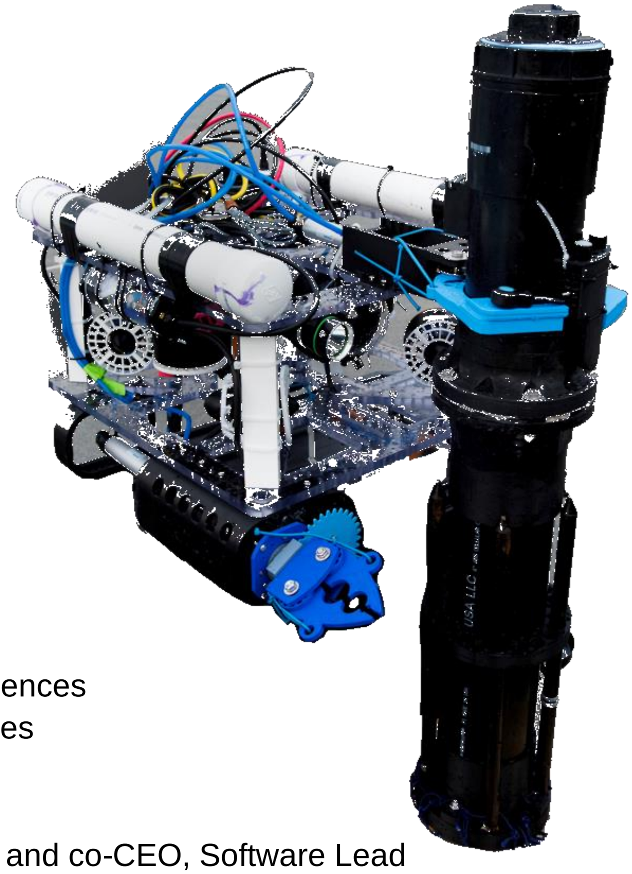
Triton Robotics

Scylla ROV and Charybdis Float Technical Documentation

2024 MATE World Championships
RANGER Class



School: Seattle Academy of Arts and Sciences
Seattle, Washington, United States

Team:	Thomas Gust	Co-Founder and co-CEO, Software Lead
	Tenzin Larkin	Co-Founder and co-CEO, Engineering/Design Lead, Chief Safety Officer
	Miles Lipson	Lead Pilot, Lead for Soldering / Wiring, Assembly Co-Lead
	Theo Lipson	Float Lead, Lead for Documentation
	Robbie Miyano	Chief Marketing Officer, Assembly Co-Lead
	Max Wilken	Pneumatics Lead, Systems Design

(all team members are in 9th grade)

Mentors: Gerald Elliott
Charles Gust
Sim Larkin

Triton team (left to right): Max, Robbie, Thomas, Tenzin, Miles, Theo.

Contact: Tenzin Larkin, Engineering Lead, tenzinlarkin@seattleacademy.org

Cover Photos by J. Miyano

Table of Contents:

ABSTRACT

Triton Robotics is small 9th grade company affiliated with the Seattle Academy of Arts and Sciences from Seattle, Washington. Triton Robotics' mission is to use marine engineering to combat the ever-evolving problems in ecological monitoring and restoration, as well as climate change mitigation. We have built our Scylla ROV and Charybdis float to accomplish challenges outlined the United Nations Decade of Ocean Science for Sustainable Development (*Ref: 1*) and the MATE RANGER class competition (*Ref: 2*). Scylla was explicitly built to protect and replant coral, deploy SMART cable for continuous marine monitoring, recoveri data collecting devices, collect sediment samples, and deploy and recover floats. Scylla includes multiple manipulators and pneumatic releases to optimize operational efficiency. Our float Charybdis uses a buoyancy engine to perform depth profiles and telemeter data back to surface stations.

Both Scylla and Charybdis are versatile, robust platforms that result from our year-long development cycle that uses a rapid iterative design-build-test-learn process. Both have been tested extensively in lab tests, shallow water pool tests, and over 17 deep water pool deployments. Through this building and testing, Triton adheres to strict safety standards, meeting the MATE competition requirements, but also additionally implementing our own safety standards and protocols. Our small six-person team works together on all aspects of the devices, with different members contributing expertise in different areas and teaching other members new skills such as fabrication, CAD, software, and electronics. This teamwork and our iterative methodology allow our team to create unique, capable products.

1. TRITON ROBOTICS TEAM AND PROJECT MANAGEMENT

1.1 Mission Statement

Triton Robotics is dedicated to helping the environment through engineering. To accomplish this, Triton employs a philosophy of constant iteration and learning, allowing us to evolve adaptable, nimble, easy to use, and dependable systems.

1.2 Company Overview

Triton Robotics is a company brought together by our shared love of robotics and the drive to work towards an environmentally friendly future. We are a second-year company of all high-school freshmen (9th graders), and this is our first year in the Ranger division, having competed in Navigator last year. This year, we had four returning members and two new employees. With this small company size, we have to be efficient in operating our company. While all our employees work on all aspects of the ROV, we have defined roles and responsibilities for designing, fabrication, software, and operational testing. Specific defined roles were:

- Thomas Gust, Co-Founder and co-CEO, Software Lead

- Tenzin Larkin, Co-Founder and co-CEO, Engineering Lead, Chief Safety Officer
- Miles Lipson, Lead Pilot, Assembly co-lead, Lead for Soldering and Wiring
- Theo Lipson, Float Lead, Assembly, Lead for Documentation
- Max Wilken, Systems Design, Fabrications, Pneumatics Lead
- Robbie Miyano, Assembly co-lead, Chief Marketing Officer

Additionally, every member of the team takes on a different learning leadership role, for example, learning OnShape CAD, CNC milling, software development, or 3-D printing, and then teaches at least two other team members to have redundancy in each skill.

1.3 Development Schedule

Our development cycle was divided into four phases at the beginning of the year, as detailed in Table 1. Each phase had varying foci and scheduling times, culminating in the PNW Regional MATE Competition in May 2024 (*Ref: 2*). Due to the small nature of our team, specific scheduled meeting times varied by phase and from week to week in order to fit other team member commitments (e.g., school sports teams, musical ensembles, and training). Phase 1 (Summer-Oct 2023) involved intermittent practices and focused on brainstorming, idea testing, and goal setting for core ROV systems. Phase 2 (Oct-Dec 2023, 14 weeks) involved regular 2-3 times a week (M/W 3:15-5:15, Sa 10-4) meetings and focused on the development of specific component systems such as a multi-axis gripper. Phase 3 (Jan - Mar 2024, 13 weeks) focused on ROV and mission-specific buildouts and added regular pool tests once a week (Su 1-4). Phase 4 (Apr-May 2024, 6.5 weeks) focused on full system and mission task testing with meetings 5-7 days a week for 2-4 hours during the week and 6-10 hours on the weekends and included 1-2 pool tests per week depending on the availability of pools.

Table 1: Project Phases, Timing, Goals, and Scheduling

	Phase 1 Jun-Oct	Phase 2 Nov-Dec	Phase 3 Jan-Mar	Phase 4 Apr-May
Practices / Meetings	1-2x / week	2x / week	4x / week	Daily
Iterative Design Goals	Design Brainstorm Core systems build	Design other Core systems System Development	Design mission specific systems	Finalize and build mission specific
Pool Testing		Occasional pool tests	Weekly pool tests	2x week pool tests

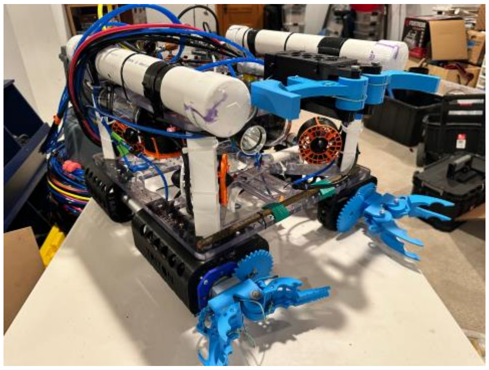
1.4 <u>Project and Resource Management</u>

Development of the Scylla ROV and Charybdis Float was Triton's biggest development project to date. To aid in building a successful product, three critical things were identified early in the development cycle (during Phase 1): (1) a wish list of features and functions was developed; (2) an investigation list of unknowns/ things we needed to research and solve and (3) prioritizing the investigation list into critical, needed, and nice-to-have categories. Investigations were then carried out and assessed as having long lead times or short lead times before they would produce results. This process allowed us to better allocate time and funds early in the project to longer lead time and more critical investigations. These lists and categorizations were referred to at the start of most practices, especially in the more unstructured Phase 1 and Phase 2 periods.

2. DESIGN RATIONALE

2.1 <u>Overall Design Goals</u>

The Scylla ROV was designed to prioritize adaptability, agility, and ease of use. In addition, it is purposely overbuilt to make it as robust and reliable as possible. We believe these features are key to giving Scylla users the best chance at mission success. These features are the guiding principle of every system described below.



Scylla ROV. Photo: Larkin

2.2 <u>Design Philosophy</u>

We created the design for Scylla through constant iteration and testing, trying out as many different designs and methods as possible. Such designs that were eliminated through testing included parallel thruster configuration, electrical closing of grippers, and a separate sediment sample collector. Ultimately, some of these ideas were combined with other designs, such as allowing our grippers to collect sediment.

2.3 <u>Innovation</u>

Scylla features numerous novel solutions, refined through extensive testing and iteration, to create a highly mission-capable ROV. Scylla includes three specially designed and unique grippers: a central, top-mounted one for dealing with larger objects such as our float and recovered floats, and two rotating ones lower down, each with individually and specially designed multi-function interactors optimized to meet the challenges put forward by MATE in its challenge this year (*Ref: 2*). Our overall ROV design is fully custom-made to maximize adaptability, ensure safety, and consider cost constraints. We have expanded our capabilities to include a specialty downward-facing camera for unobstructed views of our environment and an extended tether temperature probe for pinpoint temperature measurements. Much of Scylla is custom-designed by

Triton; overall, Scylla contains 53 unique 3-D printed parts designed from scratch by Triton and over 150 3-D printed parts are present on the Scylla, with most of these having gone through at least three iterations to optimize their design, with many going through well over a dozen. Other parts of Scylla are re-purposed items such as used dive lights as ROV lights, and pneumatic releases from left over soft-tipped syringes that have been customized for our needs.

2.4 Problem Solving and Decision Making

Our problem-solving technique typically started with a discussion about our functional goals. Once we agreed on the functionality goals we iterated with different concepts. For example, when we first started addressing the gripper design, we experimented with existing tools (e.g., spatulas). This helped us visually think through the pros and cons of a possible design. Secondly, we considered the cost of the different solutions to each problem. Considering both functionality and cost helped us when we were confronted with Build vs. Buy and New vs. Used decisions (see 2.16 for more information).

2.4.1 Material Decisions

In the building of Scylla, we had to make numerous decisions on what materials to use. To make these decisions, we had to account for how it would interact with its surroundings as well as its strength for use in such demanding applications. For example, we use stainless steel for all exposed bolts, washers, and nuts to avoid corrosion. For custom-made parts, we relied on a variety of plastics. Extruded polycarbonate was used for our frame due to its similar density to water (1.2 g/cm^3 vs 1 g/cm^3, *Ref: 3*), durability, and shatter resistance compared to other readily available materials such as acrylic. For the majority of our custom printed parts, we use acrylonitrile butadiene styrene (ABS) because it is cheap, strong, durable, and (with treatment) waterproof. These characteristics the ideal choice especially compared with polylactic acid (PLA), which is more likely to swell in water and may lose strength over time in water (*Ref: 4*). We limited the use of PLA to specific parts like the gripper heads. This is due to our experience that PLA has better texture for gripping items.

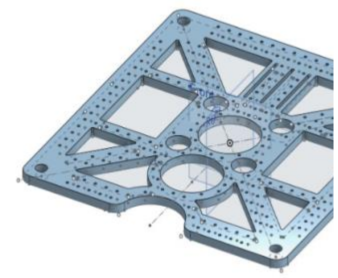
2.4.2 Power Decisions

We use 12VDC electrical power for all of the basic functions of the ROV. The main electrical user is our thrusters, which are overrated in terms of the amount of available power (25 Amp fuse, while our thrusters can take a maximum of 17 Amps each). This means that we are running the thrusters below their maximum capacity, which preserves their lifespan. 12VDC power is converted to 5VDC for computers and logic-based systems and to 3.4VDC for lights. We are using electric servo motors to control our rotating grippers due to the integration with our overall control systems and the fine-scale level of control this gives us compared with fluid power.

For our grippers and releases we chose pneumatic power. Pneumatic power requires active maintenance (removing liquid from the system and ensuring no leaks), but offers fast action and a strong holding force. Additionally, this preserves electrical power for our thrusters and reliability in underwater applications compared to other methods. Future ROVs may investigate hydraulic power as an option, but given the construction schedule and unknowns involved with this, hydraulics were not considered for Scylla.

2.5 Frame

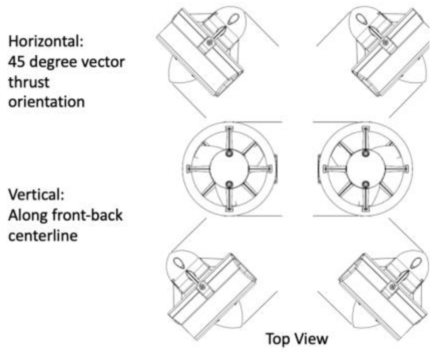
We wanted the frame to be strong and adaptable, so we decided on two custom CAD-designed polycarbonate plates. Each plate has hundreds of mounting holes (0.004m in size spaced every 0.02m) that we use to attach grippers, releases, or other mission-specific tools. The plates are 0.48m long and 0.51m wide (the top plate is 0.010m thick, and the bottom plate is 0.013m thick). We chose polycarbonate for the plates for the reasons mentioned in 2.4.1(Material Decisions). While the plates are large and heavy, polycarbonate’s density is similar to that of water, which helps with ballasting. The two plates size also allows us to be resilient to impacts (see next section).



Bottom plate in CAD. Image: Larkin

2.6 Thrusters

We have two vertical center-mounted motors and four horizontal motors in a corner vector thrust orientation. With this orientation, we can move in all directions horizontally to manipulate objects with our grippers and move around obstacles. Our two-plate frame design allows us to have protected inboard motors protecting us if we hit objects. For our motors, we chose the Blue Robotics T-200 thrusters for their reliable thrust capacity, low maintenance, and price point. The motors use the surrounding water for lubrication and cooling. The thrusters are over-rated for this ROV, accepting a maximum of 17Amps each. Since we use the thrusters in pairs, at most we can supply ~12 Amps per motor, but this means that our thrust tops out at 3.3 Kg-f = 32.3 N (*Ref: 5*), providing ample thrust for our 17.1 kg ROV.



Thruster orientation. Motor image from Blue Robotics.

2.7 Ballasting and Alignment of Centers of Thrust & Mass

To ballast our ROV, we balanced our design, checked the balance on land, and then iteratively tested in pools until our ROV operated up to our standards. Weights are used to balance the ROV left / right and front/back. The negative buoyancy of the ROV is offset by two polychloride vinyl (PVC) ballast tanks cut and built to size on the top. We vertically separate the center of buoyancy from the center of mass to stabilize our ROV.

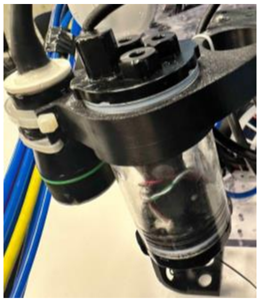
We align the center of thrust and the center of mass to ensure linear motion. The vertical motors are aligned symmetrically to ensure even motion. The horizontal motors are positioned vertically below our electronics container and vertical thrusters to align them center of mass vertically. To minimize drag, holes are built into the system, such as in our plates, skids, and gripper heads. We also iterate the size and positioning of parts to ensure that the center of drag also aligns with the centers of mass and horizontal thrust, thereby ensuring linear motion.

2.8 Tether

Our tether provides power and communication. We provide electrical power using two 8AWG marine tinned wires, sized to trade off voltage loss against good handling. At maximum current 85% of power still reaches the ROV. For fluid power, we use 4mm ID pneumatic lines. These are chosen to allow for good handling, but are undersized for our pneumatic actuators. This tradeoff allows for better ROV motion, but slows down the activation cycle, creating a safer motion. Our actuators are still adequately fast for operational use. The tether also enables communication via an ethernet cable. Communications by ethernet are slowed down by Fathom-X compression boards on either side, as full speed communications tend to result dropouts and loss of communication. Strain relief protects the tether at all connection points. We make the tether neutrally buoyant using pool noodles for smoother ROV motion.

2.9 Cameras

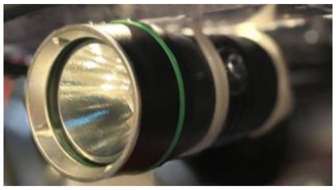
Scylla has two cameras: one in the front and one in the back. We designed Scylla with two cameras to help with positioning, drop functionality, and overall field of vision. The positioning of the cameras was chosen to ensure we had a field of vision at all times without obstruction. For example, the front camera is obstructed when we are carrying the float; designing Scylla with an additional camera placed in the back allows us to maintain an unobstructed field of vision. The front camera (inside the main electronics container) provides our primary field of vision and is attached to a camera tilt system so we can tilt to turn up and down. The back camera (in a separate electronics container) is pointed downward to help us with photogrammetry and movement. Both cameras are low-light HD USB *Blue Robotics* cameras with 1080p resolution for light sensitivity and can utilize H.264 onboard compression resulting in less bandwidth.



Rear downwards facing camera and light. Photo: Lipson

2.10 Lights

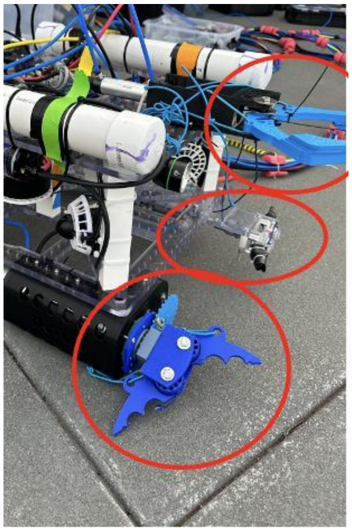
Scylla has two lights, positioned near each camera. This allows the pilot to see in dark conditions. Our lights are repurposed old dive lights that were not being used. We redid the wiring and created custom parts. They are wired in parallel and powered through a 12VDC - 3.4VDC converter; due heating of the converter, it is placed in a secondary enclosure.



Front light. Credit: Gust

2.11 Grippers

Scylla has three grippers: two rotating grippers placed below the bottom plate and one larger gripper mounted centrally above our top plate. The quantity and location of the grippers ensure they can all operate independently and carry objects simultaneously. The top gripper can grab and carry large items such as our float and is positioned to allow the ROV body to help maneuver these items. The lower rotating grippers are able to get as close as possible to the bottom them objects on or near the ground, such as the acoustic receiver and the release pin on the multifunction node. The gripper heads are all iteratively designed to help with multiple specific tasks.



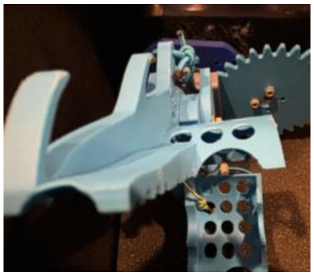
Phase 3 testing of gripper design – float gripper on top, rotating gripper on bottom right and here a fixed gripper in bottom left (later changed to a rotating gripper). Photo: Gust

2.11.1 Pneumatic Design

All of our grippers use a pneumatic actuator to close and open that is attached via a cord to the head of the gripper. This allows for reasonably fast closing action and a strong holding force. To maintain safety while using our pneumatics, we employ strict procedures (see Section 5. Safety)

2.11.2 Float Gripper

Our float gripper utilizes a 36mm-bore, 50mm-stroke Tailonz actuator with a double string connection, increasing the reliability of the gripper; the consistency of the open and close positions are of increased importance due to the need to fit around large objects that require precise positioning of the grippers head.



Rotating gripper. Photo: Lipson

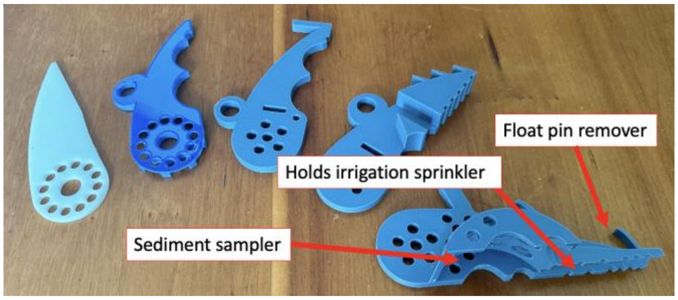
2.11.3 Rotating Grippers

Our rotating grippers use a 25mm-bore, 100mm-stroke Tailonz pneumatic actuator. The shock cord on our rotating grippers allows for the automatic opening of the gripper when pressure is released, eliminating the need for a rigid connection between the actuator head and allowing for a greater range of motion compared to the double string configuration used on our float gripper.

Servo being waterproofed. Photo: Larkin

2.11.4 Servo

Our rotating system utilizes 3-D printed and customized slew bearings that allow the head to rotate without the rest of the gripper moving. Rotation is enabled through the use of a HiTec D95WP servo motor with 0.19 kg-m (19kg-cm) (*Ref: 6*) of stall torque at 5VDC. The servo is IP67 waterproof rated (1 m for 30 min) as purchased. We then waterproof them using our custom-created 6-step waterproofing process that uses multiple layers of epoxy, grease, custom-designed and printed 3-D parts, and more epoxy and grease. The waterproofing has been tested with extended immersion shallow water tests and over a dozen deep (3.5m+) pool tests. These servos provide 150 degrees of rotation that, when paired with a custom 3:1 gear that we have implemented, creates over 360º degrees of rotation, allowing for full activation of the irrigation system. The rotating gripper also allows for the gripper head to be optimally positioned depending on the task and what is trying to be manipulated.



Evolution of the right rotating gripper head. Final design has many task specific features. Many iterations not shown. Photo: Larkin

2.11.5 Gripper Head Design

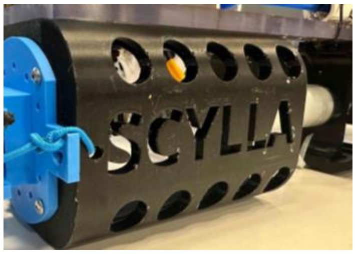
All of our grippers have different head designs that are tailored for different tasks, such as holding large objects, gathering sediment samples, and grabbing and carrying small objects, such as hooks. Every aspect of the head design is carefully considered and tested for the best result; these different designs increase the versatility of Scylla and allow for the completion of different tasks. The right rotating head alone allows for the collecting of sediment samples, the deployment of the irrigation sprinkler, the ability to carry hooks such as the ones on the smart repeater and AUV, as well as providing the full functionality of a regular gripper.

2.12 Pneumatic Releases

Scylla includes two pneumatic releases created from soft-tipped syringes. These releases are used to carry and position the irrigation system and the ADCP but can also be easily reconfigured for different tasks. These releases allow the ROV to carry more items and reduce potential trips to the surface, increasing operational efficiency.

Pneumatic release. Photo: Lipson

2.13 Skids



Left skid. Photo: Larkin

We added skids to protect the actuators and servos that power the two grippers on the bottom of the robot. The skids were custom-designed and 3-D printed using ABS to maximize their strength and waterproof properties. Placing the skids on the bottom of the robot allows us to have more mission-specific objects on the bottom to maximize versatility.

2.14 Float

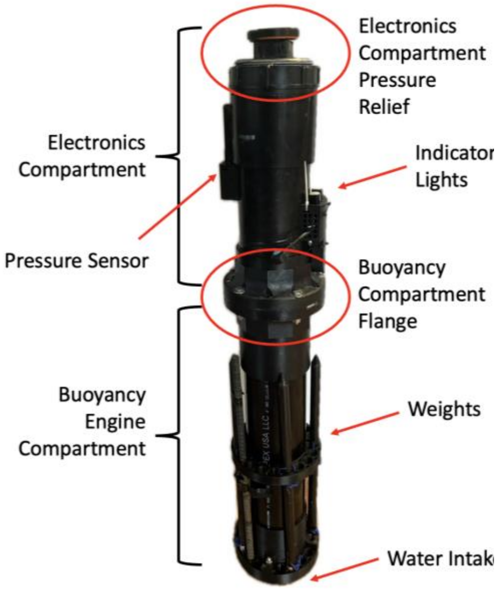


Diagram of float. Photo: Lipson

Our float, Charybdis, is named after the Greek monster that spits out and takes in water. Charybdis is a two-compartment vertical profiling float that utilizes a buoyancy engine for movement. The buoyancy engine consists of a linear actuator paired with a 500mL syringe tube and a custom-printed syringe head.

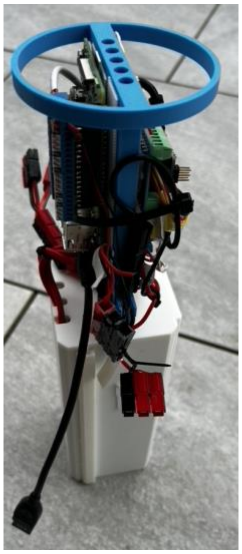
Basics: Our float has a 0.17m max diameter and is 0.96m long. The sturdy, impact-resistant frame is made from extruded 4” ABS pipe and custom-designed and printed ABS.

The float consists of two compartments connected by a 3-D printed compression flange. This means that leaks in the actuator compartment do not jeopardize the electronics. The purpose of the flange is to provide accessibility to the actuator compartments for repair or replacement of the buoyancy engine. The flange is sealed using a 0.1397 m (5.5 in) o-ring.

Electronics: Our custom wired electronics are centered around a Raspberry Pi, Arduino Nano, and relay. The purpose of having a Pi, Nano, and relay is to separate the communication from control, giving us the full processing power of both of these devices on one task. We run two battery systems (8x AA, 8x D-cell), one for our main electronics compartment and one for linear actuator, respectively, we also include a 12VDC to 5VDC converter to meet the voltage needs our Raspberry Pi and other electronics. All power and ground wires are being fused with 7.5A ATO mini blade fuses less than 0.05 m away from the sources. We have a .026 m (2.6 cm) holed pressure relief valve for the battery compartment for safety as per MATE guidelines. Our Raspberry Pi sends and receives data from the temperature, depth, and pressure sensor to our top-side computer. We use homegrown data analytics software to graph this data, as having our own code ensures we get the correct data in a customizable and easy-to-read way. Our computer sends commands to our Pi, then relays via a command string, causing the actuator changes its polarity, and our lights move and signify when the actuator should be moving respectively up and down for the float's vertical profiles, helping us test the float and diagnose possible issues without having to disassemble the float. After receiving a message to profile, the float will go down by pulling the actuator head in, allowing water to enter the space allotted to it in our syringe tube, and then up by pushing the water out once again. Once it reaches the surface, it will send the data captured back and wait for the next message. Lastly, in a geometrically square fashion, for balanced weight distribution, our float has metal rods to ballast itself, keeping it neutrally buoyant. This allows the buoyancy engine to determine where the float will be in the water and for the user to have as much control as possible.

2.15 Electronics and Software

When designing our core software and electronics architecture, we wanted to do two things: expand our capabilities to directly control the ROV using custom software and components, and simultaneously provide a robust, adaptable, and easy to use system. The result of this was the development of many new custom software controls, while also incorporating more standard open-source solutions. Advanced users can work with our control API or experimental autonomous mode, while less experienced users can effortlessly pilot Scylla with an XBox controller using QGroundControl. We also built in expansion into our electronics; for example, we landed on a 3 electronics container architecture, which allows for versatility in adding new systems and components to Scylla. We believe that these choices provide a balanced tradeoff between learning and system capabilities.


Our custom float electronics designed to fit in 4” pipe. Photo: Gust

2.15.1 Main Electronics Container Architecture

Scylla’s electronic architecture is centered around a Raspberry Pi 4B, which provides the full functionality of a computer on our ROV. We chose the Pi for Scylla due to its small form factor, ethernet networking capability, USB ports, and high GPIO pinout. Sitting on top of the Pi is our Navigator Flight Controller board, which provides an onboard IMU and allows us to interface with sensors such as our leak sensors, and onboard and external thermometers and external barometer. These sensors allow for the completion of tasks such as the SMART cable temperature check. Additionally, the Navigator Board provides 16 PWM output channels, granting us seamless control of our main motors and the servos in each of our rotating grippers.

In order to enable effective communication to and from the ROV, we use a FathomX Ethernet Compression Board to reduce the pack size of data in the ethernet connection between the ROV and our topside controller. This allows for high bandwidth, low latency communication across our tether without any need for intermediate repeaters. The FathomX board is connected to the Pi through a standard ethernet cable and interfaces with our tether via a single twisted pair of 22AWG wires.

The main electronics container also includes six 3-phase ESCs, which were built to control our T200 motors, given a PWM signal supplied by our flight controller board. Each ESC is directly connected to the 12VDC power entering our ROV through our tether.

In order to supply power to our control electronics, we utilize 12VDC to 5VDC voltage converters. 5V power is split and directed to two power inputs on our flight controller board. A main power input supplies the Raspberry Pi 4B and the board itself, while an auxiliary 5VDC input supplies our sensor peripherals.

2.15.2 Secondary Electronics Containers

Scylla also includes two secondary electronics containers to help support any number of mission-specific tasks. One container provides a second, downward-facing, low-light USB camera connected to the main ROV through a waterproofed, shielded active USB cable. We found these measures necessary due to the high electromagnetic interference generated by Scylla’s powerful motors.

Our third electronics container supports both our lights and enables easy access to multi-channel servo control. 12VDC power enters this container and is shifted down to 5VDC in order to meet the voltage requirements of our servos. We also include a 3.4VDC voltage shifter board to supply power to our two lights. By splitting power within our third container we eliminate the need for an excessive number of cables connecting it to the main electronics container. This makes Scylla much more expandable and provides the ability to control up to 8 servos. From this container, a PWM signal and power are delivered to each of the servos in our rotating gripper.

2.15.3 ROV software

Scylla features a robust, customizable software architecture that allows low-level control for every function of our ROV. Scylla runs BlueOS and ArduSub, which expose control of our essential functions through the MAVLINK protocol. Our users also have the freedom to switch between three different control modes all offering unique benefits.

QGC: Scylla supports high-level control through QGroundControl, allowing pilots of any experience level to pilot Scylla effortlessly with nothing more than an XBox Controller.

API: We also implemented a lower-level control API using the Python bindings of the MAVLINK protocol, PyMavlink. This API enables us to build custom piloting software, such as our WASD keyboard control, and even stream video from our ROV into custom piloting applications.

Autonomous: Being able to stream video from our ROV is also critical for our experimental autonomous mode. Analyzing Scylla's video streams through the Python bindings of OpenCV has allowed us to recognize patches of different colors in images and structural features of different corals. By combining this image analysis with directional orientation from our onboard IMU, Scylla is able to accomplish some simple tasks autonomously. We will continue to build on this functionality in future ROV software rollouts, recognizing autonomous control is essential for the marine engineering tasks of tomorrow. Triton expects a fully functional autonomous mode in Scylla's successor when we compete next year.

2.15.4 Photogrammetry

Scylla also includes many options for marine photogrammetry, developed by Triton. All of these methods offer specific benefits and are better used in certain situations.

Point Clouds: Recorded ROV video can be fed into both open-source photogrammetry software and Triton's experimental photogrammetry platform. This software considers each camera position to generate a point cloud of any scene, scaled to its real-world size. Due to the high computing requirements of this method, Scylla also provides an in-house, alternative photogrammetry program for cases when rapid distance measurement is necessary.

Rapid Distance Measurement: We developed a custom measurement program using Python 3.10, which leverages OpenCV 4.9 to find distances between objects from camera views that are orthogonal to the surface we wish to measure. Users first draw lines representing known lengths in an image, which are used to scale any unknown lengths they wish to measure.

By changing the quality and granularity of our measurements, Scylla supports everything from digitizing an entire reef structure all the way down to measuring the distance between fish in a school.

2.15.5 Float Software

We designed and built our float software ourselves. It was important for us to design a dropout resistant communication protocol and, after testing, we settled on PyBluez, the Python library for the popular Bluez Bluetooth framework. The client, in this case the float, connects to the server, our topside computer, whenever it is visible. When the server is visible, the float will begin automatically sending a JSON file containing a buffer of data points from our pressure and temperature sensors, transmitting an entire dive cycle. Our float is controlled by transmitting command sequences, a list of commands and how long they should be executed (e.g., IN 30 sec, HOLD 20 sec; OUT

30 sec). This allows us to customize our profiles for longer or shorter dive lengths, increasing the versatility of Charybdis. In order to visualize our dives, the server contains functionality to visualize the data we receive from the float through custom code utilizing MatPlotLib.

2.16 Build vs. Buy, New vs. Used

Triton always tries to design and build our components wherever feasible. For example, we created our own frame, grippers, and motor guards, among other things. Overall, Scylla and Charybdis have over 53 different custom-designed parts. We also relied on learning from household and other items around us and either repurposed these directly - as we did with some discarded dive lights - or incorporated their form and function into our custom 3-D parts as we did with our gripper heads. We reused elements where possible to reduce waste and bring down costs, for example, we had access to a main electronics container and thrusters from a previous ROV. Our iterative design process placed extreme value on the ability to build and test our own parts. We see creating unique features as a way to build skills and capabilities in-house for the future. This is why all of our grippers, releases, and other mission specific features are entirely in-house custom designed. We are proud that Scylla and Charybdis overall have more individual custom designed and printed parts than purchased ones (excluding screws, nuts, and washers). These parts provide unique, purpose-built, and tested capabilities that enhance our design and the functionality of Scylla and Charybdis.

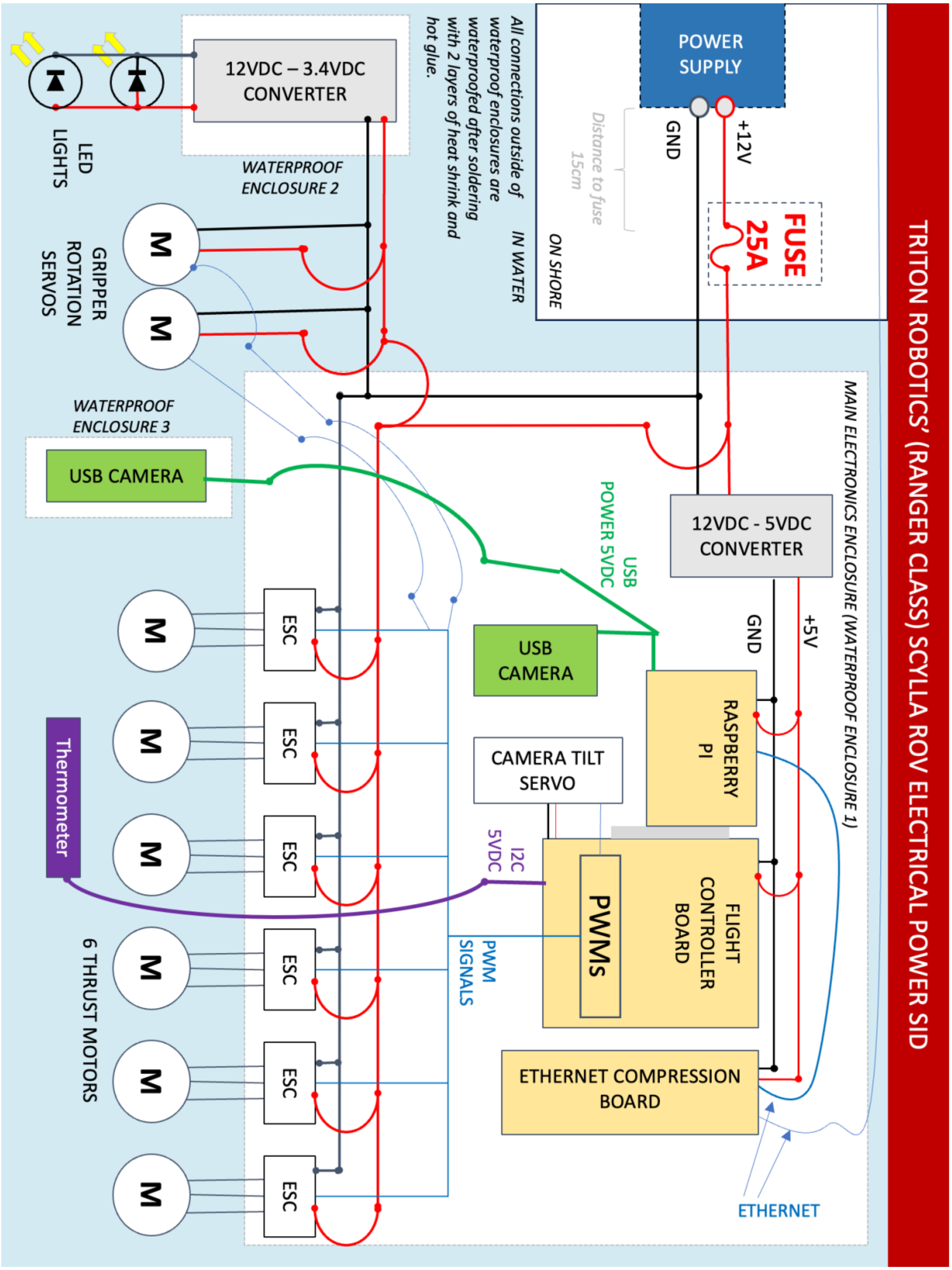
In some cases, we tried to build our own parts but ran into problems and eventually decided to purchase. This is the case for our secondary camera’s watertight enclosure where the optics of our initial custom milled polycarbonate enclosure did not meet our standards, causing us to purchase.

In general, the things that we did buy new were for the reliability of the ROV. We bought our electronics boards and containers due to how much it would take away from the time spent on other components and could potentially lead to expensive losses if these components were to fail, especially our electronics enclosures.

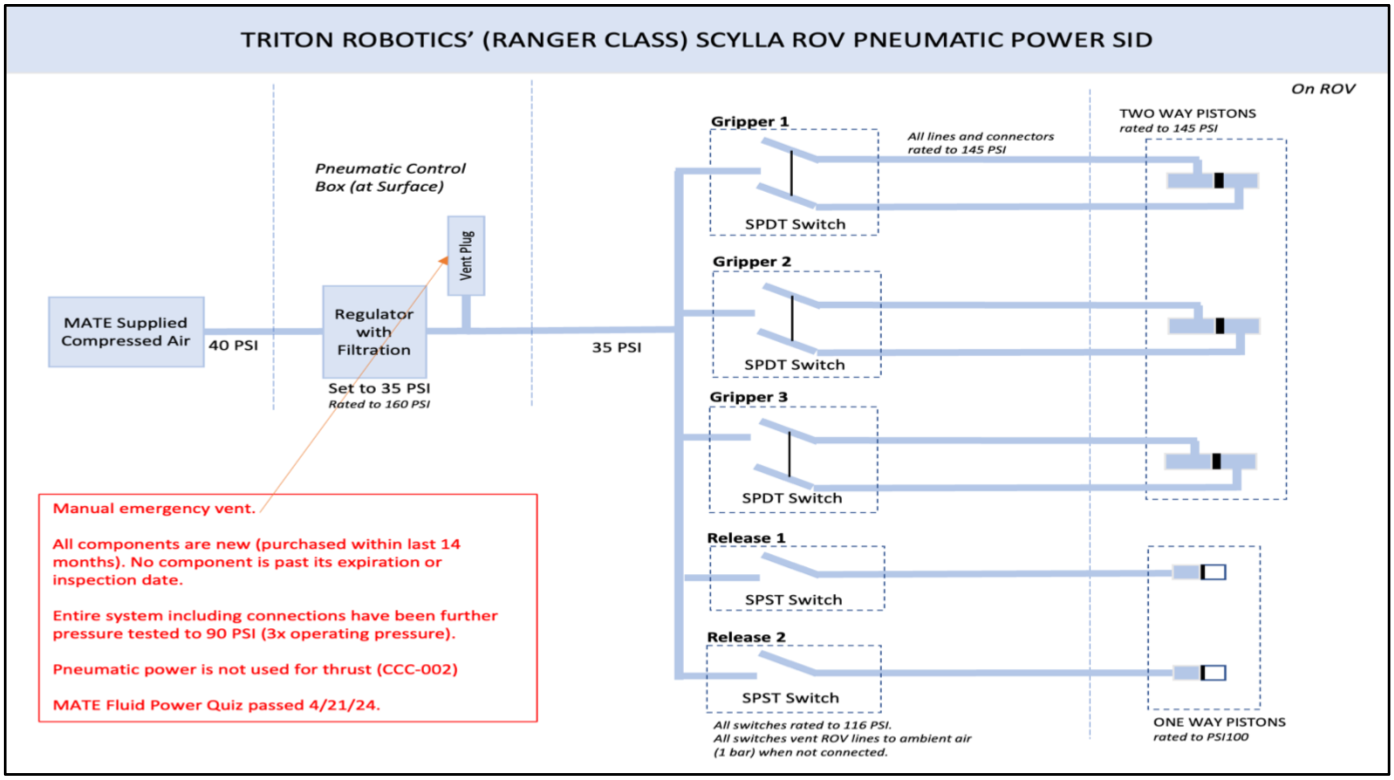
We take pride in the fact that there are more different custom parts on our ROV than purchased parts, and that all of our custom parts except for two – the motor guards and the slew bearings in our grippers – were designed from scratch. This effort to build our own designs means that Scylla and Charybdis are unique, robust, and highly capable.

3. SYSTEM INTEGRATION DIAGRAMS (SIDs)

3.1 Scylla ROV Electrical SID



3.2. Scylla ROV Pneumatics SID



Manual emergency vent.

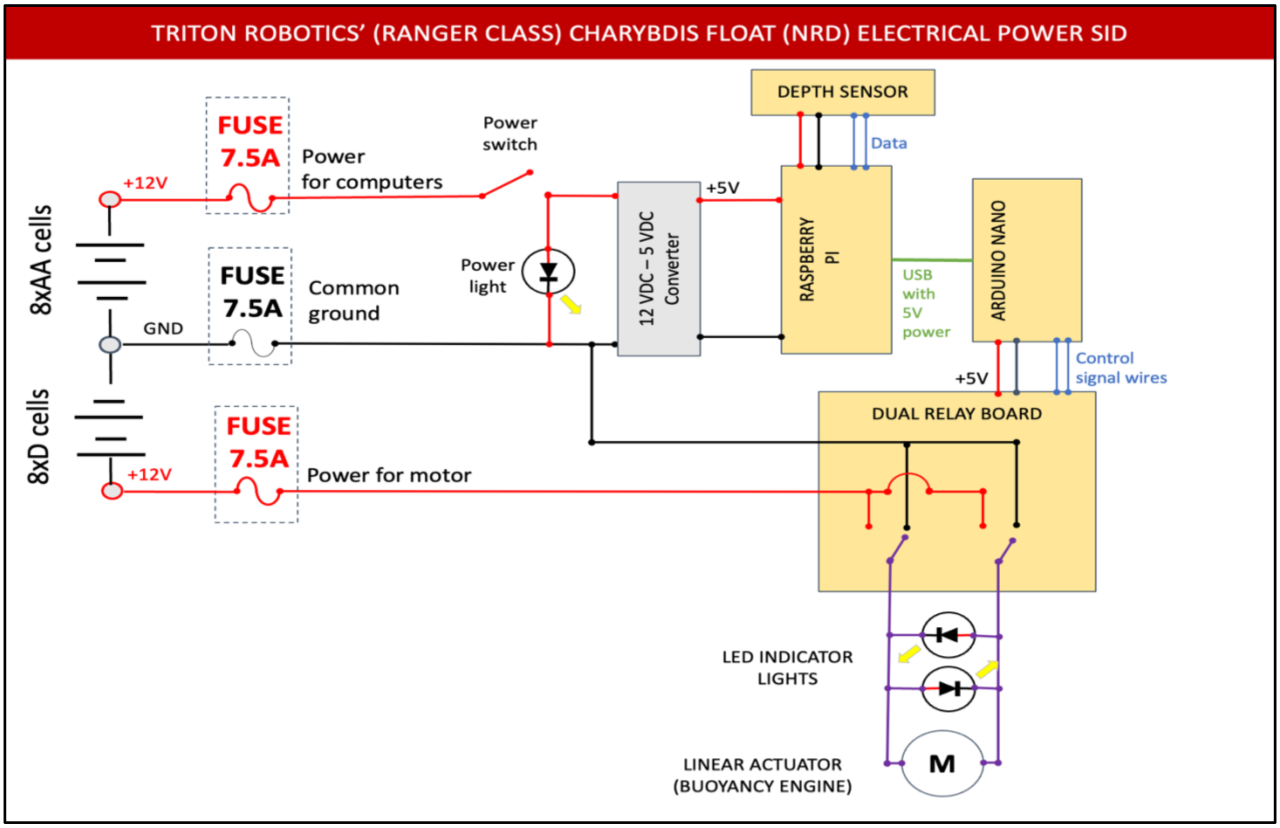
All components are new (purchased within last 14 months). No component is past its expiration or inspection date.

Entire system including connections have been further pressure tested to 90 PSI (3x operating pressure).

Pneumatic power is not used for thrust (CCC-002)

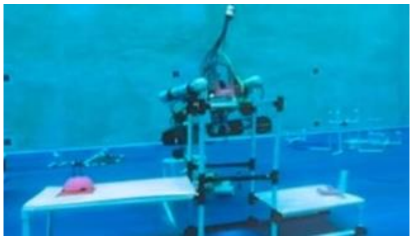
MATE Fluid Power Quiz passed 4/21/24.

3.3. Charybdis Float Electrical SID



4. TESTING AND TROUBLESHOOTING

4.1 Testing


Task-specific testing. Photo: Seelig.

We actively look for flaws in all of our products through repeated testing. Finding these flaws allows us to build a new, better version. This is done both in mission specific task testing, but also past the limits of these challenges. Our testing starts in the lab with individual component tests. These are designed to see if the part works at all; if it passes reliably, we move on to component system tests. The component systems must pass shallow water pool testing until it works reliably underwater before being mounted on the ROV. Finally, it is used in deep pool (3.5m+) testing to check waterproofing at pressure and also for first for mission task performance. At any point the component may be scrapped or sent back for redesign; this rigorous process leaves us with all the highest quality components for our ROV. In building Scylla, we rigorously tested every system at least five times in deep water pool tests before it was accepted into our final product. All of this testing allows for a high degree of confidence that all of Scylla's systems will work together seamlessly to accomplish the mission.

4.2 Troubleshooting

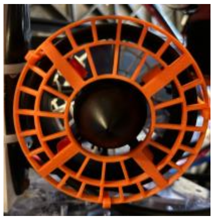
As described above, every part of both our ROV Scylla and our float Charybdis is a product of multiple troubleshooting and problem-solving iterations. For example, it took three major redesigns and over 20 iterations and fixes before we found a way to create a water-tight compartment for our linear actuator that could be sealed reliably and still open to all for full access and replacement of the actuator. In the end, we found two solutions: one with an O-ring that had to be redesigned at multiple depths until it worked and one with an ABS compression fit system. We then tested both and actively tried to find ways to make these solutions fail, before we chose the one we wanted for our final product (the O-ring solution).

4.3 Learning

As a second-year company made of 9th graders, we recognize that we are still learning and building our skills as a team. To do so, we prioritized both learning new skills and also ensuring that those with specific skills passed on their knowledge to other team members. Skills such as CAD grew enormously this year, with initial clunky designs being replaced by more complex designs. Only two components – our motor guards slew bearings - are customized from existing online diagrams. All our other custom parts were designed from scratch. For fabrication, in addition to laser cutting, CNC milling, and 3-D printing, we had to figure out how to reliably waterproof servos and create watertight ABS parts. For software, we greatly expanded our knowledge of how to program the ROV, in the end creating a rudimentary autonomous control from scratch by combing a custom thruster control routine with a custom image red-tracking algorithm. While this design is not being used this year in the competition, it was a huge milestone that we can build upon in the future. Additionally, we learned major lessons about time management and project management, using things like time boxing for tasks, phase identification, and planning for the whole project. While we often learned these lessons the hard way this year, this is one of the big things we can build upon next year. These skill advancements will allow us to grow as a company and release even more advanced products in the future.

5. SAFETY

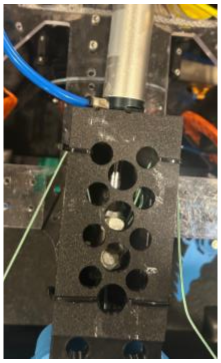
At Triton, safety is our core principle; we ensure everyone's safety through personal protective equipment (PPE), checklists, continuous communication, including call and response protocols, job safety analyses (JSAs), materials and engineering research, and specific design decisions. In doing so, Triton meets and exceeds all of the MATE safety requirements. Safety decisions are built into every planning meeting, design discussion, fabrication session, and operational test. By being fastidious and conscientious of safety and making it a habit, we can better focus on our design and engineering to build advanced functionality into our systems.



Our custom expanded motor guards. Credit: Lipson

We considered safety measures to address personnel, equipment, and operations. (Note: For safety checklists and Job Safety Analyses (JSAs) see Appendices.)

5.1 <u>Personnel</u>



All moving actuator parts are shielded. Credit: Lipson

The three most impactful personnel safety hazards are pneumatics, motors, and electrical hazards. We have mitigated injury risk from these hazards by:

- Pneumatics: Shielding and proper placement of pneumatic tubing
- Motors: Motor guards and shrouds.
- Electrical: Using fuses, enclosure of electrical components, and ensuring that wires are properly shielded.

These personnel safety precautions allow us to test more advanced functionality and challenge ourselves to try more technically advanced systems. Finally, strong communication across the team in everything we do helps to ensure everyone thoroughly understands the dangers and how to reduce them.

5.2 Equipment

We also built safety precautions to avoid damage to the most vital ROV components, including:

- Lifting: Always done with a minimum of 2 people.
- Power and electronics: Fuses, protocols for turning on and off, leak detection, silica packets.
- Pneumatics: Emergency pressure relief valves, lower than standard pressure, protocols for turning fluid power on and off
- Actuators and motors: Moving parts protected from impact by shielding to prevent items reaching them and to protect against impacts.

5.3 Operational

When operating the ROV, the team communicates through a call-and-response protocol that allows for coordination between members. We also have set up and take down protocols to create an environment that allows users to operate safely. We ensure the operational security of Scylla through more than 20 deep pool tests and numerous shallow water tests, creating the highest quality and reliability. All elements of the Scylla have been inspected with the goal of finding flaws, leading to a product that operates without surprises and mitigates potential dangers to users and the ROV. Additional operational safety measures include:

- Motor guard mesh: The motor guards on the ROV allow us to place the Smart Cable without fear of the cable intruding into the motors.
- Grippers: The grippers are rounded to prevent damage to the environment.
- Gripper/Actuator Gripper strength has been limited to protect items that are held.
- The frame is built to be robust and is overbuilt to accomplish all tasks and ensure the safety of the mission.

The ROV skids permit it to land without disturbing the marine environment, which enables it to be nibbler and reach tasks better as well as protecting the ROV itself.

6. BUDGET DISCUSSION

For budget tables, please see Appendix 3.

Triton estimated a budget at the beginning of the year of $4000 based on our experience the previous year and the understanding that we would be building and testing more than the previous year due to a more ambitious Ranger class build and the need to build a float for the first time. This was estimated as $1250 for Electronics, $500 for Structure and Waterproofing, $1250 for Grippers and Mission Specific buildouts, and $1000 for Miscellaneous expenses.

For the most part, our initial budget worked very well. We bought things if they were affordable, and if they were a little pricey, we had discussions of value vs. cost and other options that involved the Engineering Lead and/or Software Lead as well as one of our Mentors. This helped determine how critical certain items were (see Build vs Buy, New vs Used, for more information). In the end, we spent just over our yearly budget in building Scylla and Charybdis (see tables in the Appendix). This was largely due to the unexpected need to replace our borrowed air compressor.

We had no sense we might win our regional contest and have the opportunity to travel to the World Championships. While we are incredibly grateful for this experience, it did create an unfortunate budget crisis, as going to the World Championships costs more than our annual budget. To cover this, we have had to have meetings between our families and our school, and develop a proposal for funding from our school's administration. Making this particularly tricky is the timing; we are near the end of our school's yearly budget cycle. We are grateful to our school and families for their support in meeting this funding challenge and making it possible for us to attend.

7. ACKNOWLEDGEMENTS

We at Triton Robotics know that we could not have done this alone and would like to thank everyone who helped us along the way. A special thanks to our wonderful mentors at school, especially Gerald Elliott, and to our parent mentors, Charles Gust and Sim Larkin. We also want to especially thank our families. Thank you to Underwater Sports, Jennifer Cast and Liffy Fanklin, and Overlake Club for allowing us to use your pools. Thank you to Blue Robotics, Fishery Supply Company and Tacoma Screw for discounted supplies.Thank you to our school for the financial backing to go to Worlds and to our parents for their financial backing throughout the year. Thank you to the MATE Competition and to the MATE PNW Regional Competition organizers and volunteers for the support, advice, and opportunity to present Scylla and Charybdis.

8. REFERENCES

1. *United Nations Decade of Ocean Science for Sustainable Development, https://www.unesco.org/en/decades/ocean-decade, Accessed 5/17/24.*
2. *MATE 2024 Ranger Competition Manual, https://materovcompetition.org/ranger; Accessed 5/17/24.*
3. *Polycarbonate specifications via British Plastics Federation, https://www.bpf.co.uk/plastipedia/polymers/Polycarbonate.aspx; Accessed 5/17/24.*
4. *Waterproofness and water absorption, Ultimaker website: https://ultimaker.com/learn/how-to-3d-print-waterproof-parts/ Accessed 5/17/24.*
5. *T200 Thruster specifications via Blue Robotics:*
6. *HiTec D946WP Servo specifications via ServoCity, https://www.servocity.com/d956wp-servo/; Accessed 5/17/24.*

APPENDICES:

A.1 BUDGET TABLES

ROV and Float Expenses (*All prices in US Dollars, USD$). Start of year budget estimates totaling $4000 are included in table under each category.*

Category	Items	Donated	Reused	Purchased
Electronics	Raspberry Pi 4B boards		139.99	139.99
	Navigator Board		320.00	320.00
	Arduino Nano and Relay Boards			93.68
	Pressure sensor			170.00
	Temperature sensor			150.00
	USB Camera		189.00	189.00
	12VDC-5/3.4VDC converters			81.85
	Dive Lights	79.90		
	Anderson Powerpole Connectors		9.00	45.00
	Ethernet Tether Cable		162.50	
	T200 Thrusters		1,400.00	
	Batteries (AA and D)			141.56
	Battery Holders			17.50
	Subtotal Electronics (est $1250)	**79.90**	**2,214.49**	**1,432.73**
Structure and Waterproofing	Waterproof Enclosures		418.00	250
	Heat shrink (various)			24.95
	Hot glue sticks			9.95
	O-rings and grease			86.95
	ABS 4” pipe and fittings			120.54
	Wetlink Penetrators		175.00	100.00
	Epoxy			34.95
	Subtotal Structure (est $500)		**593.00**	**627.34**
Grippers and Mission	ABS + PLA Filament Rolls			151.92
	HiTec D956WP Servos + Mounts			455.32
	Pneumatic line, fittings, actuators		120.00	245.19
	Linear Actuators			119.97
	Subtotal Grippers (est $1250)		**120.00**	**994.08**
Tools	Air Compressor (unexpected)			189.00
	Borrowed Tools	5,000.00		
	Borrowed 3-D Printers	3,500.00		
	Subtotal Tools (est $0)	**8,500.00**		**189.00**

Misc. (est. $1000)	Miscellaneous supplies			334.46
	Stainless Steel Bolts and Nuts			85.00
	Shipping			130.00
	Tax			360.97
	Subtotal Misc (est $1000)			**910.43**
ROV AND FLOAT ITEM TOTAL		8,579.90	2,927.49	4,153.58

World Championship Expenses (*All prices in US Dollars, USD$).*

Travel	Quantity	Per Item	Estimated Expenses
Airfare - 5 team members, 3 mentors	8	967/person	7,736.00
Rooms (6 nights each)	3	159/night	2,862.00
Purchase shipping boxes	2		825.00
Shipping	5 boxes		763.47
Subtotal Worlds			**12,186.47**

Total Costs and Total Funding from Sources (*All prices in US Dollars, USD$).*

Expense Category	Estimated Budget	Actual Expenditures
ROV and Float Materials - Purchases	4,000.00	4,153.58
ROV and Float Materials – Reused / Donated	n/a	2,893.39
World Championship	n/a	12,186.47
TOTAL		19,233.44
Funding from School		10.256.47
Funding Donated / Contributed		8,976.97
Reused Parts		2,927.49
Donated Tools and Parts		8,579.90

A.2 SAFETY CHECKLISTS

Setup:

- Unravel the tether.
- Secure Strain Relief to prevent the tether from being pulled.
- Place the ROV near the pool (2 people). Check for loose items.
- Set up the Pneumatics box. Secure box. Call and response before attaching pneumatics to compressor. (Members closest to components must respond "Clear"; this practice is followed throughout.) If clear, connect. Notify connected.

- Place computers securely. Connect USB adapters between ethernet and computer, and X-box controller. Turn on computers.
- Ensure power supply is off. Call and response to connect to power. If clear, connect to power. Notify power connected.
- Call and response to turn on power. If clear, turn power on. Notify power on.

Operations

- Check ROV for unsecured items.
- ROV personnel call and response “Ready to Launch”. If navigator and pilot ready, have two members gently place the ROV in water. Notify in water.
- Pilot and Navigator indicate ready to arm. If ROV personnel indicate clear, arm.

Post Run:

- ROV personnel indicate ready to remove from water. Pilot and Navigator disarm ROV then say ready. Once all clear, multiple people lift ROV out of water.
- Pneumatics indicates ready to de-power. ROV personnel indicate clear. Once clear, release pressure with relief valve.
- Once no pressure, disconnect pneumatics from compressor.
- Pilot and Navigator power system off and notify all. Wait 10 seconds. Okay to remove power connector from
- Pack up ROV and tether.

A.3 JOB SAFETY ANALYSES (JSAs)

Fabrication and Assembly

TASK	HAZARD	PROTOCOL
Power Tools (req. supervision)	Electrical Shock	Check wires; Check for water in workspace.
	Flying Debris	Safety Glasses for all in vicinity; Check material; Material secured down; Notify when starting
	Winding Injuries	Hair tied back; Loose clothing removed
	Direct Injuries	Hands and bodies out of way; Use pushing sticks; Notify all of task before starting
Soldering	Burn injuries	Check soldering iron; Use helping hands; Secure items
	Eye injuries	Safety glasses
	Fumes	Use ventilation. Wear masks as needed; Notify all.
Gluing & ABS Printing	Fumes	Outside; ventilated; wear masks; notify all before starting
	Burns	Use gloves; Wash hands immediately after
	Eye injuries	Safety Glasses; have wash out kit handy

Transporting

TASK	HAZARD	PROTOCOL
Carrying ROV	Heavy lifting	Always lift ROV with a partner. Lift with legs. 2 people to lift ROV; Communicate with partner
	Crushing by toppling	Toolboxes and items stacked can topple; Avoid making stacks too high; Dedicate watcher
	Tripping	Be aware of tether and items on ground; Clear path; Call out items not movable to partners before starting; No running.

Operations

Throughout	Slipping	Watch for water; No running; Call out slippery areas;
	Tripping	Designate walkways; Create specific pathway for tether;
	Heavy Lifting	Always lift ROV with a partner. Lift with legs. 2 people to lift ROV; Communicate with partner
Setup	Pneumatics	Only attach pneumatics if pressure is zero; Visual check of lines before attaching; Do not turn on pneumatics until everyone has responded that they know and are wearing safety glasses
	Electrical	Check wires; Check for water; Ensure GFCI; Ensure all wearing safety glasses;
Operations	Tether	Communicate with tether manager when approaching; Follow designated walkways; No running
	Pinching	Communicate with Pneumatics officer when working around ROV; Do not touch grippers without Pneumatics officer permission; Use Call and Response
	Props	No hands inside ROV when activated. Communicate with Operations and use Call and Response to ensure disarmed.