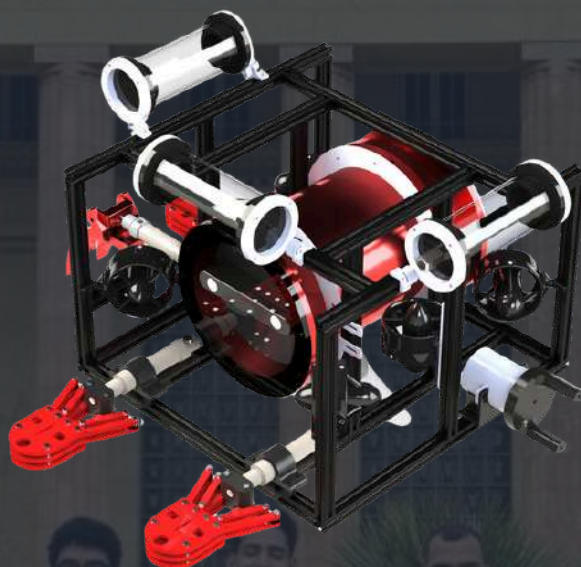


GLACIUS



TITANS ROBOTICS TECHNICAL DOCUMENTATION

ALEXANDRIA UNIVERSITY
ALEXANDRIA, EGYPT

SUPERVISED BY **Dr. Abdelrahman Ismail**

COMPANY STRUCTURE

SOFTWARE ENGINEERS

28' Marwan Eltete **CEO**
27' Hamdy Ahmed **CFO**
27' Youssef Emara **FM**
27' Ali Ahmed **CV/ML Lead**
29' Mohamed Ashraf **Control Lead**
28' Youssef Mohamed **Float PM**
28' Yassin Khaled **TDR & PR Lead**
27' Salma Hassanien **Media Lead**
27' Ammar Elsaadany*
27' Aya Aziz*
27' Fajr Muhammad*
28' Abdelrhman Hazem*
28' Ahmed Hany*
28' Amr Kenawy*
28' Farah Fawzy*
28' Jana Mehanna*
28' Tasneem Ashraf*
28' Mariam Elshamy*
28' Mostafa Elshafey*
28' Abdelrahman Nabil*
29' Rodina Ghazaly*

ELECTRICAL ENGINEERS

29' Saif Tabouna **FM**
27' Ahmed Fawzy*
28' Mohamed Samir*
29' Ahmad Abdelghany*

MECHANICAL ENGINEERS

30' Noureldeem Hassanien **FM**
26' Ahmed Hatim*
26' Seif Elsayed*
27' Mohamed Hany*
27' Yousab Youssef
28' Ahmed Farouk*
28' Mohamed Youssef*
28' Saifeldeen Khafagi*

Graduation Year

*Denotes New Members

PM : Project Manager

FM : Functional Manager

TDR : Technical Documentation

PR : Public Relations

MENTORS

Abdelrahman AbouKlila	Ahmed Fathy
Abdelaziz Yousry	Asmaa Aboshadi
Mahmoud Reda	Mazen Sakr
Moustafa Hala	Esmail Salah
Abdelrahman Essam	Ahmed Kamel
Ali Moenes	Maryem Mohamed
Mustafa Mohamed	Omar Ahmed

ABSTRACT

Titans Robotics is a student-led company from Alexandria University, engineering innovative underwater robotic systems and uniting students across disciplines in pursuit of one goal: advancing the frontier of subsea exploration. Our interdisciplinary team integrates mechanical, electrical, and software engineering expertise to build practical, high-impact solutions for real-world underwater challenges, as shown in Figure 1.

For MATE ROV 2026, we introduce GLACIUS. Named after the Latin root for ice, the vehicle directly embodies this year's theme; pushing performance in the harshest underwater conditions of currents, waves, and ice. GLACIUS represents our commitment to reliable, mission-driven engineering beneath the surface.

GLACIUS features a modular architecture enabling seamless component adjustment and maintenance, alongside a robust control system engineered to maintain stability and precision against disruptive environmental forces. The ROV is purpose-built to tackle this year's missions; coral ecosystem surveying and 3D modelling, invasive species identification, iceberg threat assessment, offshore wind platform infrastructure installation, and autonomous under-ice float deployment alongside our companion float, FLOATILLA.

Development followed a rigorous, iterative process emphasizing system stability, safety, and reliability at every stage. At MATE ROV 2026, GLACIUS reflects our company's dedication to pushing the boundaries of underwater robotics, one mission at a time.



Figure 1: Titans Robotics Team
Photo By : Abdullah Fawzy

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MATE Center & Marine Technology Society: For organizing and sponsoring the MATE ROV Competition.

AASTMT & AASTMT Stadium: For hosting the MATE regional competition in Egypt and providing an inspiring venue for our ROV journey, and always allowing us to train and test Float.

Alexandria University: For serving as our official entity, providing continuous support, and covering registration fees that facilitated our participation.

Vortex Academy: For providing hardware equipment and resources essential to our development process.

Makers Electronics & Ampere Electronics: For providing the resources and facilities that enabled us to successfully complete this project.

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Flaticon & GStreamer: For enhancing our design and system integration.

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Vortex Explorers 2025: For their continuous technical support.

Our mentors: whose invaluable guidance and insight throughout the process helped this project reach its current success.

Dr. Abdelrahman Ismail: For his continuous support throughout our journey.

Our families, friends, and company members: For their unwavering support and encouragement throughout this journey.





Teamwork

Company & Personnel Overview

Titans Robotics is a student-led company of 30 members from Alexandria University, dedicated to pushing the boundaries of subsea robotics, uniting mechanical, electrical, and software engineering expertise to address real-world underwater challenges, as illustrated in **Figure 2** and summarized in **Table 1**.

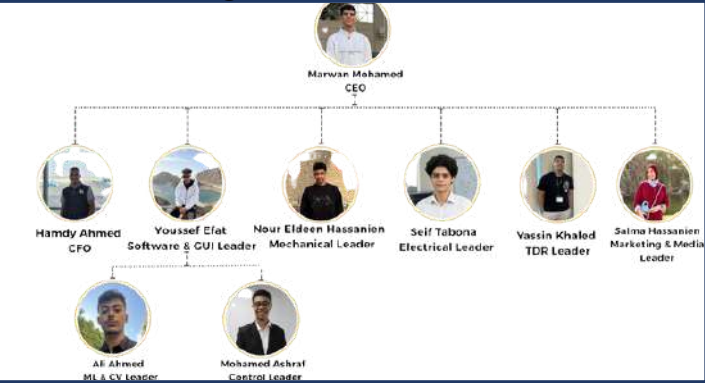


Figure 2: Company Structure
Photo by Yassin Khaled

Corporate Structure & Leadership

Position	Responsibilities
CEO	Defines the overall strategy, sets long-term goals, and manages external relations and partnerships
CFO	Oversees financial planning, budgeting, and resource allocation
Leaders	Coordinate between team members, manage workflow, and ensure tasks are completed on time and aligned with team objectives
Members (Technical & Non-Technical)	Contribute to project execution across different domains, including engineering, programming, marketing, media, and documentation, while collaborating with leaders for guidance and direction.

Table 1: Corporate Structure [15]
Made by Yassin Khaled

Project Management

Schedule

In August, the entire team came together to lay the foundation for the project. This phase covered defining the overall scope, establishing a timeline, dividing work into clear development phases, and setting Key Performance Indicators (KPIs) to track progress, evaluate departmental productivity, and identify areas needing additional support. These KPIs are revisited regularly to ensure continued alignment with project goals, as illustrated in **Figure 3**.

Phase 1: R&D and Recruitment (September – November 2025)

This phase focused on two parallel efforts: R&D: We performed a detailed analysis and enhancement of the previous ROV model (MEGATRON) [3] and float system. Issues identified in past performance were addressed, and new design opportunities were explored. Training and Recruitment: New team members were onboarded and trained in department-specific fundamentals (e.g., PCB design, SolidWorks, embedded systems). Cross-training sessions promoted interdisciplinary awareness.

Phase 2: Design and Ideation – December 2025 to January 2026

Following the release of the official competition manual, R&D findings were combined with the new competition requirements to develop GLACIUS's concept. Each subsystem; mechanical, electrical, and software; proposed initial designs that were collaboratively reviewed and refined. Mission-specific tools and payloads were also designed during this phase, ensuring every element was purposefully built for this year's challenges.

Phase 3: Manufacturing and Assembly – February to March 2026

With designs finalized, subsystems moved into fabrication and assembly. Mechanical components were 3D printed and machined, electrical systems were soldered and tested, and software was integrated into embedded systems. Interdepartmental collaboration was central to this phase, ensuring smooth handoffs and efficient system integration throughout.

Phase 4: Debugging and Continuous Improvement – April 2026

With the full system assembled, the team entered an intensive and iterative testing phase. Each subsystem underwent rigorous evaluation under competition-simulated conditions, with extensive in-water testing informing targeted refinements to tools, payloads, and control systems. Continuous debugging cycles progressively strengthened system response, operator control, and overall reliability.

Phase 5: International Preparation and ROV Overhaul – May to June 2026

Following a 3rd place regional finish and nomination to the MATE International Competition, the team is currently undertaking a comprehensive overhaul of GLACIUS. Lessons learned from the regional competition are driving significant design and engineering changes, with every subsystem being revisited to meet the harsh demands of the international stage. Competing in Canada under this year's theme; Pushing Performance: Science, Technology, and Discovery in Harsh Environments [1]; GLACIUS is being re-engineered to withstand strong underwater currents and arctic-simulated conditions, with a sharper focus on stability, adaptability, and mission readiness.

ROV Project Gantt Chart

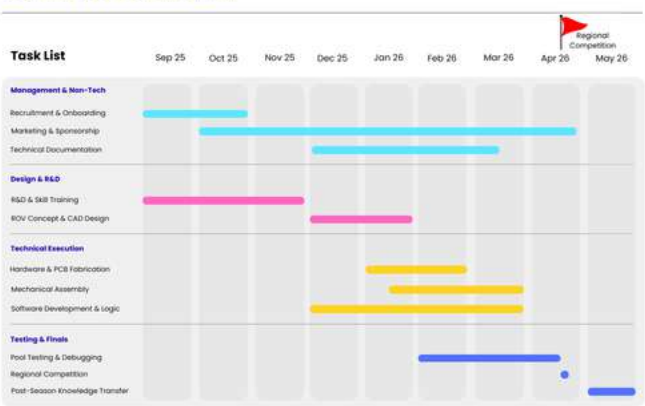


Figure 3: Gantt Chart Showing Project Schedule
Made by Fajr Mohamed



Resource, Procedure, & Protocol Management
Operational Management

To maintain a high operational tempo, Titans Robotics operates on a framework established during the planning phase, prioritizing agility and traceability to ensure every engineering decision is data-backed and every resource is utilized to its fullest potential.

The company follows a structured meeting cadence to ensure alignment at every level. Weekly meetings bring all department leads together to share progress updates, surface challenges, and maintain transparency across the company. Board meetings are held periodically to review strategic decisions, assess overall project direction, and ensure departmental accountability. General meetings gather the broader team to align on milestones and address cross-functional concerns. Notably, a full team gathering was held during Ramadan 2026, bringing all company members together to reflect on progress and strengthen team cohesion (Figures 4 and 5).

Beyond regular correspondence, the team relies on a suite of collaborative tools tailored to each department's needs. Communication transitioned from Slack to Discord [18] for more efficient real-time coordination; GitHub manages version control, code collaboration, and software integration; Google Drive organizes documentation across leadership and subteams; and Google Photos archives media from pool testing, events, and project milestones, as summarized in Table 2.

These integrated tools and practices promote effective collaboration, accountability, and scalable progress throughout the development cycle.



Fig 4: Ramadan Gathering
Photo By: Jana Mehanna

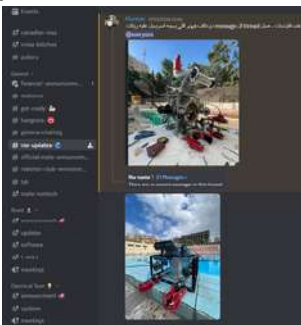


Fig 5: Discord Progress Update [18]

Resource	Usage Area
Slack → Discord	Started with Slack during training phase, then transitioned to Discord for more efficient team communication, coordination, and real-time collaboration
GitHub	Version control, code management, and collaboration on software and system integration
Google Drive	Organizing documents for leadership, subteams, and administrative workflows
Google Photos	Storing and sharing media from pool testing, events, and project milestones

Table 2: Communication Protocols [15]
Made by Yassin Khaled

Safety

At Titans Robotics, safety is not an afterthought, it is a core value embedded in every aspect of our work. Our safety framework spans personnel, operations, equipment, and vehicle systems, ensuring that every team member and every component is protected throughout the development cycle (Figures 6 and 7).

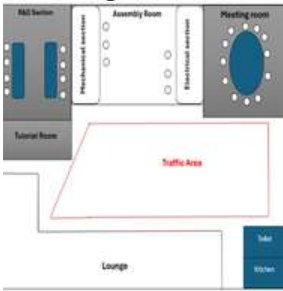


Figure 6: Titans Workshop
Made by Mohamed Ashraf



Figure 7: Titans First Aid Kit
Photo by Yassin Khaled

Personnel Safety

All members complete a structured safety training program before participating in any technical activity, including initial safety inductions covering lab rules, risk assessments, emergency protocols, and proper PPE use. Hands-on supervised sessions allow members to practice safe handling of electrical, mechanical, and pneumatic systems, supported by periodic refresher workshops and safety drills. During all in-water testing, Personal Flotation Devices (PFDs) are mandatory for all personnel [1], as shown in Figure 8.



Figure 8: Youssef Mohamed wearing PFDs during pool testing.
Photo by Marwan Mohamed

Operational Safety

Before each task, a Job Safety Analysis (JSA) is conducted to assess potential risks and define mitigation strategies. The company follows Standard Operating Procedures (SOPs) [1] for tasks such as soldering, ROV deployment, and software flashing. Technical issues are handled within the subteam, escalated to the department head if unresolved, and logged for follow-up. Clean bench policies are enforced across all workstations to maintain an organized and hazard-free environment.

Equipment Safety

All tools and test setups undergo scheduled inspections to ensure functionality and safety compliance. Electrical systems are tested for voltage regulation and current draw before integration, and all wiring is insulated with heat shrink tubing to minimize short circuit risks (Figure 9).



Figure 9: Propeller Shrouds
Designed & Manufactured by Mohamed Hany

Vehicle Safety

GLACIUS incorporates several hardware safety measures; a 25A fuse placed within 30 cm of the Anderson connector in compliance with competition requirements[1], color-coded and separated power and signal cables, rounded frame edges with cap nuts on exposed bolt threads, thruster guards around all rotating components, O-ring face seals [12] and cable glands for waterproofing, and warning labels on all critical components including thrusters, high-pressure areas, and electrical systems. **Refer to Appendix E for the full safety checklist**, with fuse placement shown in Figure 10.



Figure 10: Fuse placement within 30 cm of Anderson Connector
Photo by Marwan Mohamed

Design Rationale

Mechanical Design

Design Methodology:

The design process followed a systematic engineering approach:

- Defining mission requirements
- Brainstorming concepts
- Trade-off analysis
- CAD modeling
- CFD simulation
- Prototyping and testing
- Final optimization

GLACIUS's mechanical design followed a systematic engineering approach directly driven by this year's theme; Pushing Performance in Harsh Environments [1]. The process began with defining mission requirements, followed by brainstorming, trade-off analysis, CAD modeling in SolidWorks (Figure 11) [11], CFD simulation, prototyping, and final optimization. Every decision was evaluated against three primary environmental challenges; currents, waves, and ice-simulated conditions expected at the international venue in St. John's, Canada.

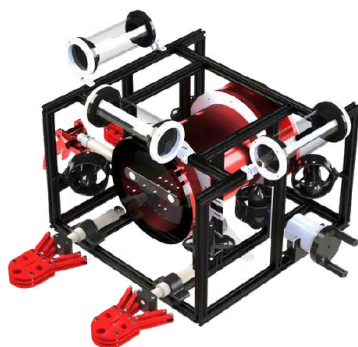


Figure 11: GLACIUS CAD Model Isometric View [11]
Made by Nouraldeem Hassanien

Engineering Design Rationale and Systems Approach

GLACIUS was developed using a systems-based design approach ensuring smooth integration between mechanical, electrical, and software subsystems [1]. Mission objectives were broken down into specific design requirements, ensuring every component had a clear purpose within the overall system. Trade studies evaluated options based on cost, efficiency, manufacturability, reliability, and performance under harsh environmental conditions. Mechanical, electrical, and software teams collaborated closely throughout, maintaining continuous communication to ensure subsystem designs aligned with the overall vehicle. An iterative design process relying on simulations, prototyping, and testing was used to refine GLACIUS's performance, with subsystems validated individually before full system integration.

The overall design directly addresses this year's three core challenges. Current resistance was tackled through a compact frame geometry and optimized weight distribution. Wave disturbance was addressed through a lowered center of gravity and horizontal enclosure configuration. Ice-simulated freezing conditions were addressed through sealed electronics, freeze-tested components, and thermally stable material selection [1], as shown in Figures 12 and 13



Figure 12: GLACIUS' Frame CAD Model Isometric View [11]
Made by Nouraldeem Hassanien



Figure 13: GLACIUS' resting after the trial drinking REDBULL
Taken by : Marwan Eltete

Vehicle Structure

GLACIUS features a modular open-frame structure manufactured from anodized aluminum extrusion, providing an optimal balance between structural rigidity, corrosion resistance, and weight reduction. The frame geometry was redesigned from NEPTUNE-X to address stability issues observed during the regional competition, where the ROV experienced significant instability and drag during descent toward underwater structures and task targets. The new compact geometry measures 830 mm in length, 720 mm in width, and 400mm in height, compared to NEPTUNE-X's 830 × 560 × 440 mm, with a total mass of 18 kg, as shown in **Figure 14**. The reduced height lowers the vehicle's hydrodynamic profile, minimizing drag and current-induced displacement during vertical maneuvering, directly improving task execution precision in **Tasks 1.1, 2.5, 3.1, and 3.2** [1].

The center of gravity is maintained below the center of buoyancy throughout the design, providing passive restoring stability that resists unwanted rolling and tilting during manipulation tasks and wave disturbance. The compact frame geometry reduces the effective surface area exposed to lateral currents, improving positional stability without increasing thruster demand.

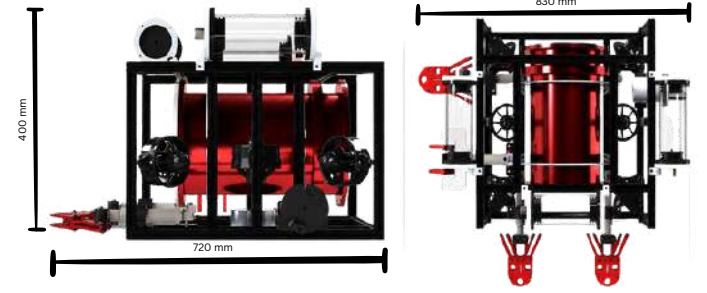


Figure 14: GLACIUS Technical Dimensions, Side and Top Views [11]
Made by Nouraldeem Hassanien

Main Enclosure

The main enclosure underwent a fundamental redesign from NEPTUNE-X to GLACIUS, transitioning from a vertical to a horizontal cylindrical orientation (**Figures 15 and 16**). This change was driven directly by the stability issues observed at the regional competition; the vertical enclosure's upright profile created a high drag surface during descent and introduced a pitching moment under current forces, causing operational delays during task execution [1]. The horizontal orientation lowers the enclosure's hydrodynamic profile, distributes its mass along the vehicle's longitudinal axis, and significantly reduces pitch instability during both descent and forward motion.

An enclosure extension was added to the horizontal configuration to accommodate the ZED 2i stereo camera internally, eliminating the external bracket that was used in NEPTUNE-X. The external ZED bracket introduced additional drag and vibration transfer to the camera under current conditions, compromising depth perception accuracy during navigation and reconstruction tasks. Housing the ZED 2i inside the enclosure extension eliminates this drag source and protects the camera from direct current and wave impact, improving perception reliability in **Tasks 1.2, 2.1, 2.2, and 3.1** [1][9].

The ZED camera enclosure bracket developed for NEPTUNE-X, manufactured from Aluminum 7075-T6 with an acrylic front face and O-ring face seal, remains available as an option depending on pre-trial strategy and pilot preference. If task requirements demand an extended field of view or servo tilt capability, the bracket can be reintegrated with minimal modification [9].

The main enclosure is manufactured from aluminum with a cylindrical HDPE housing featuring an O-ring face seal, rated to operate at up to 5 bar, suitable for the expected underwater conditions [12][15]. The sealing system was validated through repeated hydrostatic pressure testing at 0.5 bar, with a load-distribution ring introduced to resolve acrylic cracking under uneven stress distribution identified during NEPTUNE-X testing.



Figure 15: GLACIUS Main Enclosure; Horizontal Configuration with ZED 2i [11]
Made by Nouraldeem Hassanien

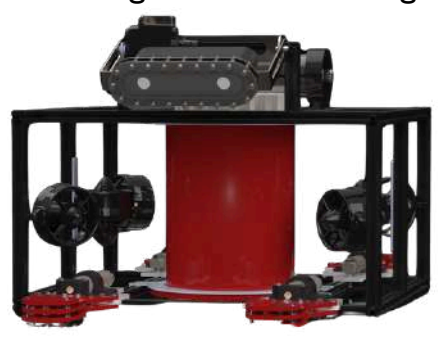


Figure 16: NEPTUNE-X Vertical Enclosure Configuration [11]
Made by Ahmed Hatim

Material Selection

Materials were selected based on a deterministic engineering trade-off analysis considering strength, weight, corrosion resistance, manufacturability, and cost [12]. The final approach adopted anodized aluminum extrusion for the frame, providing an optimal balance between structural rigidity and weight reduction while enabling modular assembly and efficient heat dissipation in cold underwater environments.

Table 3 presents the full material comparison across HDPE, Acrylic (PMMA), Aluminum, PLA, and Stainless Steel 304.



	HPDE	Acrylic (PMMA)	Aluminum	PLA	Stainless Steel 304
Density (g/cm³)	1	1.2	2.7	1.24	8
Impact Strength (J/m)	260	74	294	96.1	325
Flexibility (MPa)	24	71	90	80	540
Cost	Moderate	Moderate	Moderate	High	Moderate

Table 3: Mechanical Materials [15]
Made by Yousab Youssef

CFD Analysis

A Computational Fluid Dynamics simulation was conducted using ANSYS Fluent [17] to evaluate GLACIUS's hydrodynamic performance and analyze water flow behavior around the vehicle at the operating conditions expected in this year's current-affected competition environment [1]. The simulation assessed pressure distribution and streamline patterns at an operating velocity of 0.8 m/s, directly relevant to the strong current conditions anticipated in St. John's, Canada[1].

Results demonstrate that the horizontal enclosure orientation and compact open-frame geometry effectively reduce turbulent flow regions and improve overall water circulation through the vehicle. High pressure concentrations are observed at front-facing surfaces, while low-pressure wake regions develop behind the frame due to flow separation. The simulation estimates a drag force of approximately 20.5 N at 0.8 m/s, confirming efficient flow characteristics suitable for stable underwater maneuvering, as shown in **Figure 17**, and reduced current-induced resistance during mission execution across **Tasks 1.1, 2.5, 3.1, and 3.2** [1].

These findings directly validated the enclosure orientation change from NEPTUNE-X; the horizontal configuration reduces the frontal pressure area compared to the vertical configuration, contributing to improved pitch stability and reduced drag under sustained current loading [17].

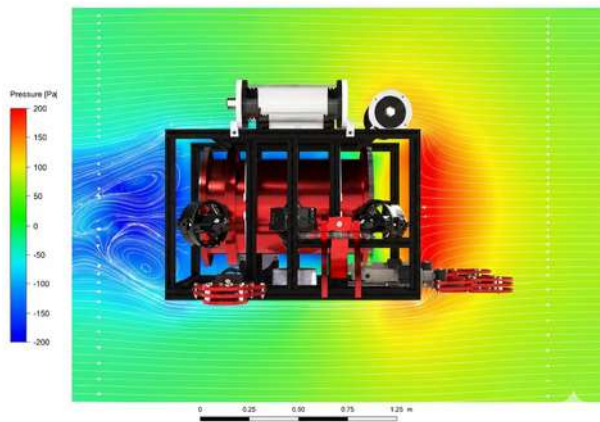


Figure 17: GLACIUS CFD Pressure Distribution [17]
Made by Ahmed Hatim

Propulsion System

GLACIUS employs six Blue Robotics T200 thrusters [6] in a vectored configuration, providing all necessary degrees of freedom; surge, sway, heave, yaw, and roll; for precise maneuvering under the strong currents and wave disturbance expected at this year's international venue [1]. The T200 was selected for its proven reliability, compact form factor, high thrust-to-weight ratio, and ability to operate continuously in cold saltwater conditions [6]. At 12V, each T200 draws approximately 15A at full throttle, producing up to 34.8 N forward thrust and 29.4 N reverse thrust, making it the most cost-effective thruster at this performance level for competition ROV applications [6].

Thruster Configuration and Placement

Four horizontal T200 thrusters are mounted at 30°/60° angles for stable horizontal movement and even force distribution, while two vertical T200 thrusters enable heave and roll control [6]. The vectored configuration was selected over an axis-aligned alternative following comparative testing during NEPTUNE-X development, where axis-aligned mounting produced positional drift under load; the vectored arrangement maintained significantly more stable directional control through corner-distributed force application, an advantage critical under this year's current conditions [1]. Thruster mounts are 3D printed in PETG at fixed angles, with two vertical thrusters retaining 90° aluminum mounts (**Figures 18 and 19**) carried over from NEPTUNE-X.

Power Consumption and Mission Trade-off

Each T200 contributes 180W at full throttle, bringing maximum propulsion demand to 1,080W across six thrusters; within the 1,440W available from the 48V/30A supply after DC-DC conversion [6]. Average operational consumption remains well below this ceiling as thrusters rarely operate at full throttle simultaneously. This power budget was a key selection factor (**Table 4**); higher-thrust alternatives would have demanded a larger supply, increasing cost and weight and compromising GLACIUS's neutral buoyancy [1][6].

Direction	Maximum Thrust
Upward	$2 \times 3.55 \approx 69.6 \text{ N}$
Downward	$2 \times 3.0 \approx 58.9 \text{ N}$
Forward	$4 \times 3.55 \times \sin(45^\circ) \approx 117.7 \text{ N}$
Backward	$4 \times 3.0 \times \cos(45^\circ) \approx 100.1 \text{ N}$
Lateral	$(2 \times 3.0 \times \cos(45^\circ)) + (2 \times 3.55 \times \sin(45^\circ)) \approx 90.2 \text{ N}$

Table 4: Propulsion System [15]
Made by Yassin Khaled

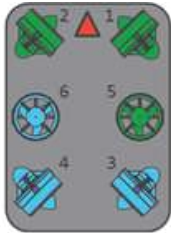


Figure 18: Thruster Configuration
Made by Ahmed Farouk

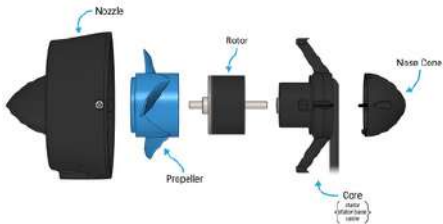


Figure 19: Blue Robotics T200 Thruster Exploded View [6]



NEPTUNE-X to GLACIUS — Design Trade-off and Evolution

The transition from NEPTUNE-X to GLACIUS was driven by direct lessons learned from the regional competition and a focused re-engineering effort to address this year's harsh environment theme [1]. The table below summarizes the key design decisions, what changed, and why. This structured evolution reflects Titans Robotics' commitment to data-driven design improvement, ensuring that every change made for GLACIUS is directly justified by regional performance data, as summarized in **Table 5**, and this year's harsh environment challenge requirements [1].

Design Element	NEPTUNE-X	GLACIUS	Rationale
Frame Dimensions	830 × 560 × 440 mm	650 × 770 × 330 mm	Reduced height lowers hydrodynamic profile, minimizing drag and current-induced displacement during descent
Frame Mass	21.8 kg	18 kg	Slight mass increase accommodates additional tooling while maintaining near-neutral buoyancy
Enclosure Orientation	Vertical	Horizontal	Vertical profile created pitching moment and drag under current forces; horizontal orientation improves pitch stability and reduces drag
ZED 2i Mounting	External aluminum bracket	Inside enclosure extension	External bracket introduced drag and vibration under current conditions, internal mounting eliminates drag and protects camera
ZED Enclosure Bracket	Primary configuration	Pre-trial strategy dependent	Retained as valid option if extended field of view or servo tilt is required
Gripper Configuration	4 axial grippers	2 front + 1 left axial + jaw gripper	Reduced complexity, improved weight distribution, dedicated right side for DC motor tool
Camera System	1 ZED + 3 IP cameras	1 ZED + 4 IP cameras	Additional IP camera added to cover side gripper zone
Buoyancy System	Foam in upper region	Foam + acrylic buoyancy tubes	Distributed buoyancy modules improve longitudinal pitch stability under wave disturbance
Thruster Configuration	6 T200; 30°/60° vectored	6 T200; 30°/60° vectored	Configuration proven stable under load; retained for international competition
Thruster Mounts	PETG 3D printed	PETG 3D printed	Proven rigid and reliable across regional testing

Table 5: NEPTUNE-X to GLACIUS Design Evolution and Trade-off Summary [15] Made by Yassin Khaled

Gripper Configuration

GLACIUS transitions from NEPTUNE-X's four-gripper layout to a three-gripper configuration; two axial HDPE grippers mounted at the front and one axial HDPE gripper mounted on the left side, accompanied by the pneumatic jaw gripper. The right side houses the DC motor tool. This reconfiguration was driven by the need to reduce frame complexity, improve weight distribution, and allocate dedicated side access for mission-specific tooling without compromising manipulation capability across tasks [1]. Full gripper coverage is maintained through strategic placement referenced in the Payload and Tools section. Refer to Pneumatic SID, Appendix D

Buoyancy and Stability

GLACIUS was tuned to achieve near-neutral buoyancy through the addition of buoyancy foam in the upper region of the vehicle [1]. Placing foam above the main mass raises the center of buoyancy relative to the center of gravity, improving restoring stability and resulting in smoother underwater motion under wave and current disturbance. This configuration reduces continuous thrust demand on the vertical thrusters, improving energy efficiency during depth control across all mission tasks. Buoyancy was validated through up to 15 pool test trials, with weight distribution adjusted iteratively until stable neutral buoyancy was achieved. Acrylic buoyancy tubes are integrated as buoyancy modules, as shown in the exploded view (**Figure 20**), providing distributed buoyancy control across the vehicle's longitudinal axis and contributing to pitch stability during forward motion in current-affected conditions [1].

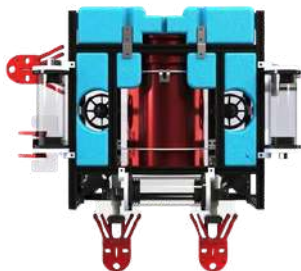


Figure 20: GLACIUS' Buoyancy [11] Made by Mohamed Youssef

Problem Solving

At Titans Robotics, problem solving follows a structured principle; understand before acting. Every challenge is broken down to its root cause before any solution is implemented, ensuring decisions are precise, data-backed, and sustainable rather than reactive [1].

Brainstorming and Ideation Process

Periodic interdepartmental meetings were held every two weeks, bringing together leaders and subteam members to review progress, surface challenges, and evaluate design alternatives collaboratively. Mechanical design received the highest meeting frequency during early development phases, as the frame and enclosure configuration formed the foundation upon which all other subsystems depended. Each design decision was discussed, sketched, and evaluated against mission requirements[1], environmental conditions, and system integration constraints before being approved for development.

Design Alternative — Initial Frame Configuration

The first proposed frame design featured a flat panel structure on the top and bottom with four front-facing grippers. Pool testing revealed critical failures across multiple criteria; the configuration performed poorly in stability and maneuvering, created significant pilot control difficulty, and failed to meet weight distribution requirements. The flat panel geometry trapped water flow rather than allowing it to pass through the frame, generating unpredictable hydrodynamic forces under current conditions [1]. This design was rejected and the open-frame aluminum extrusion architecture was adopted, as illustrated in **Figure 21**, which resolved all identified issues and formed the basis of GLACIUS's current structure.



Figure 21: Rejected Initial Frame Design Concept [11] Made by Ahmed Hatim



Enclosure Orientation Trade-off

A key design decision involved the orientation of the main electronics enclosure. A vertical orientation offers marginally lower drag in the forward direction due to its smaller frontal cross-section; however, regional competition testing with NEPTUNE-X demonstrated that the vertical configuration created a significant pitching moment and lateral instability when the ROV descended toward underwater targets, causing operational delays across multiple tasks [1]. A structured evaluation weighed drag reduction against stability impact, and the horizontal orientation was selected as the superior configuration for this year's current and wave-affected environment despite its slightly higher forward drag profile. This decision was validated through CFD analysis at 0.8 m/s, confirming acceptable drag characteristics of 20.5 N while delivering substantially improved pitch stability under current conditions, as summarized in **Table 6** [17].

Criterion	Vertical Enclosure	Horizontal Enclosure
Forward Drag	Lower	Slightly Higher
Pitch Stability	Poor under current	Significantly Improved
Descent Stability	Unstable	Stable
Mass Distribution	Concentrated vertically	Distributed longitudinally
ZED 2i Integration	External bracket required	Integrated internally
Overall	Rejected	Selected

Table 6: Enclosure Orientation Trade-off Evaluation.
Made by Yassin Khaled

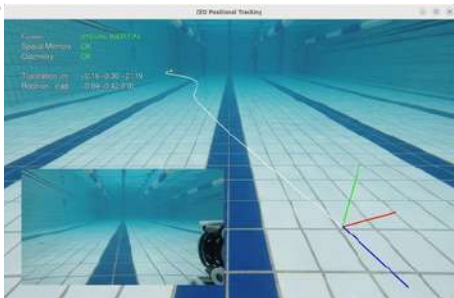
Innovation

GLACIUS's innovations focus on in-house engineering solutions that deliver higher functionality at reduced cost, directly addressing this year's harsh environment challenges [1]. Every innovation listed here represents original design or software work developed by Titans Robotics.

Position Hold Without DVL

Maintaining stable position under strong underwater currents is one of this year's primary challenges [1]. The standard solution requires a Doppler Velocity Log (DVL) sensor costing approximately \$8,700 USD; exceeding the team's budget. A custom ROS2 node was developed in-house to interface directly with the ZED 2i's spatial localization output, feeding real-time positional data into ArduSub's position hold mode [4][9]. This software innovation replicates DVL-level positional stability at zero additional hardware cost, enabling precise hover and manipulation in Tasks 2.5 and 3.2 (**Figure 22**) where current-induced drift would otherwise compromise task execution [1].

Figure 22:
GLACIUS' Path
Tracking by our
Control Lead [5][9]
Taken from RViz2
by Mohamed
Ashraf



ELMASRY Hook

The ELMASRY Hook is a fully passive snap-shut collection tool designed and manufactured in-house from 10 mm acrylic. Its elastic band mechanism automatically closes the jaws upon contact with the target O-ball without requiring any motors, electronics, or external actuation signals [1]. This eliminates electrical complexity, reduces failure points, and delivers highly reliable basket star collection in **Task 1.1** at minimal manufacturing cost.

Jaw Gripper Design

The jaw gripper was uniquely designed and manufactured in-house to address the specific geometric requirements of **Tasks 2.5 and 3.2**. Powered by a 30 mm bore, 50 mm stroke pneumatic piston, the gripper handles object cross-sections from 9 to 91 mm, purpose-built to connect the eDNA biodiversity sensor to the Holyrood subsea observatory port and remove the power connector cap from the offshore platform [1] [12]. No commercially available gripper matched these dimensional and force requirements at a comparable cost.

DC Motor Tool and In-House Sealing

The DC motor tool was designed and manufactured entirely in-house, with the sealing mechanism representing the key innovation. Developing a reliable waterproof seal for a rotating shaft in an underwater environment is a significant engineering challenge; the in-house sealing solution eliminated the need for a commercially sealed motor unit, reducing cost while maintaining full operational reliability under competition depth conditions [12].

In-House Safety Circuit — Control PCB

A dedicated safety circuit was designed and integrated directly into the main Control PCB, incorporating optocoupler isolation, fused power lines, filtering capacitors, and protective circuits. Embedding the safety circuit into the PCB reduces component count, eliminates potential failure points from external connections, and ensures compact, reliable protection within GLACIUS's sealed electronics environment.



Electrical System

Electrical System Design



Figure 23: Electrical System Diagram [16]
Made by Youssef Mohamed

System Overview

Operating reliably under the currents, waves, and ice-simulated conditions of this year's competition demands an electrical system built for modularity, redundancy, and operational safety [1]. GLACIUS's electrical system supports propulsion, sensing, actuation, and onboard computation while maintaining full electrical isolation from the surrounding underwater environment. The architecture is divided into three primary subsystems; Power Distribution, Control Electronics, and Sensors and Actuators, allowing each to be independently tested, replaced, or upgraded (Figure 23) without disrupting overall vehicle operation, Refer to Appendix D Electric SID.

Control Electronics and PCB Design

Operating in the harsh currents and dynamic conditions of this year's competition demands an electrical system that is not only reliable but rapidly serviceable under time pressure[1]. GLACIUS's control electronics are consolidated on a custom PCB delivering a compact layout that minimizes wiring clutter, enhances signal integrity, and simplifies maintenance during both testing and competition (Figures 24 and 25) . High-current power paths are segregated from delicate signal traces, ensuring minimal electrical noise and sustained reliability throughout operation.

Fuse Calculation

Total system power consumption is 1,192.325W. At 48V, the current rating is calculated as $1,192.325 \div 48 = 22.95A$. A 25A fuse was selected to provide appropriate over-current protection with a safe margin, in compliance with competition requirements [1], as detailed in Table 7.

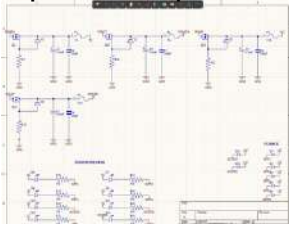


Figure 24: Safety Circuits
Made by Saif Tabouna



Figure 25: Control PCB
Made by Ahmed Fawzy

	Quantity	Voltage (V)	Current (A)	Power(W)	Total (W)
Thruster	6	12	15	180	1080
ESC	6	12	0.15	1.8	10.8
Bilge pump	1	12	4	48	48
Jetson Nano	1	5	3	15	15
Pixhawk	1	5	0.125	0.625	0.625
DCV	4	12	0.3	3.6	14.4
Z Camera	1	5	0.5	2.5	2.5
Underwater Servo	1	7	3	21	21
					1192.325

Table 7: Power Calculation [15]
Made by Yassin Khaled

Power PCB

The Power PCB houses six ESCs with thruster connectors, powered through XT60 connectors rated at 60A . Signal transmission to each ESC is handled via a 6-pin JST connector receiving PWM signals from the Pixhawk [5]. PCB trace widths are calculated to carry full thruster current without thermal buildup, ensuring stable operation under sustained high-load conditions.

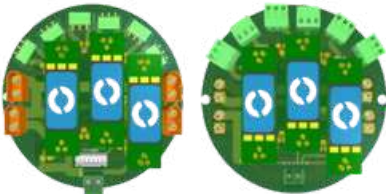


Figure 26: Power PCB
Made by Saif Tabouna



Figure 27: ESC Module
Made by Mohamed Samir

ESC Module

Each ESC is individually mounted on a compact, removable PCB module connected directly to the Power PCB via polarized MT-30 connectors . This modular approach simplifies maintenance, significantly reduces downtime, and eliminates damage risks (Figures 26 and 27) associated with traditional soldered connections; a critical advantage when rapid reconfiguration is needed between competition runs.

MOSFET Control

Two mechanisms handle low-level actuation. Optocoupler gate drivers bridge the Pixhawk's output signals with electrical isolation and amplification, switching the four DCVs, servos, and motors [5]. An Arduino Nano embedded directly into the PCB manages low-level peripheral tasks, receiving commands serially from the Jetson Nano [7][13]. Power flows through fused lines, filtering capacitors, and protective circuits, stabilizing voltage across propulsion and auxiliary systems without faults.

Actuation and Motor Control

GLACIUS employs multiple electric actuators to achieve full maneuverability and mission capability under this year's harsh environmental conditions [1]. Thrusters are controlled through Electronic Speed Controllers (ESCs), enabling precise speed and directional control [6]. A brushless DC (BLDC) motor drives mission-specific tools and payload mechanisms, selected for its high efficiency, reliability, and compatibility with electronic control systems.

Tether

The tether serves as GLACIUS's critical lifeline, enabling power delivery, high-speed data transmission, and pneumatic control while maintaining the flexibility, buoyancy, and robustness required for effective underwater operation in strong currents and wave-affected conditions [1]. Its design was developed to meet MATE's RFP specifications while ensuring safe and streamlined operation throughout competition, as illustrated in **Figure 28**.



Figure 28: ROV Tether Structure
Made by Yassin Khaled

- **Power Cable**

An 11 AWG two-core power cable (4mm² diameter) delivers 48V DC to GLACIUS. Selection was based on a current carrying capacity of up to 45A and a minimal voltage drop of approximately 0.4% over 25 meters, ensuring stable power delivery throughout all mission phases.

- **Data Cable**

Cat6 Ethernet cable (23 AWG) provides high-speed communication, supporting up to 10 Gbps for real-time video streaming and control data transmission between GLACIUS and the surface station.

- **Pneumatic Tubes**

Two 6mm polyurethane tubes rated at 10 bar deliver compressed air to the pneumatic grippers. The system operates at 2.75 bar, well within the tube's rated capacity, preventing overpressure and ensuring reliable gripper actuation across all manipulation tasks.

- **Tether Length Calculation**

Tether length was determined mathematically rather than estimated, ensuring full pool coverage without excess cable introducing unnecessary drag under current-affected conditions [1].

Using the Pythagorean theorem in three dimensions, the maximum diagonal distance across the competition flume tank (22m × 8m × 4m) was calculated as:

$$d = \sqrt{(22^2 + 8^2 + 4^2)} = \sqrt{(484 + 64 + 16)} = \sqrt{564} \approx 23.75 \text{ meters}$$

A tether length of **25 meters** was selected to provide approximately 1.25 meters of operational buffer beyond the calculated maximum diagonal, accommodating tether sag, current deflection, and dynamic slack requirements during mission execution [1].

- **Tether Construction and Buoyancy**

All cables are organized within a braided sleeve to prevent abrasion and mechanical damage while maintaining flexibility. Closed-cell foam is applied at strategic intervals to achieve near-neutral buoyancy, reducing drag and minimizing entanglement risk in current-affected conditions [1]. A strain relief mechanism at the ROV interface absorbs dynamic movement forces, minimizing mechanical stress and reducing the risk of cable fatigue or operational failure.

Tether Management Protocol

A structured tether management protocol was developed and strictly followed across all pool tests and competition runs to address entanglement and tension risks introduced by underwater currents [1].

- **Pre-Deployment:** The tether is visually and physically inspected for wear, kinks, or seal damage before every session. It is coiled in consistent figure-eight loops to prevent memory-induced tangling and stored in a dedicated dry container between sessions.
- **Deployment:** The tether is fed into the water in controlled segments by a dedicated tether manager. Slack is maintained at all times to prevent tension transfer to the ROV, and the tether entry angle is monitored to avoid contact with pool edges or props.
- **During Operation:** The tether manager maintains continuous active monitoring, adjusting slack in real time as GLACIUS moves between mission zones. A minimum slack buffer of 1 meter is maintained at all times to absorb sudden directional changes caused by current disturbance. Communication between the tether manager and pilot is maintained throughout to coordinate movement and prevent snagging.
- **Post-Operation:** Upon ROV retrieval, the tether is carefully recovered hand-over-hand to avoid sudden tension spikes. It is inspected for wear, abrasion, or connector damage before being re-coiled and stored in a clean, dry environment to preserve longevity across sessions.



Control System

Achieving stable and precise operation under this year's harsh conditions; strong currents, wave disturbance, and ice-simulated environments; demands a control system that is both responsive and fault-tolerant [1]. GLACIUS's control system follows a distributed three-layer architecture where mission processing, real-time flight control, and peripheral I/O are assigned to purpose-built hardware selected through a comparative trade-off analysis based on processing capability, power efficiency, features, and cost.

Table 8 summarizes the hardware trade-off across evaluated architectures. Refer to Software SID, Appendix D

Feature	NVIDIA Jetson	Intel NUC	Raspberry Pi 5
Processing Power	High	Very High	High
Power Consumption	Moderate	Very High	High
4K Video Streaming	Yes	Yes	Yes
CUDA Support	Yes	No	No
Integrated AI Capabilities	Yes	Yes	No
Hardware I/O	Good	Moderate	Extensive
Cost	Moderate	High	Low

Table 8: Control System Architecture Comparison [15]

Layer 1 — Mission Processing and Perception (Jetson Nano)

The Jetson Nano sits at the top of the control hierarchy, receiving pilot commands from the topside surface station over Ethernet through the tether, supporting routerless operation with any Ethernet-capable laptop[7]. It hosts the following software modules (Figure 29):

- **MAVLink Bridge (mavp2p):** Relays Pixhawk feedback including depth, orientation, and flight mode to the surface GUI and manages flight mode switching [5].
- **Heartbeat Failsafe Protocol:** Continuously monitors the communication link between the topside station and Jetson Nano. If no heartbeat is received within a defined timeout of 5 seconds, a thruster disarm is triggered via MAVLink, maintaining GLACIUS at its current depth until control is restored. This failsafe is critical for safe operation under the current-affected conditions of this year's competition [1].
- **Video and Depth Stream Relay:** Compresses and streams the ZED 2i RGB feed, depth data, and ML inference overlay to the topside GUI over Ethernet [9].
- **Serial Command Interface:** Triggered by pilot controller inputs, forwards gripper and servo commands to the Arduino Nano over USB Serial [13].



Figure 29: NVIDIA Jetson Nano [7]

Layer 2 — Flight Control (Pixhawk / ArduSub)

Running ArduSub firmware independently of the Jetson Nano's compute load, the Pixhawk manages all time-critical flight operations [5][4]. It receives MAVLink commands from the Jetson Nano and generates PWM signals for the six T200 thrusters [6]. The Pixhawk's Extended Kalman Filter (EKF) continuously fuses IMU and Bar30 pressure sensor data to estimate orientation and depth, driving PID corrections that actively oppose current-induced drift (Figure 30) ; a direct response to this year's harsh environment challenge [1].



Figure 30: Pixhawk [5]

Control Modes and Mission Applications

GLACIUS utilizes multiple control modes managed by the Pixhawk's ArduSub firmware, each tailored to specific mission requirements [4][5].

Table 9 summarizes control modes and their corresponding mission applications.

Control Mode	Mechanism	Mission Application
Stabilize Mode	• Pixhawk allows manual control while automatically correcting roll and pitch angles, preventing sudden tilts and ensuring smooth navigation.	Task 1.3: Hold position over coral garden in flume tank Tasks 2.5 & 3.2: Stable hover for fine manipulation.
Depth Hold Mode	• Pixhawk locks the ROV at a fixed depth, ensuring consistent positioning while allowing free horizontal movement.	Task 1.2: Consistent altitude for photogrammetry image overlap. Task 2.2: Precise depth for iceberg keel measurement.
Manual Override	• Full pilot authority; all stabilization disabled. Direct PWM control via topside joystick.	Scenarios that require full manual control.

Table 9: Control Modes [15]
Made by Yassin Khaled

Stabilize and Depth Hold Mode Validation

Each control mode was validated by engaging it separately while a team member rotated and displaced the ROV in random directions and depths, then monitoring orientation, heading, and depth readings as the ROV self-corrected. The ROV successfully returned to its original orientation and depth in all tests. During validation, an unintended roll was observed in Stabilize Mode during operation; this was traced to incorrect vertical thruster orientation and resolved by flipping the two vertical thrusters, restoring stable roll behavior [5].

Layer 3 — Peripheral I/O (Arduino Nano)

Low-level actuator operations outside the flight controller's scope are managed by the Arduino Nano [13]. It receives single-character commands from the Jetson Nano over USB Serial and translates them into digital signals for gripper and actuator control, ensuring precise and responsive tool deployment across all mission tasks (Figure 31).



Figure 31: Arduino Nano [13]



Software Design

Custom Topside Application — YESTER

Operating reliably under this year's harsh environment demands a control interface that minimizes operational complexity and maximizes pilot responsiveness under competition pressure [1]. YESTER, Titans Robotics' custom-built topside GUI, was developed to directly address critical operational issues identified during NEPTUNE-X's regional run, introducing purpose-built features that streamline pilot control, system diagnostics, and camera management across all mission tasks[1].

Pilot Profile System

During the regional competition, manual reconfiguration of controller settings between pilots caused significant time loss under competition conditions. A dedicated pilot profile system was developed within YESTER, allowing each pilot to create, save, and instantly load personalized controller configurations including sensitivity, button mapping, and axis preferences [6]. This eliminates reconfiguration time entirely, enabling seamless pilot transitions and improving operational tempo across all tasks[1], as shown in **Figure 32**.



Figure 32: YESTER Controller Settings
Screenshot by Youssef Emara

Camera Settings Management

Camera frame rate and image quality requirements vary significantly between mission tasks and water conditions. Capturing fine targets in Tasks 1.1 and 2.1 demands higher image quality and frame rate, while navigation tasks prioritize low-latency streaming over resolution [1]. A dedicated camera settings menu was developed within YESTER, enabling the operator to adjust frame rate and image quality per camera in real time based on mission requirements, balancing visual clarity against Jetson Nano computational load (**Figure 33**) [7].



Figure 33: YESTER Camera Settings
Screenshot by Youssef Emara

Integrated Motor Testing — Replacing QGroundControl

Previously, individual thruster testing required closing the GUI and launching QGroundControl, resulting in significant time expenditure during debugging sessions. A dedicated motor testing menu was integrated directly into YESTER, enabling individual thruster testing and parameter configuration without leaving the application [6]. This significantly reduces diagnostic time during pool testing and pre-competition checks, directly improving system readiness under the time constraints of competition day (**Figure 34**).



Figure 34: YESTER motor test
Screenshot by Farah Fawzy

Side Gripper Camera Switch

GLACIUS features grippers on the front and left side, requiring the pilot to maintain visual awareness across multiple operational zones. A dedicated feature was developed within YESTER enabling the operator to instantly switch the active camera feed to the side-facing IP cameras while simultaneously reversing all controller directional settings, ensuring intuitive and effective operation of the side gripper without requiring physical vehicle repositioning [10]. This feature is particularly critical in Tasks 1.1, 2.5, and 3.1 where precise lateral manipulation is required under current disturbance [1].

Interactive 3D ROV Position Simulation

An interactive 3D model was developed within YESTER that responds in real time to IMU readings and depth data, providing the pilot and surface team with a continuous visual representation of GLACIUS's orientation and position throughout operation. This feature enhances situational awareness under the turbid and current-affected conditions expected at the international venue, reducing pilot disorientation during complex multi-axis maneuvering.

Vertical Profiling Float

Building upon last year's validated float design, we enhanced precision by increasing the pneumatic cylinder capacity to 150ml (from 60ml), enabling greater buoyancy control precision while retaining the unified aluminum extrusion core, stepper actuation, IR sensing, ESP32 integration, Bar30 for depth sensing, and lead-acid power. This targeted evolution eliminates past granularity limitations, enhances reliability in harsh underwater environments, and positions the system for optimal competition performance (**Figure 35**). Refer to Float SID, Appendix D

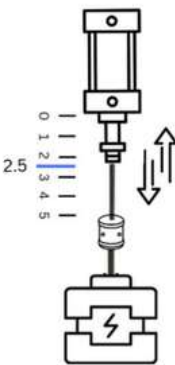


Figure 35: Floatilla Mechanism
Rendered by Youssef Mohamed



Vision System

Vision System Overview

GLACIUS's vision system delivers comprehensive situational awareness, centimeter-level spatial measurement, and real-time object detection through a multi-camera architecture consisting of one stereo depth camera and four auxiliary IP cameras [10].

Video Streaming

The streaming system uses two separate pipelines optimized for each camera type [14]. The stereo camera streams via RTP at 720p/60 FPS using the Jetson Nano's hardware-accelerated encoding [7], minimizing computational load while delivering real-time spatial data. IP cameras are streamed via GStreamer RTSP pipelines [14], providing low-latency feeds accessible from multiple operator laptops simultaneously, ensuring continuous visual feedback at the control station.

Image Processing and Color Restoration

Underwater light attenuation degrades red and yellow channels with depth, compromising detection accuracy. A real-time color restoration pipeline using the Gray World Assumption filter was implemented and selected over Histogram Equalization for its stability in low-light conditions and absence of visual artifacts [8]. The initial Python implementation produced insufficient frame rates under concurrent AI workload on the Jetson Nano [6]; rewriting the pipeline in C++ with optimized OpenCV recovered 5–10 FPS, achieving a consistent 60 FPS output and eliminating pilot-facing latency, as shown in Figure 36.

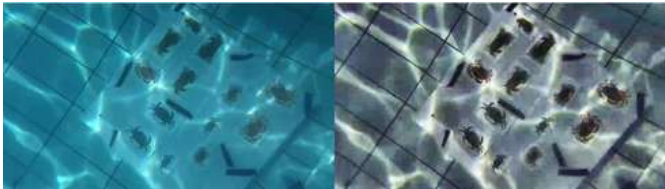


Figure 36: Color Restoration Result
Photo by Ammar Elsaadany

Camera Calibration

ChArUco marker-based calibration was applied to all IP cameras to eliminate fisheye distortion [10], while the stereo camera underwent dedicated calibration for metric accuracy and depth consistency [9]. All calibration data is pre-loaded and applied in real time throughout operations (Figure 37).



Figure 37: Stereo Calibration Marker Detection
Photo by Jana Mehanna

Crab Detection

In Task 2.1, detecting European green crabs on a complex seabed presents two primary challenges: variable target orientation and high background noise. Oriented Bounding Boxes (OBB) were implemented over standard axis-aligned boxes, aligning each detection window to the crab's principal axis and reducing background noise by approximately 30% (Figure 38) [8]. A custom dataset of 600 images was built from GLACIUS's camera footage and expanded from 400 images using synthetic instance-pasting and geometric augmentation, achieving a 30% improvement in mean average precision over the baseline model while maintaining stable detection under low-visibility conditions [8].

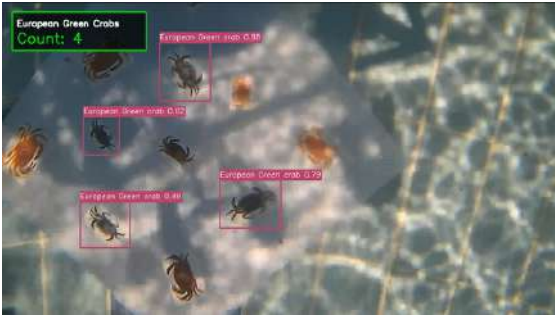


Figure 38: European Green Crabs Detection
Photo by Aya Aziz & Fajr Mohamed

Table 10: summarizes benchmark results across all evaluated YOLO architectures.

Metric	YOLOv11(Small)	YOLOv26(Nano)	YOLOv26(Small)
Precision (P)	99.9%	98.6%	99.2%
Recall (R)	100.0%	95.2	98.4%
mAP50 - 95	0.937	0.933	0.964
Parameters	9.41 M	2.37 M	~5.4 M
Inference Time	13.2ms	14.1ms	13.8ms

Table 10: Evaluation Metrics [8],[15]
Made by Ali Sherif

Depth Measurement Approach

In Task 1.2 and Task 2.2, the depth system combines RGB video with real-time stereo depth for target identification and accurate 3D measurement [9]. Confidence filtering rejects unreliable depth points caused by surface ice effects, wave motion, and current disturbance, while spatial averaging suppresses sensor jitter; keeping measurements within the mission's 5 cm tolerance window (Table 11, Figure 39) [1].

Feature	ZED 2i	RealSense D455	OAK-D Pro
Price	\$499	\$419	\$429
Depth Range	0.3 – 20 m	0.6 – 6 m	0.7 – 12 m
FOV (H x V)	110° x 70°	87° x 58°	80° x 55°
Processing	Host GPU (NVIDIA)	Low (On-chip ASIC)	Onboard VPU
Mapping / SLAM	Strong	Moderate	Moderate

Table 11: Stereo Cameras Features Comparison [15]
Made by Yassin Khaled

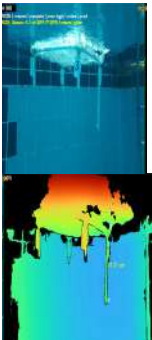


Figure 39: Stereo Depth-Based Measurement [9]
Made by Rodina Ghazaly



Coral Garden 3D Modeling

In Task 1.2, stereo-based Spatial Mapping was selected as the primary reconstruction pipeline with Instant-NGP as a validated backup, offering the best balance of metric accuracy, speed, and hardware compatibility. The pilot executes controlled left-to-right sweeps at a 0.3–0.5 m standoff distance, optimized for the fused point-cloud pipeline to resolve thin ½-inch PVC geometry and capture all eight color targets [1]. GEN_3 positional tracking maintains spatial consistency throughout the scan, preventing frame drift [9]. The resulting .PLY point cloud is imported into CAD where the true mission length is applied as a scale factor, estimating coral garden height within the required 5 cm tolerance (Figure 40) [1].

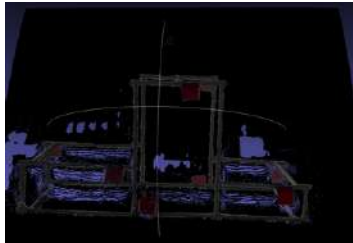


Figure 40: Dense Point Cloud Output [9]
Made by Tasneem Ashraf

Table 12 summarizes the comparative evaluation across three reconstruction approaches.

Approach	Target Quality	Pipe Quality	Processing	Hardware	Edge
Spatial Mapping	Accurate	Moderate	Real-time	Stereo cam + GPU	Real-time accurate point cloud
DUST3R (Local)	Moderate	Moderate	Fast	6-16GB VRAM CUDA 11.8+	Local, multi-view best perf.
Instant-NGP (Local)	High	Moderate	Moderate	RTX 3060 CUDA	Fast training, no depth cam

Table 12: 3D Approaches Evaluation [15]
Made by Yassin Khaled

Camera Configuration

Strategic Placement

Each camera position was determined through deliberate analysis of task geometry, pilot visibility requirements, and gripper coverage across all mission zones [1]. GLACIUS features one ZED 2i stereo camera and four auxiliary IP cameras, as shown in Figures 41 and 42 [9][10].



Figure 41: GLACIUS front view CAD model showing camera placement and enclosure configuration [11]
Made by Noureldeem Hassanien

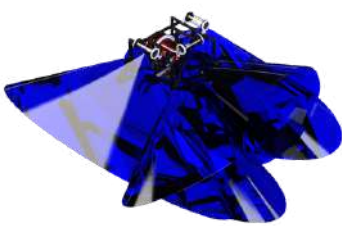


Figure 42: GLACIUS isometric view CAD model showing side camera positions and overall frame layout [11]
Made by Noureldeem Hassanien

ZED 2i Stereo Camera

The ZED 2i is housed inside the main horizontal enclosure, providing full protection from the strong currents and wave disturbance expected at the international competition venue [9]. Its placement inside the enclosure eliminates the risk of seal failure at the camera interface under dynamic pressure conditions, directly addressing one of the key harsh environment challenges of this year's competition (Figure 43) [1]. Depending on pre-trial strategy, a servo tilt mechanism may be integrated to extend the camera's vertical field of coverage without repositioning the vehicle.



Figure 43: ZED With Servo Enclosure [9]
Photo by Ahmed Hatim

IP Camera 1 — Bottom-Facing

Mounted underneath GLACIUS, this camera provides a near-perpendicular view of the seabed dedicated to crab detection in Task 2.1 [10]. This placement reduces perspective distortion and improves consistency between training data and live deployment imagery, while also giving the pilot a stable view for bottom-aligned maneuvering and target inspection.

IP Camera 2 — Front-Facing

Mounted on top of the frame facing forward, this camera provides direct coverage of the two front axial grippers, giving the pilot precise visual feedback during manipulation tasks across Tasks 1.1, 2.5, 3.1, and 3.2 [10].

IP Camera 3 — Left Side-Facing

Mounted on top of the frame facing the left side, this camera is dedicated to monitoring the left axial gripper, providing the pilot with direct visual feedback during lateral manipulation tasks [10].

IP Camera 4 — Right Side-Facing

Mounted on top of the frame facing the right side, this camera mirrors the left-side placement, covering the right axial gripper and ensuring full lateral manipulation visibility [10].

All four IP cameras are unified through a single Gigabit PoE switch, consolidating power delivery and data transmission into a single cable pathway [10]. This architecture eliminates cable redundancy, minimizes signal overhead, and ensures stable high-throughput feeds across all channels simultaneously.

Payload & Tools

Manipulators

1. Main Manipulator

GLACIUS features three horizontal (axial) HDPE grippers utilized across multiple mission tasks. After three prototypes; PMMA proved too brittle, fiberglass-reinforced polyethylene lacked rigidity, and HDPE was selected for its durability, machinability, and underwater resistance. The three-gripper configuration enables simultaneous object handling, enhancing efficiency and reducing mission time with a red polish that enables great underwater visibility (**Figure 43**).

2. Jaw Gripper Manipulator

GLACIUS's jaw gripper is a pneumatically actuated HDPE manipulator powered by a 30 mm bore, 50 mm stroke piston, handling object cross-sections from 9 to 91 mm. Wide fingers and two movable end effectors ensure precise, controlled gripping for connecting the eDNA sensor to the Holyrood subsea observatory in **Task 2.5** and removing the power connector cap in **Task 3.2** [1] (**Figure 45**).

3. ELMASRY hook

The ELMASRY Hook is a passive snap-shut tool for collecting the Basket Star in **Task 1.1**. [1] Manufactured from 10 mm acrylic, the jaws are forced open as GLACIUS pushes into the O-ball and automatically snap shut via elastic bands, requiring no actuation and ensuring high reliability during competition (**Figure 46**).

4. Rope tool

The Buoy-Anchor System was engineered specifically to address the requirements of **Task 2.4** [1], providing a streamlined mechanical solution that maximizes mission efficiency through the use of buoyancy physics. By utilizing a dual-gripper approach to transport the assembly and a force-actuated metallic hook for secure anchoring to the U-bolt, the system allows the ROV to transition immediately to subsequent objectives while the positively buoyant PVC canister independently delivers the tether to the surface. This specialized design eliminates the time-intensive requirement of a manual ascent, demonstrating a sophisticated integration of mechanical simplicity and strategic time management (**Figure 47**) that directly enhances the team's operational agility.

5. Sealed DC-Motor

For **Task 2.5** [1], the biofouling removal mechanism was upgraded from the low-torque bilge pump to the high-torque JGA25-370 motor, ensuring the ROV can reliably overcome physical resistance at the valve site. Furthermore, by replacing standard cable glands with a permanent epoxy-potted entry and implementing an innovative dual-casing system with integrated air chambers, the team has engineered a redundant, pressure-resistant actuator. This combination of elevated torque and a fail-safe sealing strategy guarantees maximum operational uptime and mechanical reliability during deep-water mission tasks (**Figures 48 and 49**).

Sensors

ZED 2i — Depth and Spatial Sensing

Beyond its vision capabilities, the ZED 2i (**Figure 50**) serves as GLACIUS's primary spatial sensor, providing real-time metric depth estimation, positional tracking, and dense point cloud generation through stereo disparity computation [9]. Its onboard inertial sensing ensures stable positional tracking throughout navigation and reconstruction processes, essential for maintaining position against current-induced drift in **Tasks 1.1, 1.2, 2.1, 2.2, and 3.1** [1][9].

Bar30 — Depth and Pressure Sensing

The Bar30 high-resolution pressure sensor (**Figure 51**) is mounted externally on the enclosure with its power routed internally, providing accurate real-time depth and water pressure measurements to the Pixhawk [5]. The Bar30 data is continuously fused with IMU readings through the Pixhawk's Extended Kalman Filter (EKF), enabling precise depth hold and stable maneuvering against wave motion and current forces [5]. This sensor is critical for **Depth Hold Mode** operation across **Tasks 1.2, 2.2, 2.5, and 3.2**, where stable hovering at a fixed depth is required for fine manipulation and accurate measurement [1].



Figure 44: GLACIUS Gripper CAD [11]
Made by Yousab Youssef



Figure 45: GLACIUS Jaw Gripper CAD [11]
Made by Mohamed Youssef



Figure 46: ELMASRY Hook CAD model [11]
Made by Ahmed Hatim



Figure 47: Rope tool CAD [11]
Made by Nouraldeem Hassanien

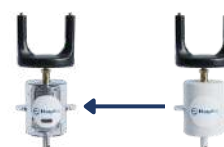


Figure 48: Sealed DC-motor CAD [11]
Made by Ahmed Hatim



Figure 49: Bilge Pump Photo by Nouraldeem Hassanien



Figure 50: Zed 2i [9]
Photo by Tasneem Ashraf



Figure 51: Bar30 Photo by Jana Mehanna



Mission Systems Approach

Table 13 summarizes the tool and payload deployment plan across all mission tasks.

Tasks		Gripper	Jaw Gripper	EDMASRY	DC Motor	Rope Tool	Sensors	Cameras(Zed &/ IP)
1.1	Collect two basket stars and return to surface	☒		☒				
	Collect two coral species by substrate	☒						
	Create 3D photogrammetry model of coral garden							☒
	Fly transect / maintain position in current						☒	☒
2.1–2.4	Identify invasive European green crabs (image recognition)						☒	☒
	Survey iceberg perimeter and measure keel depth						☒	☒
	Recover lobster pot / attach recovery line to buoy anchor	☒				☒		
2.5	Recover old eDNA sensor to surface	☒						
	Place new eDNA sensor in designated area	☒						
	Connect eDNA sensor to Holyrood subsea observatory		☒		☒		☒	
3.1	Place bubble curtain around micropile location	☒	☒					
	Guide micropile into designated location via camera							☒
	Pull pin to release micropile	☒					☒	
3.2	Retrieve power connector from wind farm subsea station	☒						
	Remove cover from oil platform port	☒	☒					
	Install power connector into oil platform port	☒					☒	

Table 13: Mission Planning and Execution [15]
Made by Yassin Khaled

Critical Analysis

Testing Methodology

GLACIUS underwent a methodical, multi-stage testing approach throughout development to guarantee robustness and optimal performance. All test results were recorded and shared via Google Drive through Discord, ensuring full accessibility for all team members.

Prototyping

Prototyping was central to GLACIUS's development, with each subsystem going through iterative cycles before final manufacturing.

Mechanical Prototyping

The axial grippers went through three material iterations; PMMA proved too brittle, fiberglass-reinforced polyethylene lacked rigidity, and HDPE was selected for its durability and machinability. The jaw gripper was prototyped across multiple pneumatic pressure settings, confirming 99% gripping force efficiency against design calculations. Thruster mounts were 3D printed in PETG and tested at multiple angles before the final 30°/60° configuration was selected [2]. The main enclosure underwent repeated seal testing, with a load-distribution ring introduced after acrylic cracking was observed under uneven stress during early pressure tests.

Electrical Prototyping

PCBs went through three prototype iterations before final approval, with each iteration bench-tested before committing to the final layout. ESC modules were individually validated across prototype iterations to confirm consistent performance before integration into the Power PCB.

Software Prototyping

The color restoration pipeline was first implemented in Python before being rewritten in C++ after prototype testing revealed insufficient frame rates on the Jetson Nano [7]. The crab detection model was expanded from 400 to 600 images through synthetic augmentation, achieving a 30% improvement in mean average precision [8].

Float Prototyping

FLOATILLA's pneumatic cylinder capacity was increased from 60 ml to 150 ml after prototype testing revealed buoyancy control granularity limitations in Task 4.1 [1].

Testing

Mechanical Testing

Structural Integrity Assessment

Stress analysis simulations were first conducted using ANSYS [17] to predict component behavior before physical testing. Load tests were applied to key parts and the fully assembled ROV, repeated three times per configuration, achieving a 97% match against simulation predictions.

Enclosure Hydrostatic Pressure Test

0.5 bar pressure was applied using a pneumatic cable and the enclosure was observed for air bubbles. Each test was held for 10 minutes and repeated every time the enclosure was opened. Zero bubbles throughout the full hold duration was the passing criterion.

Buoyancy and Stability

Neutral buoyancy and stability were tested in water across up to 15 trials, with weights and internal components adjusted iteratively and buoyancy recalibrated before each session.

Pneumatics

Pneumatic circuits were tested on shore at approximately 3.4 bar, with each line manually triggered and all components actuated individually to confirm consistent pressure response. Gripper force testing confirmed 99% efficiency against design calculations.

Electrical Testing

Power Distribution Analysis

Voltage regulation and current draw were tested using oscilloscopes and multimeters at 48V and 30A, repeated at every system modification. Passing required stable voltage under full load with no irregular drops or spikes.

Component Verification

All electrical components including PCBs, ESCs, cameras, and sensors were tested across three prototype iterations before final approval [10], with each component tested multiple times until consistent, fault-free performance was achieved.

System Integration Testing

Full electrical integration was tested on shore and underwater, evaluating power flow, data transmission, and response times. Acceptance criteria required no voltage drop, stable data transmission with no packet loss, and response times consistently under 100 milliseconds.

Software Testing

System Integration Testing – HITL

Hardware-in-the-loop simulations evaluated software and control system performance under real-time conditions before physical hardware deployment, repeated until stable and consistent results were achieved.

Fault Injection Testing

Eight primary fault scenarios were tested including ZED 2i stream failure, Pixhawk communication loss, and thruster output failure [5][9]. Each scenario was repeated under different system states, with a passing result requiring full recovery or safe fail-state within 2–4 seconds.

Structured Testing Approach

Full system integration followed a step-by-step approach; Jetson Nano first, then Pixhawk, Arduino Nano, T200 thrusters, full control loop, and finally the ZED 2i camera system [5][6][9]. Approximately 18 test bench sessions were completed before moving to full hardware assembly (Figure 51).

System Stress Testing

GLACIUS was tested under sustained high-load conditions including continuous 3-hour runtime, concurrent camera stream processing, full-output thruster operation, and simultaneous computer vision, MAVLink control, and telemetry communication[6][9][10]. Passing required stable communication, acceptable response times, and no critical failures throughout.

Troubleshooting

When issues arose, a structured isolate-divide-and-conquer approach was followed; problems were categorized as mechanical, electrical, or software-related, systematically broken down to identify root causes, and fully documented for future reference.

Case 1 – Erratic Thruster Behavior

Thrusters exhibited erratic motion at random intervals while at rest. PWM pulse width testing revealed inconsistent outputs with a ~30μs error, traced to software-emulated PWM instead of hardware timers following an overlooked code dependency during MCU migration from F1 to F4 [6]. Switching to hardware timers resolved the issue.

Case 2 – Single Thruster Underperformance

One thruster was spinning significantly slower than others. ROS logs confirmed nominal commanded values, ruling out software. T200 diagnostic tones confirmed ESC and signal integrity [6]. Physical inspection revealed propeller screws had come loose into the rotor. Refastening restored normal operation, confirming the value of full systematic elimination before modifying unaffected subsystems.



Figure 52: Titans Robotics team deploying Neptune-X-Regional ROV during the MATE ROV Egypt Regional Competition 2026
Credits to Media Team in Mate ROV Egypt Regional



Accounting

Budget Planning

The board maintained a structured cashbook throughout the season to track all income and expenditure in real time. Projections were built from last season's data with buffer margins applied to account for local and international inflation. Successful procurement kept costs below projections, as detailed in **Tables 14 and 15**; the ZED 2i stereo camera was sourced at \$250 USD against a \$449 projection and the ZED enclosure at \$100 against a \$700 estimate, saving \$799 USD in total [9].

Funding Sources

Total cash funding of \$4,050 USD was secured from two sources; a direct grant from Alexandria University (\$650 USD) and team member contributions (\$3,400 USD). We extend our sincere gratitude to Alexandria University whose support was instrumental throughout our development journey.

Cost Accounting Approach

A clear distinction was maintained between newly purchased components and reused assets.

Appendix A : Proposed Budget

Reused components are assigned fair market values based on current retail pricing; six T200 thrusters and ESCs valued at \$2,100 USD, station box and control equipment at \$744.80 USD, and IP cameras at \$58 USD [6][10]. These assets carried no new cash cost but are fully accounted for to reflect the true value of all deployed resources.

Budget Performance

Total actual cash spending came to \$2,491 USD against \$4,050 USD collected, leaving a reserve of \$1,559 USD (38.5%), demonstrating disciplined budget management. All figures are presented in both USD and CAD at a rate of 1.375 CAD/USD [1]. **Refer to Appendix B: Cost Projection for full breakdown.**

Travel Expenses

Total estimated travel cost per member is \$2,450 USD (\$3,368.75 CAD), covering flights at \$1,200 USD, accommodation at \$800 USD, meals at \$300 USD, and local transit at \$150 USD [1]. **Refer to Appendix A: Proposed Budget for full breakdown.**

Table 14: Budget Planning [15]
Made by Youssef Mohamed

TITANS Robotics — BUDGET PLANNING (From 1/11/2025 to 20/5/2026)								
Exchange Rates: 1 USD = 1.375 CAD 1 USD = 50 EGP Re-used = fair market value (no cash outlay)								
Main Category	Sub Category / Purpose	Type	Description	Projected (USD)	Actual (USD)	Projected (CAD)	Actual (CAD)	Funding Source
Administration	Regional Registration	Purchased	MATE ROV Regional Fees	\$245.00	\$245.00	CAD 336.88	CAD 336.88	Alexandria University
Administration	International Registration	Purchased	MATE ROV International Fees	\$390.00	\$390.00	CAD 536.25	CAD 536.25	Alexandria University
Administration	Testing Logistics	Purchased	Pool Rent, Transportation	\$600.00	\$600.00	CAD 1,100.00	CAD 825.00	Team Members
Electrical	Electrical Components	Re-used	30m CAT6 Ethernet Cable	\$0.00	\$0.00	CAD -	CAD -	Team Members
Electrical	Electrical Components	Purchased	Connectors, DC Motors, etc.	\$130.00	\$27.00	CAD 178.75	CAD 37.12	Vortex Robotics
Electrical	Electrical Components	Re-used	DC-DC Converters, T200 Thrusters & ESCs (7 each)	\$2,100.00	\$0.00	CAD 2,887.50	CAD -	Vortex Robotics
Electrical	Microprocessors	Purchased	1x Arduino Nano	\$25.00	\$5.00	CAD 34.38	CAD 6.88	Team Members
Electrical	Vision System	Purchased	1x ZED2i Stereo Camera	\$449.00	\$250.00	CAD 617.38	CAD 343.75	Team Members
Electrical	Vision System	Re-used	4x IP Cameras	\$58.00	\$0.00	CAD 79.75	CAD -	Vortex Robotics
Fabrication	Zed Enclosure	Purchased	Underwater Structural Camera Housing	\$700.00	\$100.00	CAD 962.50	CAD 137.50	Team Members
Fabrication	Pneumatic	Purchased	Pneumatic Hoses, Fittings, Solenoids (4x DCV 5/2)	\$124.00	\$25.00	CAD 170.50	CAD 34.38	Team Members
Fabrication	Pneumatic	Re-used	Air Compressor, Regulators, Actuators (4x pistons)	\$139.58	\$0.00	CAD 191.92	CAD -	Vortex Robotics
Fabrication	Raw Material	Purchased	Aluminum Sheets, 3D-Printing, Acrylic, Extrusions	\$325.00	\$316.00	CAD 446.88	CAD 434.50	Team Members
Fabrication	Sealing	Purchased	O-rings, Wire Glands, Teflon, Mechanical Seals	\$50.00	\$40.00	CAD 68.75	CAD 55.00	Team Members
Propbuilding	Propbuilding	Purchased	PVC & Connectors	\$150.00	\$140.00	CAD 206.25	CAD 192.50	Team Members
Propbuilding	Safety	Re-used	Life Jackets, Goggles, Gloves, Ear Plugs	\$33.00	\$0.00	CAD 45.38	CAD -	Vortex Robotics
Propbuilding	TPU	Re-used	Station Box, X-Box Controller, Power Supply, 25A Fuse	\$744.80	\$0.00	CAD 1,024.10	CAD -	Vortex Robotics
Total Income:				\$4,050.00	\$4,050.00	CAD 5568.75	CAD 5568.75	
Total Purchased:				\$3,386.00	\$2,138.00	CAD 4658.5	CAD 2939.75	
Total Reused / Donated:				\$3,875.38	\$0.00	CAD 4228.65	CAD 0	
Total Estimated Cost of Project:				\$6,463.38	\$2,138.00	CAD 8887.15	CAD 2939.75	

Table 15: Financial Overview
*Mixed means Reused & Purchased [15]
Made by Youssef Mohamed

TITANS Robotics — FINANCIAL OVERVIEW (Season 2025–2026)							
Exchange Rates: 1 USD = 1.375 CAD 1 USD = 50 EGP All figures shown in USD and CAD							
Section	Category / Item	Description / Notes	Type	Projected (USD)	Actual Cash (USD)	Projected (CAD)	Actual Cash (CAD)
INCOME SOURCES	Alexandria University	Direct disbursement from the university	Donated	\$650.00	\$650.00	CAD 893.75	CAD 893.75
	Team Members	Collected from all team members	Cash	\$3,400.00	\$3,400.00	CAD 4,675.00	CAD 4,675.00
	Total Income			\$4,050.00	\$4,050.00	CAD 5,568.75	CAD 5,568.75
FINANCIAL SUMMARY	Administration & Logistics	Marketing, Registration, Testing Logistics	Mixed	\$1,435.00	\$1,269.00	CAD 1,973.12	CAD 1,744.88
	Electrical Components	Sensors, Microprocessors, Vision, Power Systems	Mixed	\$2,762.00	\$502.00	CAD 3,797.75	CAD 690.25
	Mechanical & Fabrication	Enclosures, Pneumatics, Raw Materials, Sealing	Mixed	\$1,338.58	\$580.00	CAD 1,840.55	CAD 797.50
	Operation & Safety	Propbuilding, Safety Gear, Control Station	Mixed	\$927.80	\$140.00	CAD 1,275.72	CAD 192.50
	Total Portfolio			\$6,463.38	\$2,491.00	CAD 8,887.14	CAD 3,425.13
TRAVEL EXPENSES	International Flights	Egypt ↔ Canada return, per person		\$1,000 / person	\$10,000.00	CAD 13,750.00	CAD 13,750.00
	Accommodation	Airbnb shared housing for competition week		\$470 / person	\$4,700.00	CAD 6,462.50	CAD 6,462.50
	Meals & Daily Expenses	Per diem over competition period		\$200 / person	\$2,000.00	CAD 2,750.00	CAD 2,750.00
	Local Transportation	Airport transfers & competition venue		\$330 / person	\$3,300.00	CAD 4,537.50	CAD 4,537.50
	Total Travel (10 members)			\$20,000.00	\$20,000.00	CAD 27,500.00	CAD 27,500.00

Appendix B : Cost Projection

Reused components are listed at fair market value (FMV) in the Projected column to reflect their true contribution to the project, consistent with MATE ROV accounting guidelines. Their Actual cost is \$0.00 since no new cash was spent. The Total Estimated Cost (Actual) of \$2,138.00 represents the real cash outlay for purchased items only; adding the \$3,075.38 FMV of reused assets gives a full project value of \$6,463.38. Key budget variances between Projected and Actual reflect successful procurement: the ZED2i stereo camera was sourced at \$250 vs. a \$449 estimate (saving \$199), and the ZED enclosure at \$100 vs. \$700 (saving \$600). Testing logistics similarly came in under budget at \$600 vs. \$800 projected due to optimized venue arrangements.[9] All savings remained in the team reserve and were not reallocated to other spending categories, as shown in Table 16.

Category	Type	Item(s)	Description	Amount (USD)	Amount (CAD)
Administration	Purchased (cash)	Regional Registration	MATE ROV Regional Competition Fee	\$245.00	CAD 336.88
Administration	Purchased (cash)	International Registration	MATE ROV International Competition Fee	\$390.00	CAD 536.25
Administration	Purchased (cash)	Testing Logistics	Villa Rent & Team Transportation Logistics	\$600.00	CAD 825.00
Administration	Purchased (cash)	Marketing Display	Poster, Flyers, ROV 3D-Printed Models	\$34.00	CAD 46.75
Administration	Re-used	Marketing Display	Poster, Flags, Banners	\$0.00	CAD -
Electrical Components	Purchased (cash)	Arduino Nano	Microcontroller for embedded control	\$5.00	CAD 6.88
Electrical Components	Purchased (cash)	DC motor	General actuation	\$7.00	CAD 9.63
Electrical Components	Purchased (cash)	Signal Switch 5v	Logic-level switching	\$14.00	CAD 19.25
Electrical Components	Purchased (cash)	DC fan 12V	Cooling for electronics	\$7.00	CAD 9.63
Electrical Components	Purchased (cash)	buck converter 48->12V 15A	Low-power step-down	\$6.00	CAD 8.25
Electrical Components	Purchased (cash)	PCB 12x13	Custom circuit board	\$13.00	CAD 17.88
Electrical Components	Purchased (cash)	2 Buck Converter 48->12V 60A	High-power step-down for thrusters	\$200.00	CAD 275.00
Electrical Components	Purchased (cash)	1zed 2i	Stereo depth camera	\$250.00	CAD 343.75
Electrical Components	Re-used	6 T200 thruster	Main propulsion	\$0.00	CAD -
Electrical Components	Re-used	7 ESC	Speed controllers	\$0.00	CAD -
Electrical Components	Re-used	4 IP Camera	Underwater video	\$0.00	CAD -
Electrical Components	Re-used	1 cytron	Motor driver	\$0.00	CAD -
Electrical Components	Re-used	1 pixhawk	Flight controller	\$0.00	CAD -
Electrical Components	Re-used	1 Nvidia nano	Onboard GPU computing	\$0.00	CAD -
Electrical Components	Re-used	1 connector poe switch 48V	Power over Ethernet	\$0.00	CAD -
Electrical Components	Re-used	1 cat 6 cable 25m	Tether - data	\$0.00	CAD -
Electrical Components	Re-used	1 power cable (+, -) 25m	Tether - power	\$0.00	CAD -
Electrical Components	Re-used	mt30	High-current connector	\$0.00	CAD -
Electrical Components	Re-used	PCB (power distribution)	Power distribution board	\$0.00	CAD -
Electrical Components	Re-used	Bus Bar	High-current bus	\$0.00	CAD -
Mechanical & Fabrication	Purchased (cash)	Zed Enclosure	Underwater structural camera housing	\$100.00	CAD 137.50
Mechanical & Fabrication	Purchased (cash)	4 piston pneumatic	Mechanical actuators for grippers	\$60.00	CAD 82.50
Mechanical & Fabrication	Purchased (cash)	Shelf acrylic	Internal mounting shelf	\$18.00	CAD 24.75
Mechanical & Fabrication	Purchased (cash)	Face acrylic	Viewing window	\$15.00	CAD 20.63
Mechanical & Fabrication	Purchased (cash)	Face stainless steel	Enclosure end panel	\$20.00	CAD 27.50
Mechanical & Fabrication	Purchased (cash)	Brackets aluminum	Frame connecting brackets	\$16.00	CAD 22.00
Mechanical & Fabrication	Purchased (cash)	Gripper artilon	Manipulator end-effector	\$80.00	CAD 110.00
Mechanical & Fabrication	Purchased (cash)	Zed enclosure metal	Protective housing for ZED2 camera	\$86.00	CAD 118.25
Mechanical & Fabrication	Purchased (cash)	4 DCV 5/2	Pneumatic directional control valves	\$25.00	CAD 34.38
Mechanical & Fabrication	Purchased (cash)	Sealing Materials	O-rings, Wire Glands, Teflon, Mechanical S	\$40.00	CAD 55.00
Mechanical & Fabrication	Purchased (cash)	T200 Propellers & Fasteners	Propellers and hardware installation	\$120.00	CAD 165.00
Mechanical & Fabrication	Re-used	2 pneumatic cable 25m	Tether - air lines	\$0.00	CAD -
Mechanical & Fabrication	Re-used	Pod Artylon	Main electronics enclosure	\$0.00	CAD -
Mechanical & Fabrication	Re-used	Air Compressor	Regulators, Actuators (4x pistons)	\$0.00	CAD -
Operation & Safety	Purchased (cash)	Propbuilding Materials	PVC & Connectors	\$140.00	CAD 192.50
Operation & Safety	Re-used	PVC	Propbuilding items	\$0.00	CAD -
Operation & Safety	Re-used	Life Jackets	Goggles, Gloves, Safety Gear	\$0.00	CAD -
Operation & Safety	Re-used	Station Box	2K Monitor, X-Box Controller, Power supply	\$0.00	CAD -
Total Project Cost (cash outlay)				\$2,491.00	CAD 3,425.13
Total Income (cash)				\$4,050.00	CAD 5,568.75
Remaining Balance (cash)				\$1,559.00	CAD 2,143.63

Table 16: ROV Expenses [15]
Made by Youssef Mohamed

Appendix C : Build vs. Buy, New vs. Used

Component	Build vs Buy & New vs Reuse	Justification	Relevant Task
Pixhawk Flight Controller + Depth Sensor	Buy + Reuse/New	Requirements met for Buy: Provides stable depth hold, PID tuning, and underwater stabilization through integration between the Pixhawk and depth sensor. Benefits for Reuse/New: Pixhawk is previously tested and fully compatible with the ROV system, while the new depth sensor improves measurement accuracy and reliability underwater	Multiple tasks support, Task 1.3
NVIDIA Jetson Nano	Buy + Reuse	Requirements met for Buy: Provides sufficient processing power for autonomous control, computer vision, and ZED2i processing. Benefits for Reuse: Already integrated with the system, reducing setup and development time.	Tasks 1.2, 2.1, 2.2, 2.5
Thrusters (6 Units)	Buy + Reuse	Requirements met for Buy: Ensures stable propulsion and full maneuverability underwater. Benefits for Reuse: Proven underwater reliability and performance from previous testing.	Multiple tasks support
Sealed DC Motor with Canister	Build + New	Requirements met for Build: A custom waterproof canister was designed to protect the DC motor during underwater operation. The motor provides high rotational torque required for rotating the observatory mechanism in task 2.5 Benefits for New: Newly integrated system improves underwater reliability and operational performance.	Task 2.5
Electronics Pod	Build + Reuse	Requirements met for Build: Custom enclosure optimized for waterproofing, internal organization, and component placement. Benefits for Reuse: Existing pod remains reliable and reduces manufacturing effort.	Multiple tasks support
IP Camera Enclosure	Build + Reuse	Requirements met for Build: Custom enclosure provides waterproof protection while supporting wide-angle visibility with fewer cameras. Benefits for Reuse: Existing design still meets current system requirements	Multiple tasks support, task 2.1
Manipulators (4 Units)	Build + New	Requirements met for Build: Three standard manipulators support a wide clamping range for general object-handling operations, especially in Task 1.1, while one jaw gripper is specifically designed for connector placement into the observatory in Task 2.5. Benefits for New: Newly developed manipulators improve gripping precision and operational flexibility underwater.	Multiple tasks support
ZED 2i Camera	Buy + New	Requirements met for Buy: Provides stereo vision and accurate depth perception for navigation and autonomous operation. Benefits for New: Improved image quality and 3D sensing support precise measurements and object detection.	Tasks 1.2,2.2
ROV Frame	Build + New	Requirements met for Build: Custom frame optimized for stability, strength, and modular component integration. Benefits for New: Redesigned structure improves internal organization and supports multiple mission requirements.	Multiple tasks support

Table 17: Build vs. Buy, New vs. Used Analysis [16]
Made by Rodina Ghazaly

Appendix D : System Integration Diagram (SID)

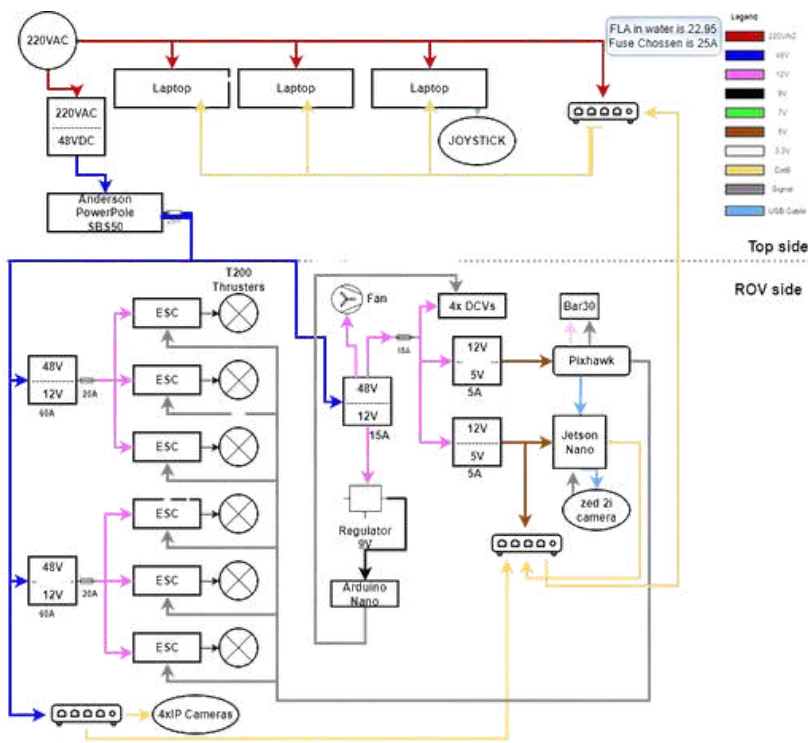


Figure 53: Electrical SID
Made by Saif Tabouna

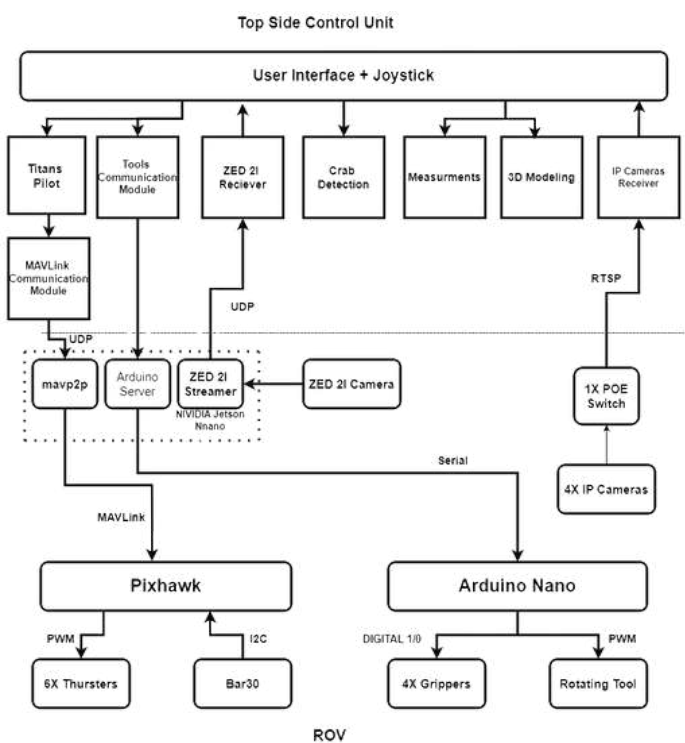


Figure 54: Software SID
Made by AbdElRahman Hazem

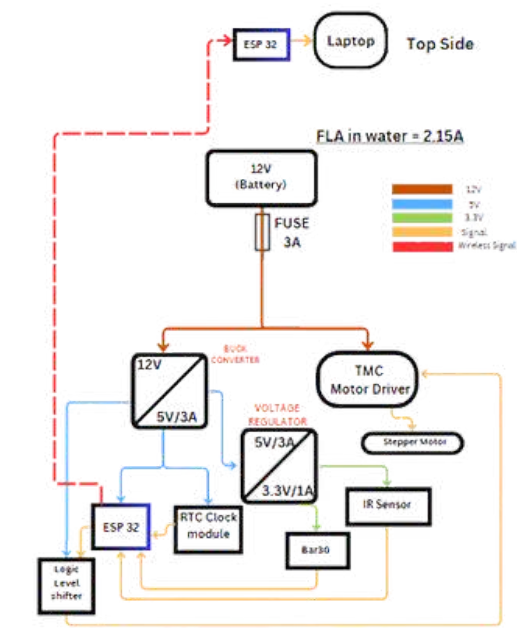


Figure 55: Float SID
Made by Youssef Mohamed

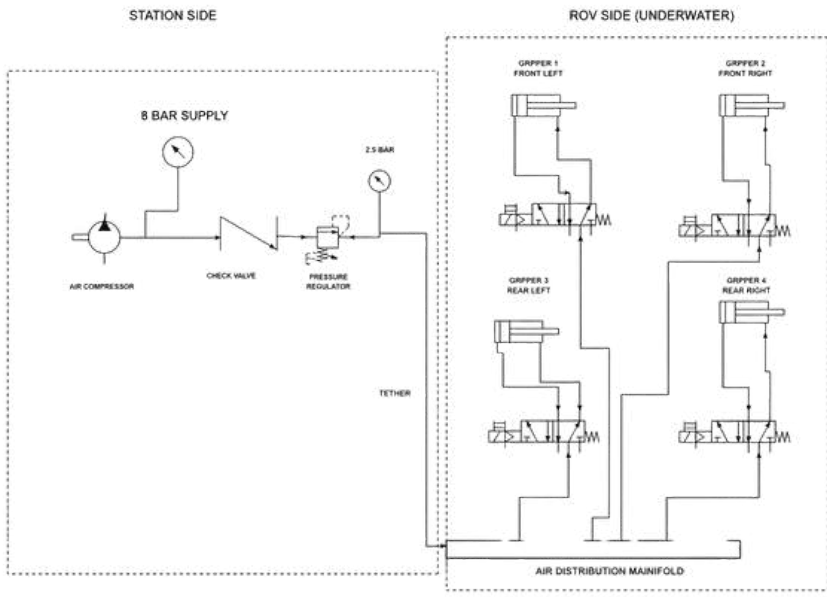


Figure 56: Pneumatic SID
Made by Mostafa Elshafey

Appendix E : Safety Checklist

Pre-Operational Safety Checklist

- ☐ General Workspace Safety
- ☐ Confirm a secure and clutter-free workspace.
- ☐ Ensure no obstacles or trip hazards.
- ☐ Verify no personnel running around the pool area.

Equipment Inspection

- ☐ Check the sealing of electronics housings.
- ☐ Verify unobstructed thrusters.
- ☐ Confirm power source is securely connected to ROV.
- ☐ Ensure cables are secured and leakproof.
- ☐ Check for protective gear availability.

Communication

- ☐ Establish clear and audible communication protocols.
- ☐ Test all communication devices.

Power Verification

- ☐ Ensure the ROV is receiving the correct nominal voltage.
- ☐ Test power systems for proper operation.

Thruster Testing

- ☐ Test all thrusters for proper operation.
- ☐ Confirm controller movements correspond with thruster activity.

Camera and Sensor Checks

- ☐ Verify functionality of all cameras and sensors.
- ☐ Test camera positioning and video feeds.

Leak Tests

- ☐ Perform leak tests on the pressure hull.

Pre-Dive Preparations

- ☐ Prepare the dive site, including clearing any hazards.

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