2025 Technical Documentation

Underwater Remotely Operated Vehicles Team (UWROV)

at the University of Washington

Seattle, WA, United States

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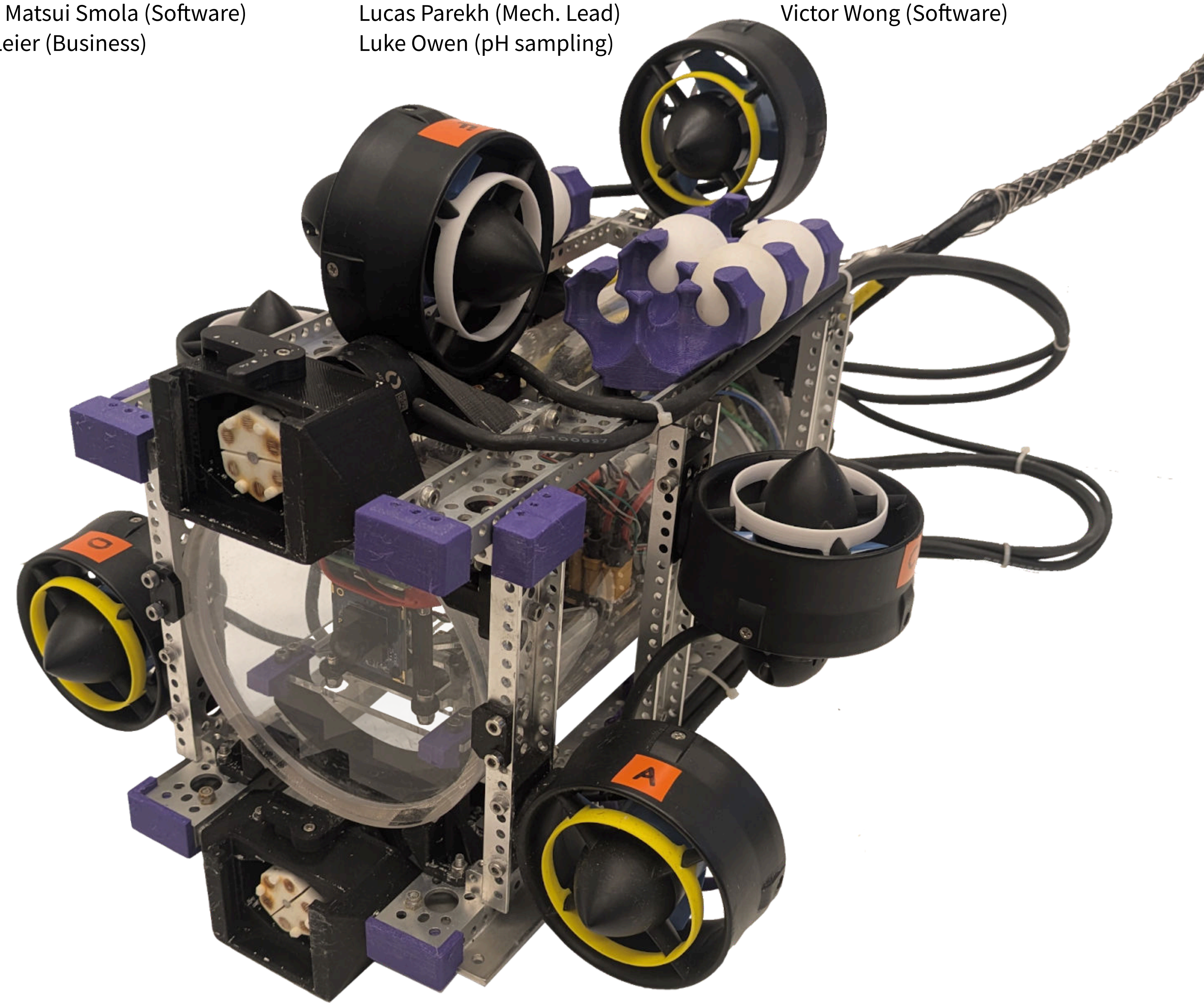

Abstract

The Underwater Remotely Operated Vehicles Team (UWROV) at the University of Washington (Affiliated with the College of the Environment's School of Oceanography) is an undergraduate student team that designs, builds, markets, and competes at the MATE ROV Competition. UWROV is excited to present ***Boxfish 2.0***, a remotely operated vehicle (ROV) designed to complete tasks for the 2025 MATE Request for Proposals (RFP), including shipwreck analysis, monitoring environments, and maintaining marine renewable energy infrastructure. *Boxfish 2.0* is modular, lightweight, and specially designed to be a competitive ROV to complete the MATE RFP tasks. This document provides an overview of the development and design of *Boxfish 2.0*, including timeline, technical features, cost, and more.

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Teamwork

Project Management

Company & Personnel Overview

UWROV personnel consist of a leadership team and employees, with positions and roles detailed in Table 1 and Figure 1. Personnel and their roles are detailed on the title page. All UWROV personnel collaborate in **interdisciplinary project-based teams** which focus on specific components of the ROV to meet the needs of the MATE RFP.

Position	Responsibilities
CEOs	Establishes team processes, long term goals, and external relationships.
CTO	Establishes technical vision and guides integration between technical leads.
Safety Officer	Oversees safety processes and documentation.
Technical Leads	Guide employees working on projects in their domain.
Employees	Work on interdisciplinary projects, consulting leads for guidance.

Table 1. UWROV Positions and Responsibilities.

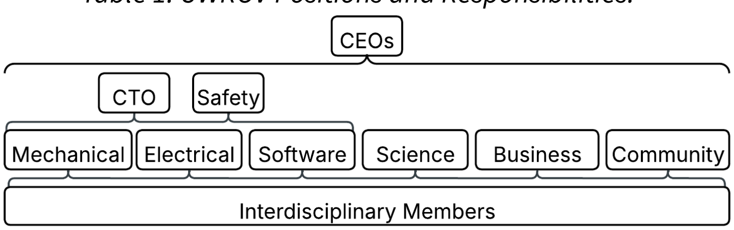


Fig. 1: UWROV Org. Chart.

Schedule

UWROV plans various development phases based around the timing of the MATE ROV Product Demonstration as well as project management principles (see Resources and Protocols). Planning is done before development, outlining timelines and goals for the development phases. The schedule (Fig. 2) is intentionally flexible, allowing for readjustment when blockers occur.

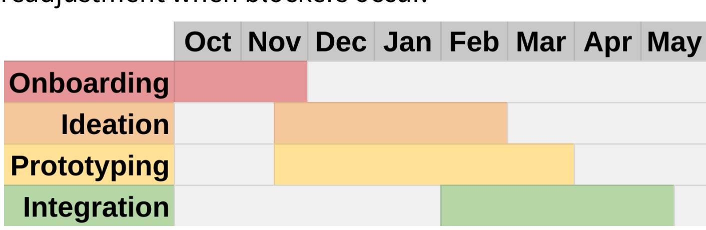


Fig. 2: UWROV Year-Round Schedule.

UWROV holds weekly full-team meetings centered around collaborative project work time. In-water testing is conducted as needed, but more often during prototyping and integration. Throughout any given week, miscellaneous work sessions and longer testing bouts are scheduled for project teams. During these times, employees meet together or work asynchronously to monitor progress and address any blockers.

Resources & Protocols

Various resources and protocols are implemented and made available to all employees to ensure **cohesive day-to-day project work** as well as ensure the overall team stays on track with **achieving mission objectives.**

Resources:

We use the **Google Suite** for file storage and document sharing (Shared Google Drive). We use **Outlook** for email and external communications, and for internal communications use **Discord**, with dedicated channels and threads for areas of development and specific projects. We use **Onshape CAD** for mechanical design, and **KiCAD EDA** for electrical design. Software is developed in an open source **Github** repository, and project management and tracking is done through **Notion**. With the exception of KiCAD, all of these resources allow for **online collaboration and communication**, speeding up the development process and limiting miscommunication.

Protocols:

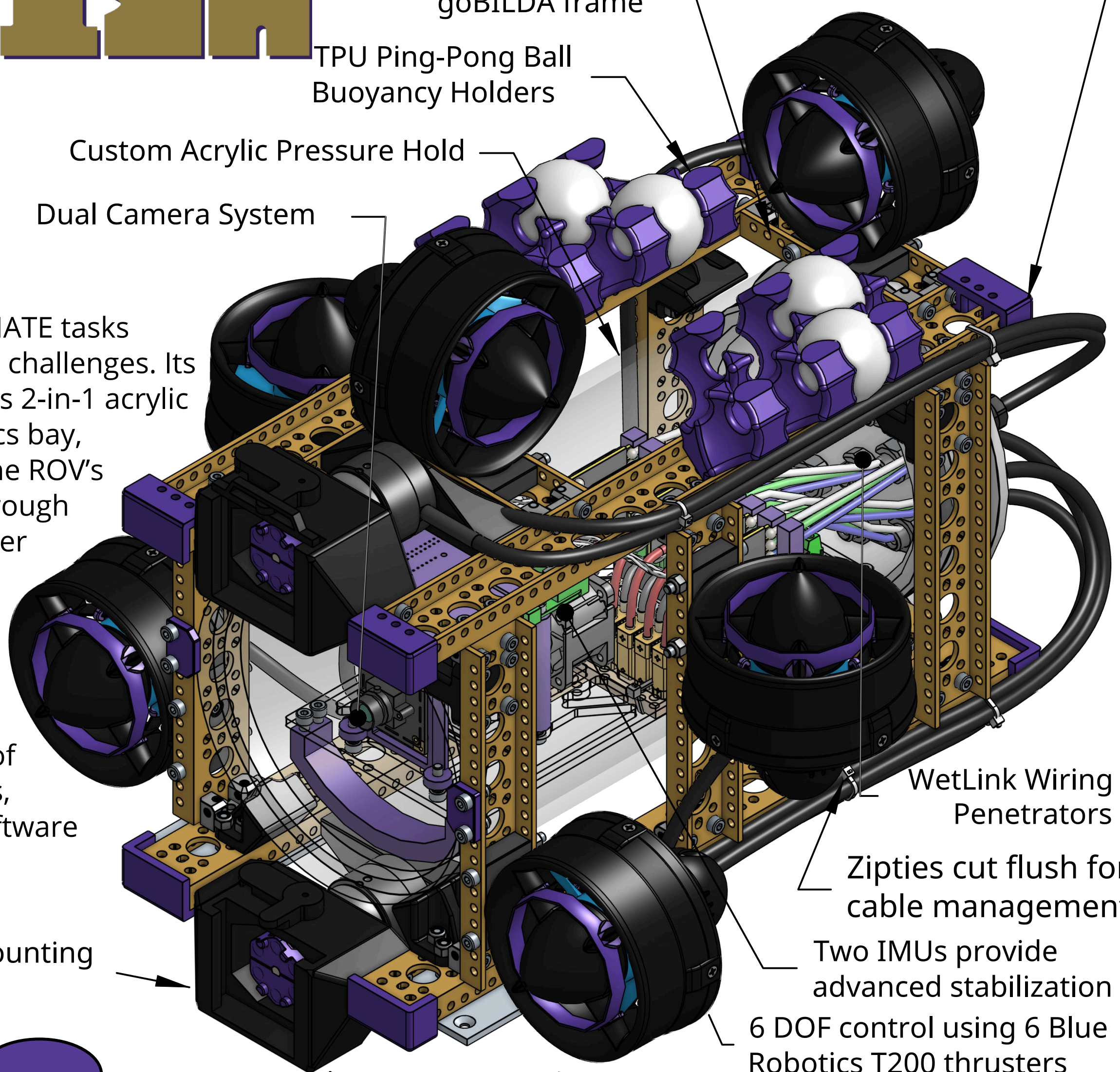
UWROV makes use of an **'Agile'** development methodology, utilizing short-term, interdisciplinary project subteams in order to work towards larger-scale, long-term goals for the ROV [1]. Drawing from that methodology, every weekly team meeting begins with a **standup**, in which every employee and lead gives an update on their progress and any blockers they are facing. Then, as a team, suggestions to any blockers are given, solving problems collaboratively. These updates are reflected in the associated Notion project page by the project team. These pages serve as the primary **day-to-day form of documentation** that tracks project progress, plans, and other materials such as links, pictures, and project metadata. Rather than assigning employees to specific topics (such as electrical, mechanical, software, business, etc.), we create projects that have these specific topics in mind and encourage employees to join projects they are interested in, allowing employees to explore new skills and promote the interdisciplinary aspect and smooth integration of robotics systems work.

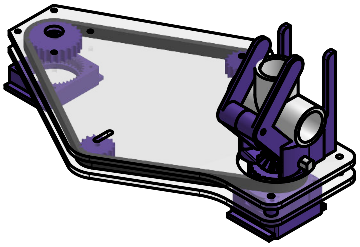
BOXFISH

Design Overview

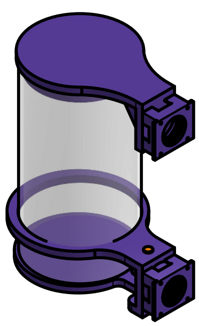
All dimensions in this document are in millimeters unless otherwise specified!

Boxfish 2.0 *is* optimized for MATE tasks while minimizing deployment challenges. Its ruggedized chassis protects its 2-in-1 acrylic buoyancy module + electronics bay, while the risk of damage to the ROV's environment is minimized through protective features like thruster guards and TPU bumpers. Two integrated modular manipulators allows specializing for every MATE RFP task, letting *Boxfish 2.0* effectively complete a range of challenging missions. Sensors, cameras, and stabilization software provides assistance to pilots.

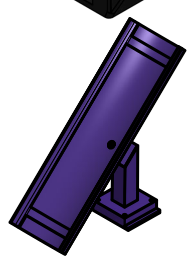




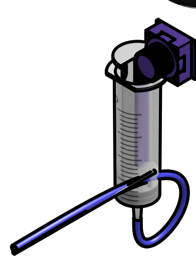
All-Purpose Dual Axis Claw



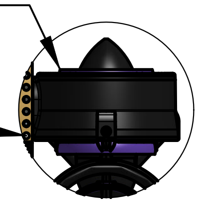
Task 2.2: Collect Medusa Jellyfish



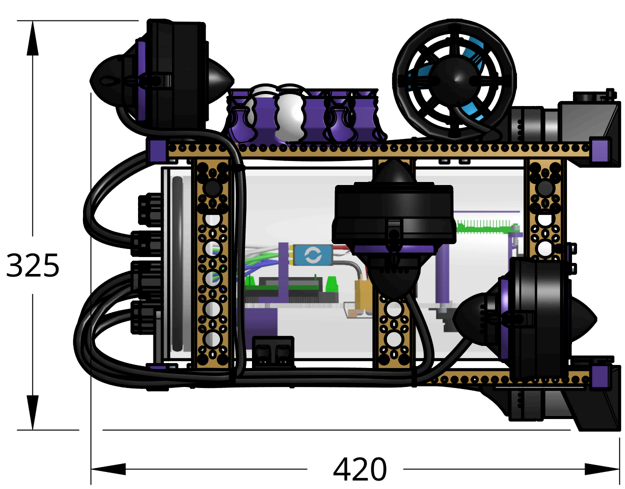
Task 2.1 Underwater Epoxy Patch

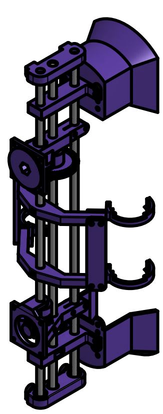


Task 1.3: Collect Water Sample

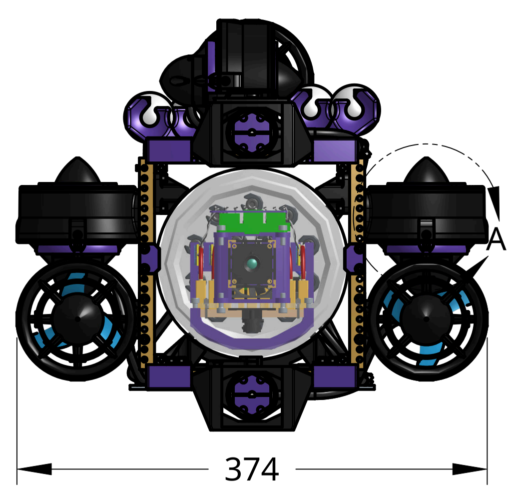


DETAIL A





Task 1.2: Thermistor Replacement



Design Rationale

Planning and Design Process

Boxfish 2.0 iterates on UWROV's previous ROV, *Boxfish*, allowing our company to focus on improving the reliability and performance of pre-existing systems while adapting key systems to meet the needs of the MATE RFP. Our company has adopted a **concurrent engineering** approach, considering all aspects of the product life-cycle during design [2]. This shift responds to difficulties with integration for past ROVs. Our design process consists of several key stages:

Identify Problem and Constraints: Problems, often from feedback or the MATE RFP, are defined, along with constraints.

Brainstorm Solutions: In agile project groups, many solutions are considered to the problem. Data and trade studies are used to inform aspects of the design. Final integration, serviceability, and reliability are central goals in our designs, and considered during brainstorming. At standup meetings, project groups receive feedback from the entire company on their brainstorming solutions.

Design and Prototype: After selecting the most effective design(s), prototypes are made. Factors that we look for include the ease of designing the prototype, the cost of the prototype, and the effectiveness of the prototype at achieving its task. All members of the company can provide input when deciding what designs are developed into prototypes.

Testing: Prototypes are tested, and the data from testing informs the design and further iteration of the part.

Push to Market: Once the design has been sufficiently tested, ensuring quality, it is pushed to the final ROV.

When planning, our company prioritizes problems that are presented in the MATE RFP, relate to ROV reliability and performance, and that are beneficial to building skills of employees.

Systems Approach

Boxfish 2.0's system design approach focuses on **subsystem integration and iteration.** This involves designing the mechanical, electrical, and software components of the ROV in concert, all while making **reasonable compromises** to maximize total system performance for MATE RFP tasks.

Our **digital twin system** involves electromechanical CAD integration. All ROV physical components are modeled together and reflect real-life layout. Modeling interactions between new parts and existing components minimizes design oversights when prototyping new parts. Details such as wire lengths and camera visibility can be examined in our modeling, saving time and effort. Additionally, we create a digital twin of **all parts the ROV must interface** with as outlined in the MATE RFP tasks (Fig. 3). Finally, the digital twin is hosted online and can be accessed at any time, accelerating remote prototyping of new parts and promoting collaboration across different subsystems and groups.

By analyzing new components digitally before physically constructing and testing them, we have confidence in how the ROV will function before the components are integrated. This reduces overhead with in-water testing: rather than debugging large issues pool-side, we have the time and ability to make more nuanced refinements.

In conjunction with the digital twin system, the overall adaptability and modularity of our ROV allows for **efficient mission operations.** For example, our modular manipulator design allows us to create swappable manipulators that complete tasks efficiently, from anode removal to collecting jellyfish polyps from a solar panel array. Our digital twin approach makes it straightforward to develop these different manipulator options in parallel in preparation for the MATE RFP tasks.

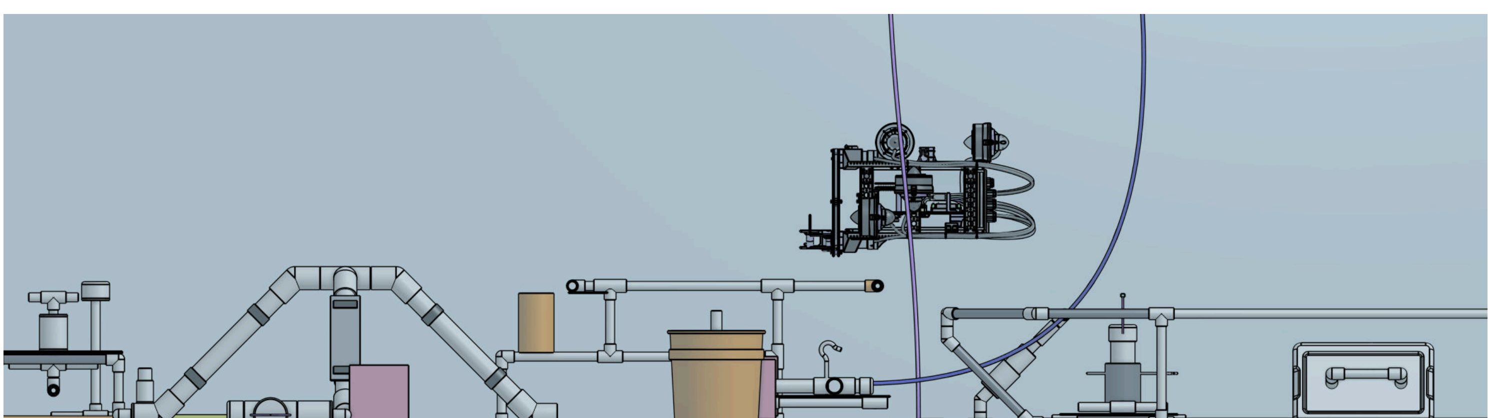


Fig. 3: Digital Twin of Boxfish 2.0 in UWROV's MATE RFP Environment.

Vehicle Structure

Our ROV balances priorities of being **low cost, size, and weight**. Small, lightweight ROVs can be made at a lower cost, are more maneuverable, can be safely handled by a single poolside operator, and have no need for a deployment crane. A small size and frame are optimal for navigating without accidental contact, which is important for the tasks near the shipwreck, however, a lower weight also reduces the inertia, making the ROV more susceptible to unwanted movement. With the benefits of a small, lightweight frame outweighing the costs, *Boxfish 2.0* is designed to be as small as capable while being capable of all tasks in the MATE RFP. A comparison between *Boxfish* and *Boxfish 2.0* is shown in Table 2.

Component	*Boxfish (2024)*	*Boxfish 2.0 (2025)*
Aluminum Frame	1174g	917g
	399mL	318mL
	$190	$154
Structural 3D prints	815g	414g
	536mL	246mL
	$20	$12
Manipulator system	402g	844g
	147mL	356mL
	$205	$380
Electronics bay	1320g	840g
	$795	$639

Table 2: Weight/cost compared to previous ROV iteration.

Vehicle Systems

Component Selection

Boxfish 2.0 consists of a frame, pressure hold, manipulator mount, and modular buoyancy system. The frame of *Boxfish 2.0* utilizes **aluminum goBILDA Mini Low U Channel** and **Dual Block Mounts**, diverging from *Boxfish's* use of the wider goBILDA Low U Channel. This change allowed us to remove 257g of weight to the ROV, while maintaining a comparable amount of modularity and mounting points.

All mounting and frame construction is standardized to **M4 hardware**, allowing serviceability and modularity.

Boxfish 2.0 features a custom pressure hold consisting of a clear **acrylic** cylinder and front plate with an **aluminum** backplate. Produced in-house utilizing a lathe, these parts ensure good sealing, safety for personnel, as well as wiring and O-ring safety through smooth surface finishes and chamfered edges. Producing parts in house allowed our company to grow employee skills and reduce manufacturing costs. Our custom pressure hold is designed to be as large as possible while fitting comfortably in the frame and staying dry at MATE RFP task depths, increasing floatation and volume of electronics.

Relevant properties and attributes of different materials were considered, displayed in Table 3. While acrylic has a lower compressive yield strength, its clear appearance, low cost, relatively low density, and machinability made it an ideal choice for *Boxfish 2.0*'s pressure hull. The clear appearance allows electronics to be easily surveyed for repairs, and the lower compressive strength is acceptable for the MATE RFP required product demonstration. Furthermore, the low thermal conductivity of acrylic is addressed by the use of aluminum–with a very high thermal conductivity—on the backplate for conduction and fans for convection inside the hull. We also chose Aluminum for its lower cost, machinability, low density and compressive strength suitable for the MATE RFP. While aluminum may corrode quicker than more traditional materials, we decided to trade off some lifespan of the vehicle in exchange for significantly lower cost and weight.

Manipulator mounts, requiring less strength, are 3D printed using **PLA**, which allows us to quickly and cheaply make parts. 100% infill is used so water does not seep into parts, changing the buoyancy of the ROV during operation. Similarly, most components in our manipulators do not require as much structural integrity as the frame, and are also made of PLA. Some components are machined from aluminum for increased strength when size constrained.

Boxfish 2.0 features a modular buoyancy system, allowing for dynamic reballasting in the field. Modular buoyancy units can be snapped into place at several points on the frame, shifting the center of buoyancy forward or backward without tools/equipment.

Material	Cost	Able to Machine In House?	Compressive Yield Strength [Mpa]	Corrosion Resistance	Density [kg/m^3]	Thermal Conductivity [W/m-K]
Aluminum	$	Yes	530	Medium	2830	$1.25*10^2$
Acrylic	$	Yes	120	High	1185	$2.00*10^{-1}$
Stainless Steel	$$	No	700	High	7720	$1.67*10^1$
Titanium	$$$	No	970	Excellent	4430	$6.70*10^0$

Table 3: Properties of Possible ROV Structure Materials [3-10].

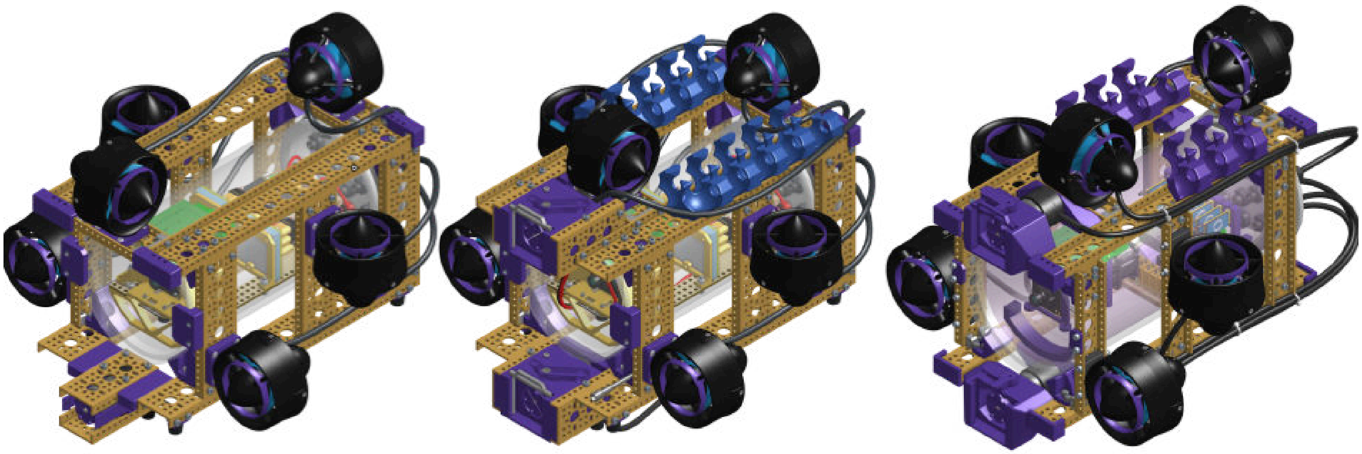


Fig. 4: Evolution of Boxfish 2.0.

Design Evolution

The evolution of *Boxfish 2.0* is shown in Figure 4. While *Boxfish 2.0* saw iterations off of its predecessor, *Boxfish*, in nearly every way, some changes stand out. Notably, *Boxfish 2.0* features two manipulator mounts, located at the front of the ROV. This allowed our company to mount more complex manipulators to the ROV, which was particularly necessary for tasks requiring fine motor skills, such as replacing the anode in task 2.1 of the MATE RFP. Additionally, flotation mounts at the top of the ROV were added that allowed for the quick attachment of ping pong balls, making it even easier for *Boxfish 2.0* to adjust buoyancy between the varying environments required in the MATE RFP. Increased buoyancy also allows *Boxfish 2.0* to require less hard buoyancy, reducing drag to allow more effective movement between tasks.

The electronics hull of *Boxfish 2.0* also saw a major overhaul from the start of the season (Fig. 5). These improvements were made with the goal of reducing the weight of the ROV and improving efficiency in MATE RFP tasks. We added a second IMU, feeding into stabilization code that helps better accomplish delicate tasks and achieve precise motion which is needed for several of the tasks such as anode thermistor replacement. Components were hard mounted to mitigate tangling and prevent undue stress on solder joints, increasing safety and reliability.

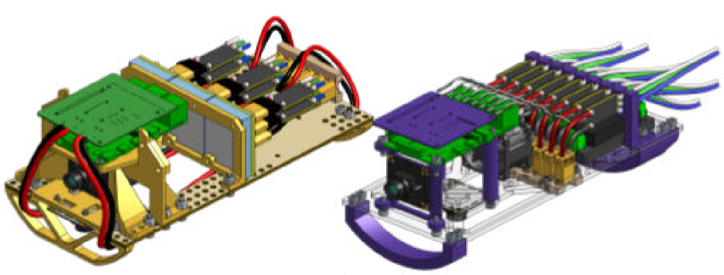


Fig. 5: Evolution of Boxfish 2.0*'s Electronics Bay.*

Control and Electrical Systems

Electronic Design and Cabling

We custom designed our electrical system to emphasize modularity, safety, and performance in order to maneuver the ROV and power relevant devices. The thruster controls let the ROV navigate around underwater structures, and the powering of the manipulators allows the ROV to repair devices and interact with the environment. We standardized all our 48 to 12 V and 48 to 5 V power systems to be equipped with **XT60 and XT30** connectors respectively. Compared to screw terminals, the **standardization** of connectors allows for quick swapping of spare components, easy implementation of new designs, and increase of space. We also custom-designed printed circuit boards (PCBs) using **KiCad EDA** to conserve space, improve efficiency, simplify mounting, and enhance reliability. Our Pi Hat PCB (Fig. 6) connects the Raspberry Pi to our electronic speed controllers (ESC), cooling fan,

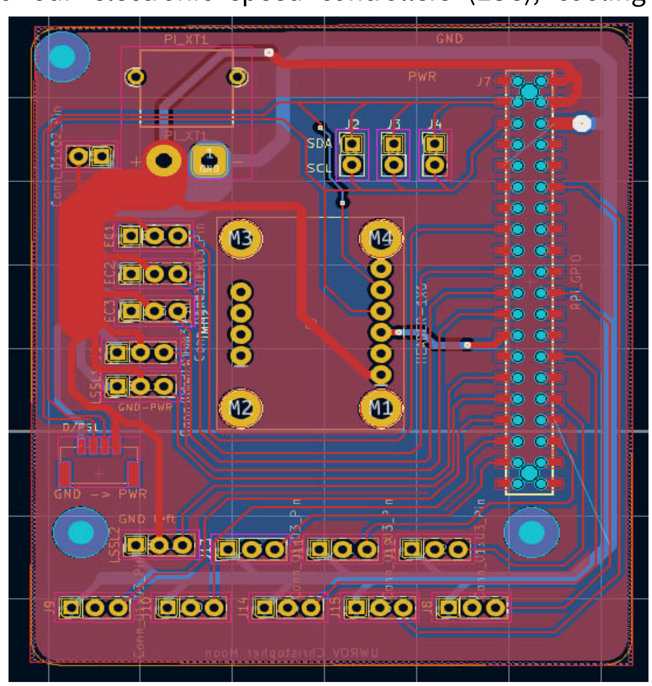


Fig. 6: Raspberry Pi Hat PCB.

cameras, and sensors. The PCB connections ensure that users have a **stable electrical system** during operations.
Our 48 to 12 V power system utilizes a singular powerful converter to drive the power demands of the thrusters [12]. The output of this converter feeds into our **custom-built** copper bus, (Fig. 7) that is capable of supplying safe continuous power. The structure of the bus consists of two copper plates with equally spaced holes drilled into it. These holes house the XT60 connectors for all of the motors. We used pure copper to **minimize** resistive losses, which helps keep the electronics at a **functional** temperature. The 48 to 5V power system also utilizes a single power converter to drive the Raspberry Pi and other sensitive electronics.

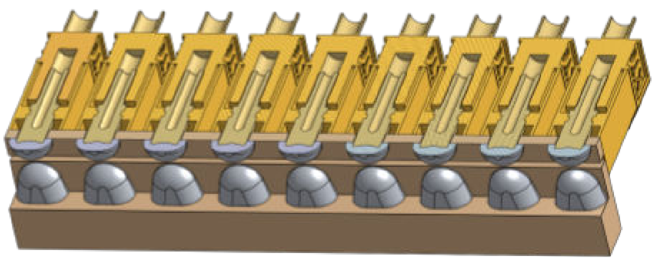


Fig. 7: XT60 Copper Bus.

Control Station

The **control station** is the collection of equipment the pilot uses to operate the ROV. *Boxfish 2.0*'s control station consists of a **Lenovo ThinkPad E16** laptop and **Logitech F310** controller, in which the laptop is connected to the ROV directly via ethernet. It should be noted that while we utilize this specific laptop, *Boxfish 2.0*'s control system is compatible with **any computer with an ethernet port**. The ROV's Raspberry Pi works as a DHCP server, enabling **zero-configuration, routerless operation** with any ethernet-enabled surface station to **maximize ease of deployment by customers**. This design is intentionally simple, ensuring **efficient, reliable processes** for setup and teardown during MATE operations.

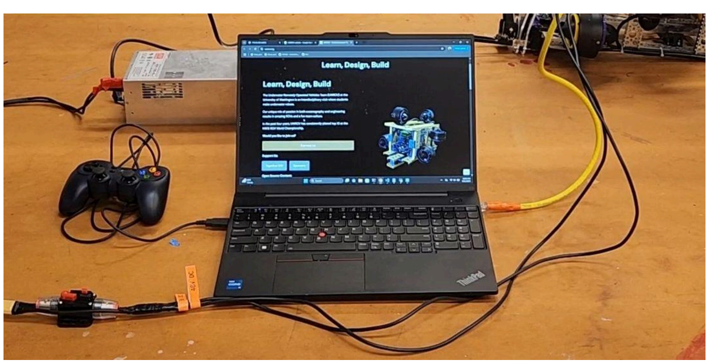


Fig. 8: The surface side of Boxfish 2.0. *A generic laptop and Logitech controller connect to the ROV via ethernet.*

Control System Software

Our software system consists of two parts, a surface station computer and an onboard **Raspberry Pi 4**. The two parts communicate with each other through **websockets**. This design promotes modularity and simplicity of communication between the ROV and control station.

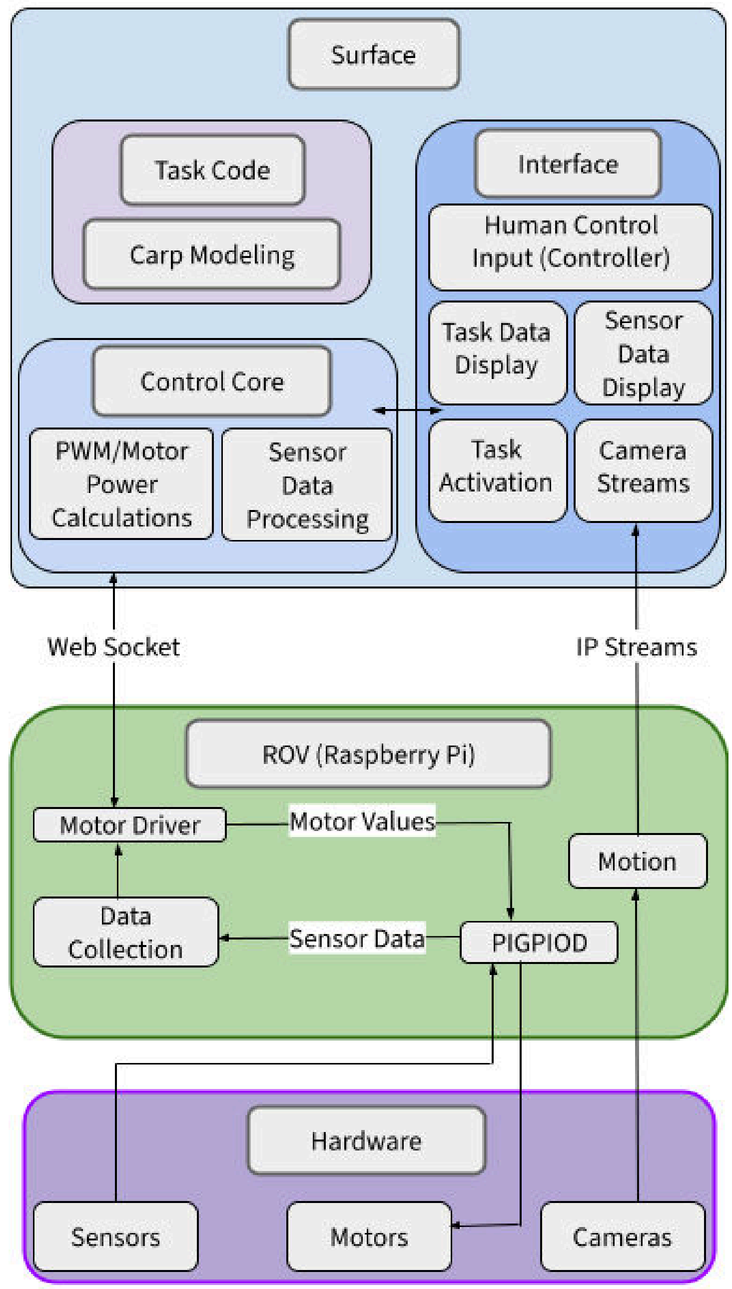


Fig. 9: Architecture diagram of ROV software systems.

The software on the surface station is divided into 3 components: Interface, Control Core, and Task Code. The Interface and Control Core components work in tandem to manage ROV control, while Task Code operates independently from the rest of the system to handle MATE task-related processes. The Interface component accepts human input from a controller and sends movement commands to the Control Core. The Control Core translates the commands into **pulse-width modulation values** and sends them to the Raspberry Pi via websockets. The Task Code creates a computer-animated model of invasive cap movement for Task 1.3.

The onboard Raspberry Pi is the intermediary between the surface station and the ROV's sensors and actuators. It relays pulse-width modulation values from the surface station to the motor system and transmits data from sensors and cameras back to the surface station.

The software of the ROV is implemented in **Godot** and **Python**. Godot's capabilities as a game engine allow it to natively accept inputs from the controller as well as provide a simulated visualization of the ROV's rotation. Meanwhile, Python is utilized throughout the rest of the ROV's system for movement-related computations. The Task Code is implemented in MATLAB, which takes the .csv data given at competition and generates an animated graph showing the movement of invasive carp through the Illinois River Watershed for Task 1.3.

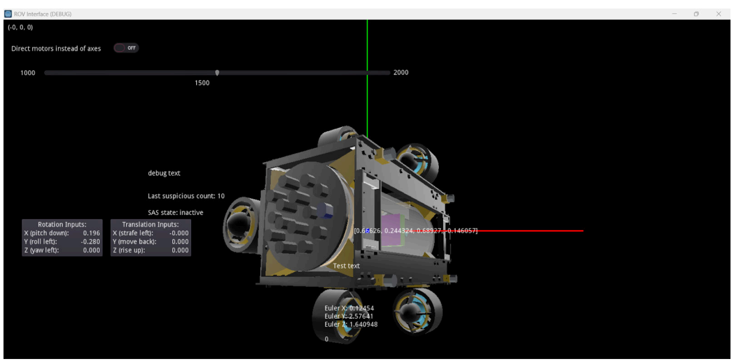


Fig. 10: Surface Station Godot interface of ROV.

The control software includes a software copilot that aids ROV piloting. The copilot is designed to assist pilots by enhancing accuracy and stability during operation. It leverages data from the onboard accelerometer and gyroscope to account for unwanted rotational drift and oscillation. Fusion of **dual inertial sensors** along with **Kalman filters** improves reliability and accuracy, allowing the ROV to account for outliers and noise in data. An onboard depth sensor is used in conjunction with linear acceleration data to create a **depth-hold** mode, allowing the pilot to maintain a consistent depth when faced with disturbances in the water. This is particularly useful for tasks that require consistent stationary hovering, such as anode replacement, or tasks that make use of precise depth-based maneuvering. All copilot error correction (unwanted rotational velocity, depth displacement from setpoint) is powered by **proportional-integral-derivative (PID) controllers**, tuned to balance aggressive correction, dampening to prevent overshoot, and steady-state error correction.

Tether Construction

Flexibility, low weight, durability, and reliability when transporting power and data were the design goals of *Boxfish 2.0's* tether (Fig. 11). For power, we use **10 AWG UL 1426 marine-grade wire** for its good efficiency-to-weight ratio for our 48-volt system. The two cable power system allows us to use modified WetLink Penetrators to connect to the pressure hold, while its PVC jacket and flexible stranded copper conductors enable safe, dynamic underwater deployment. A **Blue Robotics Fathom ROV Tether** acts as a CAT 5 ethernet cable for data transfer. Its flexibility and resistance to damage provide a stable backbone for the ROV's control system. The three cables are covered with a braided polyester sheath, protecting the cables from abrasion while keeping the tether flexible. It uses a 12 mm (½" nominal) sheathing.

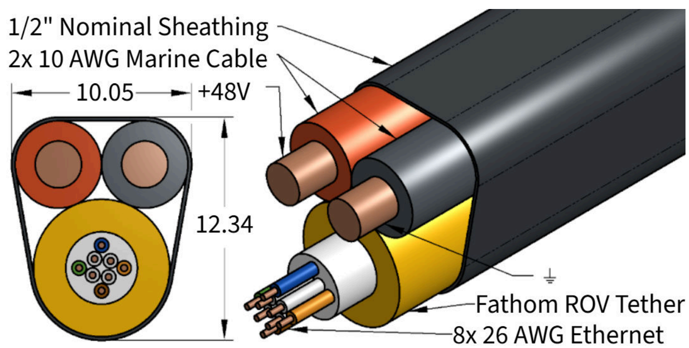


Fig. 11: Cross Section of the Tether.

We chose a **20 meter length** for the tether based on a CAD model of the MATE pool specifications, plus ~10% margin (Fig. 12). By limiting the length of our tether to what we need, we reduce tripping hazards while mitigating voltage drop. From our determined full load amps (FLA), *Boxfish 2.0* draws its maximum current of 22.2 A, creating a voltage drop of at most 2.92 V, leaving **45 V (93.75% of maximum possible) available** for use. The minimum voltage accepted by our power converters is 44 V, so the ROV will always have sufficient voltage.

The tether's internal wires are protected through **strain relief grips** on each end of the tether and a **braided cable sheath** covering the cable run. When the tether is pulled, the strain relief prevents the wires from experiencing extraneous tension, mitigating damage and improving ROV performance. On the surface, the data cable connects directly to our surface station. The power cables connect to the MATE power supply via a resettable 30 A inline breaker that serves as an **emergency shutoff switch**. They are also outfitted with the MATE-specified 30 A inline fuse, and MATE-specified powerpoles. With a working strength of 36 kg and a breaking strength of 159 kg, the tether is strong enough that the ROV can be safely lifted by the tether with the installed strain relief.

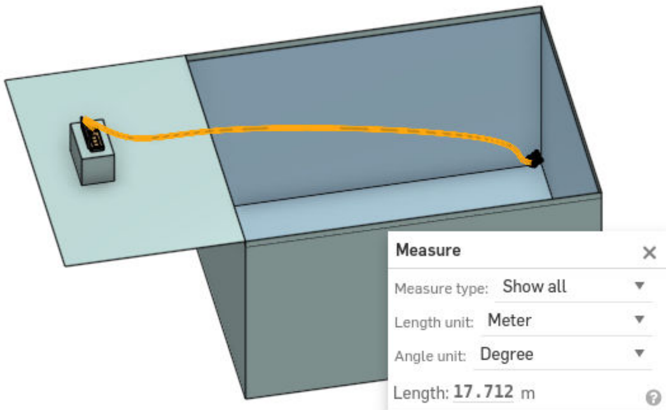


Fig. 12. CAD of MATE pool specifications showing minimum tether length.

Tether Management Protocol

1. Designate someone as tether tender for the duration of operations.
2. Tether tender uncoils tether in a figure eight on the deck, preventing the tether from kinking or tangling.
3. Tether is connected to the surface station strain relief, then power, then ethernet.
4. Strain relief is checked on both ROV and surface side.
5. Tether tender must provide enough tether length necessary to allow the ROV to reach its working depth. Too little will inhibit the ROV, too much will cause tangling.
6. ROV pilot avoids 360 degree rotations & close maneuvers around obstacles to mitigate tangling.
7. Never step on the tether, as this could damage signal and power wires.
8. Once operations are completed, tether tender is in charge of disconnecting the tether from the surface station and power.
9. After disconnection, the tether tender coils the tether.

Adapted from Christ & Wernli, 2013 and Moore, Bohm, & Jensen, 2010

Propulsion

Boxfish 2.0 utilizes 6 **Blue Robotics T200** thrusters for propulsion. We chose to use these thrusters due to their moderate cost and good efficiency at lower power levels. Each thruster is run at 12 V with a max current draw of 17 A, consuming a theoretical maximum of 1.2 kW in total, meaning they could be run continuously without issue. The PWM signal of 1100µs-1900µs corresponds to nonlinear thrust: 37.1N in the forward direction and 29N in reverse, allowing a **maximum lift capacity of 95.1N** when running all three Y-axis thrusters [2*(29N)+37N=95.1] [13]. Based on the positions and orientations of the thrusters relative to the ROV center of mass, we construct a 6x6 matrix representing the combined wrench exerted on the ROV, and by taking the inverse, we can calculate required thrust for a requested CoM acceleration.

To refine the system model for the ROV, we ran a **characterization study** (Fig. 13) on the resultant ROV motion by logging the commanded acceleration against IMU measurement data. From this, we were able to identify and address several less obvious issues, namely that the Y-axis translation had a strong correlation with induced roll behavior. We determined that this was caused by propeller handedness - all three propellers spinning the same way resulted in a torque on the ROV rotating it around its Y-axis. We **used this data to evaluate alternative thruster configurations**: changing the central thruster propeller handedness eliminated nearly all of the induced roll.

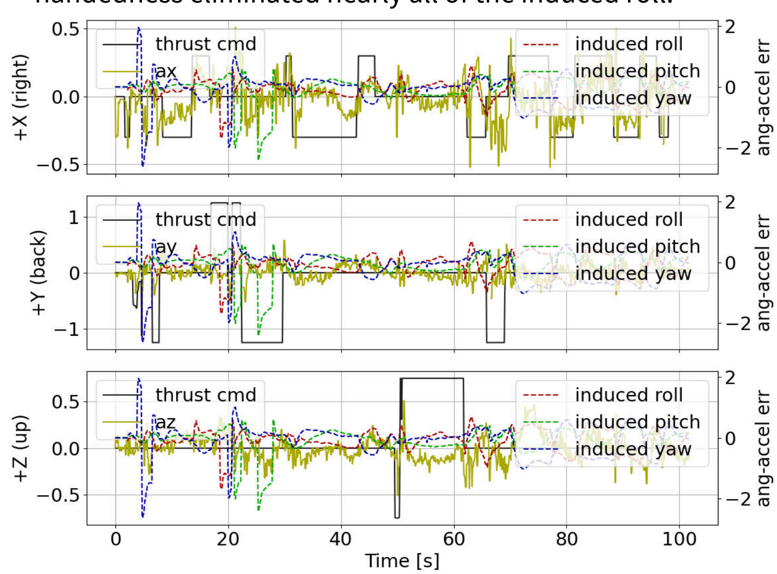


Fig. 13: Thrust characterization data.

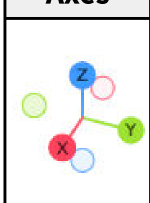
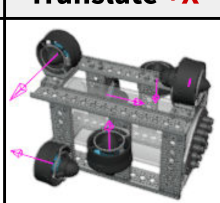
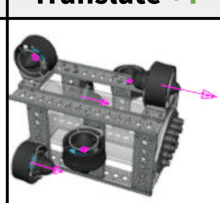
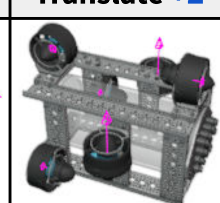
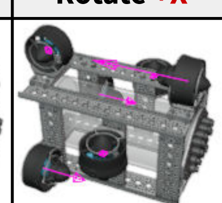
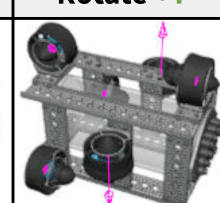
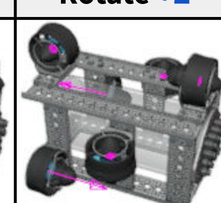
Axes	Translate +X	Translate +Y	Translate +Z	Rotate +X	Rotate +Y	Rotate +Z
						

Table 4: Table of thrust directions (pink) for each axis of movement and rotation (red, green, blue).

Our custom **IP2X motor safety shrouds** provide improved thruster efficiency compared to more traditional protective gratings often seen on ROVs. The increased efficiency allows the ROV pilot to traverse distances more quickly in open waters, decreasing the amount of time it takes to return to the surface and switch manipulators. This allows us to complete more of the MATE tasks within the given time limit. *Boxfish 2.0's* six thrusters are arranged to enable **Six Degrees of Freedom (6 DOF) motion**. Although 6 DOF increases the complexity of our control and stabilization systems compared to more traditional layouts, it raises our performance ceiling, making the tradeoff worthwhile. Based on mission task requirements, we allocated motors to different axes of movement:

- **Y axis (fwd/bwd)**: 3 thrusters, prioritizing speed over long distances to move efficiently between MATE mission tasks located in different areas
- **Z axis (up/down)**: 2 thrusters for moderate vertical speed when delivering payloads to/from seafloor
- **X axis (left/right):** 1 thruster used for slow, precise alignment during manipulation tasks

With these allocations in mind, we selected positions on the ROV that optimize serviceability and control authority. During ROV operation, a Python script solves for necessary motor powers through using the desired force and torque on the ROV combined with thruster orientations and locations in our CAD model.

Buoyancy and Ballast

The main source of our buoyancy comes from our custom pressure hold. Combined with the low weight of the frame and other components, this makes our ROV **neutrally buoyant prior to ballasting**. This year, we revised our ballasting system to prioritize ease of use and modularity, while still considering granularity of the system. **Ping pong balls**, each providing 32g of buoyancy, are attached to the ROV via a 3D printed mounting rack to dynamically shift the center of buoyancy when changing tools

We used our digital twin CAD model to predict ballasting needs before making actual adjustments to the ROV. Our CAD model estimates that our ROV has a mass of 7.991 kg (compared to a real-world weight of 7.969kg - a **0.27% deviation**) while displacing 8.067 liters (8.05kg of freshwater), resulting in a near-perfect neutral buoyancy without any ballast. When testing in saltwater, we attach modular stainless steel ballast plates to increase the density to match the medium.

We made the negatively buoyant tether neutrally buoyant by attaching **closed-cell foam** to counteract the weight of wires and minimize the tether's interference with ROV operations. While closed cell foams, such as those found in pool noodles, crush and leak under pressure, they are suitable for pressures that will be experienced in the MATE task scope [14]. Pool noodles can be adjusted so the tether floats at the surface of the water when the ROV is at the bottom of the body of water we are operating in, minimizing the risk of entanglement for the ROV

Payload and Tools

Cameras & Sensors

The ROV has various sensors to aid in the control of the ROV. It is equipped with two **BR-100126 low-light HD cameras**, which provide clear, high-quality visuals even in low-light underwater environments. We chose this model for its great image quality with minimal processing load during video compression. This ensures the pilot has quality live video feeds when driving, allowing *Boxfish 2.0* to perform the different tasks that are required. The front camera sits between the differential manipulators and provides the user with the view to precisely control the ROV and the manipulators . A downwards facing camera that enables the pilot to have a view of the environment as the ROV descends. This allows for visual analysis of shipwrecks, facilitates the water sample collection process, and helps identify safe places for the ROV to operate, preventing damage to the environment. An additional **Insta360 ONE X2 360 Degree Action Camera** can be attached to the ROV, powered via a waterproofed USB cable connected to the main ROV to create and capture 360° photosphere images of shipwreck environments. We chose this camera due to its fisheye lens which, in conjunction with its waterproofing, make it an apt fit for photographing such environments.

In addition to the cameras, our sensors offer essential data to efficiently interface with users. Two **Adafruit BNO055** Inertial Measurement Units are hard-mounted to our custom Raspberry Pi PCB hat. We average the data coming out, reducing noise and letting us more effectively filter outliers. The sensors are inverted relative to each other, meaning any bias in the sensors is at least partially mitigated. A Blue Robotics **Bar30** depth sensor is mounted into the backplate and tracks the depth of the ROV. By tracking our orientation and depth, we can stabilize the ROV to maintain certain positions, making the ROV extremely accurate when performing precise maneuvers to achieve the tasks.

Modular Manipulator Interface

To address the tasks in the 2025 MATE RFP, *Boxfish 2.0* uses a variety of manipulators via a single interface. This year, we redesigned that interface from the ground up to utilize a slot-and-key system instead of clips in order to improve mounting **reliability**. This new design underwent extensive prototyping and testing, as well as multiple iterations before we arrived at our final interface design.

The assembled manipulator can be seen in Figure 14 (Right), and the components are detailed in Figure 15 (Below).

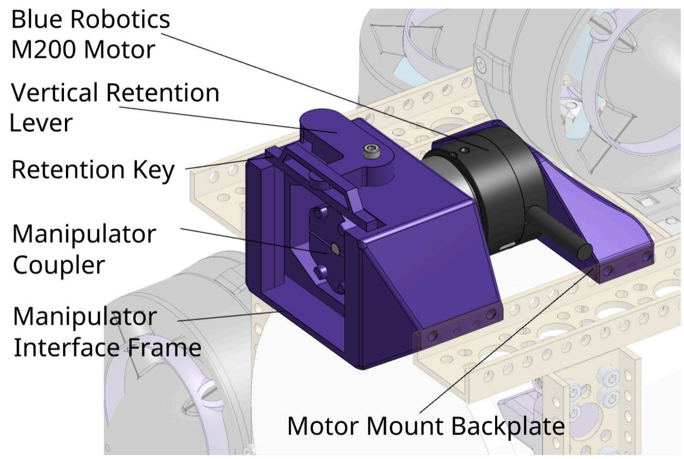


Fig. 14: Layout of the manipulator mount.

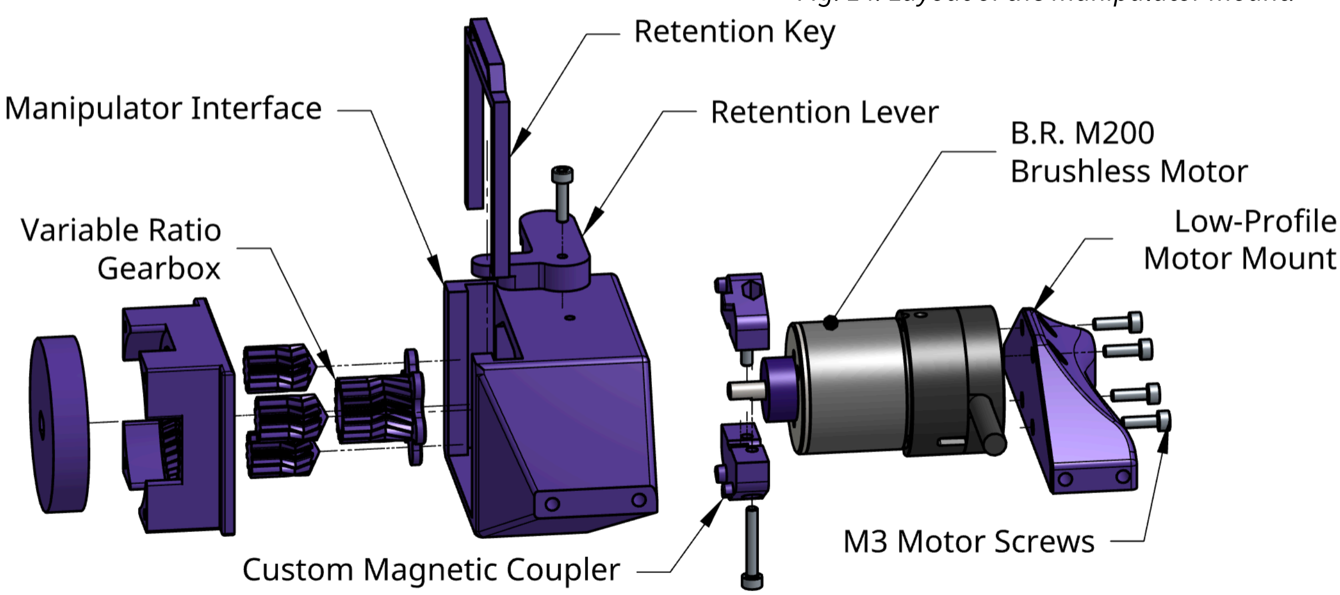


Fig. 15: Manipulator interface exploded view.

Motor Mount: Rigidly mounts Blue Robotics M200 motor to the ROV frame using the minimum amount of material necessary to maintain stability in order to avoid interference with other ROV components and the inclusion of unnecessary mass.

Manipulator Coupler: Facilitates interface between driving motor and Variable Ratio Gearbox for manipulators with magnetic alignment. Fasteners are rotationally symmetric to allow for high-speed input with minimal vibration. Magnets ensure quick-connect alignment, while splined teeth provide positive drive.

Manipulator Interface Frame: Mounts around Blue Robotics M200 motor, providing the slot for the variable ratio gearbox and key to fit into. Design avoids excess material while maintaining strength and providing protection for the motor itself.

Retention Lever: Prevents retention key from moving along its slot, keeping it in position and preventing the key from falling out. The back of the lever clips onto an M3 bolt to maintain the correct rotational positioning when in use.

Retention Key: Holds the variable ratio gearbox in place, allowing it to clear extrusions on manipulator coupler during installation, then slides in front of tabs on gearbox to prevent forwards/backwards motion and maintain both rigidity and meshing with manipulator coupler.

Variable Ratio Gearbox: Used for all drivers, specialized gear ratios for each dynamic manipulator, houses clip shelves. Reduction ranges from **1:1** (for high speed tools used when removing jellyfish polyps) to **64:1** (for high-torque, precise movement when interacting with subsea structures like hydrophones).

Manipulator Design

Our modular manipulator system is compatible with both static and dynamic manipulators. Dynamic manipulators achieve independent motion via a driving module that connects to the external servo via a custom motor coupler. Miniature neodymium magnets in the couplers help automatically align them during installation to engage a positive splined drive. Static manipulators don't move relative to the ROV, and instead take advantage of our high overall agility to maneuver props. static and dynamic manipulators can be installed interchangeably in the quick-connect interface, allowing for rapid tooling changes in the field

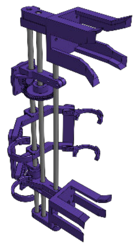
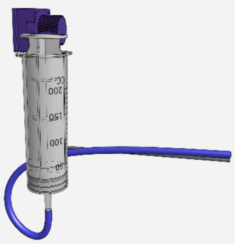
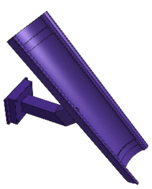
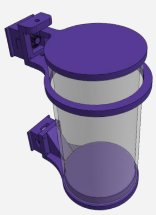
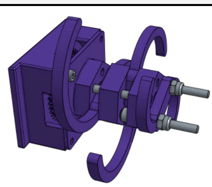
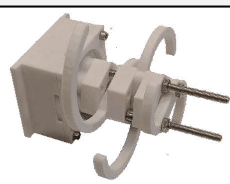
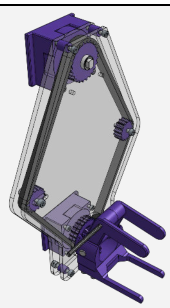
CAD Model	Photo	Description
		***"Scylla"*** Designed to remove and replace the thermistor in one trip. Funnels guide the thermistor into position where it is clipped into place, then the caps are removed and rotated out of the way to insert the new thermistor. *Used for task 1.2 Thermistor Replacement*
		***"Leech"*** Single motor manipulator used to collect a water sample via syringe. The syringe capacity allows for sample collection of up to 200mL, exceeding the MATE requirements. *Used for task 1.3 Collect Water Sample*
		***"Remora"*** Static manipulator used to apply the epoxy patch. The curve of the manipulator matches the pvc pipe of the subsurface station and is slanted outwards at the end to make alignment easier. *Used for task 2.1 Underwater Epoxy Patch*
		***"The Bloop"*** Single motor manipulator used to capture the medusa stage jelly. We used acrylic for the container so that the ROV cameras can see through, both for navigation, and to ensure successful medusa jelly collection. *Used for task 2.2 Collect Medusa Jelly*
		***"Sawfish"*** Single motor manipulator used to hook onto polyp stage jellies. In order to improve the chances of successful collection, the gear reduction factor is decreased to increase speed and reduce torque. *Used for task 2.2 Collect Polyp Stage Jellies*
		***"Clawcodile"*** General purpose grabbing manipulator designed to hold items like PVC pipes. In addition, the manipulator also has a hook that is designed to hold the hydrophone pin. The claw uses a differential system to be able to rotate and close, improving the functionality of the manipulator in certain tasks like replacing sacrificial anodes. *Used for all other tasks*

Table 5: Modular manipulators designed specifically for MATE tasks.

Float Design

NanoFloat 1.1 (NF1.1), shown in Figure 17 (right) returns as a rework and update of UWROV's profiling float system. NanoFloat is designed around two primary objectives: reliable and controlled profiling combined with accurate pressure data transmission for **Task 3: *MATE Floats!***.

NanoFloat 1.1 uses a brushed DC motor with an integrated encoder assembly to accurately **adjust the buoyancy** of the float via a screw-driven piston. A limit switch at the end of piston travel is used in accordance with safety best practices to provide a failsafe against overextension and flooding. The piston flange aligns the piston assembly with the electronics carousel, rotationally constraining the piston. The central **ESP32 microcontrolle**r communicates with the pressure sensor over the I2C bus and **transmits depth data to the surface.** The central microcontroller also uses pressure data in conjunction with a motor position encoder to allow for **precise buoyancy changes and depth holds.** This makes NanoFloat perfect for the depth hold challenge outlined in **Task 3.1.**

NanoFloat 1.1's endcaps measure 37.3mm in diameter and are 270mm long at full extension, lending to its overall small size. Its uniquely small size enables an excellent **displacement-volume ratio** of **0.003:1**, which allows *NanoFloat* to accelerate quickly during profiles.

The parts on *NanoFloat 1.1* are optimized for cost and performance, delivering a superior product at under $100 total cost.

The components of *NanoFloat 1.1* were tested for **maximum current draw**, as displayed in Table 6, providing the necessary data to select a correct and safe fuse. *NanoFloat 1.1* utilizes a single 500mA fuse 2.2cm away from the battery pack, as shown in Figure 16. All systems are powered by a **6V battery pack** consisting of four 1.5V alkaline AAA batteries in series.

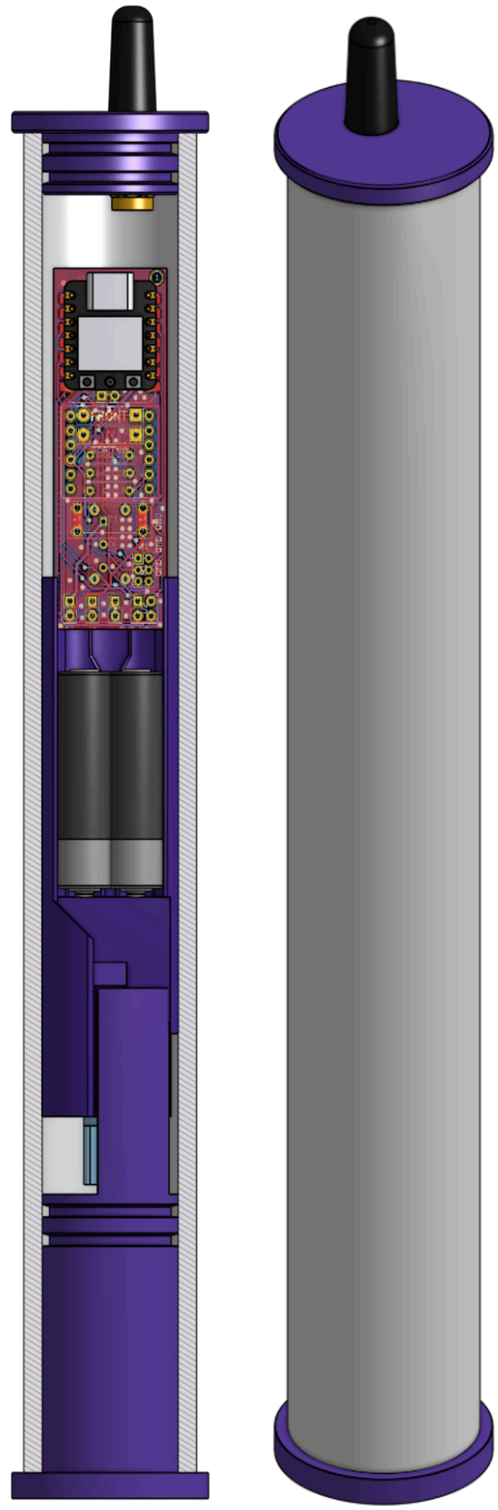
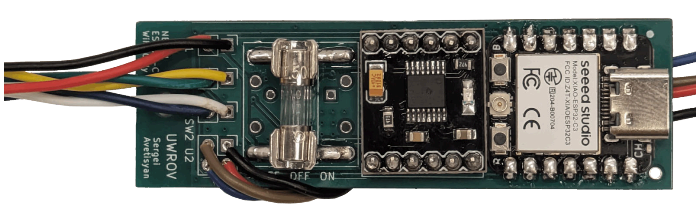


Fig. 17. Nanofloat 1.1 *Section View (Left) and Isometric View (Right)*

Figure 16. 500mA fuse attached to the PCB of NanoFloat 1.1.



Component	Max Current Draw mA
Motor	320
Microcontroller	80
Sensor	~0
Total	**400**

Table 6. Current Measurements for Components of Nanofloat 1.1.

Build vs. Buy, New vs. Used

UWROV **reuses** components of the ROV when they meet requirements and are not performance bottlenecks. Reusing components allows us to reduce development costs and increase reliability by using previously **qualified systems**. We can then focus our development energy on the components that are our current performance bottlenecks. Last year, we implemented a customized manipulator system that enables the use of specialized, high-performance tools for every MATE task. This year, our main focuses were refining that system, as well as improving ROV reliability, maintainability, and performance. We also innovated on our profiling float, expanding data collection capabilities per Task 3 of the MATE RFP.

System	Justification
Raspberry Pi 4	Meets requirements: compute, power draw, ROV systems control, camera & data streaming
Logitech Controller	Meets requirements: control scheme, pilot familiarity, reliability
Cameras	Meets requirements: sufficient visibility for pilot & autonomous systems for MATE tasks requiring underwater visibility (ex. Task 3.2 of MATE RFP)
B.R. T200 Thrusters	Meets requirements: provides sufficient thrust and maneuverability for MATE Tasks

Table 7: Reused Purchased UWROV Systems.

System	Justification
Pressure Hold	Meets requirements: space, mass, visibility, serviceability, and electrical connectivity
Tether	Meets requirements: efficiency, safety, strength, abrasion resistance, and strain relief
Thruster Guards	Meets requirements: IP2X rated, minimal drag, compatible with B.R. thrusters

Table 8: Reused Custom-built UWROV Systems.

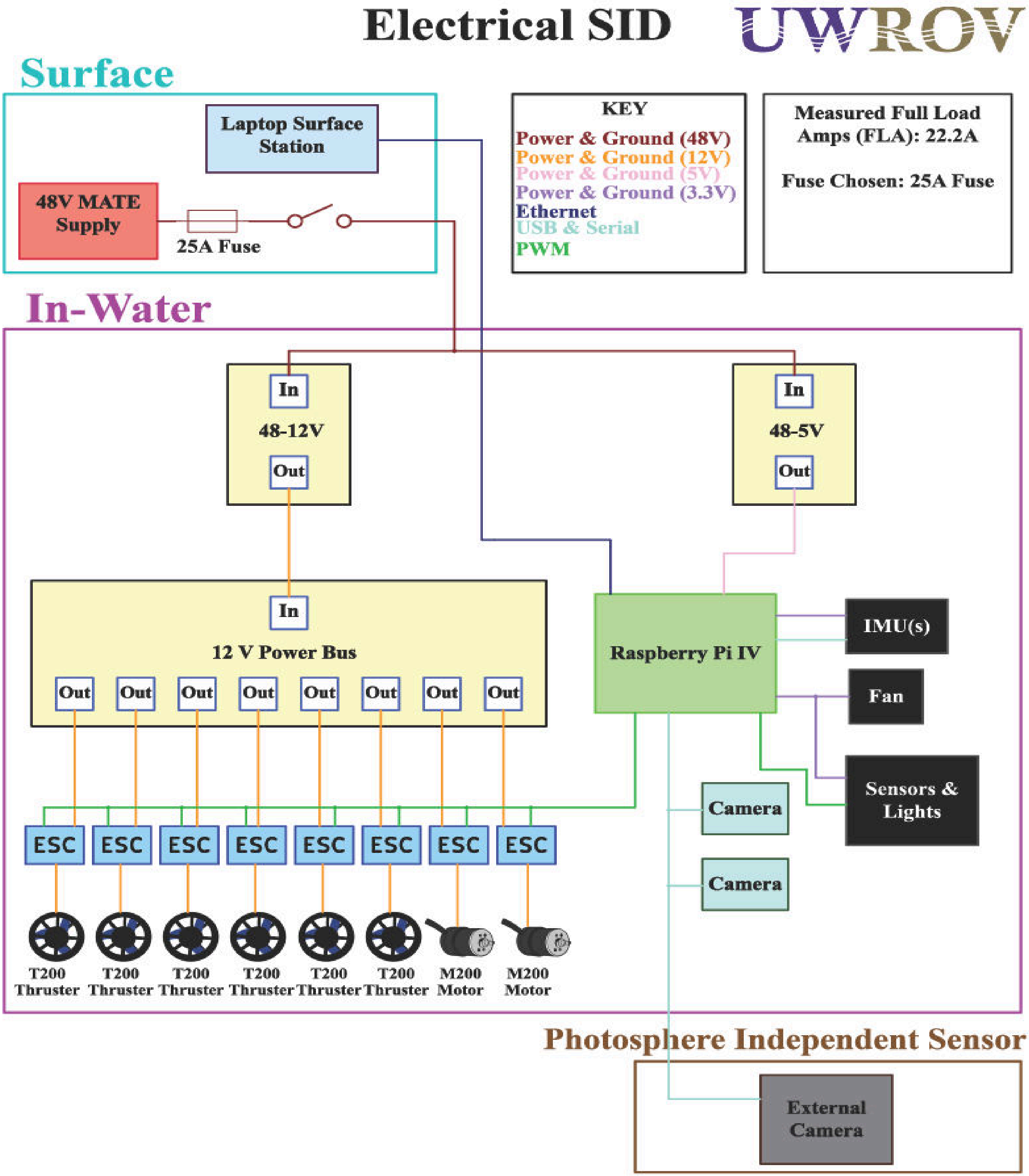
System	Justification
M200 Motor	Dual modular tooling systems use B.R. brushless motors, near-zero maintenance.
316 Hardware	Increased ROV lifespan and mechanical reliability with marine-grade stainless steel
Float Hardware	Iterated float design with a better price to performance, reliability
48V-12V Power Converter	Higher amperage rating yields better power stability for ROV ESCs & thrusters
Surface Station	Old surface station belonged to a former employee. New surface station bought with adequate specifications (handles control inputs, communication with ROV via tether, etc.)

Table 9: Newly Purchased UWROV Systems.

System	Justification
Electrical Systems Chassis	Meets requirements: mounting structure, security, visibility, serviceability
Manipulator Base	Enables specialized manipulators for every MATE task
Manipulators	Specialized tools improve consistency and speed in completing MATE RFP tasks
Bumper System	Protect environment and personnel from sharp/hard corners on ROV
3D Printed Structure	100% infill prevents flooding with water, keeping buoyancy constant
Float Buoyancy Engine	Ultra-cheap, compact float buoyancy driver designed from scratch
CAD Tools	Custom scripts for CAD streamline design process of ROV components

Table 10: New Custom-built UWROV Systems.

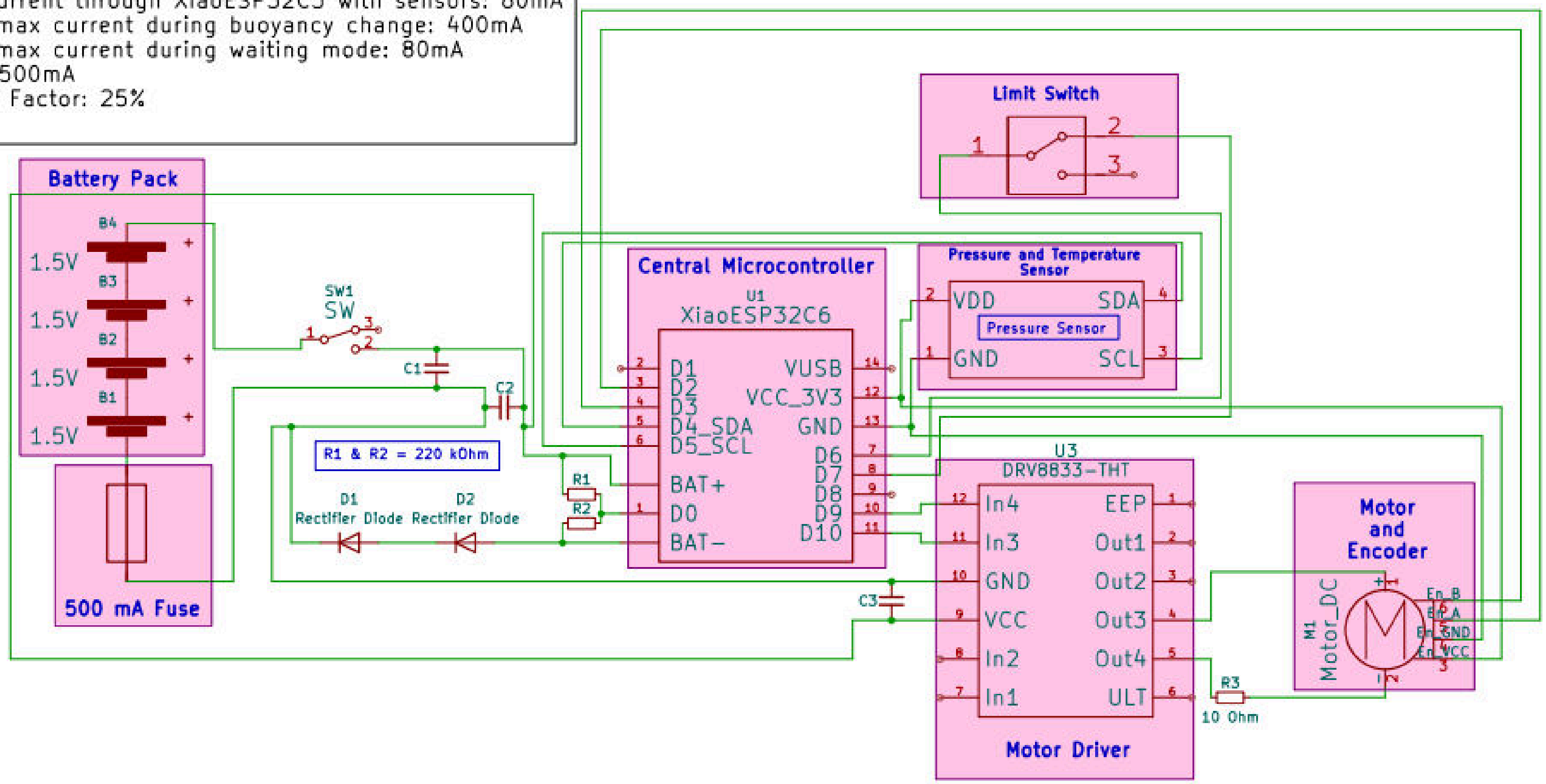
System Integration Diagrams (SIDs)



NanoFloat SID

UWROV

Fuse Calculations:
Max stall current from motor @ 6V: 320mA
Max current through XiaoESP32C3 with sensors: 80mA
Total max current during buoyancy change: 400mA
Total max current during waiting mode: 80mA
Fuse: 500mA
Safety Factor: 25%



Safety

UWROV's safety philosophy is to mitigate risks long before unsafe situations occur. **Personnel and equipment safety** are highly prioritized due to an influx of new employees with little to no experience with engineering equipment. Our leadership team includes a designated **safety lead**, ensuring that employees learn and comply with safety standards set forth by the team and local regulations.

Fig. 18: UWROV employees wearing proper PFDs during an in-pool test.

Personnel Safety

Before using the lab, all employees undergo **mandatory lab safety training**. This training covers safe usage of hand tools, safety equipment location (first aid kits, fire extinguishers, eye showers), accident procedures, required PPE and lab attire (safety glasses, closed-toed shoes, etc.), chemical storage locations, and emergency contacts.

For employees to use power tools such as a drill, bandsaw, lathe, bench grinder and soldering iron, they must undergo **one-on-one, live training with an experienced lead.** This includes live training with the lead, a written exam that covers the different parts of the tool and operational procedures, and a **practical exam** where the employee demonstrates their proficiency with the tool.

Equipment Safety

A major design element during *Boxfish 2.0*'s development revolved around **preventing injury through vehicle safety features.** By making hazards visibly clear to employees and eliminating as many dangerous features and surfaces as possible, UWROV upholds its commitment to safety. Sharp edges or corners of the frame have been either filed down or covered with soft rubber elements to prevent injury to employees and sensitive environments, such as offshore wind farms. Moreover, wiring is kept as close to the ROV frame as possible to prevent them from tangling with the task elements. *Boxfish 2.0*'s thrusters are covered by custom 3D-printed IP2X compliant thruster shields to both avoid employee harm during ROV operations and to prevent ropes or cables from being caught in the thrusters.

All electrical connections are done through enclosed connectors or a lineman splice that has been flooded with solder and protected with a heat sink. Operational safety procedures ensure that there are no exposed electrical connections within the pressure hold. Additionally, an internal fan in the pressure hold circulates air and prevents the formation of hotspots. Our tether is protected from damage through a braided cable sleeve, along with tether strain relief on the ROV and surface station.

To ensure the ROV does not leak during deployment, our standard operating procedure includes pulling a vacuum on the pressure hull if it has been opened/modified since the last deployment. We use a custom-built 12V vacuum pump with <0.25mL/min bleed rate[11] to pull the hull to at least -50kPa (pressure differential equivalent to a 5m depth underwater), and wait at least 10 minutes. Any non-negligible pressure drop means we immediately halt deployment to identify the leak and fix it.

Operational Safety

UWROV identified potential hazards during operation of the ROV by performing a Jobsite Safety and Environment Analysis (JSEA) and implementing operational checks to mitigate potential risks. Examples include ensuring proper restraint of tools and equipment, clamps on materials being manipulated, and removing loose debris in or around the ROV. Built-in questions in the surface station software upon booting up reminds employees to ensure proper safety procedures during operation, such as verifying if the thrusters and thruster guards are secure.

Precautions are taken to ensure the **safety of the environment during MATE RFP tasks.** Stability software and extreme caution is used when operating near shipwrecks, handling biological samples, and handling sensitive equipment.

Safety Procedures

UWROV's safety procedures mitigate the potential for accidents to occur while assembling and deploying the ROV. The safety procedures have been drafted, reviewed, and confirmed by dedicated safety personnel under 2 documents [see Appendix A: Safety Checklist and Appendix B: Lab Safety Policy] for ease-of-use by UWROV employees.

Critical Analysis

UWROV employs a **data-driven** engineering approach to testing and troubleshooting. We collect extensive data through measuring prototypes, collecting operational telemetry, and analyzing design alternatives, and we use this data to inform trade studies, optimization procedures, and design decisions. This season, *Boxfish 2.0* was tested in-water for **over 60 hours**. Findings from these tests informed improvements in manipulator prototypes, software control parameters, and competition strategy.

Ultra-Compact High-Reduction Gearbox

Our gearbox used to actuate manipulators on *Boxfish 2.0* underwent significant testing and iteration, achieving a reduction ratio of 64:1 within a 48.0x48.0x23.6mm volume, with a maximum **dynamic load of 10N*m**, and a static load of 23.7N*m. To characterize the failure modes of the design and optimize the gearbox for robustness and reliability, we measured the maximum torque by attaching weights to a lever arm on the gearbox for both static and dynamic failure (Fig. 19, below), tracking the failure mode, torque, and wear characteristics.

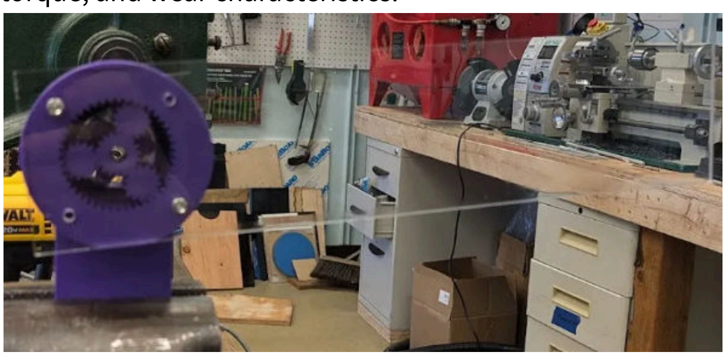


Fig. 19: Gearbox testing setup.

Factors impacting failure included the module of the gear, printer seam placement, and tooth count. Since the gearboxes are 3D printed, we were able to manufacture and test over a dozen configurations that varied one aspect of the gearbox in order to **quantitatively** determine the effect on the failure torque and failure mode. We evaluated performance based on maximum sustained torque, and the failure mode helped us diagnose how to improve the gearbox. For example, we discovered that the planet gear teeth broke along print seams, and achieved a 14.2% average increase in failure strength by manually placing seams at specific locations.

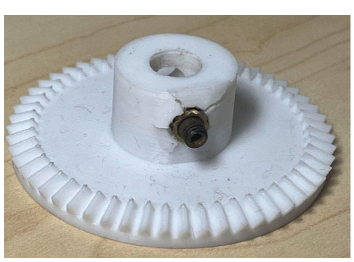


Fig. 20: Failure mode discovered through testing.

Wireless Communications

Testing the wireless communication range of NanoFloat's WiFi communications module was vital to its performance on Task 3, and was subjected to thorough testing. WiFi range was measured by progressively distancing the surface receiver from the float in 1-meter increments and performing a boolean test of transmission and response. Various antenna styles, positioning arrangements, and encasements were tested in this manner, leading us to our current design and antenna choice.

Electrical

At the start of the year, we faced challenges with ESCs restarting unpredictably during regular operation. One of the first steps we took to address this was to develop a test kit (comprised of a known functional ESC, brushless motor, 12V battery, PWM generator, and portable oscilloscope) to rapidly debug electrical issues and isolate whether problems were originating due to power, ESC, or motor issues. With it, we were able to identify two issues:

- ESC header cables were in tension when assembled in ROV, leading to faulty connections
- Thermal throttling of power converters and ESCs would worsen stability with extended operation

We addressed both of these by revising the electronics architecture: Swapping to a single, higher-current rated power converter enabled better heat dissipation and stability, and hard-mounting ESCs eliminated cable strain.

Manipulator Testing

Manipulators undergo rigorous testing both in and out of water, and designs are adjusted based on the results. For example, when designing the "Scylla" manipulator for the thermistor replacement task, we found that the manipulator functioned fine when out of the water, but when conducting in-water testing, hairline cracks appeared in certain parts after one use. We noticed that fractures only appeared on parts that used heat set inserts, and identified factors that could have caused this problem, such as temperature when placing the insert, pressure from the set screw on the insert, and filament quality. Based on these variables, we created test pieces to isolate what caused the issue, and found that the pressure of the set screw had caused the parts to break. Based on this, we changed the design to use metal shaft collars, which were sturdier than heat set inserts. We verified this solution through data from subsequent in-water tests, confirming that the new design wouldn't fracture.

Accounting

Budget

At the beginning of the year, we created a high-level budget for the season, conducting analysis of budgets and spending from 2023 and 2024 and re-evaluating sections and budgeted amounts. Science Initiatives were a new addition to budget allocation this year to increase development on research and other explorations that do not directly contribute to ROV development, but assist the team in academic and community impact. Additionally, this year we moved our operations to a different shop space, spending funds to organize the space to fit our needs.

Our budget decreased from last year, from $21,950 to $17,025. This is because of a decrease in the funds we received from sponsors this year due to significant budget cuts. This significant decrease in funds made us reevaluate the areas in which we spend most of our budget. In particular, the Tooling & Equipment, Electronics, and Surface Station allocations were greatly reduced, as we saw an excessive budget allocation in 2024. This year, we focused on reusing and repurposing most of our tools and equipment from past years, as well as stretching our thinking to create innovative, inexpensive solutions to problems that arise.

Travel Estimate				
Category	Description	Cost (USD)	Qt.	Subtotal
Airfare	Reimbursement per employee	$100	10	$1000
Lodging	Lodging rental, total (Airbnb)	$2300	1	$2300
Car Rental	Rental for a SUV (Enterprise/National)	$730	2	$1460
			Total:	**$4760**

Table 11 (above): Costing for world championship travel.

Budget Allocation				
Category	Description	Yearly Costs (USD)		
		2023	2024	2025
Lab Safety	Items used for Lab Safety. Ex: Safety glasses, first aid kits, etc.	$300	$200	$200
Tooling & Equipment	Items used in the lab for fabrication, designing, etc. Ex: Wire crimpers, benchtop lathe, soldering iron, etc.	$3,500	$1,000	$500
R&D	Prototypes and materials used in our iterative design process. Ex: props, prototypes of PCBs, sensors, etc.	–	$3,000	$3,000
ROV Surface Station	Items used for the surface side portion of the ROV. Ex: case, computer, router, controllers, etc.	$400	$1,600	$150
ROV Structure	Items used for ROV Frame, tether, and pressure hold. Ex: stock for frame, stock for ballasting, O-rings, etc.	$400	$1,600	$150
ROV Electronics	Items used for internal electronics of the ROV. Ex: sensors, power converters, cameras, etc.	$1,500	$2,500	$700
Float	Items used for the Float. Includes onboard computer, sensors, etc.	$150	$500	$500
Team Operations	Items used to run the team. Ex: shirts/polos, merch, website hosting, etc.	$700	$700	$500
Science Initiatives	Items used to support UWROV's science endeavors including community & materials research	–	–	$500
Competition Logistics	Shipping costs for checking in luggage with the ROV	$180	$350	$350
Competition Fees	Registration fees for the MATE ROV Competition	$450	$500	$475
Competition Travel	Transportation and lodging for the MATE Competition	$6,050	$10,000	$10,000
	Total:	**$13,350**	**$21,950**	**$17,025**

Table 12 (above): 2025 total budget allocation.

Cost Accounting: See **Appendix C**

Acknowledgements

Our operations would not be possible without support from our sponsors. We are incredibly grateful for the help and support we have received this year, and thank the following organizations and people for their contributions:

- Many thanks to MATE II for the organization of the MATE ROV competition and creation of opportunities for students to learn, design, and build ocean technologies,
- Rick Rupan and Alnis Smidchens for his mentoring and guidance of UWROV,
- The University of Washington School of Oceanography, Sam Drucker, and Sasha Seroy for laboratory/classroom space and support,
- The Applied Physics Laboratory at the University of Washington and Marine Technology Society for the continued guidance and support,
- Andrew Meyer for oversight of our lab space, machining guidance, and technical support,
- Romeo Balagot, Taylor Hospenthal, Yun Hutchinson, and Monica Cohn for assistance with administration, finance management, travel logistics, and guidance,
- And the UW Student Technology Fee for financial support.

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Appendix A: Safety Checklists

address safety concerns. Examples of hazards include electrical hazards, mitigations include only working on ensuring that equipment is de-energized before working on it

ROV Construction:

Disassembly:

- [ ] Outside of ROV and work surfaces are completely dry.
- [ ] Work surface is free from debris, including metal shavings, hair strands, dirt, and equipment.

Before closing:

- [ ] Ensure no wires are disconnected or loose, and no wire conductors are exposed to avoid electrical hazards.
- [ ] The pressure hold has no clouding or cracking, and the inside of the pressure hold is completely dry.
- [ ] O-rings & grooves are clean, undamaged, and lubricated (no hairs, dirt, or metal shavings).
- [ ] No wires are pinched between components or the walls of the pressure hold.
- [ ] *Remove pressure vent plug to avoid pressure build-up while closing.*

While closing:

- [ ] Align backplate end cap with main cylinder. Maintain alignment during the entire closing process.
- [ ] Check that tether wires are oriented at the top of the backplate.
- [ ] Use a vacuum pump attached to the pressure vent to pull the backplate endcap onto the ROV.

After closing:

- [ ] *Insert pressure vent plug and verify it is screwed all the way in.*
- [ ] Internal assembly is horizontally level.
- [ ] Both endcaps are flush with the main cylinder.
- [ ] Visually verify that both O-rings form a complete seal.
- [ ] Pressure hold retaining arm is raised.

ROV Operation:

Pre-Deployment:

- [ ] There are enough company employees present to safely operate the ROV (at least Operations Director, Pilot, and Poolside Tether Manager).
- [ ] There is no damage in the ROV frame or pressure hold (watch out for clouding & cracks).
- [ ] Clear the poolside of all loose objects and debris.
- [ ] All ROV attachments (thruster shrouds, buoyancy and ballasting elements, thrusters) are secure.
- [ ] There are no loose connections in the pressure hold.
- [ ] Ensure the tether is laid out neatly without tangling, and away from common walkways.
- [ ] Battery/power supply is completely dry and away from the side of the water to avoid electrical injury.
- [ ] Surface station tether strain relief carabiner is attached to a rigid structure.
- [ ] Surface station laptop is plugged in, powered on, and connected to ROV
- [ ] All personnel are wearing close-toed shoes, safety glasses, no loose clothing, and long hair is tied back.
- [ ] Recovery equipment (pole, net, etc.) handy.
- [ ] Control center and tether staging area are clear of clutter and tripping hazards.

Pre-Initialization:

- [ ] Ensure no water is flooding the pressure hold to prevent electrical risks.
- [ ] Ensure no parts have come loose from the ROV.
- [ ] Verify that all connections are secure to avoid damages to the ROV or electric hazards.

Deployment:

- ☐ ROV Handler exchanges tools and payloads on ROV.
- ☐ Pilot announces “READY FOR HANDS ON”.
- ☐ ROV Handler picks up the ROV by its frame and announces “HANDS ON”, and holds it in the water in the deployment zone.
- ☐ Pilot announces “READY FOR HANDS OFF” when ROV state has stabilized based on cameras & data.
- ☐ ROV Handler releases ROV and announces “HANDS OFF” when no longer touching the ROV.

During Operation:

- ☐ Poolside Tether Manager is following designated tether management protocols to prevent entanglement.
- ☐ Operations Director is facilitating communication between poolside and surface side.
- ☐ To minimize the risk of tripping, do not run near the pool.

Resurfacing after Operation:

- ☐ Pilot navigates ROV to launch & deployment zone, then announces “READY FOR HANDS ON”.
- ☐ ROV Handler picks up the ROV by its frame, then announces “HANDS ON”.

Post-Deployment:

- ☐ If ROV was deployed in saltwater, thoroughly rinse or submerge in freshwater to prevent corrosion and damage to the ROV.

Appendix B: Lab Safety Policy

1. NEVER WORK IN THE LAB WITHOUT LEAD SUPERVISION.
2. Wear lab-appropriate clothing at all times in the lab: safety glasses or side-shields; close-toed, no-slip shoes; gloves (never when working with rotating/moving machinery); no loose clothing; no rings, watches, or bracelets; long hair must be tied back.
3. All injuries or accidents must be reported **immediately** to the Shop Supervisor.
4. If you are in doubt as to a proper or safe procedure, **stop work** and ask for guidance.
5. Report unsafe or hazardous conditions wherever noted. Correct them if possible.
6. Eating or drinking is prohibited in lab spaces.
7. Be thoroughly knowledgeable concerning the equipment you are using.
8. Use tools for their intended purpose only.
9. Do not use fingers or hands to remove chips from moving or stationary machines.
10. Never adjust a moving or rotating machine unless motion is necessary to make adjustment. Always allow the machine to come to a standstill before making adjustments or repairs.
11. Never leave a machine running while unattended, unless machinery is intended to do so.
12. Do not attempt to slow down or stop rotating or moving equipment with hands or tools.
13. File all machined parts or stock with sharp edges.
14. Always clamp or secure the workpiece properly.
15. Use appropriate respiratory protection when working with dusts, mists, fumes or vapors.
16. Read the SDS for all lubricants, resins, adhesives, or other chemicals you are working with.
17. Concentrate on what you are doing. Do not talk or be distracted while operating equipment.
18. Use proper techniques and obtain assistance when lifting, moving, or carrying loads.
19. Watch for tripping hazards. Do not place material or objects in thoroughfares or passageways.
20. Know the location of fire extinguishers, fire exits, eye showers and first aid kits.

Adapted from the UW Mechanical Engineering Machine Shop Rules (College of Engineering, 2021). [16]

Appendix C: Cost Accounting

Available Funds:

Category	Name	Amount (USD)
	Carryforward Balance from 2024	$8,348.00
Sponsorship	Applied Physics Laboratory	$2,000.00
Sponsorship	Spokbee	$325.76
Grant	Student Technology Fee Grant	$13,649.00
	Total:	**$24,322.76**

ROV Total Cost:

Budget Category	Type	Item(s)	Est. Value (USD)
ROV Surface Station	Reused	Controller	$20
ROV Surface Station	Purchased	Lenovo ThinkPad E16	$729
ROV Power Electronics	Reused	Tether Components	$400
ROV Power Electronics	Purchased	Blue Robotics Speed Controllers x4	$152
ROV Power Electronics	Reused	Blue Robotics Speed Controllers x4	$152
ROV Power Electronics	Reused	Raspberry Pi 4 B 4 GB	$75
ROV Power Electronics	Purchased	Custom Power Converters	$125
ROV Power Electronics	Purchased	M200 Motor x 1	$160
ROV Power Electronics	Reused	M200 Motor x 1	$170
ROV Power Electronics	Reused	T200 Thruster x 6	$1,200
ROV Power Electronics	Reused	Cameras (USB Camera, BR-100126 x2)	$198
ROV Structure	Reused	Acrylic Pressure Hold	$60
ROV Structure	Purchased	goBILDA Low U Channel and Side Block Mounts	$167
ROV Structure	Manufactured	3D Printed Parts	$25
ROV Structure	Reused	Stainless Steel Hardware	$135
		Total:	**$3,768**

Expenses (September 2024 to June 2025):

Budget Category	Example Items	Budgeted	Total Value*	2025 Spending
Lab Safety	Safety glasses, First Aid Kit, Face Shields	$200	$487.71	$221.13
Tooling & Equipment	Chuck Key, Lathe Turning Tool	$500	$4852.00	$1,611.09
Research & Development	Plywood, 3D Printer Filament, Magnets, Test Motor, Prop Materials	$3,000	$2014.11	$1,287.29
ROV Surface Station	Controller, Laptop	$150	$747.99	$805.55
ROV Structure	Frame, Spray Paint, Hardware, 3D Prints	$150	$340.18	$167.39
ROV Power Electronics	Power Converters, Cameras, Tether Components, Thrusters, Motors	$700	$2841.41	$709.84
Science Initiatives	Sensors, Lumber, Float-Related Materials	$500	$59.57	$59.57
Float	Antenna, Microcontroller, Sensors, Batteries, PVC Body	$500	$442.58	$166.64
Team Operations	Projector, USBC Adaptors, Printer	$500	$807.16	$166.18
Competition Fees	Explorer Registration Fees, Fluid Power Quiz Registration	$475	$675.00	$675.00
Competition Travel	Airfare, Car Rental, Lodging	$10,000	$460.00	$4760.00
	Total:	**$17,025**	**$13,727.71**	**$10,629.68**

**Total Value includes the value of all ROV operations, including both reused, purchased, and manufactured items.*