Robosharks Technical Report

Boulder High School

https://robosharks.org/
Boulder, Colorado
Team: Robosharks
Mentors: Jessica Klauzer-Zimmerman, Ashleigh Hitchcock
ROV Report

Our Company

Figure 1: The Robosharks

Left to right, front to back:
Eli Diamond, Year 10 - Electrical, Float
Ada Tessar, Year 11 - CEO, Chief Electrical, Chief Programming
Kooper Quigley, Year 11 - Mechanical, Electrical
Karissa Murra, Year 12 - Float Lead, Mechanical, Operations
Gustaf Courter, Year 12 - Additive Manufacturing, Mechanical
Kieran Abbott, Year 12 - CFO, CSO, Mechanical Lead, Float, Operations
Yanitxan Arellano, Year 10 - Programming
Jackson Wysong, Year 12 - Mechanical

Team: Boulder High School Robosharks
Distance to competition: 2,330km
All but two company members have competed before
ROV Name: Wobbegong
Size (cm): 74.5 x 50 x 37
Weight (kg): 10.7
Total student-hours spent to design, build, and program the ROV: 1500 hours

Budget: $2,450

Abstract

We are the Robosharks, a MATE ROV team located in Boulder, Colorado, that provides innovative solutions to a wide variety of underwater problems. We are composed of one new and five returning members. Additionally, our company supervises a large Navigator subteam to recruit, train, and mentor new engineers. This year, the Robosharks are proud to present Wobbegong to the RFP.

We had two goals in mind when designing Wobbegong: simplicity and versatility. Pursuing these goals, we designed Wobbegong to be an extremely capable substratum, easily modified for further capabilities. Its streamlined frame provides lots of space for additional attachments, while also providing stability to our core mechanisms. It allows us to mount our eight commercial thrusters onto two easily accessible rails, reducing the cost and effort of assembly and maintenance. The external camera is placed directly above the manipulator, allowing us to easily see both the task at hand and a wide angle of the environment in front of us.

Inside the drybox, Wobbegong uses a repurposed roboRIO to communicate with the surface station, send control signals to our thrusters, maps camera views and sends them to the surface, and calculates our ROV's precise orientation and position with its onboard gyroscopes.

Wobbegong is, above all else, an exceptional example of our company's continued focus on iteration, invention, and safety. With many independent shutoffs, IP-20 rated thruster guards, and a robust strain relief system, Wobbegong is dedicated to our commitment to high-quality, innovative, and safe products.

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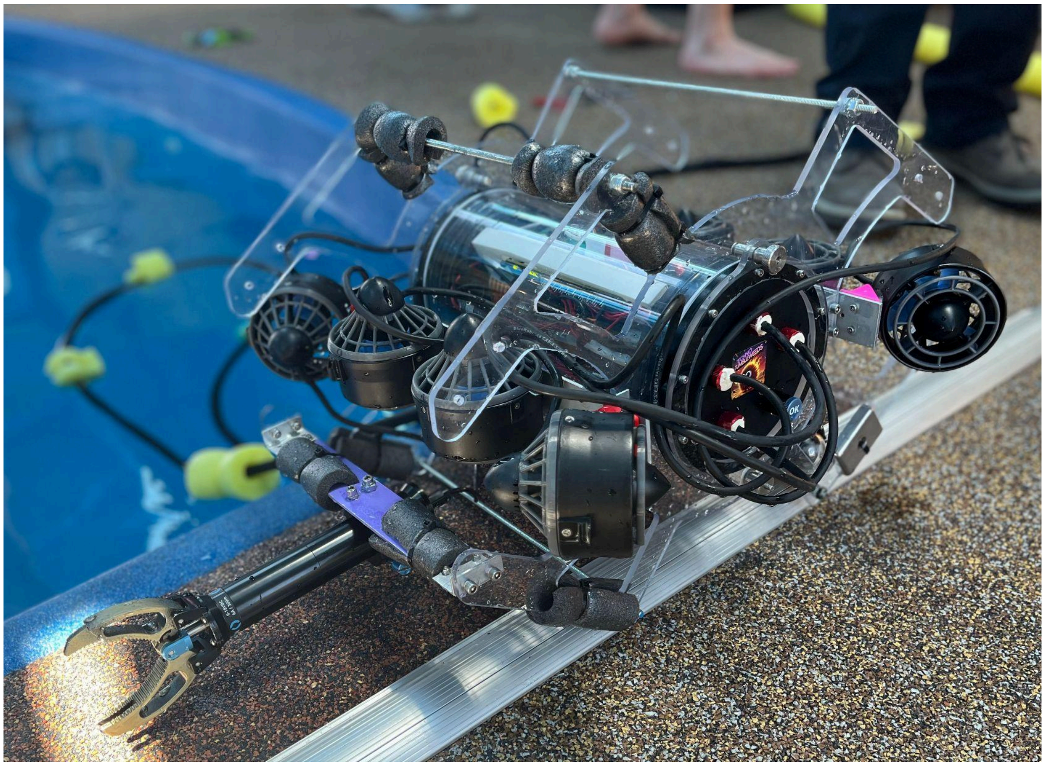


Figure 2: Wobbegong

Design Philosophy

Wobbegong was designed to address many of the issues we've faced with our past products. For example, while last year's ROV sacrificed maneuverability and stability for speed, and the one before that was small and hard to work on, with a tiny drybox that couldn't be easily accessed. In response to issues like these, Wobbegong sports a wide thruster layout, providing both power and stability in all degrees of freedom, while also having a large frame to allow for easy access to the drybox and easy assembly and disassembly for maintenance.

Wobbegong also addresses issues in the core drivebase designs of previous ROV's. While our 2023 ROV pursued ideal stability, and last year's product chased minimalism and raw power, Wobbegong is based on two underlying tenets: simplicity and versatility. We made a commitment to create a strong foundation before adding complicating factors. We wanted an ROV that could be easily expanded upon, but one that would be relatively easy to create the minimum viable product that was a better base platform than anything we had made before. Wobbegong's large frame was devised to fulfill this requirement. Relatively easy to manufacture, either with our in-shop CNC or just with a jigsaw and a piece of scrap polycarbonate, the ample space available on the faceplates provides the potential for near-limitless modularity and additional systems, such as our manipulator and camera mounting.

Teamwork and Scheduling

Teamwork and Teambuilding

At the beginning of the year, most of the members of our company had not worked with each other. This necessitated a learning period near the beginning of the year, as we grew accustomed to each other's strengths and weaknesses. This was accomplished through various projects, including an off-season FRC competition and participating in the Boulder Lights of December Parade in downtown Boulder. When the competition manual was released, we began to shift our focus back towards MATE. With our new understanding of how our company worked, we were able to give members specific tasks that suited their strengths and weaknesses. However, due to the interdisciplinary nature of the ROV's construction, multiple members' expertise were often required, so we frequently needed several people working on any one task simultaneously. This cooperation has ensured high-quality outputs on all aspects of the project, and helped us identify problems before they even showed up, as multiple people could voice ideas and point out potential issues during all stages of the ROV's construction. This philosophy is similarly shown in our leadership structure, which we created through voting in our CEO, CSO, and CFO based on who we thought would be able to effectively lead and organize the project.

Scheduling & Project Management

At the beginning of the year, we established a meeting schedule centered around accessibility and consistency to ensure all members could participate effectively. After determining that Wednesdays worked best for everyone, we initiated weekly meetings from 4:00–6:00 PM during the fall and early winter. These sessions focused on recruiting and training new members, as well as conducting initial design work for our ROV.

As the second semester began and our workload increased, we expanded our schedule to include Monday meetings, allowing for more consistent progress and collaboration. In the final weeks leading up to the competition, we extended our Wednesday meetings by an additional hour to accommodate last-minute adjustments, testing, and improvements.

To keep the project organized and on track, we developed a detailed to-do list (Figure 3) that was updated regularly throughout the season. This list included deadlines, task dependencies, and individual responsibilities to ensure accountability and transparency. Additionally, we documented our accomplishments at the end of each meeting and shared these updates online with the entire team. This practice allowed absent members to stay informed and helped us monitor progress to avoid falling behind schedule.

Item	Priority Level	Deadline	Progress Level	Person(s) Responsible	Dependencies
Machine faceplates	URGE...	1/29/2025	Finished, Tested	Ada Kieran	None
wire thrusters to escs	URGE...	2/19/2025	Finished, Tested	Kooper Eli	None
power Ethernet switch and roborio	URGE...	1/29/2025	Finished, Tested	Kooper Eli	None
wire roborio to esc pwm, newton pwm	URGE...	1/29/2025	Finished, Tested	Kooper Eli	None
wire tether Ethernet to Ethernet switch	URGE...	1/29/2025	Finished, Tested	Kooper Eli	None
wire escs and newton to power	URGE...	1/29/2025	Finished, Tested	Kooper Eli	None
mount everything to the electrical mid plate	URGE...	1/29/2025	Finished, Tested	Ada Kooper	A3 - A7
create thrusters mounts	URGE...	2/5/2025	Finished, Tested	Gus Kieran	
mount newton	High	2/19/2025	Finished, Tested	Karissa	A2
Test camera and waterproofing	High		Finished, Untested	Eli	None
Create camera mount	High		Finished, Untested	Gus Kooper	A11
Buy or find & tap aluminum rods	High		Finished, Tested	Kieran Karissa	None
Create strain relief system	Medium		Finished, Untested	Ada Gus	A2-A8
Design & build float	Medium		In progress	Kieran Ada Eli Karissa	None
Design & build secondary systems systems (pump, extra camera(s) & manipulator,etc)	Medium		In progress	Ada Kieran	A2-A14
Shirts	Optional	5/3/2025	Finished, Untested	Karissa Ada	None
Pool Test #1	URGE...	4/6/2025	Finished, Tested	All	A2-A14, A15 for float testing
Pool Test #2	URGE...	4/27/2025	Not started	All	
Pool Test #3	URGE...	4/28/2025	Not started	All	
Build props	Medium	2/26/2025	In progress	Gus	None
Disassemble Mako	High	1/15/2025	Finished, Tested	Karissa	None
Final v1 assembly	High	2/19/2025	Finished, Tested	All	A2-14, A17
Code	URGE...	2/26/2025	Finished, Tested	Ada	
Tech docs on outreach	Medium	4/26/2025	In progress	Kieran Ada	
Tech docs on build	Medium	4/19/2025	In progress	Karissa	A22
Tech docs on code	Medium	4/19/2025	In progress	Ada	
Tech docs on electrical	Medium	4/19/2025	In progress	Eli Kooper	

Figure 3: Part of our company’s to-do list

Communication

Our primary platform for communication and planning is Discord, where we utilize channels for different categories to expedite communication and have space for people to discuss specific projects, timelines, and challenges as we work. In addition, we also use email to send out important information to the company, to ensure that everyone receives and is notified of company-wide announcements.

Additionally, we use a hosted Git instance for our programming collaboration, version control, and branch management. Finally, we used a company-wide Google Drive to easily share PDFs, spreadsheets, and text documents.

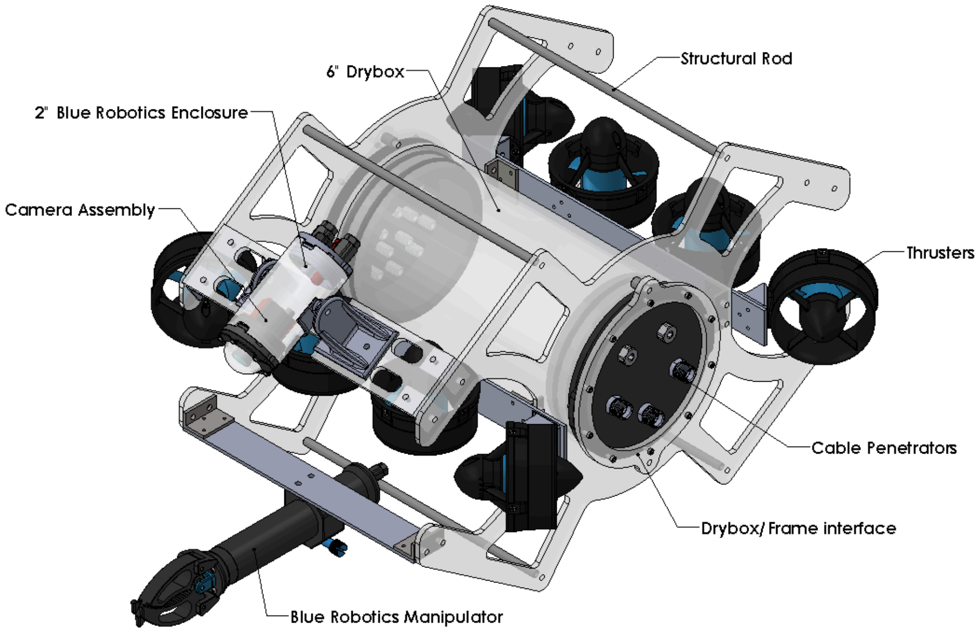


Figure 4: CAD model of Wobbegong

Design Rationale

Brainstorming and Iteration

We began the design process for Wobbegong by coming together and deciding what the guiding principle for the year's design would be. This year, we decided to create a design that could be easily added on without sacrificing simplicity. In December, we came up with two designs, one similar to the final one and with a much more substantial frame and only six thrusters, with each pair giving us exactly two degrees of freedom. As we were coming up with these ideas, we wanted to utilize our experience while incorporating new, more efficient ideas. We wanted to be sure we were learning from our team's past mistakes and introducing fresh concepts. We decided to go with Wobbegong's base design because while the alternative did offer a slightly more effective thruster layout, we decided that based on previous experience with thruster placement that having them in a single row would be simpler to work with. After we had our initial CAD, we held a design review with five alum to receive feedback and further input on how we could further iterate and incorporate new ideas. Additionally, we used a flow simulation (Figure 5) to judge how well our ROV would move before we even started construction.

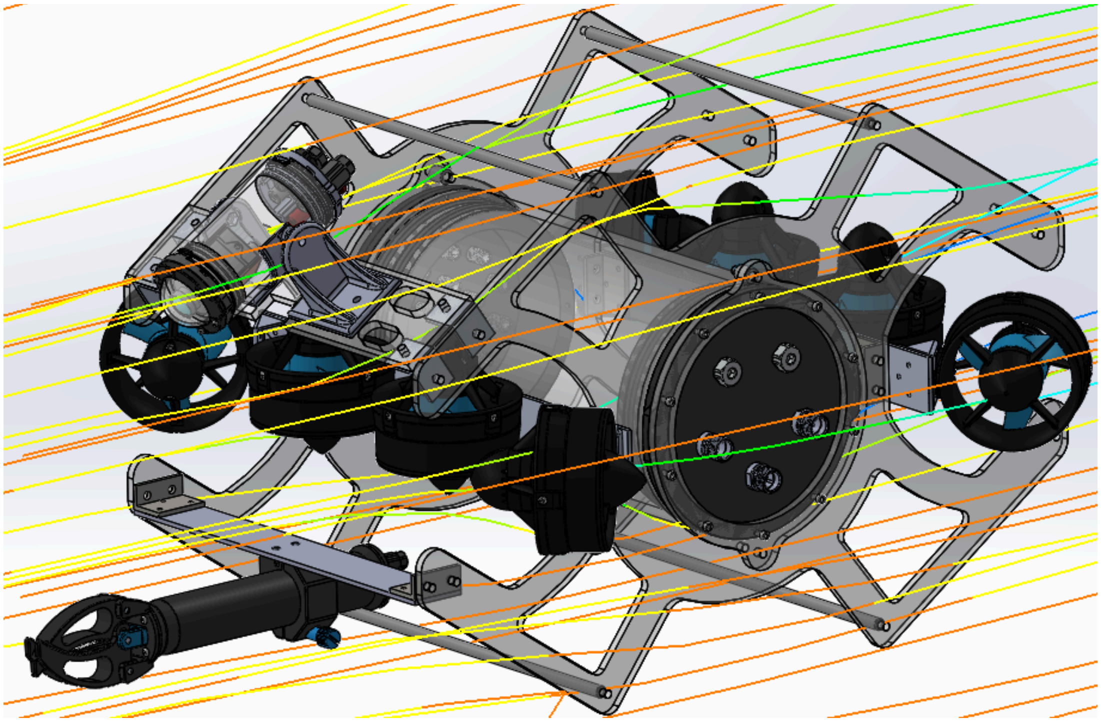


Figure 5: Flow simulation of Wobbegong

Mechanical

Overview

Driven by the desire for a stable platform for future improvements, Wobbegong's spacious frame provides both stable attachment points for the camera and manipulator, but also allows for an easy expansion of its capabilities through the attachment of additional sensors and manipulator systems for a variety of challenges.

Main Enclosure and Penetrators

Our main enclosure is a Blue Robotics 6 in waterproof enclosure. We reused this enclosure because it both provides necessary space for our internal electronics, and also gives us a clear view of any potential internal problems, from flooding to wire disconnects. The enclosure is fitted with two aluminum penetrator plates, one with five M10 penetrator holes and the other with 15. These 20 holes are mostly filled with Blue Robotics potted penetrators for all of our outboard systems, however three of them are Blue Trail Engineering Cobalt penetrator bulkheads for our tether's power and ethernet cables. We chose these penetrators because they've been proven to provide simple, yet incredibly reliable waterproof interfaces in the past. Additionally, the Cobalt penetrators provide a way to easily disconnect the tether for storage and transit, lessening the logistical requirements of moving the bot from place to place.

Thrusters

We chose to use an array of eight BlueRobotics T200 thrusters as they are fully-flooded brushless motors with encapsulated motor windings and stator as well as coated magnets and rotor. They have the perfect balance between speed and efficiency for this application, while having community adoption and incredible reliability. To choose an optimal thruster configuration, we utilized the Thruster Arrangement Utility (TAU), a tool developed by members of the club.

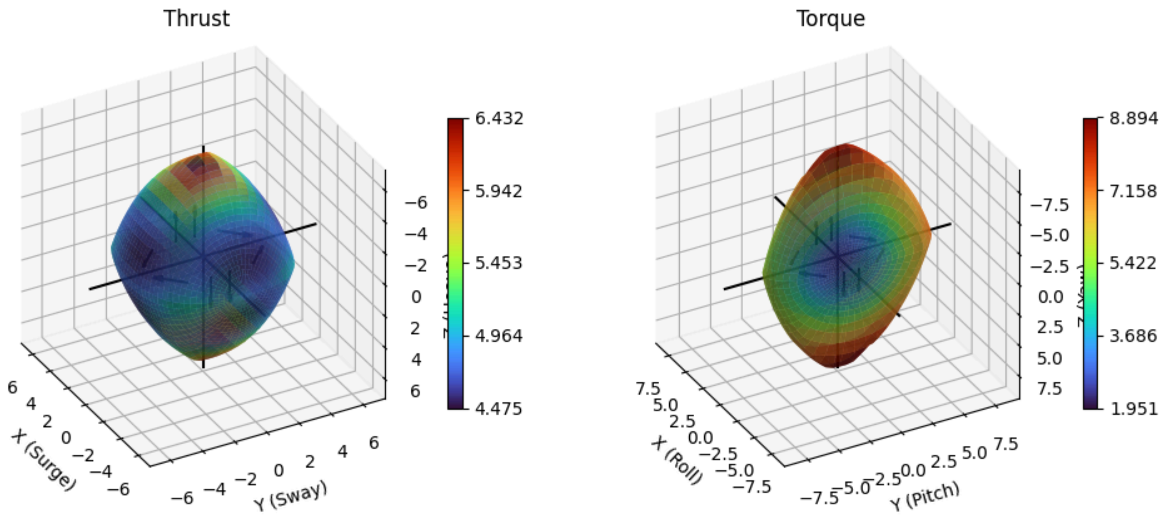


Figure 6: TAU graph of Wobbegong's thrusters

Outboard Camera

Our outboard camera is housed on a static mount directly above our manipulator and is angled down to provide a view of both the environment in front of us and our manipulator's alignment with whatever object we're affecting.

The camera itself is a Microsoft Lifecam HD300. It communicates and is powered over USB to an onboard Raspberry Pi The camera is housed in an external enclosure, and gives us low-latency, high quality video. The camera is pointed through a domed port on the front of the enclosure to prevent image distortion, and we chose a wide-angle lens for a large field of view. We chose the camera because of its simplicity and quality of footage. Additionally, we were able to reuse it from our prior years as a FIRST Robotics Competition team, saving on cost.

This camera is housed in an auxiliary 2 inch Blue Robotics locking enclosure, with an acrylic dome to waterproof the assembly, minimize the distortion from the water, and allow us to get the most out of our camera's wide-angle lens.

Internal Camera

To facilitate more views of the ROV's surroundings for the driver, there are multiple USB cameras connected to the roboRIO that are mounted inside the main drybox facing outwards.

This allows us to see both directly above and below our robot, ensuring alignment for tasks that require precision maneuvering.

Buoyancy

Wobbegong is designed to be slightly positively buoyant, so that it will float to the surface in case of a total system failure. To achieve this and make it stay oriented in the direction desired, pieces of foam have been attached to the top, and multiple ballast weights to the bottom. Additionally, the onboard gyroscope and IMU system allow the robot to be stable even when interacting with its environment.

Systems Design

Electrical

This year, we wanted to ensure that all of our cable interfaces going into the drybox were detachable to allow for easy removal and maintenance. To achieve this, connections between an external component and internal electronics are done through a WAGO lever nut, allowing us to disconnect any wire with the flick of a finger.

Tether

Wobbegong's tether is incredibly simple. It consists of two 6-gauge power conductors and a single Ethernet cable. The cables are wrapped in a sheath to protect them and keep them bundled together. To mitigate our tether's impact on our ROV's maneuvering, it's fitted with foam at regular intervals to make it neutrally buoyant. Due to our use of Blue Trail Engineering Cobalt penetrators, our tether is also fully removable, allowing for ease of transit and storage.

On the top side, our tether uses an Anderson SB50 connection with an adapter to plug into the Anderson Powerpoles. During competition, we have a poolside member who manages our tether in order to ensure there are no tangles or complications.

Onboard Electronics

Our onboard electronics center around a National Instruments roboRIO industrial computer board that controls eight BlueRobotics Basic ESCs using a multi-gyroscope and imu module for sensored closed loop control. We use Wago wire connections and soldered connections for a balance of reliability, efficiency, and serviceability.

Topside Electronics

Topside control of Wobbegong is done entirely using a laptop and Xbox controller connected over Ethernet. The laptop is connected to several auxiliary monitors to view telemetry, secondary camera feeds, and goals for the current dive.

Control System

Control Box

Wobbegong's control box is made up of a pelican case with a mechanical keyboard, optical mouse, Xbox game controller, 3 displays, and a Windows laptop. The entire control box packs inside the pelican case and is stored securely for transit with custom printed boxes and form fitting holders.

Control Software

Our control software is written in and runs onboard the ROV on our real-time Linux install on the roboRIO. Wobbegong's onboard control code is written in Java with a command-based, declarative structure. The command-based pattern is based around two core abstractions: commands and subsystems.

Commands represent actions the ROV can take. Commands run when scheduled—based on time, user input, or after another command completes—until they are interrupted or their end condition is met. Commands are recursively composable: they can be combined to accomplish more complex tasks. Subsystems represent independently-controlled collections of ROV hardware (such as motor controllers, sensors, grippers, etc.) that operate together. Subsystems back the resource-management system of the command-based structure: only one command can use a given subsystem at a time. This abstraction allows us to hide the internal complexity of our hardware from the rest of the code, making it easier to maintain and extend.

Graphical User Interface (GUI)

We use a dashboard written in flutter for system statistics, sensor feedback, operation notifications, and the cameras connected directly to the roboRIO over USB. Controller inputs and enabling/disabling the ROV are handled by FRC Driver Station Powered by NI LabVIEW for its superior safety and reliability. For our high performance external cameras mounted on the ROV, we use a custom application developed with SPINNAKER SDK. Our user interfaces are designed to make operating the ROV as efficient and intuitive as possible, without restricting our abilities.

Payload and Tools

Manipulator

In order to interact with props, Wobbegong has a Blue Robotics Newton Subsea Gripper mounted on its side. The gripper's position is centered at the front of our ROV, allowing us to yaw and satisfy any orientation need. The Newton's distance from the bot means the ROV will not interfere with surrounding objects. It can also be removed and stored inside the ROV for safe transportation.

pH Sensor

The pH sensor (DFRobot Gravity: Analog pH meter V2) we use is specifically designed to measure the pH of the solution and reflect the acidity or alkalinity. It communicates over analog signals with the roboRIO, which then interprets and uses the data. To maintain accuracy and reliability, the pH sensor is calibrated prior to every product demonstration or mission run. This calibration process involves using a buffer solution with a known and stable pH value to fine-tune the sensor's readings and ensure it reflects true pH levels under varying conditions.

Float

For one of the tasks, we deploy a float we constructed to complete vertical profiles of the area. The float operates through the use of a buoyancy engine powered by a servo, which changes the volume of the float by moving a syringe's plug. This causes the float's density to change, letting it complete its vertical profiles without any outside assistance. This is controlled by an ESP32 with a wifi transmitter, which takes data from a depth/temperature sensor, and real time clock to keep track of the time of day. The transmitter enables the float to transmit this data to a surface device. The float uses a control loop to ensure stability at almost exactly 2.5 meters of depth, using the clock to track the time. A simple water bottle is used as the main enclosure, with a store-bought PVC pressure relief valve providing pressure release.

Build vs. Buy, New vs. Used

The ROV uses a mix of custom-built and COTS (commercial off-the-shelf) parts tailored for low cost with high reliability and efficiency. COTS parts offer a higher degree of reliability making them ideal for critical components such as our drybox that is responsible for keeping our electronics dry. We reused the vast majority of our COTS parts this year.

Because this is our fifth year competing with MATE and our 22nd year as a robotics club we were able to reuse many of Wobbegong's components from previous years. For components such as the ROV's frame, manufacturing them ourselves allows for the components to be better suited to our specific needs for a lower price with faster turnaround time.

Most of these materials came from Mako, our competition bot last year, but a number of parts came from older bots. Additionally, our company's history as a FIRST Robotics team allowed us to reuse old components from that competition, with our roboRIO and gyroscopes being the most notable of these repurposed components.

Accounting

We began the year by planning out what we would need to both keep the company running and create the bot that we wanted to. Because our bot's base design is so general, we were able to create a rudimentary plan for its rough components before the competition manual was even released. We devised three different budgets: the first was the simplest, designed as the minimum to keep company operations running; the second gave us a little bit more leeway for changing plans for aspects of the robot and the ability to replace some of the aging tools in the shop. Our final budget was our stretch goal. It gave us funds not only for replacing old equipment, but also for any prototyping costs we might incur and for participating in additional activities, such as the Kendrick Castillo Memorial Tournament in the fall.

Our team sent these budgets to the Bartlett Foundation, from which we received a very generous donation of $7,400, our highest budget proposal. In addition, we also received a $2,500 donation from the Boulder PAC, $1,000 from SpectraLogic and $100 from Black Swift Technologies. These funds were far beyond what we had expected, and gave us a lot of breathing room for our RFP development.

To keep track of our remaining funds, we regularly spent time balancing all of our expenses and to ensure that we weren't going over the planned budget despite extra funds. See appendix E for more information.

Safety

Safety Rationale

The Robosharks operate under the principle that safety is everyone's responsibility. Therefore, if anyone feels like what they or someone else is doing is unsafe, they can stop it and start a discussion as to why it is. Our CSO is appointed to resolve disputes and be the final authority on the matter, but the ideal is that everyone is responsible for the team's safety. In the shop, this is shown through all members being trained on the machines they're using, knowing safety procedures for fires and injuries, and knowing where first aid and emergency shut-offs are. Additionally, everyone is expected to follow the construction checklist (detailed below) when working in the shop. During ROV operations, the same principle guides us, with a comprehensive safety checklist completed before each use.

Safety Checklists

Operational

Task to be completed	Y/N
No internal wires/components loose	
All O-Rings properly greased	
Penetrators/blanks tightened down all the way	
End Caps on securely	
Visual inspection of end caps for sealing issues	
Vents tightened down properly	
End Cap - frame bolts hand tightened	

Check thruster guards are securely attached	

Construction

Task to be completed	Y/N
Always have teacher mentor present when operating tools	
Wear proper PPE (ear, eye, and hand protection) and closed toed shoes when in the shop at all times	
Turn ventilation on for all tools that require it.	
Remove or secure loose clothing, hair and jewelry	
Never leave CNC or laser cutter unattended	
Unplug tools and clean up work area when finished	

Safety Features

Strain Relief

Our tether is passed through a custom printed cable clamp attached to the frame before going into the main body of Wobbegong. This ensures that there is no tension on the cable penetrators and allows us to pull the ROV out by the tether if the need arises.

Propeller Guards

Our propeller guards are custom 3D printed guards designed for use with our thrusters. They are sturdy enough to resist breaking during extreme use and are rated at IP-20 (finger-proof). The rear guard is also easily removable to allow maintenance on the thrusters when powered off.

Fuse

The ROV uses a 25 amp fuse inside of an inline waterproof ATC blade fuse holder, located within 30 cm of the power supply and before any other devices for overcurrent protection.

Emergency Shutoffs

Wobbegong features layered, independent emergency shutoffs in addition to the fuse to ensure safety and reliability. A breaker and power switch immediately accessible topside provides manual total power cutoff, while inside of our ROV an FPGA watchdog monitors the system in real time and any error or communications loss cuts power to all motors. Our use of the WPILib motor safety class prevents runaway motion, and a custom ESC safety class adds motor-level protection. The system includes multiple software disable buttons, always accessible via keyboard and mouse. Motor power is cut unless explicitly re-enabled via a handshake between the topside and bottom side every 20 milliseconds, and PWM signals default to neutral unless actively commanded at the same interval. Together, these redundant systems enforce safety across both hardware and software layers.

Critical Analysis

Challenges

Interpersonal:

At the beginning of the year, we struggled to achieve an efficient and effective workflow, as we were all unfamiliar with how each other worked. While a lot of this had been mitigated through us working on secondary projects during the fall, it still resulted in us making slower progress than anticipated at the beginning of the season. However, as we've become more comfortable in working and communicating with each other, our pace has quickly improved as members share ideas and move between tasks fluidly.

Mechanical:

Many of our mechanical issues were diagnosed during our initial prototype construction. Most important was the large amount of extra material we had at the ends of our frame, as our initial design had the top and bottom of our side plates come together at a point. This was identified as a potential snag point, so we decided to redesign the side plate right before machining the final pieces. However, due to that prototype the issue was corrected before making its way to the final iteration.

Electrical:

We had difficulty in creating easy disconnects inside our drybox for regular maintenance and disassembly, as fraying wires when using our WAGO connectors proved to cause issues early on in our development. This was eventually resolved by instituting a procedure for attaching WAGOs by twisting the wire around itself to ensure a strong connection.

Software:

In implementing the thruster control math for Wobbegong, we repeatedly struggled with creating complex trigonometric functions, which was eventually solved by writing more segmented code and switching much of it over to matrix based formulas and constants derived through robot simulation and real world testing. Additionally, our only club laptop had a significant failure right before our first pool test, although no significant progress was lost due to our use of Git for everything from ROV code to GUI layouts.

Operational:

Due to changes in our school's policies, our shop was heavily reorganized during the season. This created both a manpower issue, as members were diverted to helping move items around, but it also created confusion over where specific tools and items had been placed, slowing down construction. This was eventually remedied with the acquisition of a Robosharks-only tool and parts cabinet, which now houses all of our tools and hardware in an organized manner, and ensures that Boulder High students don't accidentally move items to a place they don't belong.

Lessons Learned

Throughout the season, the Robosharks encountered a variety of challenges that led to meaningful growth and improved processes. One of the most significant takeaways was the value of parallel design and iteration, which we explored through the development of divergent ROV concepts early in the season, that then evolved into the current version of Wobbegong. By encouraging members to pursue multiple design paths simultaneously, we were able to compare and refine ideas more effectively, ultimately accelerating innovation and leading to a stronger final product.

Another key lesson was the importance of collaboration through version control. Our adoption of Git for software development enabled us to work concurrently on different features without conflict, while also maintaining a clear and recoverable history of our codebase. This greatly reduced integration errors, code loss via hardware failure, and made troubleshooting more efficient.

Finally, we found that team-building exercises had a lasting impact on our overall effectiveness. By taking time to intentionally strengthen interpersonal relationships, we built trust and improved communication across all subteams. This cohesion translated into better collaboration, a more enjoyable working environment, and ultimately a more successful product.

Testing and Troubleshooting

Our entire development process was based off of rapid iteration based off of testing, with weekly pool tests to measure our changes and provide evidence based findings for our development. To test the design behind Wobbegong, we created an initial prototype (Figure 7), utilizing scrap polycarb in our shop to test the frame shape. This test allowed us to identify potential snagging points, leading to our current frame shape.

Figure 7: Wobbegong's initial prototype

With real-time logging of almost every part of our ROV, we were able to rapidly debug, tune performance, and validate Wobbegong's behavior during development and operation. Wobbegong also has a selectable "Test" mode in the GUI, allowing an out of water full systems test of every subsystem with user prompting for manual actions and gyroscope calibration.

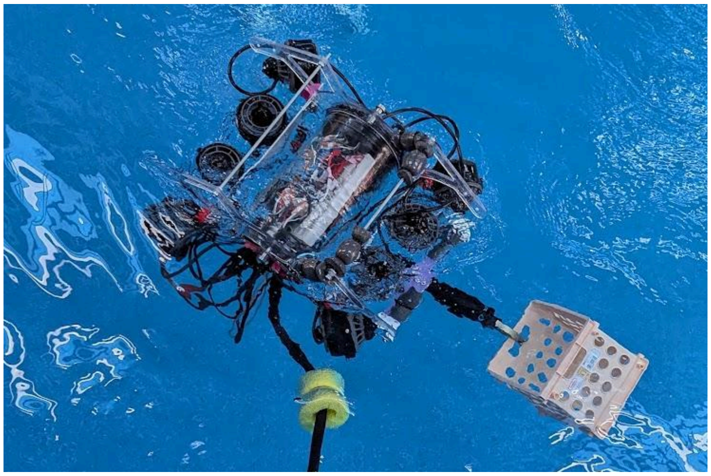


Figure 8: Wobbegong at a pool test

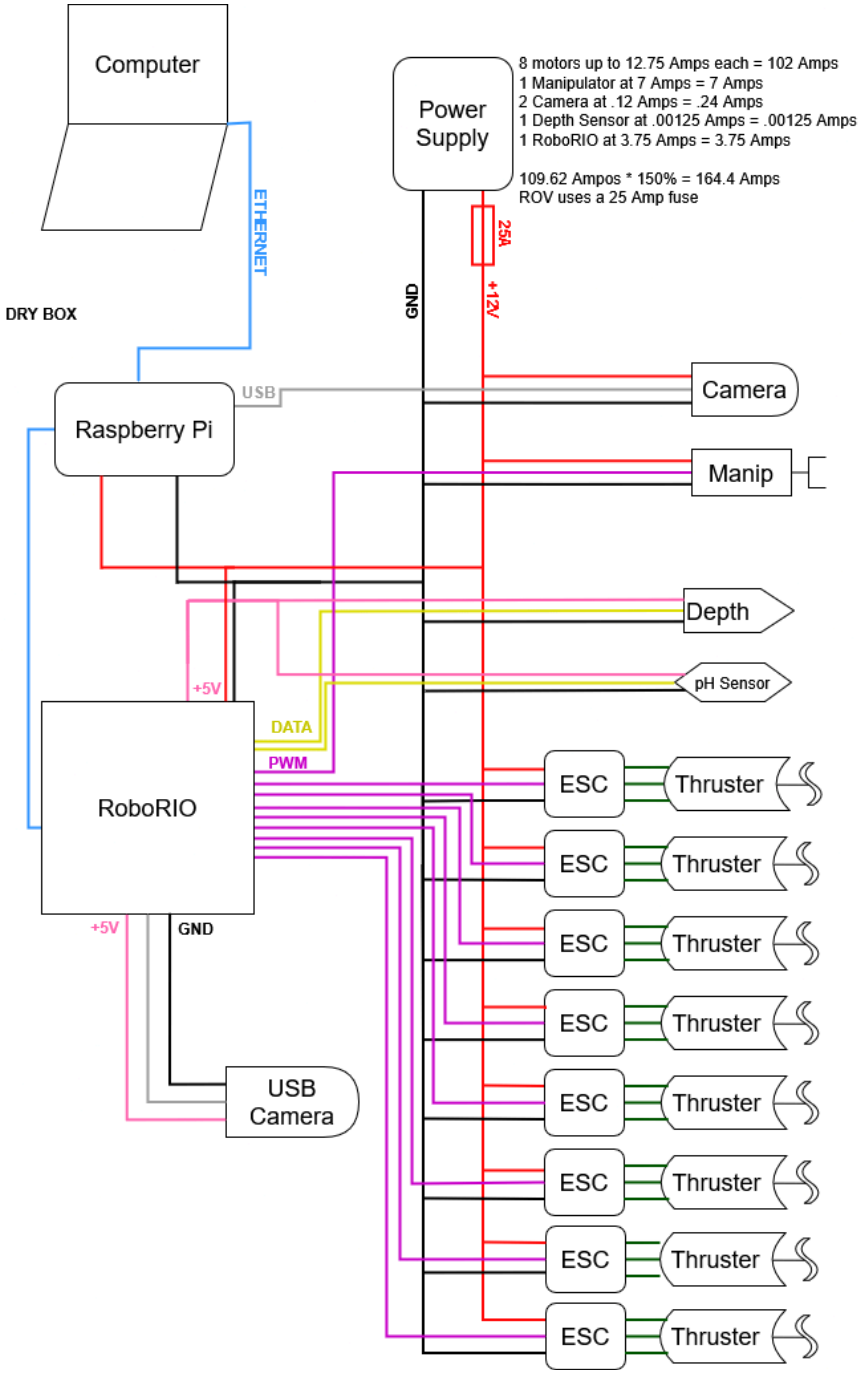
Additionally, we have a Simulation subsystem in our code, which allows us to practice driving the ROV on a desktop computer using the exact same controller inputs, user interfaces, and code as on the real ROV. Additionally, the simulation subsystem acts as an estimation of our velocity and acceleration independent of the gyroscopes that we use for optimizing our motor power to stay within our current limit while providing as much torque as possible without causing a brownout or blowing the fuse.

Possible Additions

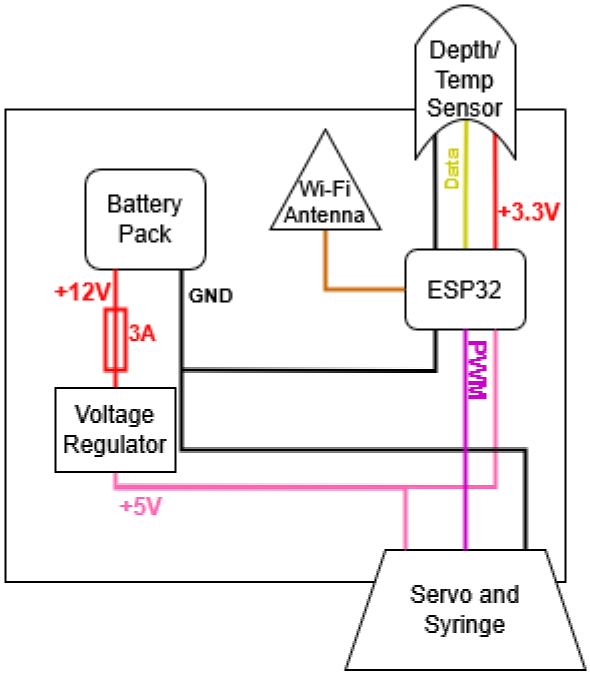
The central design of Wobbegong is a fundamentally expandable frame that allows for rapid integration of payloads containing anything from a water pump to additional sensors, such as new cameras or scientific measurement devices.

Appendices

Appendix A: ROV SID



Appendix B: Non-ROV Device SID



Appendix C: Jobsite Safety and Environment Analysis

Job Task	**Potential Hazards**	**Control Measures**
Entering / exiting operational area	A. Slipping on pool deck B. Lifting injuries from heavy loads C. Dropping equipment	A. Walk carefully and be aware of surroundings, staying away from pool edge B. Have more than one person lift heavy items C. Secure all loose equipment into containers and cases before transit
System set up	A. Getting water on electrical components B. Tripping over wires C. Environmental factors	A. Keep power and ethernet cables off of the ground B. Take note of where the tether is and keep it flat on the ground C. Do not operate during electrical storms
Power up checks	A. Voltage spikes B. Electrocution	A. Plug in the ROV and apply power in the correct

		order via the breaker B. Check for loose wires or damaged connections
Pool-side operations	A. Falling in the pool B. Injury from ROV	A. Do not reach too far in the water A2. All team members know how to swim A3. Two team members (Gus Courter and Kooper Quigley) have first responder training B. Do not grab the ROV until it is disabled B2. Do not interfere with objects in the manipulator until communicated by operators

Appendix D: Bill of Materials

Item	Cost	Quantity	Source
T200 Thrusters	$1,600.00	8	Reused
T200 ESC's	$288.00	8	Reused
6" Waterproof Enclosure (and end caps)	$425.00	1	Reused
Potted Penetrators M10 for 6mm cable	$90.00	13	Reused
Blue Trail 3-pin Power Penetrators	$92.00	2	Reused
Blue Trail 8-pin Penetrator	$65.00	1	Reused
Blue Trail 8-pin Cable Termination Kit	$25.00	1	Purchased
Blue Trail 8-pin Cable Termination Tool	$45.00	1	Reused
36"x36"x1/4" polycarb	$97.00	1	Purchased
Architectural 6063 Aluminum Bar, 1/8" Thick, 1-1/2" Wide (8t)	$29.93	1	Purchased
Angle Brackets	$8.47	12	Purchased
18-8 Stainless Steel Socket Head Screw M3 x 0.5 mm Thread, 10 mm Long	$6.00	100 pack Req: 66	Reused
18-8 Stainless Steel Nylon-Insert Lock	$6.94	100 pack	Reused

Nut M3 x 0.5 mm Thread, 5.5 mm Wide, 4 mm High		Req: 66	
18-8 Stainless Steel Unthreaded Spacer 10 mm OD, 12 mm Long, for M5 Screw Size	$16.92	4	Reused
18-8 Stainless Steel Socket Head Screw M5 x 0.8 mm Thread, 14 mm Long	$15.15	100 pack Req: 24	Reused
Button Head Hex Drive Screw Passivated 18-8 Stainless Steel, M5 x 0.80 mm Thread, 45mm Long	$10.00	25 pack Req: 20	Reused
303 Stainless Steel Knurled Knob with M5 x 0.8mm Threaded Through Hole, 19mm Head Diameter	$48.90	4	Reused
18-8 Stainless Steel Nylon-Insert Lock Nut M5 x 0.8 mm Thread, 8 mm Wide, 5 mm High	$8.77	100 pack Req: 20	Reused
Blue Robotics Subsea Gripper	$640	1	Reused
Blue Robotics 2" Enclosure	$121	1	Reused
Lifecam HD300	$25	1	Reused
Ethernet Switch	$16.00	1	Reused
USB Camera	$45.00	1	Reused
WAGO Lever-Nuts	$109.75	1	Purchased
Fuses	$30.75	1	Purchased
NI roboRIO	$485	1	Reused
Blue Robotics Depth/ Temperature Sensor	$75.00	1	Purchased
pH Sensor	$65	1	Purchased
Gyroscopes & IMUs	$933	1	Reused
Total Cost:		$5,423.58	

Appendix E: Budget

RANGER/NAVIGATOR	Allocated $	Spent	**General**	Allocated $	Spent
Polycarbonate	$100	$100	Tools	$500	$93.24
Penetrators (replacement ethernet penetrator, blue robotics penetrators)	$350	$241	Misc Materials	$500	$60.00
Hardware (aluminum bars/rods, nuts/bolts, hose clamps, washers)	$200	$80	Misc Extras	$400	$398.00
Float	$250	$113	Printing Docs	$100	
Electronics (control boards,instruments, etc)	$900	$179	Shirts/Hats/ Swag	$750	$511.91
Cables & Connectors (ethernet tether, jumper cables, WAGO/crimp connectors, etc)	$350	$123.70	Props	$150	$75
Prototyping/ experimenting	$300		Control system	$500	
Navigator Training Team	$650	$650	Feeding the team (snacks, pizza, etc)	$600	$600
			Outreach/Non-MATE Activities (shopping cart, mecanum drive, KCMT)	$400	$700
			Registration	$400	$750
	Total	$3,100		Total Allocated	$4,300
	Spent	$1146.70		Spent	$3,188
	Excess	$1,653		Excess	$1,111
Total Allocated:	$7,100	Total Spent:	$3,984	Total Excess:	$2,765

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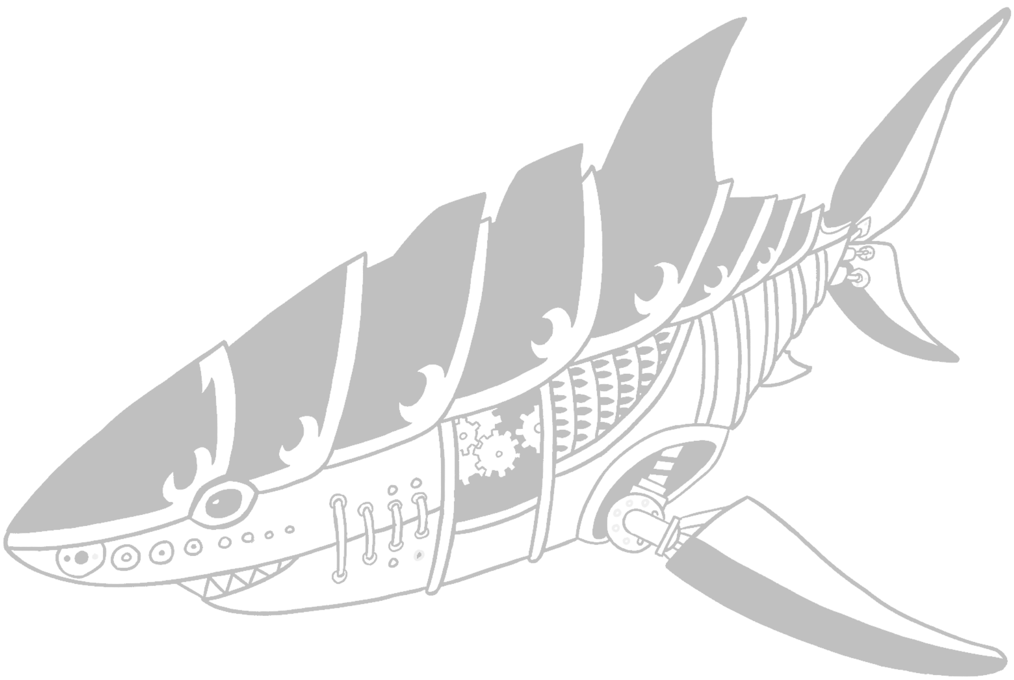

"You know what would help waterproof our enclosure? Putting the enclosure on"
- Kieran Abbott