EAST TENNESSEE STATE UNIVERSITY

JOHNSON CITY,
TENNESSEE,
USA

BUCCANEERS

2024 TECHNICAL REPORT

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Abstract

The Buccaneers are a seven-person company from East Tennessee State University in Johnson City, Tennessee. With extensive experience in underwater robotics, the team has designed, manufactured, and tested the most advanced Remotely Operated Vehicle (ROV) yet, named *Calypso*. This ROV was engineered to address the tasks set forth by the Marine Advanced Technology Education (MATE) organization, including deploying deep-sea cables, transplanting coral, recovering acoustic receivers, and servicing coastal arrays.

Calypso is the result of the team's determination to create an efficient, safe, and innovative yet straightforward ROV. The ROV features a vectored eight-thruster propulsion system, a progressive control scheme, and a compact, robust frame. These attributes ensure superior maneuverability, reliability, and ease of operation in various underwater environments.

This year's report includes a comprehensive engineering design process, which underpins the successful ROV development. This includes an iterative design methodology, testing procedures, and commitment to safety standards. The continuous adaptability of the team and ROV have enabled the development of a competition-ready ROV that meets and exceeds the rigorous demands of the MATE competition.

By detailing the experiences and insights, the Buccaneers aim to contribute to the broader ROV and MATE community. Sharing this journey and innovations will inspire and elevate the performance of all ROV teams, fostering a spirit of collaboration and advancement in the field of underwater robotics.

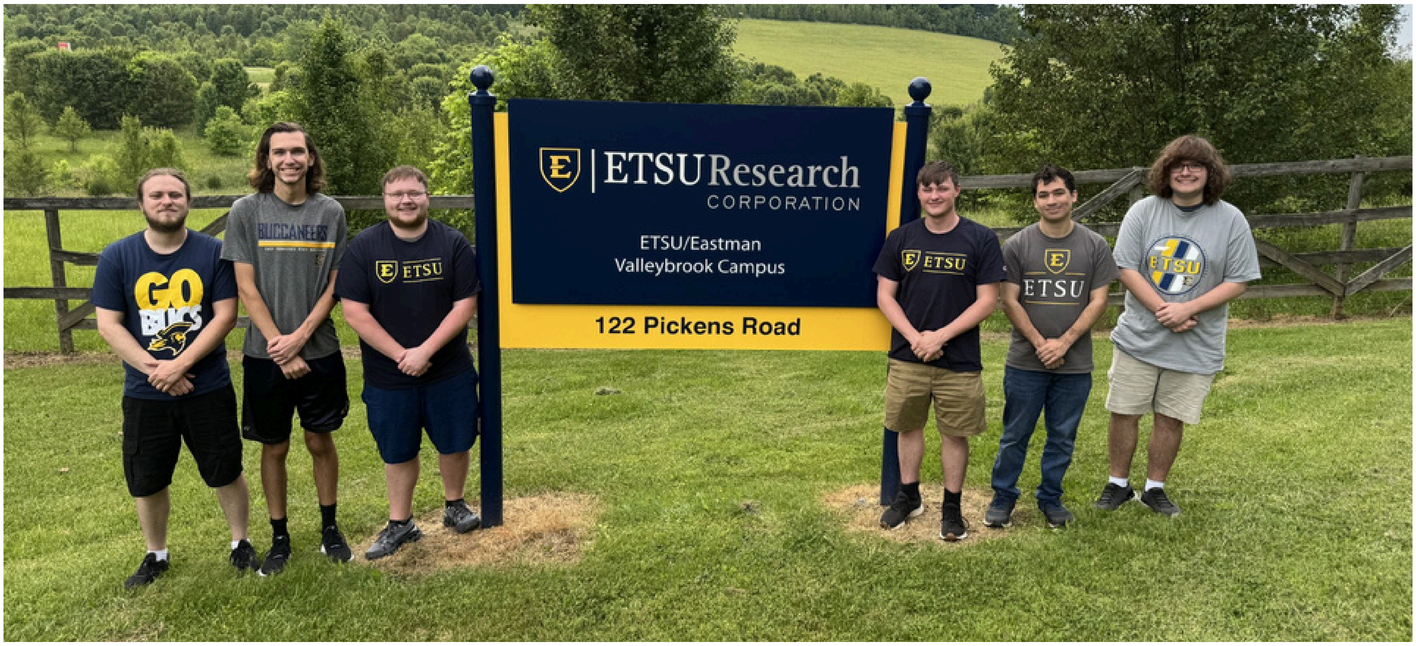

Figure 1: (left to right) Nicholas Sells, Pearson Mills, Quintin Folkner,
Gavin Bentley, Samuel Deaton, Matthew Smith (not pictured: Quinn Bentley)

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Teamwork

Company Profile

The East Tennessee State University Buccaneers are a well-experienced underwater robotics team, dedicated to Earth's contemporary environmental issues, while focusing on sustainability and efficiency. The team is comprised of eight undergraduate students with a combined 39 years of experience in MATE. Each member has a unique skillset, which led to the natural delegation of tasks to each member. This logical organization guided new members to their department. The team's departments include mechanical, electrical, and software. With such a small team, members often overlapped between departments, leading to a well-rounded knowledge of the project for all members.

Scheduling

The Buccaneers implemented a flexible scheduling system that adapts to the varying demands of each week. This dynamic approach allows for the efficient allocation of resources and personnel based on project priorities, member availability, and specific task requirements. By adjusting the schedule on a weekly basis, productivity can be optimized and project milestones can be reached. This manner of scheduling fit work sessions to the availability of the majority of members, while also considering if purchased parts had arrived. Also, if only one department was needed, that department could meet on their own schedule.

Name	Position	Year	MATE Experience
Gavin Bentley	CEO	Sr.	7
Quintin Folkner	COO/Pilot	Sr.	7
Quinn Bentley	Mechanical	So.	6
Samuel Deaton	Electrical/Float	Fr.	6
Pearson Mills	Mechanical	So.	6
Nick Sells	Software	Sr.	2
Matthew Smith	Mechanical	Fr.	5

Figure 2: Information on company members.

Resources, Procedures, Protocols

In day-to-day operations, the Buccaneers employed various methods to ensure their success. To determine the design of the ROV for the year, company members would meet and brainstorm ideas. Cost-benefits analyses were conducted for multiple components and members would discuss what would be best for the design.

The Buccaneers meet at East Tennessee State University's Valleybrook campus. The company has a designated workspace and access to tools and materials. The workspace is available to company members whenever they need it for their projects. The Valleybrook campus also houses a small indoor above-ground pool used for thruster and buoyancy testing.

To communicate online, Discord was used. Discord was used for sharing ideas, pictures, and meeting plans. Also used was Microsoft OneDrive for technical documentation and file storage. Onshape was used as computer-aided design (CAD) software.

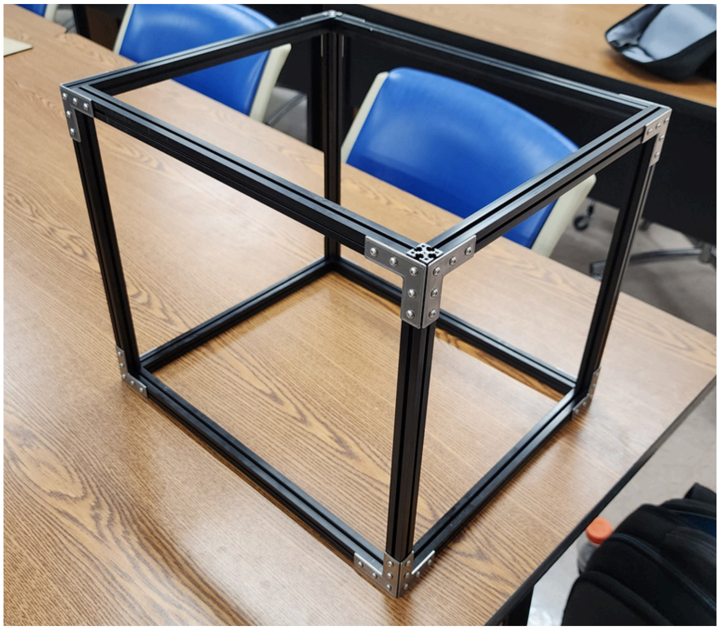


Figure 3: Structure of *Calypso* early in construction.

Design Rationale

Frame and Structure

The vehicle's structure consists of 12 anodized extruded aluminum beams, each 1.5 cm in width. The beams assembling the front and rear of the vehicle each measure 30.2 cm. The lengthwise beams measure 34.6 cm. In the frame's arrangement, the ROV's frame is 37.8 cm in length, and 31.8 cm in width, and 31.8 cm in height.

Extruded aluminum was selected as ROV's frame for its modularity, strength, and its ability to easily mount additional components. The extruded aluminum contains T-slot channels which allow for the convenient attachment of thrusters, manipulators, and electronics capsule. All components mounted to the frame required no permanent modification. This means that, if necessary, any components can be readily replaced.

Previously, the frame consisted of extruded aluminum and high-density polyethylene (HDPE). This year, the frame is comprised of solely extruded aluminum. HDPE proved to have a relatively low flexural strength with the vibrations of the thrusters. Extruded aluminum, however, has a much higher flexural strength, as well as compressive strength and tensile strength.

Propulsion

Calypso is propelled by eight Blue Robotics T200 thrusters. T200s were selected for their reliability, strong thrust capability, and compatibility with the control system. Additionally, they have their own electronic speed controllers designed specifically for their operation, from Blue Robotics. Each thruster is located in a corner of the ROV’s structure, mounted at a 55° angle. Mounting the thrusters within the frame of the ROV protects the thrusters from being bumped during operation and transportation. Moreover, locating the thrusters closing to the ROV’s center of mass naturally decreases torque, allowing more precise rotation in piloting. The front thrusters and rear thrusters are both directed towards a point in front of and behind the ROV, respectively. This configuration allows for high maneuverability and thrust efficiency. When moving in any direction, every thruster can contribute to the propulsion of the ROV.

Furthermore, if a thruster fails, the remaining thrusters can compensate for it, a feature not as strong in a six-thruster configuration. When carrying a heavy load, power can be increased to the front thrusters, allowing the ROV to stay level as it is piloted. Each thruster is fitted with 3D-printed thruster guards to ensure the safety of operators and to prevent outside interference with the propellers.

Manipulator

Calypso is outfitted with an Actobotics gripper. This gripper is mounted on the front of ROV to a vertical extruded aluminum beam. It is capable of grasping items up to 10.6 cm wide. The gripper was selected for its simplicity, affordability, and light weight. Without the servo attached, the gripper weighs less than 50 grams. To open and close the gripper, a Savox waterproof servo is used. The vertical orientation of the gripper was determined after examining the mission specifications set out by the MATE organization. Examples include transplanting brain coral in Task 3.2 and placing a probiotic irrigation system in Task 3.1. Additionally, in the event of a mechanical or electrical failure, the gripper can be used as a hook.

Figure 4: Actobotics gripper

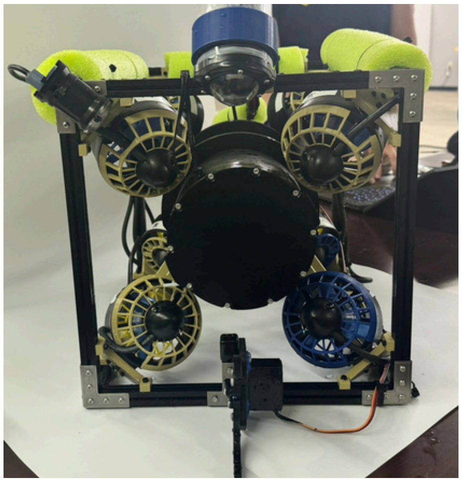


Figure 5: Thruster configuration on *Calypso*

Buoyancy

After testing and calculations, *Calypso* is neutrally buoyant. Originally through in-water testing, *Calypso* was discovered to be negatively buoyant. Aluminum comprises a large portion of the ROV and has a density of 2.7 g/cm3, meaning that it is negatively buoyant. To counteract this force, Subsea R-3312 buoyancy foam is mounted to the top of the frame of ROV. The foam, made of polyurethane, has a density of 0.192 g/cm3, making it positively buoyant. To find the correct amount of foam to use and where to locate it, the foam was methodically placed on the frame in varying amounts. Once determined, the appropriate size of foam was mounted closer to the rear of the ROV, as the camera watertight enclosure provided some buoyancy for the front.

Vision

Calypso is outfitted with a single analog RunCam Racer Nano FPV (First Person View) camera, commonly used in drone racing for its high-performance imaging capabilities. This analog camera is securely housed within a 2-inch Blue Robotics Locking Watertight Enclosure, ensuring reliable operation under underwater conditions. The enclosure (Figure 6) is mounted using a custom-designed 3D-printed bracket, optimized for stability and minimal vibration. The ROV also has two 16 MP USB cameras. All three cameras have wide-angle views, facilitating precise manipulation tasks by providing the pilot with clear, real-time visual feedback of the manipulator operations.

Calypso also has a Lumen Subsea Light (Figure 7), which is an LED light capable of outputting 1500 lumens of light. The light gives *Calypso* the ability to perform in low-light conditions.

Power

Power enters the system at the tether as 48-volt power after passing through a 30-amp fuse then enters the watertight enclosure. From there, a 48-volt-to-12-volt converter reduces the voltage to 12 volts. This power is distributed through Blue Robotics ESCs to the T200 thrusters, and to the RunCam camera, back to the surface, and a 12-volt-to-5-volt converter. This converter sends 5 volts to the Raspberry Pi Pico, Raspberry Pi 3B+, and to the servo for the manipulator. At the topside control system, 12-volt power is received and converted to 5 volts which goes to a Raspberry Pi 5.

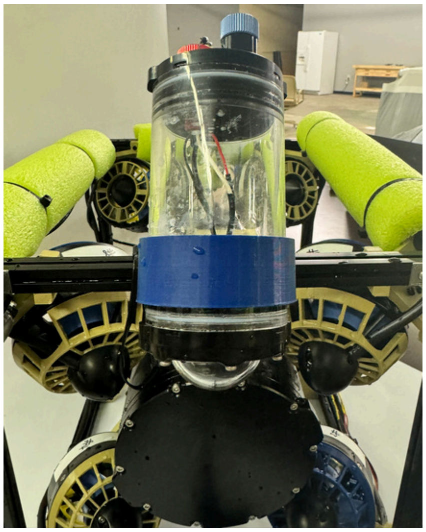


Figure 6: RunCam Racer Nano camera.

Figure 7: Lumen Subsea Light.

Tether

Calypso receives power and control signals from the topside control system through its tether. The tether consists of two 48-volt power wires, a camera wire, an ethernet cable, and two 12-v power wires. The wires are collected in an expandable braided sleeving with buoyancy attached. The tether is 15 meters in length. This length was calculated with knowledge of the MATE product demonstrations occurring within 10 meters of the pool's side, the pool having a maximum depth of 4.5 meters, and the workstation being no further than 3 meters from the edge of the pool. The tether length was limited to 15 meters after considering voltage drop and reduced tripping hazard during poolside operation and transport.

Strain relief is implemented at both the ROV (Figure 8) and the topside control system. At the ROV, the strain relief is detachable, which allows the electronics within the watertight enclosure to be removed conveniently. While *Calypso* is not in operation, the tether is coiled and placed in an adjustable cable clamp to minimize tangling or tripping hazards (Figure 9).

Figure 9: Tether coiled and in clamp.

Figure 8: Tether strain relief before entry into watertight enclosure.

Watertight Enclosure

The electronics of *Calypso* are housed within a Blue Robotics aluminum watertight enclosure. The enclosure has a 13-cm diameter and is 30-cm in length. The enclosure's aluminum body is very durable and allows the electronics to stay cool by quickly adjusting to the water's temperature. This means that the enclosure serves as a heat sink, transferring the heat created by the electronics to the water.

The wires enter and exit the enclosure through the end cap at the rear of the enclosure. This end cap contains 26 M10 holes. The 26-hole end cap was selected for its ability to accept a large number of wires, which is vital for the use of eight thrusters. Furthermore, more components can easily be added to the ROV's design in the future, such as additional cameras or manipulators. Both caps can lock to the enclosure tube via a locking cord, further enhancing the enclosure's ability to remain watertight.

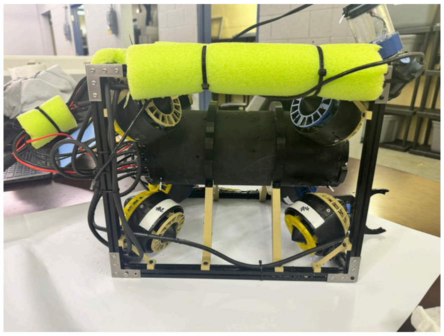


Figure 10: The watertight enclosure as found on *Calypso*.

In the past, a 15-cm acrylic capsule had been used. This was found to cause excessive drag and contained large amounts of empty space, which contributed to the positive buoyancy of the ROV. This year, the capsule is smaller, and thus contains less empty space. Another benefit to the aluminum enclosure is its 1000-meter depth rating; the acrylic enclosure had a depth rating of 65 meters.

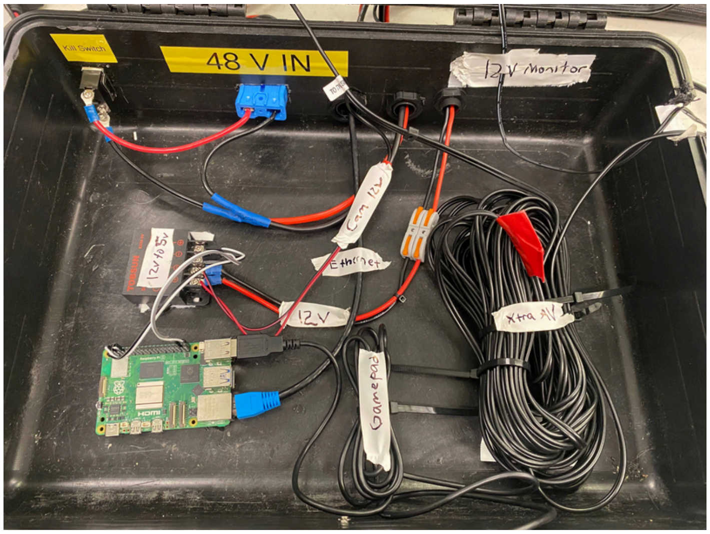
Enclosure	**13-cm Diameter (2024)**	**15-cm Diameter (2023)**
Mass of Tube	1450 g	1134 g
Quantity of Holes	26	15
Depth Rating	1000 m	65 m
Material	Aluminum, anodized	Acrylic
Locking Ability	Present	Absent
Cost	$200	$200

Figure 11: Comparison between current enclosure and past enclosure.

Topside Control System

The electronics of *Calypso* are housed onboard, leading to a streamlined topside control system with minimal components (Figure 12). Inside the lid of the topside system is a monitor that displays real-time footage from the ROV's cameras. The topside control system features strain relief and abrasion protection for the camera, power, and communication wires entering the control system, ensuring stable power and communication from the surface to the ROV. Additionally, a 12V to 5V power converter within the topside system supplies power to both the Raspberry Pi 5 and the camera.

Figure 12: Topside Control System with labeled components



Coding and Thruster Control

The propulsion system of *Calypso* is designed for omnidirectional movement and rotational control, utilizing a Raspberry Pi 5 to process inputs from a gamepad with two joysticks. For movement, the control system constructs a target direction vector from the X and Y axes of the left joystick for left/right and forward/backward movements, and the Y axis of the right joystick for up/down movement. Thruster positions relative to the ROV's center are used to calculate the required thrust via the dot product of the target vector and each thruster's position vector, mapping this to a 1100-1900 PWM signal range for the ESCs.

Rotation is controlled by mapping the right joystick's X axis to the same PWM range, where 1100 and 1900 represent counterclockwise and clockwise rotations, respectively, with these values sent to generate the necessary net torque. As both movement and rotation require full thruster commitment, the control system defaults to movement mode, switching to rotation mode when the pilot holds a designated button on the controller, thereby ensuring precise and efficient ROV maneuverability.

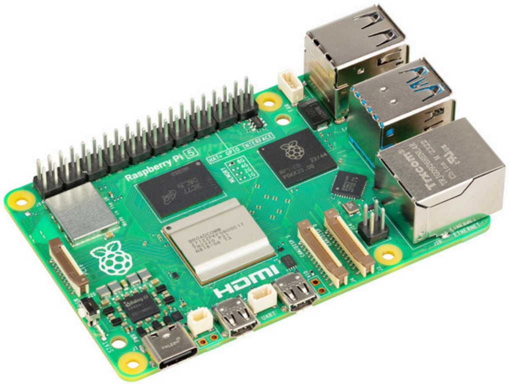


Figure 15: Raspberry Pi 5.
Credit: Newark

Sensors

Calypso is equipped with two sensors that enhance its operation and performance. Housed within the main watertight enclosure are two SOS Leak Sensors. Each leak sensor is plugged directly into the Raspberry Pi Pico. If either sensor detects water, a signal is sent to the topside control system and the pilot's controller vibrates.

The other sensor found on *Calypso* is a Bar30 sensor, capable of measuring depth, pressure, and temperature. The ROV has this sensor for its temperature measurements, required for Task 2.1: "measure the temperature to check the SMART cable sensor readings". The sensor can also read the depth of the ROV, allowing the pilot to gain further knowledge of where the ROV is in the water.

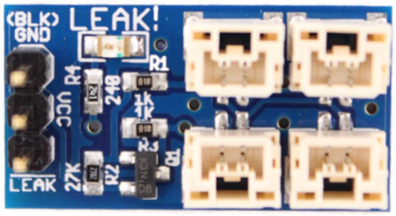


Figure 14: SOS Leak Sensor. Credit: Blue Robotics

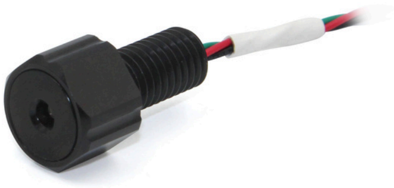


Figure 16: Bar02 Sensor.
Credit: Blue Robotics

Build vs. Buy vs. Reuse

This year, the design of *Calypso* incorporates a combination of new, commercially available components, custom-designed and 3D printed mounts, and reused components from previous versions. The new components were purchased based on comparison with previous components. The 3D-printed mounts were selected for their customizability and affordability. The reused parts were chosen for their known reliability and no cost to use.

Component	**Reasoning**
Blue Robotics T200 Thrusters	The new eight-thruster configuration required new T200s which had to be purchased.
Capsule	The previous capsule was too large for the amount of electronics in it, so ROV is fitted with a 13-cm capsule.
Frame	The extruded aluminum had to be purchased as there was not enough to reuse from last year's design.

Figure 17: Newly purchased components of *Calypso*

Figure 18: Reused components of *Calypso*

Component	**Reasoning**
Manipulator	The manipulator was implemented on the previous year's design and proved to excel where it was needed.
Four Blue Robotics T200 Thrusters	Four of the T200 thrusters from last year's design were reused on Calypso. The previous thrusters still operate efficiently and powerfully, allowing the thrusters to be reused.

Component	Reasoning
T200 Thruster Guards	The design for the thruster guards was obtained from Thingiverse and the design was printed and attached to each thruster.
T200 Frame Mounts	Custom thruster mounts were designed on a 3D-design software then printed and attached to each corner of ROV's frame and to the T200, allowing for convenient mounting.
Enclosure Mounts	To attach the watertight enclosure, custom mounts were designed and printed. The mounts fully encircle the enclosure and attach to the frame in four locations.
Camera Mount	A camera mount was designed and printed after determining the best angle for piloting the ROV and viewing the manipulator.
Tether Strain Relief Attachment	An attachment for the tether strain relief was designed, allowing for a carabiner to connect the tether thimble and the ROV's frame.

Figure 19: 3D-Printed Components of *Calypso*.

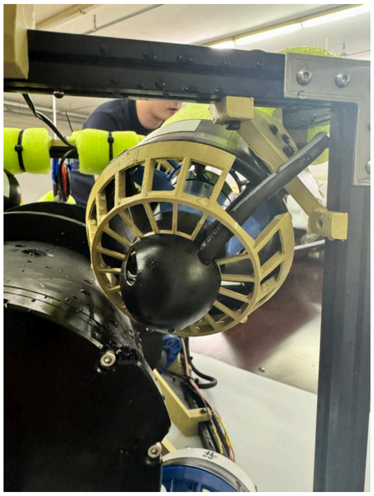


Figure 20:
Thruster fitted with guards and attached to mount.

Figure 21:
CAD design of single enclosure mount.

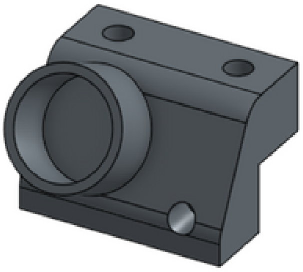
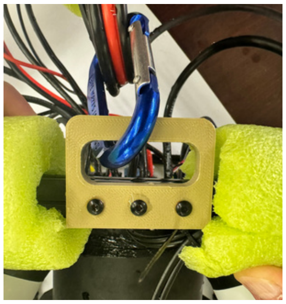


Figure 21:
CAD design of RunCam mount.

Figure 22: Printed tether strain relief attachment on frame of *Calypso*.



Vertical Profiling Float

The Buccaneers have also created a vertical profiling float designed to perform multiple vertical profiles and wirelessly transmit data to a surface control station. The float consists of a 4-inch inner diameter capsule housing a syringe, batteries, and the necessary electronics. The float is fitted with a rubber pressure release stopper and internal leak sensors.

Safety

Company Safety

During the operation of *Calypso*, the company adheres to a strict set of protocols to ensure the safe handling of the vehicle. For example, whenever *Calypso* is to be deployed, the team executes a "Pre-Flight Checklist." This checklist consists of various steps such as a fuse check, thruster test, a thorough enclosure test, tether check, visuals check, and basic ROV operation safety protocols. Operational safety measures the Buccaneers observe when utilizing Calypso include general things laid out in the Job Site Safety Analysis. These measures ensure avoidance of the risk of injury and damage to individuals or the ROV.

While constructing the ROV, all company members are required to wear safety glasses as part of their Personal Protective Equipment (PPE). Additionally, it was mandatory to wear closed-toed shoes and remove any jewelry, particularly when using power tools. Team members with long hair were required to tie it back to prevent it from getting caught in any machinery.

ROV Safety Features

Apart from the operational safety procedures that the Buccaneers employ, there are also many safety features built into the ROV. These various features range from electrical to mechanical to software safety measures, which ensures the lowest chance of personal harm or machine damage.

In terms of electrical safety, *Calypso* utilizes a 30-amp fuse to prevent unsafe shorts that could harm the electrical components or members of the team. This is an inline fuse that is housed within 30 centimeters of the Anderson power pole connectors. The surface-side control box contains a kill-switch so that in the case of a short, fire, or any other possible electrical issue that may damage electronics, a team member is able to instantly prevent any connection from sending power. With the idea of electrical workmanship in mind, this also serves as a safety feature, wherein wires are not contributing to any other safety risks such as loose wires, bad jumpers, or improper wire gauge size.

Mechanical safety includes the reduction of sharp edges, securing the frame, utilizing tether thimbles and strain/abrasion protection at key places of possible movement. The motors are equipped with 3D-Printed motor shrouds that prevent any undesired contact to the propellers. On the software side of safety, there are several features that have been included to ensure *Calypso* and the Buccaneers can always run at the fullest potential. Leak sensors allow the company to identify when a possible short could arise due to water leakage. When the sensor identifies a leak, the Raspberry Pico will notify the Raspberry Pi 5 and return the signal to the surface to be viewed via a custom graphic user interface. In order to prevent unnecessary damage, the power output by the thrusters is reduced by a code multiplier in the PWM output signals. Because of the 8-thruster configuration *Calypso* has, the power can be greatly reduced, otherwise it is too powerful to use safely.

Testing and Troubleshooting

Vehicle Testing Methodology

The Buccaneers employed a careful vehicle testing methodology where each system was tested independently prior to integration into a unified system. This approach ensured that any potential issues within individual components were identified and resolved before they could affect the overall functionality of the ROV. By isolating and examining each system separately, the Buccaneers confirmed the operational integrity of each component, enhancing the reliability and performance of the final assembled vehicle.

Troubleshooting Strategies and Techniques

For troubleshooting, the Buccaneers utilized a validation and verification method. This strategy involved independently testing each system to pinpoint the source of any issues within the ROV. By systematically verifying the functionality of each subsystem, the team could effectively isolate and address specific problems. This methodical approach not only allowed members to facilitate the identification of faulty components but also streamlined the repair process, ensuring a robust and dependable ROV.

Prototyping

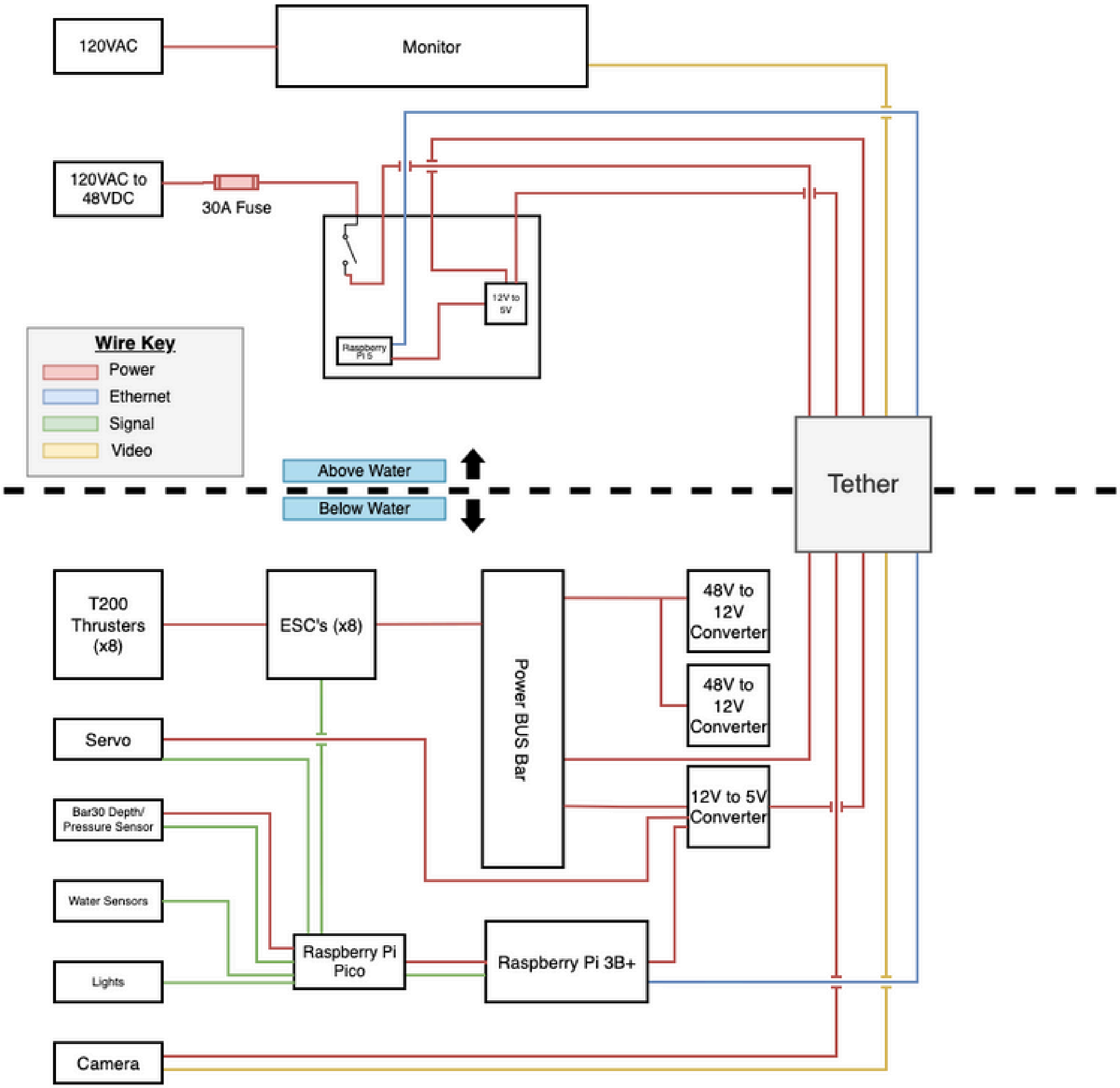
The Buccaneers used prototyping and testing to evaluate and refine their design options. Various components of *Calypso*, such as thruster mounts, capsule mounts, and camera mounts, were created using 3D printing (Figure 19). Each prototype was tested, and modifications were made as necessary to enhance performance and compatibility. This process of prototyping and testing allowed the Buccaneers to optimize the design and functionality of ROV components, leading to a more efficient and effective underwater vehicle.

Finances

Accounting

To track the Bucs' financial status over the academic year, a running budget was kept throughout the season. The budget sheet detailed all incomes in the top section. As donations came in, the sheet was promptly updated. Below the incomes, all expenses were recorded, including the components of the ROV. For a breakdown of year’s expenses, see appendix B.

This season, the Buccaneers’ budget was set at $4000 for the ROV. Since the international competition is in our hometown, travel expenses are not a concern. The team was supported by several sponsors who were committed to the Bucs' achievements. Overhead costs were significantly lower than last year because many of the expensive components were reused, and STREAMWORKS allowed us to use the tools at their ETSU Valleybrook campus. Once the vehicle was completed, team members itemized every part to determine the true final cost. For a breakdown of the ROV cost, see appendix C.

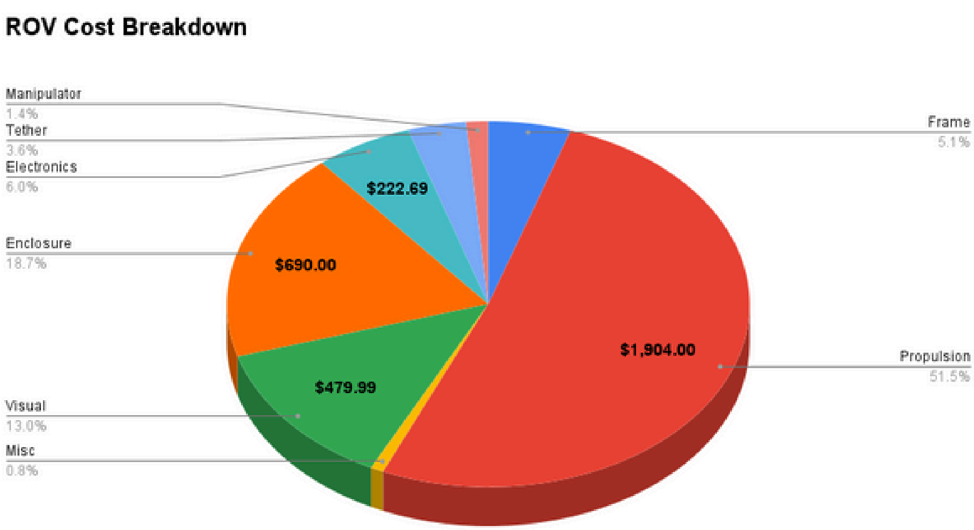


Fuse Calculations
T200 Thrusters: 8 x 2A = 16 A
Raspberry Pi: 2 x 1A = 2A
Servo: 1 x 1A = 1A
Leak Sensor: 4 x 0.005A = 0.2A
Temperature Sensor: 1 x 0.0014 = 0.0014A
Raspberry Pi Pico: 1 x 0.2A = 0.2A

Appendix A: Electronics SID Diagram

School Name:				East Tennessee State University	
Income:					
Source:					Amount:
ETSU Research Corporation					$2,700.00
Tennessee Valley Authority (TVA)					$2,400.00
TVA Credit Union					$500.00
STREAMWORKS Education					$2,000.00
Honda Kingsport					$400.00
Expenses:					
Category	**Sub-Category**	**Type**	**Description / Examples**	**Projected Cost**	**Budgeted Value**
Hardware:					
	Frame	Purchased & Re-Used	Extruded Aluminum	$200.00	$120.00
	Enclosure	Purchased and Re-Use	Acrylic, Caps, & Penetrators	$1,000.00	$733.00
Electronics:					
	Propulsion	Re-Used	Thrusters & ESCs	$1,100.00	$980.00
	Power	Purchased & Re-Used	Power Converters	$100.00	$51.22
	Control System	Purchased & Re-Used	Raspberry Pi (x2) & Pico	$100.00	$98.00
	Tether	Re-Used	Camera wires, ethernet, and power wires	$50.00	$50.00
	Manipulator	Re-Used	Two Claws	$120.00	$120.00
Sensors:					
	Visual	Purchased	Camera	$200.00	$260.00
Travel:	Flight:			$0.00	$0.00
	Hotel:			$0.00	$0.00
	Food:			$250.00	$250.00
				Total Incomes:	$8,000.00
				Total Expenses:	$2,662.22
				Total Expenses - Re-use / Donations:	$1,461.00

Appendix B: Budget Spreadsheet



Appendix C: ROV Cost Breakdown

EAST TENNESSEE STATE UNIVERSITY

Preflight Prep

1. Connect to power
2. Notify team members power has been connected
3. Flip on power
4. Pilot call out "Power on"
5. Team member place ROV in water
6. Team member calls out "hands-off"
7. Initiate Motor test
8. Pilot drive Forward
9. Pilot Turn Right
10. Pilot Turn Left
11. Pilot Lift Down
12. Pilot Lift Up
13. Pilot Drive Back
14. Pilot call out "Motor Test Complete"
15. Visual systems Check
16. CEO asks teammates if systems are ready to go
17. When all confirmed, CEO says "mission launch"

Appendix D: Pre-Flight Checklist

References

Moore, Steven W., et al. Underwater Robotics: Science, Design & Fabrication. Marine Advanced Technology Education (MATE) Center, 2010.

M.A.T.E. *2024 Explorer Manual*. [ebook] Marine Advanced Technology Education. Available at: <2024_EXPLORER_Manual_FINAL_1_16_2024_with_Cover.pdf (hubspotusercontent-na1.net)>

Acknowledgements

MATE Center and Marine Technology Society - Sponsoring this year's competition
STREAMWORKS - Use of equipment, i.e 3D printers

The Buccaneers would like to extend their deepest gratitude to the ETSU Research Corporation for their immense financial support, allocation of space at the ETSU Valleybrook Campus, and invaluable guidance throughout this project. The resources and expertise offered by the ETSU Research Corporation were instrumental in the development and success of our ROV. The Buccaneers could not have done this without the support of the ETSU Research Corporation. To David Golden, Betsy Cunningham, and the rest of the team at the ETSU Research Corporation, the Bucs say **thank you**!