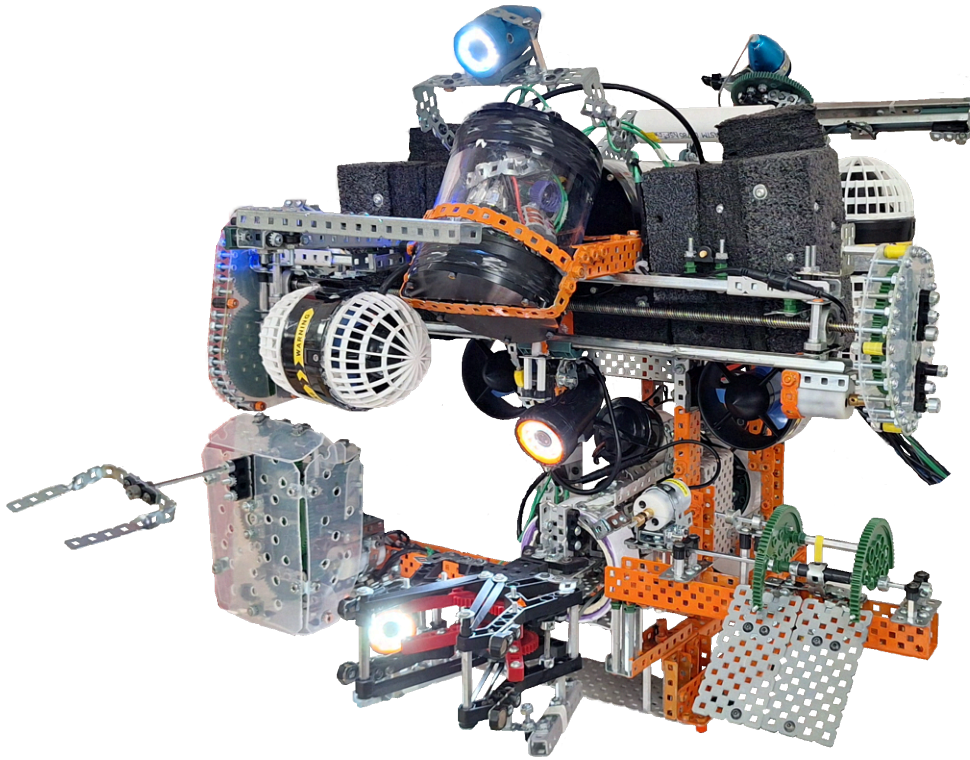




PROP-PULSION

ROBOTICS

Simply Complex



Ω OMEGA

Technical Documentation

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Table of Contents

Abstract	2
Company Profile	2
Project Management and Scheduling	2
Engineering Design Rationale	4
2026 Guiding Design Goals	4
Innovation	5
Design Tradeoffs	5
Problem Solving	6
Systems Approach	7
Control System System	7
Electrical System: Topside Control Box (TCB)	8
Electrical System: Tether	8
Electrical System: Watertight Enclosure (WTE)	9
Electrical System: Coding	9
Propulsion	10
Buoyancy and Ballast	11
Payload and Tools: Camera	12
Payload and Tools: ROV Tool Overview	13
Payload and Tools: Raptor	13
Payload and Tools: Multifunction Gripper	14
Payload and Tools: Riser Base	14
Payload and Tools: Chopsticks	15
Payload and Tools: Scrambler	15
Payload and Tools: AI Crab Identification Software	15
Payload and Tools: Rear Camera Swivel Mount	16
Payload and Tools: Buoy Anchor Retrieval Spool	16
Payload and Tools: Buoyancy Operated Buoy Bot (BOBB)	17
Prototyping	17
Testing	18
Troubleshooting	19
Build, Buy, Reuse Considerations	19
System Integration Diagram (SID)	20
Safety Features and Procedures	20
Budget	20
Cost Accounting	21
Acknowledgements	21
Sources	21
Appendix A	22
Appendix B	22
Appendix C	23
Appendix D	24

Abstract

As the oceanic cryosphere faces unprecedented change, Prop-Pulsion Robotics is developing the necessary tools to protect and explore these fragile environments. We design versatile, reliable, and cost-effective submersible ROVs and data-collecting floats. Guided by our company motto, *Simply Complex*, we focused on engineering an extremely capable ROV using simple yet reliable design choices. Precisely because of its simplicity and the reliability inherent in our component and system choices, our newest ROV, Omega, is custom designed to meet the unique demands of the oceanic cryosphere, including monitoring invasive species, maintaining scientific instruments, supporting gas platforms, surveying icebergs, and sampling fragile cold-water coral species. Omega features a comprehensive camera system, precision coral collection tools, custom AI-based invasive species identification software, and a proprietary buoy anchor retrieval spool. Through experience gained in previous competitions we determined that in the high stress competition environment, pilot error and fatigue were the greatest hindrance to team success. Throughout the design process we focused on cutting out sources of pilot error and control complexity wherever possible. Due to this focus, and through our adherence to the agile design process and collaboration, Omega is heavier and slower than any of our previous models but completes each task faster, at higher success rates, and with significantly less strain on the pilot than ever before. Finally, our latest autonomous data-collecting float, B.O.B.B., is also well equipped for the cryosphere due to the development of ice-avoidance software that enables it to safely collect oceanic data beneath sea ice.

Company Profile

Prop-Pulsion Robotics is dedicated to and passionate about, developing advances in submersible robotic technology that allows our customers to meet their goals of studying and improving global ocean health. Our products are constructed to the highest standards of safety, quality, and effectiveness and are precisely created with the current, 2026, needs of the Global Ocean Community (GOC) in mind.¹ Our designs also meet the UN's Ocean Decade Challenge Goals.² We currently employ five experienced team members who range in company experience between two and four years. As a company we spend significant time studying the needs of our customers so that we can design specialized solutions to the problems they intend to tackle with our product. Failure in previous seasons has taught us that clearly understanding the needs of our customers, and the parameters in which the ROV must operate, is the key to designing submersible ROV technology that meets not only the goals and needs of our customers but our own company goal of finishing on the podium at the MATE ROV World Championships.

Project Management and Scheduling

As stated previously, Prop-Pulsion Robotics is currently staffed by its smallest, yet most experienced team. We are composed of all upperclassmen members, four of which are seniors, and all of which are returning members. This presents unique pros and cons. Our knowledge base and familiarity with the demands of the MATE competition season have never been greater, but the manpower to get the ROV to the finish line has never been smaller. Additionally, when a team is small, decisions can be made quickly, but the number of viewpoints and ideas can often be low, potentially leading to less than ideal solutions. We worked very hard to ensure that the strengths of this year's situation were accentuated and that the weaknesses did not derail our progress. One way we did this was by creating and sticking to a clear division of labor which can be seen in Figure 1. Max and

Dominic shared the CEO role. This ensured, despite the numerous afterschool commitments that each of us had to juggle, that there was always a CEO present at each meeting and work session. We

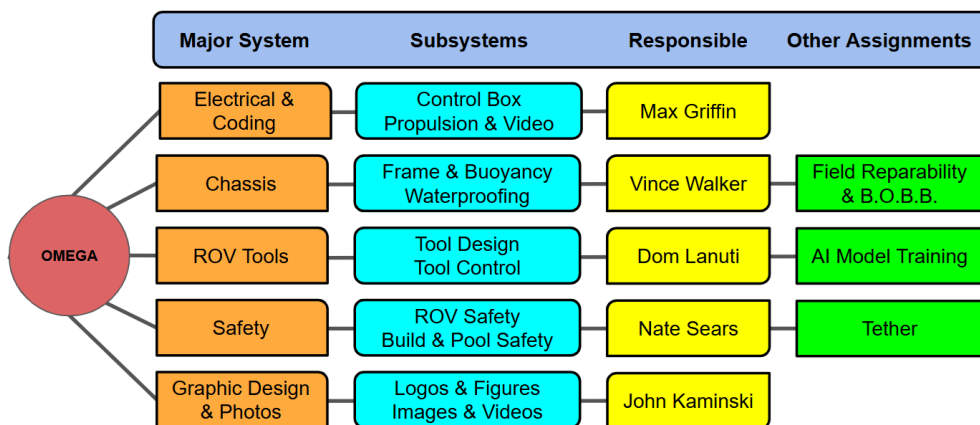


Figure 1: Division of Labor

Credit: J. Kaminski

divided the work up into five major categories. Our main area of focus this year was to move away from building one or two multipurpose tools and to instead create a suite of surgical, task specific tools for OMEGA. To ensure that tools were not an afterthought Dominic was singularly focused on their development. We stayed organized and informed through the use of shared Google Docs, Onshape files, text messaging and Discord chats. In a team as small as ours, roles and tasks had to be

shared. Each person was assigned an area to oversee, but that did not mean that they were the only one to work on that system. Everyone pitched in and helped out on nearly every system as needed, but it was the job of the overseer to do the planning, organizing, testing analysis and to make the final call on when the system was ready to be officially integrated into OMEGA.

In 2026, Prop-Pulsion was funded by a generous but not unlimited budget. Each item that needed to be purchased came out of the same account. Practically this meant that spending funds in one area meant that someone else had to make due with less as they designed their system and components. We frequently discussed the purchases and resources each department was using and how those choices were affecting the rest of the team. We held many brainstorming sessions to determine how we could create the part, system or functionality using spare or repurposed parts that we already had on hand free of charge.

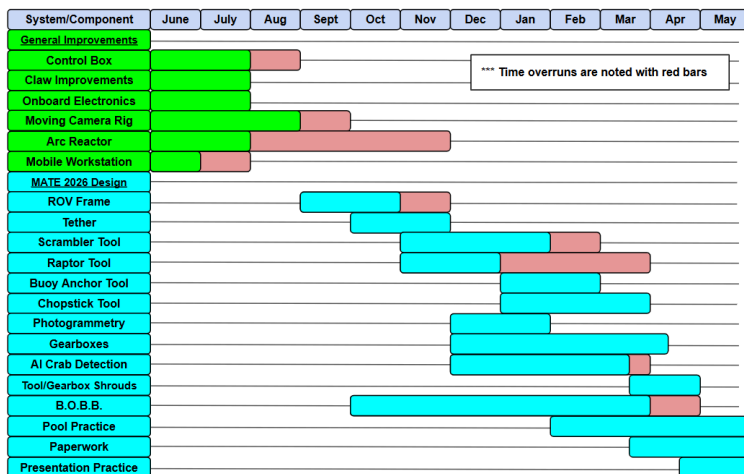


Figure 2: '26 Build Schedule

Credit: J. Kaminski

Figure 2 shows our schedule and the time we allotted for each component/system. We have noted any schedule overruns with a red bar. Scheduling was prioritized to ensure we completed our work by the regional competition. We determined that we were unlikely to fall behind schedule from decision making paralysis or bureaucracy, but we were very worried we would fall behind due to the sheer volume of work that needed to be completed. Knowing our 2026 team would be our smallest yet, we aimed to get ahead right out of the gate and held our first 2026 team meeting less than a week after

we got home from Alpena. We analyzed our 2025 performance and decided on a batch of what we called,

global or general, ROV improvements. These were improvements that we were confident would be needed no matter what the specific 2026 MATE season tasks were. We determined that our Mobile workstation, topside control box, multifunction gripper and subsea electronics all needed improvements,

organization, and quality upgrades. At this time we also dreamed of an ROV that had numerous specialty tools built directly into the ROV as opposed to our previous strategy of designing one or two very general and/or removable tools that each completed multiple tasks. We also imagined a movable tool camera that could relocate itself along the front of the ROV to allow multiple tools to be permanently attached to the front of the ROV. We also dreamed up the beginnings of a subsea analog multiplexer that would allow us to use a single set of tether wires and controller switches to control four or more tools. These became our moving camera rig and our arc reactor. We set a goal of designing and realizing these global improvements before the end of August. We felt that getting those designs done before our school year officially began would allow us the time we would need to design OMEGA to meet the GOC specific requirements for MATE 2026. We understood from the start that our schedule was ambitious and while we expected some time overruns, there were many more than we planned on. Instead of cutting in certain aspects of the project to get back on schedule the team chose to devote significantly greater amounts of time in April and May in order to get OMEGA to the finish line.

Engineering Design Rationale

Prop-Pulsion Robotics has been using the Agile Design Process for the last three years. The visual of this process, that we have posted around our workroom, can be seen in Figure 3. Agile Design is just as effective, iterative and cyclical as a traditional seven step Engineering Design Process, but is significantly more nimble and simple for team members to understand and implement.³ It is this simplicity and nimbleness that Prop-Pulsion Robotics finds so appealing. Essentially Agile Design prompts our team to 1.) study the needs of the customer and create an informed design 2.) build that design and test it 3.) Analyze and understand the performance data and 4.) decide whether to continue iterating or to finalize and implement the design. During the development of the Scrambler tool we went through this iterative cycle at least a dozen times. Partway through its development, Dominic determined that the ability to fold or swivel out of the way would be too complex, take significantly more build time, add significant mass and would lead to the being less sturdy. After a group discussion we decided to scrap designing the ability to swivel Scrambler out of the way and move forward with a rigidly mounted design. After that addition by subtraction we went through numerous cycles that increased the gear ratio to increase its torque output. In the last few cycles we had to modify Scrambler's height and the routing of the geartrain to ensure that it fit in the space available. We attribute much of our recent string of MATE success to our intentional adherence to the Agile Design process.

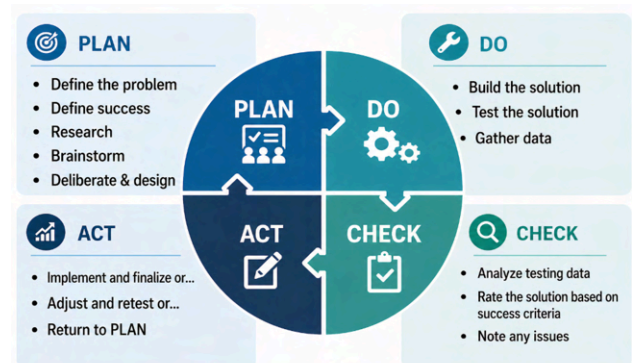


Figure 3: Agile Design Process
Credit: J. Kaminski

2026 Guiding Design Goals

For the first time during the 2026 season we took the time to define a small set of goals that would guide every aspect of our design. We felt this would help us keep our “eye on the prize” so to speak, and we used a rubric through which to test each design idea we had. Our four Guiding Design Goals were; “Simply Complex” design, permanent/ specialized tools, low pilot complexity, and high field repairability. The rationale and execution of each goal can be seen in Figure 4. During the design process the rationale was the most important part of the rubric. If we came up with a design, component or idea and we were unable to clearly explain how it met each of our four guiding goals, then we either had to modify it until it did meet all four goals or scrap it in favor of an idea that was more

closely aligned. Committing ourselves to creating this set of goals and turning them into a design matrix that we used to evaluate every component (explained in detail in the Problem Solving section) was key to our 2026 success.

Innovation

Innovation is often described as changes, modifications or new creations that solve problems, increase functionality and reduce costs. Innovation can also be described by the size of its effect. Incremental innovations are small changes that fine tune a component or system, Evolutionary innovations take the component or system in a completely new direction and Revolutionary innovations are so large that they completely disrupt the market.⁴ While OMEGA was created with

innovation at its core, we would like to highlight three specific examples. Our control box once again underwent incremental innovation as it became more organised and was split into a control half and a video feed half. Our Arc Reactor was certainly an evolutionary innovation. The Arc Reactor is a low tech, low cost, yet highly reliable way to get the performance of a Raspberry Pi and six waterproof servo's (\$400.00 +) using only an Arduino Uno, DPDT switches and less than \$70.00 of DC motors. Finally, our movable camera rig represents a revolutionary innovation for our team. By moving the camera to the tool, we were able to install three permanent tools to the front of the ROV, which reduces the required number of time consuming surface trips by 50%. Monetarily, having a single camera that can do the work of three, saves us over \$250.00 that was spent elsewhere in our budget. Each of these innovative components is explained in greater detail in later sections.

Design Trade-offs

Building a complex machine like OMEGA requires consistent, in-depth analysis of tradeoffs. Improvement in one area inevitably involves "trading" for a decrease in another area. There is rarely a solution or decision that creates only positives while having no negative costs associated with it. OMEGA is constructed from a delicate balance of tradeoffs in dozens of areas. Prior to deciding on a design choice we discussed and defined the gains and sacrifices associated with that particular

choice. Three of those choices, and their associated gains and sacrifices, can be seen in Figure 5. One of the biggest tradeoffs was sacrificing ROV speed for an increase in task completion speed through the development of numerous specialized and permanent tools. In previous competitions we designed a lightning fast ROV that to our constant frustration actually completed tasks slowly or unreliably due to repeated "misses". This created high stress for the pilot and led to very inconsistent product demonstrations. If the pilots nailed every difficult maneuver on the first try we scored very highly,

2026 Guiding Design Goals		
Goal	Rationale	How Achieved
"Simply Complex" Design	We desired a sophisticated ROV that uses simple and cost effective components. Does not require a degree in computer science to trouble-shoot, repair or operate	Prioritized analog, non-software solutions. Tool control, camera movements and video feeds do not use our central processor.
Permanent Specialized Tools	Reducing complex maneuvers and trips to the surface, increases operator efficiency and profitability	We developed seven precise, specialty tools for the toughest 2026 tasks
Low Pilot Complexity	Reducing stressful maneuvers, allows the pilot to drive better for longer	Tools were designed to allow OMEGA to sit on the bottom during use
Highly Field Repairable	In the field, time is money. OMEGA can be quickly diagnosed, repaired and put back into action	Snap, screw and quick connections were used throughout the design to speed repairs

Figure 4: Guiding Design Goals

Credit: J. Kaminski

Notable 2026 Tradeoffs		
Design Choice	What was gained	What was sacrificed
Specialized, precision tools	1.) Task reliability 2.) Task speed 3.) Reduced pilot stress	1.) ROV is slower 2.) ROV is larger 3.) ROV is complex
Mobile Cart	1.) Faster setup 2.) Team & gear safety	1.) Cant fit everywhere 2.) +5min to go mobile
Analog, non-servo tools	1.) Easy to install/repair 2.) Easy to troubleshoot 3.) No added coding	1.) Gearboxes required 2.) Space for gearboxes 3.) Increased shrouding

Figure 5: Trade Off Assessment

Credit: J. Kaminski

however most often the poor fit of our generalized tools led to repeated “misses” on most tasks and many tasks being left unattempted at the end of the run. In 2026 our highly specialized tools allow the pilot to consistently complete tasks on the first try even though moving between tasks and getting aligned at a task takes longer. This has actually allowed us to improve our target score from around 225 points to well over 300 points and has increased the consistency of our pool run scores from +/- 90pts to +/- 30pts. Our mentor compared it to this adage, “slow is fast and fast is slow”.

Problem Solving

At Prop-Pulsion Robotics we see engineering as an exercise in problem solving. Each day we solve not only the problems our customers, the GOC, have asked us to solve, but also the problems that inevitably arose on our journey to solutions. Brainstorming is the first and most important step on the path to a solution. At Prop-Pulsion we like to engage in what we call “informed” brainstorming and then send those possible solutions through our two level design matrix process. First we “get informed” by carefully studying the problem or mission task the customer gave us. We used the MATE Competition Manual,⁵ MATE Video Flythrough,⁶ MATE Prop instructions⁷ and the Prop Demonstration Q&A on Twitch⁸ in order to gain a complete understanding of what each task was and what the various components needed to be able to do. We also committed to building each of the mission props as early in the build as possible. Having the physical props on hand allowed us to clearly visualize how the ROV would/could interact with the prop and it also allowed us to take accurate measurements that would be critical to the design. This was an essential part of our tool design process. Second, we took all that information and used it to design Task Specific Rubrics for each task. Third, each team member combined research of similar solutions, data studies and their own creativity to design possible solutions. Basic CAD designs we created often created in OnShape at this point to help clearly convey each idea. Fourth, as a team we debated how well each solution might work, determined pros and cons and rated each solution using the task specific design matrices we created earlier. Finally we sent the winning solution through our Guiding Goal Rubric to ensure that it met the overarching goals we set for OMEGA. Figure 6 shows the results of this two level design matrix process during the development of the Chopsticks tool. Ideally we prefer that a solution rates at least 30/40 on this top rubric. If it does not we have to decide whether to make small tweaks to raise its score or to take it back to the drawing board and start over. This happened initially with the Chopsticks, and we had to nearly triple its length in order to reduce pilot complexity enough to rise above the 30 point threshold. We feel strongly that using design matrices to guide our work, while costing time on the front end, saves us significantly more time on the backend and ensures that we meet the criteria and functionality our customers demand.

Guiding Goal Rubric (1-10 Scale)					
Idea	Simply Complex	Permanent & Specialized	Low Pilot Complexity	Field Repairable	Guiding Goal Score
Chopsticks	10 -Simple materials -Uses existing claw	5 -Specialized but not permanent	10 -Great view -Forgiving -ROV sits on bottom during use	9 -No new electronics -Nuts, bolts & rubber bands	34/40 -Could only be better if ROV didn't have to surface to install or detach

Task Specific Rubric (1-10 scale)					
Idea	Grasp or control a Basket Star	Grasp or control a branching coral by its substrate	Reliable grip on the coral sample	Ease of alignment to grasp and place sample	Final Score
Current Gripper	10	4 -will touch branches	10	5 -placing is blind	29/40
Chopsticks	10	10	9	9	38/40
Shovel	10	10	5 -coral not grasped	3 -hard to get to slide off	28/40

Figure 6: Dual Level Design Matrix
Credit: J. Kaminski

Systems Approach

Our use of custom design matrices early in the design process helped us design tools and components that effectively completed the tasks at MATE 2026, but it was our commitment to a systems approach that ensured that each tool or component that we designed or included actually functioned cohesively within OMEGA as a whole. Our decision to divide and assign ROV systems to individual team members could be seen as an admission that those systems work in isolation. That could not be farther from the truth, no ROV system works in isolation and each system supports, and is supported by, numerous other ROV systems. Our decision to divide them is simply a way to organize and focus our work flow. Throughout the build changes to any system or component had ripple effects on every other system. A specific example of this occurred when Dominic completed the Scrambler tool. This tool was a fairly large, heavy and non-hydrodynamic addition to OMEGA. In response Nate was finally able to begin to design efficient and hydrodynamic safety shrouding around Scrambler's gearbox. Vince had to adjust the frame and buoyancy by adding support and stabilization beams to better support Scrambler's mass. He also used pool time to adjust the buoyancy and balance by strategically adding more flotation foam. Finally Max could integrate Scrambler into the electrical system and ensure that our tether voltage drop calculations were accurate and that the tool was getting the voltage it required. He also had to ensure that the camera angle and feed allowed Scrambler to be effectively controlled. Constant, clear communication and a commitment to proactively looking at how our design choices affected the rest of the build were essential to this year's success.

Control System

OMEGA's control systems exemplify our motto of "simply complex". Our choice to use minimal software and simple hardware loops, make breakdowns rare and repairs efficient. The software controlled component on Omega is the control of our thrusters. Our code, run on an Arduino, maps analog joystick signals to Pulse Width Modulation (PWM) signals that control the thrusters through six dedicated ESC's. We have used a similar version of our thrust control code for several years, but this year we made the small, yet very significant, change to individually assign the center of each joystick range to counteract stick drift. This is discussed in more detail in the coding section.

Hardware handles the control for the rest of the systems on omega. All of our tools and camera actuators are powered by DC motors and are controlled by the directional flow of electricity using double pull double throw (DPDT) switches. By controlling the direction the electricity flows through a DC motor we can achieve bidirectional control of each tool and actuator. We chose this configuration because it reduces the coding complexity as well as the required processing power. It also makes troubleshooting more straightforward. We saved significant funds by being able to use simple waterproof DC motors as opposed to expensive waterproof servos motor controllers to operate our tools. The DPDT switches themselves are also very reliable and inexpensive. We are able to save valuable troubleshooting time by knowing with certainty that the cause of any tool malfunction will be hardware based. Our hardware based tool/actuator system is cost effective, highly reliable, just as effective as a software based system and allows us to meet our goal of designing a capable and complex machine through simple component and system choices.

One final way that our control system exemplifies "simply complex" is through our dual pilot system. The pilot uses the propulsion controller to maneuver the ROV around the demonstration area and into position for the various tasks. The Co-Pilot uses the tool/camera controller to adjust camera angles and operate each of Omega's surgical tools. The specialization of each pilot's roles allows more familiarity and higher efficiency in their respective roles. We dedicate significant practice time for the pilots to master both their roles and their ability to work in tandem.

Electrical System: Topside Control Box (TCB)

OMEGA's electrical system is composed of three primary features, the topside control box (TCB), tether and two water tight enclosures (WTE) installed on the ROV itself. Our system uses 120v AC from a wall outlet. As a safety measure this electricity first passes through a surge protector. A PowerWerx 120v AC to 12v DC converter and our monitor are plugged into this surge protector and receive 120v AC. After the convertor, everything runs on DC power. For the 2026 season we prioritized completely redesigning the topside control box. The box itself is IP65 rated and has a clear cover that allows for easy basic troubleshooting. In order to keep the box well organized we split it into a propulsion/tool half and a video feed half. We use an arduino UNO as our processor. It takes analog signals from the controller potentiometers, executes our code and sends out pulse width modulation (PWM) signals to the ESC's in the water tight enclosure on the ROV. A topper securely connects each wire to the Arduino using screw terminals. All tool control wiring is organized within this side of the TCB as well. On the video side of the box a convertor reduces voltage to 9.5V for our two tool cameras. The front navigation camera and rear view camera take 12 volts each. Power runs down the tether to the cameras and then returns to the TCB as an RCA video feed. As soon as it arrives it is converted to HDMI and is sent to an HDMI switcher that allows all four feeds to be viewed simultaneously on our monitor. Each side of the control box has its own 12V distribution blocks which significantly reduce wiring clutter and long wire runs. This division can be clearly seen in Figure 7.

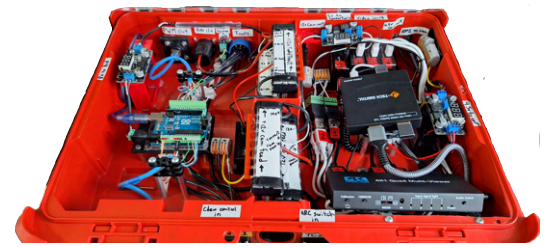


Figure 7: Control Box

Credit: J. Kaminski

Each wire that leaves the TCB and heads down the tether to the ROV has its own connection point. In previous seasons we combined wires from different systems into larger connectors in an effort to be organized and efficient during setup. While this decision made setup and takedown faster it made troubleshooting and repairs much harder, as it was difficult to isolate components to find and repair root causes. Our new configuration allows us to unplug any system or component as needed to aid in troubleshooting or testing. An example where this really helped was during our dry bench testing for our many tools. Our thrusters are water lubricated and should not be run out of the water. Last season when we wanted to test tool performance or camera feeds the thrusters had to be on as well due to our multi system connectors. This made testing other components stressful and rushed as every second the thrusters were powered mattered. This season we were able to leave them unplugged for weeks, if needed, and could test our tools and camera functionality without restriction. This strategy significantly increased the speed and efficiency of our build, and will also allow our customers to be able to troubleshoot much more effectively. We clearly labeled and color coded every individual connector to help reduce the risk of connection errors.

Electrical System: Tether

In order to determine tether length our team studied the project demonstration area dimensions. The product demonstration area can be seen in Figure 8, and is generally considered to not exceed 10m in length, 4m in width and 4.3m in depth. We calculated that an 11m tether would be needed to go from the center of the pool edge to the bottom right or left corner of the demonstration area. We researched an appropriate percentage to add for tether sag and settled on adding 20%. This created a 13.2m section of “wet cable”. Finally we added an additional 3.5m of “dry cable” that would be needed to get from the control box to the edge of the pool. Our total tether length is 16.7m. We used 12AWG MTW wire to get power to and from the ROV thrusters. MTW stands for Machine Tool Wire and is an

extra flexible variety of wire which reduces the overall stiffness of our tether. We used 14AWG wires to get power too and from our tools and camera actuator motors. Running 12V electrical wires right next to camera video feeds caused brownouts on our camera feeds due to electromagnetic interference (EMI). We were able to mitigate the effects of EMI using strategically placed ferrite barrel clamps placed on the wire for each DC tool motor and a toroid ring on the wiring for Scrambler as its high rpm's caused the most disruptive interference. The ferrite barrels and toroid ring were able to effectively soak up the unwanted EMI and stabilize our camera feeds. Our cameras came prewired and we used a CAT5 ethernet cable to send the PWM signals to our esc's. Each wire was carefully cut to length, neatly zip tied and covered in our flexible mesh tether sheath. This sheath protects the wire and reduces trip and entanglement hazards. We prioritized keeping the tether as short as possible as every extra centimeter of tether length reduces the voltage available to the thrusters and tools. Our tether is neatly coiled on our cart during transport. During product runs we have a dedicated and experienced tether manager to optimize the amount of tether in the water, and neatly coil any unused tether to prevent tripping and equipment damage.

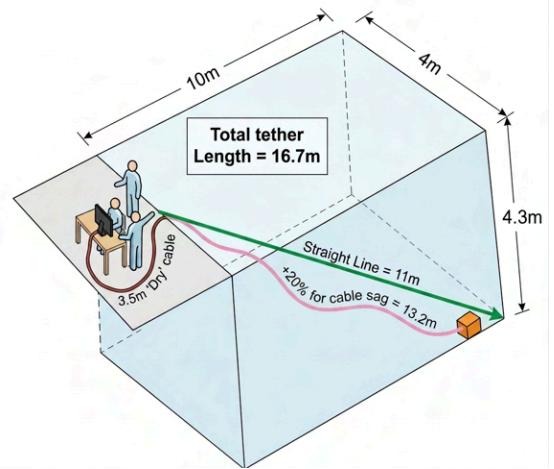


Figure 8: Tether Diagram

Credit: J. Kaminski w/AI Assistance

Electrical System: Watertight Enclosure (WTE)

The propulsion and tool wires from the tether terminate in two WTE's. Each is a Blue Robotics 10cm acrylic enclosure with aluminum endcaps. All wires entering and leaving each enclosure are potted with marine epoxy in Blue Robotics penetrators. We still find the older potted penetrator method to be more reliable than Blue Robotics wet link penetrators. We used these last season and had a few issues with leaks due to not using the exact wires that the penetrators require. Potting them with epoxy lets us put more than one wire through each penetrator without issue. WTE1 holds the six ESC's that control the direction and power of each thruster. The internal design of this enclosure was completely redesigned in August to be more organized and reliable. Experience has taught us that ESC's can make a lot of heat, leading to premature failure. Our new ESC holder was designed to take care of that issue by evenly spacing the 6 ESC's around the enclosure with plenty of air space above them. Even though the water outside the WTE is a great heat sink for the air inside, we chose to add small finned self adhesive heat sinks to the top of each ESC to further improve its ability to dissipate heat. WTE2 is the destination for the tether tool control wires. Our custom servo and DPDT multiplexer is housed inside this enclosure and is responsible for allowing the copilot to switch between tool and camera actuation modes. A switch on the tool controller spins a servo 45 degrees to the left or right. A custom yoke was attached to the servo that is able to actuate the DPDT switch that flips the copilot controller from controlling Raptor and Scrambler to controlling the two tool cameras. This was a cost effective way to get the same performance as a much more expensive switch or multiplexer for the cost of a simple servo and one DPDT switch.

Electrical System: Coding

Our code is written in C++ on the Arduino IDE coding platform and is downloaded, stored and executed on an Arduino Uno. Our thrust control code is reliably simple, a sample of which can be seen in Figure 9. Prop-Pulsion Robotics sees this simplicity as a significant advantage, as it leads to very few software issues and makes troubleshooting a potential software issue much easier and faster than it

CodeThatWorksBecauseLEMFixedit_copy.ino

```
50  Strt.writeMicroseconds(1500);
51  // send "stop" signal to ESC.
52
53  delay(7000); // delay to allow the ESC to recognize the stopped signal
54  }
55
56  void loop() {
57
58    valLForBac = analogRead(analogLForBac);
59    //valLefRig = analogRead(analogLefRig);
60    valRLeFrig = analogRead(analogRLeFrig);
61    valRForBac = analogRead(analogRForBac);
62    valWheel = analogRead(analogWheel);
63    // read the input pin
64    //Serial.println(valLForBac); // debug value
65    //Serial.println(valLefRig); // debug value
66    //Serial.println(valRLeFrig); // debug value
67    Serial.println(valRForBac); // debug value
68    //Serial.println(valWheel); // debug value
69
70
71    escLForBac = map(valLForBac, 432, 594, 1715, 1215);
72    //escLefRig = map(valLefRig, 432, 594, 1300, 1700);
73    escRLeFrig = map(valRLeFrig, 432, 594, 1300, 1700); //1100-1900_old_Apr11
74    escRForBac = map(valRForBac, 432, 594, 1200, 1800);
75    escWheel = map(valWheel, 0, 1000, 1900, 1100);
```

Figure 9: Sample ROV Code

Credit: J. Kaminski

would be if the code were more complex. Code execution begins at our repurposed DJI drone controller with four potentiometers which constantly send a degree value to the Arduino. When in the neutral position the potentiometers send a value of 511, as the stick/wheel is pushed “up from neutral the value increases to its max of 1023. As the stick/wheel is pushed down from neutral the value decreases to its minimum of 0. We instructed the Arduino to read this incoming value and then to map it to a PWM signal frequency, in microseconds, that the ECS’s are able to read in order to control the thrusters. The frequencies the speed controllers need is between 1100us and 1900us. They use this to increase or decrease thruster voltage and direction. A map function essentially aligns the min and max of two separate scales, in order to set them proportional to each other, so that we reach the max and min of the thruster power as we reach the max and min of the potentiometer range. After receiving the potentiometer signal the Arduino follows the map, calculates the frequency of the signal it needs to send and then sends it out through the assigned output port. After videotaping our ROV underwater, playing it back and hearing ESC chimes, we realized that our ESC’s were momentarily shutting down and then instantly re-initializing often during complex maneuvers. This shocked and worried us. After significant research and study of what part of our electrical and signal pathway might be causing this we discovered that our strategy of sending all four PWM signals back on the same shared ground was reducing our signal stability, introducing interference and overloading the signal ground wire. After consulting our computer science teacher Mr. Parker, we determined that we needed to use all eight wires of the CAT5 cable in a “shared pair” configuration. Our four signals, left, right, up/down and strafe were each assigned their own pair of wires, one for the signal to go down and one for the return. The signal now spirals around itself on the way down and back which greatly increases its strength, reduces interference, and shares the signal ground load four ways. This change significantly improved thruster performance and eliminated ESC re-initialization during poolruns

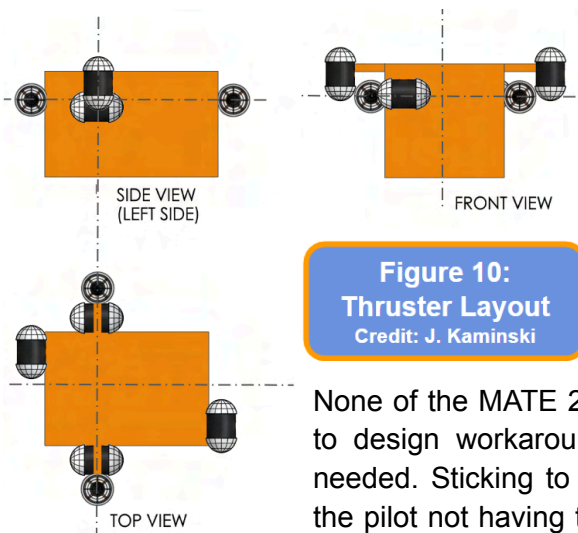


Figure 10: Thruster Layout

Credit: J. Kaminski

Propulsion

Our team was committed to the continued implementation of our signature “Tank Style” steering, 4 degree of freedom thruster placement we have used in previous seasons. We use this as opposed to vectored steering in other ROVs. We did this for many reasons. First it has the shortest pilot learning curve, allowing new pilots to get up to speed quickly. Our thrusters are configured in a way that gives up four degrees of freedom, Omega is not able to pitch or roll.

None of the MATE 2026 tasks require this ability. If it was needed we were able to design workarounds such as our raptorclaw so that pitch and roll weren't needed. Sticking to our goals of simply complex and reducing pilot complexity, the pilot not having to consider unnecessary axes while completing tasks solves two problems at once. Omega’s propulsion layout is shown in Figure 10, and

consists of six Blue robotics T-200 thrusters, two for forward/back control, two for up/down control, and two for strafing. We were also able to reuse five T-200’s from our previous ROV. Our “tank style” steering uses an optimal 6 thrusters for our design with two thrusters for forward and back control, two thrusters for up/down control, and two strafe motors for fine adjustments. The two up down thrusters

and two strafe thrusters work as a unit, and the forward and back thrusters work independently of each other allowing the ROV to “spin turn” left and right. Carefully planning was undertaken to ensure that the thrusters prop wash did not interfere and thus degrade their performance. We chose to place the two up/down thrusters on the wings of the ROV. This gives the ROV excellent stability and roll resistance when ascending and descending due to this wide “stance” and centered position. These two thrusters were placed just far enough apart that their prop wash would not come in contact with the forward/back thrusters installed just beneath them. Our strafe thrusters are placed on the very front and back of the ROV. Due to the installation of other components the strafe thrusters are not centered on the ROV nor are they in line with each other. The front strafe is on the left side of the ROV and the rear strafe on the right side of the ROV. This configuration, while unique, actually balances the thrust and allows the ROV to strafe effectively. This was a configuration we pioneered three seasons ago and revived for this season when the need arose. To ensure the ROV moved in a balanced way where it did not try to flip up or down when moving forward/back or try to roll when strafing, we installed those 4 thrusters as close as possible to the horizontal plane that cuts through OMEGA's center of mass. The forward and back thrusters were placed slightly forward of the geometric center of the ROV to align with the vertical plane that passes through the center of mass.

Buoyancy and Ballast

In order to function effectively, ROVs need to be as close to neutrally buoyant as possible. Neutral buoyancy can be defined as having the same density as the surrounding water (1 g/cm³). This is achieved by having the ROV's displacement in cm³ equal its mass in grams. OMEGA's frame is built mostly from aluminum, which has a density of 2.70 g/cm³. Despite being very efficient with how much frame material we used, we still had a lot of mass to offset. We were unable to conduct full ROV displacement tests, due to not having a tank of the proper size. We brainstormed a creative workaround. We put OMEGA in the pool and zip-tied chunks of spare foam to it until we achieved neutral buoyancy. We then removed all that foam and performed individual displacement tests on the foam pieces in a bucket using tiny skewers to push the foam underwater so the volume change for each piece could be measured. After adding up those values we knew the total volume of foam that had to be attached to the ROV. We then created two equal-sized float pods to be attached to the ROV. During that pool test, we were also able to determine that the ROV was front-heavy due to its

front-mounted tools. Through trial and error we determined the front to back balance point on the ROV to be right above the camera rail. We did not have to consider a left-to-right flotation offset as the two halves of the ROV are nearly identical. A stable ROV is one that has its center of

Body of Water	Water Type	Water Temp (C)	Est. Density (g/cm3)	% Change from Baseline	Ballast to Add (g)
Home Pool	Fresh w/ chlorine	26	996.6		
MU Tanks (OMEGA)	Fresh w/o chlorine	13	999.5	0.29%	53
MU Ice Tank (BOBB)	Fresh w/ EGADS	0	1.0045	0.79%	57
St. John's Harbour	Saltwater	7	1.0265	3.00%	546

Figure 11: Buoyancy Change Analysis

Credit: J. Kaminski

buoyancy above its center of mass. Our team liked to think of it as a hot air balloon, and Vince very non-technically described it by saying, “the floaty part always wants to be above the sinky part.” Nearly all our foam and the two water tight enclosures are installed in the top 10% of the ROV to ensure this. There is very little mass higher than our flotation. Every time a change was made to the ROV or a tool was added, Vince went back to the pool to check and adjust the buoyancy and balance. Knowing that we are only allowed a single run in each pool and that we would likely not be able to test our ROV or its buoyancy accurately prior to our pool run, we spent considerable time researching the condition of the pools we will compete in. We know that any increase in salinity and any decrease in temperature increases the density of the water, which would make our ROV more buoyant. Our research confirmed

that the competition pools will be much different than our home pool, and our findings are summarized in Figure 11. The ROV pools do not have chlorine; however, research shows this has almost no effect on density. The ICE tank uses an Ethylene glycol aliphatic detergent and sugar (AEG/AD/S) solution added to the fresh water to help ice form. EG/AD/S also increases water density. Finally, the Harbour will be salt water, which substantially increases water density. The ROV pools will likely be closer to ambient ground temperature for St. John's (13°C), the Ice tank will be at or near 0°C and the Harbour will most likely be around 7°C by the end of June. Our calculations show that we will have to add mass in every pool to keep OMEGA and B.O.B.B. at the buoyancy they were designed for. In order to determine the exact amount we first researched the specific density of the water at each venue by considering the type and temperature of the water. We then calculated the percent change between the water density of our home pool and each of the competition venues. Finally, we multiplied the mass of OMEGA (18.2kg) and B.O.B.B. (7.2kg) by the percent change to determine the buoyancy increase that will need to be offset by the addition of mass. We have premeasured sets of weights to add for each venue, so we do not need to frantically perform buoyancy adjustments during our setup period. We will attempt to confirm the temperature at each venue prior to our sessions and make any mass adjustments as needed.

Payload and Tools: Camera

Four sealed underwater LED cameras provide vision for OMEGA. We chose off the shelf underwater fishing cameras as they are designed exactly for being submerged, are pre-sealed, come prewired with an appropriate length tether wire and have the field of vision video quality we desire. Figure 12 shows our camera layout. Two of the cameras are installed to provide a close up view of the multiple tools installed on the front of the ROV. The main tool camera runs on a track across the front of the ROV in order to allow it to be precisely positioned above each tool as needed. This actuation is controlled by the copilot from the tool controller and is powered by a DC motor and 7:1 great train to provide the necessary torque. When positioned above the scrambler tool the camera needs to be moved from its 45degree orientation to a 90degree orientation to properly clean the observatory camera

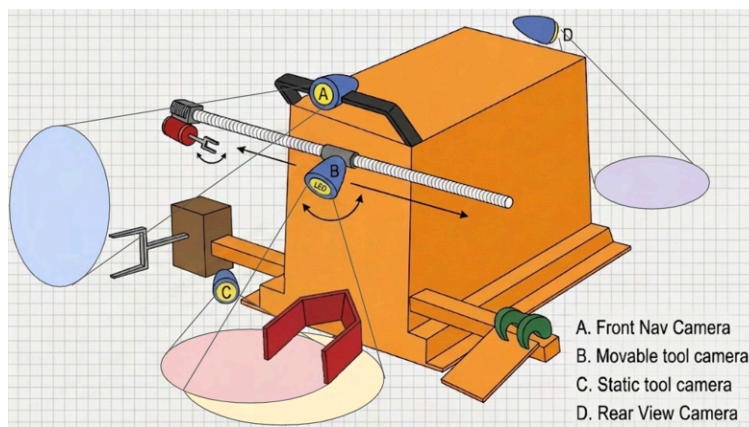


Figure 12: Camera Placement

Credit: J. Kaminski w/AI Assistance

and to align and show the judges the proper color in the view square. An additional DC motor, with a 7:1 gear ratio, meshes with the camera's frame allows the copilot to flip the main tool 45 degrees into the correct position. When that task is completed, the copilot flips that camera back into its normal 45 degree position. A stationary camera is mounted at the bottom of the ROV under the scrambler tool to give an additional angle of the multifunction gripper. Our front mounted navigation camera gives the pilot a field of view that is used to navigate and orient the ROV. This camera is also installed higher on the ROV than our up/down thrusters. This means that we are able to "periscope" this camera above the water. This is a very useful feature in the event the pilot becomes disoriented and cannot locate the pool side. Our final camera gives a view out the back of the ROV to allow the pilot to be aware of subsea assets he may back into and to allow the pilots to keep track of the tether and avoid entanglement. This camera is also able to swing out to the side of the ROV, rotate into a downward position and spin 180 degrees in order to complete AI crab analysis. This is explained in greater detail

in that section. Significant time was spent adjusting camera angles during dry bench testing to ensure that the pilots have the view they needed to complete the tasks. All camera feeds initially RCA feeds but are converted to HDMI in the TCB, sent through an HDMI switcher that allows all four feeds to be displayed simultaneously on our large 81cm monitor. We have seen many teams use small 30cm or less monitors because they are easy to transport and store. We think the ease of transport and storage does not make up for the increased precision and decreased pilot stress that is produced by a large monitor. The “price” we pay setting up and storing our monitor is well worth the performance we gain from it.

Payload and Tools: ROV Tool Overview

This year we focused on creating the most surgical and specialized tools that our team had ever created. Failure in previous seasons was often attributed to our ROV having “generalist” tools. These were tools that could do a given task, but that often weren't optimized to the task. Our pilots often missed and had to reset and try again. This increased pilot stress and wasted valuable time. Previously we also tried to cut costs by creating tools that were able to complete multiple tasks, this again led to tools that were capable of all but masters of none. Through this new focus, our Scrambler, Raptor, Chopstick, Buoy Anchor Retrieval and camera swing arm tools are all designed to complete just a single task in the most reliable and efficient way possible. Their layout is shown in Figure 13. We custom designed and built each tool out of vex parts and materials we already had on hand in our shop, saving significant funds. DC motors to power mechanized tools were the only components we purchased for our suite of 2026 tools. Although building custom tools took longer than purchasing a tool would have, by designing specifically for a task we greatly improved their effectiveness and their ability to lower pilot comple

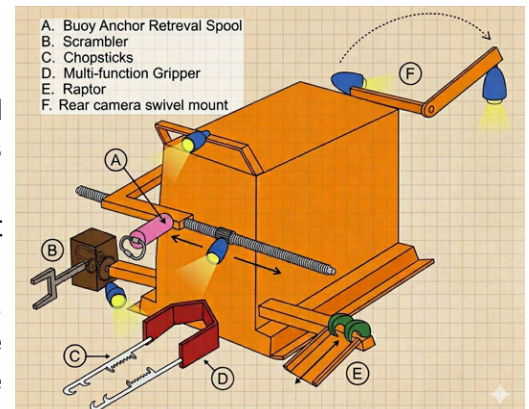


Figure 13: ROV Tool Placement

Credit: J. Kaminski w/AI Assistance

Payload and Tools: Raptor

Raptor is one of our highly specialized surgical tools. Its layout can be seen in Figure 14. It is designed to reliably and efficiently connect the eDNA sensor to the Holyrood Observatory while working in tandem with both the multifunction gripper and the riser base. On the surface, deckhands attach the

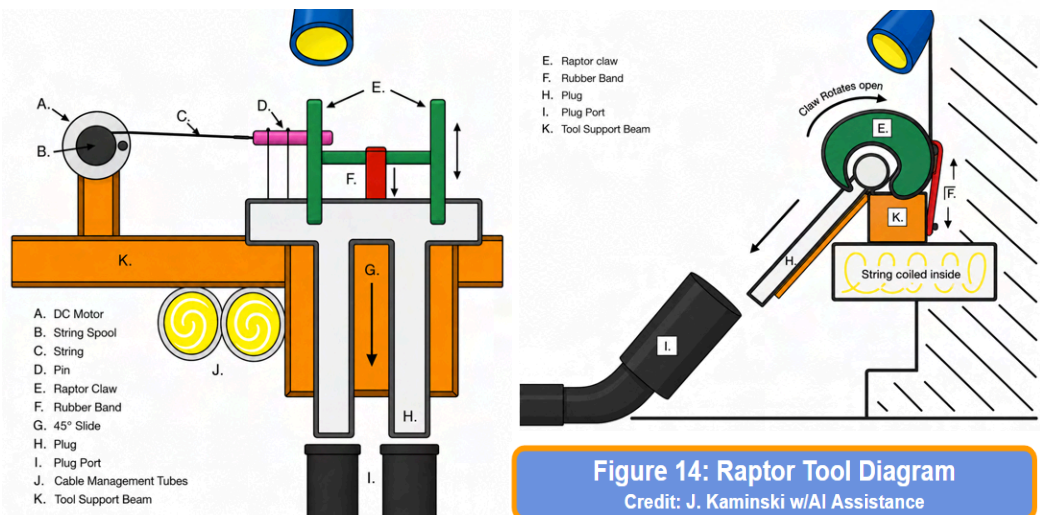


Figure 14: Raptor Tool Diagram

Credit: J. Kaminski w/AI Assistance

riser base, place the eDNA sensor into the multifunction gripper, lock the plug into Raptor's rubber band powered, spring action jaws and then coil the cord neatly into the two cable management tubes. The pilots use the multifunction gripper to carry and place the eDNA sensor into position. After placement the sensor's cord spools out safely as the ROV moves toward the Holyrood Observatory. The riser base raises OMEGA to the correct height for Raptor to insert the two pronged plug into its port. By

eliminating the need to control the ROV's depth the pilot only has to control two axes to align the plug and does not have to worry about drifting out of position during alignment. Once in position the copilot activates Raptor's motor which spins the spool and pulls the pin. Without the pin the claw springs open allowing the plug to slide into its port. Raptor was initially more complex. We started with a geared design that powered by the opening and closing of the claw around the plug. More torque was needed than the motor could produce so we created a gearbox and increased its ratio three times before it became so large that it no longer fit on the support arm and would have led to balance issues. We went back to the drawing board and redefined the criteria required for the design. We realized that the claw only needed to open remotely and could actually be closed manually by a deckhand. The spool and string pin pulling idea came to us pretty quickly after we simplified our criteria due to our team's interest in fishing. Raptor is a great example of the execution of our "Simply Complex" motto. By statically controlling Raptor's height and using a combination of simple materials combined into a simple system, OMEGA is equipped to reliably and efficiently complete one of this year's most complicated tasks.

Payload and Tools: Multi Function Gripper

The multifunction claw is OMEGA's most versatile tool, and works in synergy with the specialized surgical suite of tools. It is capable of manipulating a variety of objects up to 10cm in diameter and rotating 90 degrees to grab and place objects in multiple orientations. Figure 15 shows the gripper in action. This tool is the "guts" that allow the surgical tools to get the "glory". MATE 2025 proved that our unique bilge pump to lead screw claw actuator and custom 52:1 torque multiplying gearbox were highly reliable and were deemed worthy to be reused for MATE 2026's tasks as well. Despite its great performance, we were unhappy with the actual gripping end of the claw and rebuilt it from scratch this year to make it more precise, and reliable. We also secured four neodymium magnets into the end of the claw to further enhance its versatility. OMEGA's multifunction claw is designed to be used to pull the acoustic release on the whale safe fishing gear, handle the eDNA sensors, coral retrieval net, and bubble curtain. It can pull the micropile release pin using its magnets and is the mounting point and actuator for the chopstick claw extension tool that recovers coral samples and plugs the wind farm into the oil platform. Being custom built in-house with two \$20.00 USD bilge pump motors and an assortment of vex parts from our supply, this versatile tool costs less than \$75.00 USD to make, and provides outstanding value to our customers. Grippers with similar versatility and functionality, such as the Blue Eye Reach Alpha Two-Axis Rotating Gripper⁹, can cost upwards of \$3000.00 USD.

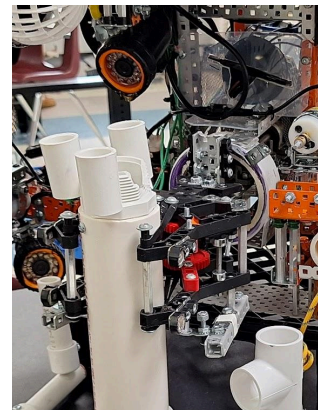


Figure 15: Multi-Function Gripper
Credit: J. Kaminski

Payload and Tools: Riser Base

Shown in Figure 16, this removable tool is designed to manually change the height of the ROV when installed. This allows OMEGA to complete more tasks from a stationary position on the pool bottom. When installed the ROV is at the correct height to perform the eDNA sensor and AI crab analysis tasks. When removed the ROV is at the correct height to complete the buoy anchor retrieval, wind farm power plug, coral sampling and Holyrood camera cleaning tasks. Coral ridge photogrammetry and iceberg analysis can be completed with or without the riser base installed. Velcro was used to make attaching and detaching the riser base quick and efficient. We used the bottom of a milk crate for the base due to its excellent strength to weight ratio, neutral buoyancy and hydrodynamic honeycomb design. Pool testing showed

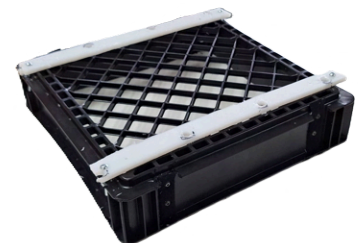


Figure 16: Base Riser
Credit: J. Kaminski

us that we needed to further improve hydrodynamic flow around the riser base by strategically removing all material except the corners, leaving enough material to retain the rigidity needed to support OMEGA.

Payload and Tools: Chopsticks

The Chopsticks are extensions that attach to the underside of the main claw and allow us to complete the coral removal and the oil platform power plug tasks. The Chopsticks are made from thin fiberglass driveway stakes that are very light yet sturdy. The Chopsticks have a flexible inner grip, installed at the exact height needed to harvest branching coral by its substrate without harming the organism.

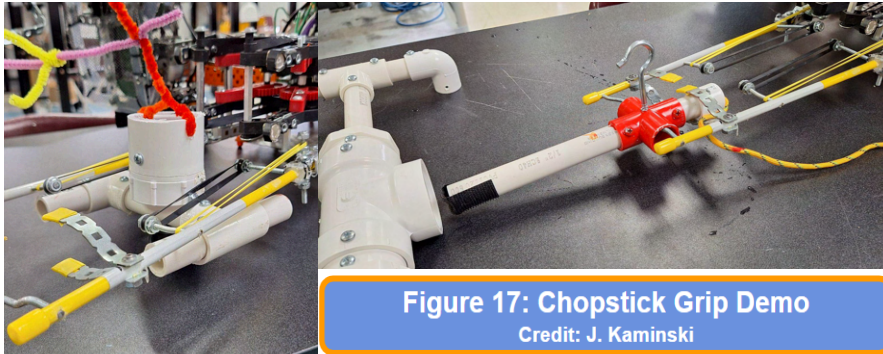


Figure 17: Chopstick Grip Demo

Credit: J. Kaminski

The outer teeth were custom designed to securely grip the wind farm power plug, hold it at 1cm above the pool bottom and in a horizontal position so it can be efficiently plugged into the oil platform port. This dual ability can be seen in Figure 17. The Chopsticks can be easily installed and removed when needed and

they still allow the multifunction gripper to grasp other items while installed, allowing it to collect another object or complete another task on its way back to the pool deck to remove them.

Payload and Tools: Scrambler

Scrambler is another of our surgical specialty tools. It was designed to the exact specifications of the Holyrood Observatory's camera, can spin in either direction and can stop precisely on either color. The forked shape that was designed to fit the camera handle exactly is shown in Figure 18. A custom gearbox with a 315:1 ratio increases the motor's torque in order to reliably turn the camera shutter. This extreme torque increase also slows the rotation of the fork enough the pilots and judge can reliably count the disk rotations and stop the disk precisely on the chosen color. Scrambler was designed to allow Omega to sit still on the bottom during use, again meeting our guiding goal of significantly increasing efficiency and reducing control complexity for the pilot.

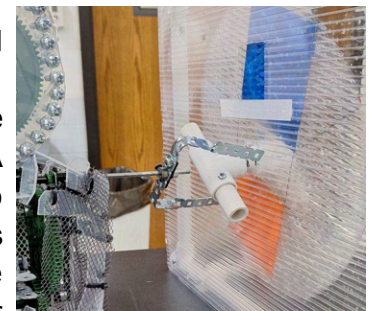


**Figure 18:
Scrambler at Work**

Credit: J. Kaminski

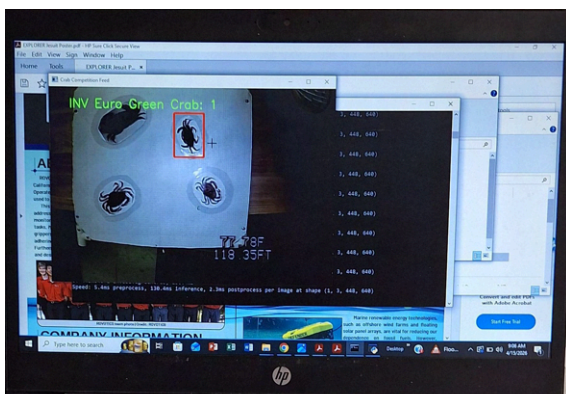


Figure 19: AI Crab ID Software

Credit: J. Kaminski

Payload and Tools: AI Crab Analysis Software

This was our team's first foray into AI model training and object analysis and came with a significant learning curve. Many hours were spent researching the best tools and methods to use to design and train our software. We settled on using Roboflow to train our initial model, and using YOLO v8 as our object analysis platform. Our code was written in Python and runs on an external laptop to save processing power for the ROV. We use the feed from camera four to analyze the crab area. An HDMI duplicator splits the HDMI video feed to the monitor and to a separate HDMI port. This allows the pilot and the laptop to each have their own

dedicated video feed, simplifying the operation. The laptop is plugged into this port and a video capture dongle allows the laptop to accept the incoming HDMI feed. Our code processes the video, identifies the green crabs with red bounding boxes and displays the total number on the screen (Figure 19). Training our model took considerable time. Initially we felt it best to give the model as many images as possible to train on. We used all the individual crab images as well as the multicrab images provided by MATE. We then duplicated and adjusted the images to train the model to account for angle, blur, rotation, gradient, anything we could think of that might affect identification accuracy. After weeks of failure designing a model that could reliably identify the invasive crabs we realized we needed to narrow the training to just what the camera would see underwater. We were trying to create a “sentient” model that could detect a green crab anywhere, when we really needed to create a “specialist” program for the specifics of this task. To do this we only uploaded the multicrab images to Roboflow to create our training script. After final training of this model on the laptop this model was found to be incredibly accurate and robust and could be set to have a confidence interval of .73. Pool testing has shown that our AI crab detection software counts the correct number of invasive crabs 95% of the time. The program continuously scans the camera feed and updates the crab count on the screen.

Payload and Tools: Rear Camera Swivel Mount

This custom mount was designed to allow camera four to send consistently high quality video to the AI crab detection software with little to no stress on the pilot. When the swivel mount is retracted, camera four serves as the rear view camera that helps the pilot keep OMEGA from damaging subsea assets or tangling the tether. When it is extended the camera is in the perfect, downward position for AI analysis (Figure 20). The mount swings the camera off to the side of the ROV. The camera itself is rotated 180 degrees so the pilot can use it for alignment without being inverted. All of this is done by a deckhand and the arm is locked in position with a pin. The pilot simply guides on the bottom until the entire crab area is in view. The ROV parks perfectly still in the spot until analysis is completed. The fact that the ROV can remain perfectly still and never needs an altitude adjustment is a huge reason why our software is so accurate. Our rear camera swing arm was custom designed to make that possible.

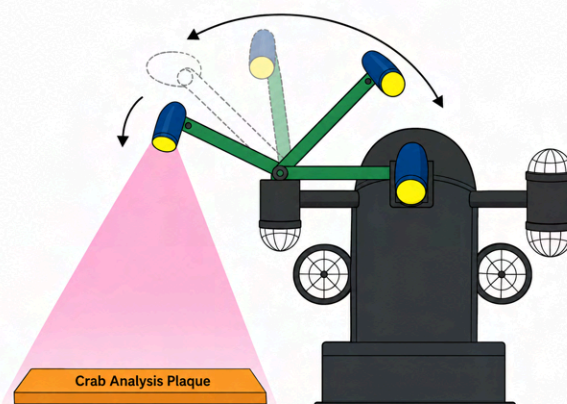


Figure 20: Rear Camera Swivel Arm

Credit: J. Kaminski w/ AI Assistance

Payload and Tools: Buoy Anchor Retrieval Spool

The buoy anchor retrieval tool is another specialty tool and was designed only to attach the retrieval line to the buoy anchor. Deck hands preload the retrieval line into the tool housing and join the two pieces. The entire tool is then attached to the front of the ROV as shown in Figure 21. The tool mount was designed to be at the exact height needed for the pilots to slide the ROV along the bottom in order to attach the retrieval line. This again meets our company goal of reducing pilot complexity. After the carabiner clip makes a secure latch on the buoy anchor the pilot reverses OMEGA to separate the two halves of the tool. The clip end stays attached to the buoy anchor while the other end of the string stays attached to the rest of the tool. The retrieval line spools out as the ROV ascends to the surface. A deckhand removes the locking pin and detaches the tool from the front of the ROV to complete this task.

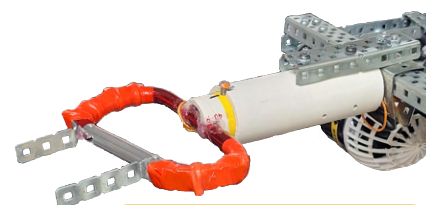


Figure 21: Locking Retrieval Spool

Credit: J. Kaminski

Payload and Tools: Buoyancy Operated Buoy Bot (BOBB)

BOBB is our third iteration of Global BioGeoChemical (GOBCG) analysis autonomous float technology (Figure 22). Although not a directly connected tool, it is often launched and manipulated by OMEGA. BOBB has been completely upgraded from earlier versions and is our most capable float yet. BOBB is made to complete vertical profiles using a buoyancy engine. This engine is composed of a VEX 7.2V DC motor that spins a 9:1 gearbox to increase torque. That gearbox is connected to a central gear that spins three threaded rods simultaneously. These rods are connected to syringe plungers. As the plungers move up in unison the float takes in water and decreases its volume. This lowers its buoyancy and makes it sink. As the plungers expel water they float becomes positively buoyant and floats to the surface. BOBB is controlled by a VEX EXP Cortex processor. Our engineering program uses VEX robotics and each of us is very proficient at coding sensors, variables and complex logic sequences on this platform. That is why we chose it over more common processors such as Arduino or Raspberry Pi. The tradeoff for using this technology was that we were unable to connect a commercially available digital depth/pressure sensor to the VEX cortex, and VEX does not manufacture their own. To compensate for this we reused a strategy from our previous float but updated it to be much more responsive and accurate. We use an analog “needle based” pressure gauge installed into the float housing. As the water pressure changes the needle on the gauge moves. We installed a bright yellow rectangle to the gauge face under the needle. We then attached a lightweight paper cover to the needle that covers nearly all of the yellow rectangle. As the water pressure increases the needle and cover move, exposing more and more of the yellow rectangle. We installed a VEX AI vision sensor right above the gauge and trained it to recognize and measure the pixel width of the yellow rectangle. Through extensive testing and calibration we were able to create an equation that mapped the depth of the float to the pixel width of the yellow rectangle. In doing so we created an effective “analog-digital” depth sensor that was compatible with our VEX cortex. Depth data is constantly monitored to control ascent, descent and holding. Depth and time data is stored to a Micro SD card every five seconds for topside data analysis. BOBB’s coding allows the float to descend to 2.5m, hold there for 45 seconds, ascend to 0.4m to avoid contacting the sea ice, and hold there for 45 seconds. BOBB completes two of these profiles before surfacing. Once at the surface BOBB uses a wireless SD card to wireless transmit its data to the surface station.



Figure 22:
BOBB

Credit: J. Kaminski

Prototyping

Pro-Pulsion relies heavily on rapid prototyping and “proof of concept”. At the end of our brainstorming phase team members often built “proof of concept” prototypes of the top competing ideas. These prototypes are constructed rapidly, out of analogous materials that are readily available, cheap and easy to modify. Building these proof of concept prototypes allowed the team to rate each design much more accurately on our design matrices, and ultimately allowed us to focus on the best ideas with the least

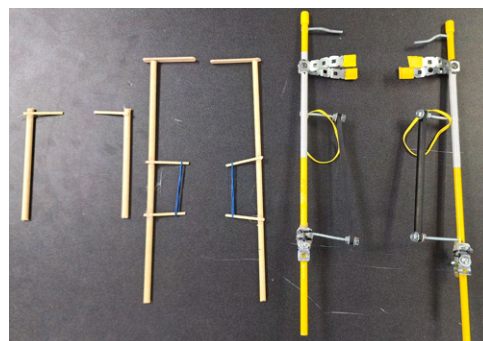


Figure 23: Chopstick Evolution

Credit: J. Kaminski

amount of wasted time. An example of this was our Chopsticks tool. Initially the tool prototype was constructed mostly from bamboo cooking skewers. These allowed us to rapidly get a working prototype onto the ROV and see how effectively it could grasp the coral samples and what sizes and lengths might be appropriate based on the camera angles and field of view. We were able to rapidly make changes and additions to the design before deciding to move forward with it based on its matrix

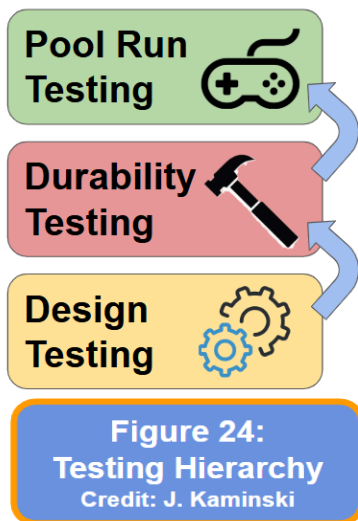
performance. Ultimately the chopsticks were created using fiberglass driveway snow stakes which had the durability and weight profile we desired. Our design iterations can be seen in Figure 23.

Testing

Every component on OMEGA passed through the three levels of rigorous testing shown in Figure 24. **Design Testing:** First components went through what we called Design Testing. This was the second stage of our agile design process. Notes and data were collected during these tests and were used to make improvements or refinements to the design. That information was also used as research data when a complete redesign of the component was required. This year we had very limited access to a pool and the vast majority of our Design Testing was conducted “dry”. Our tool control motors are sealed and self lubricated, meaning, unlike our T-200 thrusters, they can be run “dry”

without incident. We were able to test grip, orientation, alignment, fit, sizing and many other criteria for each tool by interacting with the prop on the workbench. Sometimes the design of the tool required that we see the interaction of the tool to the prop while the ROV is moving or aligning itself. In this case we simply moved the robot to the floor and lifted and slid the ROV and/or the prop around as if they were in the pool. Our pilots analyzed the tool’s effectiveness through the video feeds, just like in competition. This gave us valuable information on how easily and consistently the pilots would be able to align and use the tool and allowed us to fine tune camera angle and placement. We worked hard to make the testing, whether in the pool or out, as true to life as possible. This workaround helped us mitigate losing access to our pool for a good chunk of the season. **Durability Testing:** After the tool or component was thoroughly tested, finalized and integrated into the ROV we put it through durability testing. During durability testing we worked the tool/component hard for a long period of time, essentially trying

to make it break, in order to identify the weak points. This level of testing led us to replace or strengthen numerous components, and tighten many fasteners and setscrews. During durability testing the setscrews that connected our tool motors to the axles routinely loosened due to the vibration from the gearboxes. We solved this issue by adding a tiny amount of marine epoxy inside each setscrew before attaching it to the motor and axle, correctly thinking that it might give the setscrew the extra bite it needed to hold fast. After pushing each tool to the limits and repairing its deficiencies we are confident that our tools can handle the harsh competition environment. **Pool Run Testing:** Finally we engaged in at least 15 hours of Pool Run testing where our team put the entire ROV through its paces as they practiced completing the 2026 tasks. This final level of testing also led to some major changes. Due to our regional being cancelled we had to submit our World Championship entry via the video demonstration protocol. This required our mentor to use a GoPro to film the ROV underwater as we completed the required tasks. After watching the video back we realized the GoPro had allowed us to see and hear things underwater that we had never noticed before. First we were able to see clearly that the thrusters were twitching and spinning when they should not be, second we were able to hear the esc initialization chime regularly during complex maneuvers. Both of these realizations alarmed us as they were signs that a system we thought was sound, was actually quite unhealthy. After significant research we determined that our PWM signals were likely getting scrambled due to interference and overloading the combined PWM ground. This caused the thrusters to receive “ghost” or “garbage” signals. We were also able to discover that a rapid change in thruster direction can cause a milliseconds long voltage spike as the thruster turns into a generator or can cause a milliseconds long voltage drop as the thruster stalls against the water. Both of these phenomena can cause the esc to



shut down and immediately reinitialize. After understanding the causes we researched possible fixes and settled on reorganizing our tether ethernet PWM wires to use a shared pair strategy (4 signals and 4 grounds). We also installed a 35V, 10,000uf capacitor in our water tight enclosure to smooth out voltage irregularities. This dramatically improved the handling of our ROV and will also keep our speed controllers working better for longer. This frustrating situation helped us gain performance we never knew we were missing!

Troubleshooting

After finalization and installation, components inevitably malfunctioned. When this happened we followed our troubleshooting protocol, shown in Figure 24, to find and correct the problem. At propulsion when a problem arises we first define what the symptom is. We then discuss what systems could be contributing to this, and then use our knowledge of those systems to determine the most likely place to start troubleshooting. We then begin to remove components and hardware from the system, and often substitute in fresh or spare parts to bypass components we think may be the issue, until

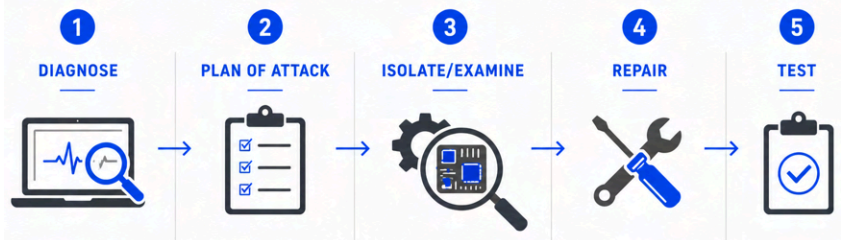


Figure 25: Troubleshooting Methodology

Credit: J. Kaminski

we are finally able to determine the root cause. An example of this happened early in the build, when, during brief benching testing, we noticed our strafe motors were continually spinning at low speed even when the control stick was not being moved. Both motors were behaving the same way so we ruled out a single bad motor or bad esc as it was unlikely that two separate components would fail the same way at the same time. We determined that the issue must be the electrical system or the code itself. We ran an analysis of the code and no issues were found. We bypassed the ethernet from the controller to the control box and from the control box to the ROV and nothing improved. We also switched Arduino ports to no avail. Finally we switched potentiometers in the controller and the behavior improved but was not eliminated. This gave us some direction. After much research we determined that our older potentiometer might not be perfectly centering itself at 511 anymore. We created a few lines of code that printed out the joystick values in the debugging screen in real time and found the center value of our strafe control stick to be at 501. This meant that at rest the stick was outside the deadzone and was constantly sending a thrust signal to the ESC. After more research we figured out that we could manually set the center point for that control stick and the problem was eliminated completely. We used this new knowledge to fine tune all our control potentiometers to their individual midpoints. Field reparability was one of our teams guiding goals this season. Troubleshooting quickly to find the issue does little good if the repair itself is time consuming. We made every effort to make OMEGA as field repairable as possible. Specific field reparability considerations can be seen in Appendix A.

Build, Buy, Reuse Considerations

Each component on OMEGA was carefully and intentionally selected. Once the performance characteristics were settled we then had to decide whether to build, buy or reuse the component or system. Factors such as reliability, cost, task characteristics, and time usage were all factored into our decisions and we used a matrix to help us keep everything straight. We often had to deliberate over difficult tradeoffs. Buying an expensive part is often the easiest path but it could destroy our budget. Making that part inhouse could lead to reliability issues and could hijack significant amounts of time that could have been better spent elsewhere. Re-using parts allows us to know exactly how the component

will work, but it may not meet the new mission specs exactly and since it is used we have to worry about where it is at in its lifespan to avoid midseason failures. Figure 26 shows a selection of our build, buy, reuse decisions for the 2026 season.

System Integration Diagram (SID)

At propulsion we take great care to ensure that all ROV subsystems work together and are integrated in an optimal way. Our SID can be found in Appendix B.

Safety Features and Procedures

Safety is a top priority at Prop-Pulsion Robotics. OMEGA comes fully equipped with numerous built-in safety features, fifteen of which can be seen in Fig 26 along with our rationale for their inclusion. These features aim to keep operators, divers, marine life and the ROV itself safe and in good working order. Team members undergo yearly training on how to safely use drills, handsaws, belt sanders, hot glue guns, soldering irons, and heat guns. We have a designated cutting/drilling table and a designated “hots” table in our shop. Safety glasses are worn at all times and care is taken to ensure the shop and all work tables stay neat and organized. When in the pool area we ensure that at least three team members are always present. Running and roughhousing on the pool deck is never allowed and team members are trained to know where the life preservers and AEDs are located. As a final safety feature we have developed a Job Safety and Environmental Analysis (JSEA) and an operational safety checklist to be used by the pilots and crew during ROV operation. The safety checklist can be seen in Appendix C.

Component	Build		Buy		Reuse	
	Pros	Cons	Pros	Cons	Pros	Cons
Main Gripper	Customize to our needs	Time consuming	Costly	May not fit into our rove or tasks	Reliable already built	The “forward” jaw action is difficult
Up Down Thruster	Customize to our needs	Time consuming to learn and do	Reliable, known performance, matches other thrusters	Costly	N/A, had no spares	N/A, had no spares
Monitor	Could be custom sized	Difficult, construction still have to purchase the parts	Save time Reliable	Costly, may have features we won't use	Free, already on hand	To small fit fit 4 video feeds, Heavy
Mini WTE for the Arc Reactor	Custom sized, have materials on hand	Requires time, may not seal properly	Reliable seal, less time	Costly	N/A do not have a WTE this size	N/A do not have a WTE this size
Video swtcher	Customize to our needs	Take time to acquire this knowledge	Saves time, reliable	Costs funds, may have features we won't use.	N/A Have not used before	N/A Have not used before
Build, buy, reuse choice is shown in green						

Figure 26: Build, Buy, Reuse Decisions

Credit: J. Kaminski

Safety Feature	Rationale for Inclusion in ROV Deisgn
Surge Protecior	Prevents system damage from power surge
25A Fuse	Prevents TCB overload and electrical damage
Clear TCB Labeling	Prevents component damage
IP30 Distibution Block Covers	Prevent electrocution and short curcuiting
100% screw & snap connectors	Prevent electrocution and short curcuiting
IP65 rated TCB	Prevents water and dust from entering the TCB
IP20 rated thruster shrouds	Prevents injury to marine life and divers
IP20 rated gear & motor covers	Prevents injury to marine life and divers
Rear view camera	Prevents damage to ROV and subsea assets
LED lights on ROV cameras	Aid in presice naviagation in all water conditions
Top & ROV side tether strain relief	Ensures the ROV does not become disconnected
Screw tight plugs for controllers	Ensure pilots do not lose contol of the ROV
Center of mass lift handle	Ensures the ROV is balanced when being lifted
Carry cart system	Reduces equipment damge and muscular strain
Tether Sheath	Reduces trip and entangled risk in and out of the water

Figure 27: Notable Safety Features

Credit: J. Kaminski

Budget

Although we are a School affiliated team, Prop-Pulsion Robotics only receives a relatively small construction stipend from Brother Rice High School. This year's stipend was set at \$1,500 USD. We worked as a team to split our build costing into six major categories, Electronics, Propulsion, Camera, Tools, Waterproofing and General materials. We then deliberated on the amount of our total budget that should be allocated to each area. Knowing that we were going to need to purchase one new T200

thruster and completely redesign our control box, water tight enclosure and video system we allocated 66% of our budget to those areas. All budgeting decisions were organized into a shared Google Sheet. We then worked within this budget for the remainder of the build. World Championship airfare, lodging, food and ROV shipping for our team, mentor and a chaperone came in at \$22,500 USD. The Brother Rice Alumni Relations Department was able to secure donors to cover \$17,500 USD worth of World Championship expenses. The remaining costs were split evenly between our team members and their families. Our proposed budget and travel costs can be seen in Appendix D.

Cost Accounting

Prop-Pulsion Robotics is committed to simplicity and cost effectiveness. Our preferred construction and component acquisition strategy is to re-use, repurpose and build components and systems in house from the \$1,000-\$2,000 USD worth of spare parts and leftover materials we have accumulated and saved over the last four years. We also have access to \$20,000 USD worth of VEX Robotics parts shared by the Brother Rice Engineering Program. We don't simply re-use or re-integrate, we completely redesign and re-engineer to meet the new needs of our ROV, but at a greatly reduced cost. This strategy allows us to build an ROV that would actually be very expensive to build from scratch but that on a year-to-year basis actually costs us relatively little. As a team we democratically discussed any proposed purchases, their benefit to the ROV's performance and the effect it would have on the budget. Final purchase approval was decided via a team vote. We carefully labeled and tracked which components were purchased and which were re-used. New purchases were counted against the 2026 budget in their respective categories and the fair market value of all reused components was logged in order to calculate the total cost of the ROV that should be passed on to the customer, should the design go into production. To build OMEGA from scratch would cost nearly \$4,300 USD, but by using nearly \$3,000 USD in reclaimed parts OMEGA only cost \$1,300 USD in new components. This represents a savings of 70% on construction costs. We used the formula features of Google Sheets to add and track our spending in real time. Our commitment to careful spending and creative reuse of previously purchased parts, the 2026 build actually came in 14% under budget. All cost accounting information can also be found in Appendix D.

Acknowledgements

Prop-Pulsion Robotics would like to thank Brother Rice High School for their continued support as well as the alumni who donated funds to our travel expenses. We would like to thank our mentor Mr. Van Dyke for his support and patience, Mr. Steve Parker for his software and electrical knowledge and Mr. Noah Scott for his photography and video expertise. Finally Prop-pulsion would like to thank MATE and MTS for this competition and opportunity.

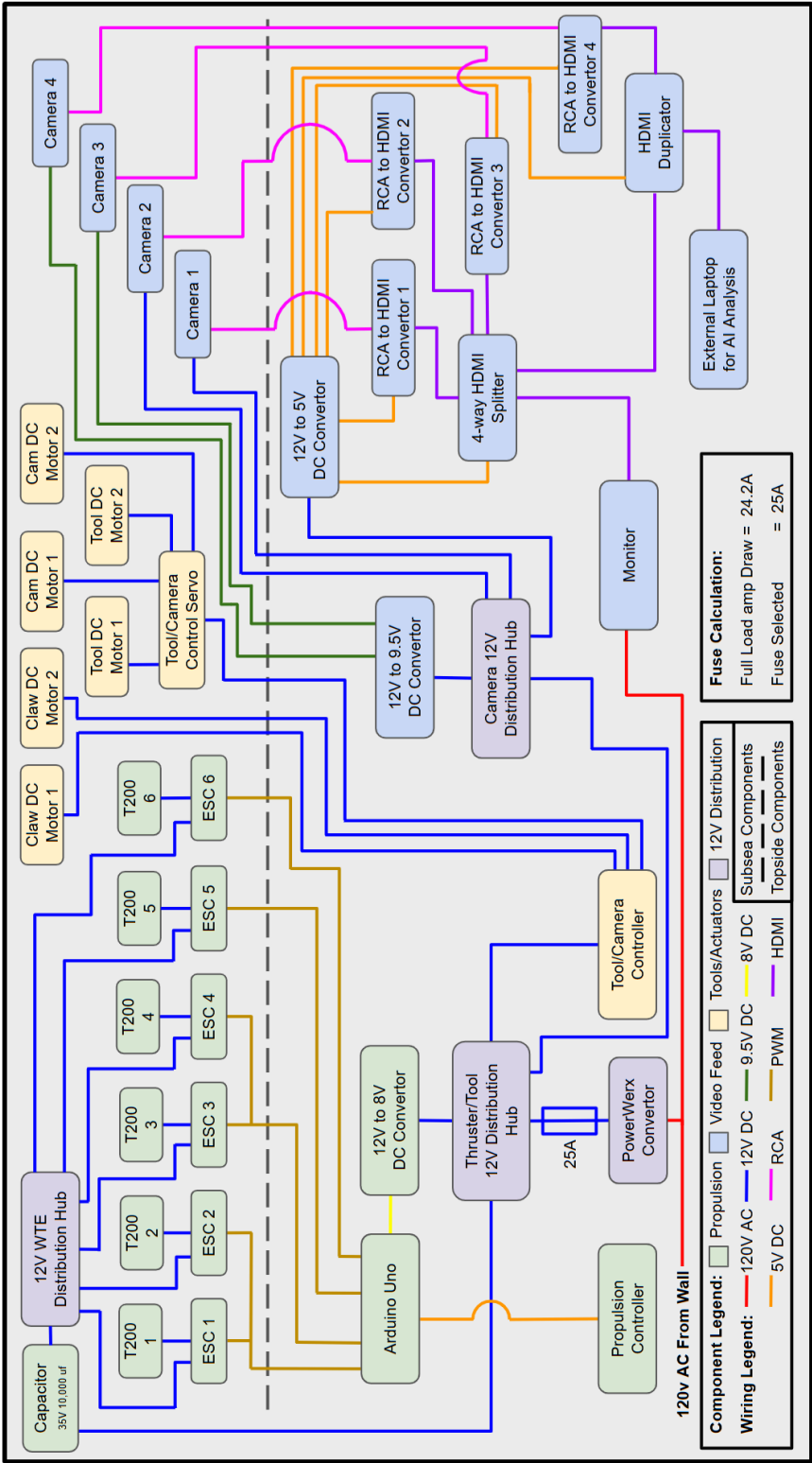
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Appendix A:

Field Repairability	
Feature	Description of Effect on Field Repairability
Phoenix Connectors on ESCs	All ESCs are connected via quickconnect Phoenix connections for easy removal and installation. Space ESCs are pre-wired with these connections
Snap/Screw Connectors	Every component in the TCB can be quickly removed in seconds, by hand or using a standard screwdriver
DC Motor Quick Disconnects	All DC tool motors come standard with waterproof quick disconnects for efficient motor replacement
Standard 8/32 Fasteners	Any fastener that breaks or falls out can be quickly replaced with standard hardware store materials
Pre-Potted Spare Thruster	Since we do not use the Wet Link potting system we have a spare thruster pre-potted with marine epoxy, eliminating the 12+ hour cure time
Spade connections on DPDT Switches	If on of our many DPDT switch fails the six wires are easily removed from it and easily reattached to the new switch without the need for tools
Requires Standard Hex Wrench Tools	No specialty tools are required to repair any of OMEGA's components

Appendix B:



Appendix C:

Operational Checklist
A.) Pilot and Crew Considerations
☐ Ensure that all individuals have closed toed, grippy footwear
☐ Ensure that all individuals minimize loose/baggy clothing
☐ Ensure that all individuals understand their roles and responsibilities
B.) Pre power up Procedure
☐ Visually inspect the operating area for potential hazards
☐ Position the cart within 3m of the water
☐ Chock all 4 cart wheels
☐ Ensure that all wires are properly connected to the TCB
☐ Adjust monitor position
☐ Plug the power strip into a 120v outlet
☐ Grab front and back of ROV frame to remove from cart
☐ Place ROV near the water's edge
☐ Visually inspect the ROV for damage/issues
☐ Remove tether from cart spool and coil neatly near ROV
C.) Power up Procedures
☐ Turn on the power supply
☐ Listen for the correct motor chime pattern
☐ Ensure camera feeds are working
☐ Perform a motor functionality test
☐ Perform a tool functionality test
☐ Adjust camera angles on ROV if needed
D.) Launch Procedures
☐ Use the lift handle to lower ROV into the water
☐ Tilt ROV in all directions once submerged to release any air pockets
E.) Retrieval Procedure
☐ Use lift handle to remove ROV from water
☐ Place ROV on water's edge
☐ Grab the front and back of the ROV frame and place on the cart
☐ Coil the tether on the cart spool
☐ Ensure that both controllers are hooked on the cart
☐ Tilt the monitor down into its traveling position
☐ Remove the 4 wheel chocks
F.) Continual Maintenance of the operating area
☐ Ensure that the operating area is well organized and free of tripping hazards
☐ Ensure that all tools and equipment are placed only in their designated positions
☐ Continually ensure that excess tether is neatly coiled on the ground

Appendix D:

2026 ROV Budget

Income	
Brother Rice HS	1500
Travel Donation	17500
1000 per team member	5000
Total Income	24000

Expenses	
ROV Supplies	1290.24
Marketing Display	75
Team Apparel	100
Travel to St. John's NL	22500
Total Expenses	23965.24

Category Projections/Analysis			
Category	Allocation	2026 Total	Funds Left
Electronics	500	480.55	19.45
Propulsion	250	250	0
Camera	250	240.69	9.31
Tools	200	160.23	39.77
Waterproofing	150	102.8	47.2
General Materials	150	55.97	94.03
Total	1500	1290.24	209.76

2026 Account Balance	34.76
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Cost Accounting

Purchased Component/Material	
Propulsion	Cost (USD)
Blue Robotics T200 & ESC	250
Waterproofing	Cost (USD)
Marine Epoxy	48
4in x 12in Acrylic Tube	24.15
Blue Robotics Penetrators	30.65
Electronics	Cost (USD)
Milwaukee Tool Box	39.99
Wagos	22.11
Phoenix Connectors	12.89
IP 68 Aviation Plug Connector x 5	104.32
12 NiMH batteries	63.96
4 Dual C Battery Holders	15.98
Distribution blocks	31.66
500ft 14AWG Wire	75.23
RJ45 Connector IP68 x2	13.99
35V Capacitor	9.79
Power Pole Connector w/fuse	9.95
15ft USB-C to USB-A	29.82
Momentary DPDT Switch x3	9.99
Anderson PP Ends	16.99
Butt connectors	5.99
Heat shrink	17.89

Purchased Component/Material	
General Materials	Cost (USD)
Milk Crate	5.51
8/32 nuts and bolts	15.48
Velcro	24.99
Mesh Fabric	9.99
Camera	Cost (USD)
Amazon Fire TV	75
4X HDMI splitter	38.99
HDMI Duplicator	25.52
RCA to HDMI convertor	12.99
Ferrite Barrels	19.98
Toroid Ring	12.95
12 in HDMI connector	20.39
Threaded rod/slider	14.98
Video Capture Dongle	19.89
Tools	Cost (USD)
5 Apis Queen DC thrusters	60
2 snow stakes	16.78
Pressure gauge	9.99
60ML Syringes	10.99
Neodymium Magnets	9.99
Servo Motor	3.96
Misc 4" PVC	48.52

Reused Component/Material	Category	Fair Market Value
Vex metal		100
Vex gears		50
Vex fasteners		50
Vex axles and collars		25
Foam		10
Cameras x 4		500
T200 x 5		1250
Vex claw		40
Threaded rod and slider		15
RCA to HDMI convertor x 3		30
Arduino		35
DROK voltage convertor x 5		75
55ft Ethernet		20
55ft 12AWG wire x 2		55
Power supply		140
Power strip		15
WTE		250
Blue Robotics ESC's x 5		150
Phoenix connectors		15
Wagos		10
Bilge pump motors x 2		50
Spare WTE ends/caps		100
Vex Cortex		250
Vex motor		40
Micro SD to SD adapter		8
Wifi SD Card		20
Misc Wires		75
Tether Sheath		100