked and signed. The main tab is entirely inaccessible until this is done. To assist in troubleshooting throughout the code, log statements tell the Error Logger to write to log files and display error messages in the GUI, allowing problems to be identified during and after the operation of Caribou. The Software is also created to be easy to use despite the program's complexity; the user must only perform a few straightforward actions to begin operating Caribou. Moreover, users can create custom control profiles for their preference for recognized controllers.

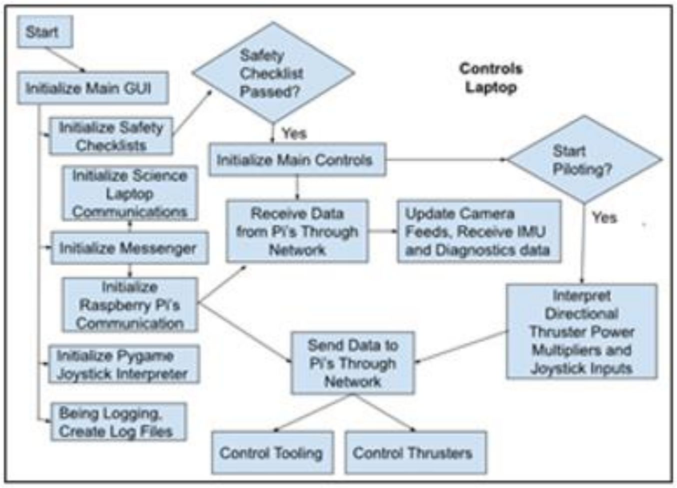


Figure 27. Topsides laptop flowchart showing major processes. Photo Credit: Zaid Duraid

Main Controls Tab

The Main Controls Tab, shown in Figure 28, contains essential features to pilot Caribou. These can initialize the connection between the ROV and a joystick using a custom control preset, apply power multipliers to all thrusters or specific movement directions, and view the camera feed from Caribou's onboard Pi cameras.

The "Magic Button" in Figure 19 allows the camera feeds to be detached from the GUI as a separate window and reattached. The other buttons will enable you to stop the camera feeds (for window resizing), start them again, and reorder them. The button "360 Camera Toggle" arranges the cameras with respect to camera positions to the ROV.

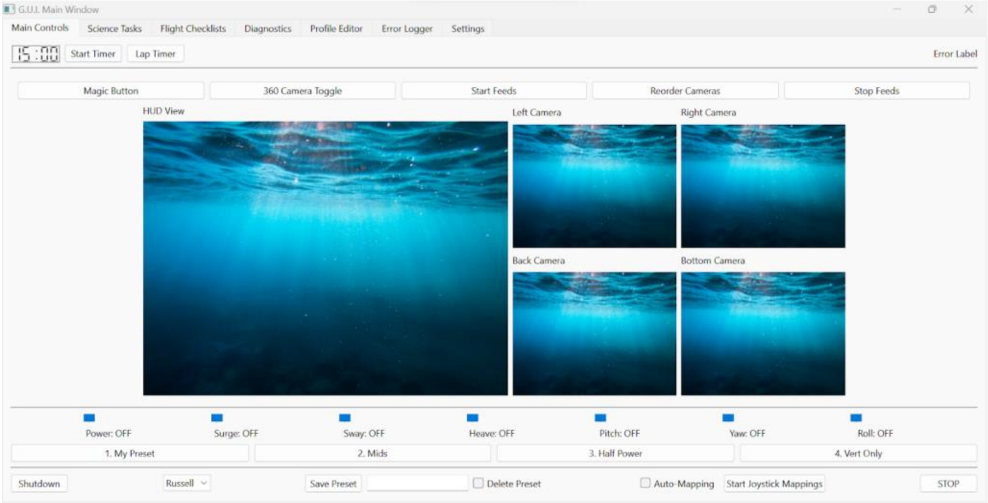
Another feature of the camera feeds is the heads-up display (HUD) which is overlaid atop whichever feed is under 'HUD View" in Figure 19. The HUD uses real-time ROV orientation data from Caribou's IMU. This is displayed in the HUD as rotation about whichever axis the camera of the "HUD View" faces and the vertical "up and down" angular displacement of that camera.

Science Tasks

The Science Tasks tab on the controls laptop enables the co-pilot to initiate autonomous tasks like photogrammetry and autonomous docking. The co-pilot also calculate the diseased area of coral using a function in the GUI.

Preflight Checklists

The GUI features a preflight safety checklist which must be completed before vehicle control is enabled.



Power: OFF
Surge: OFF
Sway: OFF
Heave: OFF
Pitch: OFF
Yaw: OFF
Roll: OFF
Russell
☐ Delete Preset
☐ Auto-Mapping

Figure 28. Main Controls Tab of the GUI. Photo Credit: Zaid Duraid

The preflight checklist records the user's name and the time the checklist is completed for auditing in the future.

Diagnostics

The vehicle diagnostics tab displays data from internal sensors. These sensor readings are not critical to the pilot but would be useful in debugging. This includes data from current sensors for each thruster and tool and temperature sensors. This data can also be recorded and used in the future for debugging.

Profile Editor

The profile editor tab allows the user to configure the Gamepad or Joystick they will use to pilot the ROV. The user can map any button or axis to any axis of motion or tool on the vehicle.

Error Logger

The Error Logger tab and overall feature help identify the events during flights, allowing the company to spot errors and inefficiencies. The integration of the error logging feature into code is nearly as easy as using a print statement. The following lines demonstrate this:

```
“from error_logger import log
log(“topsides”, “As easy as print()”, “info”)”
```

Whenever the log() function is called, it must take in the device associated with the log (topsides, raspi4, raspi5, or science), the error message, and the error level. The defined error levels are consistent with the standard Python logging library. The log() function updates the Error Logger Tab and writes to a log file that can be accessed when the software is closed. The log entry also includes the error level, date, time, and message.

Settings

The settings tab allows for quick functional changes during runs. Safety items can be added and removed, the current Raspi running specific systems can be swapped, and the operational status can be switched.

IV. Critical Analysis

J. Testing and Troubleshooting

Eastern Edge recognizes the crucial value of testing and troubleshooting to create a quality product. These values lead to strict testing and troubleshooting protocols with all components and systems before integration. Independent testing of systems allows the company to find and resolve issues before they are integrated to streamline the troubleshooting process later.

Before being integrated with the ROV, all electrical systems were bench tested with the rest of the control systems. The employees tested the thruster control and communications software on the 2022 ROV. With mechanical and electrical design similarities between the previous and current contracts, the 2022 ROV has acted as an effective testing platform for all elements of this year's contract.

In addition to testing before integration, Caribou was developed with modularity and simple assembly in mind. To ease the redesign of the enclosure system, a 3D-printed tray design was utilized to easily modify or rearrange the internal electronics system with minimal manufacturing time and costs. The electronics connection was designed for quick connecting assembly, which improved the assembly time of the enclosure and the ability to connect the system on a benchtop for isolated electronics testing without a significant number of cable connections.

Caribou was designed with live troubleshooting in mind. Both sensors and software aids help employees diagnose and fix problems as they occur. The ROV is equipped with multiple leak sensors to quickly identify leaks so that the ROV can be safely shut down and retrieved, reducing the risk of damage to the electrical system. Caribou's electrical system is also equipped to monitor the power distribution throughout, with voltage and current sensors throughout the PCBs. The GUI is also equipped with an integrated live updated error logger to notify the pilot of issues such as unresponsive pi's. A copy of this log is saved to review later.

V. Acknowledgements

Eastern Edge would like to thank the following organization for their monetary support in the development of Caribou, travel expenditures to Longmont, Colorado, and of the MATE ROV Competition both regionally in Newfoundland and Labrador and internationally.

ExxonMobil; Atlantic Canada Opportunities Agency; Department of Tourism, Culture, Industry and Innovation; Fugro GeoSurveys Inc; Hibernia Company Ltd; Crosbie Group Ltd; Husky Energy; Equinor; Marine Institute of Memorial University; Memorial University Faculties of Engineering, Humanities and Social Sciences and Science; Memorial University Technical Services; City of St. John's; RobotShop; Blue Robotics; CoLab Software; Kraken; Raspbian; SubC Imaging; Subsea 7; InpectAR; Quidi Vidi Brewery

Eastern Edge would also like to thank the following organizations for donating software or material resources: GitHub; Leoni-Elocab; Solace Power; and OnShape.

The Company extends a heartfelt thank you to our mentors Paul Brett, Joe Singleton, Anthony Randell, Shawn Pendergast, Chris Batten and Michaela Barnes for their time, administrative support, and unwavering encouragement, as well as to the MATE Center for making this all possible.

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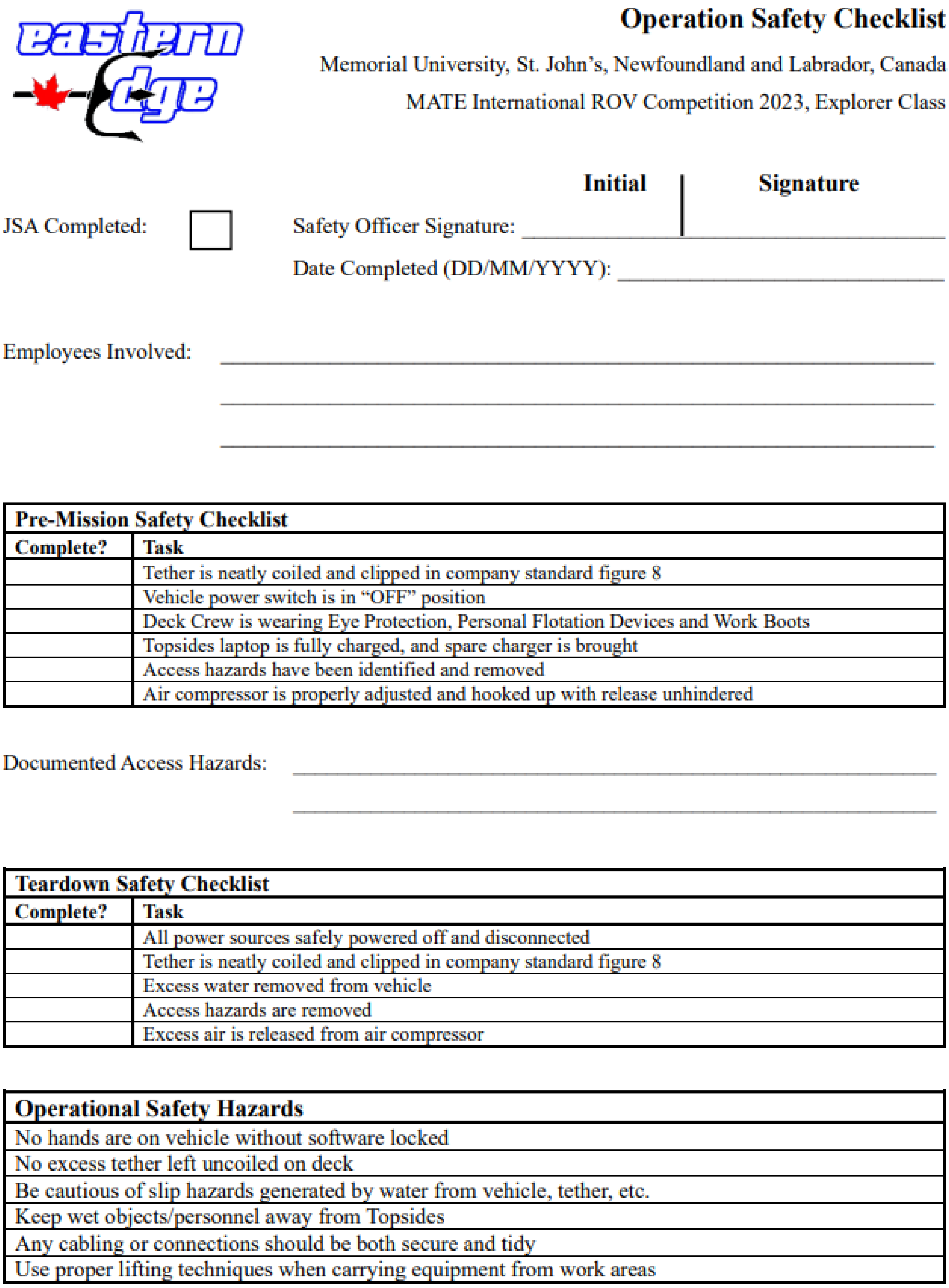
Appendix A – Operational Safety Checklist



Operation Safety Checklist

Memorial University, St. John's, Newfoundland and Labrador, Canada
MATE International ROV Competition 2023, Explorer Class

	Initial	**Signature**
Safety Officer Signature:	____________	____________

JSA Completed: ☐

Date Completed (DD/MM/YYYY): ______________________

Employees Involved: ______________________________________

____

____

Pre-Mission Safety Checklist	
Complete?	**Task**
	Tether is neatly coiled and clipped in company standard figure 8
	Vehicle power switch is in "OFF" position
	Deck Crew is wearing Eye Protection, Personal Flotation Devices and Work Boots
	Topsides laptop is fully charged, and spare charger is brought
	Access hazards have been identified and removed
	Air compressor is properly adjusted and hooked up with release unhindered

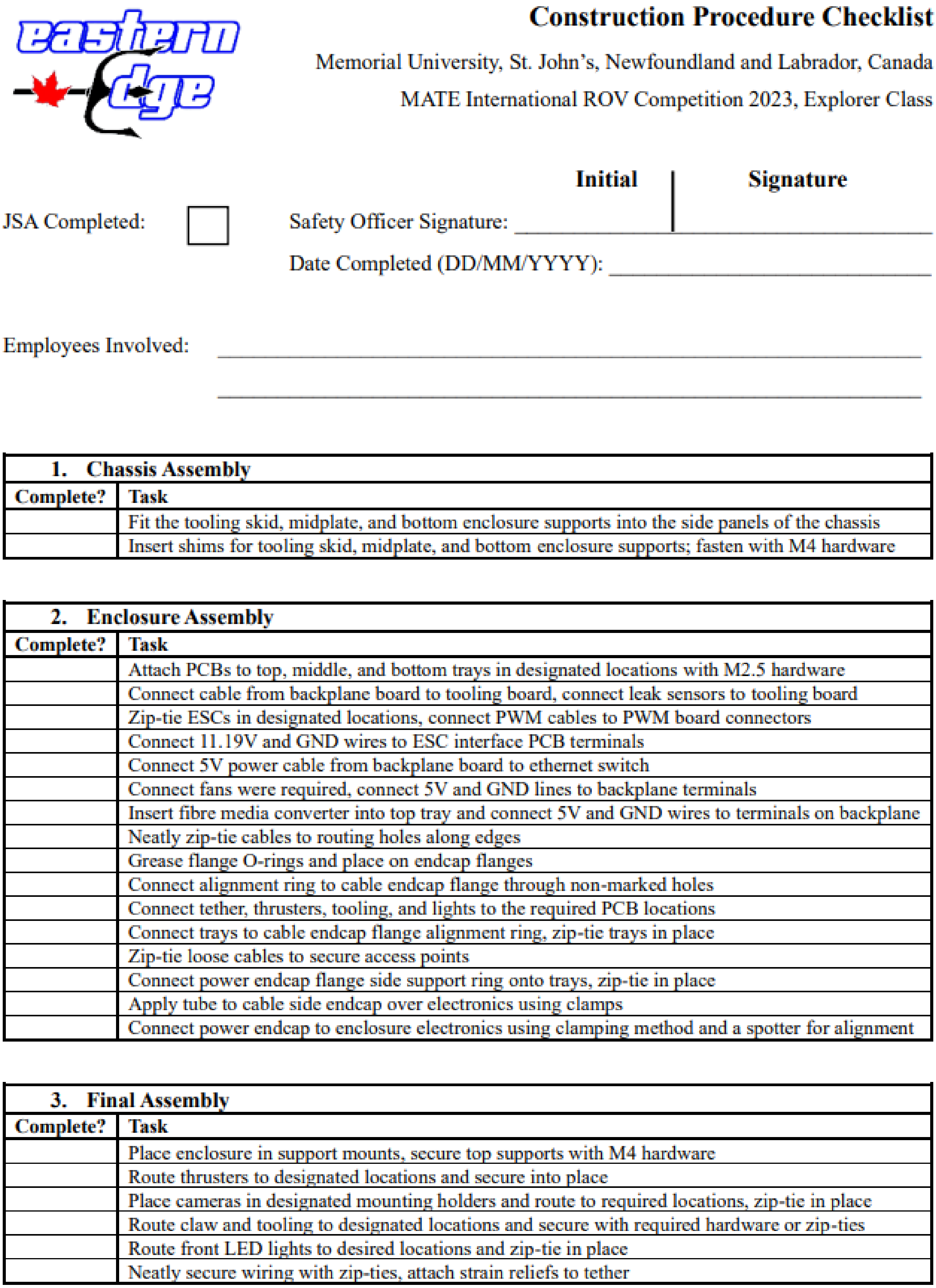
Documented Access Hazards: ______________________________________

____

Teardown Safety Checklist	
Complete?	**Task**
	All power sources safely powered off and disconnected
	Tether is neatly coiled and clipped in company standard figure 8
	Excess water removed from vehicle
	Access hazards are removed
	Excess air is released from air compressor

Operational Safety Hazards
No hands are on vehicle without software locked
No excess tether left uncoiled on deck
Be cautious of slip hazards generated by water from vehicle, tether, etc.
Keep wet objects/personnel away from Topsides
Any cabling or connections should be both secure and tidy
Use proper lifting techniques when carrying equipment from work areas

Appendix B – Construction Procedure Checklist



Construction Procedure Checklist

Memorial University, St. John's, Newfoundland and Labrador, Canada
MATE International ROV Competition 2023, Explorer Class

JSA Completed: ☐

Initial | Signature

Safety Officer Signature: ____________________

Date Completed (DD/MM/YYYY): ____________________

Employees Involved: ____________________
____

1. Chassis Assembly

Complete?	Task
	Fit the tooling skid, midplate, and bottom enclosure supports into the side panels of the chassis
	Insert shims for tooling skid, midplate, and bottom enclosure supports; fasten with M4 hardware

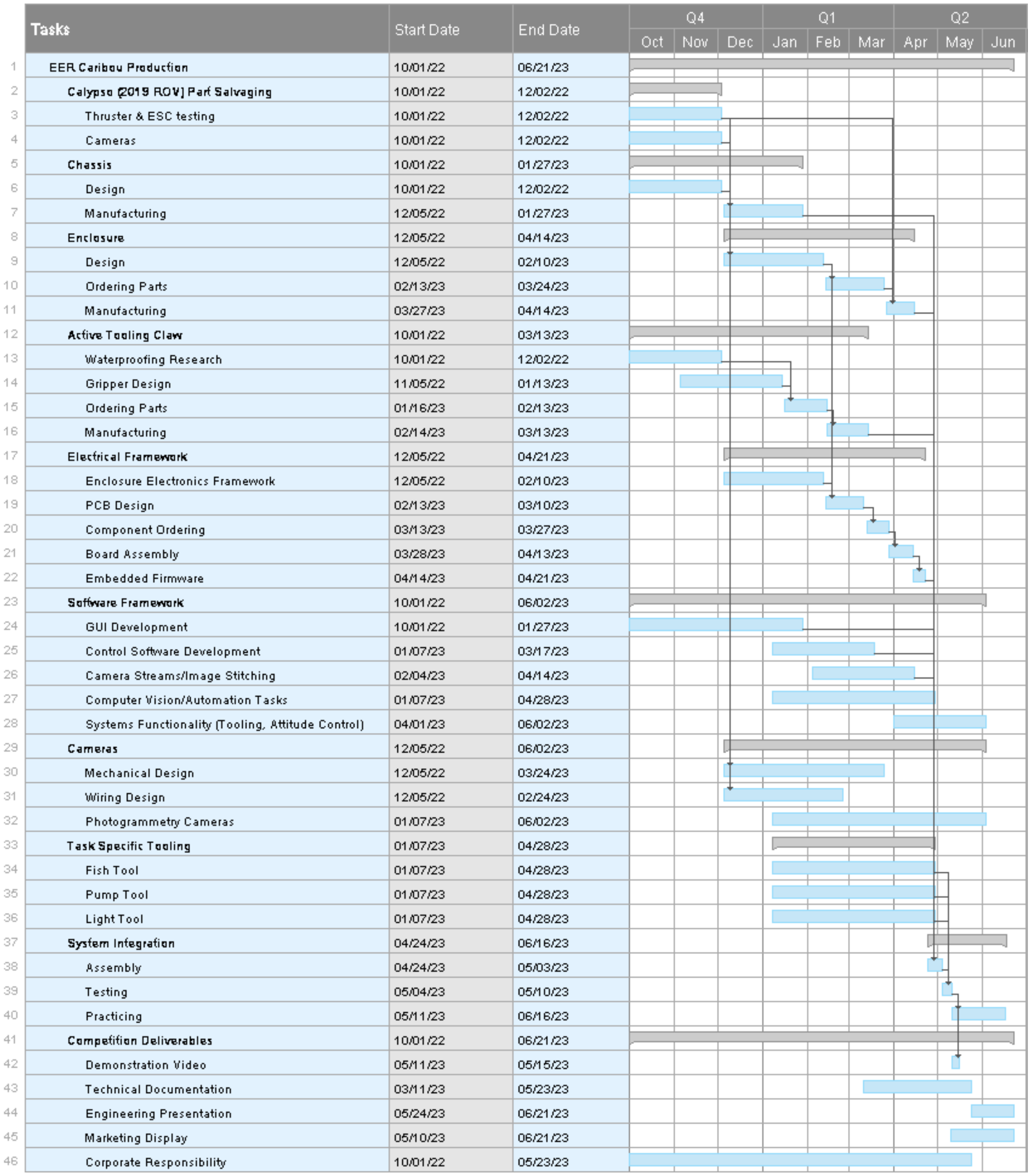
2. Enclosure Assembly

Complete?	Task
	Attach PCBs to top, middle, and bottom trays in designated locations with M2.5 hardware
	Connect cable from backplane board to tooling board, connect leak sensors to tooling board
	Zip-tie ESCs in designated locations, connect PWM cables to PWM board connectors
	Connect 11.19V and GND wires to ESC interface PCB terminals
	Connect 5V power cable from backplane board to ethernet switch
	Connect fans were required, connect 5V and GND lines to backplane terminals
	Insert fibre media converter into top tray and connect 5V and GND wires to terminals on backplane
	Neatly zip-tie cables to routing holes along edges
	Grease flange O-rings and place on endcap flanges
	Connect alignment ring to cable endcap flange through non-marked holes
	Connect tether, thrusters, tooling, and lights to the required PCB locations
	Connect trays to cable endcap flange alignment ring, zip-tie trays in place
	Zip-tie loose cables to secure access points
	Connect power endcap flange side support ring onto trays, zip-tie in place
	Apply tube to cable side endcap over electronics using clamps
	Connect power endcap to enclosure electronics using clamping method and a spotter for alignment

3. Final Assembly

Complete?	Task
	Place enclosure in support mounts, secure top supports with M4 hardware
	Route thrusters to designated locations and secure into place
	Place cameras in designated mounting holders and route to required locations, zip-tie in place
	Route claw and tooling to designated locations and secure with required hardware or zip-ties
	Route front LED lights to desired locations and zip-tie in place
	Neatly secure wiring with zip-ties, attach strain reliefs to tether

Appendix C – Caribou Development Schedule

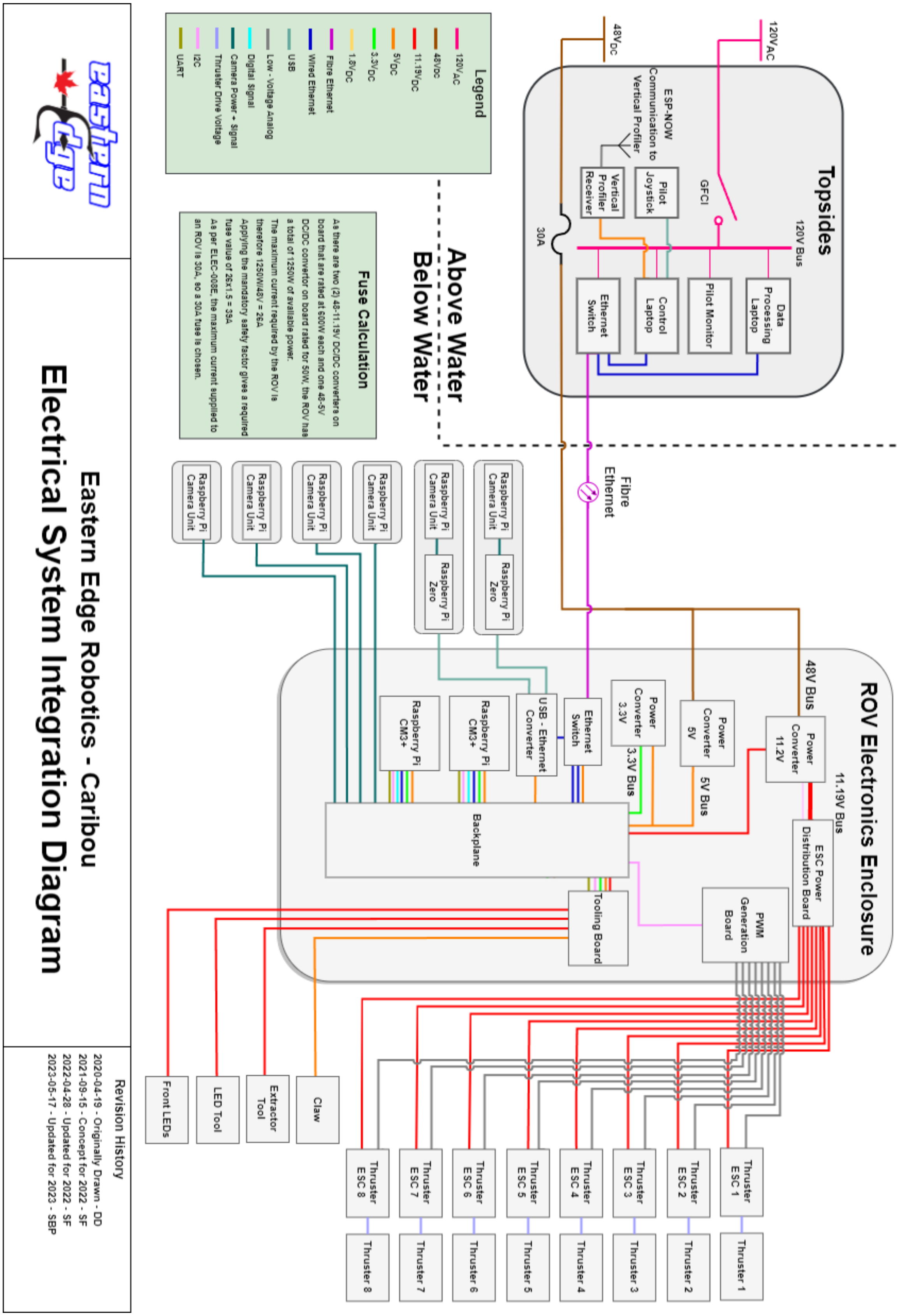


	Tasks	Start Date	End Date
1	**EER Caribou Production**	10/01/22	06/21/23
2	**Calypso (2019 ROV) Part Salvaging**	10/01/22	12/02/22
3	Thruster & ESC testing	10/01/22	12/02/22
4	Cameras	10/01/22	12/02/22
5	**Chassis**	10/01/22	01/27/23
6	Design	10/01/22	12/02/22
7	Manufacturing	12/05/22	01/27/23
8	**Enclosure**	12/05/22	04/14/23
9	Design	12/05/22	02/10/23
10	Ordering Parts	02/13/23	03/24/23
11	Manufacturing	03/27/23	04/14/23
12	**Active Tooling Claw**	10/01/22	03/13/23
13	Waterproofing Research	10/01/22	12/02/22
14	Gripper Design	11/05/22	01/13/23
15	Ordering Parts	01/16/23	02/13/23
16	Manufacturing	02/14/23	03/13/23
17	**Electrical Framework**	12/05/22	04/21/23
18	Enclosure Electronics Framework	12/05/22	02/10/23
19	PCB Design	02/13/23	03/10/23
20	Component Ordering	03/13/23	03/27/23
21	Board Assembly	03/28/23	04/13/23
22	Embedded Firmware	04/14/23	04/21/23
23	**Software Framework**	10/01/22	06/02/23
24	GUI Development	10/01/22	01/27/23
25	Control Software Development	01/07/23	03/17/23
26	Camera Streams/Image Stitching	02/04/23	04/14/23
27	Computer Vision/Automation Tasks	01/07/23	04/28/23
28	Systems Functionality (Tooling, Attitude Control)	04/01/23	06/02/23
29	**Cameras**	12/05/22	06/02/23
30	Mechanical Design	12/05/22	03/24/23
31	Wiring Design	12/05/22	02/24/23
32	Photogrammetry Cameras	01/07/23	06/02/23
33	**Task Specific Tooling**	01/07/23	04/28/23
34	Fish Tool	01/07/23	04/28/23
35	Pump Tool	01/07/23	04/28/23
36	Light Tool	01/07/23	04/28/23
37	**System Integration**	04/24/23	06/16/23
38	Assembly	04/24/23	05/03/23
39	Testing	05/04/23	05/10/23
40	Practicing	05/11/23	06/16/23
41	**Competition Deliverables**	10/01/22	06/21/23
42	Demonstration Video	05/11/23	05/15/23
43	Technical Documentation	03/11/23	05/23/23
44	Engineering Presentation	05/24/23	06/21/23
45	Marketing Display	05/10/23	06/21/23
46	Corporate Responsibility	10/01/22	05/23/23

Appendix D – Eastern Edge Budget and Expenditures

Eastern Edge Robotics Budget 2023				
Description		**Procurement Method**	**Budgeted USD**	**Expenses USD**
Electrical Expenses	48-to-11.4V DCDC Convertors	New	$279.41	$279.41
	Tooling Board	New	$104.96	$111.96
	Power Board (Without new DC-DC Converters)	New	$233.87	$317.46
	Backplane Board	New	$124.88	$222.96
	Tether Interfacing Board	New	$50.13	$27.22
	ESC Interfacing Board	New	$45.10	$124.96
	Camera Adapter Boards	New	$71.53	$29.93
	Extra Components	New	$148.15	$111.43
	Electrical Budget+Contingecy & Expenses Total :		**$1,163.81**	**$1,225.33**
Mechanical Expenses	Mech. Hardware	In-stock/Reused	$117.27	$162.26
	Enclosure	New	$397.27	$469.69
	HDPE	In-stock/Reused	$194.10	$0.00
	Lift Bag	In-stock/Reused	$148.15	$0.00
	Cameras	New	$94.00	$218.43
	T200 Thrusters	Reused	$0.00	$0.00
	ESCs	Reused	$0.00	$0.00
	Non-Budgeted Items	N/A	$0.00	$0.00
	Mechanical Budget+Contingecy & Expenses Total :		**$1,019.07**	**$850.38**
Payload Expenses	Active Tooling Manipulator	New	$206.80	$198.07
	Vertical Profiler	Reused	$333.66	$98.02
	Props for Testing	New	$151.44	$210.81
	Other Required Tools	New	$24.80	$27.25
	Paylaod Budget+Contingecy & Expenses Total :		**$1,003.39**	**$534.15**
Administration Expenses	Competition Registration	New	$450.00	$450.00
	Printing	New	$24.53	$24.53
	Website Fees	New	$14.48	$14.48
	Open House	New	$113.45	$113.41
	Poster Printing	New	$203.70	$0.00
	Fluid Power Quiz	New	$25.00	$25.00
	Shirts/Polos	New	$666.67	$666.67
	Topsides Laptop	New	$666.67	$666.66
	Non-Budgeted Items	New	$0.00	$89.39
	Administrative Budget+Contingecy & Expenses Total :		**$2,374.70**	**$2,050.14**
Travel Expenses	Flights (17 people)	New	$22,666.67	$22,000.00
	Accomodations (11 rooms, 7 nights)	New	$8,400	$8,400
	Vehicle Transporation	New	$3,200.00	$3,200.00
	Misc. Travel Costs	New	$4,590.00	$4,500.00
	Travel Budget & Expenses Total:		**$38,856.67**	**$38,100.00**
Taxes and Shipping Expenses	**Shipping Costs Budgeted & Expensed**		**$370.37**	**$149.16**
	Taxes Budgeted & Expensed		**$834.14**	**$589.29**
Total Budgeted & Expensed:			**$45,622.15**	**$43,498.45**
Total ROV Budgeted+Contigency & Expenses (Not including props for testing):			**$3,034.83**	**$2,399.04**

Appendix E – Caribou System Integration Diagram (SID)



Fuse Calculation

As there are two (2) 48-11.19V DC/DC converters on board that are rated at 600W each and one 48-5V DC/DC convertor on board rated for 50W, the ROV has a total of 1250W of available power.
The maximum current required by the ROV is therefore 1250W/48V = 26A
Applying the mandatory safety factor gives a required fuse value of 26x1.5 = 39A
As per ELEC-008E, the maximum current supplied to an ROV is 30A, so a 30A fuse is chosen.

Eastern Edge Robotics - Caribou

Electrical System Integration Diagram

Revision History

2020-04-19 - Originally Drawn - DD
2021-09-15 - Concept for 2022 - SF
2022-04-28 - Updated for 2022 - SF
2023-05-17 - Updated for 2023 - SBP