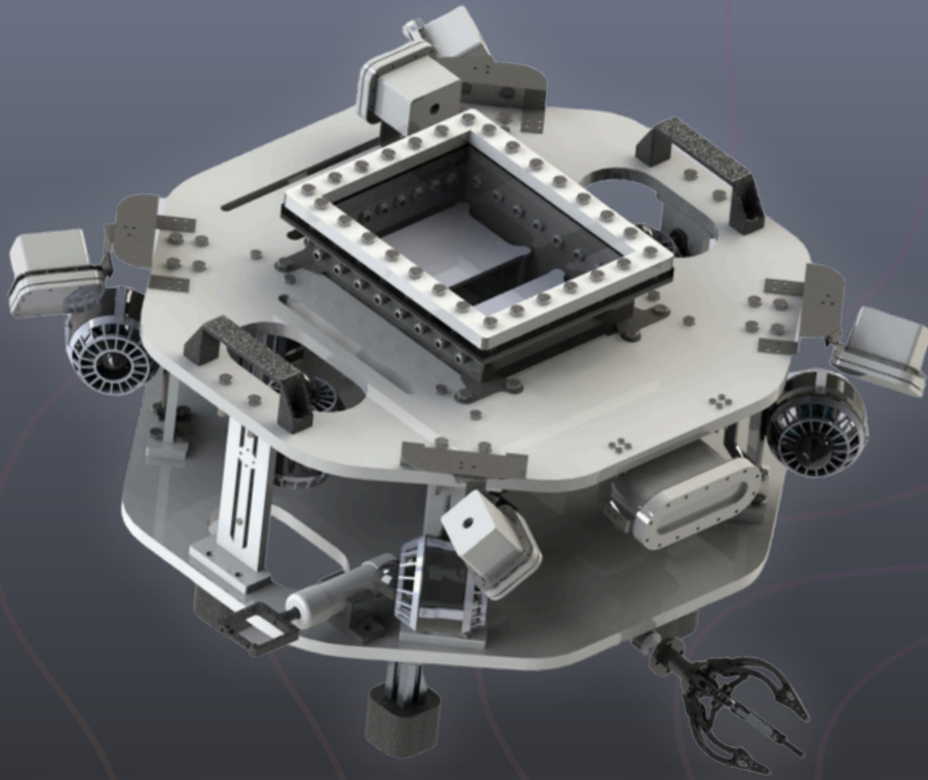




NEMESIS

MATE ROV '26

TECHNICAL DOCUMENTATION

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ABSTRACT

OI ROV team, proudly representing Obour Higher Institute in Obour City, Egypt, brings four years of rigorous engineering expertise to the 2026 MATE ROV Explorer class. Building upon the foundations of our previous iterations, our student run engineering firm proudly presents this year's Remotely Operated Vehicle **NEMESIS**. Engineered with a core design philosophy centered on modularity, maintainability, and precise task execution, **NEMESIS** represents a significant leap forward in our structural and electronic integration. We transitioned to a hybrid open-layered frame architecture combining CNC-machined HDPE plates with AL 6063-T5 aluminum profiles to achieve an optimal balance between load-bearing rigidity and hydrodynamics. This allowed us to maintain a total mass of 21 kg with a deliberately slightly negative buoyancy for enhanced positional stability during delicate manipulation tasks. **NEMESIS** is powered by a 48V power distribution architecture to drastically reduce I²R tether losses, driving a highly responsive 6-thruster configuration. Utilizing vector-based thrust mapping, the vehicle achieves exceptional 5-DOF maneuverability. At the heart of its electronic system lies a robust distributed control architecture, employing a Raspberry Pi 5 for high-level command routing and multi-camera situational awareness, alongside dual ESP32 edge nodes for precise, low-latency actuation and sensor acquisition. Equipped with custom-manufactured pneumatic manipulators and an extensive multi-camera vision system, **NEMESIS** is designed not merely to compete, but to execute intricate underwater interventions with uncompromising reliability and operational awareness.



Figure (1). OI ROV Team Members 2026

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6. Appendix

Our team would have not been founded nor able to overcome the challenges it faced without the help of these organizations and individuals:

- **Obour institute for computer science** – for funding our company in all previous years, as well as funding our new vehicle **NEMESIS** and supporting us.
- **MATE Center** for sponsoring this year's competition and for their generous awards.
- **Arab Academy** for Science and (AAST) for hosting and organizing the regional Technology competition.
- **Prof. Dr. Abdullah EL-Dahshan, Eng. Waleed EL-Dahshan, Prof. Ehab Ashour Farag, and Dr. Ibrahim Abdullatif** have all provided invaluable technical and non-technical support, for which I am sincerely grateful.
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- **JLCPCB** – for their valuable technical support and contribution to our electronic development efforts.
- **Makers Electronics** for importing electronic parts from USA .
- SolidWorks, Altium, Ansys for providing the team members with access to their products.
- **Our Families and friends** – Their unwavering encouragement and support.



1 Design Rationale

1.1 Design Evolution

Mitigating legacy architectural bottlenecks related to hydrodynamic maneuverability, integration density, and field-maintenance turnaround times was imperative for achieving higher operational efficiency. Following an intensive lifecycle of research, empirical testing, and iterative development, OI ROV engineers successfully engineered the **NEMESIS** platform. The finalized vehicle architecture achieves an optimal equilibrium between structural robustness, modularity, and fluid efficiency. As demonstrated in **Figure 2**, **NEMESIS** systematically overcomes previous operational limitations while seamlessly integrating enhanced mechanical and electrical frameworks to guarantee mission reliability.

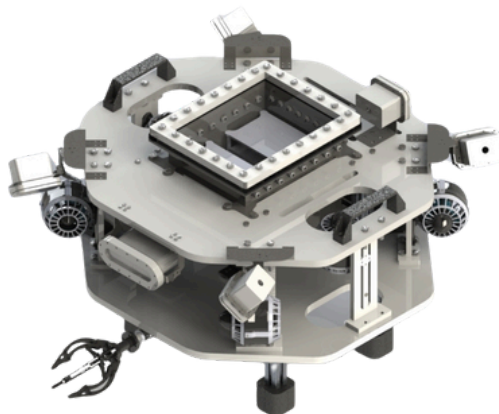


Figure (2). Rendered Finalized Model of NEMESIS

1.2 Innovations

Hybrid Frame

Securing the main electrical enclosure and ensuring absolute structural integrity without introducing parasitic mass or restricting rapid maintenance access presented a significant engineering challenge. To resolve this, OI ROV designed a hybrid chassis, structurally integrating CNC-machined Artelon plates with AL 6063-T5 aluminum extrusion profiles. These aluminum profiles provide highly secure, rigid mounting points

for the main enclosure, drastically expediting assembly and field maintenance. Concurrently, a redesigned compression sealing methodology was integrated, fortifying the system against water ingress. This hybrid approach ensures the ROV is unequivocally supported under dynamic operational loads while optimizing the overall strength-to-weight ratio.

Unique Manipulator

Conventional 2-jaw manipulators often fail to maintain a secure, symmetric grip on mission objects featuring irregular or highly variable geometries. Overcoming this limitation, the mechanical department engineered and custom-manufactured a proprietary 4-jaw gripper, coupled with an actuated manipulator capable of continuous 360-degree rotation. The 4-jaw geometry guarantees uniform load distribution, enabling the stable handling of complex payloads. Both mechanisms definitively resolved previous manipulation constraints, vastly expanding the ROV's capacity to execute specialized underwater interventions with extreme precision.

Web-Based GUI & Dynamic Control

Desktop-dependent software introduces severe installation bottlenecks and restricts pilot mobility, while hardcoded control schemes severely limit real-time adaptability. Consequently, the software team architected a completely cross-platform, web-based Graphical User Interface (GUI). A dynamic mapping feature was engineered, allowing the pilot to reconfigure joystick assignments on the fly directly through the interface. By eliminating local installation dependencies, the control system became instantly accessible and scalable across any network-connected device. This transition guaranteed seamless inter-subsystem communication and granted the pilot unprecedented operational flexibility during active deployment.

Real-Time Color Correction

Severe underwater color distortion and light attenuation compromise visual navigation and autonomous tasks, yet deploying heavy AI-based models introduces unacceptable latency. To address this, a highly deterministic, fast image-processing algorithm was developed utilizing OpenCV. The logic applies the Gray World Algorithm to normalize color intensities, sequentially followed by a red-blue mathematical compensation model to restore attenuated red wavelengths. Initially prototyped and validated in Python, the algorithm was aggressively re-written and optimized in C++. This strategic architectural shift slashed computational overhead, consistently delivering ultra-low latency, real-time performance at 30 FPS. This directly enhances navigational clarity and vision-based task execution without overloading the central processing unit.

1.3 Design & Manufacturing Process

Design Process

Translating conceptual requirements into a highly precise, manufacturable ROV geometry required seamlessly integrating successful legacy components into a newly optimized modular footprint. The engineering team adhered to a strict, iterative design methodology. Primary structural parameters were defined during intensive brainstorming sessions and immediately drafted into freehand engineering sketches, as shown in **Figure 3**.

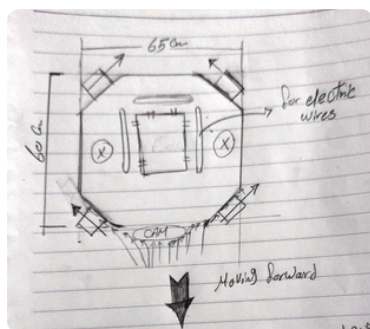


Figure (3). NEMESIS Two Hand Sketches Design

To rigorously justify the material selection for the ROV's structural chassis, a quantitative decision matrix was formulated. Options were evaluated on a scale of 1 to 10 across five critical engineering criteria, each assigned a specific weight based on mission priority. The total score is calculated using the weighted sum model

$$\text{Total Score} = \sum (\text{Weight} \times \text{Score}).$$

Evaluation Criteria	Weight (W)	Hybrid (Ertalon + AL 6063-T5)	Full Aluminum 6061	Full Ertalon / HDPE	Stainless Steel 304
Structural Rigidity under Load	0.25	8	10	4	10
Buoyancy Profile (Specific Gravity)	0.25	8	3	9	1
Machinability & Modularity	0.2	9	6	9	4
Corrosion Resistance	0.15	9	7	10	9
Cost Effectiveness	0.15	8	5	9	4
Total Weighted Score	1	8.35	6.25	7.9	5.5

Table (1) : Trade-off Matrix

As demonstrated in **Table 1**, while monolithic Aluminum 6061 and Stainless Steel 304 offer maximum structural rigidity (scoring 10/10), they suffer severe penalties in their buoyancy profiles, which would require excessive artificial ballast and disrupt the ROV's targeted slightly negative buoyancy. Conversely, a Full Ertalon framework excels in buoyancy and corrosion resistance but fails to provide the necessary rigidity (scoring 4/10) to support dynamic manipulation loads. The Hybrid (Ertalon + AL 6063-T5) architecture emerged as the definitive optimal solution, achieving the highest overall score (8.35). It provides the critical load-bearing strength via the aluminum extrusions while preserving a near-neutral buoyancy profile and excellent machinability through the Ertalon plates.

These concepts were systematically translated into SOLIDWORKS CAD models to enforce spatial optimization and extract exact dimensional tolerances **Figure 4**. The previous generation's highly reliable enclosure was preserved and virtually integrated into the new frame topology to verify clearance and accessibility prior to physical fabrication.

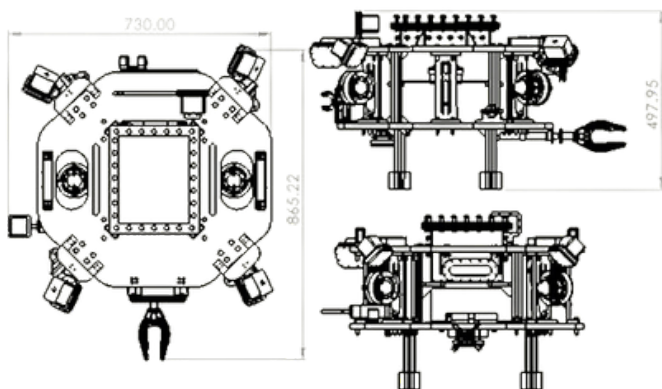


Figure (4). NEMESIS Detailed Drawing and Dimensions

Manufacturing Process

Achieving the stringent physical tolerances dictated by the CAD models was critical to guarantee watertight integrity and flawless mechanical actuation. A multi-disciplinary fabrication strategy was actively deployed to meet these standards. CNC machining was utilized for the Artelon plates to guarantee exact alignment for thruster and profile mounting. Lathe and Laser cutting operations were executed to form precise customized cylindrical and planar interfaces. Furthermore, FDM 3D printing (PLA) was extensively leveraged for rapid prototyping and the final production of complex, lightweight geometries, such as the rotational manipulator housings. This integrated manufacturing approach yielded a highly refined, competition-ready ROV that perfectly conforms to its simulated digital twin.

1.4 Vehicle Core Systems

1.4.1 Mechanical

Frame

Establishing a structural backbone that balances compact maneuverability with sufficient internal volume for subsystem integration presented a primary engineering challenge. To resolve this, OI ROV engineers designed a modular, open-layout chassis fabricated entirely from 10 mm thick High-Density Polyethylene (HDPE) sheets. This material was specifically selected for its excellent corrosion resistance, high impact strength, and ease of manufacturability. The finalized frame occupies a highly optimized footprint of 60 × 65 × 22 cm. By utilizing the same HDPE material for the thruster mounts, the design ensures consistent mechanical properties and structural compatibility across the entire vehicle, yielding a highly durable platform capable of reliable operation and rapid maintenance in harsh underwater environments.

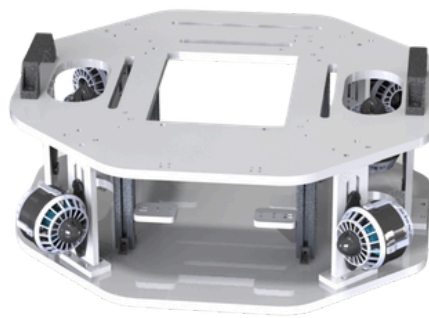
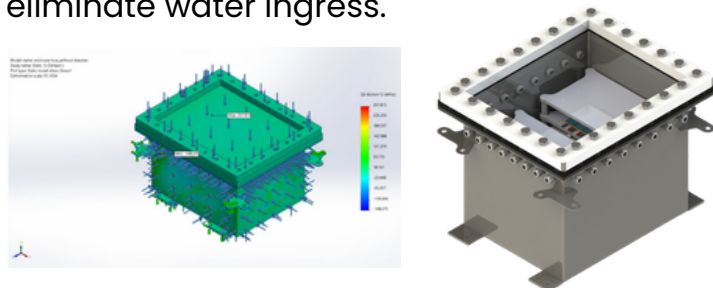


Figure (5). NEMESIS Rendered Hybrid Frame

Enclosure

To optimize spatial footprint, the legacy enclosure was downsized to a 250 × 200 × 200 mm³ chassis. Prior to fabrication, the geometry was mathematically validated via Finite Element Analysis (FEA) to ensure structural integrity under maximum hydrostatic pressure. The physical chassis is fabricated from 1.5 mm AISI 304 stainless steel using Argon-shielded TIG welding. Fail-safe waterproofing combines a 6 mm rubber compression

gasket, a 6 mm transparent acrylic cover for pre-dive inspection, and a 10 mm Artilon mechanical shield. All cable entries are strictly isolated using metal PG7 glands to eliminate water ingress.



Figures (6, 7): FEA pressure validation & assembled enclosure.

Camera Casing

To enhance the ROV's computer vision capabilities, two types of camera enclosures were developed for the depth camera and wide-angle USB cameras. The enclosures are manufactured from High-Density Polyethylene (HDPE) using CNC machining, ensuring a lightweight, compact, and durable design. A dual-level camera configuration was implemented to improve underwater visibility and support detailed three-dimensional perception. All camera housings are sealed using stainless steel PG7 cable glands and O-rings, combined with a 6 mm acrylic front lens and an external Artilon protective layer, ensuring reliable waterproofing and protection under underwater operating conditions.

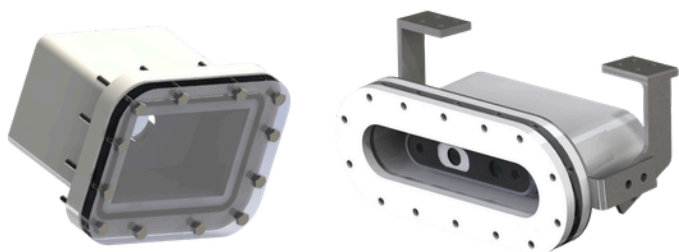


Figure (8): NEMESIS Rendered Camera Cases

CFD Analysis

To validate hydrodynamic efficiency, a Computational Fluid Dynamics (CFD) analysis was executed on the open-frame architecture. Simulations confirm that the streamlined geometry minimizes turbulent

recirculation and drag forces. This optimized fluid interaction ensures highly stable maneuverability and maximum propulsion efficiency during operations.

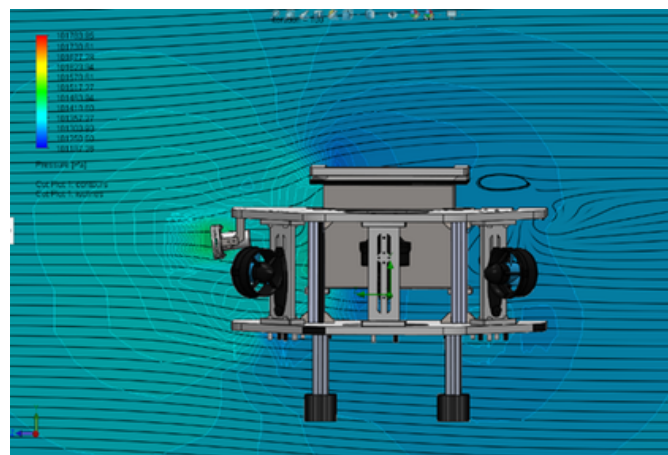


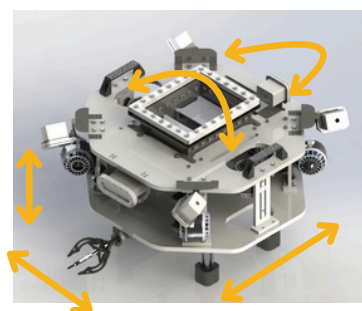
Figure (9): SOLIDWORKS flow Simulation

Propulsion

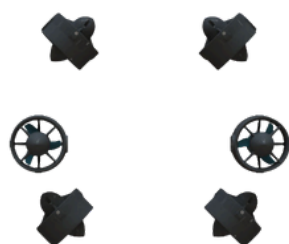
Achieving holonomic, highly controlled motion required a propulsion layout capable of overcoming dynamic fluid resistance without overloading the power distribution network. The propulsion system was engineered with four thrusters mounted horizontally at 45° to provide simultaneous forward, lateral, and yaw movements, coupled with two vertical thrusters dedicated to ascending and descending heave control. To rigorously validate this configuration, the expected hydrodynamic resistance was calculated using the standard drag equation:

$$F_D = C_D \cdot A \cdot \rho \cdot \frac{V^2}{2}$$

Where F_D is the drag force, C_D is the drag coefficient, A is the projected frontal area, ρ is the fluid density, and V is the flow velocity relative to the vehicle. This mathematical analysis ensured that the 6-thruster configuration provides sufficient thrust to overcome theoretical drag forces, guaranteeing stable maneuverability and efficient thrust distribution during complex mission tasks.



(a) Degrees of Freedom



(b) Thruster Configuration

Figure (10). Propulsion

Buoyancy and Stability

Achieving near-neutral buoyancy while enhancing hydrostatic stability is critical to ensuring efficient control during delicate underwater interventions. The buoyancy system was engineered based on Archimedes' Principle, where the buoyant force acting on each component was calculated according to its exact volume and the density of the surrounding fluid. A detailed volumetric evaluation determined a total structural mass of 15.109 kg against a displaced water mass of 11.9603 kg, resulting in a total calculated buoyant force of -53.53 N. This dictates that the ROV experiences a deliberate net negative buoyancy of approximately -54 N. To transform this into a stabilization asset, buoyant elements were strategically integrated so that the Center of Buoyancy (CB) is positioned strictly above the Center of Mass (CG). This geometric relationship produces a strong positive righting moment, enhancing passive stability and preventing unintended pitching or rolling. Ultimately, this optimized internal distribution significantly reduces the need for continuous thruster corrections, minimizing power consumption and vastly improving pilot control during task execution.

Item	Material	Quantity	Volume (cm ³)	Mass (Kg)	Displaced Mass (kg)	Buoyant Force (N)
Top Plate (Frame)	Ertalon	1	3492.87	4.02	3.5767	-4.3488
Bottom Plate (Frame)	Ertalon	1	4401.17	5.06	4.5068	-5.4269
Main Cam Case	Ertalon	1	95.04	0.109	0.0973	-0.1148
Normal Cam Case	Ertalon	6	93.26	0.107	0.573	-0.6769
Enclosure Support Tubes	Ertalon	4	26.79	0.03	0.1097	-0.101
Enclosure Face	Acrylic	1	735.92	0.883	0.7536	-1.2694
Main Cam Face	Acrylic	1	43.61	0.052	0.0447	-0.0716
Normal Cam Face	Acrylic	6	28.53	0.034	0.1753	-0.2816
ROV Arm	PLA	1	66.05	0.082	0.0676	-0.1409
Thrusters Shroud	PLA	6	24.77	0.027	0.1522	-0.0961
Thrusters Support	PLA	6	14.16	0.017	0.087	-0.1472
Hands & Legs	PLA	4	153.67	0.19	0.6294	-1.2812
Pipe Support (PVC in Carabiner)	PLA	1	15.25	0.018	0.0156	-0.0235
Supports up	AL Profile 6063-T5	4	62.29	0.17	0.2551	-4.1682
Supports Legs	AL Profile 6063-T5	4	65.87	0.177	0.2698	-4.2987
Piston Support	Steel AISI 304	1	7.364	0.04	0.0075	-0.3188
Enclosure (Structural)	Steel AISI 304	1	479.83	3.838	0.4913	-32.8311
Normal Cam Supports	Steel AISI 304	6	21.03	0.166	0.1292	-8.5033
Main Cam Supports	Steel AISI 304	1	18.04	0.089	0.0185	-0.6916
Total		-	9845.514	15.109	11.9603	-53.5326
Total buoyancy						-54.1232

Payload and Mission Manipulators

To successfully address the diverse and complex intervention requirements of the MATE competition—ranging from forceful gripping to continuous rotation and passive recovery—OI ROV engineered a suite of highly versatile, multi-functional manipulators. By systematically departing from single-purpose actuators, the mechanical team prioritized rapid geometric customization, weight reduction, and operational reliability across all mission-specific tools.

4-Jaw Pneumatic Gripper

Fully 3D printed to achieve a lightweight profile and rapid geometric customization, this custom gripper is pneumatically actuated via a highly compact cylinder (6 mm diameter, 100 mm stroke). It is specifically designed to seamlessly grasp objects with highly variable cross-sections in both horizontal and vertical orientations, ensuring maximum stability during complex manipulation tasks.



Figure (11). 4-Jaw Pneumatic Gripper

360° Rotational Manipulator

Developed primarily for observatory servicing missions, this proprietary, completely 3D-printed tool couples mechanically driven jaws with a precision gear-based system. It achieves full 360° continuous rotation, granting the pilot unprecedented orientation control and mechanical repeatability during delicate underwater interventions.



(a) Arm 360 with Box



(b) Arm 360 Details

Figure (12). 360° Rotational Manipulator

Passive Carabiner Mechanism

Constructed from a robust hybrid of 3D-printed components and PVC, this tool is strictly optimized for buoy anchor recovery. The design deliberately prioritizes operational simplicity and rapid engagement. By functioning completely passively, it eliminates all actuator failure points, ensuring highly secure and efficient retrieval operations under dynamic water conditions.

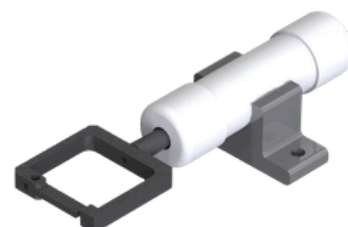


Figure (13). Passive Carabiner Mechanism

1.4.2 Electrical System

Built on four core pillars—Safety, Streamlined Assembly, Modularity, and Efficiency—the electrical system is optimized for reliable operations. A fully grounded enclosure eliminates EMI and protects operators from hazardous return currents. To accelerate field diagnostics, a strict color-coded wiring schematic instantly identifies distinct voltage levels and signals. Furthermore, internal hardware is strategically organized into vertically stacked functional layers, prioritizing accessibility and drastically reducing debugging time.

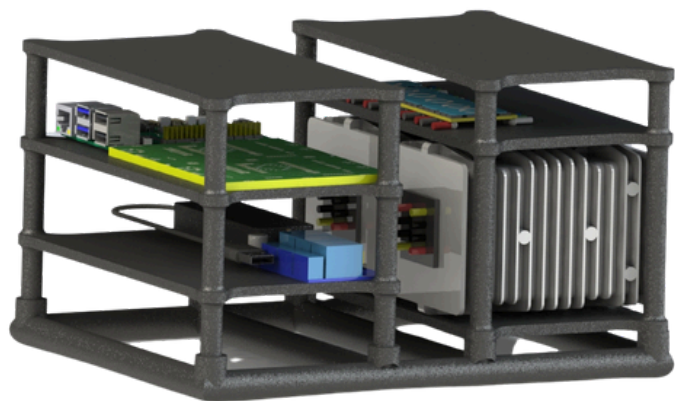


Figure (14). Enclosure Layers

Power Management & Connectors

Power enters the ROV securely via a heavy-duty, polarity-safe Anderson Connector. To prioritize thermal efficiency and introduce critical redundancy, three parallel 30A (48V-to-12V) DC-DC buck converters are utilized to handle total current requirements instead of a single, non-redundant unit. Additional 96%-efficient converters safely distribute stable 5V logic power to sensitive microcontrollers and the multi-camera network.

To ensure optimal power delivery, a trade-off analysis was conducted. The modular 3x 30A configuration was selected as it maximizes redundancy while maintaining an excellent thermal-to-weight ratio.

Criteria (Weight)	Single Large Converter (1x 100A)	Multiple Small Converters (8x 12A)	Modular Approach (3x 30A)
System Redundancy (0.30)	2	10	8
Thermal Dissipation (0.25)	4	9	8
Weight & Volume (0.25)	9	3	7
Cost Effectiveness (0.20)	8	4	8
Total Weighted Score	5.45	6.8	7.75

Table (3). DC-DC Buck Converter Topology Trade-off

Hardware Control

Hard-real-time operations, including motor actuation and solenoid valve control, are offloaded to powerful ESP32 microcontrollers. This separation of low-level hardware control from high-level processing eliminates signal delay and ensures instantaneous response times during complex underwater manipulation and propulsion tasks.

PCBs

Relying on off-the-shelf control modules introduces severe spatial constraints and wiring bottlenecks. To address this, proprietary Actuator and Sensor Printed Circuit Boards (PCBs) were engineered completely in-house using Altium Designer. This bespoke board topology ensures optimal spatial utilization, drastically reduces wiring clutter, and grants engineers immediate diagnostic access.

Single Board Computer & Cooling

To handle high-bandwidth multi-camera streams and intensive data processing without bottlenecks, a Raspberry Pi 5 serves as the primary high-level Single Board Computer (SBC). To sustain maximum processing performance and prevent thermal throttling under heavy utilization, an active cooling system is integrated directly with the SBC, ensuring zero-latency video telemetry.

Processing multiple camera streams and vision algorithms requires a specialized SBC. The Raspberry Pi 5 was selected for its superior raw processing power and active cooling compatibility.

Specification / Feature	Raspberry Pi 4B (8GB)	Raspberry Pi 5 (8GB)	Winner
CPU Architecture	Quad-core Cortex-A72 @ 1.5GHz	Quad-core Cortex-A76 @ 2.4GHz	RPi 5
I/O Bandwidth	Shared PCIe (Bottlenecks)	Dedicated PCIe 2.0 interface	RPi 5
Thermal Management	Passive/Basic Active	Advanced Active Cooling Mounts	RPi 5
Overall Performance	Baseline	2-3x Faster execution	RPi 5

Table 4: Single Board Computer (SBC) Trade-off

Navigation Sensors

Precise spatial awareness is critical for autonomous stabilization. The ROV utilizes a high-resolution pressure sensor for precise depth-locking. To achieve drift-free orientation and enhanced navigational redundancy, the system computationally fuses data from the primary onboard IMU with the secondary IMU embedded directly within the depth camera, delivering ultra-stable, real-time positional telemetry to the pilot.

Safety First

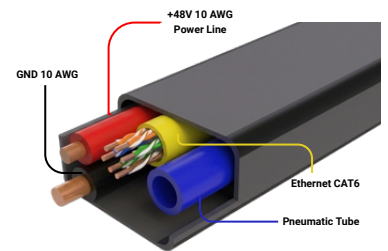
Operator and equipment safety dictates the foundation of the electrical architecture. The system is fully grounded, and strategically placed inline fuses instantly isolate the system during overcurrent events. Furthermore, highly sensitive internal leakage detectors are installed within the enclosure to provide immediate diagnostic alerts upon moisture ingress, enabling an emergency shutdown protocol to prevent hardware damage.

Tether

The ROV is connected via a 30-meter centralized umbilical encased in a high-durability protective sheath to prevent environmental wear. The internal core integrates a 48V 10-AWG power line, a single pneumatic tube, and a CAT6e Ethernet cable for 1000 Mb/s telemetry. To ensure unobstructed maneuverability, the tether is engineered to be neutrally buoyant, preventing it from dragging on the seabed or obstructing the ROV's path. Furthermore, both ends are secured with robust strain relief mechanisms to protect internal connections from excessive tension and accidental strong tugs during dynamic missions.



(b) Real Life Photo of NEMESIS's Strain Relief



(b) Tether Cross-Section

Figure (15). NEMESIS Braided Tether

Tether Management Protocol

To ensure operational longevity and prevent entanglement, a strict management protocol is executed across all mission phases. Preparation involves rigorous pre-deployment checks for structural integrity. During Deployment, a dedicated tether-man monitors tension and dynamic slack to accommodate the ROV's vector without overloading. Continuous Monitoring and Adjustment allow for real-time length optimization based on environmental conditions. Post-mission Retrieval is performed systematically to eliminate twists, followed by a final Inspection to detect micro-abrasions, ensuring the umbilical remains mission-ready.

1.4.3 Software System

Control System

Our ROV employs 6 T200 thrusters in a fully vectored configuration, granting 5-DOF maneuverability and an increased vertical payload capacity. The precise relationship between the pilot's input and individual thruster contributions is computationally mapped using a custom kinematic matrix (K), executed in real-time.

Hold Your Depth

To maintain a constant depth, the control system utilizes a highly tuned PID controller reading real-time data from the high-resolution pressure sensor. The pilot can seamlessly toggle between auto-depth and manual-depth modes. This precise depth lock is crucial for maintaining a stable altitude while battling simulated currents during Task 1.3 (Fly a transect over the coral garden).

Hold Your Depth

We developed an active attitude control system utilizing independent PID controllers to constantly correct for pitch, roll, and yaw by fusing data from the dual-IMU setup. This ensures dynamic stability even when carrying uneven payloads. This feature allows the ROV to securely lock its heading, an absolute necessity for precision alignment during Task 3.1 (Guiding the micropile into its designated location) and Task 2.5 (Connecting the eDNA sensor).

Soft-Starting Thrusters

T200 thrusters draw massive inrush currents when aggressively accelerated. To prevent power system strain and protect our parallel 30A DC-DC converters, we implemented a software-based gradual ramp-up algorithm. This system smooths out current spikes and inertial shifts, enabling delicate micro-adjustments during complex interventions.

Precision Mode

At extremely low speeds, T200 thrusters exhibit a mechanical dead zone (~300 RPM) causing inconsistent motion. "Precision Mode" idles the thrusters just above this threshold, computationally bypassing the dead zone. This ensures buttery-smooth control and instant attitude response, which is essential for delicate operations like Task 2.4 (Attaching the recovery line to the buoy anchor U-bolt).

Communication Architecture

Instead of relying on heavy, monolithic middleware frameworks, our team engineered a custom, lightweight communication architecture from scratch. We utilized low-level Python Sockets to establish a highly reliable, bidirectional data pipeline between the Raspberry Pi 5 and the surface station. By strategically deploying UDP sockets for high-bandwidth, latency-tolerant video streams, and TCP sockets for mission-critical, lossless control commands (actuator triggers and PID tuning), we completely eliminated network overhead and guaranteed microsecond-level responsiveness.

AI & Autonomous Assistance

To actively mitigate invasive species (Task 2.1), we deployed a custom-trained AI object detection model using OpenCV and neural networks. When surveying the sample area, the algorithm autonomously identifies the European Green Crab (*Carcinus maenas*), drawing a bounding box exclusively around the invasive targets while ignoring native Rock and Jonah crabs. It instantly computes the total count and displays it on the GUI, ensuring a rapid and 100% accurate data upload to the SmartAtlantic database.

Topside Control System (Web-Based GUI)

To maximize portability and eliminate complex topside software dependencies, we developed a fully custom Web-Based Graphical User Interface (GUI). Hosted directly from the Raspberry Pi 5 via a lightweight web server, the GUI is accessible from any standard web browser. The frontend dynamically renders real-time IMU telemetry, pressure data, and multi-camera feeds into a single, highly ergonomic, distraction-free dashboard. This plug-and-play approach ensures rapid deployment and significantly reduces the pilot's cognitive load.

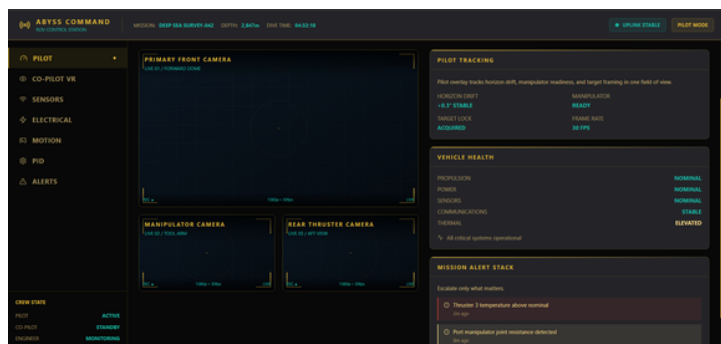


Figure (16). NEMESIS Braided Tether

System Automation & Dockerization

Ensuring consistent performance across multiple testing environments and rapid field deployment is critical. To achieve this, the entire software ecosystem encompassing the Python socket servers, ESP32 serial communication bridges, and the Web GUI backend is fully containerized using Docker. This container-based architecture guarantees strict fault isolation, eliminates host OS driver conflicts, and ensures that all critical processes automatically launch flawlessly upon the Raspberry Pi 5's boot sequence.

Vision System & MJPG Streaming

Underwater perception is driven by a comprehensive multi-camera network. We utilize MJPG (Motion JPEG) streaming processed directly on the Raspberry Pi 5. MJPG encoding, optimized via C++, drastically reduces transmission latency while maintaining the high visual fidelity required for accurate pilot navigation. To combat severe underwater color attenuation, optimized algorithms actively apply Gray World and Red Blue compensation, restoring visual clarity to accurately identify targets during the iceberg survey (Task 2.2).

MJPG was selected as it perfectly balances CPU processing overhead with ultra-low latency, a critical requirement for real-time ROV piloting.

Feature	MJPG-streamer	FFmpeg	GStreamer
Performance	High	Moderate	High
Power Consumption	Low	High	Moderate
Latency	Ultra-Low	High	Low
Processing Overhead	Low	High	Moderate

Intel Depth Camera & 3D Modeling

The ROV is equipped with an Intel Depth Camera to provide advanced spatial awareness and 3D mapping capabilities. During Task 1.2 (Coral garden ridge modeling), the camera captures sequential high-resolution images of the subsea targets. We utilize a photogrammetry algorithm to stitch these images, autonomously outputting a highly accurate, scaled 3D CAD model displaying the exact length and height of the Funk Island Deep coral garden.

2. Safety

2.1 Safety Philosophy

Our engineering approach dictates that safety is never an afterthought; it is the foundational pillar of our ROV design and operational protocol. We are committed to establishing a secure environment for our crew, bystanders, and the marine ecosystem. This is achieved by proactively identifying potential hazards during the design phase and implementing strict, multi-layered mitigations—ranging from hardware fail-safes to operational redundancy—before the ROV even touches the water.

2.2 Awareness & Training

A safe ROV requires a safe team. Every member undergoes comprehensive hazard recognition training prior to interacting with the vehicle's electrical or pneumatic systems. During pool tests and mission deployments, we maintain a strict code of conduct and designate a dedicated Safety Officer. This officer ensures the workspace is free of tripping hazards, enforces the use of Personal Protective Equipment (PPE), and rigorously executes the pre-dive Safety Checklist to guarantee operational readiness.

2.3 Safety Standards & Features

The ROV is engineered with comprehensive, integrated safety mechanisms across its mechanical, electrical, and software domains:

- **Mechanical Integrity:** The frame is meticulously deburred to eliminate sharp edges, and all structural bolts are recessed or capped to prevent snagging. To ensure the safety of the handlers and marine life, all T200 thruster propellers are fully enclosed within protective hydrodynamic shrouds.

- **Electrical Fail-safes:** Power enters the ROV via polarity-safe Anderson Connectors, eliminating the risk of reverse-polarity short circuits. A properly rated, fast-acting inline fuse is strategically placed close to the power source to instantly sever the connection during catastrophic overcurrent events. Furthermore, the main electronics enclosure is fully grounded to eliminate electromagnetic interference (EMI) and protect the tether-man from hazardous return currents.
- **Thermal & Power Redundancy:** Instead of relying on a single, high-capacity converter, we utilize three parallel 30A (48V-to-12V) DC-DC buck converters. This distributed load architecture drastically reduces individual thermal stress and provides critical redundancy; if one converter fails, the system safely sustains the load without catching fire or shorting out.
- **Proactive Leak Detection:** To safeguard the internal Raspberry Pi 5 and custom ESP32 PCBs, highly sensitive internal leakage detectors are installed at the lowest points within the main enclosure. Upon detecting any moisture ingress, these sensors instantly trigger diagnostic alerts on the Web GUI, prompting an emergency shutdown protocol before critical short circuits can occur.
- **Tether Strain Relief:** The umbilical tether is equipped with robust mechanical strain relief at both the surface and ROV terminations. This prevents operational severance, protects the internal CAT6e and power lines from excessive tension, and mitigates the risk of live wires being exposed to the water during accidental strong tugs.
- **Emergency Kill Switches:** Hardwired, easily accessible emergency kill-switches are integrated into both the topside power supply unit and the main control station, allowing the pilot or safety officer to instantly cut all power to the ROV in the event of an uncontrolled malfunction.

3. Testing and Troubleshooting

3.1 Testing Strategy

To guarantee operational reliability and validate our engineering decisions, a rigorous, multi-tiered testing protocol was executed. This strategy ensures the ROV can withstand extreme underwater conditions and execute precision tasks flawlessly.

- **Software & Communication Testing:** The custom Python Sockets architecture was stress-tested using latency-monitoring scripts to measure the delay between joystick input and actuator response. We ensured our Dockerized environment deployed reliably across different hardware without introducing processing overhead. Furthermore, Web GUI endpoint testing was performed to guarantee seamless transmission of dual-IMU telemetry and MJPG camera feeds.
- **Electrical Testing (Component & Full System):** Prior to integration, custom ESP32 PCBs underwent continuity and short-circuit tests. Theoretical power consumption was compared against practical readings using multimeters and oscilloscopes. A rigorous load test was conducted on the three parallel 30A DC-DC buck converters to verify their thermal stability and current distribution under maximum thruster draw.
- **Mechanical & Sealing Testing:** To ensure structural integrity, the main acrylic electronics enclosure was subjected to a hydrostatic pressure test. It was submerged and visually inspected for micro-bubbles. All pneumatic circuits, including valves and the pneumatic umbilical line, were pressure-tested to detect and seal any air leaks before final assembly.

3.2 Full System Integration Test

A systematic protocol dictates our full-system testing phase:

- **Dry Test:** Prior to submersion, the ROV is powered via the 48V surface supply. We verify the initialization tones of all 8 ESCs, check the actuation of solenoids, and ensure the Gray World color correction algorithm is actively processing the camera feeds on the Web GUI.
- **Wet Test (Submersion):** The ROV is deployed in a test pool. We immediately conduct a visual leak inspection, followed by validating the Auto-Depth PID controller's ability to maintain altitude. Flotation and ballast are dynamically adjusted to achieve perfect neutral buoyancy and correct the center of mass (C_g) relative to the center of buoyancy (C_b).

3.4 Troubleshooting Methodology

During development, we encountered various challenges which were systematically resolved using an "Isolate, Divide, and Conquer" methodology:

- **Define the Problem:** Accurately identify if the failure is Mechanical (e.g., jammed manipulator), Electrical (e.g., voltage drop), or Software (e.g., socket timeout).
- **Collect & Analyze Data:** Utilize diagnostic tools. For example, if a thruster fails, we check the Web GUI logger for Python errors, measure the voltage output from the 30A buck converters, and inspect the physical ESC connections.
- **Propose & Test Solutions:** Implement a targeted fix (e.g., refining the gradual ramp-up algorithm to prevent current spikes).
- **Implement & Document:** Once verified, the solution is permanently integrated into the system architecture and documented in the team's engineering log to prevent recurrence.

4. Logistics

4.1 Teamwork & Organizational Structure

Our company operates as a cohesive, interdisciplinary unit comprising students from mechanical, electrical, and software engineering disciplines. To ensure maximum efficiency, we adopted a corporate organizational structure. The executive board, led by the CEO, oversees strategy, budgeting, and project execution. The engineering departments are directed by their respective CTOs, who break down macro-objectives into actionable tasks for their team members. This structured delegation ensures accountability and streamlines the onboarding process for new recruits.

4.2 Project Management & Workflow

To consistently meet rigid competition deadlines, we implement an Agile project management methodology. Our workflow is divided into specific phases: Initial R&D, Design, Prototyping, Manufacturing, and Intensive Testing.

To manage this complex pipeline, we utilize a suite of digital tools:

- Notion: Serves as our primary project management hub. We utilize Kanban boards for sprint planning, task assignment, and progress tracking, ensuring complete visibility across all departments.
- Discord: Facilitates real-time, departmental communication and integrates automated updates for critical server events, maintaining a steady flow of information during remote work sessions.
- GitHub: Essential for our software team, providing robust version control, issue tracking, and seamless code integration for our custom Python Sockets and Web GUI repositories.

Efficiency in a shared workspace requires discipline. We maintain designated areas for specific tasks (e.g., PCB soldering, mechanical assembly, and water testing). A dedicated Workshop Director enforces our strict "Workspace Code," ensuring the environment remains clean, organized, and free of safety hazards, thereby maximizing productivity and minimizing the risk of accidents.

4.4 Accounting & Budgeting

Fiscal responsibility is managed by the Chief Financial Officer (CFO), who developed a comprehensive seasonal budget based on past expenditures and current inflation rates. To mitigate financial risks, the budget includes a strategic buffer for unexpected costs. Furthermore, the company actively offsets expenses through targeted fundraising initiatives and by securing technical sponsorships (e.g., software licenses and component discounts). A detailed breakdown of our project costing and income can be found in the Appendices.

5. Conclusion

5.1 Lessons Learned

The development of this year's ROV presented significant challenges that ultimately strengthened our team. Overcoming the initial complexities of designing a stable Python Sockets communication architecture taught us the value of network optimization. Mechanically, refining the modular enclosure taught us the critical balance between accessibility and absolute water-tightness. From a logistics standpoint, navigating budget constraints during global economic fluctuations reinforced the importance of strategic financial planning and resource optimization.

5.2 Build vs. Buy Philosophy

Our engineering philosophy heavily favors custom "Build" solutions over off-the-shelf "Buy" options whenever performance can be optimized or costs reduced. For example, engineering our own custom ESP32 Actuator and Sensor PCBs, rather than purchasing commercial controllers, drastically reduced our budget while granting us complete control over integration. However, we selectively "Buy" critical components—like the T200 thrusters and the high-resolution depth sensor—where commercial reliability significantly outweighs the time and cost of in-house development.

Component	Built / Bought	New / Used	Justification
Main Gripper	Built	New	Custom geometry tailored for precise interventions (e.g., micropile installation).
Raspberry Pi 5	Bought	New	Necessary CPU upgrade to run Docker, Python Sockets, and MJPG seamlessly.
Intel Depth Camera	Bought	New	Required for accurate 3D photogrammetry and spatial awareness (Task 1.2).
T200 Thrusters	Bought	Used (Reused)	Meets full 6-DOF needs; reused to reduce budget and minimize e-waste.
Control PCBs	Built	New	Custom-fit to our spatial constraints; optimizes power routing efficiently.

5.3 References

[1]MATE ROV Competition Manual 2025

[2]HDPE material specifications

[3]Blue Robotics store

[4]Qt Documentation | Home

[5]PID Documentations

[6]IMU 6050

[7]T200 Thrusters Documentation

[8] OpenCV, "Tutorial Root," OpenCV Documentation, 2025.

[Online]. Available: https://docs.opencv.org/4.x/d9/df8/tutorial_root.html. [Accessed: 1-Apr2025].

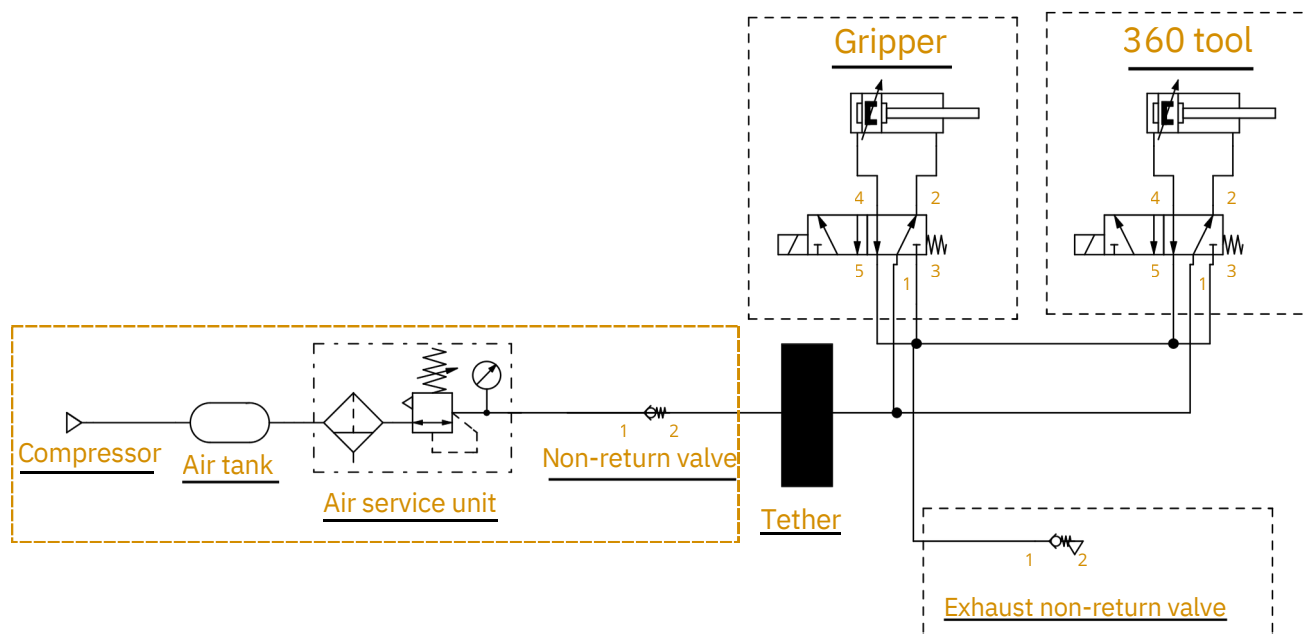
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6. Appendix

A. Safety Checklist

Construction	Pre-Power Test	Operational Safety
☐ Keep the workspace clean and free of debris.	☐ Ensure area is safe (no tripping hazards or obstructions).	☐ Only designated crew on deck.
☐ Store materials properly to prevent tripping hazards.	☐ Switches and circuit breakers are off.	☐ All crew in proper safety gear (PPE).
☐ Use safety goggles or face shields during cutting and grinding.	☐ Tether is securely attached to ROV.	☐ Poolside and deck area are clear.
☐ Use proper gloves and handling tools.	☐ Strain relief properly connected.	☐ Power remains off until all systems are checked.
☐ Inspect all machinery for wear or damage before use.	☐ Electronics housing is sealed and undamaged.	☐ No exposed wires or loose connections.
☐ Ensure guards and safety devices are in place and functioning.	☐ Visual inspection of wiring and housing nuts.	☐ Electronics housing sealed before launch.
☐ Follow manufacturer's instructions and safety guidelines.	☐ Thrusters are clear from debris.	☐ Control computer is running before power-up.
☐ Properly isolate energy sources before servicing.	☐ Set compressor output to 2.75 bar before powering up.	☐ ROV and Control Unit are powered down after retrieval.
☐ Store materials securely to avoid spills or instability.	☐ Confirm power source and TCU voltage (48V nominal).	☐ Dry test of thrusters, manipulators, and payloads.
☐ Inspect electrical cords and ensure grounding.	☐ Computers and TCU are operational.	☐ Check all video feeds.
☐ Disconnect power when making modifications.	☐ Verify thruster functionality and video feeds.	☐ Pilot surfaces the ROV before retrieval.
☐ Ensure proper grounding of electrical equipment.	☐ Ensure all deck crew members are attentive and prepared.	☐
In-Water	Loss of Communication	Pit Maintenance
☐ Two operators handle ROV during deployment.	☐ Cycle power on TCU to attempt reconnection.	☐ Check thrusters for foreign objects.
☐ Tether-man maintains control of tether.	☐ If unsuccessful, power down and retrieve ROV.	☐ Visually inspect ROV for any damage.
☐ Visually inspect for leaks and bubbles.	☐ Inspect for physical damage or leakage.	☐ Ensure cables are properly secured.
☐ Engage thrusters and begin functional checks.	☐ Resume operations only after confirming safety and function.	☐ Check tether for kinks or tangles.
☐ Test manipulators and payload tools.		☐ Confirm watertight seals and component alignment.
		☐ Test all onboard tools, cameras, and thrusters.
		☐ Clean and wash down thrusters after use.

B. Pneumatic SID

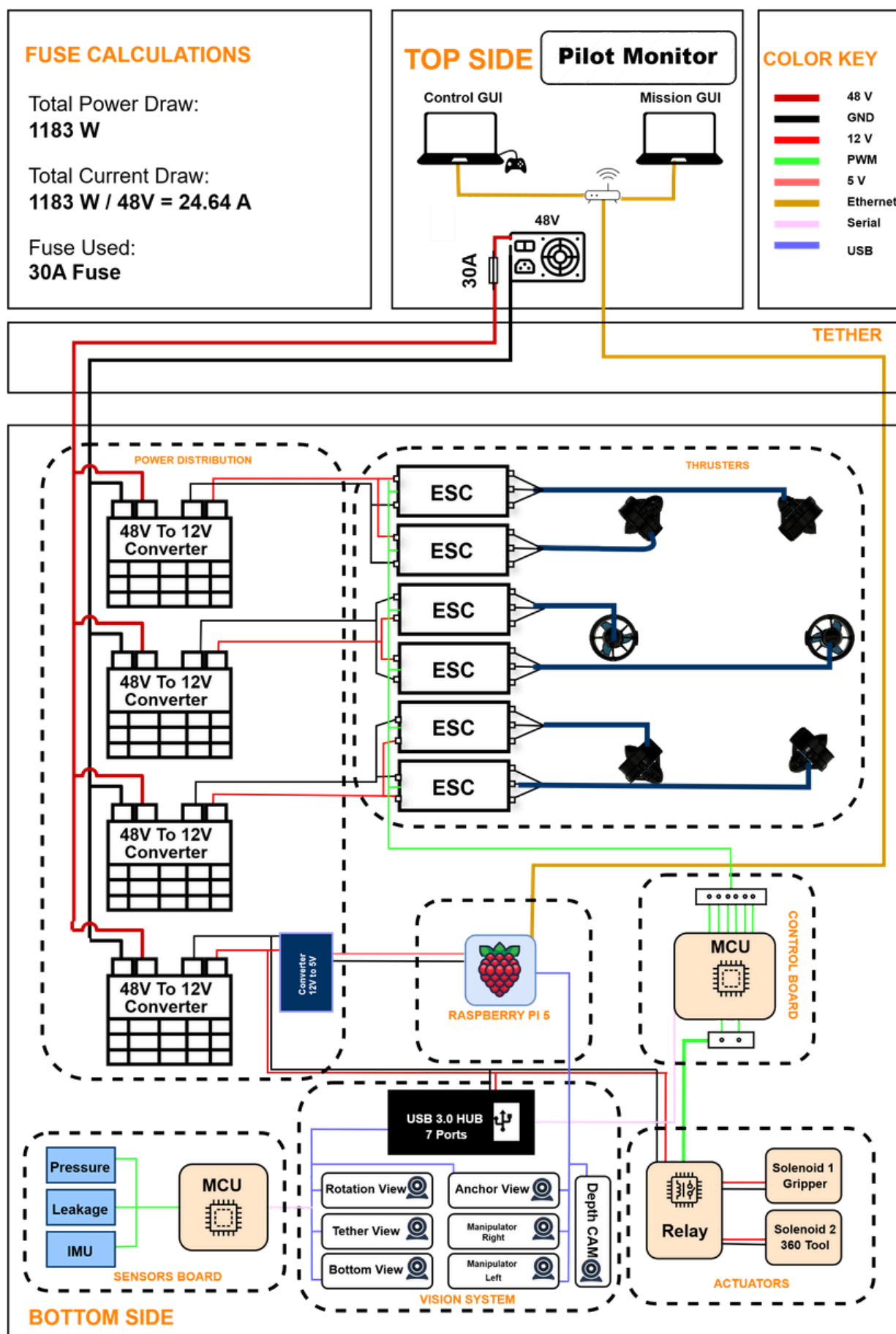


C. Electrical Power Budget

Condition	Value
Test: Full Forward + Full Down, all active	Underwater
Measured FLA	24.64 A
Total Power Draw	1183 W ÷ 48V
Fuse Selected	30A Littelfuse

Component	Model Description	Qty	Voltage (V)	Max Current (A)	Config Current (A)	Max Power per Unit (W)	Config Max Power per Unit (W)	Total Config Power (W)
Thrusters	Blue Robotics T200	6	12	14	14	168	168	1008
Buck Converters	48V-to-12V 30A (Thermal Loss)	4	48	0.25	0.25	12	12	48
Solenoids	Pneumatic Valve	2	12	1.5	1.5	18	18	36
ESC	Basic ESC	6	12	0.5	0.5	6	6	36
Main Processor	Raspberry Pi 5	1	5	5	5	25	25	25
Cameras	USB Camera	6	5	0.5	0.5	2.5	2.5	15
Microcontrollers	ESP 32	2	5	0.5	0.5	2.5	2.5	5
USB Hub	Powered USB Hub	1	5	1	1	5	5	5
Depth Camera	Intel RealSense D435i	1	5	0.7	0.7	3.5	3.5	3.5
Sensors	IMU Sensor	1	5	0.1	0.1	0.5	0.5	0.5
Sensors	Pressure Sensor	1	5	0.1	0.1	0.5	0.5	0.5
Sensors	Leakage Sensor	1	5	0.1	0.1	0.5	0.5	0.5
Total Power								1183 W

D. SID



E. Project Budget

The exchange rate between the U.S. dollar (USD) and Egyptian pound (EGP) is 52.64EGP per dollar

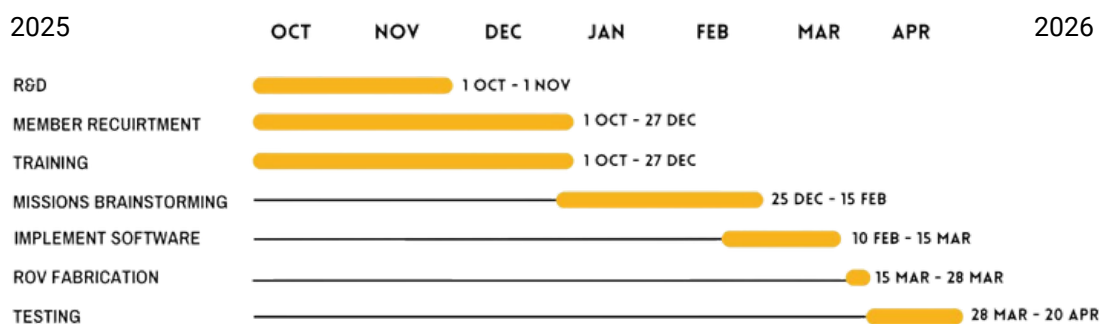
	Category	Description	Type	Projected cost (USD)	Budgeted Value (USD)
Product Costs	Thrusters	6*T200 , 6 ESC's	Re-used	1754.89	-
	Material	HDPE (Sheet + Cylinder), Aluminum Sheet, Acrylic (Sheet, Cylinder,Dome)	Purchased	169.46	169.46
	Fabrication	CNC Routing, Laser Cutting, 3D printing,Lathing	Purchased	120.32	120.32
	Pneumatic System	Pistons, Valves, Fittings, tubes	Purchased	70.02	70.02
	Fasteners	Screws, Counter Nuts, Caps (Stainless Steel)	Purchased	30.2	30.2
	Sealing	Rubber gasket, O-Rings, Glands, Epoxy	Purchased	60.54	60.54
	Electrcial System	PCBs, Electronic Components, 6*DC Converter	Purchased	196.74	196.74
	Vision System	1 IP Camera, 4 Analogue Camera	Re-used	120.36	120.36
	Depth Cam	intel depth camera d435i k39179-100	Donation	770	-
	Tether	Sheath, Power Cable, Ethernet Cable, Pneumatic Cable	Purchased	60.42	60.42
	Control Unit	Control Box, Monitor, Buttons, Joystick, AWG-6 Wires	Purchased	80.69	80.69
	Vehicle Safety Equipment	Shrouds, Caps, Stickers, Fuses	Purchased	18.46	18.46
Miscellaneous	Zipties, Heatshrink, Velcro, Weights, Buoyancy Foam	Purchased	15.96	15.96	
		Total		3,468.06	943.17
Running Costs	Playground	PVC Pipes, PVC Connectors, Spray Colors, Ropes, Plastic crate ,Brick	Purchased	80.15	80.15
	Competition Registration	Mate, Mate Egypt, Fluid Power Quiz	Purchased	663	663
	Printables	Brochures, Business Cards, Poster, Banners, Documentation Reports, Flyers	Donation	30	-
	T-shirts	Company Staff T-Shirts	Purchased	230.12	230.12
	Training	Transportation	Purchased	30.16	30.16
	Testing	Pool	Donation	-	-
		Total		1033.43	1003.43
Equipment Costs	Power Supply	4 *48V-30A	Re-used	62.25	-
	Compressor	15 Litre Compressor Unit+ FLR unit	Re-used	116.72	116.72
	Mechanical Tools	Driller, Screw Drivers, Piller, Angle grinder, Wrench	Purchased	98.46	98.46
	Electrical Tools	Soldering Iron Station, Flux, Solder, Avo Meter	Purchased	56.47	56.47
		Total		333.9	1,946.60
Total Cost				4835.39	3,893.20

Figure (21).Expenses

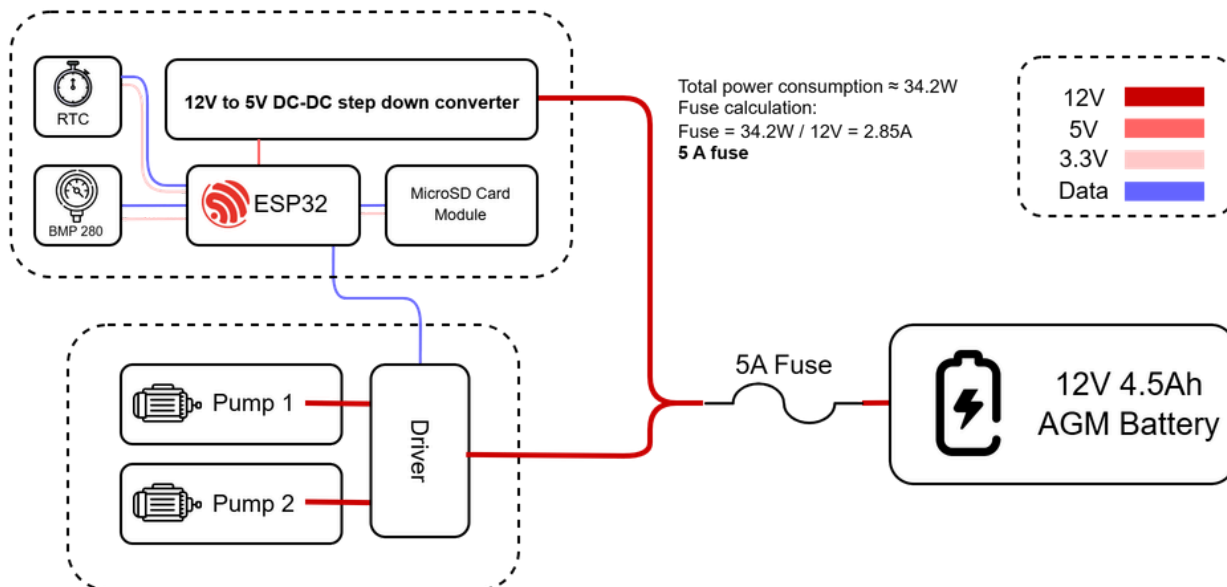
	Source	Category	Total (USD):
Income	Obour Institute	cash donate	2,650
	Employee Dues	self-fund	1,246
	Last Season	other	600
	Total (USD) :		4,496
Expenses	Category		Total (USD):
	Product Costs		3,468.06
	Equipment Costs		333.9
	Total		3,801.96

Category	Amount (USD) :
Total Income	4,496
Total Expense	3,801.96
Total Expenses-Re-Used/Donation	2330.85

F. TimeLine



G. Floating Device



Condition	Max Current Draw
Profiling (Both Pumps Stall)	2400 mA
Waiting / Transmitting (ESP32)	250 mA
Peripherals & Buck Loss	200 mA
System Total (FLA)	2850 mA (2.85 A)