UWROV

2024 Technical Documentation

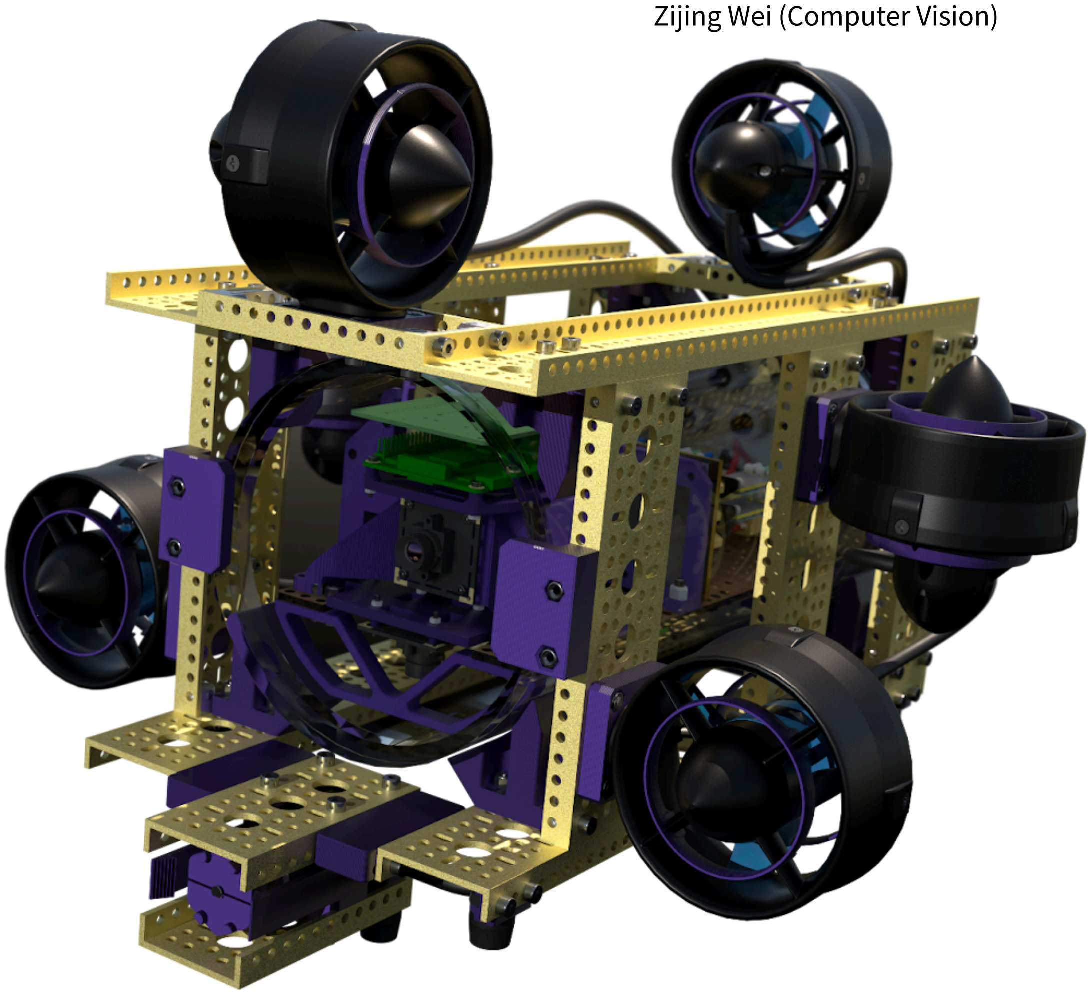
Underwater Remotely Operated Vehicles Team (UWROV)

at the University of Washington

Seattle, WA, United States

Mentored by Rick Rupan

Aidan Lee (Electrical Systems)
Abel Mitiku (Float)
Adam Benazouz (ML Challenge)
Alex Weber (Notion)
Alexandra Yankovskaya (Electrical Systems)
Alnis Smidchens (Chief Technical Officer)
Ben Fowlkes (Manipulators)
Derek Liu (Computer Vision)
Ellen Leier (Float)
Elliana Koenig (Manipulators)
Emily Meng (Float)
Ethan Yang (Software Co-Lead)
Imants Smidchens (Design Lead)
Jordan Wu (Electrical Co-Lead)
Kota Murakami (Manipulators)
Lucas Parekh (Manipulators)
Nick Leung (Electrical Co-Lead)
Olivia Wang (Co-CEO)
Prayug Sigdel (ML Challenge)
Quinn Pfeifer (Photogrammetry and Odometry)
Rowan Newell (Co-CEO)
Samuel Wang (Computer Vision)
Sergei Avetisyan (Science Lead)
Sheamin Kim (Sponsorships and Outreach)
Srihari Krishnaswamy (Software Co-Lead)
Suzu Yoshikawa (Business and Marketing)
Tegan Yao (Manipulators)
Will McClintock (Computer Vision)
Zijing Wei (Computer Vision)



Abstract

The Underwater Remotely Operated Vehicles Team (UWROV) at the University of Washington is excited to present ***Boxfish***, our Remotely Operated Vehicle (ROV) **designed to complete tasks for the 2024 MATE Explorer Challenge**, including maintenance of the Coastal Pioneer Array & SMART Cables, supporting stewardship of marine ecosystems from the Red Sea to Tennessee, and deploying MATE Floats for ocean health monitoring. UWROV's **Teamwork** approach was to follow agile principles while focusing on iteration and safety across disciplines and systems. Our **Design Rationale** was informed by the mission requirements for the tasks specified in the MATE RFP, leading us to develop an ROV with safe, consistent performance, and modular adaptability to specialized mission profiles. This includes a modular manipulator system that enables switching to a specialized tool for every MATE task, a software copilot that aids the pilot in ROV operations, and extensive custom electronics designed within the performance envelope specified by the MATE RFP. We emphasized **Safety** throughout our systems design, lab environment, and operational procedures, and verified MATE Task performance through 32+ hours of testing across 13+ in-water test sessions, collecting data to inform the **Critical Analysis** and improvement of Boxfish's systems. UWROV maintained thorough **Accounting** of income and expenses, resulting in an efficiently and sustainably developed ROV. ***Boxfish* is optimized for the tasks specified in the MATE RFP while prioritizing safety, and is therefore ready to be deployed at the MATE Championship to demonstrate its mission capabilities.**

Table of Contents

Teamwork

Project Management

Company and Personnel Overview

Upcoming Weeks / Demo Prep

Saturday	Sunday	Monday
Apr 27, 2024 - In-Water Testing/Practice Session	Apr 28, 2024 - Regular meeting; finish props for demo, find volunteers for outreach events	Apr 29, 2024 - Readiness check for video demonstration and safety video recording
May 4, 2024 - In-Water Testing/Practice Session	May 5, 2024 - Attempt to record video demonstration and safety video, finalize safety documentation	May 6, 2024 - Plan/Schedule additional video demo recording sessions for during the week
May 11, 2024 - MATE Regional Competition ROV Demo and Volunteering	May 12, 2024 - Begin finalizing technical documentation, in-water practice if possible	May 13, 2024 - Discuss documentation workflow and delegation
May 18, 2024 - Aquatic Sciences Open House Event	May 19, 2024 - Technical Documentation All-Hands	May 20, 2024 - Technical Documentation Progress Check
May 25, 2024 - In-Water Testing/Practice Session	May 26, 2024 - Team Bonding and competition preparation	May 27, 2024 - Discuss competition travel logistics

Fig. 1A. Example of scheduling over several weeks.

Underwater Remotely Operated Vehicles at the University of Washington (affiliated with the College of the Environment's School of Oceanography) is a team of undergraduate students that designs, builds, markets, and competes at the MATE ROV Competition. Members of UWROV collaborate in **interdisciplinary project-based subteams** which focus on specific components of the ROV and MATE ROV Challenge. For a full list of employees and their roles and responsibilities, see the Title page.

Schedule

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. Planning is done early in the season, with subgroup leads working with the team during September and October in order to determine general deadlines for these goals.

This focus on careful, early planning is reflected in the overall timeline of UWROV's work. Onboarding new members occurs in October, with returning members working to assist new members as they familiarize themselves with the ROV systems as well as the team's structure. The months of October and November are then spent reviewing what was built in the previous year, ensuring that systems and technology work as intended. The latter half of November, December, and January are then focused on ideation, with members exploring new possibilities for the ROV. Finally, following this period of investigation, the most efficient and practical ideas then become the focus of the team during April and May. Regular, medium-term planning breaks down milestones into achievable chunks (Fig 1A).

UWROV holds weekly meetings on Monday and Sunday. Monday meetings are primarily centered around administration, setting the direction for the team's work for the coming weeks. Sunday meetings are centered around project work time and **resolving blockers** that arise. In-water testing is conducted frequently based on minor iterations made to the ROV. Saturday is designated for longer, more in-depth testing bouts.

Resources, Procedures, and Protocols

Our company emphasized collaboration and communication in our workflow, making use of cloud-based real-time collaboration technologies as quick and convenient workspaces and encouraging interdisciplinary project work.

Interdisciplinary project subteams regularly recorded their progress on a Google Slideshow, which was presented to the whole team at the start of each meeting. During these presentations, project subteams were able to **share hurdles** encountered in development and ask other subteams for assistance with these issues.

Google Workspace was used for any sharing of all materials; data, CAD files, and visual aids were available to the entire team on a shared Google Drive. This allowed each team member access to the same data, promoting transparency and clear communication.

A Discord server was the primary platform of communication, as it allowed us to organize conversations by subject, streamlining remote communication across project subteams. Onshape CAD, KiCAD, and Github were utilized as more technically-focused platforms for CAD-focused collaboration.

Our team also relied on external software resources to efficiently manage projects and outputs. One such resource used by the team was **Notion** (see Fig. 1B). Through this platform, employees were able to organize projects by type, priority, skill level, and completion status. Notion works alongside pre-existing project management systems, integrating easily into the workflow of UWROV.

Fig 1B: Table View of UWROV Tasks in Notion

Projects

My Work | Component Board | Priority Board | Priority Matrix | Gallery | Mechanical | Software | Electrical | Business | Science | Admin | Table | Table (unsorted) | +

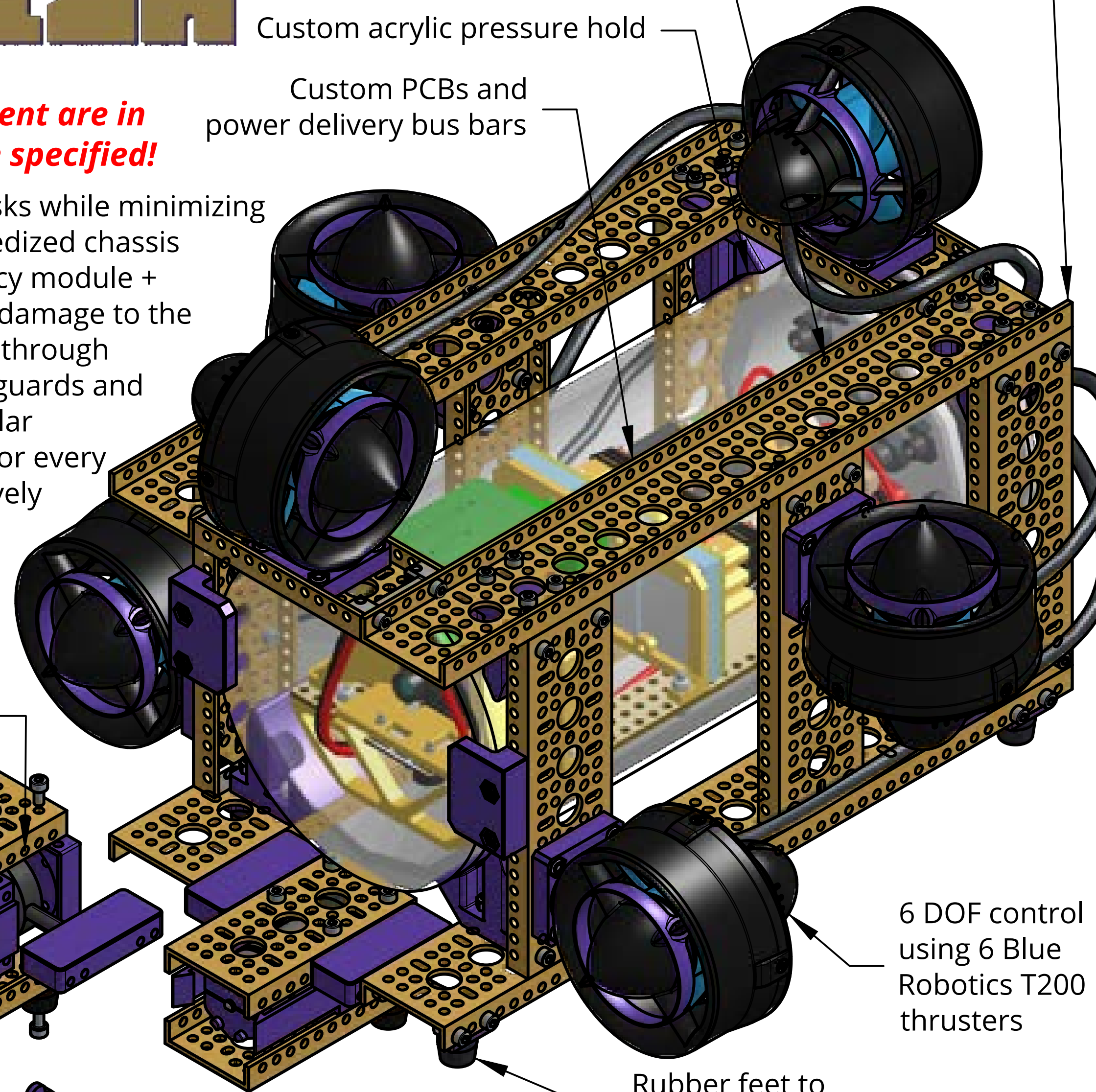
Name	Tags	Size	Priority	Experience	Status	People	Component	Discord Thread
New Electrical System Design	electrical		P1	Adept	In progress	Jordan Wu, Nick	ROV - electronics bay	discord.com/cha...07
Prop Builds	mechanical		P1	Novice	Done	Paige McKay, Lara	MATE	discord.com/cha...71
Emergency Surface Station Rebuild	mechanical, electrical	L	P1	Adept	Done	Imants Smidchens, Alnis Smidchens, Ben Fowlkes	ROV - surface station	discord.com/cha...28
Revised Ballasting System	mechanical		P1	Adept	Done	Rowan Elizabeth Newell	ROV - (misc)	discord.com/cha...33

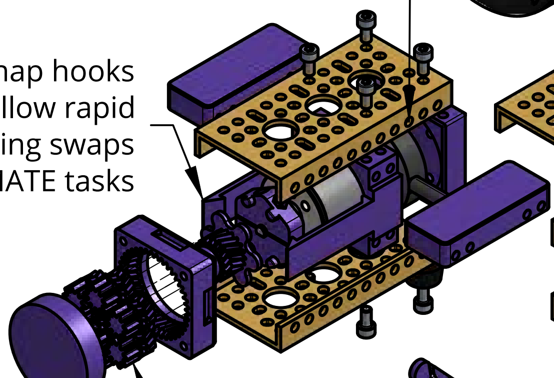
BOXFISH

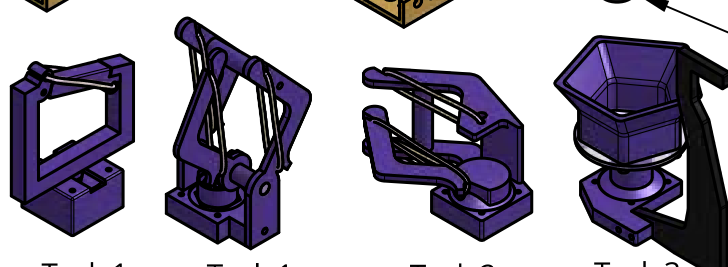
Design Overview

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

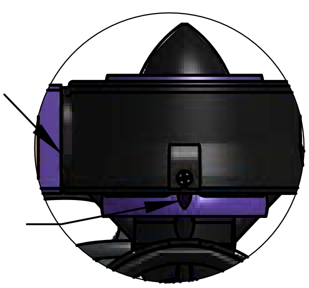
Boxfish is optimized for MATE tasks while minimizing deployment challenges. Its ruggedized chassis protects its 2-in-1 acrylic buoyancy module + electronics bay, while the risk of damage to the ROV's environment is minimized through protective features like thruster guards and rubber feet. An integrated modular manipulator allows specializing for every MATE task, letting *Boxfish* effectively complete a range of challenging missions, while digital cameras provide guidance to its autopilot and the human pilot.



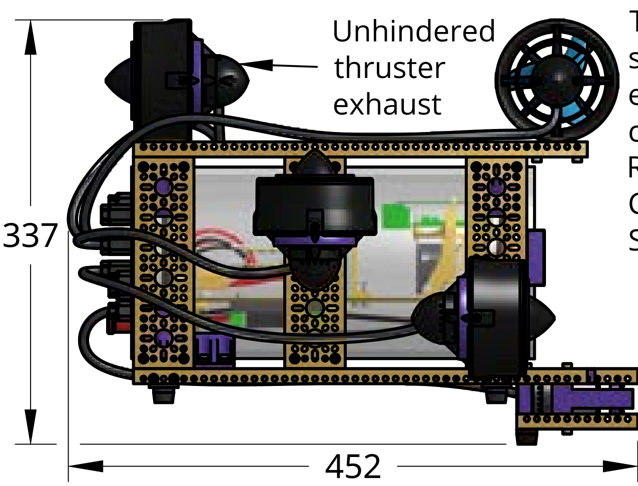




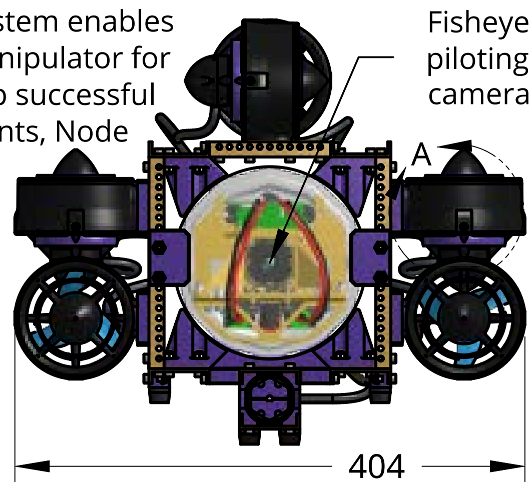
MATE tasks and their specialized manipulators:



DETAIL A

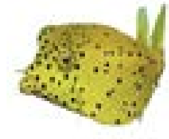


The modular manipulator system enables switching to a specialized manipulator for every MATE task, speeding up successful completion of Coral Transplants, Node Recovery operations, SMART Cable deployment, Irrigation System activation, and more.



Design Rationale

Fig. 2A (right): Boxfish image reminiscent of ROV Boxfish

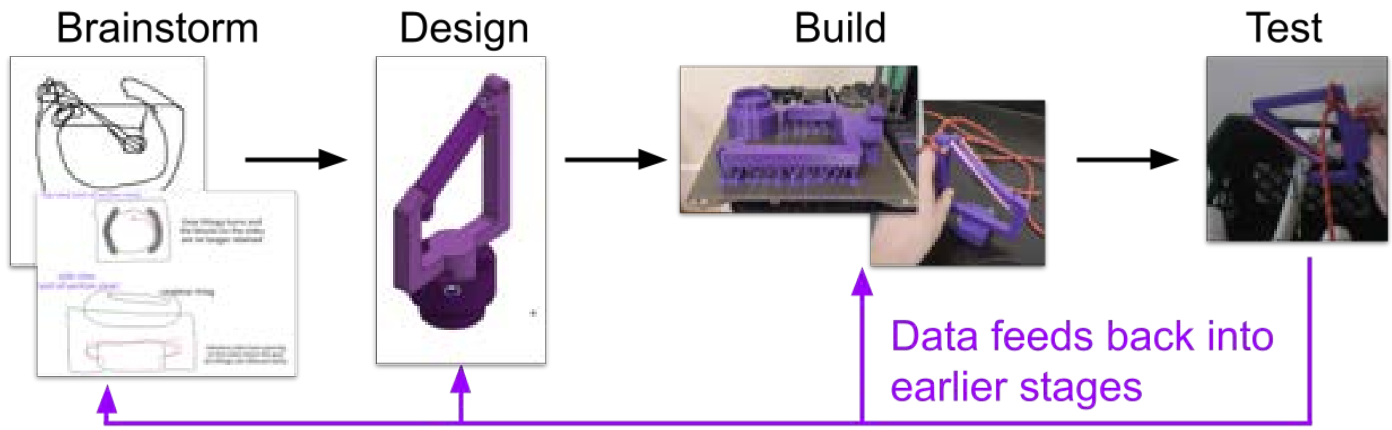


The name *Boxfish* originates from the yellow boxfish *(Ostracion cubicum)*, a reef-dwelling fish notable for its cube-like-body and impressive agility. *Boxfish* takes lessons from past years previous years designs such as *Barreleye* and is the product of rigorous iteration, innovation, and testing.

For this season's ROV, the UWROV team focused on improving the functionality and cost-effectiveness of the ROV. The company focused on designing and selecting components that are effective in competition and testing, and adaptable to the various tasks performed by the ROV, while implementing tangible changes that could be implemented with existing systems and infrastructure. All parts of the ROV were subject to revision to better fit to the challenges this year, there was an increased focus on the improvement of the manipulators to have a specialized, thoroughly tested, high-performing solution to MATE tasks (see Payload and Tools section).

Conceptual Ideation and Selection Process: Problem Solving

Fig. 2B: An example of an idea-to-product process.



Throughout the process of designing *Boxfish* and related systems, UWROV made extensive use of data collection to inform design revisions. Relevant trade studies are included where applicable throughout the documentation.

Systems Approach

Boxfish'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 tasks.

Our **digital twin system** involves electromechanical CAD integration. All of the ROV's physical components are modeled together, reflecting their real-life layout. Modeling interactions between new parts and existing components minimizes design oversights when prototyping new parts. We also examine details such as wire lengths and camera visibility in our modeling. While these elements can be tested with the physical ROV, we save time and effort by avoiding unnecessary physical prototypes. 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.

The CAD model of the ROV is also utilized to develop the software control system. The motor positions & orientations are used directly to generate control mappings using **Numpy**, a Python library. This significantly streamlines the controls development process, where controls are easy to integrate and update as the design evolves.

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, in our modular manipulator design, each mission task has a dedicated swappable manipulator which is designed to complete the task efficiently. Our digital twin approach makes it straightforward to develop these different manipulator options in parallel in preparation for the mission tasks.

Vehicle Structure

The structure of *Boxfish* prioritizes a small form factor, maneuverability, and modularity. Smaller ROVs come with several benefits and drawbacks. While the small size of *Boxfish* allows for easy transportation, reduced cost of materials, and navigation of narrow mission sites such as coral reefs, it also increases the complexity of maintaining stable control of the ROV. To address this, we have focused development towards autonomous stabilization software, using the six motors of *Boxfish* in the same way that real life Boxfish utilize their fins for stabilization.

The frame of *Boxfish* consists of **aluminum goBILDA Low U Channel** and **Dual Block Mounts,** and all mounting and frame construction is standardized to **M4 hardware** to improve serviceability and modularity. Although goBILDA is more expensive than other frame options, its lightweight material and variety of standardized interacting locations make it adaptable for the mission. For example, the ballasting system of *Boxfish* utilizes ballast that is interfaceable with the goBILDA frame via **M4 hardware**, allowing for ballast to be removed, added, or shifted to nearly anywhere on the frame. This modularity is essential for completing MATE tasks in a variety of environments, particularly when adjusting from saltwater to freshwater. The modular manipulator system was integrated directly into the frame for improved robustness in a variety of operating conditions.

Our pressure hold consists of a clear **acrylic** cylinder and front plate with an **aluminum** back plate. The cost of machining aluminum and acrylic is much lower compared to more traditional options for materials in a corrosive environment like titanium and stainless steel, making them economical options. Therefore, we traded off some lifespan of the vehicle in exchange for significantly lower cost, which is acceptable for the MATE task use case. Pressure hold parts were turned on a lathe, with special care paid to smooth finishes for good sealing, and broken/chamfered edges for personnel, wiring and O-ring safety. Our custom pressure hold is designed to be as large as possible while fitting comfortably in the frame and staying dry at MATE task depths, increasing floatation and volume for electronics.

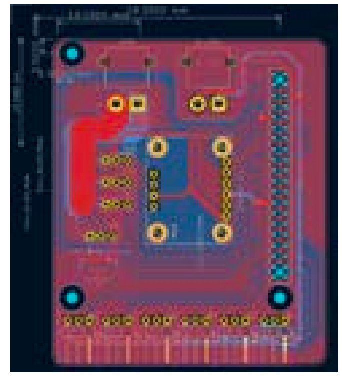
Vehicle Systems

The component systems and materials on *Boxfish* were selected to perform MATE tasks based on data from previous years of development and ruggedized testing procedures. The manipulator base was tested at several locations on our modular frame for **task accessibility** and **piloting visibility**, ultimately positioned in a low, centralized location to minimize the impact on piloting when transporting large objects like the Probiotic Irrigation System in task 3.1

Custom structural components were printed in PLA due to its non-toxicity and low cost. Each of the modular manipulators is printed in PLA as well, allowing for rapid, **cost effective**, parallelized development of tooling for tasks with very different requirements, such as recovering Sediment Samples, activating Irrigation Systems, and connecting Recovery Lines.

Previous ROVs had used nickel-plated fasteners for their moderate corrosion resistance, but we found that over time these would still degrade. *Boxfish* uses exclusively 316 stainless steel hardware for its superior corrosion resistance, which, while more expensive initially, does not need to be replaced over time, saving on costs over multiple deployments to ocean environments when deploying SMART Cables.

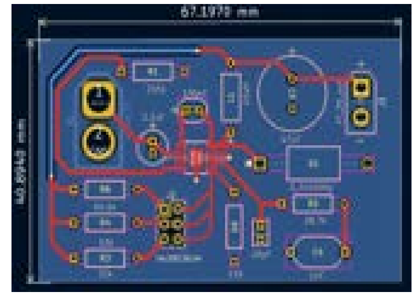
This year, our surface station evolved through several iterations, including a complete restart after our lab space was broken into and electronics systems were stolen. Ultimately, this drove us to eliminate the need for a dedicated surface station entirely by rewriting our control software and making use of Raspberry Pi firmware to allow direct connection to the ROV from **any computer** with an ethernet port.

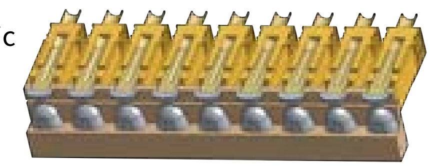


Control and Electrical Systems

Electronic Design and Cabling

Fig. 3 (right from top to bottom):
3A: KiCAD EDA of model of Pi hat PCB for onboard data & power connections
3B: 48 to 3.3/5/7.2 V power converter PCB
3C: CAD render of XT60 power buses
3D: KiCad schematic of the 48 to 12V converter





We created custom designed electronics that can provide enough power to tackle the challenges specified by the MATE RFP. Our electrical system emphasizes modularity, safety, and performance. We standardized all **48 V to 12 V** and **48 V to 5 V** power systems to be equipped with **XT60 and XT30 connectors**, respectively. Standardization allows for quick swapping of spare parts, plus space, weight, and efficiency savings of XT and Bullet series connectors over screw terminals.

We also use **custom-designed Printed Circuit Boards (PCBs)** using KiCAD EDA to save space, improve efficiency, lower part count, improve reliability, and simplify mounting. The **Pi Hat PCB** (Fig. 3A) connects the Raspberry Pi to the Electronic Speed Controller (ESC) signal wires, BNO055 IMU sensor, Raspberry Pi fan, and servo signal wires. The custom 48 to 12 V and 48 to 3.3/5/7.2 V **power converter PCBs** take minimal space within the pressure hold. With more available space for power converters, we can include one power converter per motor. Reducing the load on each power converter allows us to extract maximum power from each thruster. The custom power converter PCBs also allow for additional devices to be easily incorporated into the PCBs.

Since each thruster is connected to its own power converter, we must distribute 48 V at 30 A to all of the power converters. No small off-the-shelf solution accomplishes this. Therefore, we designed, machined, and assembled our own in-house **XT60 power buses** with copper bus bars capable of 30 A of safe, continuous power delivery (Fig. 3C).

Cooling

To keep electronics within their thermal limits, we added forced convection (fans) to aid the rejection of waste heat from the raspberry pi and power electronics. As a result, our ROV is capable of running continuously with no thermal time limit, **verified with multiple 5-hour test runs**.

Power Calculations

We created a spreadsheet to track the ROV's total power consumption. It contains current, power draw, and efficiency loss estimates linked to automated calculations. The spreadsheet is readily accessible by all employees, and has a user guide to explain how to use, test, and update the calculations.

Table 1 (below): Power calculations for Boxfish operating at maximum power.

System	Power Draw	
Provided MATE Power Supply	30 A @ 48V =	+1440 W
Tether efficiency losses to environment (voltage drop)	30 A @ 3.9V =	-117.9 W
Sensitive electronics such as Raspberry Pi 4. Isolated from actuators to prevent damage from voltage spikes.	1 Raspberry Pi 4: -12 W 2 USB cameras: -2 W Power Loss (converter inefficiency): -1.4 W	-15.38 W
Mid Voltage Actuator, T200 Thrusters	6 × T200 @ 12 A: -864 W 1 M200: -144 W Power Loss (converter Inefficiency): -137.45 W	-1145.45 W
	Remaining margin for efficiency losses and future additions:	162.62 W

Our system consumes **1278.73 W** at peak load. Seven 240 W, 48 V to 12 V power converters are used to power the six ESCs and T200 motors onboard, resulting in **144 W (60%) peak load on each converter**. Furthermore, the design incorporates one 15 W, 48V to 5 V converters, as indicated by Table 1, to provide power to sensitive electronics. This measure is implemented to safeguard delicate components against potential harm induced by voltage spikes.

Control Station

The **control station** is the collection of equipment the pilot uses to operate the ROV. *Boxfish*'s control station consists of a laptop and Logitech F310 controller, where the laptop is connected to the ROV directly via ethernet. 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.

Control System Software

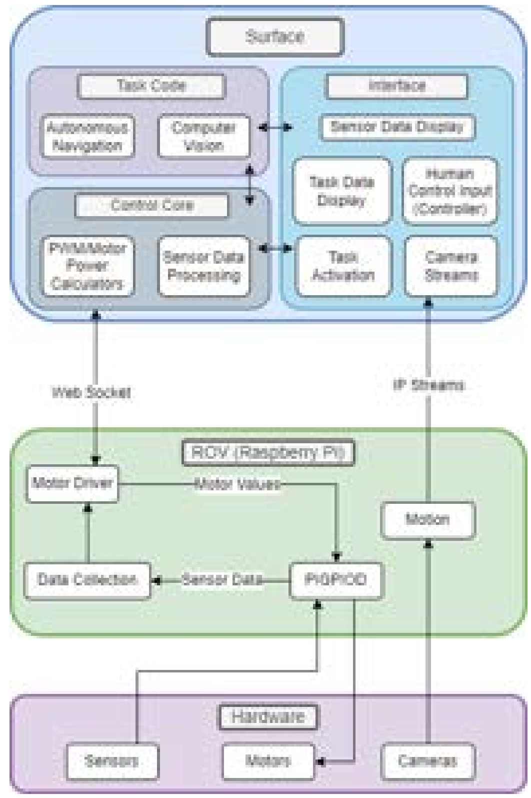


Fig. 4 (right): Architecture diagram of ROV software systems.

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 robot and control station.

The software on the surface station is divided into 3 components: interface, control core, and task code. 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. Task code is responsible for MATE tasks that involve autonomous navigation and computer vision.

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 accept inputs more naturally as well as provide a digital simulation of the robot and its movement. Meanwhile, Python is utilized for the rest of the robot for movement-related computations as well as task code.

The control software includes a software copilot which aids ROV piloting. Various controllers and filters combine accelerometer data with control inputs to provide stabilization, heading hold, and depth hold modes to the pilot.

Tether Construction

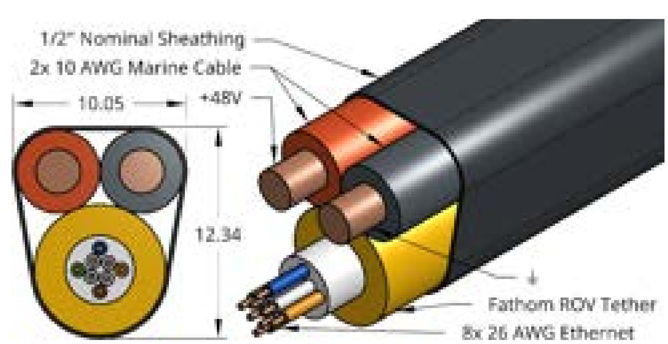


Fig. 5 (right): A digital 3D model and cross section of our tether configuration. Dimensions are given in mm unless otherwise noted.

Flexibility, low weight, durability, and reliability when transporting power and data were the design goals of *Boxfish's* tether. For power, **10 AWG UL 1426 marine-grade wire** was used 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 based on our CAD model 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. By limiting the length of our tether to what we need, we reduce tripping hazards while mitigating voltage drop. When the ROV pulls its maximum of 30A, the voltage drop is at most 3.91 V, leaving **44.1 V (92% of maximum possible) available** for use. The minimum voltage accepted by our power converters is 36 V, so the ROV will always have sufficient voltage.

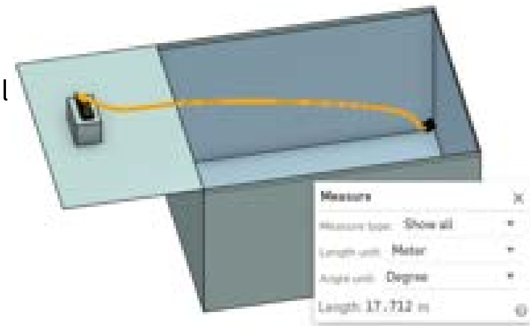


Fig. 6 (right): CAD of MATE pool specifications showing min. tether length

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 (See Vehicle Safety Features).

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. This prevents 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 station 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 must avoid 360 degree rotations & close maneuvers around obstacles when possible to avoid 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 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. In order to stay within our total power budget, each thruster is run at 12 V with a current draw of 12 A, and the PWM signals sent to ESCs range from 1160 to 1840 microseconds. The 6 thrusters consume approximately 982 W of power in total (88% power efficiency), staying within our total power budget of ~1.3 kW for the ROV's onboard systems. Our thrusters are operating at 70.6% of their maximum capabilities (max of 17 A). This percentage along with the PWM signal threshold determined that each thruster provides 3.01 kg F in the forward direction and 2.34 kg F in reverse, allowing a maximum lift capacity of 6.02 kg F when both side thrusters work together to move the ROV upward when neutrally buoyant (BlueRobotics, 2024, May 21)).

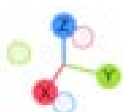
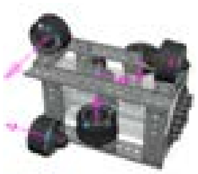
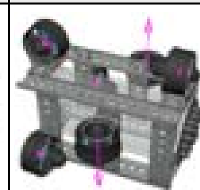
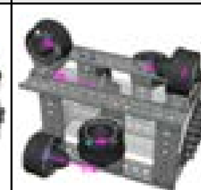
Boxfish's precision of motion is achieved through **variable motor thrust** based on inputs from the control system. Thrust from the T200s operates on an input scale ranging between -1 to 1, denoting the amount of thrust for forwards or backwards force. Additionally, our custom **IP2X motor safety shrouds** provide improved thruster efficiency compared to more traditional protective gratings often seen on ROVs. This allows the ROV pilot to maneuver accurately in smaller spaces and traverse distances rapidly in more open waters. Through this arrangement, *Boxfish*'s T200s meet requirements for completing a wide variety of MATE tasks.

Boxfish's six thrusters are arranged to enable **Six Degrees of Freedom (6 DOF) motion,** taking inspiration from the Ariana-I ROV. 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 (forward/backward)**: 3 thrusters, prioritizing speed over long distances to move efficiently between MATE mission tasks located in different areas
- **Z axis (up/down)**: 2 thrusters used 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.

Table 2 (below): Table of thrust directions (pink) for each axis of movement and rotation (red, green, blue)

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

Buoyancy and Ballast

The main source of buoyancy comes from the electronics pressure hold filled with air. Combined with the low weight of the frame and other components, this makes our ROV overall **positively 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. **Stackable 0.90$\pm$0.01kg 304 stainless steel plates** are attached via screws onto the frame to remain **neutrally buoyant underwater**. The aluminum plates can be removed or added to regulate the weight of the ROV at any location, and are typically added to the bottom of the frame to increase stability.

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 **7.70kg** while displacing **8.06 liters** (**8.06kg** of freshwater), so the difference of **0.36kg** gave us a starting point of how much mass to add. After adding our initial estimate of ballast, we iteratively test drive and redistribute ballast to optimize its amount and distribution.

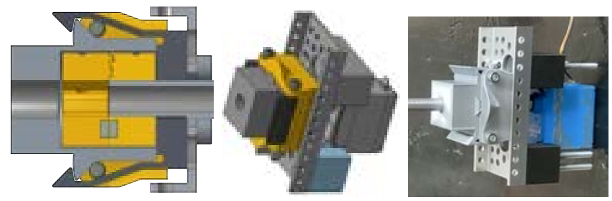
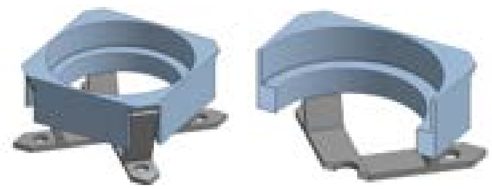
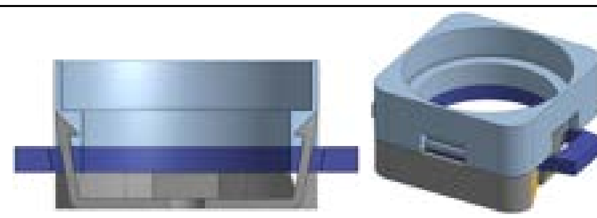
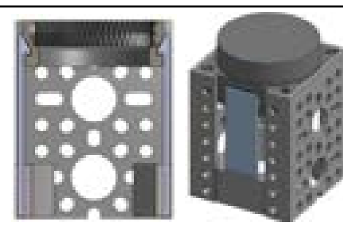
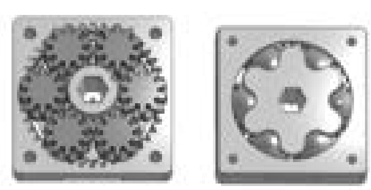
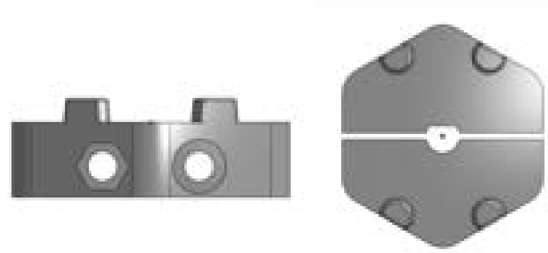
Additionally, **our tether is a source of ballast for the ROV**. When the tether is in the water, *Boxfish* becomes **negatively buoyant**. To help compensate for this, our tether features buoyancy in the form of pool noodles. While pool noodles crush and leak under pressure, they are suitable for pressures that will be experienced in the MATE task scope. These pool noodles can also be adjusted so that 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

Modular Manipulator Interface

To address the diversity of tasks in the 2024 MATE Explorer Competition, we use a variety of manipulators that use a single interface. Our interface allows us to frequently and uniformly swap manipulators and ultimately specialize the ROV to the tasks. This interface and each of its swappable components underwent extensive prototyping, testing, and iteration as documented in Table 3 and in the 'Critical Analysis: Testing & Troubleshooting' section.

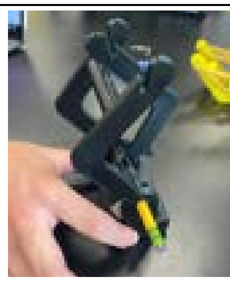
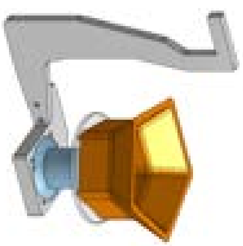
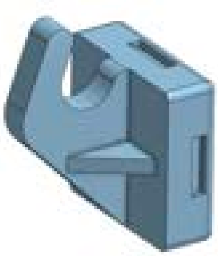
Table 3 (below): *Concepts and prototypes of the ROV's modular manipulator interface.*

Design Idea	Concept Models and Prototypes
Updated from the 2023 UWROV Boxfish Modular Manipulator Interface. Problems included entrapped salt water crystallization, requires two hands for disengaging manipulator, and degradation in plasticity	
Driver Version 1: Rotational symmetry for easy alignment, functional, less material used, clips are less accessible, houses a hybrid splined & magnetic coupler to transmit torque to dynamic manipulators.	
Driver Version 2: Rotational symmetry for easy alignment, horizontal clips, fewer arms for less material use, easy engagement but less accessible technique for disengagement	
Driver Version 3: Thin PLA clips, mounted further from coupler for easier disengagement, exposed top of clip for increased accessibility, fits within GoBilda geometry for sleeker look and lateral protection	
Variable Ratio Gearbox: Used for all drivers, specialized gear ratios for each dynamic manipulator, houses clip shelves.	
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	

Manipulator Designs

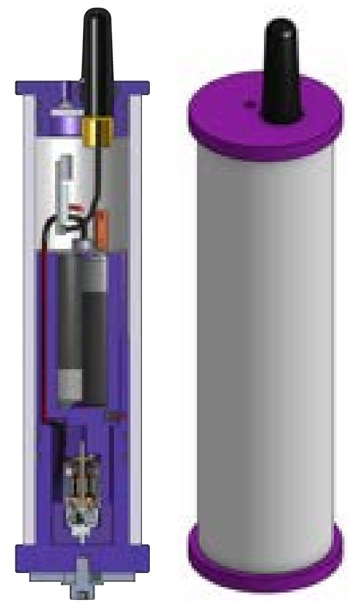
Our modular manipulator system is compatible with both static and dynamic manipulators. Dynamic manipulators achieve **independent motion** through a driving module that connects to the external servo via a hybrid magnetic & splined coupler. The alternating poles of the **miniature neodymium magnets** in the couplers help automatically align them during installation to engage positive splined drive. Static manipulators do not move relative to the ROV, and instead take advantage of our **high overall agility** to maneuver props. Modular static and dynamic manipulators can be installed interchangeably in the quick-connect interface, allowing for rapid tooling changes in the field.

Table 4 (below): Interchangeable dynamic (moving) manipulators designed for specific MATE tasks

Models and Images	Description
 	***"Lobster Claw"*** General Purpose vertically mounted grabbing manipulator designed to grab items like PVC pipes from below the ROV. Rubber is mounted around each arm for an enhanced grip on items. *Used for multiple tasks.*
 	***"Moray"*** This is a general purpose forward grabbing manipulator designed to grab items such as PVC pipes to complete tasks. Rubber is wrapped around each arm to enhance the grip of the manipulator (see "Lobster Claw" for general purpose vertical grabbing manipulator). *Used for multiple tasks across competition.*
 	***"Anglerfish"*** Manipulator used to rotate the valve on the irrigation system. The pentagonal mouth allows for easy self-centering on the valve, and the hook allows the ROV to hold the frame of the irrigation system. An acrylic base is added to the hexagonal valve interface to allow the pilot to see the rotation of the valve in real time. *Used for Task 3.1 (rotating valve on irrigation system)*
 	***"Lamprey"*** This is a company designed recovery line designed to clip onto a U-bolt. The clip will have a rope attached. Once the clip is attached to the U-bolt, the manipulator can be spun to a particular orientation then released. *Used for task 1.1 (Securing Connection to U-bolt)*
 	***"Barnacle"*** Static hook manipulator designed to deploy and retrieve items. In the prototype, a 3D printed piece is attached to prevent the manipulator from sliding within the manipulator interface. *Used for Task 3.1 (deploying irrigation system framework)*

Float Design

UWROV's 2024 profiling float, the NanoFloat 1.0, is unprecedented in its innovative design, specially optimized for the 2024 MATE RFP. NanoFloat is designed around two primary objectives: fast profiling for **Task 4: Vertical Profiling**, and remote pressure data transmission for **Task 4: Data Visualization**. To excel at these primary objectives, NanoFloat is built with reliability, operational simplicity, and cost-effectiveness as its core design principles. We prioritized NanoFloat's Task 4 performance by maximizing buoyancy differential and wireless performance, while maintaining sufficient mission duration, processing power, and sensor accuracy.



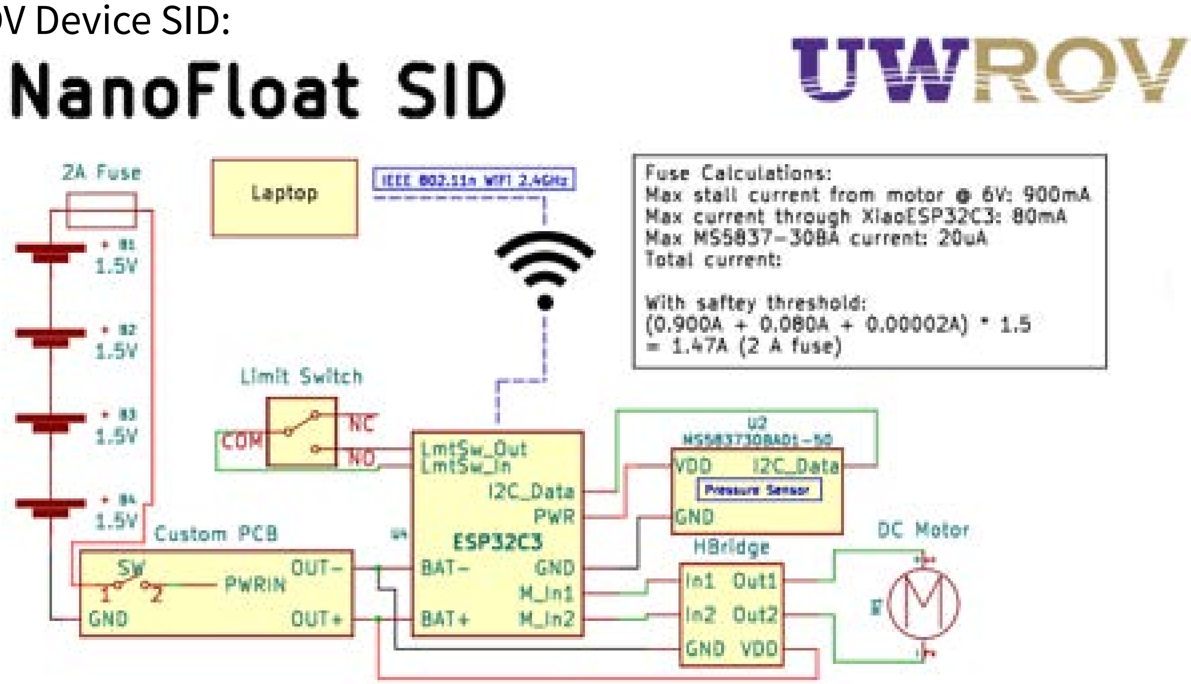
The buoyancy drive uses a custom linear actuator to extend the bottom endcap, with a brushed DC motor-driven screw serving as the actuator. The central ESP32 microcontroller communicates with the pressure sensor and uses its data to inform motor actuation. When the float surfaces, the ESP32 generates a WiFi network to which the surface station connects for wireless communication and visualization of the logged data. All these systems are powered by a 6V battery pack consisting of four 1.5V AAA batteries in series.

144.0mm long at full extension and 38.1mm in diameter at the endcaps, the NanoFloat's uniquely small size allows for a displacement-volume ratio of 0.083:1, giving it an excellent buoyancy differential and great acceleration for quick profiles. This small size also minimizes the overall price of the NanoFloat components. Small size is not without disadvantages, however, and many sacrifices were necessary to realize this design:

- Choosing one of the smallest ESP32 breakout boards on the market led to limited processing power and input/output pins.
- The float's sensor payload is space-limited.
- Minimum mission duration is limited to 3.2 hours under normal operation, 25 minutes as a theoretical limit.

These drawbacks are serious, and accepting them was difficult during the design process, but strategically choosing which sacrifices to make allows the NanoFloat to be optimized for performance at the MATE ROV competition, where sensor payload is limited to a single pressure sensor, mission duration is only 15 minutes, and complex processing is not necessary. In addition to these sacrifices in favor of size and acceleration potential, we also had to navigate the tradeoffs between the transmission range offered by radio and the reliability and simplicity of WiFi wireless communication, as well as the balance between extreme pressure-rating and cost-effectiveness.

Non-ROV Device SID:



Build vs. Buy, New vs. Used

UWROV **reuses** components of the ROV when they meet requirements and are not performance bottlenecks. Reusing hardware allows us to reduce hardware 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 mission critical upgrades to our manipulator, power distribution, and software. This year, our main focus was developing a manipulator system that allows the use of specialized, high-performance tools for every MATE task. We also innovated on our profiling float, improved the longevity and efficiency of our ROV, and recovered from a laboratory break-in resulting in the theft of many critical systems and components.

Table 11 (below): Reused Purchased UWROV Systems

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)

Table 12 (below): Reused Custom-built UWROV Systems

System	Justification
Pressure Hold	Meets requirements: space, mass, visibility, serviceability, and electrical connectivity
Electrical Systems Chassis	Meets requirements: mounting structure, security, visibility, servicability
Tether	Meets requirements: efficiency, safety, strength, abrasion resistance, and strain relief

Table 13 (below): Newly Purchased UWROV Systems

System	Justification
B.R. T200 Thrusters	Increased thrust enables greater lift capacity and navigation speed to MATE tasks
Laptop	Theft: our original control laptop was stolen.
M200 Motor	Redesigned modular manipulator system requires more power, improved reliability
goBILDA channels	Construction of a second ROV for non-MATE scientific missions
Hardware	Increased ROV lifespan and mechanical reliability
Float Hardware	New float design from the ground up

Table 14 (below): New Custom-built UWROV Systems

System	Justification
Custom Power Converters	Enhanced stability in driving ROV thrusters at high power
Manipulator Base	Enables specialized manipulators for every MATE task
Manipulators	New set of MATE tasks requires enhanced specializations and adaptations
Surface Station	Theft: our originally implemented surface station was stolen
Bumper System	Protect environment and personnel from sharp/hard corners on ROV
3D Printed Structure	100% infill prevents flooding with water, keeping buoyancy constant
Buoyancy Engine	Ultra-cheap, compact float buoyancy driver designed from scratch
CAD Tools	Streamlines design process of ROV components

System Integration Diagrams (SIDs)

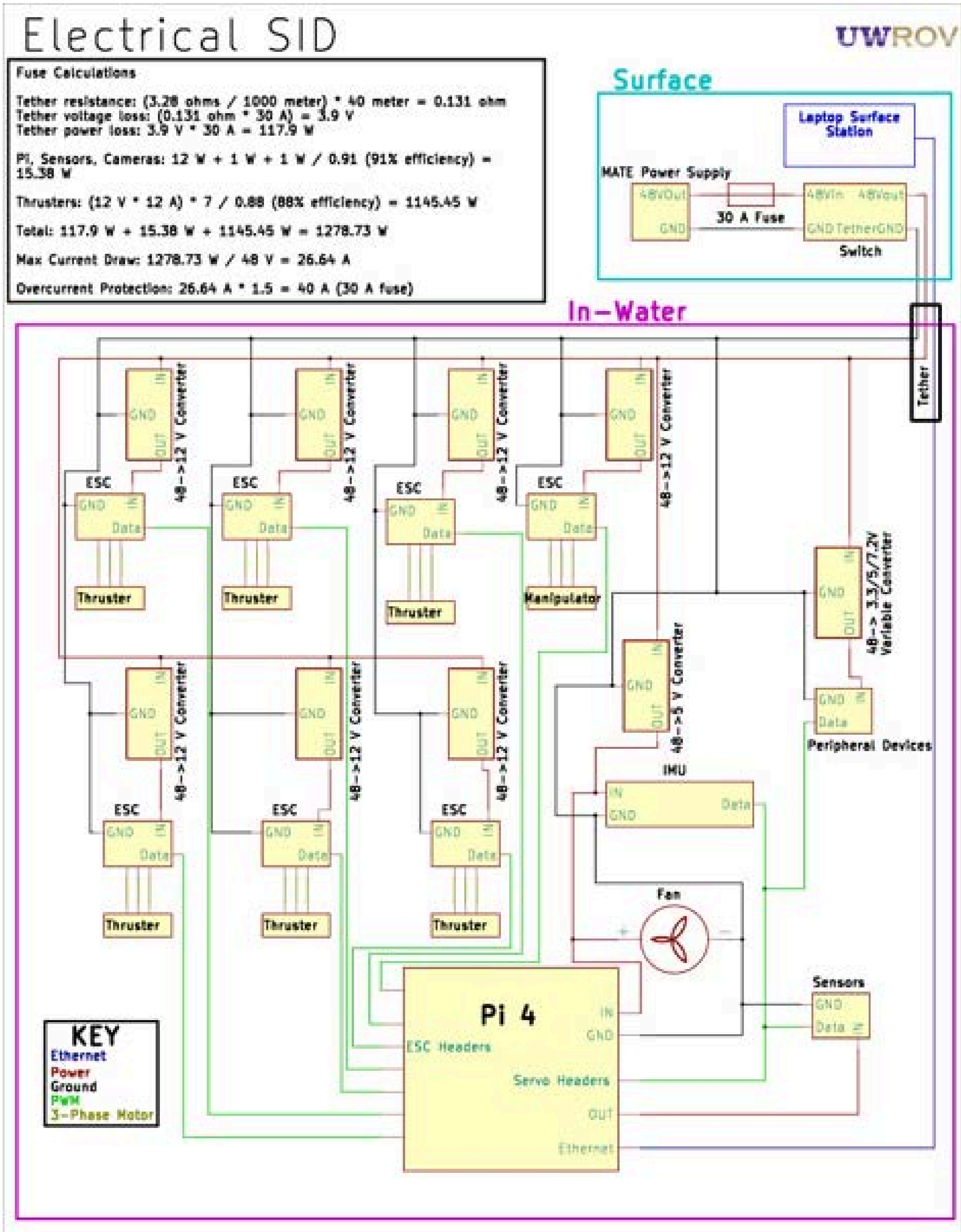
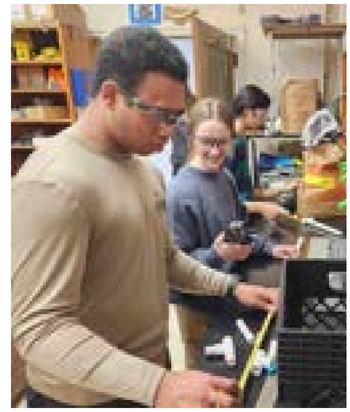


Fig. 7: Electrical System SID

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 team's shop lead fulfills the duties of a **safety officer**, ensuring that employees learn and comply with safety standards set forth by the team and local regulations.

Fig. 8 (right): UWROV employee wearing safety goggles while working.

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 the use of power tools such as soldering irons, drills, and lathes, employees must also undergo an additional one-on-one training course with our shop lead. The course includes live training with the shop 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. The shop lead also supervises the acquisition and usage of all equipment in the lab. Employees must demonstrate an understanding of safety procedures, awareness of hazards, and proficient usage of lab equipment to the shop lead before they are permitted to use equipment independently. For a complete list of lab safety rules and procedures, see **Appendix B**.

Equipment Safety

A main priority when designing *Boxfish* was preventing injury through vehicle safety features. This was done by eliminating as many potentially dangerous features as possible and making hazards very visibly clear to employees. Sharp edges and corners have been covered by soft rubber feet and bumpers, respectively, to allow employees to safely carry and handle the ROV. Additionally, sharp edges are broken, typically by filing, preventing damage to poolside surfaces and sensitive marine environments. Our thrusters are covered by custom 3D-printed IP2X compliant thruster shields to prevent injury when handling the ROV. These shields also prevent ropes or cords from getting caught in the thrusters when navigating around them. We have also applied ANSI Z535.3-2011 compliant warning labels to the thrusters to warn employees of potential injury. Additionally, all materials on our ROV are non-toxic and non-corroding for the safety of employees, marine environment, and the ROV itself.

From an electrical standpoint, all of *Boxfish's* wiring complies with NASA Workmanship Standards (NASA, 2002). All electrical connections are done through enclosed connectors or a lineman splice that has been flooded with solder and protected with a heat sink. There are no exposed electrical connections within the pressure hold. Additionally, an internal fan has been installed to prevent the formation of hotspots by circulating air within the pressure hold. Our tether is protected from damage due to tension by a braided cable sleeve, along with tether strain relief on the ROV and surface station.

Fig. 9 (above): Operational safety checklists in use by a UWROV employee.

Operational Safety

UWROV identified potential hazards during operation of the ROV by performing a **Jobsite Safety Analysis (JSA)** 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.

Safety Procedures

We use a series of safety checklists when assembling and deploying the ROV to reduce the risk of harm to employees or the ROV (see **Appendix A** and **Appendix B**). These checklists are integral to our zero-accident, zero-leak record for in-water testing over the last three years.

Critical Analysis: Testing & Troubleshooting

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. *Boxfish* was **tested in-water for over 32 hours.** Findings from these tests informed improvements in manipulator prototypes and software control parameters.

Structures & Materials

We evaluated frame material options through a trade study, and determined that goBILDA was the best option:

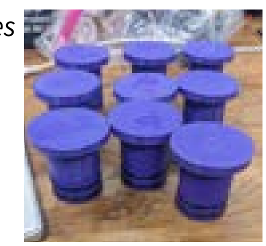
(Table 15)

System	Performance				Ease of Development			
	Versatility	Strength	Weight	Bulky	Metric	Cost	Already in lab	Design Work
goBILDA	High	Mid	Low	No	Yes	High	Yes	Challenging
Actobotics	Mid	Mid	Low	No	No	Mid	No	Challenging
80/20	Mid	High	High	Yes	Yes	Mid	Some	Moderate
PVC pipe	Low	Low	Mid	Yes	No	Low	Yes	Easy

We also utilized 3D prints substantially throughout our ROV and float. Our **telemetry from ROV tests indicated** increasing weight over time, which we determined to be **3D prints filling with water**, so we printed all submerged components at **100% infill** with more perimeters for greater strength and leak prevention. After **observing corrosion** on zinc-plated steel fasteners, we replaced all hardware with **316 stainless steel** alternatives for corrosion resistance.

Seal Design, Testing, and Optimization

Fig. 10 (right): sealing size prototypes



NanoFloat utilizes 3D printed watertight endcaps to seal the inner electronics bay and as a critical component of the buoyancy engine. Our initial prototype prints were found to leak, even with O-rings and lubricant. We alleviated this through rigorous testing of sealing surfaces by:

1. Measuring PVC housing component inner diameter using precision calipers from 16 different angles, averaging measurements for a true inner diameter.
2. Sourcing O-rings matching true PVC diameter with appropriate compression.
3. Incrementally machining down O-ring groove diameters in PTFE stock, then inserting test piece with lubricated O-rings into 10ft PVC pipe filled with water, testing the seal quality and actuation force.
4. Selecting lowest actuation force watertight diameter and printing prototype endcaps of varying infill settings, perimeter settings, and groove depths (see Fig. 11).

Wireless Communications

WiFi signal range, another critical aspect of *NanoFloat's* **Task 4** performance, was also subjected to 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 with a range of 30m.

Electrical

The *NanoFloat* electrical systems have a brushed DC motor at their core. Under load, this motor initially generated noise in the circuit, which threatened **Task 4** performance as it could affect pressure sensor readings and microcontroller operation. We tested multiple power smoothing capacitors in several configurations to stabilize the system-wide voltage. Pictured are two oscilloscope testing screens, the top one showing unsmoothed noise with the motor under load and the bottom one showing 220uF capacitor smoothed noise under the same load conditions.

Modular Manipulators

Fig. 11 (right): prototype of valve turning manipulator

Boxfish's modular manipulator system enables switching to a specialized tool individually designed for specific MATE tasks (see Table 8). **Manipulators undergo rigorous testing both in and out of water, and designs are adjusted based on the results**. For example, when developing the "anglerfish" manipulator (see Table 8) for rotating the irrigation system valve in task 3.1, we conducted both in-water and dry testing of the manipulator head. During our dry testing we found that the pentagonal opening worked extremely well for centering the valve in the bottom of the rotation interface (Fig. 10), allowing for ease of alignment when attached to the ROV. However, **during in-water testing, we encountered an issue** where rotating the interface would push the valve away, disengaging the manipulator. **Based on this data**, we added the hook feature to allow the ROV to index itself off of the frame of the irrigation system. We **verified this solution through data from subsequent in-water tests**, finding that the time to acquire and the duration of successful engagement with the valve decreased.

Ultra-Compact High-Reduction Gearbox

Fig. 12 (right): close up of gear print

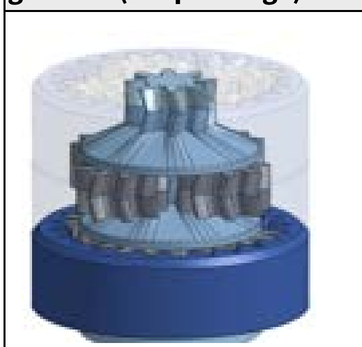
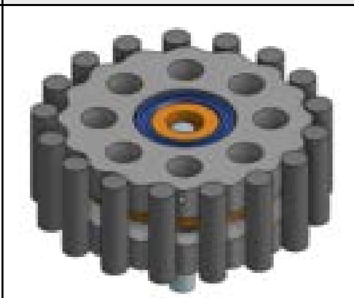
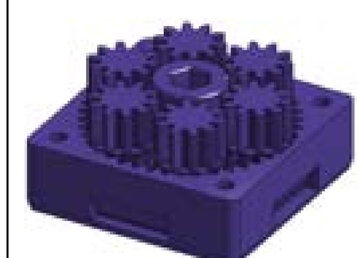
Our Ultra-Compact High-Reduction Gearbox used to actuate the dynamic manipulators of *Boxfish* underwent significant testing and iteration to reach a reduction ratio of 240 to 1 within a 43x43x32mm volume. The gearbox is a print-in-place (PIP) part, and employees conducted tests with 3D slicing and printing technology to optimize settings to maximize performance. Results were examined via software and equipment such as microscopes. Optimized values for key parameters are summarized in (Table 16).

Setting	**Original Value**	**Optimized Value**	**Results**
Slice Gap Closing Radius	0.49mm	0.02mm	Prevents gear teeth from merging during the slice process and enables tighter tolerances in small geometry.
External Perimeter Extrusion Width	0.45mm	0.32mm	Increases tooth engagement without requiring a smaller nozzle and allows for additional perimeters inside teeth.
Extra Perimeters on Overhangs	OFF	ON	Improved bridging paths, quasi arc overhangs, drastically better top layer for captive magnets.

Furthermore, we conducted wear testing of the gearbox to verify its lifespan, finding that after over 600,000 cycles driven by a lathe (2000 rpm for 5+ hours), the gearbox remained undamaged, and even ran smoother. Maximum torque was tested by clamping the output and increasing torque applied to the housing until destruction, measuring a 1700 oz-in failure torque.

Prototypes:
The gear reduction system also went through a number of iterations improving robustness and reduction ratios, summarized in the following table:

Table of Major Design Revisions of Gearbox System

Stackable PIP planetary gearbox (4:1 per stage)	**Cycloidal gearbox, ceramic bearings (16:1 per stage)**	**Split ring planetary gearbox (80:1)**	**Offset planet split ring gearbox (up to 240:1)**
			

Accounting

Budget

At the beginning of the year, we focused significant attention on creating a high level budget for the year, conducting analysis of budgets and spending from 2022 and 2023 and re-evaluating sections and budgeted amounts. Because of the heavy focus on iterative design and prototyping, we added the "Research and Development (R&D)" portion of the budget, meant to account for the cost of prototypes and materials used in the design process, but not on the final ROV.

Furthermore, the overall budget was increased significantly from 2023, but reflects budgeting from 2022, where the total budget came out to a total of $18,725. The budget was increased in part due to a greater allocation toward travel–this year, we will have 10-12 employees traveling as a part of our competition team compared to 7 last year. Other than travel, our budget is primarily focused on engineering, with a total of $9,200 being dedicated to R&D, ROV components, and the float. Notably, we increased the budget for our Float in anticipation of developing an entirely new design compared to last year.

To compensate for this increase portions of the budget were also decreased, such as Lab Safety and Tooling and Equipment. Higher spending in these portions for past years allowed us to reuse, rather than purchase new, equipment.

Travel Estimate				
Category	Description	Cost	Qt.	Subtotal
Airfare	Reimbursement per employee	$270	10	$2700
Lodging	Lodging rental, total (Airbnb)	$3600	1	$3600
Car Rental	Rental for a SUV (Hertz)	$2000	2	$2000
			Total:	**$8300-**

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

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 for his mentoring and guidance of UWROV,
- The University of Washington School of Oceanography for laboratory space and support,
- The Applied Physics Laboratory at the University of Washington and Marine Technology Society for the continued guidance and support,
- Foundry10, Washington Sea Grant, Sound Water Stewards, and Dan Vogel of Eight Diving Co. for guidance and financial support,
- Andrew Meyer for oversight of our lab space, machining guidance, and technical support,
- And the UW Student Technology Fee for financial support.

References

American National Standards Institute. (2011). *ANSI Z535.3-2011*.

Americas Region HSE Employee Handbook 2012. (2013). Oceaneering. files.materovcompetition.org/HSE_Handbook_number_3_As_of_11_19_2013_AW.pdf

BlueRobotics. (2024, May 21). *T200 Thruster*. https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster-r2-rp/

Christ, R., & Wernli, R. Sr. (2013). *The ROV Manual: A User Guide for Remotely Operated Vehicles*. Butterworth-Heinemann.

College of Engineering. (2021, September 17). *Machine Shop rules*. Mechanical Engineering. Retrieved May 23, 2022, from https://www.me.washington.edu/shops/policies/machine-shop

Moore, S. W., Bohm, Harry, & Jensen, Vickie. (2010). Underwater Robotics: Science, Design, and Fabrication. Marine Advanced Technology Education (MATE) Center.

NASA. (2002). NASA Workmanship Standards (Vol. 4). workmanship.nasa.gov/lib/insp/2%20books/links/sections/407%20Splices.html

Appendix A: Safety Checklists

ROV Construction:

Disassembly:

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

Before closing:

- ☐ No wires are disconnected or loose, and no wire conductors are exposed.
- ☐ 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 vacuum hand 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 lowered.

ROV Operation:

Pre-Deployment:

- ☐ There are enough company members 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).
- ☐ All ROV attachments (motor shrouds, floats, weights, motors) are secure.
- ☐ There are no loose connections in the pressure hold.
- ☐ The tether is laid out neatly without knots or tangles.
- ☐ Battery/power supply is completely dry and away from the side of the water.
- ☐ Surface station tether strain relief is connected, and tether ethernet and power are connected.
- ☐ Surface station is stable and on a level surface.
- ☐ Surface station computer, router, and monitors are plugged in, powered on, and connected.
- ☐ All personnel have close-toed shoes, safety glasses, no loose clothing, and long hair tied back.
- ☐ Recovery equipment (pole, net, etc.) handy.
- ☐ Control center and tether staging area are clear of clutter and tripping hazards.

Pre-Initialization:

- ☐ No water is flooding the pressure hold.
- ☐ No parts have come loose from the ROV.
- ☐ All connections are secure.

Deployment:

- ☐ ROV Handler exchanges tools and payloads on ROV.
- ☐ ROV Handler picks up ROV by its frame 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.
- ☐ Operations Director is facilitating communication between poolside and surface side

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, wash off with freshwater, especially plastic components & penetrators.

Appendix B: Lab Safety Policy

1. NEVER WORK ALONE IN THE LAB.
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 Lab 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, and first aid kits.

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

Appendix C: Cost Accounting

Available Funds:

Category	Name	Amount
	Carryforward Balance from 2023	$6652.00
Sponsorship	Foundry10	$5000.00
Sponsorship	Applied Physics Laboratory	$3000.00
Sponsorship	Dan Vogel of Eight Diving	$7000.00
Grant	Student Technology Fee Grant	$2396.00
	Total:	**$24048.00**

ROV Total Cost:

Budget Category	Type	Item(s)	Est. Value
ROV Surface Station	Reused	Controller	$20
ROV Surface Station	Donation	Acer Nitro 5 Laptop	$900
ROV Power Electronics	Reused	Tether Components	$400
ROV Power Electronics	Reused	Blue Robotics Speed Controllers	$228
ROV Power Electronics	Reused	Raspberry Pi 4 B 4 GB	$75
ROV Power Electronics	Purchased	Custom Power Converters	$220
ROV Power Electronics	Purchased	M200 Motor x 1	$170
ROV Power Electronics	Purchased	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	$190
ROV Structure	Manufactured	3D Printed Parts	$25
ROV Structure	Purchased	Stainless Steel Hardware	$135
		Total:	**$3821**

Expenses (September 2023 to June 2024):

Budget Category	Example Items	Budgeted	Total Value*	Spent
Lab Safety	Safety glasses, First Aid Kit, Face Shields	$200	$266.58	$0.00
Tooling & Equipment	Chuck Key, Lathe Turning Tool	$1,000	$3241.81	$64.65
R&D	Plywood, 3D Printer Filament, Magnets, Test Motor, Prop Materials	$3,000	$717.11	$717.11
ROV Surface Station	Controller, Laptop	$1,600	$918.99	$0.00
ROV Structure	Frame, Spray Paint, Hardware, 3D Prints	$1,600	$362.59	$337.59
ROV Electronics	Power Converters, Cameras, Tether Components, Thrusters, Motors	$2,500	$3397.04	$2496.04
Float	Antenna, Microcontroller, Sensors, Batteries, PVC Body	$500	$275.94	$275.94
Team Operations	Projector, USBC Adaptors, Printer	$700	$640.98	$320.78
Competition Fees	Explorer Registration Fees, Fluid Power Quiz Registration	$500	$475.00	$475.00
Travel Fees	Airfare, Car Rental, Lodging	$10,000	$6502.54	$5962.54
	Total:	**$21600**	$16,798.58	**$10649.63**

**Total Value includes the value of reused items.*