2026 Technical Documentation

Crush Depth

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Fresno, California, USA

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In loving memory of our professor, mentor, and friend...

Gurinder Khaira.

Your legacy and spirit will forver take us to new depths.



Gurinder Khaira
April 18, 1987 - May 13, 2026

Abstract

Crush Depth is a **third-year company** competing in the 2026 MATE ROV World Championship, consisting of a **48-member team** from various majors and backgrounds. Though the company is **headquartered at Clovis Community College**, our club is one of the largest in the district, drawing passionate and dedicated students from several colleges within the State Center Community College District.

After Crush Depth's 2025 underwhelming results from the MATE ROV World Championship, the company decided to undertake a massive overhaul. **Restructuring not only the approaches in engineering and organizational structure, but also those in marketing, finance, outreach, and STEM initiatives**.

The ROV designed for the 2026 MATE ROV World Championship was developed with a holistic approach and is designed for research in habitats that require collecting samples for observation, as well as for work on offshore wind and oil platforms. Named *GKAlloy*, for our late advisor Gurinder Khaira. To avoid environmental damage during launches, *GKAlloy* is equipped with several safety features, including thruster covers, bolt covers, gear shrouding, and snipped zip ties. To assist in completing mission tasks, a pressure sensor for data, manipulators for specific tasks, and a 6-degree-of-freedom range of motion were prioritized. Quick and easy access for **repairs and maintenance** while maximizing **modularity, reliability, and operational efficiency** was prioritized. The 2026 Crush Depth era marks a brand-new beginning for Newfoundland, striving for excellence in every sense.



Figure 1, Team Photo by Irery Huerta

Table Of Contents

Teamwork 5
- Project management 5
- Schedule 5

Design Rationale 6
- Housing 8
- Chassis 9
- Electrical System 10
- Backplate 11
- Tether 12
- Control System 13
- Surface Side 15
- Propulsion 16
- Buoyancy and Ballast 17
- Payload and Tools. 17
- Build vs Buy, New vs Used 20

Safety 21
- Member Safety 21
- Equipment Safety 21
- Operational Safety 21
- Safety Checklist 22

Critical Analysis 23
- Testing and Troubleshooting 23

Acknowledgements 24

References 24

Appendix 25

SID 27

Teamwork

Project Management

The Crush Depth workforce consists of a **fourteen-person management group**. The five chief members are the co-CEOs, CDO, CTO, CMO, CSO, and CFO, with the CDO and CTO sharing responsibility for the CEO role. **Nine Technical Leads** directly oversee their integrated teams, including Housing, Chassis, Manipulators, Float (2 leads), **Surface Side, SAS, Electrical, and Control Systems.** Individuals are listed by name and position on the title page. Several weekly meetings were held to develop and streamline corporate operations, with the goal of designing an environmentally safe ROV that meets Mate ROV's needs and effectively completes the required tasks. Frequent communication on Discord was utilized to solve day-to-day operational problems. To resolve critical problems, emergency meetings were held in person at the earliest availability.

Position	Responsibilities
CEO	Define and maintain the companies strategic direction
CTO	Unite the different technical sub-teams and maintain focus
CDO	Unite the different design sub-teams and maintain focus
CSO	Research, establish, and maintain safety protocols and proper procedural documentation
CMO	Define marketing strategies and organize documentation
CFO	Strategize the company financing, allocation of funds, sponsorships, & logistics.
Technical Lead	Spearhead and manage their respective projects
Team Member	Contribute to and develop their respective projects

Table 1, Member Responsibilities by Emily Brereton

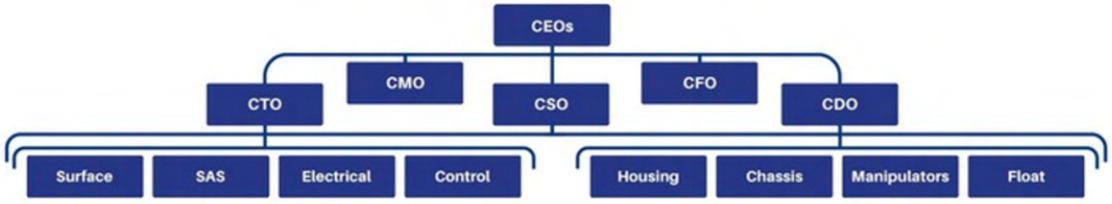


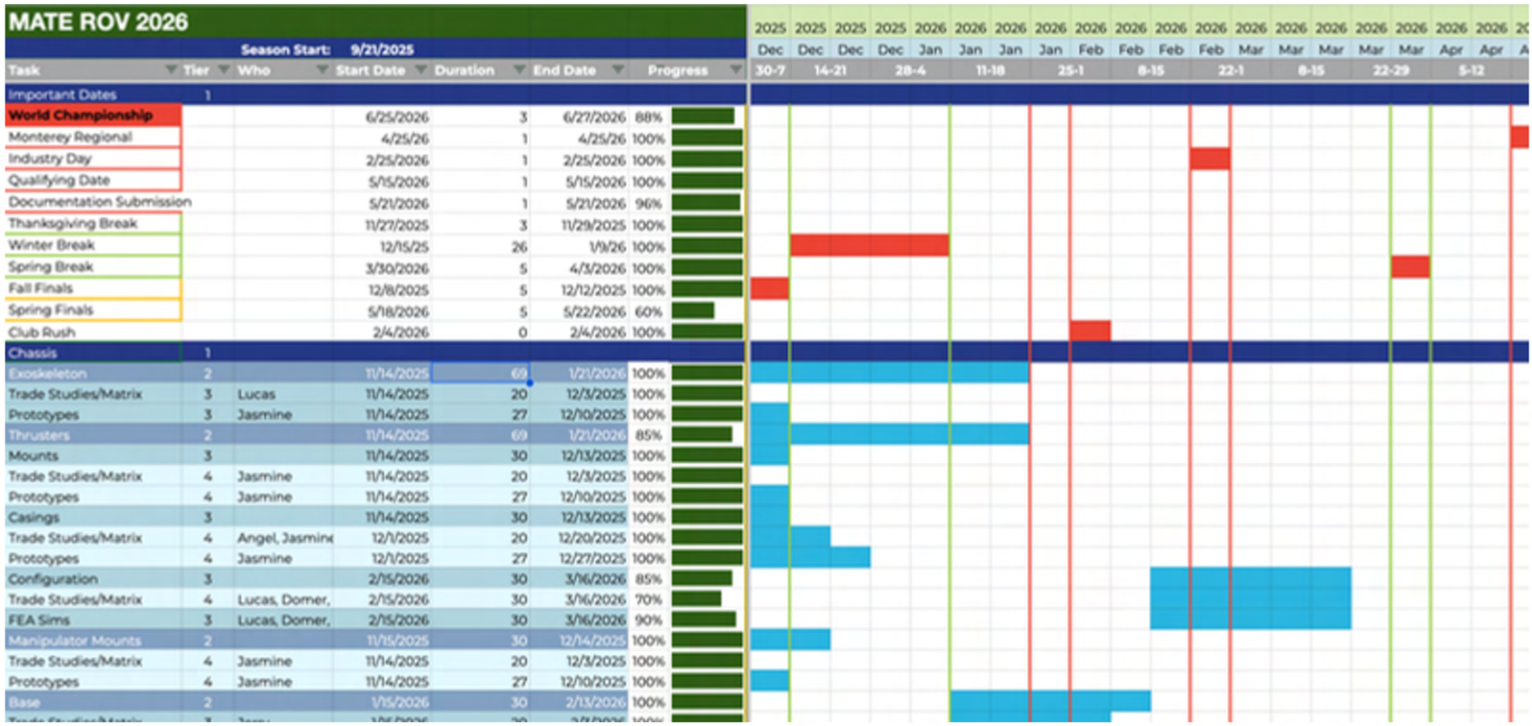
Figure 2, Company Organization Chart by Sophie Morales



Figure 3, Discord Communication Channels by Jack Jackson

Schedule

Scheduling and management were highly prioritized due to the size of the Crush Depth team. Crush Depth created a long-term weekly Gantt chart at the start of the year to plan and detail the needs of individual projects and goals. Major deadlines, school breaks, and school events were all highlighted. **Tiers one and two** were itemized by the CEOs, CDO, and CTO to establish overall goals. **Tiers three and below** were developed by Technical Leads to determine the needs and responsibilities required to reach those overall goals. Leading up to big deadlines such as Beyond The Blueprint, qualifications, and the world championship, a 4-week lookahead daily Gantt chart was created to provide a more detailed, task-by-task and person-by-person framework.



MATE ROV 2026

Season Start: 9/21/2025

Task	Tier	Who	Start Date	Duration	End Date	Progress
Important Dates	1					
World Championship			6/25/2026	3	6/27/2026	88%
Monterey Regional			4/25/26	1	4/25/26	100%
Industry Day			2/25/2026	1	2/25/2026	100%
Qualifying Date			5/15/2026	1	5/15/2026	100%
Documentation Submission			5/21/2026	1	5/21/2026	96%
Thanksgiving Break			11/27/2025	3	11/29/2025	100%
Winter Break			12/15/25	26	1/9/26	100%
Spring Break			3/30/2026	5	4/3/2026	100%
Fall Finals			12/8/2025	5	12/12/2025	100%
Spring Finals			5/18/2026	5	5/22/2026	60%
Club Rush			2/4/2026	0	2/4/2026	100%
Chassis	1					
Exoskeleton	2		11/14/2025	69	1/21/2026	100%
Trade Studies/Matrix	3	Lucas	11/14/2025	20	12/3/2025	100%
Prototypes	3	Jasmine	11/14/2025	27	12/10/2025	100%
Thrusters	2		11/14/2025	69	1/21/2026	85%
Mounts	3		11/14/2025	30	12/13/2025	100%
Trade Studies/Matrix	4	Jasmine	11/14/2025	20	12/3/2025	100%
Prototypes	4	Jasmine	11/14/2025	27	12/10/2025	100%
Casings	3		11/14/2025	30	12/13/2025	100%
Trade Studies/Matrix	4	Angel, Jasmine	12/1/2025	20	12/20/2025	100%
Prototypes	4	Jasmine	12/1/2025	27	12/27/2025	100%
Configuration	3		2/15/2026	30	3/16/2026	85%
Trade Studies/Matrix	4	Lucas, Domer,	2/15/2026	30	3/16/2026	70%
FEA Sims	3	Lucas, Domer,	2/15/2026	30	3/16/2026	90%
Manipulator Mounts	2		11/15/2025	30	12/14/2025	100%
Trade Studies/Matrix	4	Jasmine	11/14/2025	20	12/3/2025	100%
Prototypes	4	Jasmine	11/14/2025	27	12/10/2025	100%
Base	2		1/15/2026	30	2/13/2026	100%

Figure 4, Gantt Chart by Luke Salazar

Weekly club meetings were held every Friday on school property from 5:00 pm to 7:00 pm, including all members to develop and collaborate across teams, and for tech leads to delegate and collaborate on pieces with team members. Further management meetings were held at least once a week, based on needs and personal availability, to review progress, overcome any roadblocks, and improve professional **one-on-one communication and interpersonal relations**. Technical Leads hosted meetings whenever necessary to work with members on required tasks.

Design Rationale

GKAlloy was designed to serve two purposes within the CRUSH DEPTH organization. First, engineer an ROV capable of excelling in all competition tasks. Second is to establish an industry-accurate environment where **first- and second-year engineering, marketing, and pre-law students can dramatically accelerate their technical and soft skills development**.

Crush Depth's design philosophy was established before the season started to maintain strong, consistent standards across our teams and enable easy **cross-team collaboration**.

Function: First and most importantly, a part succeeds if it meets its performance goals (**weight, strength, or movement**) without failing, breaking, or deforming. Before any design is finalized, it must be certain that it accomplishes all its goals.

Form: The shape, size, dimensions, mass, and how appealing a part looks are extremely important to The Crush Depth culture. A **clean and polished design** reflects the team's attention to detail and pride in workmanship.

Maintainable: Systems should be designed so they can be assembled, understood, repaired, and improved by others. **Modular, standardized components** make the systems easier to troubleshoot, replace, and adapt over time. **M3** and **M5** hardware were made the Crush Depth standard, unless other hardware is specifically required for a niche job. If a design cannot realistically be assembled or maintained in a short timeframe, it is incomplete.

Manufacturability: Crush Depth is based out of a small community college with limited access to traditional manufacturing, machining, and materials. The company relies on access to company and employee owned 3D printers, as well as a local materials sponsor, to enable rapid manufacturing. For specialized components demanding material tolerances or mechanical strengths that FDM printing cannot

cannot provide, the engineering and design work remains entirely in-house, with fabrication handled through local machining resources.

Safety: Identifying potential hazards and risks (sharp edges (remember form), pinch points, or areas of high stress) of design. Designing for how the **end user** will interact with different parts, ensuring it is safe for the user, comfortable, and safe for the environment it works in.

Last competition season, Crush Depth was organized into broad groups: **ROV Design, ROV Electronics/Programming, Surface Side, Float Design, and Float Electronics/Programming**.

Before the start of the 2026 season, the CDO and CTO worked together to restructure the Technical Lead system to improve the team's operational structure and overall efficiency.

The new organization was designed to support a growing team better while also encouraging stronger **collaboration** and **communication** between subteams. By moving to a more granular sub-team model, the company established a clearer division of labor while structurally forcing inter-team collaboration and communication. This expanded leadership network successfully distributed project accountability across more Technical Leads, keeping development on track.

To establish a rigorous engineering culture at the start of the season, all sub-teams were required to research and formally justify every major and minor design decision, including the strategic reuse of **legacy hardware**, to the company's CDO and CTO. This justification process was standardized through a comprehensive **Trade Study Report** based on the **Analytic Hierarchy Process** (AHP). These reports systematically defined objectives, identified critical criteria, evaluated design alternatives, and assigned weighted performance ratings to remove human subjectivity. Following the calculation of comparative scores, provisional decisions underwent a rigorous sensitivity analysis to verify fairness and accuracy before delivering a final engineering recommendation. To ensure transparency and continuity, students maintained detailed engineering journals simultaneously.

These journals served as self-organizational reference tools and a comprehensive **data repository**, enabling any technical reader to replicate the team's results and providing the raw data needed to compile the competition's official technical documentation.

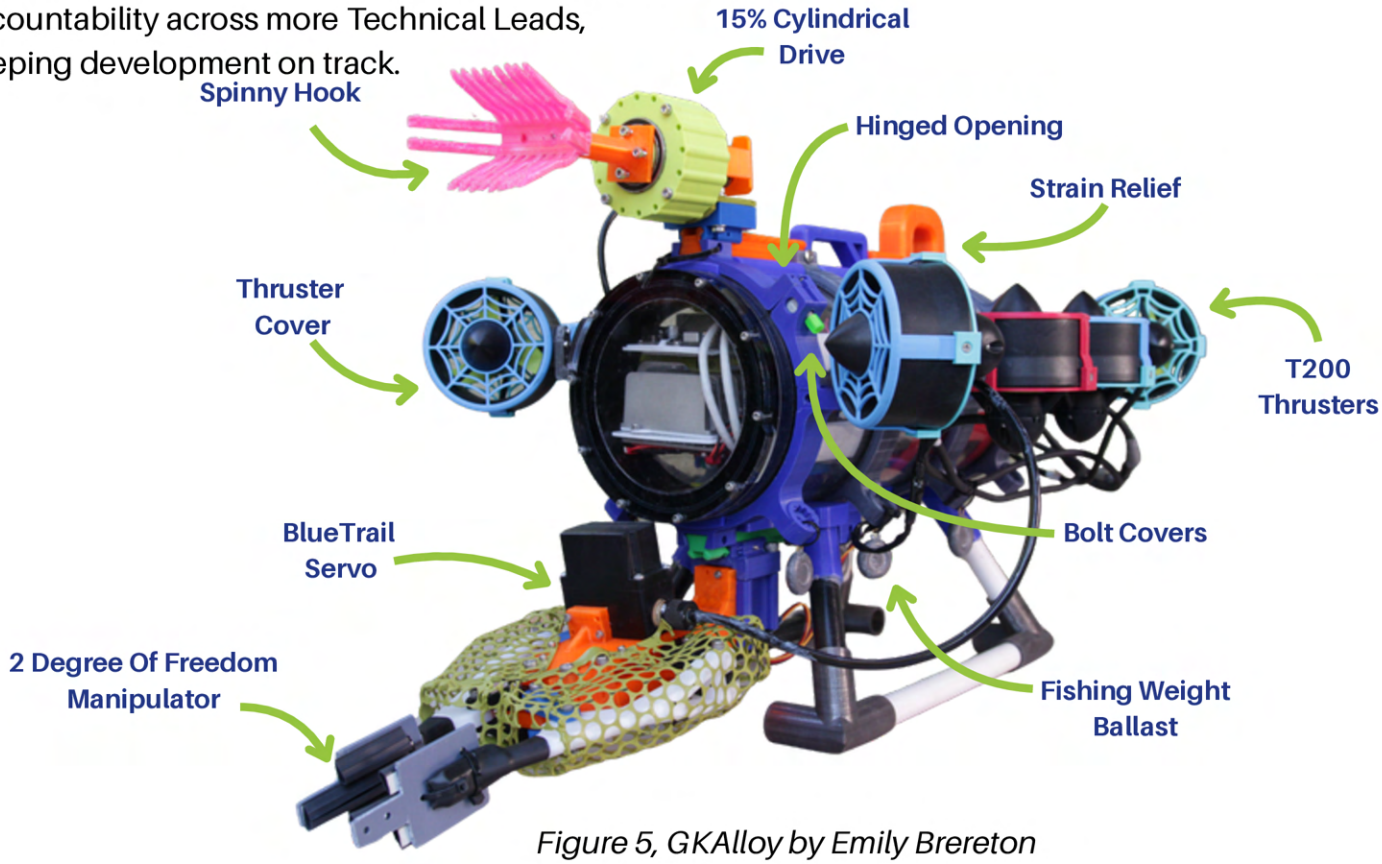


Figure 5, GKAlloy by Emily Brereton

Housing

Crush Depth's **housing team** was responsible not only for **waterproofing** but also for determining the **ROV's overall shape and internal organization**. During the design process, this team brainstormed several possible housing geometries and evaluated them using a **weighted decision matrix** (Table 2). Nine criteria were considered: cost, waterproofing capability, electronics storage, penetrator integration, manufacturability, volume, external mountability, repairability, and structural integrity, with weights assigned via pairwise comparisons of each criterion against the others. After comparing the trade-offs of each concept, a 15.24 cm (6-inch) inner-diameter acrylic tube was selected because it best **balanced cost, waterproofing, electronics accessibility, internal space,** and overall **structural performance**.

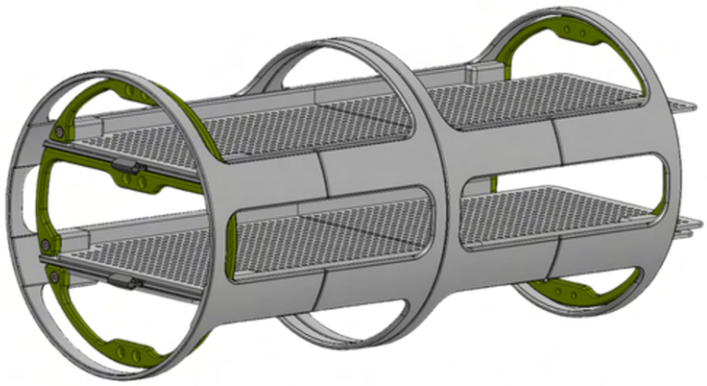


Figure 6, Housing CAD by Gavin Kiggins

Last season, one of the primary housing-related failures stemmed from **poor internal electrical organization**. Electronics mounted directly to the endcaps gradually sagged over time, compromising the seals and allowing water intrusion.

To fix this, Crush Depth evaluated three internal organization concepts:

1. **Radial wedge sections** - dividing the cylinder into 8 pie-slice chunks that could be removed individually. Rejected because the actual electronics (ESCs, buck converters, logic boards) didn't naturally partition into wedge shapes, wasting volume and complicating wiring.
2. **Horizontal layered "burger" stack** - flat trays stacked along the tube's axis. Rejected because nearly every board needs to connect to nearly every other board; too many isolated layers turned interconnects into a wiring nightmare and made any single component a full-disassembly job to service.
3. **"Titanfall Battery"** (TFB) - a cylindrical multi-layer drawer system inspired by server racks and the video game *Titanfall 2*. It grouped related electronics by function, allowed individual drawers to slide out for servicing without disturbing the others, and kept inter-board wiring runs short and accessible.

The chosen system, the **"Titanfall Battery"** or TFB, is a cylindrical multi-layer drawer system with three layers: the bottom houses the ESCs, the middle contains the buck converters, and the top contains the logic systems. The drawer-style arrangement allows for removal and servicing without complete disassembly of the electronics system. The entire assembly is almost entirely 3D printed, excluding fasteners and adhesives, and costs less than one roll of filament to manufacture. By suspending the electronics independently from the endcaps, the TFB eliminates the sagging issues experienced in the previous design and greatly improves both organization and maintenance accessibility.

Criteria	Weight	8" Tube		6" Tube		Watertight Box		Submarine Shape		Sphere	
		Performance	Weighted Score	Performance	Weighted Score	Performance	Weighted Score	Performance	Weighted Score	Performance	Weighted Score
Cost	9.36%	0.2857	0.0267	0.3571	0.0334	0.0714	0.0067	0.1429	0.0134	0.1429	0.0134
Waterproofing	30.55%	0.2424	0.0741	0.2424	0.0741	0.2727	0.0833	0.1212	0.0370	0.1212	0.0370
Electronics Storing	4.87%	0.2581	0.0126	0.2258	0.0110	0.3226	0.0157	0.1290	0.0063	0.0645	0.0031
Penetrators	9.74%	0.2692	0.0262	0.2308	0.0225	0.3077	0.0300	0.1154	0.0112	0.0769	0.0075
Manufacturability	5.07%	0.2424	0.0123	0.2424	0.0123	0.3030	0.0154	0.1212	0.0061	0.0909	0.0046
Volume	4.06%	0.1944	0.0079	0.2222	0.0090	0.0556	0.0023	0.2500	0.0101	0.2778	0.0113
Mountability (External)	10.15%	0.2333	0.0237	0.2333	0.0237	0.3333	0.0338	0.1333	0.0135	0.0667	0.0068
Repariability	11.37%	0.2667	0.0303	0.2333	0.0265	0.3333	0.0379	0.1000	0.0114	0.0667	0.0076
Structural Integrity	14.85%	0.2308	0.0343	0.2564	0.0381	0.1026	0.0152	0.1538	0.0228	0.2564	0.0381
Aesthetic	3.18%	0.2500	0.2500	0.2667	0.2667	0.0667	0.0667	0.1667	0.1667	0.2000	0.2000
Sums			0.2480		0.2505		0.2402		0.1319		0.1293
Final Score			99.0		100.0		95.9		52.7		51.6

Table 2, Housing Decision Matrix by Kevin Yazon

With the TFB architecture defined, Crush Depth began to design its physical structure using the 30.48-cm (12-inch-long) tube used in previous years. However, once the full TFB stack of ESCs, buck converters, and logic boards across three drawers was laid out, it became clear that 30.48 centimeters (12 inches) wouldn't fit the assembly. The team upgraded to a 38.10-cm (15-inch) length while deliberately preserving the 15.24-cm (6-inch) inner diameter, which kept the chassis mounting interface, end-cap tooling, and external geometry untouched. This avoided a cascading redesign of the frame and was a deliberate trade between added internal volume (+25% length) and zero impact on the rest of the vehicle.

Chassis

The chassis was designed around the 15.25-cm (6”) tube that serves as the waterproof housing for the ROV’s electronics. Most of the structural components were 3D-modeled and 3D-printed in-house due to the accessibility, **rapid prototyping** capabilities, and strength that additive manufacturing provides. While the previous year's design served as inspiration, major changes were implemented to improve durability and serviceability. One of the largest issues with the previous chassis was that removing a single chassis ring required nearly complete disassembly of the ROV's base.

To address this, the new chassis rings were redesigned to encompass surrounding components in a way that allows for easier **independent removal**. A closing mechanism was also integrated into the rings to retain hardware during disassembly, reducing the likelihood of lost fasteners and significantly speeding up maintenance and repairs. Design decisions were validated through a combination of finite element analysis (FEA), flow simulations, and real-world testing. FEA simulations were used to identify structural weak points and optimize component strength, while flow simulations were used to evaluate thruster placement and overall hydrodynamic performance. Physical testing was then used to verify simulation results and refine the final design.

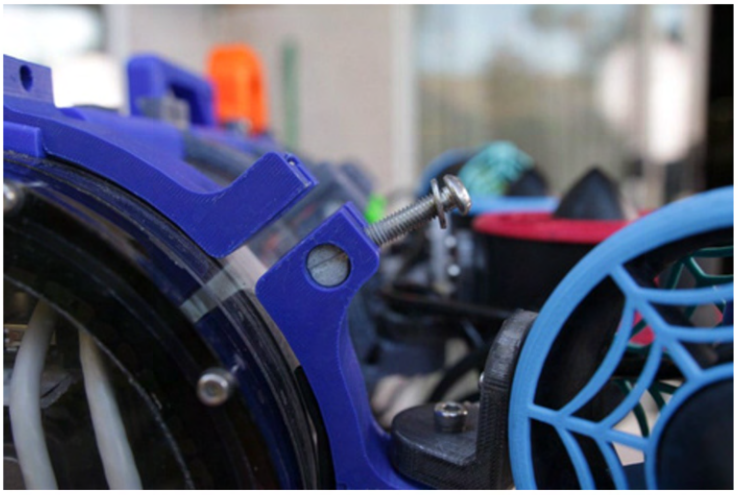


Figure 7, Unlatched Chassis Ring by Emily Brereton



Figure 8, Latched Chassis Ring by Emily Brereton

Modular Mounts

When designing the thruster mounts, several options were considered and ultimately narrowed to three based on **adjustability, compatibility, cost, ease of assembly, manufacturability, and structural integrity**. The first option was a ball mount, which offered high adjustability but relied on friction, making it prone to misalignment and difficult to accurately record or repeat a specific thruster configuration; it also included multiple small, fragile parts. The second option drew inspiration from last year's design, using notches for alignment and repositioning to easily set the thruster at specific angles, though the geometry made it difficult to remove supports and required significant sanding and post-processing despite added print tolerances. The third and final design preserved the strength and alignment of the notched approach while interlocking with a gear-like extrusion, eliminating the small angles that complicated support removal and making the part far more practical to

manufacture via 3D printing.

The **Picatinny rail system** was evaluated in an AHP report, along with other options, for its **repairability, mountability, and repeatability**. This system is mainly used in the defense industry, which Crush Depth observed and adapted to our mounting needs. It **securely mounts our two manipulators, camera system, and** sonar sensor to the ROV. The ease that this system brought to the table was hard to ignore and became a deciding factor in our decision to use it. The simple sliding nature of the rail is **user-friendly and makes repairs effortless**.

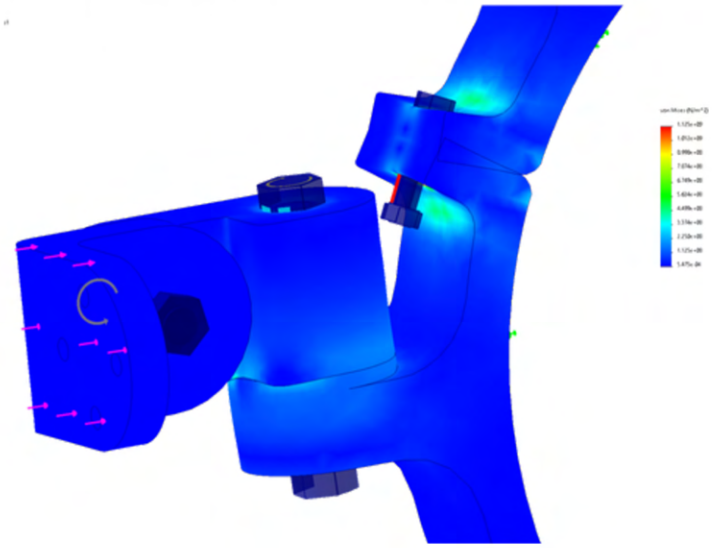


Figure 9 FEA Simulation by Aaron Pruett

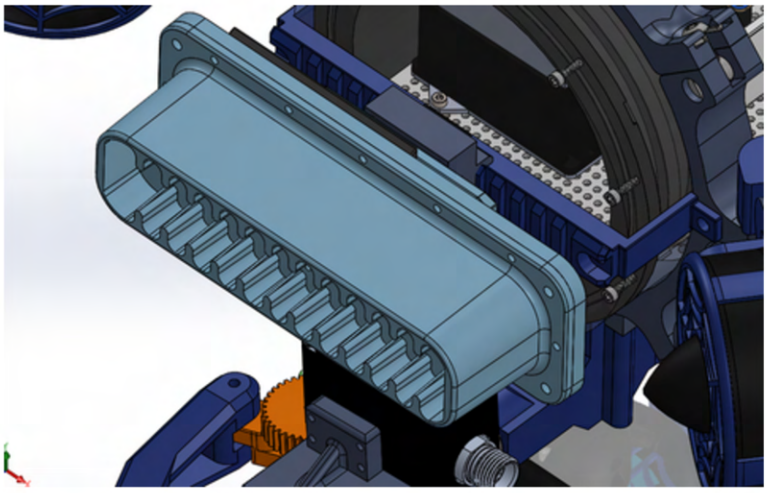


Figure 10, Omniscan Sonar Mounted by Luke Salazar

Electrical System

The electrical system was designed with functional separation in mind, organizing each subsystem onto a **dedicated layer** to improve clarity of the electrical mapping and make it easier to identify components, trace connections, and troubleshoot the system.

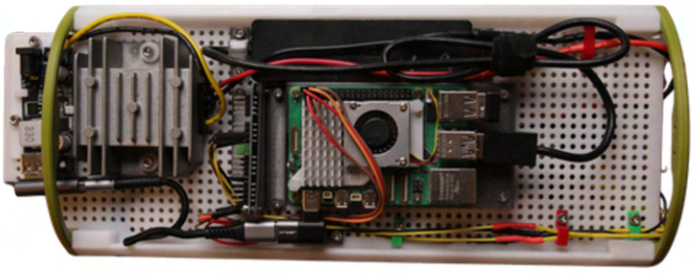


Figure 11, Electrical Layer 1 by Emily Brereton

The top layer houses the logic subsystem**,** the Raspberry Pi 5, the PCA9685 PWM driver, the MPU-6050 gyroscope, the BAR02 pressure sensor, an I^2C bus-sharing board, a USB hub, the 48 V to 12 V at 5 A that supplies power to the 12 V to 5 V at 5 A buck converter that supplies the Pi. Placing the logic subsystem on top simplifies access during operation and testing. The PCA9685 is mounted vertically on a custom 3D-printed bracket adjacent to the Pi, providing clearance for the thicker multicore wiring that connects its PWM outputs to the ESC signal lines below. The MPU-6050 and BAR02 (used for depth and station-keeping feedback, and not currently shown) sit next to the PCA9685 to minimize I^2C bus length. All three devices share the bus via a dedicated SDA/SCL-sharing board that fans the Pi's GPIO 2/3 lines out to each device without daisy-chained solder splices. The vehicle's five cameras connect through the USB hub mounted on this layer.

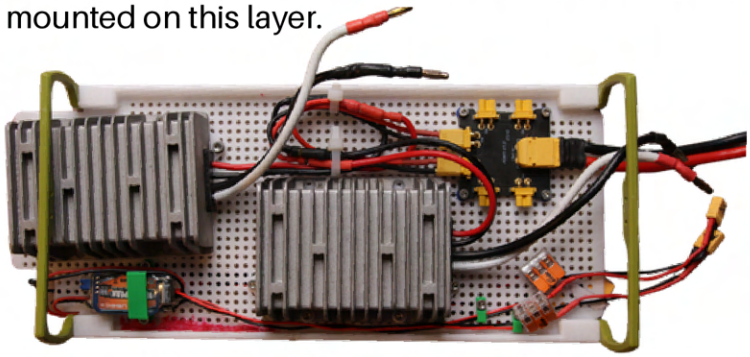


Figure 12, Electrical Layer 2 by Emily Brereton

The secondary layer is the primary layer for power conversion and distribution. It houses the main 48 V power distribution board (PDB), both high-current 48 V to 12 V at 40 A buck converters, each paired with a

bank of **three 1000 µF electrolytic capacitors** mounted on the **12 V output** side to absorb voltage transients caused by the ESCs' switching loads and protect the converters from reflected ripple (not currently shown), and two UBECs that step 12 V down to 6 V for the primary manipulator's servos (8 A for the Blue Trail gripper, 6 A for the MS825 wrist). The vehicle is powered by a **48 V, 30 A surface-side DC** supply that feeds the main distribution board through a **30 A fuse**, sized to the calculated full-load amperage of **26.25 A**, with no voltage conversion occurring topside, per ELEC-003E and ELEC-005E. Buck converter loads are split by function: BC1 supplies the four horizontal thrusters (forward/back and side-to-side movement plus yaw) and both UBECs. BC2 supplies the four vertical thrusters (up/down movement plus pitch and roll) and the ninth ESC driving the brushless motor on the rotating end effector used for Task 2.5 biofouling removal. This allocation balances the load between converters and keeps each manipulator's power path co-located with its mechanically related thruster group.

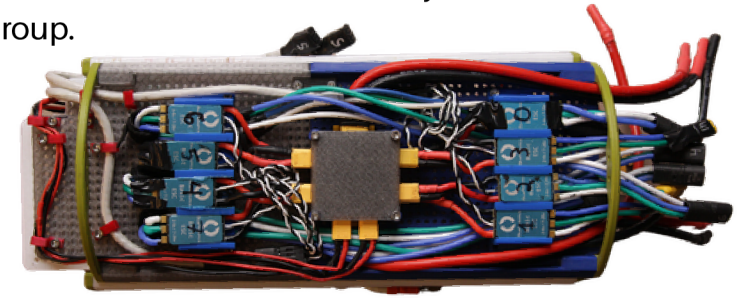


Figure 13, Electrical Layer 3 by Emily Brereton

The third layer carries the ESCs, the manipulator circuitry, and the two ESC-side PDB's that receive 12 V from the secondary-layer buck converters and fan it out to the appropriate ESC groups. The nine ESCs are arranged horizontally, with eight thruster ESCs in two rows of four, and the ninth ESC for the rotating end effector at the rear (mount fabricated, not currently shown), all of which are laid flat with heat sinks facing upward to maximize convective cooling. Each ESC sits in an elevated, **custom 3D-printed holder** with deliberate spacing to route the seven wires per ESC (three motor phases, power and ground, signal and ground) cleanly along the layer surface. Each ESC PDB is positioned adjacent to its ESC group to minimize the 12 V run length and voltage drop under load. The side-by-side, heat-sink-up arrangement creates a modular layout that simplifies maintenance and keeps each ESC physically close to its corresponding thruster connection. A threaded mounting grid secures components and wiring across all three layers, and custom 3D-printed wire holders route cables along the layer surfaces to minimize movement and mechanical strain on solder pads. A section of the housing's "ducktail" was removed to accommodate the multicore tether's bend radius without forcing a tight bend at the housing entry.

The **Raspberry Pi 5** communicates with the PCA9685, MPU-6050, and BAR02 over a shared I^2C bus on GPIO 2 (SDA) and GPIO 3 (SCL), routed through the SDA/SCL sharing board. The PCA9685's logic VCC ties to the Pi's 3.3 V rail to keep SDA/SCL at a uniform 3.3 V and protect the Pi's non-5 V-tolerant GPIO, while its V+ output rail remains at 5 V for reliable ESC triggering. The PCA9685's eleven active PWM channels drive nine ESCs and two servos: ESC signal lines route from the third layer up to the top layer through two custom inter-layer harnesses repurposed from Cat 6 Ethernet cable, with each harness carrying signal and ground for four ESCs and using the twisted-pair geometry to suppress crosstalk between adjacent PWM channels; the two servo lines run as 22 AWG stranded hookup wire directly from the PCA9685 to the manipulator backplate, with their signal grounds bonded to power ground at the second layer through a **Wago lever-nut connector**. Power and signal wiring follow separate routing paths through the layer stack where practical, with twisted-pair geometry providing primary EMI mitigation where physical separation is incomplete.

Backplate

For the 2026 competition season, Crush Depth **redesigned** the watertight housing's aluminum backplate to serve as a **high-efficiency interface** for power and signal distribution. The updated bulkhead accommodates an increased number of subsea penetrators, establishing short, direct wiring paths from the surface tether to designated power and Ethernet terminals inside the electronics chassis. This geometric optimization **prevents crosstalk** and **reduces wire management** complexity between the.

logic bays, internal ESCs, external thrusters, and peripheral camera networks, all connected via a series of XT60, XT30, and MT60 connectors. Reflecting our commitment to material reliability, the component was fabricated locally from aluminum and treated with a protective **anodized** finish. This chemical modification acts as a passive barrier against localized pitting and corrosion, ensuring robust sealing performance throughout all saltwater product demonstration tasks.

For the 2026 campaign, Crush Depth phased out the use of commercial **WetLink** penetrators in favor of potted penetrators for all new waterproof cable pass throughs. Previous performance revealed consistent water leakage into the electronics housing linked to poor assembly, maintenance, and manufacturer defects of the WetLink hardware. To build a more reliable barrier against pressure failure, the team drafted and enforced the CDP_02-Potting Penetrator Procedure. This protocol mandates proper surface prepping, uniform material mixing, curing times, and inspection guidelines, ensuring that any technician performing pass-through maintenance achieves a reliable seal.

For testing, Crush Depth designed penetrator blanks for the custom backplate. The blanks were manufactured locally using Multi Jet Fusion (MJF) in PA12S Nylon. This allowed for components of the ROV to be tested without needing the full ROV assembled.

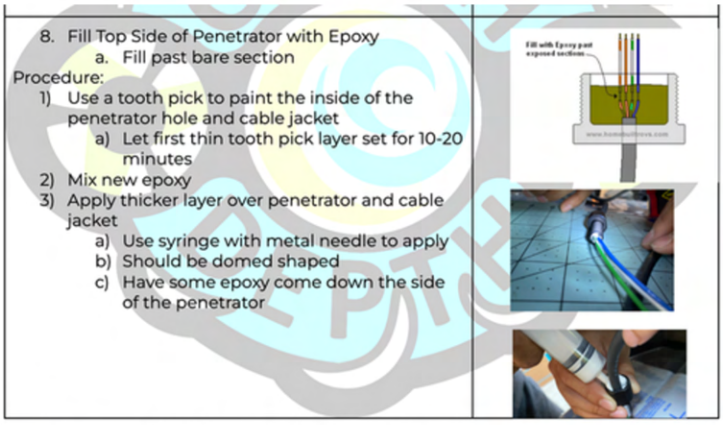


Figure 14, Step 8 CDP_02-Potting Penetrator

Tether

To maximize fiscal resources for the 2026 competition season, Crush Depth elected to reuse the tether from our previous two competition seasons. The tether uses **12 AWG landscape lighting wire** to handle power delivery. Telemetry and data transmission are transmitted through a single length Cat 6 Ethernet cable, chosen for its twisted-pair shielding that effectively dampens electromagnetic interference. To offset the material density of these conductors a 1.27 cm (0.5-inch) foam rope is run continuously alongside the lines. The entire tether is enclosed within 1.27 cm (0.5-inch) thin mesh wire sheathing. To significantly improve field serviceability and meet international transportation requirements for the World Championship in Canada, Crush Depth redesigned the system's **connectivity**. The company integrated Subconn wet-mateable connectors, establishing a highly reliable, quick-disconnect interface at the housing backplate. By reducing the overall number of backplate penetrators and connectors that far exceed competition depth specs, Crush Depth drastically minimized potential water ingress points while streamlining pre- and post-launch vehicle handling.

Tether Management Protocol
Before ROV Deployment
Inspect Tether for any Damage
Follow CDP_12-Tether Connector Attachment
Follow CDP_11-Tether Strain Relief Attachment
Tether is connected to the surface side strain relief, then 48V power, then router
Strain relief is tested on both surface side and ROV side
Power on and ensure stable connection
ROV in Water
One poolside employee controls tether deployment in pool
Pilot works with employee to ensure proper deployment
Removal of ROV
Follow CDP_11-Tether Strain Relief Attachment to remove strain relief
Follow CDP_12-Tether Connector Attachment
Cap male and female connectors
Dry Tether
Rewind tether using velcro straps

Table 3, Tether Management by Luke Salazar

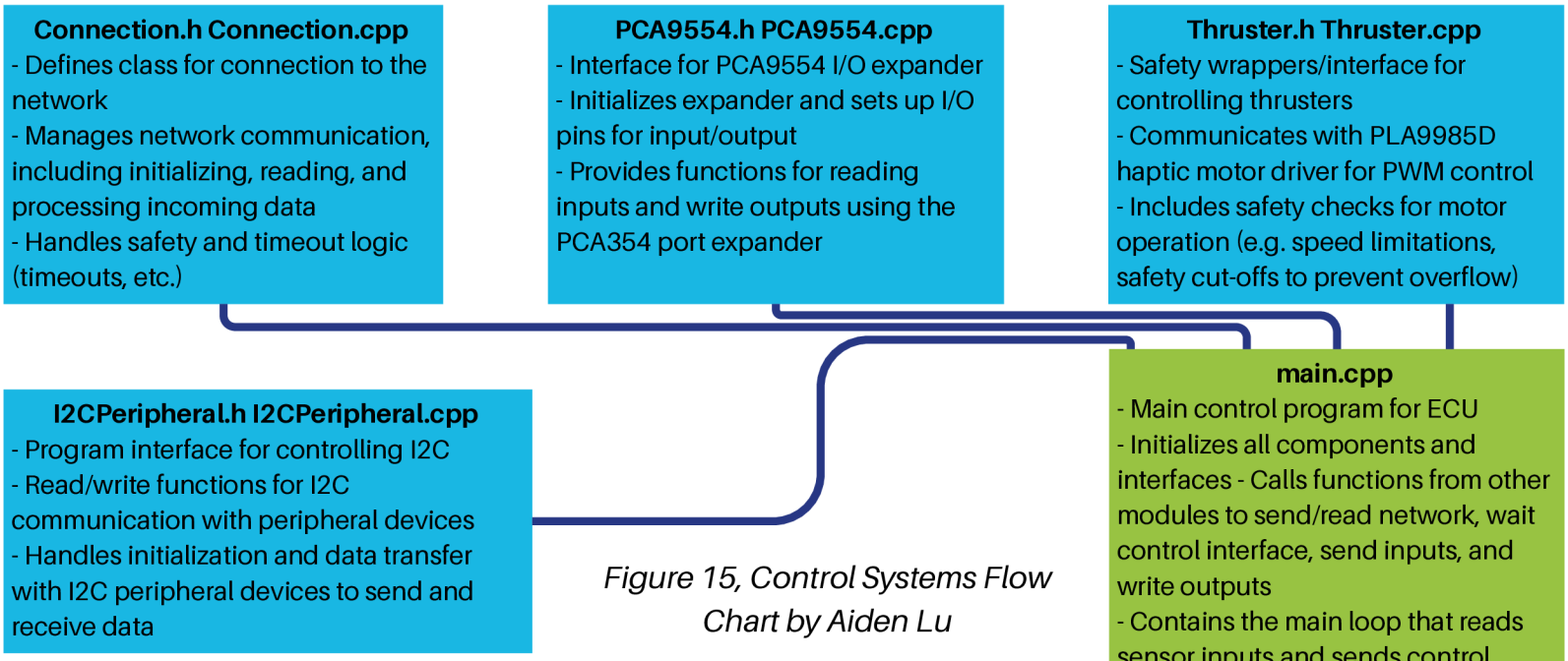


Figure 15, Control Systems Flow Chart by Aiden Lu

Control System

The control system spans **three coordinated subsystems**: a Python surface application, a multithreaded C++ program on the Raspberry Pi, and a PCA9685 PWM driver, which are linked by UDP over Ethernet and I^2C onboard (Figure 9).

Architecture and Rationale

Crush Depth's control system requirements were determined by analyzing this year's mission tasks against last year's code base and incorporating feedback from the pilot. The task analysis established the baseline hardware interface, which includes **eight thrusters** for navigation, a **two-degree-of-rotation manipulator**, and a **rotating end effector** for biofouling removal, while pilot input drove operator-facing features such as **slow mode** (a 35% thruster output cap requested for fine control during precision tasks) and the **Auto-Leveling System**. Requirements were verified through iterative pool testing of the actual mission tasks, with adjustments made as the pilot identified gaps or requested refinements during practice runs.

The surface application runs on an operator's **Windows laptop** and reads **two Xbox controllers** via PyGame. **Python** was chosen because the workload is I/O-bound rather than compute-bound, and faster iteration during pre-competition testing outweighed any execution-speed advantage of C++. A startup verification routine confirms that both controllers are connected before initialization to prevent partially configured input states. Processed inputs are packed into a **13-value UDP datagram** and transmitted at 20 Hz to the Pi. UDP was selected over TCP because real-time control prioritizes the freshness of the latest packet over guaranteed delivery: a dropped TCP packet triggers retransmission of stale input, whereas a dropped UDP packet is superseded by the next one 50 ms later. The downside of this was the acceptance of transient input loss, but it is mitigated by stale-packet detection on the receiving end.

The Pi runs a **multithreaded C++ program**. A listener thread receives and timestamps incoming packets while a control thread runs the primary loop at 20 Hz. Each cycle verifies that a valid packet arrived within the previous 250 ms. If communication is lost, all thrusters stop and servos return to neutral, preventing the ROV from acting on outdated commands.

The most significant redesign this season was the thruster mixing system. Last year's **Auto-Leveling System** (ALS) used the **Eigen linear algebra library** to compute yaw, pitch, and roll corrections through matrix operations. The Eigen dependency was added

compile-time complexity that wasn't justified by the math involved, so thruster mixing was rewritten as **direct arithmetic**, and each of the eight thrusters has its output calculated by adding and subtracting movement axes based on its physical placement. The ALS was retained as a discrete subsystem and now runs on a **PID controller** that applies **yaw**, **pitch**, and **roll corrections** to the mixer output when leveling is enabled. The result is faster compilation, more readable code, and the elimination of a dependency that previously caused build failures. The third subsystem, **the PCA9685**, generates all eleven PWM signals over I^2C, freeing the Pi's main loop from timing-sensitive output work.

Integration With Other Subsystems

The control software is parameterized by decisions made across Crush Depth. The thruster mixer's coefficients come directly from the propulsion team's SolidWorks flow simulations, where changing thruster placement requires only a coefficient update, not a code rewrite. The **MPU-6050** gyroscope, shared over the I^2C bus, feeds the **ALS PID loop**. The manipulator team's swappable BLDC end effector was accommodated by adding one ESC channel under the existing Thruster safety wrappers, requiring no changes to networking or mixing code.

Operator-Performace Features

Several features target pilot performance directly. **Analog deadzones** eliminate involuntary stick drift, **exponential smoothing** damps abrupt inputs for fine manipulator work, and **three-tier dynamic speed scaling** lets the pilot trade top speed for precision on demand, with full speed for transit, reduced for approach, and fine control for docking.

The most impactful operator-performance feature is **P.O.P.P.A.** (Pilot Optimization Program for Performance Advancement), a C++ tool that replaces intuition-based mission planning with a data-driven ordering. P.O.P.P.A. uses the pilot's task completion times and computes a points-per-second value for every mission task, then models the mission as a weighted directed graph: vertices carry the points per second values derived from the pilot's data, and edges hold the average travel time between task locations measured from points-awarded to next-prop-contact. P.O.P.P.A. searches the graph for the task orderings that maximize points within the 15-minute mission budget for each major task, and its respective subtasks, then returns the top five. This gives pilots a **primary run plan** and **four pre-considered alternatives** if a task fails. The tool also doubles as a training diagnostic, the tasks with consistently low points-per-second values flag where practice time and ROV modifications should be focused.

Development and Testing

Code is version-controlled through GitHub, with the laptop pushing commits and the Pi pulling over SSH. This ensures the deployment environment always matches what was committed, eliminating the manual-copy mismatches that caused 2025 deployment failures. Each module was tested independently before integration. A **packet-loss simulator** validated the stale-packet detector triggered within its 250-ms window. The **Thruster safety wrappers** were verified by commanding deliberately out-of-range PWM values and confirming cutoffs engaged before the signal reached the ESC. The thruster mixer was validated in two stages: **hand-calculated expected values** were compared against the arithmetic output on the laptop, and then the same inputs were replayed on the assembled ROV on a dry test stand while a logic analyzer captured and confirmed correct PWM on every ESC channel. Pool integration logs input latency, packet age, and ALS correction magnitudes to CSV, which our pilots, Daniel Larralde and Kevin Yazon, used alongside P.O.P.P.A. data to tune deadzone thresholds, smoothing constants, and PID gains.

Advantages and Limitations

The **Python-surface / C++-embedded split** lets each side use the language best suited to its workload, with UDP forming a clean boundary either side can be rewritten behind. Direct-arithmetic mixing eliminated a class of build issues without sacrificing functionality, and the modular configuration section allows any subset of hardware to be bench-tested in isolation, dramatically shortening debug cycles.

However, this architecture has known limits. The 250-ms stale-packet window is conservative the pilots will notice a perceptible pause before recovery on a

congested network. The control loop runs at a fixed 20 Hz, which is adequate for the current mission set but a ceiling if ALS gains are tuned more aggressively. The system also has no in-loop telemetry back to the surface. The pilot sees video and GUI status but not live thruster current or gyroscope readings, which would aid mid-run diagnostics. A second UDP channel for telemetry is on the backlog for next season.

Surface Side

In addition to the embedded control architecture, the project included developing a comprehensive graphical user interface (GUI) built with the Qt Framework in C++ and QML. QML, a declarative user interface markup language, was used alongside C++ to create a **responsive, modular user interface**. Choosing C++ over Python limited access to commonly used data analysis and plotting libraries such as pandas and matplotlib, but provided **significantly improved memory management and execution efficiency**. Consequently, nearly all integrated functionality—including graphs, plots, interface elements, and

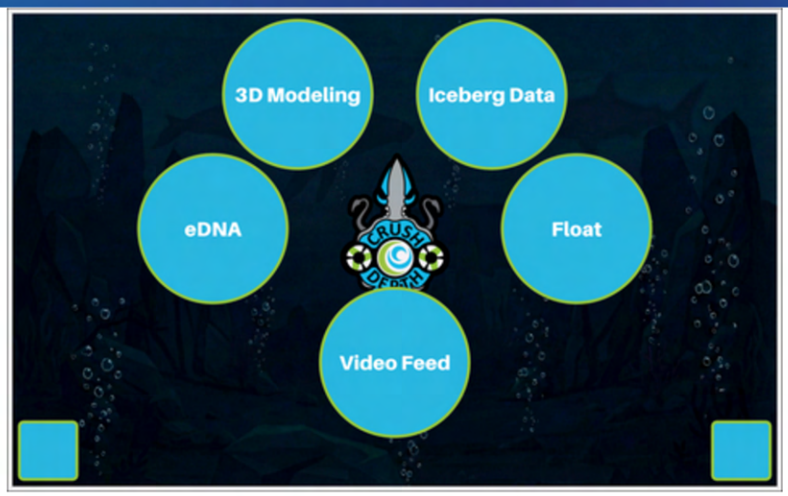


Figure 16, Graphic Interface by Justin Lu

rendering systems—was implemented using native Qt libraries and tools. The GUI was developed primarily within **Qt Creator**, which offered extensive integration with the Qt ecosystem as well as strong support for cross-platform compilation. This enabled the application to be packaged and deployed on the three primary desktop operating systems: Windows, Linux, and macOS. Camera feeds and image recognition functionality within the GUI were implemented using **OpenCV** in combination with Qt's

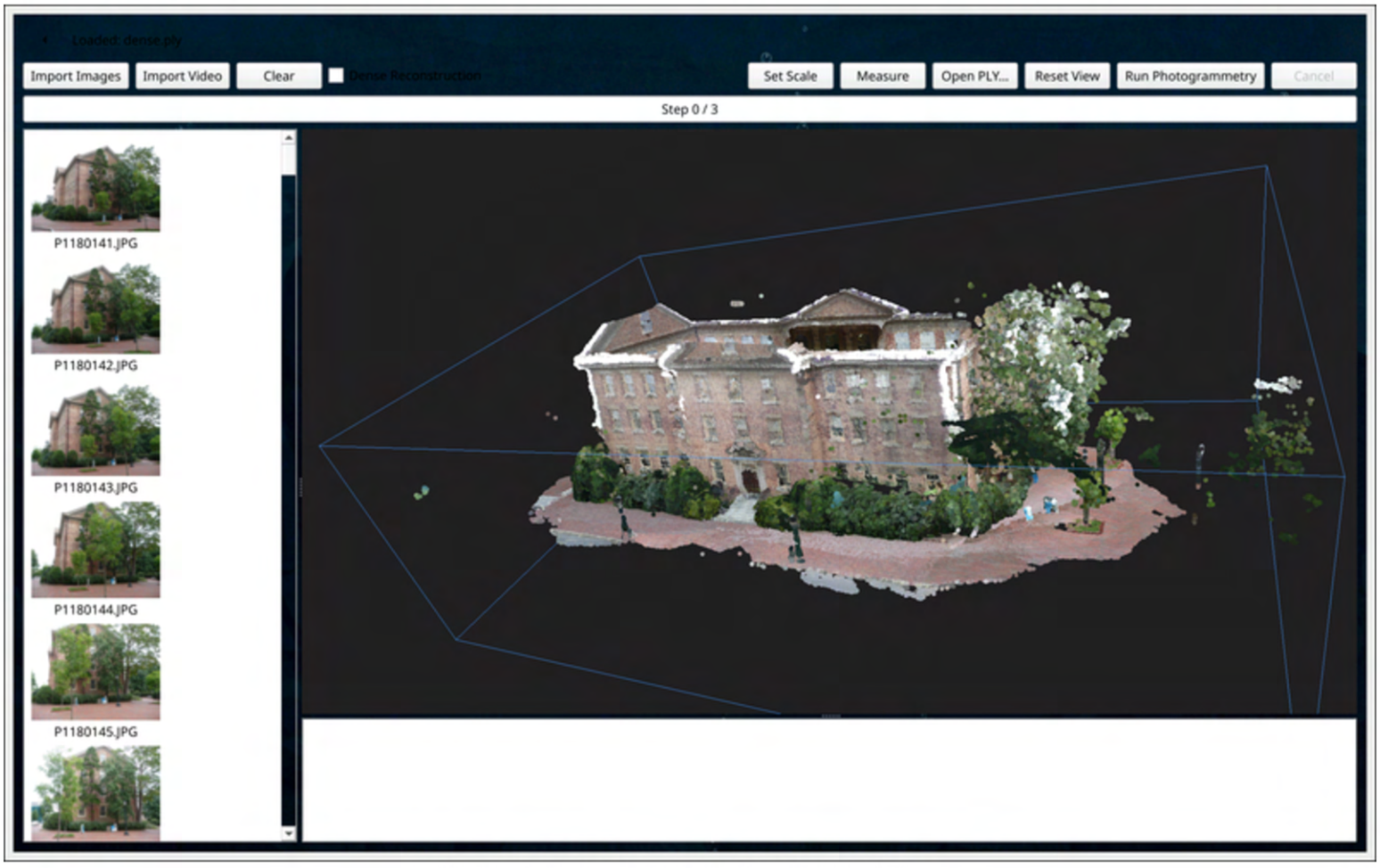


Figure 17, Photogrammetry by Justin Lu

built-in video libraries. The live camera streams were transmitted from the Raspberry Pi 5 over SSH and displayed directly within the interface.

Photogrammetry and 3D reconstruction functionality were also integrated into the GUI through embedded implementations of **COLMAP** and **OpenMVS**. COLMAP, an open-source structure-from-motion software suite, enabled image-based model generation directly within the application, while OpenMVS provided dense reconstruction capabilities for generating detailed 3D meshes. Embedding these tools into the GUI eliminated the need for external software workflows and created a **unified operating environment for vehicle control, visualization, image processing, and reconstruction tasks**.

Propulsion

GKAlloy uses eight Blue Robotics T200 thrusters arranged in a four-vertical, four-horizontal (4V+4H) configuration. The thruster model, count, layout, and vertical mounting height were each justified through a formal trade study and documented operational experience from the prior season.

Thruster selection was determined by an AHP-based trade study evaluating six candidates: the Blue Robotics T200 and T500, the ApisQueen U10, U2, and MU7, and the Diamond Dynamics TD1.2. The T200 emerged as the clear winner on the strength of its 8.69 kg/kg thrust-to-weight ratio, the highest of any candidate at 12 V, along with its 300 m depth rating, publicly available repair documentation, and compatibility with units already owned from prior seasons. Reusing existing T200's freed Crush Depth's limited budget to focus on travel and other components. **Thruster count** was set at eight rather than six (vectored) for four converging reasons: redundancy, simpler direct-arithmetic thruster mixing (versus the matrix algebra required by a vectored layout), higher per-axis thrust margin for the Auto-Leveling System, and headroom within the available power budget. The redundancy argument was validated during 2026 testing, when an ESC failure on a vertical thruster occurred with no spare available. The team disabled the affected thruster along with its diagonal counterpart and completed the test run without losing significant control over the ROV, a recovery capability that a six-thruster vectored layout cannot match.

Vertical mounting height was the open design question after the 4V+4H layout was retained from the 2025 season. Continuing its AHP-based methodology, Crush Depth evaluated top, middle, and bottom positions against three criteria: stability, flow efficiency, and impact protection, using SolidWorks CAD models and CFD simulations (Figure 20). The top configuration (Figure 19) was selected, winning decisively on flow efficiency and impact protection. The middle configuration (Figure 18) scored higher on stability, but the team prioritized close-quarters operational concerns relevant to the coral garden (Task 1.3) and the oil platform (Task 3).

Power management balances the T200's 17 A peak draw against converter capacity. Eight unrestricted thrusters at full reverse would theoretically demand ~136 A, which is well above the 80 A combined output of the two 40 A buck converters. Three-layered software caps prevent this from occurring: PWM signals are hard-limited at 1228/1772 (capping each thruster at ~7 A), thruster outputs are scaled to 85% post-mixer, and controller inputs are scaled to 75% pre-mixer. Realistic peak draw is ~56 A, leaving ~24 A of converter headroom.

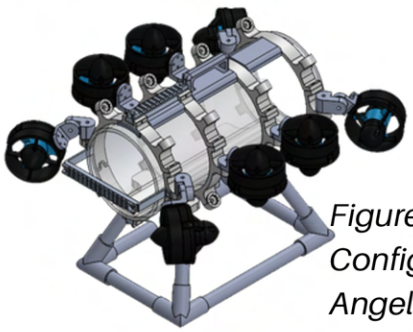


Figure 18, Bottom Config by Angel Avalos

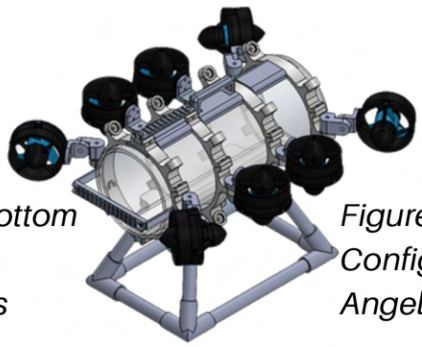


Figure 19, Middle Config by Angel Avalos

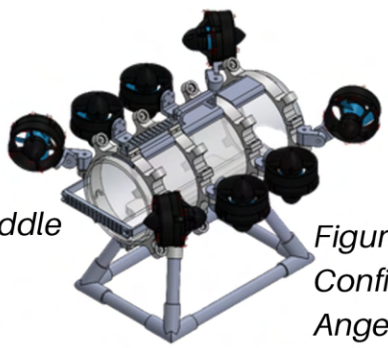


Figure 20, Top Config by Angel Avalos

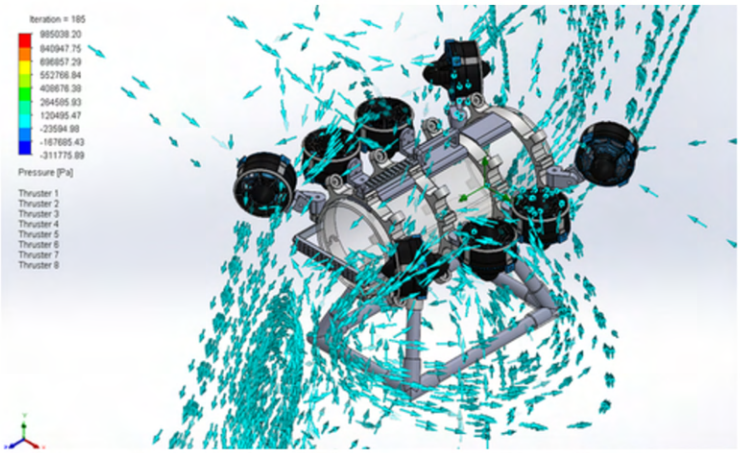


Figure 21, Flow Simulation by Domer Macarine

Buoyancy and Ballast

GKAlloy is tuned to slight **negative buoyancy** with a small **forward pitch**. Negative buoyancy was preferred over true neutral so that pilots can work close to the pool floor without active station-keeping, and the slight forward pitch was tuned in to give the front-mounted manipulators a natural working orientation for **sample retrieval** and **Task 1.3 close-quarters operations.**

GKAlloy's dry mass in air is **27.2 kg**, measured on a digital scale with the tether disconnected. Displaced volume was measured directly using water displacement after being estimated from CAD, yielding approximately 30.159 L. At freshwater density (1000 kg/m^3), this displacement produces a buoyant force of 295.9 N against the vehicle's 266.8 N dry weight — a net positive buoyancy of 29.1 N, equivalent to approximately 3 kg of ballast required to reach neutral. The dominant contribution to displacement is the air-filled electronics housing: a 38.10-cm x 15.24-cm (15-inch × 6-inch) inner-diameter acrylic tube displacing roughly 7 L on its own, with the remaining ~23 L distributed across the chassis structure, thrusters, manipulators, and foam elements.

Traditional buoyancy materials, such as pool noodles, were replaced with a more modular solution consisting of closed-cell printed foaming TPU. The TPU was selected for two reasons: it prints to custom geometries that conform around the thruster shrouds, and it is impact-resistant enough to double as an external bumper protecting the chassis and thrusters during poolside handling. The foam's net buoyancy contribution depends on the as-printed bulk density, which is governed by infill pattern, infill percentage, and print temperature, as TPU Air's foaming behavior is temperature-activated.

Initial water testing also revealed a rearward pitch caused by the concentration of dense electrical components (buck converters, ESCs, PDBs, capacitors) in the rear section of the housing. The team corrected this by adding 2-3 oz lead disk weights to the forward chassis ring to maximize the lever arm at GKAlloy's center of gravity, ultimately reducing the amount of ballast needed. Ballast was then set to dial in a small forward pitch to increase manipulator utility during mission tasks.

Payload and Tools

Manipulators

At the beginning of the season, the official mission tasks had not yet been released, so the manipulator team focused on developing **versatile tooling solutions** that could address a **broad range of potential objectives**. The team began by evaluating manipulator concepts that had proven effective in previous competition seasons and ultimately identified a **two-degree-of-freedom claw** (**Figure 21**) as the most practical starting point for a generalized end effector.

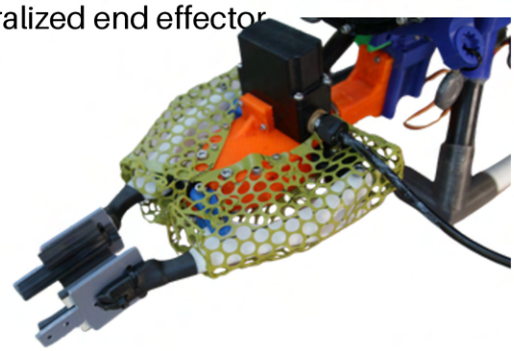


Figure 22, Final Manipulator by Emily Brereton

Several design iterations and prototypes were developed and tested throughout the early stages of the design process (Table 4). After evaluating multiple concepts, the team concluded that a **four-bar linkage parallel gripper** provided the best balance of simplicity, reliability, and adaptability for most anticipated tasks. Once this design was selected, the team focused on optimizing the gripper to increase its effectiveness across a wider range of mission scenarios.

One improvement involved **incorporating circular cutouts** into the interior gripper surfaces to **increase contact area** and **improve grip stability** on cylindrical PVC-based objects, which are frequently used throughout competition tasks. Another refinement introduced a **secondary cutout feature** that allowed rope manipulation without requiring the gripper jaws to fully close. This **hook-like geometry** significantly increased the **versatility** of the primary claw and provided an **efficient** method for completing rope-related operations, including Task 2.5, which involved connecting the sensor to the Holyrood subsea observatory. This manipulator can also accomplish tasks such as Task 1.1 to grab the basket star and corral retrieval, Task 2.3 lobster pot manipulation, Task 2.4 buoy U-bolt line collection, and Task 3.2 power connector and cover removal, to achieve continuous 360-degree rotational capability However, as the team evaluated motor selection, mechanical integration, and the additional complexity required to implement a fully rotating manipulator, it became evident that this approach would introduce unnecessary design constraints and reduce overall system simplicity. As a result, the team decided to transition away from integrating rotational capability into the primary claw and instead pursued the development of a dedicated, task-specific tool that could be rapidly swapped onto the ROV when required. This decision simplified the design of the primary manipulator while also providing greater flexibility for solving the unique requirements of Task 2.5. After extensive collaborative brainstorming and concept evaluation, the team selected a specialized rotating end effector design. The final concept consisted of a custom “Lego Hand” attachment mounted to a 15:1 bespoke cycloidal drive and brushless DC (BLDC) motor, enabling controlled rotational motion specifically intended to complete the sensor connection task. The wide legs make the pilot's job easier by providing a larger area to connect to the sensor port. It will also accomplish the three continuous revolutions with ease, as the BLDC is the chosen actuator for this specialized manipulator (Figure 22).

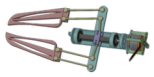
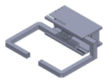
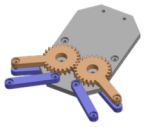
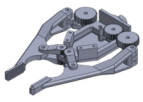
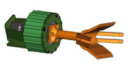
Prototype Image	Description
	***Purple Nurple*** Designed to complete a majority of tasks. With these two degrees of freedom, a four-bar linkage system. It has a spur gear pattern on the inside of the motor gear for easier modularity with a gearbox.
	***Silly Goose*** A linear actuator originally intended to be the main end effector. The problem Crush Depth experienced with this design was the cost of producing or pre-manufacturing the coupling and linear actuator system. These traits were deal-breakers for us based on our trade study examining prototypes.
	***Warm Hug*** Rack-and-pinion prototype to experiment with the famous mechanical system and assess compatibility with the competition. I wanted to try out this prototype with the props that involved rope.
	***Big Burtha*** Five to one stackable gearbox. Originally designed with the intention to mechanically slow down the BLDC's Crush Depth, would combine with any manipulator design that proved it necessary.
	***Golden Gear Lollypops*** This is the base of a different four bar linkage system that has more mounting space on the midplate towards the back. This did not get developed any further due to this category being oversaturated and needing hands-on experience with other mechanical systems.
	***Millennium Falcon*** This was the first iteration of the *Ozempified grippa* below. After Crush Depth assembled the first print, Crush Depth realized there was a lot of excess mass. Which Crush Depth ditched, and now it is our current universal manipulator.
	***Ozempified Grippa*** This is our finalversion of our team's Universal Manipulator. It is a parallel gripper with two degrees of freedom and four spur gears in series. Designed to complete a majority of the tasks this year.
	***Mordicai*** This is a three-fingered worm gear prototype that has three helical gears to match the threading of the 3D printed worm gear. This design faded out due to poor competition integration.
	***Lego hand*** This is a specially designed manipulator attachment, cycloidal gear box combo, to smash task 2.5. It is powered by a low-kV BLDC, which gets slowed down by a 15:1-ratioed gearbox, which goes into the custom end effector.

Table 4, Manipulator Prototypes by Kendall Reagan

This modular approach allowed the team to maintain a reliable and universal primary manipulator while simultaneously developing a highly optimized solution for one of the competition's most challenging mission objectives.



Figure 23, Specialized End Effector by Emily Brereton

Cameras

Five cameras were selected and positioned (see Table 5) to provide pilots with **full situational awareness** across all mission tasks. The camera count was driven by the need to simultaneously support front-facing manipulation, downward transect flying, and rearward keel-depth positioning without forcing the pilot to reposition the ROV b

#	Position	Primary purpose	Tasks served
1	Front, Lower	Main view for primary four- bar gripper	1.1 species collection, 2.3 lobster pot, 2.4 U-bolt line, 2.5 eDNA sensor handling, 3.2 power connector and cover
2	Front, upper	Visibility on the rotating end- effector	2.5 sensor port connection, 2.5 biofouling rotation
3	Downward	Transect flying view	1.3 fly the transect over the corral garden
4	Port side (rear-view)	Reverse maneuvering and keel-depth positioning	2.2 iceberg keel depth
5	Starboard side (rear-view)	Reverse maneuvering and keel-depth positioning	3.2 iceberg keel depth

Table 5, Camera Configuration by Kendall Reagan

One **OpenMV camera** was integrated for onboard use, and the remaining four cameras were selected for their plug-and-play integration, wide field of view, and low integration overhead. To ensure reliable underwater operation, **custom waterproof housings** were designed and manufactured in-house using both FDM-printed covers and SLA-printed enclosures (Figure 23).



Figure 24, Camera Housing by Kevin Yazon

Sensors

A **Blue Robotics pressure sensor** (BAR02) was mounted on the rear backplate of the ROV to enable accurate keel-depth measurement for Task 2.2 (iceberg keel depth).

The rear-mounted position allows the pilot to reverse the ROV up to the iceberg's keel using the side-facing rear-view cameras (cameras 4 and 5) and read the depth directly, rather than approximating it from a front-facing approach.

A gyroscope was selected to support two functions. First, it provides **orientation tracking** for the Auto Leveling System (ALS). Second, it enables **level-flight stabilization** during Task 1.3, where the ROV must maintain a stable position above the coral garden while flying the transect.

For Task 2.1 (invasive species mitigation), no dedicated onboard vision sensor was required. Instead, the system uses surface-side software running OpenCV that analyzes the incoming camera streams in real time. With a single button press, the operator triggers detection and counting of European green crabs, supporting the image-recognition scoring path (15 points) rather than the manual count path (5 points).

Build vs Buy, New vs Used

Crush Depth prioritized designing and building in-house first, which drove decisions for the chassis and float systems. The backplate and the plugs for the backplate were designed in-house, but would cost thousands to manufacture, so instead, **outside companies were utilized** to take the designs and construct them out of house. Electrical components are complex but cheap, with a lot of different options available for companies to utilize. To seal the cameras and motors new penetrators and potted penetrator shells were purchased. To make transporting the ROV and tether easier, **new open faced connectors** for the Ethernet power were secured. A problem with last year's design was the buck converters and power distribution system, with everything stacked on one terminal it caused inconsistencies in current draw. To fix this issue a new power distribution boards were purchased and **a new system** was designed to distribute power effectively and safely. The housing tube from last year was 30.48 cm (12 in) in length, to better organize wires and keep the system clean a new 38.1 cm (15 in) housing tube was purchased. The diameter was not changed to save money on reusing endcaps and to prevent disrupting progress with the chassis and housing teams. ESCs, watertight encloses, end caps for housing, gyroscope, and thrusters from last year are all in top condition and were reused to help with costs.

Table 1 - Re-used (Purchased in Prior Years)

System	Decision	Justification	Mission Tie-in
Blue Robotics T200 Thrusters (x8)	Re-used	Industry-standard underwater thrusters with proven reliability across 3 seasons. No commercial alternative offers comparable thrust-to-cost ratio. Re-using avoids ~$1,840 in replacement cost and maintains tuned propulsion stack.	All RFP movement tasks. Maintains 6-DOF maneuverability required for shipwreck navigation and station-keeping.
Blue Robotics ESC's (x4)	Re-used	Designed to pair with T200s; re-using maintains thruster-ESC compatibility and avoids re-tuning the propulsion stack mid-season.	Propulsion control fidelity for fine-positioning during manipulation tasks.
Xbox Controller	Re-used	Familiar input device with proven ergonomics across 3 seasons of pilot training. No reliability or performance benefit to upgrading.	Pilot control interface for all RFP tasks; minimizes new-pilot ramp time.

Table 2 - Newly Purchased (Bought New This Season)

System	Decision	Justification	Mission Tie-in
Raspberry Pi 5 (16GB)	Buy	Upgraded from Pi 4 to handle simultaneous 4K camera streams, on-board ML inference, and the real-time control loop without overrun. Building an SBC in-house was rejected on schedule grounds - the Pi 5 ships with documented thermal headroom and Linux support.	Computer vision tasks and concurrent camera feeds required for shipwreck imaging.
ELP 16MP Wide-Angle USB Cameras (x5)	Buy	Specific FOV and resolution required for shipwreck imaging and manipulator alignment. Custom camera modules would have added months of waterproofing and optics work for no performance gain over a $67 commercial unit.	Visual feedback for piloting, manipulator alignment, and photogrammetry-style imaging tasks.
Blue Robotics Basic ESCs (x4)	Buy	Spare/redundant ESCs to support a new propulsion redundancy plan; identical to re-used units to keep all spares interchangeable.	Reliability margin during competition - swap-in spare without re-tuning the control stack.
Bar02 Depth/Pressure Sensor	Buy	Pre-calibrated, sealed sensor with documented 0-2 bar range. Building an in-house depth sensor would require pressure-vessel calibration time we do not have, and would introduce reliability risk on a critical telemetry input.	Depth feedback for autonomous station-keeping and depth-based mission tasks.
Pololu Step-Down Regulators (x10 total)	Buy	Off-the-shelf precision regulators with documented current ratings. In-house regulators would introduce reliability risk on critical 6V and 12V rails powering sensors and compute.	Stable power for compute, sensors, and servo logic across all RFP tasks.
SubConn / Blue Trail Subsea Connectors	Buy	Wet-mateable connectors rated for repeated dives. No reasonable in-house alternative exists; a failed seal floods the entire ROV pressure housing.	Reliable subsea electrical pass-throughs - prerequisite for every powered mission task.
ANNIMOS 35kg Brushless Servo	Buy	Cheap commercial servo for low-stakes manipulator actuation. Building an in-house actuator for this role would be over-engineering with no payoff.	Secondary manipulator actuation; non-critical-path mission tools.
Power Distribution Boards (PDB 60A XT30)	Buy	Off-the-shelf PDBs rated to 60A handle our thruster current distribution. Building from raw copper would have offered marginal weight savings at significant time cost.	Clean 12V distribution to all thrusters; supports propulsion uptime under full load.
Power Connectors (XT30/XT60/Banana/Anderson)	Buy	Standard hobby connectors with documented current ratings and broad team familiarity. In-house connector design is not a meaningful engineering exercise.	Modular, swappable power runs to all subsystems; speeds field repairs.

Table 6, Build Vs. Buy Table by Santino Gonzolas

Safety

Crush Depth upholds high safety standards for the MATE competition and beyond. The goal is not only to ensure team members are building and assembling the robot safely, but also to encourage a positive, evolving relationship with proper **industry standards** for the equipment used. Crush Depth prioritizes **member safety** first and has a designated **safety officer** to teach and implement the established **safety principles**. Unique to this competition season, Crush Depth decided not to dedicate a team to safety but to teach all members how to properly follow MATE requirements and maintain a **safety-first culture**. The team has significantly improved the safety equipment and protocols since the last competition season, reducing hazards associated with power tools and chemical substances and establishing more **club-specific documentation standards** for data testing and assembly.

Member Safety

To highlight Crush Depth's improved safety protocols, the CEOs and CSO have implemented a new system for using the company's equipment: all members who want to use Crush Depth tools must complete **mandatory training** and demonstrate to the CEOs and Safety Officer that they know how to use the equipment properly. One of the company's CEOs developed a **design manual** so members could learn to use this equipment on their own time. The system is very accessible to all members, with the data logs and training approval trackers stored in a spreadsheet within the team's collective cloud folder. Crush Depth also set aside part of the budget this year to purchase bulk safety glasses, gloves, and respirators for use when working with chemical substances and power tools. The required PPE and warning labels are documented in each procedural document, so when other members follow the build instructions without prior knowledge, the team can reduce the risk of injury by having these documented.

Equipment Safety

In addition to the mandatory training for members to use the team's equipment, the CTO developed an **electrical safety manual** for the entire club. This allows team members to familiarize themselves with electrical tools, such as soldering irons, and understand the safety risks before actually using them. Crush Depth also has a **power system safety check** before operations begin, which covers how to use power tools and set up the ROV's electrical components for testing. For the tasks of navigating around the coral garden and the transect, having the ROV thrusters shrouded in an IP-20 finger-guard (Figure 26) ensures that the propellers don't get caught on any loose props, damage them, or ingest any potential debris. Another design feature was changing the **backplate potting procedures** to prevent water from entering the ROV chamber if a cable jacket were punctured. Neon Green TPU bolt covers (Figure 25) ensured any exposed hardware could not become a sharp hazard.

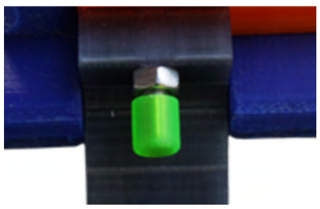


Figure 25, TPU Bolt Cover by Emily Brereton



Figure 26, IP-20 finger-guard by Emily Brereton

Operational Safety

With these precautions in place, Crush Depth also requires members to record all testing data in an organized document and have a special emphasis on safety warnings within the procedure. Team members have found that these procedures have significantly improved their productivity when testing the ROV because the information is readily available and presented in an easy-to-read format, so various teams can follow along. Crush Depth also follows a **Job Safety and Environment Analysis** (**JSEA**) document, which ensures the team understands the hazards and risks of operating the ROV.

Safety Checklist

Construction

General

- Complete the proper training through the club equipment training before use of club tools
- Wear the proper PPE required for the tool
- Inspect tools and machinery for quality check before use
- Turn off and unplug electrical equipment when not actively in use
- Any power tool that spreads dust or chemical gases should be used in a well-ventilated area
- Any electrical testing when power is on follows the one hand rule

Assembly

- Ensure work area is clear and dry when handling internal components
- Check o-ring seals for proper lubrication and ensure no cracks
- Loose wiring should be secured to the internal mountplate
- All electrical connections are properly fit
- Open and remove the pressure release valve before closing the backplate
- Screw the pressure release valve in **after** the ROV backplate has been closed
- Tighten any loose screws on the chassis

Operation

Set Up

- The pilot, tether management member, and surface side team lead are present to operate the ROV
- Physically and visually inspect the ROV for proper set up and any damage
- Look at circuit light indicators for any signal errors
- Clear poolside area of all stray equipment and debris
- Ensure the topside and ROV tether strain relief is secured
- Tether is neatly organized on poolside
- Power supply is away from water and is completely dry before powering on

Piloting

- All poolside members are wearing closed-toes shoes, have their hair secured back and have safety glasses if needed
- Surface side member receives cues from pilot to reach props in pool
- Surface side communicates "Ready" to pilot when to grab a prop entering the pool
- Control systems lead is communicating to surface side and pilot instructions and data

Take Down

- Surface side member removes ROV from pool upon pilot's instruction
- Remote controls are set down and power is turned off from the power supply by Control Systems lead
- Visually inspect ROV for damage
- Tether is gathered and stored neatly

Table 7, Safety Checklist by Julia Taylor

Critical Analysis

Testing and Troubleshooting

Our team employed a **comprehensive testing** and **troubleshooting methodology** in which each subsystem was independently evaluated before full vehicle integration. Mechanical components were first prototyped using 3D printing, often by producing scaled or partial sections of larger parts to evaluate **tolerancing, structural strength,** and **print orientation** before manufacturing final components. FEA and flow simulations in SolidWorks were used extensively to validate chassis performance, optimize structural integrity, and enable iterative design modifications without requiring a complete vehicle redesign. Because the vehicle was designed in a **highly modular** way, individual systems could be modified, tested, and replaced independently, improving efficiency during development. Manipulator systems were digitally modeled and physically prototyped to evaluate functionality, compatibility with surrounding systems, and overall effectiveness before final integration.

Waterproofing was validated through a staged submersion protocol: **housings**, **cameras**, and **sealed electronic compartments were tested empty at ~1.8 m** (**6 ft**) **depth for 10-, 20-**, and 30-minute intervals, with each duration required to pass before electronics were installed and connected. This progression prevented costly damage to electronics by confirming seal integrity under progressively longer exposure before any sensitive components were committed to the housing.

Electrical systems were initially planned using block diagrams and current-draw calculations, so Crush Depth could verify system requirements and power distribution before purchasing and assembling components. During assembly, early-stage layouts were organized on external tables for accessibility and troubleshooting, while later testing was conducted within the final housing unit to validate integrated performance.

Software development followed a similar iterative process, in which code modules were prototyped and tested individually before integration into larger systems. **Compiler flags, optimization settings, warning messages, and collaborative debugging discussions were used to efficiently identify and resolve software issues**. Across all disciplines, systems were tested independently to isolate variables and identify faults quickly before integration. Electrical troubleshooting techniques included verifying continuity and system performance with multimeters, monitoring component temperatures using thermal guns to detect overheating, and conducting visual inspections for burns, bulging, or physical deformities. These techniques were applied not just preventively but also diagnostically when failures occurred. For example, during water testing, the rear backplate repeatedly detached when the ROV was lifted from the pool. Through iterative submersion tests, including a team member entering the water alongside the housing to observe directly, Crush Depth traced the failure to a pinhole leak in one penetrator. Water slowly seeped in while trapped air had no escape path, pressurizing the housing; rapid removal from the pool created a pressure differential large enough to eject the backplate. Sealing the penetrator resolved the issue and reinforced the value of our staged waterproof testing methodology going forward. These **testing and troubleshooting practices** enabled Crush Depth to systematically evaluate design options, identify failures early, and improve overall vehicle reliability and performance throughout development.

Acknowledgements

Crush Depth would like to extend our sincere gratitude to MATE II & MTS for their continued efforts in promoting awareness and innovation in oceanic endeavors through the **MATE ROV Competition**. Crush Depth is especially thankful to our mentors, Gurinder Khaira and Benjamin Bohan, whose guidance and support have been invaluable to Crush Depth's success. e Crush Depth also deeply appreciate the unwavering financial support provided by the Associated Student Government of Clovis Community College, State Center Community College Foundation, and CCC MESA, whose assistance helped make travel to MATE ROV 2026 possible. Crush Depth is grateful to Forward Advantage Foundation, Blue Trail Engineering, OpenMV, Seasats, and Culture Fresno for their generous financial, technical, and strategic contributions. Crush Depth would also like to thank the staff and administration of Clovis Community College—most notably Dr. Armstrong, Maricarmen Figueroa, Katrina Sheets, John Loera, and Gurdeep Herbert—for their assistance, cooperation, and steadfast support of Crush Depth. Finally, Crush Depth extends our appreciation to 3D Printing Elves for donating filament for ROV and FLOAT research and development, and to ADCO Manufacturing for the in-kind manufacturing of our custom ROV backplate.

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BUDGET vs. ACTUAL

Category	2024	2025	2026 Est.	2026 Actual
Travel				
Transportation, Lodging, Per Diem	$14,250.00	$16,414.50	$28,000.00	$28,943.16
Electrical Hardware				
Propulsion (thrusters, ESCs)	$1,707.00	-	$400.00	$160.00
Payload & Tools (manipulator servos)	$325.99	$67.62	$800.00	$38.99
Power & Distribution	$432.67	$27.13	$700.00	$401.24
Compute & Vision	$96.43	$137.56	$800.00	$673.91
Sensing	-	$16.25	$100.00	$80.00
Tether & Connectors	-	-	$400.00	$347.38
Consumables (heatshrink, wire)	-	-	$350.00	-
Mechanical Hardware				
Pressure Housing	$335.23	-	$250.00	$227.46
Penetrators & Sealing	$168.00	-	$150.00	$115.00
Frame & Mounts	-	$68.00	$500.00	-
Consumables	-	-	$400.00	-
Operations				
Competition Fees	-	-	$650.00	$650.00
Shipping & Duty	-	-	$100.00	$86.63
Outreach & STEM	-	-	$400.00	$277.28
Totals:	**$17,315.32**	**$16,731.06**	**$34,000.00**	**$32,001.05**
Over / (Under) Budget:				**($1,998.95)**

INCOME

Source		Type	Notes	Amount
2024-2025 Rollover Funds		Rollover		$995.69
CCC MESA Program		Grant	Travel Grant	$14,573.08
CCC Associated Student Government		Funding Bill		$7,000.00
Bass Lake Triathlon		Fundraiser		$4,000.00
Donations - GoFundMe		Donation		$2,403.06
Professor Walk Event		Fundraiser		$2,035.00
Culture Fresno		Sponsorship		$1,200.00
Forward Advantage Foundation		Sponsorship		$1,000.00
Misc. Fundraisers		Fundraiser		$677.30
Seasats		Sponsorship		$500.00
City of Fresno		Sponsorship		$500.00
			Gross Income:	**$34,884.13**
			Net Income (excl. restricted MESA):	**$20,311.05**

Table 7, Accounting Budget & Income by Santino Gonzales

KEY	
Purchased	New items bought this season - counted at full cost.
Donated	(e.g. MATE, BlueTrail). Listed at FMV, deducted from out-of-pocket.
Re-used	"Re-used". Crush Depth-owned, carried over from prior year. Listed at FMV, deducted.

- *Source column drives everything: blank = purchased, "Re-used" = owned reuse, donor name = donated.*
- *Donations and reused items appear at fair market value (FMV), then deducted to show true out-of-pocket.*
- *Budget vs. Actual auto-pulls actuals via SUMIF on Sub-Category - re-tagging a line auto-updates the budget.*

Expenses

Operations

Item	Qty	Sub-Category	Notes	Amount
MATE Registration Fee	1	Competition Fees		$650.00
Shipping / Taxes / Duty Fees	—	Shipping & Duty		$86.63
Outreach & STEM (website, posters, supplies)	—	Outreach & STEM		$277.28
			Operations Total:	**$1,013.91**

Electrical Hardware				
Item	Qty	Sub-Category	Source	Amount
Blue Robotics T200 Thruster	8	Propulsion	MATE	$1,840.00
Blue Robotics ESC's	4	Propulsion	MATE	$160.00
Blue Robotics Basic ESC	4	Propulsion		$160.00
Blue Trail Engineering SER-200X DB961WP Servo	1	Payload & Tools	Blue Trail Engineering	$384.99
Blue Trail Engineering SER-200X MS825 Servo	1	Payload & Tools	Blue Trail Engineering	$279.99
ANNIMOS 35kg Brushless Servo 180°	1	Payload & Tools		$38.99
DC-DC 48V→12V 20A 240W Converter	1	Power		$17.99
LeMotech 48V→12V 5A 60W Converter	1	Power		$14.99
Valefod 48V→12V 40A 480W Converter	2	Power		$79.98
Pololu D36V28F6 6V 2.7A Step-Down Regulator	5	Power		$105.55
Pololu D36V28F12 12V 2.4A Step-Down Regulator	5	Power		$84.40
Power Distribution Board PDB 60A (XT30)	4	Power		$34.36
XT30 Connectors (20 pairs, M/F)	20	Power		$11.99
XT60H Connectors (12 pairs, M/F)	12	Power		$7.99
Banana Bullet Connectors 2/3.5/4mm (100pcs)	100	Power		$16.99
Anderson Power Blade Terminal 10-12AWG	4	Power		$27.00
Electrical Consumables (heatshrink, wire, solder)	—	Consumables	CCC Bookstore	$335.36
Raspberry Pi 5 16GB	1	Compute & Vision		$305.00
Meta Quest 3	1	Compute & Vision	CCC MESA	$599.99
Xbox Controller	1	Compute & Vision	Re-used	$59.99
ELP 16MP Wide Angle USB Camera	5	Compute & Vision		$334.95
OpenMV Cam RT1062 R6	2	Compute & Vision	OpenMV	$280.00
JSAUX USB-C 90° Adapter 2pk	1	Compute & Vision		$9.99
Short USB-C Cable 6" 2pk	1	Compute & Vision		$6.99
USB 3.1 90° Adapter 2pk (L+R)	1	Compute & Vision		$6.99
Anker USB-C to USB-C Cable 6ft 2pk	1	Compute & Vision		$9.99
Bar02 Depth/Pressure Sensor (0-2 bar)	1	Sensing		$80.00
SubConn SEACON 2-6 Core Waterproof Connector	1	Tether & Connectors		$102.38
SubConn MCIL-8-M / MCB-H8F Connector (#1)	1	Tether & Connectors		$62.50
SubConn MCIL-8-M / MCB-H8F Connector (#2)	1	Tether & Connectors		$62.50
Blue Trail Cobalt Series 3-pin Cable (1m)	2	Tether & Connectors		$88.00
High-Temp PUR Subsea Cable T200 (16AWG, 2m)	1	Tether & Connectors		$32.00
			Electrical Hardware Total:	**$5,641.84**

Mechanical Hardware				
Item	Qty	Sub-Category	Source	Amount
Precision Plastics Acrylic Tube	1	Pressure Housing		$213.46
Spare O-Ring Set (6" Series)	1	Pressure Housing		$14.00
Potted Cable Penetrator M6 (4-5mm)	2	Penetrators & Sealing		$10.00
Potted Cable Penetrator M6 (4-5mm)	9	Penetrators & Sealing		$45.00
Potted Cable Penetrator M10 (8mm)	9	Penetrators & Sealing		$54.00
Spare Bulkhead O-Ring Set M10	1	Penetrators & Sealing		$3.00
Spare Bulkhead O-Ring Set M06	1	Penetrators & Sealing		$3.00
3D Printing Filament (PLA, PETG, TPU, ABS)	—	Frame & Mounts	3D Printing Elves	$500.00
Mechanical Consumables (fasteners, marine grease, epoxy)	—	Consumables	CCC Bookstore	$365.97
			Mechanical Hardware Total:	**$1,208.43**

Travel				
Item	Count	Sub-Category	Notes	Amount
Flights	15	Transportation	Newfoundland, CA	$17,313.60
Lodging	15	Lodging	Newfoundland, CA	$7,513.56
Meals	15	Per Diem	Newfoundland, CA	$4,116.00
			Travel Total:	**$28,943.16**

Table 8, Expenses & Cost Accounting by Santino Gonzales

TOTALS & DEDUCTIONS		
	Gross Total:	($36,807.34)
Deductions		
	CCC MESA Program	($14,573.08)
	Donated Materials	($4,746.30)
	Reused Materials	($59.99)
	Total Deductions:	($19,379.37)
Income		
	Crush Depth Income:	$20,311.05
Net Totals		
	Deducted Total:	($17,427.97)
	Net Total:	$2,883.08
	Needed Funding:	-
	Net Profit:	$2,883.08

Table 9, Accounting Totals by Santino Gonzales

SID

ROV

