

TECHNICAL DOCUMENTATION

27' Abdulrahman Hassan – CEO
28' Mazen Hossam – CFO | Director
28' Youssef Mohamed – CSO

SOFTWARE & AI

28' Marwan Mesbah – Vice Head
27' Ahmed Ibrahim – Vice Head
26' Sameh Kalach – Member
28' Jana Adham – Computer Vision
28' Maya Islam – Member
28' Youssef Nader – Member
29' Hiba Ahmed – Member
29' Mai Ayman – Member
29' Mohamed Ayman – Computer Vision
29' Yassin Abdallah – Computer Vision

MECHANICAL

27' Omar Ragab – Mechanical Leader
28' Huda Elbadry – Media Leader
27' Kareem Abdullah – Member
27' Mohamed Hassan – Member
28' Abdallah Elbanna – Member
28' Abubakr Abdelsadek – Member
28' Ghofran Hassan – Member
28' Lujayn Mohammed – Member
28' Minna Mohammed – Member

Mentors

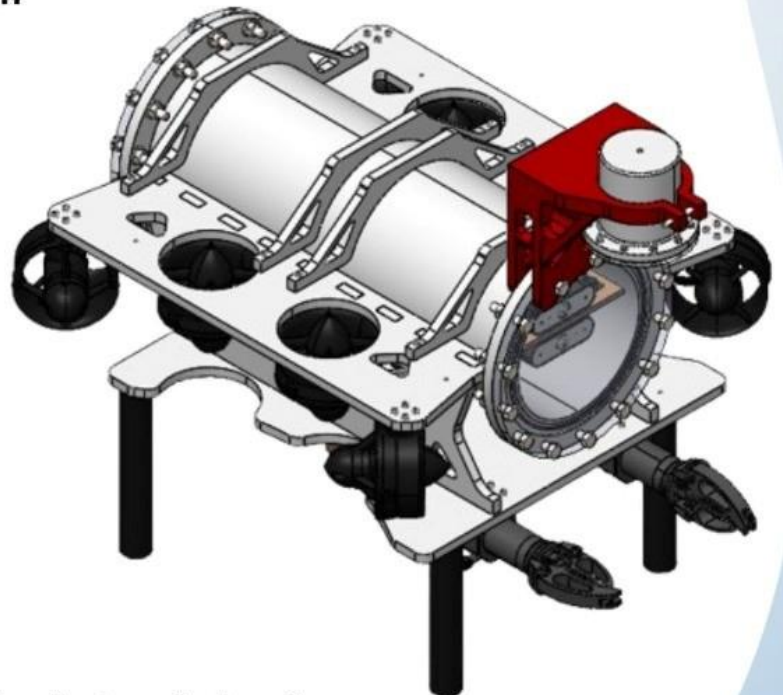
Fares Sherif – Seif Eldin Mohamed – Anton Ashraf

Arab Academy for Science, Technology & Maritime Transport.
Sheraton, Cairo, Egypt
MATE 2026

27' Ahmed Alhussainy – Pilot
28' Ali Omar – Co-Pilot
26' Mario Wassily – Software & Ai Head

ELECTRICAL & CONTROL

27' Abdullah Rostom – Control Leader
26' Mostafa Mesbah – President
27' Ahmed Ali – Member
27' Yusuf Ayman – Member
28' Khadija Kinawy – Member
28' Mostafa Akram – Member
28' Omama Elzubier – Member
27' Mohamed Hossam Eldin – Member



Abstract:

RobEn presents ORCA II, an upgraded Explorer-class ROV designed to tackle the 2026 MATE competition missions in the Great Lakes and ocean environments. It is based on our previous design, ORCA, with a smaller, streamlined frame, improved sealing of enclosures, and new IP cameras. These upgrades significantly enhance the remotely operated vehicle's (ROV) maneuverability, safety, and reliability. ORCA II is engineered for the 2026 MATE Competition and can document shipwrecks, install buoy sensors, collect water samples, and service renewable energy plant infrastructure. In this document, a comprehensive design rationale, system integration diagram, and analysis of testing and safety procedures are presented; the result of which is a refined ROV platform that meets mission tasks while exemplifying innovative solutions and professional engineering practices.



Contents

1. Organization	4	Article 20: Tether Design	11	Article 29: Troubleshooting & Verification	19
1A- Company Profile	4	Article 21: Tether Management Procedures	11	5.Resources.....	20
Article 0: Company mission and goals	4	2E- Control System	12	Article 39: Equipment & Tools	20
Article 1: Engineering philosophy	4	Article 22: System architecture	12	Article 40: Project Resources Allocation	20
1B- Project Management ..	4	Article 23: Software Control System	12	Article 41: Costing Sheet	20
Article 2: Work Breakdown Structure	4	Article 24: Pilot-ROV interface	13	6. Conclusion.....	20
Article 3: Project Timeline	4	2F- Software Development Process.....	14	Article 42: Innovations ..	20
Article 4: Team Resources	4	Article 25: Version control and early development	14	Article 43: Lesson Learned	21
Article 5: Team Protocols	5	Article 26: Module Integration.....	14	Article 44: Future Plans	21
2. Design Rationale	5	Article 27: Testing Methodology	15	Article 45: Acknowledgements.....	21
2A- Mechanical Design	5	3. Mission Tools	16	Article 46: References ..	21
Article 6: Frame Design..	5	3A- Mechanical System ...	16	7. Appendices.....	22
Article 7: Buoyancy	7	Article 30: Body	16	7A- Project Gantt Chart....	22
Article 8: Thrusters Configurations	7	Article 31: Buoyancy Engine.....	16	7B- Work Breakdown Structure	22
Article 9: Hydrodynamics	8	3B- Control & Software Architecture	16	7C- ROV SID	23
Article 10: Water Proofing	8	Article 32: LQI Control and Software Fusing	16	7D- Safety Checklist	24
2B-Electrical System Architecture	8	Article 33: State Estimation and Jitter suppression	16	7E- Costing Sheet	25
Article 11: Power Distribution	8	Article 35: AP-Mode Communication Protocol	17		
Article 12: Protection.....	9	3C- Electronics & PCB Design	17		
Article 13: Components Testing.....	9	Article 36: Power Distribution.....	17		
2C- Hardware equipment ..	9	Article 37: Safety & Electrical Compliance ...	17		
Article 14: On Board Computer	9	3. Engineering Operations...	19		
Article 15: Cameras.....	9	Article 28: Safety Management	19		
Article 16: Flight Controller	10				
Article 17: Manipulators	10				
Article 18: Depth Sensing	10				
Article 19: Connectors' Choice	11				
2D- Tether System.....	11				

1. Organization

1A- Company Profile

Article 0: Company mission and goals

RobEn focuses on developing individuals with the knowledge, experience and skills required to advance the ROV industry globally. Since 2013, the organization has been designing Explorer-class ROVs. RobEn challenges its capabilities by competing in MATE competitions annually. Through knowledge transfer, RobEn has grown significantly since then. Expanding expertise in marine exploration, environmental monitoring, and underwater infrastructure maintenance. The organization has also produced multiple graduates who now work in professional ROV operations at multinational companies, demonstrating the effectiveness of RobEn's training and engineering culture.



Figure 1. 2022



Figure 2. 2023



Figure 3. 2024



Figure 4. 2025

Article 1: Engineering philosophy

RobEn follows a design philosophy centered on iterative improvement, practical engineering, and mission-driven design. Each new ROV generation is developed by analyzing the strengths and limitations of previous vehicles and implementing targeted upgrades to improve performance, reliability, and safety. Design decisions prioritize modularity, durability, and ease of operation while maintaining cost-effective solutions.

Through structured brainstorming, prototyping, and testing, the team evaluates multiple concepts and selects configurations that best satisfy mission requirements. This systematic approach ensures that every subsystem of ORCA II contributes to a balanced, reliable, and efficient ROV platform.

1B- Project Management

Article 2: Work Breakdown Structure

The WBS (Appendix B) organizes the ORCA II ROV development into Three main subsystems: Mechanical, Electrical, and Software. Sharing it with the team from the start provided clear goals, improved trackability, and ensured smooth coordination across all tasks.

Article 3: Project Timeline

The schedule (Appendix A) utilizes overlapping phases to minimize time between conceptualization and final assembly. By running training alongside prototyping, the team applies new skills directly to the design. Also, validation window starting from day 1 of manufacturing ensures a continuous feedback loop. To support this fast-paced timeline, a thorough risk assessment for delays is conducted to mitigate potential technical or logistical bottlenecks.

Article 4: Team Resources

Over the years, the team has built an extensive **Google Drive** repository of knowledge, past documentation, and competition resources. The software Committee uses **Git** via **GitHub** for collaborative coding and stable releases. **Discord** facilitates online communication, while **ClickUp** manages tasks and team coordination. A dedicated workshop for RobEn serves as the main development space. Mechanical design is performed in **SOLIDWORKS**, and **ANSYS** enables advanced structural and fluid simulations. **ROS 2** and **Gazebo** support software development and system-level simulation before real-world testing.

Article 5: Team Protocols

RobEn's hierarchy ensures clear responsibilities and smooth collaboration. The board manages strategy, finances, and operations, sub-team leaders guide daily tasks, and members execute project work, with an advisory committee providing technical guidance.

CEO	Oversee overall strategy, team vision, and major decision-making.
CFO	Manages budgeting, funding, and financial planning.
CSO	Leads strategic planning, technical direction, and innovation initiatives.
HR	Handles recruitment, member development, and team welfare.
Sub-team leaders	Manage task breakdowns, supervise daily progress, and support team members in their roles.
Members	Execute assigned tasks, contribute technical or operational work, and collaborate within sub-teams.

Table 1. Team Hierarchy and Duties

Article 6: Frame Design

Material Selection

The ORCA II frame was built with HDPE for its strength-to-weight ratio, corrosion resistance, and ease of machining, while an acrylic front face provides visibility and durability at 30 meters depth.

Stainless steel fasteners are used to secure the structure.

Structural Design

The open-frame, rectangular design (620 × 500 × 400 mm) allows water to flow freely, enhancing maneuverability. Tubes and plates distribute loads evenly, while thrusters and subsystems are positioned for easy installation and minimal interference. Critical components are protected from vibration and impact, combining performance with accessibility.

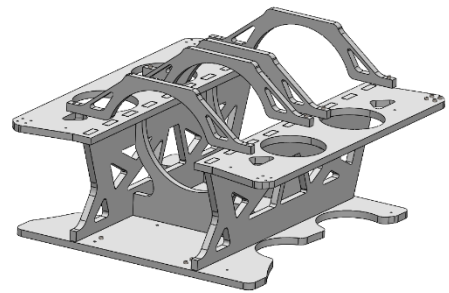


Figure 5. ORCA II Frame

2. Design Rationale

2A- Mechanical Design

The mechanical design of ORCA 2 began with an analysis of ORCA 1's strengths and weaknesses, along with changes in competition rules, to define updated goals and design constraints for the new ROV which are:

- 1- 15% overall weight reduction
- 2- Improved hydrodynamic behavior
- 3- Easier assembly and maintenance

ORCA 11

Technical Drawings

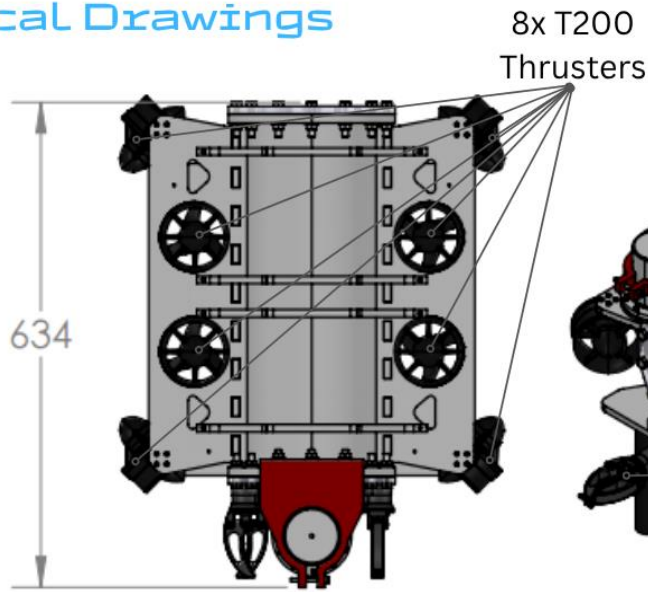


Figure 6. Top View

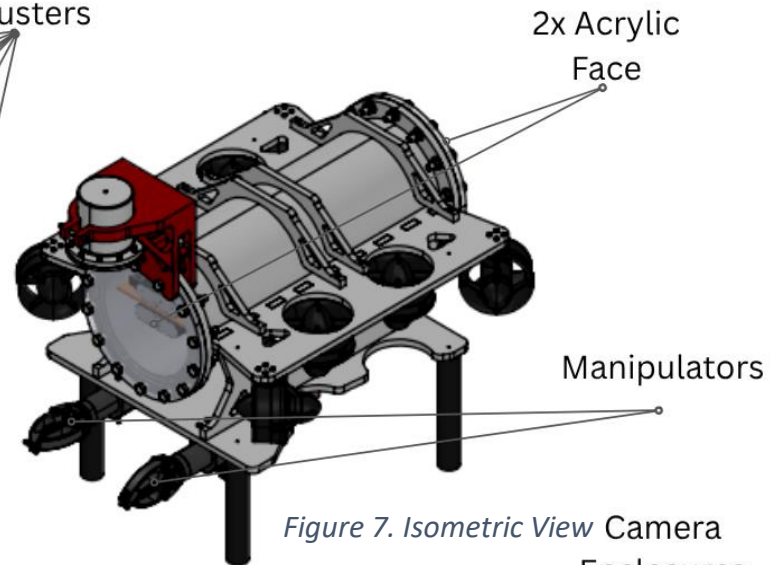


Figure 7. Isometric View Camera Enclosures

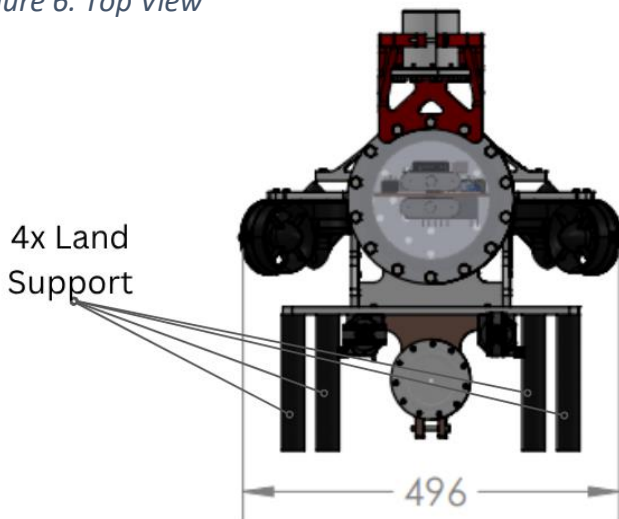


Figure 8. Front View

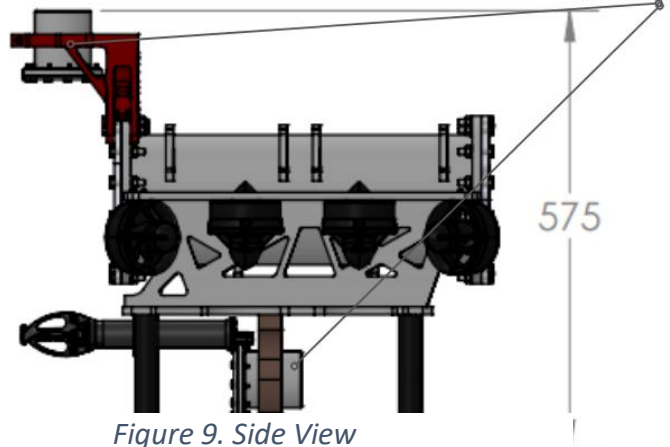


Figure 9. Side View

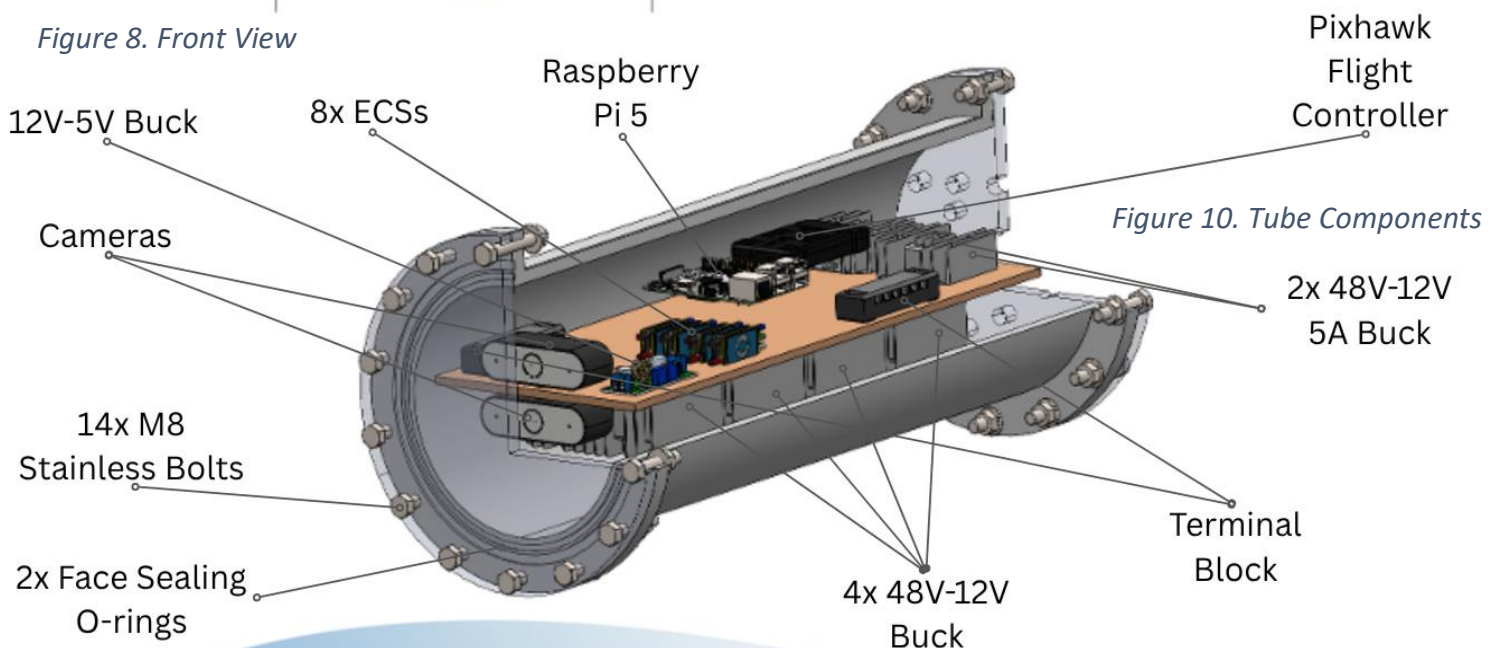


Figure 10. Tube Components

Article 7: Buoyancy

The ORCA II ROV's buoyancy system applies Archimedes' Principle by balancing the vehicle's weight with the upward buoyant force to achieve controlled motion. Stability is ensured by maintaining the center of buoyancy above the center of mass, achieved by placing lead weights at the base while flotation elements remain higher, generating a righting moment that naturally restores the ROV to an upright position. This configuration enables ascent, descent, and hovering while reducing tilting and rolling, improving balance, and enhancing overall control. According to Table 2, the system exhibits a slight positive buoyancy of approximately **16.25 N**, supporting stable and efficient operation.

Items	Q	Land Weight (N)	Buoyancy force (N)	Total Weight in water (N)
Top Tube holder	2	1.18005	1.24239	-0.06234
Top Plate	2	7.72978	8.1366	-5.40682
Side Support	2	8.88935	9.35615	-0.46681
Tube	1	21.05008	22.15739	-16.10731
Front acrylic face	1	4.31987	3.65921	0.66066
Back acrylic face	1	4.13466	3.50493	0.62973
Bottom Plate	1	10.38902	10.93581	-8.54679
Cameras	2	3.46413	2.59382	-0.12969
Top camera holder	1	1.83673	5.78496	-3.94824
Bottom tube holder	2	2.52627	2.65924	-0.13296

M8 Bolts and nuts length 4cm	25	8.90332	1.11292	2.79041
Gripper	2	12.08592	6.9948	2.09112
Thrusters	8	33.51792	13.716	14.80192
3 M8 Bolt and nuts length 6 cm	3	1.17162	0.14645	1.02517
Bottom Camera holder	1	2.93824	2.89197	0.04627
Internal Electronics	1	19.62003	2.4525	-3.5481
Total		143.75699	97.34514	-16.25433

Table 2. Buoyancy Table

Article 8: Thrusters Configurations

ORCA II is equipped with eight reused Blue Robotics T200 thrusters, providing full 6 DOF control for stability, precise maneuvering, and vertical lifting. Each thruster was tested for reliability while maintaining cost efficiency, and custom

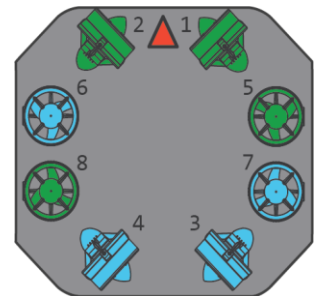


Figure 11. Thrusters Configuration

shrouds improve thrust by ~5% while enhancing safety. The symmetric layout produces 36.6 N forward and 29 N reverse per thruster, with total thrust of 73.1 N forward and 146.6 N vertical, operating up to 17 A per thruster at 12V. This season, horizontal and vertical thrusters were repositioned to reduce eddy currents, improving stability and control. Trade-offs, including the 8-thruster choice for high-stability tasks and weight reduction through optimized frame design, were

addressed with software current limiting to maintain safe operation under peak loads.

Article 9: Hydrodynamics

A computational fluid dynamics (CFD) study was conducted on ORCA II to analyze the flow field around the vehicle and evaluate its hydrodynamic performance. Figure 12 illustrates the velocity streamlines, showing how water flows smoothly around the frame with minimal separation. The results highlight the effectiveness of the open-frame design, where multiple cavities allow fluid to pass through rather than creating large wake regions behind the vehicle. Localized recirculation zones are observed near structural elements and thrusters, but they remain limited and do not significantly affect the overall flow behavior. This indicates reduced flow resistance and improved hydrodynamic efficiency during operation.

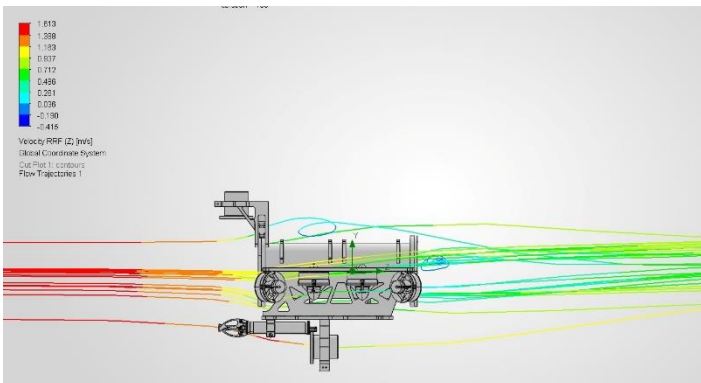


Figure 12. Velocity Streamline

Article 10: Water Proofing

Water ingress risks are mitigated through a combination of mechanical sealing and electrical insulation. All external connections pass through **sealed cable penetrators** (rated for underwater use and matched to cable diameter) to preserve enclosure integrity. The penetrators utilize compression-type sealing with elastomer grommets to ensure tight, leak-proof interfaces under pressure. Additionally, epoxy potting is applied at critical entry points to provide permanent sealing, enhance structural support, and prevent micro-leakage paths. The enclosure sealing is reinforced using a dual face-sealing O-ring configuration (**2 × O-rings, 170 × 4 mm,**

NBR70), which provides redundancy and improves resistance against pressure-induced leakage. The use of water-resistant buck converters, combined with these layered sealing methods, enhances overall system reliability during submerged operation.

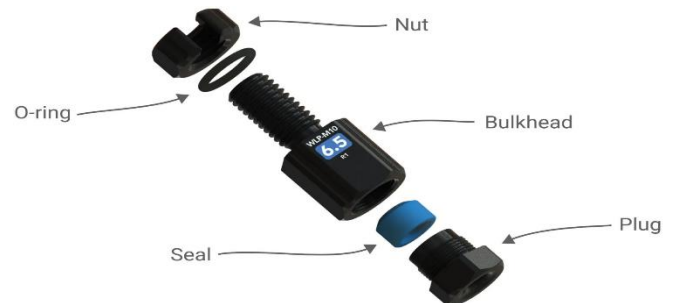


Figure 13. Penetrators

2B-Electrical System Architecture

Article 11: Power Distribution

Power distribution in ORCA II follows a modular architecture using four independent 48V–12V, 30A buck converters, each powering two thrusters to balance electrical and thermal loads and enhance reliability. The control system is isolated via separate conversion paths, with dedicated supplies for the flight controller and Raspberry Pi to ensure stable operation independent of propulsion loads. High-current paths utilize 12 AWG wiring to reduce losses, while XT60 connectors with sealed penetrators ensure reliable external connections. A common grounding scheme maintains a stable system reference. Based on Table 3, the system draws approximately 23A at 48V (1100W).

Item	Qty	Total Power Consumption [W]
Thrusters	8	832
Grippers	2	144
Raspberry Pi 5	1	15
PIXHAWK 2.4.8	1	2.5
Buck converter (360W)	4	72

Buck converter (60W)	2	6
Depth Sensor	1	1
IP Camera	3	22.5
USB Camera	1	3.5
Total		1098.5

Table 3. Power Distribution

Article 12: Protection

Protection is implemented through a distributed fault isolation approach rather than centralized protection. Each high-power buck converter is protected by a **25A inline fuse** at its input, ensuring that any overcurrent condition affects only the associated propulsion module. This prevents a single fault from disabling the entire system and allows the ROV to retain partial maneuverability.

Article 13: Components Testing

System validation was conducted through a structured, multi-stage process to ensure reliability and performance at every level before full deployment.

Component-level testing: Each thruster tested in air and underwater for thrust, responsiveness, and control behavior.

Electronics validation: Buck converters, control units, and sensors verified independently for stable operation.

System integration: Full assembly tested under combined mechanical and electrical conditions.

2C- Hardware equipment

Article 14: On Board Computer

The ROV uses a Raspberry Pi 5 as its main onboard computer, serving as the central hub for system control and communication. It runs ROS (Robot Operating System), which organizes the software into modular nodes responsible for tasks such as camera streaming, command handling, and communication with the flight controller. The Raspberry Pi manages data

exchange between subsystems and the ground station, receiving operator commands and transmitting sensor data and video feeds. It also coordinates all onboard systems to ensure synchronized and conflict-free operation.

Article 15: Cameras

The ORCA II vision system utilizes three Hikvision IP cameras to provide continuous live video streaming to the ground station, enabling full situational awareness during underwater operations. Each camera was strategically positioned to serve a specific purpose:

- One is housed inside the main pressure tube which gives frontal view.
- Another is placed between the robotic arms to give the operator a clear view of the manipulation area for accurate object handling.
- The third is mounted facing downward toward the working area, assisting in seabed approach and enhancing precision during delicate tasks.

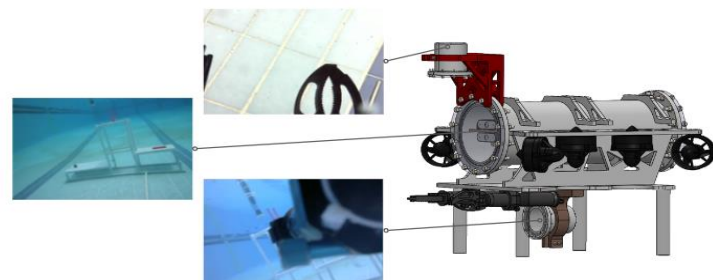


Figure 11. ORCA II Cameras

To further enhance perception, the ROV integrates a stereo camera system that provides depth estimation in the underwater environment. Using two lenses capturing images from slightly different viewpoints, the system calculates the distance to objects by analyzing the disparity between the images. This data is processed onboard by a dedicated computer, allowing the ROV to determine the relative position of objects in real time. The added depth perception improves the operator's spatial

awareness, supporting more accurate navigation and manipulation, and complements the standard camera system by adding a critical layer of visual intelligence.

Article 16: Flight Controller

The ORCA II is equipped with a Pixhawk 2.4.8 flight controller which serves as the low-level control unit, handling direct interaction with hardware components while the Raspberry Pi manages high-level operations, a separation that enhances system stability and enables real-time control. It receives commands from the Raspberry Pi and translates them into electrical signals that drive the thrusters and robotic arms, controlling motor speed, direction, and manipulator positioning with high responsiveness due to its fast control frequency. At the same time, the Pixhawk processes data from onboard sensors to perform continuous stabilization, maintaining the vehicle's orientation and smooth movement even under disturbances. Acting as a central interface between sensors and actuators



Figure 15. flight Controller
ensures precise and reliable execution of operator commands across the propulsion and manipulation systems.

Article 17: Manipulators

The ORCA II ROV is equipped with two robotic arms that enable direct interaction with the underwater environment, with their movement controlled by the Pixhawk flight controller based on operator commands. These manipulators are used to grasp, lift, and handle objects, allowing the vehicle to perform mission-critical tasks involving physical interaction with equipment or seabed

structures. The use of two arms adds operational flexibility, as one arm can stabilize an object while the other performs a specific action, improving precision and control. Through this capability, the robotic arms extend the ROV's function from passive observation to active intervention. ORCA utilizes two Blue Robotics Newton Subsea Grippers (Figure 21), compact, rugged arms made of aluminum 6061-T6 with a 300m depth rating. Each gripper has a 62-mm jaw opening and delivers 97-124N of grip force. While their single-degree-of-freedom limits underwater precision, they were chosen for their lightweight design, power efficiency (9-18V, 6A peak), and superior sealing over bulkier pneumatic alternatives.



Figure 16. Blue Robotics Newton Gripper

Article 18: Depth Sensing

The MS5837-30BA pressure sensor shown in Figure 20 is a vital component in Orca's navigation system, providing precise depth measurement and environmental monitoring. With the ability to measure up to 30 bars (at a depth of 300m) with a 2mm resolution, this sensor ensures accurate depth control for underwater operations. It operates over an I2C interface at 3.3V–5.5V, making it compatible with ArduSub, Raspberry Pi, and Arduino. Additionally, its built-in temperature sensor ($\pm 1^{\circ}\text{C}$ accuracy) enhances environmental data collection. By integrating this high-resolution



Figure 12. Pressure Sensor

sensor, ORCA II achieves better stability, automated depth regulation, and improved maneuverability, which are essential for exploration, inspection, and scientific research tasks.

Article 19: Connectors' Choice

The electrical system of our ROV has undergone significant improvements to enhance efficiency, safety, and organization. One key upgrade is the adoption of XT60 connectors (Figure 3) for the electronic speed controllers (ESCs) and power cable inside the ROV pod, which provide a secure and reliable connection while simplifying assembly and maintenance. These connectors are designed to handle high currents safely, reducing the risk of overheating or accidental disconnections during operation.



Figure 18. XT60 Connectors

2D- Tether System

Article 20: Tether Design

The ORCA's tether system consists of five Cat6 Ethernet cables, along with a positive and ground power cable. Two Ethernet cables are routed internally through the main tube using sealed penetrators to connect the Raspberry Pi and the onboard IP camera, while the remaining three are routed externally to support additional cameras. The power cables are 12 AWG copper conductors, selected to handle the required current while maintaining sufficient flexibility to avoid imposing mechanical load on ROV. Sufficient testing is done to ensure that the noise

produced by the power cables does not cause noticeable interference.

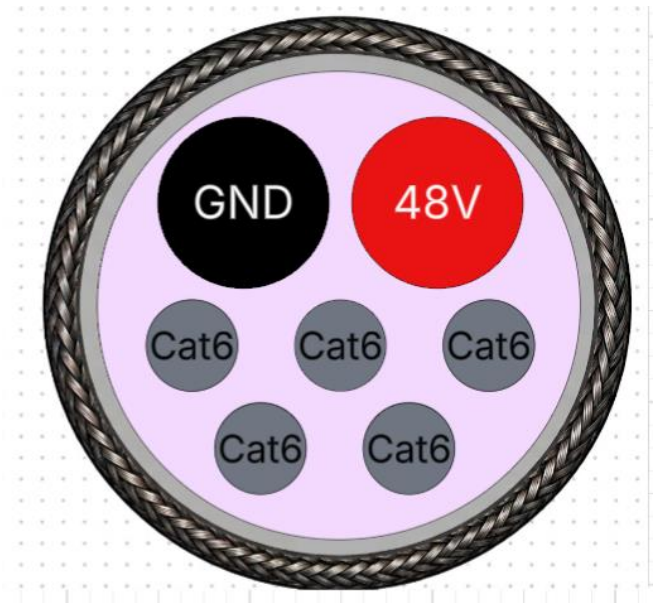


Figure 19. Tether Cross-Section

Article 21: Tether Management Procedures

- **Initial Check:** Examine the tether before use to verify it is intact and securely attached.
- **Launch Procedure:** Unroll the tether with care to avoid knots or snags, maintaining contact with the command unit throughout.
- **Operational Oversight:** Keep a constant watch on the tether's strain levels to avoid excessive stress.
- **Real-Time Tuning:** Modify the tether's length and tension on the fly to adapt to situational shifts.
- **Recovery Phase:** Wind up the tether in a methodical manner once the task is complete, ensuring it remains untwisted.
- **Post-Use Review:** After use, thoroughly check the tether for wear, fraying, or any other potential issues.

2E- Control System

Article 22: System architecture

The ORCA II ROV is built on a layered control architecture that separates mission-level software, flight control, and hardware actuation into distinct tiers, allowing modular development and independent testing. The mission layer runs on the Raspberry Pi 5 using ROS 2, where autonomous navigation, localization, sensor fusion, and mission logic are executed. Beneath it, the flight control layer is handled by the

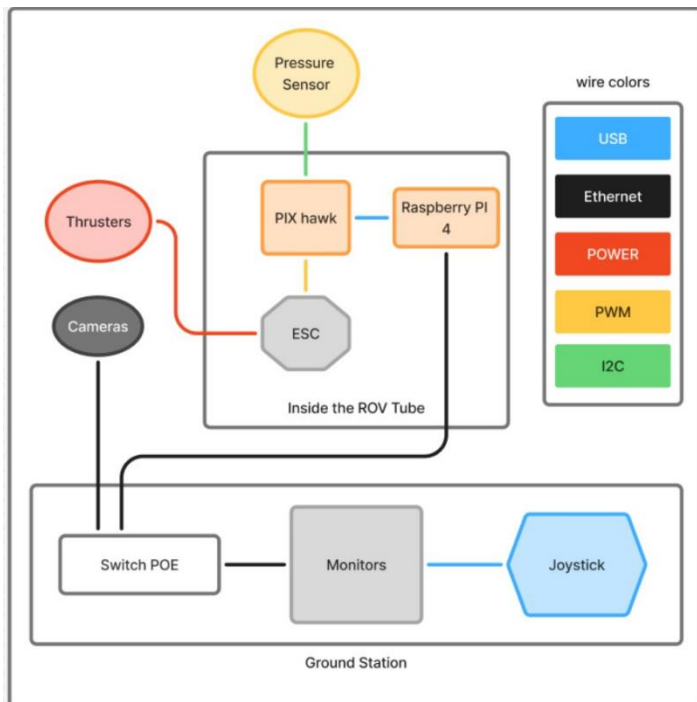


Figure 3. Control System Diagram

Pixhawk 4 running ArduSub firmware, translating high-level commands into precise motor outputs while processing sensor data such as depth and orientation. The actuation layer consists of eight brushless thrusters and two robotic arms, directly interfaced with the Pixhawk to execute movement and manipulation tasks.

The system hardware is centered around the Raspberry Pi 5 as the onboard computer and the Pixhawk 4 as the flight controller, supported by a set of sensors and peripherals that enable perception and interaction. An Intel RealSense D415 stereo camera provides depth and localization data, while three Hikvision IP cameras

deliver multiple visual perspectives for operation and monitoring. A pressure sensor supplies real-time depth feedback, and a Mercusys PoE+ network switch acts as the communication hub, powering and connecting the cameras. Together, these components form an integrated platform that supports both autonomous functionality and operator control.

Article 23: Software Control System

The ORCA II software control system is a fully custom-built ROS 2 stack developed in-house, integrating flight control, localization, sensor management, autonomous navigation, and camera supervision into a unified framework. Running on the Raspberry Pi 5, the ORCA ROS 2 stack acts as the central brain of the ROV, orchestrating autonomous behavior and managing communication with the Pixhawk 4. The software is structured into modular packages—including Orca_base, Orca_bringup, Orca_description, Orca_msgs, Orca_nav2, and Orca_shared—each responsible for specific functionalities such as control logic, system initialization, simulation modeling, messaging, navigation, and shared utilities.

Autonomous navigation is built on the Navigation2 (Nav2) framework, extended with custom 3D plugins tailored for underwater operation. These include a straight-line planner for generating 3D paths, a pure-pursuit controller for trajectory tracking, and specialized progress and goal checkers to evaluate mission execution. This framework enables the ROV to navigate in three-dimensional space with accurate path following and reliable goal validation, forming the backbone of its autonomous capabilities.

Low-level flight control is handled by the Pixhawk 4 running ArduSub firmware, which manages motor mixing, stabilization, and sensor fusion. Communication between the Raspberry Pi and Pixhawk is established through the MAVLink protocol via MAVROS, acting as a bridge between ROS and the flight controller. The system

continuously exchanges commands and feedback, with motion commands and pose estimates sent to ArduSub while attitude data is received at high frequency to support real-time state estimation. The Extended Kalman Filter (EKF) ensures stable localization, allowing the system to transition smoothly into fully autonomous operation once a reliable pose is established.

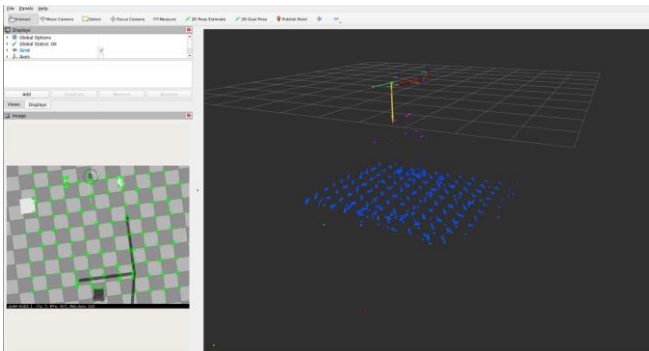


Figure 21. Autonomous Navigation in Action

Localization is achieved using SLAM with the Intel RealSense D415 stereo camera, mounted on the underside of the ROV. When the seafloor is visible, the camera provides depth data used to generate a 3D pose estimate, which is fused with onboard sensor data for accurate positioning. In conditions where visual data is unavailable, the system maintains navigation through dead-reckoning based on motion models and previous states. Loop closures and map updates further refine localization, ensuring consistent accuracy during repeated operations in the same environment.

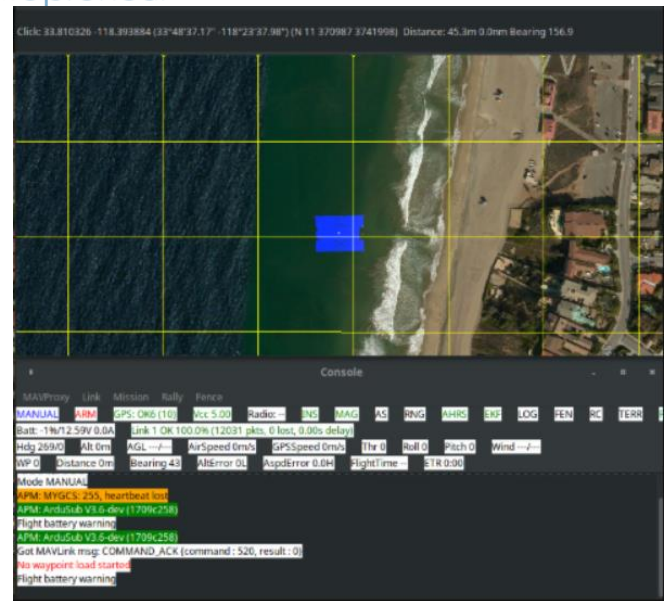


Figure 22. SITL

Operator interaction is supported through QGroundControl and MAVProxy for manual piloting, allowing seamless switching between autonomous control and pilot override. Visual feedback is provided by three Hikvision IP cameras, streamed to the ground station via the iVMS-4200 software. Each camera is positioned to offer a specific perspective—forward navigation, downward arm monitoring, and close-up manipulation—while being powered and connected through a PoE+ network switch. Together, these systems provide both control and situational awareness, ensuring efficient and reliable operation of the ROV.

Article 24: Pilot-ROV interface

The pilot-ROV interface defines the complete communication pathway between the ground station and the vehicle, supporting both manual control and mission monitoring through a centralized network architecture. At the ground station, a Mercusys MS108GP switch acts as the main node, connecting the pilot workstation, the Raspberry Pi 5 via Cat 6 Ethernet, and three Hikvision IP cameras through PoE+, while the RPi5 itself is powered internally. Pilot commands originate from QGroundControl, pass through MAVProxy using the MAVLink protocol, and are transmitted via the network to the Raspberry Pi,

where MAVROS bridges the commands into ROS 2 and forwards them via USB to the Pixhawk 4 running ArduSub, which then actuates the eight thrusters and two robotic arms. In parallel, video feedback is streamed independently through the network switch from the cameras to the ground station using iVMS-4200, providing the pilot with forward navigation, downward monitoring, and close-up manipulation views without impacting control latency, while the Intel RealSense D415 operates solely within the onboard SLAM pipeline and is not displayed to the operator.

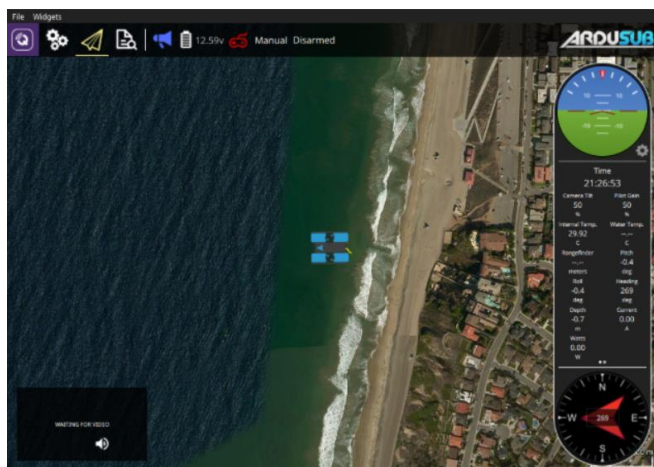


Figure 23. QgroundControl

2F- Software Development Process

Article 25: Version control and early development

All source code for ORCA II is managed through a GitHub repository, with Git used to track changes, support collaboration, and maintain a structured development workflow. Development is organized using dedicated branches for new features, bug fixes, and configuration updates, which are reviewed before being merged into the main branch to ensure stability. Commit messages follow a consistent convention to maintain a clear and traceable history of changes, aiding in debugging and development tracking. Additionally, release tags are applied at stable checkpoints, representing tested builds of the system and allowing the team to reliably reference specific versions of the software.

During early development phases, ORCA II follows a modular approach in which individual ROS 2 nodes and packages are developed and tested in isolation before full system integration. Packages are structured using standard ROS 2 conventions, with clearly defined interfaces, including topics, services, and action established prior to implementation to ensure consistency and scalability. Hardware-dependent nodes are initially developed using simulation-based stubs, allowing core logic to be validated without requiring immediate access to physical components. Additionally, configuration parameters are externalized through ROS 2 parameter files, enabling flexible deployment and seamless transition between simulation and real-world operation.

Article 26: Module Integration

Module integration for ORCA II follows a phased approach, gradually combining individual components into the complete system, with each phase validated before proceeding to the next. Initial integration occurs in a high-fidelity simulation environment replicating pool dimensions, seafloor features, and obstacles, running on Gazebo Harmonic with standard buoyancy, hydrodynamics, and thruster plugins, while the ArduSub SITL build simulates the Pixhawk 4 via the ardupilot_gazebo bridge. The full ROS 2 stack—including SLAM, navigation, and base controller nodes—is launched against the simulation to validate autonomous missions such as dives, waypoint navigation, and localization transitions prior to hardware testing. Physical integration then progresses through staged testing, beginning with network and connectivity verification between the ground station, RPi5, Pixhawk 4, cameras, and switch, followed by surface functional tests of motors, arms, telemetry, and camera feeds. Shallow water tests validate depth hold, SLAM initialization, and manual control, culminating in full mission trials executing complete autonomous profiles, including dives, navigation, SLAM loop closures,

and surface return. Stages are completed based on readiness and objectives, with non-underwater tests prioritized to reduce risk and logistical effort.

Article 27: Testing Methodology

The ORCA II testing methodology follows a three-tier strategy: unit testing, simulation-level integration testing, and real-world validation, ensuring defects are identified and resolved early in development.

Unit Testing

Individual ROS 2 nodes and utility components are tested in isolation using mock data or stubs to simulate hardware. Tests cover motion command logic, localization transitions, EKF pose processing, and navigation plugin outputs, and are executed through the ROS 2 colcon test runner. All unit tests must pass before code is merged into the main branch.

Simulation Testing

Integrated functionality is validated within the Gazebo Harmonic simulation environment, which replicates hydrodynamics, thruster behavior, and sensor outputs. Autonomous missions are executed in simulation to test initialization, descent, SLAM acquisition, waypoint navigation, loop closure, and mission completion. Simulation logs are reviewed for anomalies in pose estimation and navigation performance.

Real-World Testing

Physical testing follows the staged integration plan. Out-of-water tests verify network connectivity, telemetry, motor and arm operation, and camera feeds. In-water tests validate depth control, SLAM localization, camera coverage, and full autonomous mission execution in the deployment environment.

Acceptance Criteria

A test passes when all targeted ROS 2 nodes initialize correctly, MAVLink communication is stable, the EKF provides a stable pose, SLAM mapping and loop closures succeed, camera feeds remain live and stable, and the ROV completes the programmed mission within defined positional tolerances.

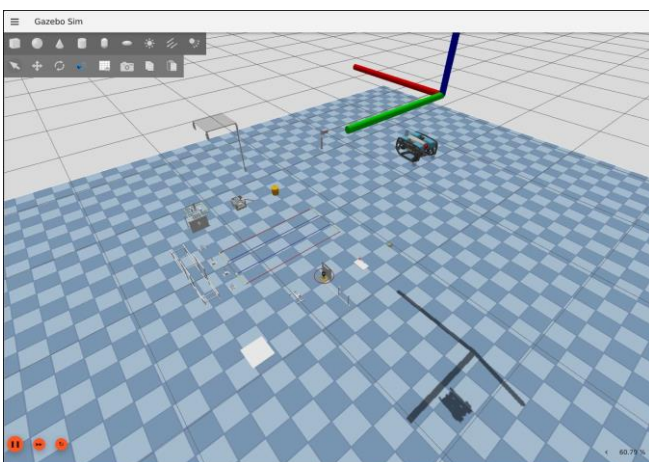


Figure 24. Our Simulation Environment

Lasagna

The Vertical
Profiling Float

3. Mission Tools

3A- Mechanical System

Article 28: Body

The float's chassis is a 1 m tall acrylic cylindrical body (radius 8 cm) with O-ring-sealed endcaps for shallow water use. The structure is supported by aluminum rods and houses the electronics, motor, and buoyancy mechanism. The system is designed with a slight positive buoyancy, allowing minor ballast adjustments to quickly change the direction of the resultant force.

Article 29: Buoyancy Engine

Motion is achieved via a DC motor with an integrated encoder, geared for high torque, driving a lead screw. This screw translates rotational motion into linear displacement of the piston to change the float's density. The ballast of the float is composed of 4 60ml syringes with a combined cross-sectional area of 20 cm².

3B- Control & Software Architecture

Article 30: LQI Control and Software Fusing

We implement Linear Quadratic Integral (LQI) control to minimize a cost function J that balances depth error against actuator effort. A critical feature of our LQI implementation is the "Software Fuse." It mathematically limits the rate of change of the motor PWM to prevent high current inrush spikes, protect the batteries, and reduce mechanical wear on the lead screw.

Article 31: State Estimation and Jitter suppression

A Kalman Filter mitigates inherent pressure sensor noise through real-time state estimation to improve measurement accuracy. Additionally, small movements are minimized near the target depth, creating a mathematical soft deadband that prioritizes battery longevity over microscopic

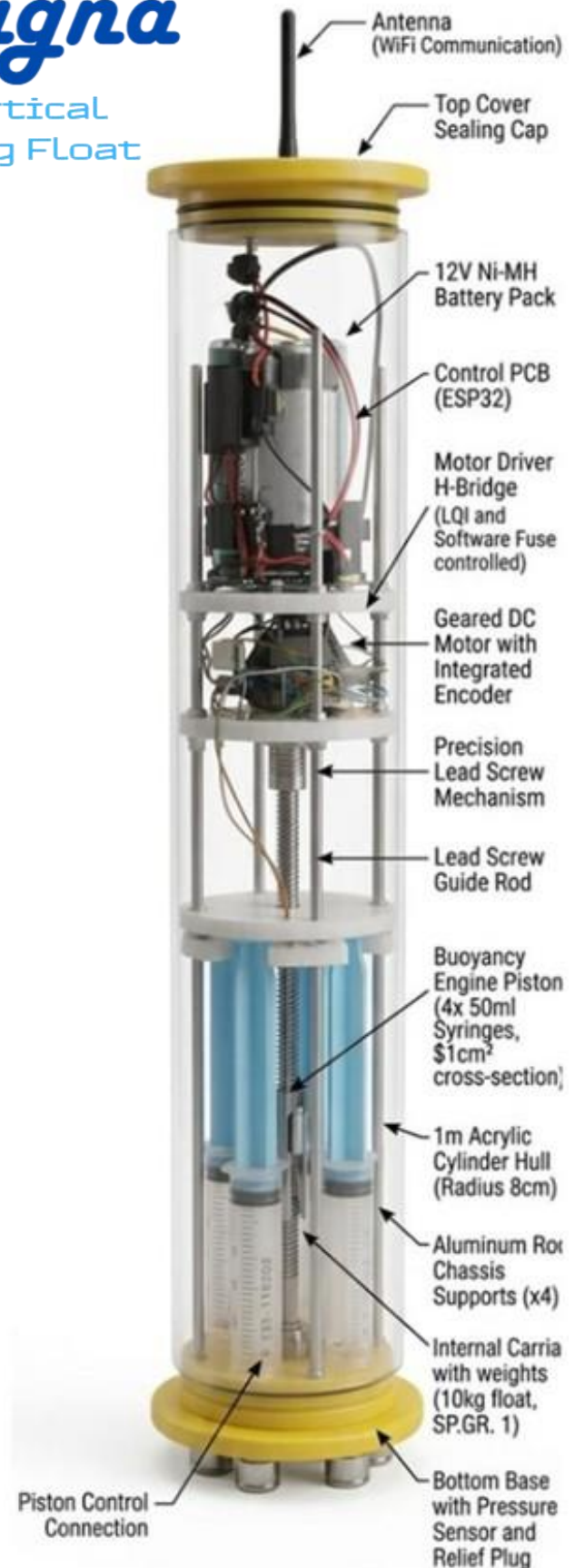


Figure 25. The Lasagna

position corrections while maintaining the 2.5m set point.

Article 32: System Identification and Optimal Learning Loop

To An outer-loop SID strategy ensures the LQI controller operates on an accurate plant model by performing pre-competition drops to characterize the drag and optimize the Q and R matrices for the best stability and least power consumption.

Article 33: AP-Mode Communication Protocol

The A Store-and-Forward telemetry strategy logs mission data in a structured onboard array and then, upon surfacing, uses a four-step handshake to securely transmit validated data to the ground station, ensuring no data is lost during operation

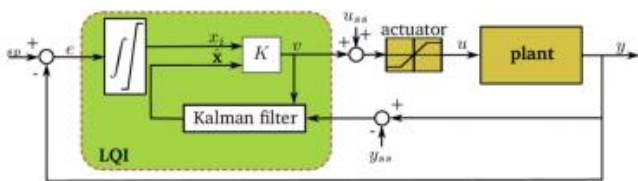


Figure 26. LQI with Kalman filtering

3C- Electronics & PCB Design

A custom PCB serves as a breakout board for the ESP32 and motor driver, enhancing robustness by eliminating point-to-point jumper wires that introduce failure points from vibration or moisture.

Article 34: Power Distribution

Two parallel chains of 3-series Ni-MH batteries provide a 12V supply to meet the motor's voltage requirements. The parallel configuration increases instantaneous current capacity (5A[fused]) to safely handle the motor's full-load current (FLA) while reducing voltage drop and providing redundancy. Power is routed through a 5A fuse to the motor driver, which supplies the 12V DC motor, while a 3.3V linear regulator steps

down voltage for the ESP32 and motor encoder.

3D- Rubric Fulfillment & Compliance

Article 35: Safety & Electrical Compliance

ELEC-NRD-001 (Power Limits): The system operates at a nominal 12V DC via two parallel Ni-MH chains, protected by a 5A fuse.

ELEC-NRD-003.1 (Battery Mounting): Batteries are secured in a custom internal carriage that slides along the 4 frame rods, keeping them immobile during profiling and handling.

ELEC-NRD-003.2 (Physical Fusing): A 5A TAN fuse is installed on the positive terminal within 5cm of the battery pack, providing redundant protection alongside software limits.

Pressure Relief: The endcap features a 16 cm diameter pressure relief plug that releases when internal pressure exceeds ambient pressure, as required by MATE safety standards.



Figure 27. The Battery Pack

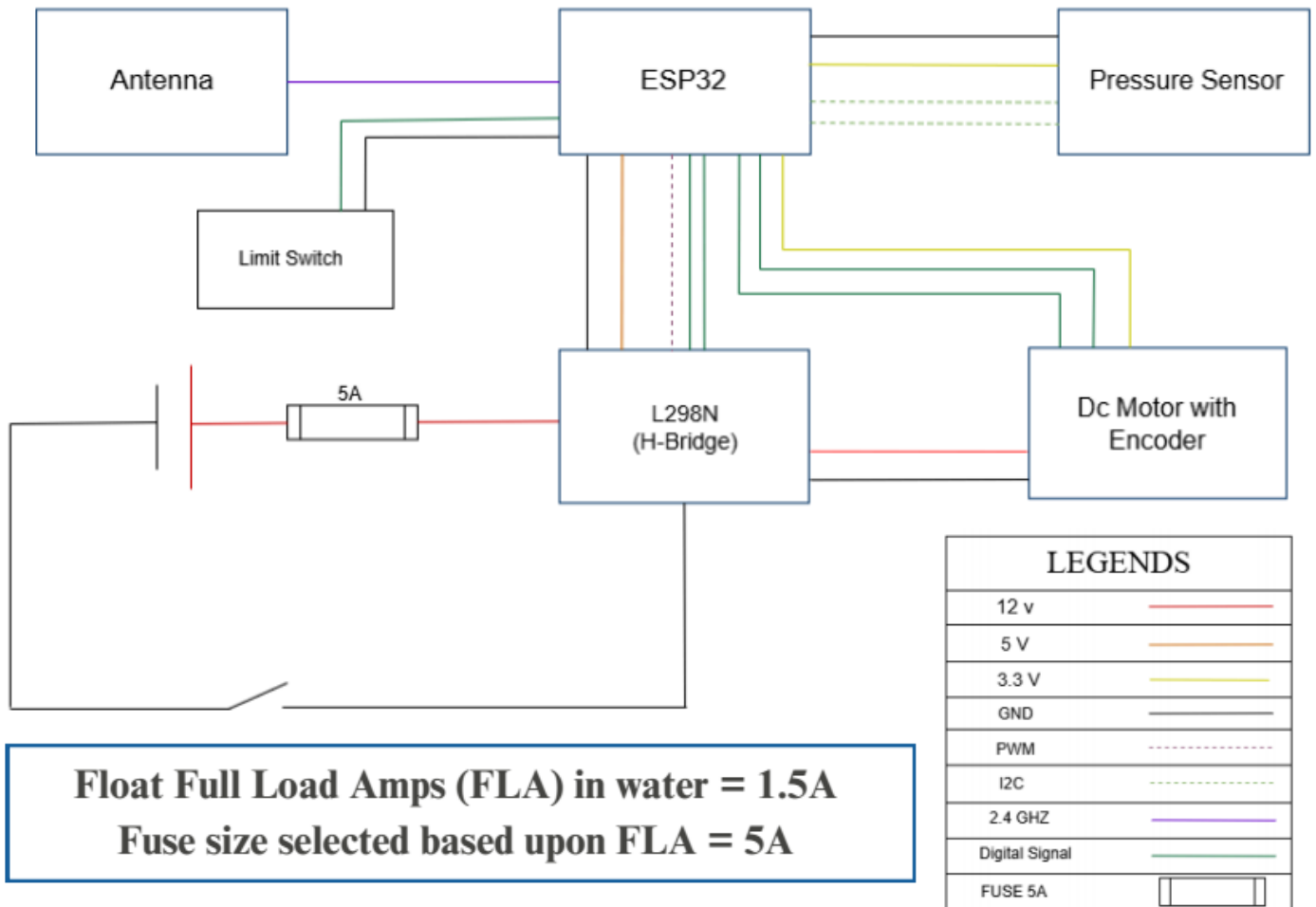


Figure 28. Float SID

Mode	Current (A)	Notes
Quiescent	0.080	ESP32 Active
Nominal Drive	0.450	LQI Optimized
Peak Stall	1.100	Software Fuse Threshold
RF TX	0.400	peak TX bursts

Figure 29 Mesured Full Load Current

3. Engineering Operations

Article 36: Safety Management

ROV Safety Standards:

The ROV complies with the safety protocols established by the MATE competition, incorporating a range of built-in safeguards across its mechanical and electrical systems. Reliable Anderson connectors are used to ensure stable power connections, and pressure release mechanisms are in place to avoid excessive internal pressure. The electrical circuitry is protected by fuses that prevent system overloads, while leak detection sensors enable rapid response to any water intrusion. To avoid cable damage, an anti-strain feature is included, and critical components are enclosed with protective barriers to guard against impact and environmental stress. Collectively, these safety measures enhance both operator protection and system reliability, particularly in demanding underwater scenarios.

Workshop Rules:

Operating within a confined workspace, our team prioritizes maximum efficiency through structured protocols and disciplined workflow management. With each academic cycle, incoming first-year members are systematically oriented on workspace layout, safety standards, and a clearly defined code of conduct. This ensures a consistently organized and hazard-aware environment, which is critical for both operational effectiveness and personnel safety.

Attention is given to slip hazard mitigation, especially during poolside operations. To address this, we implement strict guidelines, as explained in our job safety and environment analysis (JSEA), including the use of non-slip footwear and personal protective equipment (PPE) (Figure 26), immediate cleanup of water spills, clearly marked wet zones, and designated dry areas for electronic

equipment handling. Additionally, all personnel are briefed on movement protocols around the pool to reduce the risk of accidents. These procedures, combined with our overall organizational standards, contribute to a controlled, safe, and highly functional work environment suited for underwater robotics operations.



Figure 30. Employee working with PPE

Dive Authorization (Safety Checklist)

The Safety Checklist (appendix D) must be completed and signed by the CSO prior to any ROV dive. It serves as a formal record of our commitment to workshop standards and poolside safety protocols. Once all checks are finalized, the completed form must be archived with the mission logs to ensure full accountability, operational transparency, and continuous improvement of our safety management systems.

Article 37: Troubleshooting & Verification

Before initiating any ROV testing, a structured troubleshooting protocol is implemented, adhering to the systematic approach of “*divide, isolate, and analyze*.” Each specialized team—mechanical, electrical, and software—employs logical deduction to identify the nature of any anomalies. Issues are first classified according to

their domain and then narrow down progressively through subsystem and component-level inspection. This methodical breakdown enables efficient fault localization, minimizes diagnostic time, and ensures precise corrective action across all system layers.

Electrical Components Verification

- Individual testing of all electrical modules for functionality and stability
- Integration checks to ensure compatibility and prevent signal interference
- Validation of reliable communication between subsystems

Sealing Verification

- High-pressure test up to **3 bar (30 m depth equivalent)**
- Verifies waterproofing beyond competition requirements (5 m)
- Confirm safe operation with added reliability margin

5. Resources

Article 38: Equipment & Tools

The team has built a set of power and hand tools over the years that covers most of its needs, so most work is done in-house. Only specialized processes like laser cutting and machining are outsourced to dedicated workshops.



Figure 31. RobEn's Tools

Article 39: Project Resources Allocation

Resource allocation in ORCA was guided by performance requirements, cost efficiency, and system reliability. A structured decision-making approach was adopted to determine whether components should be manufactured in-house or purchased, while also evaluating the reuse of existing assets to optimize budget utilization and development time.

Buy Vs Reuse:

A significant portion of the system was developed using previously available components (see appendix D), including selected propulsion and electronic elements. Reusing these components reduced overall cost and shortened development time while maintaining proven reliability. New components were introduced where performance improvements or design requirements could not be met by existing assets. This selective upgrade strategy allowed the system to evolve without unnecessary expenditure, ensuring both competitiveness and resource efficiency.

Article 40: Costing Sheet

A detailed costing sheet is provided in the appendix, listing all system components along with their procurement status (purchased or reused), unit cost, and overall contribution to the project budget. This breakdown highlights the financial impact of design decisions and demonstrates the effectiveness of the resource optimization strategy, particularly in leveraging component reuse to reduce total system cost. (Appendix E)

6. Conclusion

Article 41: Innovations

ORCA II marks a significant shift toward a more resilient and modular architecture by decentralizing its hardware and standardizing its software. The team eliminated a critical single point of failure by routing camera feeds directly to the ground station rather than through the

onboard Raspberry Pi, while simultaneously migrating from bare OS services to ROS 2 for more maintainable inter-process communication.

This iteration significantly improves autonomy and efficiency through SLAM-based navigation, AI-driven 3D reconstruction replacing physical sensors, and a simulation-first approach using Gazebo Harmonic for reliable, hardware-independent development.

Article 42: Lesson Learned

The team gained several practical insights during the design, manufacturing, and testing of the ROV. These lessons highlighted the importance of simplicity, quality, and proper system integration.

- Simpler sealing designs performed better than complex multi-part systems
- Manufacturing accuracy and assembly quality directly affect performance
- Proper thruster spacing improved flow and efficiency
- Direct camera integration increased system complexity and reduced reliability
- Switching to IP PoE cameras improved stability and wiring
- Incorrect cable sizing caused power and reliability issues

Article 43: Future Plans

Based on these observations, the team identified several areas for improvement to enhance performance and reliability in future iterations

Investigate alternative actuation methods beyond standard motors

- Refine frame design to better align with thruster configuration
- Improve system architecture by distributing tasks across multiple processors

- Upgrade cables to properly handle higher current loads
- Continuing iterative improvements based on testing and operation

Article 44: Acknowledgements

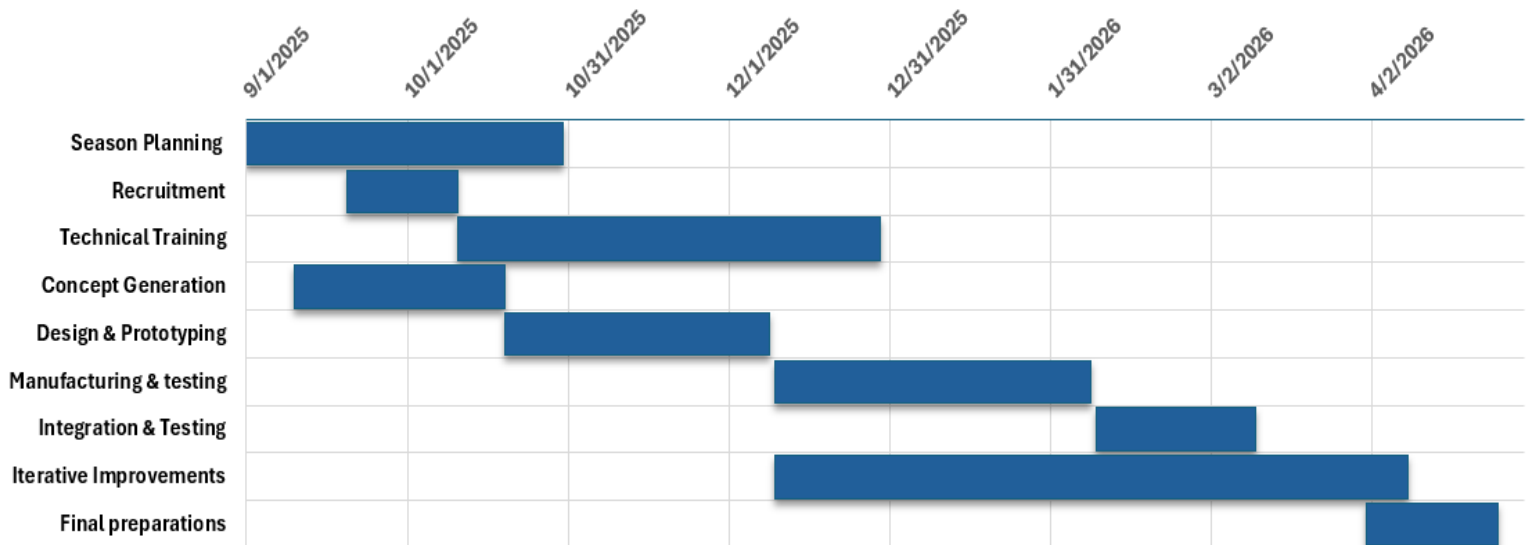
We would like to express our sincere gratitude to **Arab Academy for Science, Technology & Maritime Transport** for its continuous financial and institutional support in funding our ROV project, providing the resources necessary for design, manufacturing, testing, and system integration throughout the season. We also extend our deep appreciation to our mentors, **Fares Sherif** and **Seifeldin Mohamed**, whose guidance, technical insight, and previous competition experience were invaluable in helping the team overcome design and operational challenges. Their mentorship greatly contributed to both our engineering decisions and overall project development. In addition, we gratefully acknowledge **The Club** for generously providing access to a swimming pool facility, which enabled us to conduct essential in-water testing, calibration, and performance validation under controlled conditions. Their support played a significant role in improving the reliability and readiness of our vehicle before competition.

Article 46: References

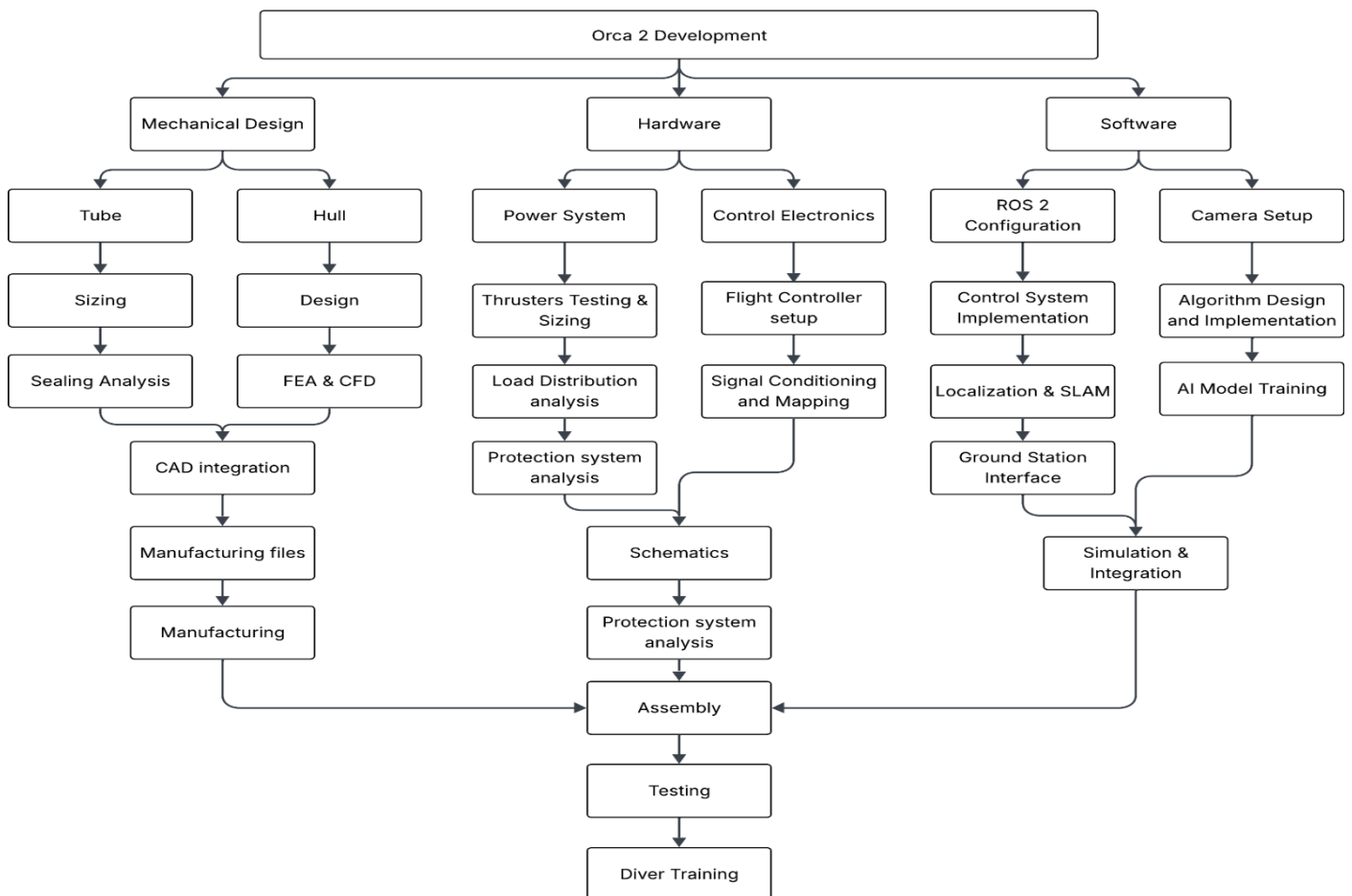
1. <https://www.marinetech.org/>
2. <https://bluerobotics.com/store/>
3. https://web.archive.org/web/20150923183329/IRP_5.V2.0.0_20180507.pdf
4. <https://www.parker.com/content/dam/Parker-com/Literature/O-Ring-Division-Literature/ORD-5700.pdf>
5. Robert D. Christ (2014). The ROV Manual – 2nd Edition. Elsevier Ltd.
6. Steven W. Moore (2010). Underwater Robotics Science, Design and Fabrication 1st_Edition. Marine Advanced Technology Edu.

7. Appendices

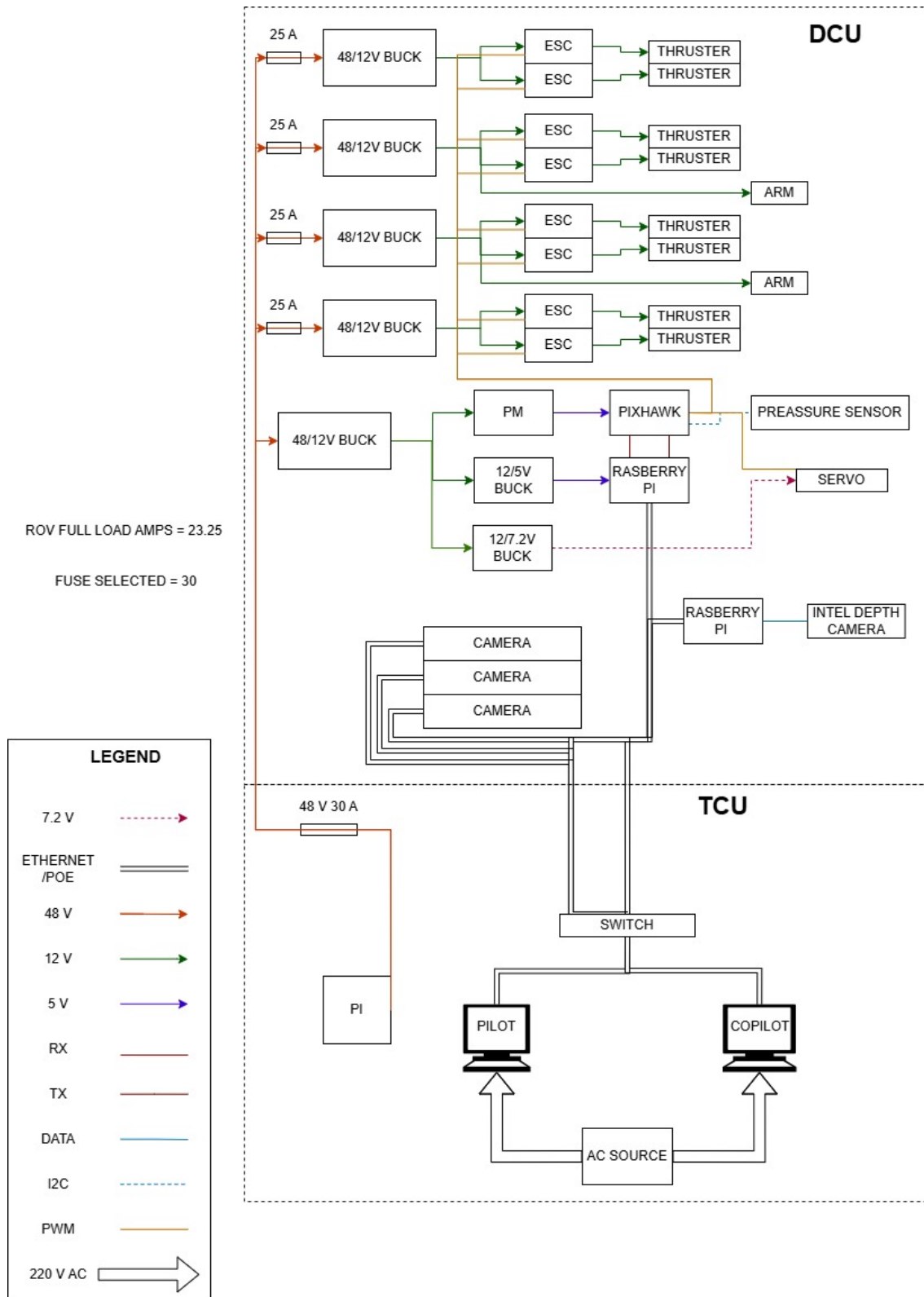
7A- Project Gantt Chart



7B- Work Breakdown Structure



7C- ROV SID



7D- Safety Checklist

SAFETY CHECKLIST

Date	
Task	
Done by	
Revised by	

CONSTRUCTION SAFETY

- ☐ Workspace clean and free of debris.
- ☐ Tools stored properly.
- ☐ Safety goggles used during cutting.
- ☐ Gloves worn when handling sharp materials.
- ☐ Inspect all equipment before use.

PRE-POWER TEST

- ☐ Verify area is free from obstacles.
- ☐ Ensure main power switch is **OFF**.
- ☐ Plug in Power Supply.
- ☐ Check tether is properly connected.
- ☐ Connect Anderson power connector between the power supply and the TCU.
- ☐ Connect the Ethernet cable to laptops and the hub.
- ☐ Power **ON** all laptops and the hub.
- ☐ Connect the control computer to QGroundControl.
- ☐ Connect the camera system to the camera monitoring laptop.
- ☐ Connect the float control system to the float laptop.
- ☐ Ensure the tether is stretched out properly.
- ☐ Connect strain relief to both the ROV and the station.
- ☐ Confirm the Tether Operator is in position.
- ☐ Confirm the tether operator is handling the tether safely.
- ☐ Tether Operator confirms readiness.

- ☐ Switch **ON** the power.
- ☐ Start the mission.

Q-GROUND TEST

- ☐ Test Thrusters.
- ☐ Test robotic arm.
- ☐ Test position control.
- ☐ Test orientation control.

SEALING TEST

- ☐ Verify that every **O-ring** is placed correctly.
- ☐ Tie the ROV with a rope for safety.
- ☐ Lower the ROV to the bottom of the pool.
- ☐ Check for bubbles.
- ☐ Remove the ROV from the pool.
- ☐ Check for a leak in the tube.
- ☐ Re-lower the ROV.
- ☐ Recheck again for leaks.
- ☐ Start a dry test.
- ☐ Start a wet test.
- ☐ Remove the rope.

COMMUNICATION LOSS

- ☐ The pilot calls out the **"KILL"** switch.
- ☐ Check Ethernet connection.
- ☐ Check communication services.
- ☐ Reboot the system.
- ☐ If communication is restored, resume the mission.

7E- Costing Sheet

Company Name:		RobEn			From:15/10/2025	To:20/3/2026
Expenses:						
category	Type	date	Component	Notes	Amount	Running Balance
Float engine	Purchased	1/11/2025	Pressure sensor	required for float mission	\$8.25	\$8.25
	Purchased	15/3/2026	PCB	circuit of the float	\$7.65	\$15.90
	Purchased	28/2/2026	antenna	for communication of the float	\$4.00	\$19.90
	Purchased	27/10/2025	Battery and fuses	to power the float	\$31.67	\$51.57
	Re-used	-	materials and manufacturing	body of the float	\$85.50	\$137.07
	Re-used	-	ESP 32 wifi bluetooth	controller for the float and station	\$8.30	\$145.37
	Purchased	15/1/2026	DC motor with encoder	to move syringes	\$18.07	\$163.44
	Purchased	15/1/2026	H-Bridge	The float's DC motor driver	\$3.00	\$166.44
Tether	Purchased	14/2/2026	CAT 6 30 meter	ethernet communication	\$22.00	\$188.44
	Purchased	15/3/2026	Power wire 40 meter	power cable	\$17.73	\$206.17
	Re-used	-	braided cable 30 meter	safety cable	\$9.80	\$215.97
Electronics	Purchased	14/2/2026	Camera	Vision of ROV	\$101.32	\$317.29
	Purchased	15/3/2026	Servo 360°	rotation mission	\$9.41	\$326.70
	Re-used	-	Buck 48/12V , 30A	used to convert power in the ROV	\$172.00	\$498.70
	Purchased	27/10/2025	Desktop Switch	connection of ethernet	\$20.70	\$519.40
	Re-used	-	Amass XT60	connector for power	\$10.20	\$529.60
	Purchased	15/2/2026	Cable AWG 16	connect power circuit	\$25.00	\$554.60
	Purchased	17/3/2026	DC to DC converters	used to convert power in the ROV	\$37.27	\$591.87
	Re-used	-	power supply	used to power the ROV	\$48.00	\$639.87
	Re-used	-	intel camera	used for autonomus missions	\$258.00	\$897.87
	Re-used	-	raspberry pi 4 8G/raspberry pi 5	microcontroller	\$265.00	\$1,162.87
	Purchased	20/10/2025	Pikhawk	flight controller	\$152.14	\$1,315.01
	Re-used	-	8° ESCs	contoller of motors	\$304.00	\$1,619.01
	Purchased	1/11/2025	pressure sensor	to measure the depth	\$8.25	\$1,627.26
	Purchased	14/2/2026	3.3V regulator	dropping higher V	\$2.67	\$1,629.93
Hardware	Purchased	7/2/2026	tube	frame of the float	\$75.00	\$1,704.93
	Purchased	7/2/2026	acrylic sheets	frame of the ROV	\$30.00	\$1,734.93
	Purchased	7/2/2026	body and frame	body of the ROV	\$107.00	\$1,841.93
	Purchased	20/2/2026	playground	used for practice	\$40.70	\$1,882.63
	Purchased	7/2/2026	O-rings	for sealing	\$38.00	\$1,920.63
	Re-used	-	glands	penetrators	\$9.00	\$1,929.63
	Purchased	10/2/2026	Epoxy	for sealing	\$18.26	\$1,947.89
	Purchased	6/2/2026	bolts and nuts	fasteners	\$14.00	\$1,961.89
	Purchased	28/11/2025	tools and testing parts	for testing	\$59.00	\$2,020.89
	Re-used	-	Newton gripper	to pick and place parts	\$1,280.00	\$3,300.89
	Re-used	-	8° T200 thrusters	thrusters	\$1,600.00	\$4,900.89
	Re-used	-	shrouds, joystick,fuses	for pilot	\$58.30	\$4,959.19
		Total re-used	\$4,108.10			
		Total purchased	\$851.09			
		Total spent	\$4,959.19			