

Technical Documentation

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iEngineering company
ROV Name: Aphex



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Abstract

iEngineering, brings veteran expertise to the competition, having actively participated in the MATE ROV network since 2018. This year, we proudly present our latest Remotely Operated Vehicle, Aphex. Designed with a focus on modern engineering solutions, Aphex features an ultra-lightweight chassis utilizing custom 3D-printed materials, alongside an integrated computer vision system that significantly enhances pilot awareness and operational efficiency.

Built to tackle complex aquatic environments, Aphex is specifically tailored for critical mission themes: monitoring delicate underwater life and executing precise manipulative tasks. To achieve this, it utilizes a highly capable robotic claw engineered to safely retrieve and interact with submerged objects. Our engineering process was guided by a core design philosophy of modularity, rapid repairability, and steadfast stability. By ensuring components can be quickly swapped or fixed on the deck, we maximize in-water operational time. Combining our years of experience with an innovative, highly adaptable vehicle, Team A aims to leverage *Aphex's* reliability to secure a top-three finish in this year's competition.



Figure 1: The Group Photo of ROV Team

Acknowledgement

MATE Inspiration for Innovation: For organising this year's competition.

The Institution of Engineering and Technology, Hong Kong: For organising the Hong Kong/Asia Regional of the MATE International ROV Competition and promoting STEM education in Hong Kong.

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1. Design Rationale

1.1. Design Overview

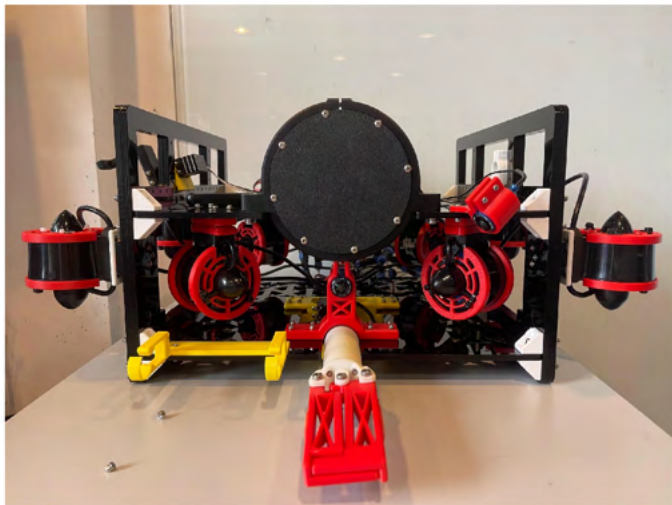


Figure 2: The overall appearance of the ROV

1.2. Modularity

To maximize operational flexibility and structural adaptability, Aphex utilizes a comprehensive modular design framework. Inherited from our proven design architecture, a standardized mounting system is deployed across all exterior subsystems, including the robotic arm, the 1080-degree servo motor, and the camera arrays. By implementing a uniform screw specification at every mounting interface, any payload can be seamlessly repositioned along the chassis without requiring bespoke brackets or adapters. This initialization standardizes our manufacturing workflow, minimizes fastener inventory, and expedites mid-mission reconfigurations or field repairs. Evolving this modular philosophy to address the strict logistical constraints of competing internationally, our team engineered a custom quick-fit system for the thruster array this year. Because transporting the ROV from Hong Kong to Canada imposed severe volume restrictions and risks of transit damage, this toolless, quick-fit mechanism allows the entire

propulsion system to be detached rapidly. This optimization minimizes the vehicle's shipping envelope, safeguards delicate components during international freight, and guarantees rapid, plug-and-play reassembly with precise alignment upon arrival at the competition.

1.3. Portability

Previous spider-like ROVs have proven the difficulty in transportation, requiring dedicated storage holders and the constant detachment of protruding robotic arms. Our new box-like architecture resolves this by directly integrating the manipulator, eliminating disassembly entirely. Additionally, replacing bulky spherical tether foams with streamlined tubular alternatives significantly minimizes the overall spatial footprint.

Also, because the holders of the ROV are big, it will be easy for our members to hold the ROV.

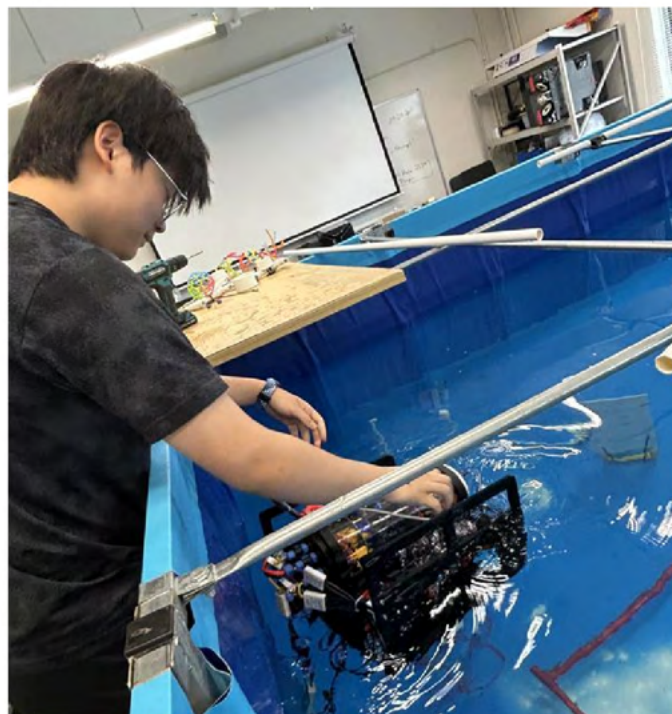


Figure 3: The way of holding the ROV (when putting it into water)

1.4. Eco-friendliness

Our team values sustainability throughout our design. To minimize environmental impacts, our ROV utilizes recyclable acrylic boards, reusable nails, and eco-friendly PETG filaments. This significantly reduces waste and enhances operational sustainability.

1.5. Design and Manufacturing Process

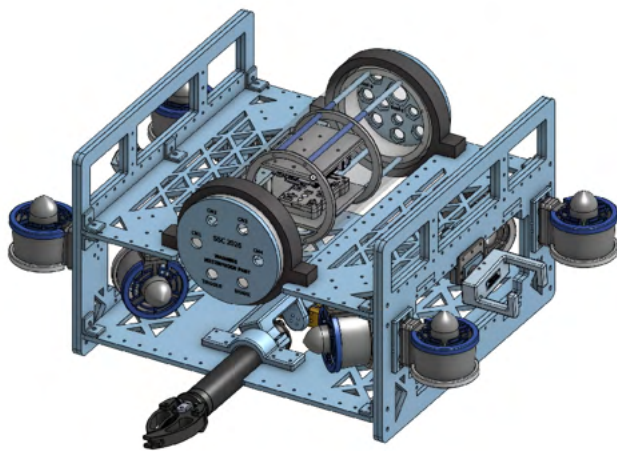


Figure 4: The 3D model of the ROV

Our engineering team adheres to a structured, iterative design and manufacturing process to ensure a systematic approach from conceptualization to final assembly. The design cycle initiates with comprehensive research and empirical evaluation of the previous year's ROV. By conducting practical underwater pilot tests, the team actively identifies operational disadvantages and mechanical vulnerabilities. To address these shortcomings, we apply fundamental physics principles and conduct extensive research into successful industry-standard ROV architectures. These insights are systematically documented in an analytical matrix spreadsheet, which efficiently

catalogs identified problems alongside their proposed engineering solutions.

Following the research phase, the team transitions to the 3D structural modeling stage. To streamline communication and concurrent development, we utilize Onshape, a cloud-based CAD platform. By establishing a dedicated Onshape collaborative workspace, our engineers can seamlessly manage daily 3D modeling tasks, ensuring real-time feedback, synchronized dimensions, and rapid iteration of the ROV's structural design.

Once the digital models are finalized, the manufacturing phase commences, prioritizing precision and material durability. Complex custom components are fabricated using a Bambu X1 Carbon 3D printer equipped with high-strength PETG filament, while structural acrylic boards are precisely shaped utilizing a laser cutter. During final assembly, a standardized combination of M3, M4, and M5 fasteners is utilized to securely integrate all hardware. To standardize this installation process and preserve our team's knowledge base, we authored a comprehensive assembly tutorial PDF. This instructional document significantly lowers the learning curve, enabling incoming team members to efficiently and accurately participate in the ROV's construction.

1.6. Decision and Trade-offs Process

Throughout the ROV development cycle, our engineering team relies on a structured, data-driven methodology to resolve critical design trade-offs. To systematically evaluate competing concepts, we utilize collaborative

Excel spreadsheets to index identified problems, catalog potential engineering solutions, and conduct weighted quantitative analyses. This ensures that every design choice prioritizes operational efficiency, structural integrity, and manufacturing feasibility.

A primary technical challenge during this cycle involved selecting the optimal chassis material for our newly integrated box-like architecture. We evaluated two primary structural candidates: PVC Tubes and Acrylic Boards. The evaluation prioritized factors such as rapid manufacturability (specifically compatibility with our laser-cutting workflow), structural rigidity, cost-efficiency, and alignment with our eco-friendliness goals.

To determine the most viable option, we constructed the following decision matrix, scoring each parameter on a scale of 1 to 5 (with 5 being the most advantageous):

Criterion	Wt.	PVC	Acrylic
Manufacturability	25%	3	5
Structural rigidity	25%	3	4
Cost efficiency	20%	5	4
In-water weight	15%	4	4
Eco-friendliness	15%	2	5
Weighted total	100%	3.45	4.40

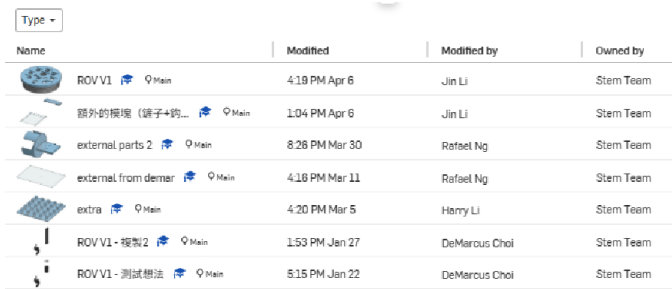
Figure 5: The trade-off table

As demonstrated in the quantitative analysis, Acrylic Boards achieved the highest aggregate score. PVC Tubes are economical and lightweight, but fail to provide the flat, stable geometry essential for housing our integrated robotic manipulator. Acrylic boards perfectly complement our manufacturing ecosystem—allowing for precise, rapid laser-cutting—while maintaining the robust

structural integrity and recyclable eco-friendliness required for our updated box-like ROV design.

1.7. Vehicle Structure

The ROV utilizes a rectilinear, box-like chassis fabricated from high-grade acrylic boards, a geometric configuration specifically chosen to optimize spatial efficiency and modularity. This orthogonal frame provides flat, parallel mounting surfaces that facilitate the precise integration of external sensors, manipulators, and thrusters directly onto the side walls. To ensure operational stability, the primary electronics cylinder—which now integrates all main control units into a single enclosure—is centrally positioned within the chassis. This layout perfectly aligns the vehicle’s Center of Gravity (CoG) with its geometric center, minimizing rotational inertia and simplifying the PID tuning for all motion axes. Complementing this structure is a standardized grid of 3mm diameter apertures distributed across the frame. This grid serves as a universal mounting interface for M3 fasteners, allowing for the rapid deployment of mission-specific accessories without requiring further structural modification.



Type	Name	Modified	Modified by	Owned by
	ROV V1	4:19 PM Apr 6	Jin Li	Stem Team
	额外的模型 (盖子+轴...	1:04 PM Apr 6	Jin Li	Stem Team
	external parts 2	8:26 PM Mar 30	Rafael Ng	Stem Team
	external from demer	4:18 PM Mar 11	Rafael Ng	Stem Team
	extra	4:20 PM Mar 5	Harry Li	Stem Team
	ROV V1 - 複製2	1:53 PM Jan 27	DeMarcus Choi	Stem Team
	ROV V1 - 測試想法	5:15 PM Jan 22	DeMarcus Choi	Stem Team

Figure 6: The Onshape platform outlook

1.8. Hydrodynamics

The ROV’s hydrodynamic profile is engineered to minimize the drag coefficient while

maintaining high operational mobility. By adopting a streamlined box-like chassis, internal components remain within the frame's silhouette, effectively reducing the frontal projected area compared to previous iterations. To further optimize fluid-structure interaction, the acrylic frame features a series of strategic perforations. Large triangular cutouts are designed to facilitate fluid bypass during vertical and lateral movements, which significantly reduces "added mass"—the volume of surrounding water the ROV must displace to accelerate. These specific cutouts utilize a truss-inspired geometry, which preserves the high structural rigidity and load-bearing capacity of the acrylic board while minimizing its overall hydrodynamic footprint and drag.

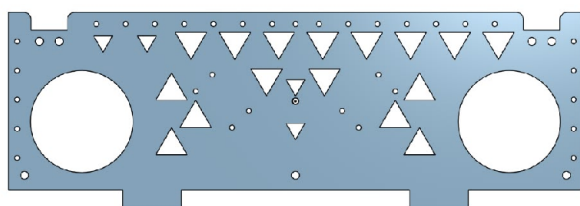


Figure 7: Hydrodynamics design of the ROV board

1.9. Buoyancy

To achieve stable and efficient underwater operation, our ROV is engineered for intrinsic neutral buoyancy without the reliance on external flotation foams. A key refinement this year involves the consolidation of the primary pressure vessels; while previous iterations utilized separate cylinders for the vision system and the central control units—housing the Pixhawk, Raspberry Pi, and power converters—we have integrated these components into a single, high-volume enclosure. This integration allows for more precise internal mass distribution, ensuring that the vehicle's Center of Gravity (CoG) is

perfectly centered within the chassis. Furthermore, by optimizing the volume-to-weight ratio of the acrylic frame and the integrated electronics cylinder, we have matched the ROV's aggregate density to the standard density of water. This approach ensures the vehicle remains naturally suspended in the water column, significantly enhancing passive stability and reducing the vertical propulsion required to maintain constant depth.

1.10. System Integration Diagram (SID) of ROV

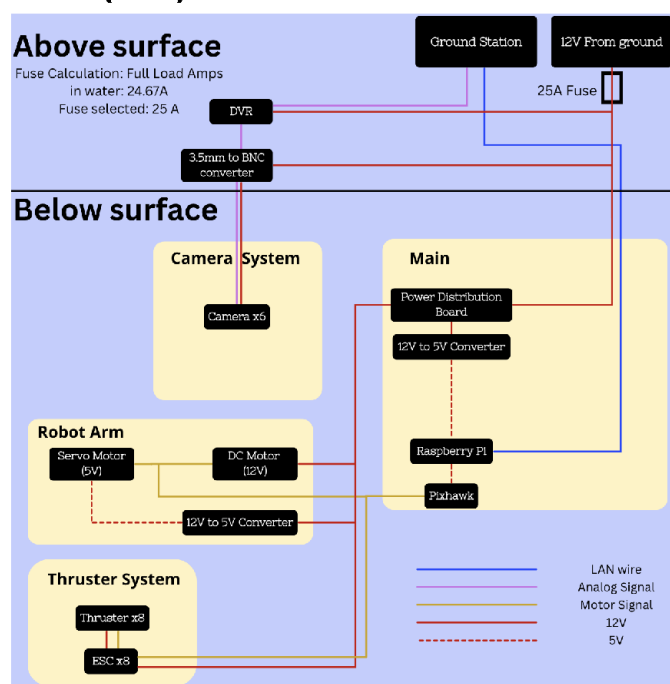


Figure 8: SID of ROV

1.11. Wiring System of the ROV

Communication and Control System

The ROV's control architecture integrates a Pixhawk flight controller and a Raspberry Pi [11] companion computer. This dual-processor configuration efficiently manages low-latency flight stabilization alongside high-level computational tasks. For the pilot interface, we utilize QGroundControl to provide a comprehensive dashboard for real-time vehicle

telemetry. To facilitate high-speed data transmission between the onboard processors and the offshore station, we implemented a Local Area Network (LAN) backbone utilizing Cat5e/Cat6 Ethernet cabling wired to the T568B standard, ensuring robust communication and minimal latency.

Vision System and Signal Integrity

The ROV's vision system is designed to provide stable visual feedback during underwater operation. The AHD camera feeds are routed directly to the surface through dedicated signal lines, using custom 3.5 mm-to-BNC adapters before connecting to the DVR. The stereo camera uses a separate digital path, transmitting USB video through Ethernet to the control station.

To improve signal reliability, camera and data lines are physically separated from high-current power cables. This reduces electromagnetic interference from thrusters and motor controllers, helping maintain a clear, low-noise video feed for the pilot.

1.12. Power Distribution

To optimize electrical efficiency and mitigate transmission losses, the ROV's primary power architecture was upgraded to a 12V standard for high-draw components, including the propulsion system. By transitioning away from the previous 5V-dominant setup, we significantly reduced the overall current draw required for equivalent power output. Low-voltage (5V) routing is now strictly isolated to the Raspberry Pi and two servo actuators, necessitating only three localized step-down converters. This highly streamlined configuration minimizes internal thermal output, saves critical chassis space, and maintains an exceptional safety margin that operates comfortably within competition

thresholds. Plus, our full load amperage of the ROV is 24.67A, which is lower than the 25A amperage limit.

1.13. Motor Driver Boards

To drive the ROV's brushless DC (BLDC) propulsion system, we utilize dedicated Electronic Speed Controllers (ESCs) for each of the eight thrusters. Because brushless motors lack physical commutators, these driver boards are essential for dynamically converting the standard 12V direct current (DC) from the power distribution module into precise, three-phase alternating current. We selected ESCs equipped with specialized bidirectional firmware, allowing for instantaneous forward and reverse thrust—a critical requirement for holonomic underwater navigation and rapid attitude correction. These controllers interface directly with the Pixhawk flight controller via high-resolution Pulse Width Modulation (PWM) signals [1], translating pilot commands into low-latency motor responses. Furthermore, the selected drivers feature a high continuous current rating that comfortably exceeds our system's peak operational loads, providing a robust safety margin against thermal overload during sustained high-torque maneuvers.

1.14. Thrusters

The vehicle's physical thrust is generated by 12V brushless DC (BLDC) motors driven by dedicated Electronic Speed Controllers (ESCs) [2]. These ESCs utilize specialized bidirectional firmware to dynamically convert direct current into the precise three-phase alternating current required for instantaneous forward and reverse thrust. In addition to electrical efficiency, we implemented critical mechanical safety modifications to the thruster hardware. To systematically mitigate laceration hazards posed by exposed impellers, our team utilized CAD software to design and 3D-print

custom protective shrouds for each unit. These integrated guards restrict the intake aperture gap to exactly 5mm, effectively preventing accidental human contact with the rotating blades without restricting fluid flow. Furthermore, the shrouds are fabricated using high-visibility red filament, establishing a standardized visual hazard indicator for operators during deck handling and deployment.

1.15. Propulsion

The propulsion architecture utilizes an eight-thruster configuration engineered to balance high maneuverability with robust attitude control. For horizontal translation, four thrusters are arranged in a 45-degree vectored layout. This orientation provides an optimal ratio between longitudinal thrust and rotational moment, enabling precise yaw control and holonomic positioning. To enhance vertical stability, the remaining four vertical thrusters have been repositioned from a central cluster to the peripheral extremities of the chassis. By maximizing their distance from the Center of Gravity (CoG), this layout significantly extends the moment arm. Consequently, the vertical propulsion system can exert much higher corrective torque, ensuring rapid pitch and roll stabilization against external underwater disturbances.

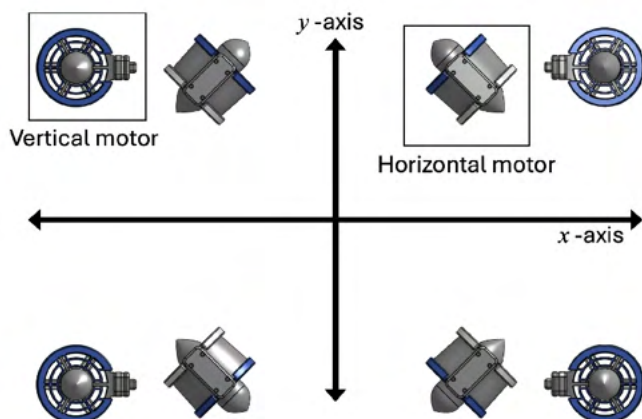


Figure 9: Orientation of the thrusters

1.16. Tether and Strain-relief.

The tether connects the ROV to the ground station and protects the external wiring. This design is central to our tether strain-relief system. Unlike last year, we integrated a dedicated, non-conductive metallic "tether wire" solely to handle mechanical tension.

When pulling the ROV from the pool, significant tension is applied to the cable bundle. Without this tether wire, that tension would act directly on the electrical wires, risking wire breakage and dangerous electrical leakage. With the tether wire installed, all tensile forces act on it instead of the electrical lines, preventing any damage.

Unlike the electrical lines that route to functional connection points, the tether wire anchors to a rigid structural point on the vehicle. For this ROV, we secure the tether wire to a metal ring bolted directly to the frame, ensuring the connection is strong enough to withstand high tension. On the ground station side, it connects firmly to the control box. In a real competition scenario, we can also anchor it to other stable structures, such as tables.

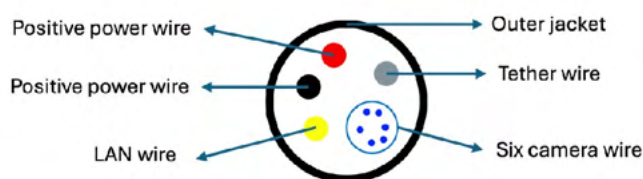


Figure 10: Diagram of the tether

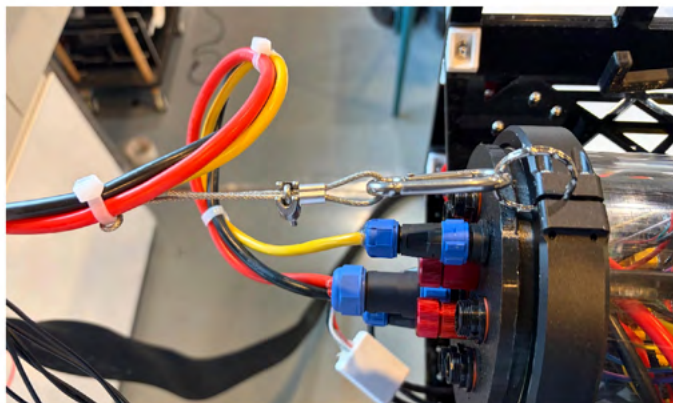


Figure 11: Strain-relief design of ROV



Figure 12: Strain-relief design of Groundstation

1.17. Cameras

Camera System 1 — Modified Automotive Cameras, AHD 720p × 4

Four modified automotive reversing cameras are mounted at the four corners of the ROV to provide wide situational awareness for the pilot. Each camera outputs a 720p video signal using the AHD protocol, which provides reliable, low-latency video with a simple analog transmission design. Unlike the previous setup, the camera signal lines now connect directly to the surface station. A custom adapter converts each camera's 3.5 mm signal connector to BNC, allowing the feeds to be connected directly to a DVR for monitoring and recording. This reduces onboard video-processing complexity while keeping the system compact and robust. The automotive camera form factor also provides a small size and basic

water-resistant construction, making it suitable for integration into the ROV frame.

Camera System 2 — USB Stereo Camera over Ethernet × 1

The second camera system uses a stereo camera mounted inside the ROV tube. This camera communicates through USB and is used to provide a higher-quality digital video stream for vision-based tasks. The USB signal is converted and transmitted to the surface through an Ethernet link, allowing the camera feed to reach the control station with greater flexibility than a purely analog setup. The stereo camera can also support future depth-estimation or measurement functions, making it useful for tasks that require more spatial information than a standard single camera can provide.

1.18. GUI

Aphex's ground station utilises QGroundControl, an open-source ground control application widely adopted in the unmanned vehicle community. QGroundControl was selected for its proven stability, cross-platform compatibility, and built-in support for real-time telemetry and video feeds, allowing the team to focus development efforts on the ROV itself rather than building a custom interface from scratch. The application provides the pilot with a unified view of camera feeds, vehicle orientation, depth, and system status during missions.

1.19. Image Processing

To support the detection of invasive crab species, the team developed an image recognition pipeline using **RF-DETR-S**, a lightweight real-time object detection model. The model was trained on a custom dataset of crab images to identify and localise invasive specimens in the ROV's camera feed. RF-DETR-S was chosen because it combines

real-time inference speed with strong detection accuracy while using an end-to-end, NMS-free detection approach. This makes it suitable for time-limited competition tasks where the pilot needs immediate visual feedback to locate and respond to targets efficiently.

2. Payload and Tools

2.1. Non-ROV Device (Float)

The motion of the float is powered by a custom-engineered ballast system housed within a reinforced plastic pipe. The engine utilizes a DC motor coupled to a threaded lead screw mechanism; as the motor rotates, the screw translates this rotational energy into linear displacement, actuating the plungers of three synchronized syringes. To maintain a watertight environment, the assembly is integrated using high-grade epoxy and precision O-rings, which prevent external leakage into the dry compartment. By drawing water into the syringes, the float increases its total mass (m) while maintaining a constant displacement volume. This increase in weight causes the gravitational force (F_g) to exceed the upward buoyancy force (F_b), resulting in a controlled descent. Reversing the motor direction expels the water, reducing the float's density and allowing it to ascend.

		Value	Unit	Convert to SI Unit	
Height of Bottle	h	20	cm	0.2	m
Diameter of Bottle	d	9	cm	0.09	m
Net Weight of Bottle	mg	1.04		1.04	kg
Water Volume	V	150	ml	0.15	kg
Water Density	ρ			958	kgm ⁻³
Drag Coefficient	C _d			0.84	
Volume of Bottle	$\pi \times \text{height} \times \text{radius}^2$			0.0012723	m ³
Required Bottle Mass	$\rho \times \text{Volume}$			1.26800335	kg
Additional Mass		0.2		0.20	kg
	$\text{Required Weight} - \text{Net Bottle Weight} - \text{Additional Mass}$				
Extra Mass need to add				0.03	kg
Water Mass use for Hold Depth				0.03	kg
				19.87%	%
Water Mass use for moving				0.12	kg
				80.13%	%

Figure 13: Float calculator

2.2. Non-ROV Device (Float) Battery Safety

The battery pack is built from 10 NiMH cells connected in series, producing a nominal output of 12 V (1.2 V per cell $\times$ 10) with a fully

charged peak of approximately 14 V. The pack is rated for a continuous 2 A discharge and is protected against short circuits by a 32 V, 3 A blade fuse. The highest voltage present anywhere in the float electronics is 12 V, matching the pack output, and the float device's full-load current requirement is approximately 1.8 A, which sits comfortably below the pack's 2 A rating. Under normal operation the battery pack can therefore supply the float's entire voltage and current demand, while the blade fuse guarantees that any fault condition is safely interrupted before damage can occur.

2.3. System Integration Diagram (SID) of Non-ROV Device (Float)

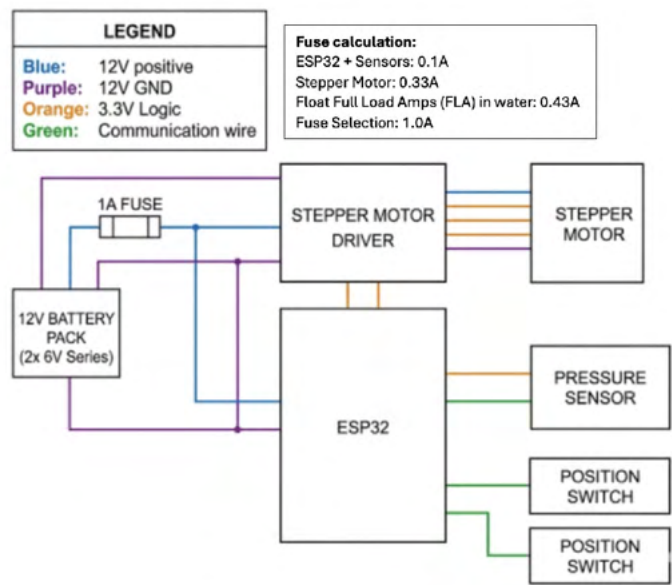


Figure 14: Float SID

2.4. 1080-degrees Motor

To successfully execute the biofouling removal task on the Holyrood subsea observatory camera, our engineering team designed a custom 1080-degree rotating claw integrated directly into the ROV's primary payload bay. After meticulously measuring the dimensions

of the simulated observatory props, we tailored the claw's geometric tolerances to ensure a secure, slip-free engagement with the observatory's rotating PVC framework.

To drive this multi-turn manipulator, we selected the LIEYING QFS0030/360 IP68 rotary servo motor [6]. A major engineering advantage of this specific actuator is its intrinsic IP68 waterproof rating, which guarantees absolute watertight integrity under continuous submersion without the need for bulky, custom-machined pressure housings. Furthermore, operating on a 5V direct current standard, this motor integrates seamlessly with our localized step-down converters. This strategic component selection completely eliminates the need for expensive high-voltage underwater actuators, significantly reducing the overall manufacturing cost and making the vehicle highly affordable while strictly maintaining our established electrical safety margins. Ultimately, the motor's multi-turn capability provides the precise rotational torque required to spin the observatory's inner mechanism the necessary three full revolutions, efficiently completing the task.

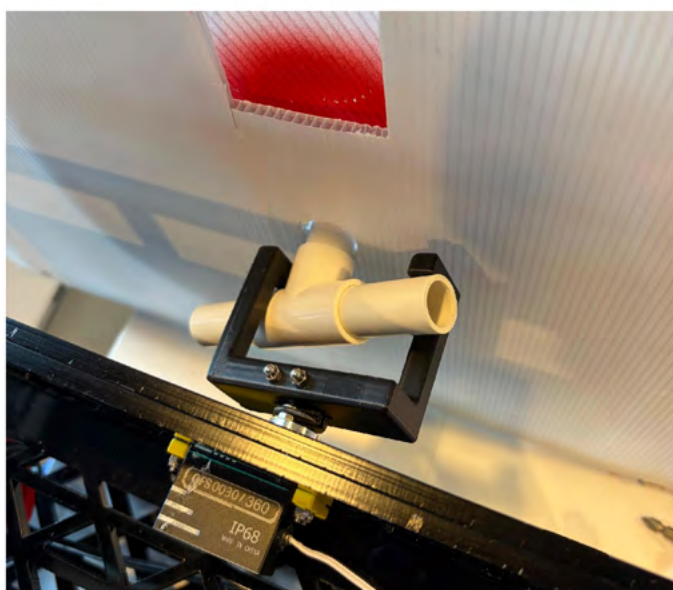


Figure 15: The overview of 1080-degrees DC motor

2.5. Robotic Arm

For general mission tasks such as retrieving props, relocating objects, and handling irregular shapes, Aphex uses the Blue Robotics Newton Subsea Gripper as its primary manipulator. The Newton is a commercially available, fully sealed underwater gripper that delivers reliable performance straight out of the box, allowing our engineering effort to be focused on the custom 1080° manipulator used for the spinning-object task rather than on developing a second in-house claw. The unit on Aphex is carried over from our 2025 ROV; it was fully inspected, bench-tested under load, and re-greased before integration into the new chassis, avoiding the cost of purchasing a second gripper while still meeting all of this year's performance requirements.

Newton Subsea Gripper Key Specifications

We used Newton Subsea Gripper Key as the robotic arm last year in the Hong Kong regional competition, however, this year, we have changed the design of the mechanical part of the gripper, letting the gripper become bigger to let it hold bigger objects.

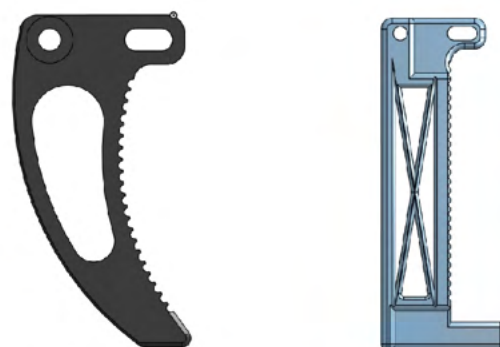


Figure 16: The gripper design between last year (left) and this year (right).

The Newton accepts a 9–18 V supply and is powered in Aphex directly from the main 12 V rail, drawing a peak current of approximately 6 A, which removes the need for any additional

step-down converter on the gripping mechanism itself. It is commanded through a standard servo-style PWM signal (1500 μ s neutral, >1530 μ s to open, <1470 μ s to close) driven from the Pixhawk auxiliary output, giving the pilot proportional control through the existing QGroundControl interface. Mechanically, the gripper produces 97 N of grip force at the jaw tip and 124 N further down the jaw, opens to a 62 mm jaw gap, and completes a full open-or-close cycle in approximately 1.6 seconds. Its Aluminum 6061-T6 housing with Buna-N O-ring and X-ring seals is rated to a depth of 300 m, which is far beyond MATE Ranger pool depths and provides a substantial safety margin against accidental water ingress. The unit measures 303 mm long by 36 mm in body diameter and weighs 524 g in air (267 g in water), making it a compact and near-neutrally-buoyant payload that does not disturb Aphex's centre of gravity.

Custom Wrist Rotator

To give the pilot an additional degree of freedom when aligning the jaws with irregularly oriented props, we designed and built a custom wrist rotator that mounts the Newton gripper to the chassis through a rotating interface. The rotator is driven by a 5 V servo fed from its own localised step-down converter, keeping it electrically isolated from the 12 V gripper supply so that a stall or inrush on one rail cannot disturb the other. Unlike the separate 1080° manipulator used for the spinning-object task, this wrist rotator provides only a limited angular range—sufficient to tilt and orient the gripper for precise prop engagement—rather than continuous multi-turn rotation. All of the rotator's mechanical components (the mounting plate, the rotating collar, and the servo housing) are custom-designed and 3D-printed in-house to match the Newton's body diameter and Aphex's central mounting bay.

Mounting Strategy

Rather than mounting the gripper on an extended arm at the front of the chassis, we installed the Newton at the geometric centre of the ROV, with only the jaws protruding forward through the opening in the front face of the box-like frame. This central placement keeps the gripper's mass—and any object it is carrying—as close as possible to Aphex's Centre of Gravity, which significantly reduces the pitching moment induced by picking up props. Because the moment arm is minimised, the vertical thrusters need to apply far less corrective torque during manipulation tasks, which in turn improves hover stability, reduces power draw, and makes fine positioning considerably easier for the pilot. The front face of the chassis also acts as a mechanical guard for the gripper body, protecting the Aluminum housing and PWM cable from incidental contact with pool walls or mission props while leaving the jaws fully exposed for task execution.

2.6. Sensors

Pressure Sensor

Our pressure sensor is installed at the back of the ROV tube. It has two functions. Firstly, it can use the pressure to calculate the water depth to do measurements. Secondly, it can compare the pressure inside the tube and outside the tube, if water leakage happens, it will detect and automatically shut down the machine to maintain safety.

Accelerometer, Temperature Sensor, Compass Sensor (In Pixhawk)

Those sensors are inside the tube and bundled with Pixhawk. The Accelerometer can examine the vertical orientation of the ROV, to automatically adjust thrusters and help maintain the balance of the ROV. The

temperature sensor can measure the temperature inside the tube, if the temperature is larger than 333K, it will automatically shut down the machine to maintain safety. For the compass sensor, it can show the direction of the ROV, helping the pilot to navigate underwater.

3. Safety

3.1. Personnel Safety

All engineers must acknowledge and comply with the workshop safety guidelines before entering the workshop. These guidelines outline the proper use of equipment, required protective gear, and emergency procedures, reinforcing awareness of associated risks and responsibilities. Ventilation systems and fume extractors remove harmful substances during soldering electronic components, operating 3D printers, and handling epoxy glue. At the same time, a Google Site is created by our experienced members, having tutorials describing the safety guidelines of the workshop.

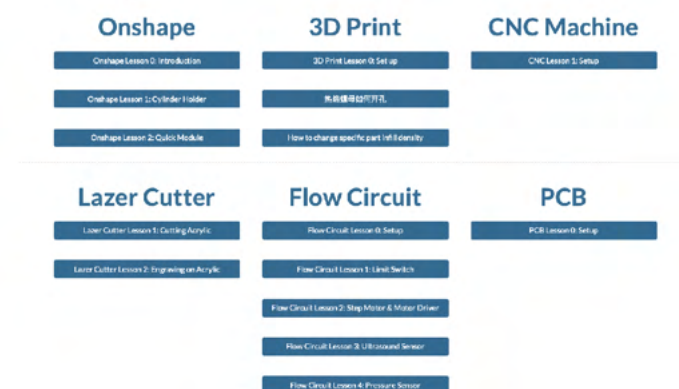


Figure 17: The safety guideline page in the Google Site

3.2. Operational Safety

Fire extinguishers and first aid boxes are located both on the inside and outside of the workshop area, allowing for instant responses

in case of emergencies. We also keep all of the workspaces clean and tidy, also making sure emergency exits and fire escape routes are always clear, which helps prevent accidents and allows quick and safe evacuation if needed. Annual fire drill training is also mandatory for all members to enhance their emergency preparedness.



Figure 18: The fire extinguisher below 3D printers

For safe ROV operation, our engineers also use epoxy-filled, 3D printed shells to protect electrical components from water-induced short circuits. Our control box features a clean and organized internal layout with no exposed wiring, ensuring safety and quality workmanship. We operate the ROV using a Windows 11 paired with a controller for intuitive and responsive control. The round-edges of the ROV ensure smoother operation and increase efficiency when doing tasks. Furthermore, rounded and blunt edges prevent accidental scrapes, which protect the surroundings and diver. By minimizing physical interference, being edge-free enhances the operational safety and environmental protection during underwater exploration. The driver gives the specific team commands which

ensures clear communication. For example, "Arm" to start the ROV or "Disarm" to stop the ROV. After a confirmation from team members, operations proceed. This protocol prevents ROV operation while crew members are performing maintenance and enables prompt shutdown during emergencies. The clear communication structure reduces human error and ensures smooth running mission execution.

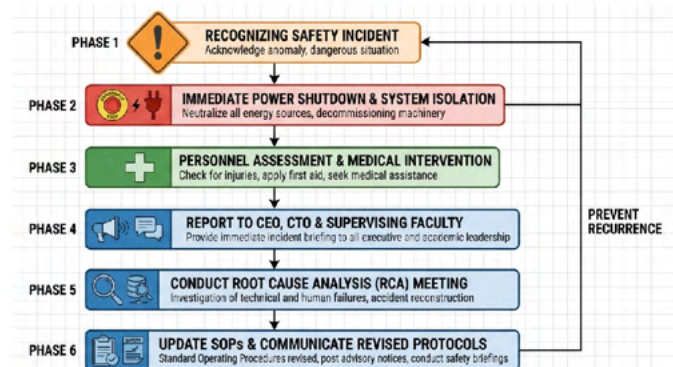


Figure 19: The flow chart of solving accidents in our workshop

3.3. Equipment Safety

To ensure a safe working environment, our team has implemented rigorous atmospheric and chemical safety protocols. During thermal and chemical processes—specifically laser cutting and epoxy curing—dangerous volatile organic compounds (VOCs) and noxious gases are generated. To mitigate this risk, high-velocity extraction fans are strategically positioned at these workstations to facilitate immediate gas displacement and maintain air quality. Furthermore, all flammable and hazardous materials, including industrial adhesives and epoxy resins, are stored in a dedicated, fire-rated safety cupboard. This storage is centralized within the administrative office to isolate high-risk chemicals from the general workspace and prevent accidental ignition or exposure [9].



Figure 20: The fans near the laser cutter

The ROV workshop operates under a strict "supervised-access" policy to eliminate unauthorized use of dangerous machinery. The facility remains locked whenever faculty or designated safety officers are not present. Students are required to obtain formal teacher approval before handling any high-risk equipment or materials. This hierarchical access control system ensures that all technical operations are conducted under expert oversight, significantly reducing the statistical probability of operational accidents and ensuring the long-term integrity of the equipment.

Our engineering team maintains a preventative maintenance schedule, conducting comprehensive safety inspections on a monthly basis. These audits serve to verify that all hardware components and safety sensors meet established industrial standards. Our commitment to these protocols was demonstrated in July 2025 during a routine pre-start inspection of the laser cutter. The team identified that the system's operational parameters had been modified incorrectly, creating a potential fire and structural hazard. Following our emergency response protocol, the machine was immediately decommissioned. A "lock-out" directive was issued to prevent further use until a full system recalibration was performed by a qualified technician. This immediate intervention prevented potential equipment damage and

ensured the continued safety of the workshop personnel [7].

3.4. Operational and Safety Checklists

Operational and safety checklists (**Appendix E**) ensure strict adherence to safety measures before, during, and after operations. Employees follow the operational guidelines to protect wildlife and ensure the safety of all crew members.

At the same time, some printed versions of safety checklists are stored in Google Drive, in our daily training, we print them out and use pens to tick each requirement if fulfilled

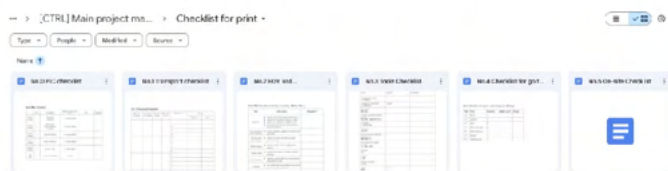


Figure 21: Printed version of safety checklists (different from the one in Appendix)

3.5. Vehicle Safety

In our ROV Vehicle, we also have adopted many safety features.

Power Management

All electronic devices and components of the vehicle have their power supplied from the provided 12V DC supply. Anderson power connectors are used to connect the power supply to our control station in order to lower the possibility of users touching the metal wire. A 25A fuse is inserted within 30 cm from the Anderson Power pole connector to stop current flow when an abnormally large current exists due to short-circuited or any other unexpected situation (The fuse calculation is in the SID chapter).



Figure 22: The 25A fuse

The Elimination of Sharp Edges

All (metal and non-metal) edges and corners of the ROV are polished and rounded with a polisher. Then, handled with file and sandpaper at last to ensure no sharp edges remain that could cause injury during handling or operation.



Figure 23: The round corners of ROV

The Warning Sign of Moving Parts

All moving parts (Including the thrusters, robotic arms, servo motors) in our ROV are with the "WARNING! MOVING PART!" sign in red and yellow to let users and other people know and be aware of the moving parts.



Figure 24: The warning sign of moving parts

4. Critical Analysis

4.1. Overview

Throughout the 2026 development cycle, iEngineering evaluated Apex against the design goals defined at the start of the season: modularity, portability, neutral buoyancy, low-latency control, and reliable manipulation of mission props. This section summarises how the ROV was tested, which design choices succeeded, which fell short, and what the team intends to improve in future iterations. Our aim is to present an honest, data-driven assessment rather than a promotional summary.

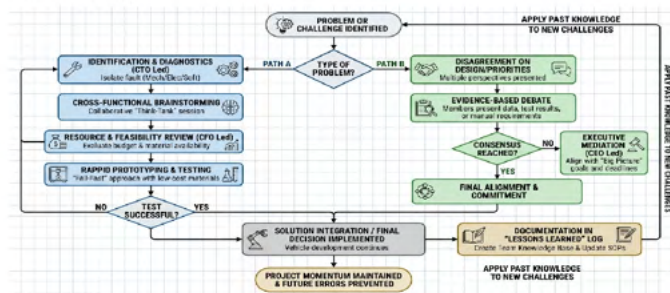


Figure 25: Our team's product-development flow chart [8]

4.2. Testing Methodology

Apex was tested twice weekly in the St. Stephen's College swimming pool, with additional dry-bench testing performed in the workshop before each wet run. During each pool session the team logged thruster response, buoyancy trim, camera latency, tether drag, battery current draw, and mission-task completion time. Instrumentation included a digital multimeter for current measurements, a stopwatch for task timing, QGroundControl telemetry logs for attitude and depth data, and the onboard Raspberry Pi for recording camera feeds. Every test run was documented in a shared Google Sheet so that

trends across sessions could be compared quantitatively rather than anecdotally.

However, in our daily ROV testing, errors are unavoidable, troubleshooting is obviously needed when developing ROV.

The iEngineering team's troubleshooting methodology is rooted in a systematic, data-driven approach that prioritizes efficiency by leveraging a comprehensive hardware repository of functional prototypes and historical configurations. Whenever a system failure is identified, the initial diagnostic phase involves a comparative analysis between the malfunctioning assembly and a known-working baseline from our archive. By maintaining the habit of preserving successful sub-system examples, the team can isolate variables effectively, debugging one component at a time through direct comparison. This iterative process allows for the rapid identification of specific hardware or software deviations, ensuring that repairs are targeted and do not interfere with the vehicle's remaining functional architecture [4].

In instances where a fault cannot be resolved through baseline comparison, the team transitions to advanced technical diagnostics using specialized instrumentation to probe the system's internal state. As an illustrative example, a digital multimeter [3] is frequently employed to perform continuity checks and verify that voltage distribution across the power rails adheres to the rated electrical parameters of each component [10]. Furthermore, when analyzing complex communication or control signals, the team utilizes an oscilloscope [5][12] as an additional example of our diagnostic capabilities. This allows for the real-time visualization of Pulse Width Modulation signals, ensuring that the timing and duty cycles produced by the microcontrollers are clean and within the required tolerances for the motors and

sensors. By rigorously comparing these empirical measurements against official technical specifications, the team can pinpoint the root cause of an error with high precision and implement a verified engineering solution [7].

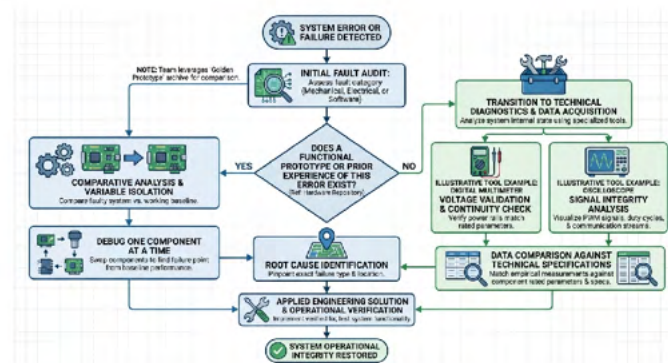


Figure 26: Our team's troubleshooting flow chart

4.3. Performance Against Design

Goals

Measured performance was compared against the targets defined during the initial design phase. Neutral buoyancy was achieved within a trim error of approximately ± 30 g, well inside the ± 50 g target, confirming that integrating the vision and control units into a single enclosure successfully centred the vehicle's mass. Camera latency through the AHD pipeline measured around 110 ms, comfortably below the 150 ms threshold required for responsive piloting. Horizontal translation speed, however, reached only 0.65 m/s against a 0.8 m/s target, and the 1080° claw generated approximately 12 N of grip force versus the 15 N target. These shortfalls directly informed the improvement list below.

Successes

The standardised M3 mounting grid proved to be the single most valuable design decision of the season. During mock mission runs, the

team was able to swap the pH sensor and syringe payloads between configurations in under 30 seconds, compared with several minutes on last year's spider-frame ROV. The integrated electronics cylinder also delivered its intended benefit: passive stability improved noticeably, and PID tuning for pitch and roll converged in a fraction of the time required in 2025. Finally, the decision to physically isolate the camera transmission lines from the high-current power rails eliminated the intermittent video noise that plagued earlier prototypes.

Failures and Root Causes

Not every subsystem performed as intended. During the March pool tests, one of the 3D-printed thruster shrouds detached after roughly eight minutes of continuous operation. Root-cause analysis traced the failure to fatigue cracking around the M3 mounting hole in the PETG shroud, caused by thruster vibration transmitted through an insufficiently stiff mounting tab. The shrouds were reprinted at 60% infill with a thicker mounting boss and re-validated without further failure. A second issue appeared in the manipulator: the 1080° rotary servo occasionally stalled when gripping heavier props, because the 5 V rail sagged under simultaneous load from the Raspberry Pi and the servo. This was mitigated by splitting the 5 V supply into two independent step-down converters so that the servo no longer shared a rail with the compute stack. Finally, horizontal speed fell short of its target because the 45° vectored thruster layout, while excellent for yaw and holonomic motion, sacrifices a component of forward thrust; this is a trade-off the team accepts for the manoeuvrability benefit, but it is documented here as a known limitation.

Trade-offs Revisited

Reviewing the major decisions with the benefit of test data, the team would make the same choice on chassis material: acrylic continues to offer the best balance of machinability, rigidity, and cost. The consolidation of all electronics into a single enclosure also proved correct, reducing the number of waterproof penetrations and simplifying assembly. The one decision the team would reconsider is the exclusive reliance on PETG for high-vibration structural components such as thruster shrouds; a tougher filament such as PETG-CF or ABS would likely be a better fit for parts exposed to sustained mechanical stress.

Lessons Learned

Three broader lessons emerged from this cycle. First, integration testing must begin earlier in the schedule; several issues were only discovered once the full electrical and mechanical stack was assembled, leaving limited time to iterate. Second, waterproofing needs a written sign-off checklist rather than verbal confirmation, because two of the early leaks traced back to miscommunication about whether a joint had actually been potted. Third, power-budget calculations should be performed per-rail rather than in aggregate, since the 5 V servo-stall incident demonstrated that a comfortable total-system margin can still hide a localised under-supply.

Future Improvements

Looking beyond the 2026 competition, the team has identified several concrete improvements. On the mechanical side, high-stress 3D-printed components will be reprinted in a tougher filament, and the thruster mounting tabs will be redesigned with a larger fillet to reduce stress concentration. On the electrical side, the team plans to add per-rail current monitoring so that localised load issues

can be detected in telemetry rather than in post-mortem analysis. On the software side, the RF-DETR based detection pipeline will be extended with a confidence overlay in QGroundControl so the pilot can quickly judge whether a detection is reliable. Collectively, these changes are expected to close the remaining gaps between measured and target performance while preserving the modularity and reliability that defined Aphex this year.

5. Teamwork

5.1. Company Overview:

iEngineering, a dynamic team that consists of 38 dedicated members, affiliated with the school St. Stephens College. We are dedicated to advancing ROV technology so as to support marine conservation and to address climate change. Our goal is to develop a Remotely-Operated-Vehicle with high-resolution cameras to monitor marine ecosystems and robotic-arms that supports ocean protection initiatives. We believe that by achieving a strong sense of teamwork and cooperation, it can foster a positive environment within our school that provides students with lifelong skills and innovation.

5.2. Company Organisation:

With our mission of marine conservation, we aim for progress and continuous improvement, emphasizing both sustainability and safety. Our employees are the foundation of success, and seamless collaboration is achieved through a clear hierarchical structure across four departments: Mechanical, software, and the leader. Department leaders mentor junior members, ensuring effective delegation and professional growth. The Leader governs the entire team, providing strategic oversight and hosting regular cross departmental meetings to foster unity and operational efficiency. Our

mechanical team designs the case of the ROV and several components which were 3D printed such as the claws and the clamps. Our software team manages the ROV's control part through QGroundcontrol, adjusting the connection between the ground station and ROV, and adding code to the ROV to fulfill task requirements. Our approach allows for a clear structure within our team that fosters teamwork, collaboration and effectiveness. Allowing tasks to be completed on time. This integrated framework drives efficiency, safety, and progress toward our goal.

structure and task specific designs. The Hardware department designs PCBs, and the Software department begins coding the initial ROV system, laying the foundation for mission-specific refinements. With the mechanism design, the Mechanical department manufactures the ROV frame and manipulator prototypes, enabling the Hardware department to integrate PCBs and wiring. Concurrently, the Software department programs mission-specific codes, preparing the ROV for testing. Next, The Props Department which mainly consisted of new members. They help build the props for the pilot, to further enhance the pilot's experience and familiarity with the tasks. Lastly, The Float Department. A department that consists of members who excel at software skills, they help design and build the float. They make designs and changes to ensure that the float is suitable and working for the specific environment. Ensuring consistent ROV performance, pool tests are conducted twice a week, on every Monday and Thursday. Refinements are made to optimize ROV's sophisticated systems. Everyone is involved with the process of compiling documents, finalizing reports as the ROV framework is validated, ensuring alignment with MATE ROV

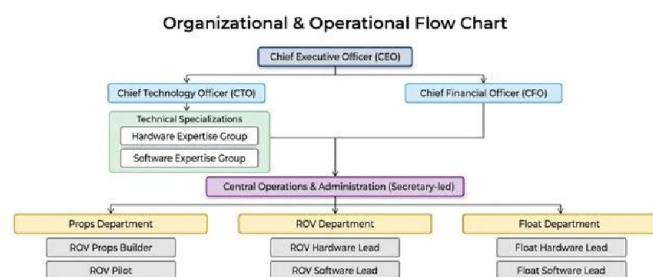


Figure 27: Our team's organizational chart

5.3. Project Schedule:

Aligned with our cohesive organizational structure, our project schedule is divided into four distinct phases: From September all the way to April, we focus on recruiting passionate and proactive new members to ensure team sustainability and morale. The selected new members will enter Team A, which consists of new members or members still in training. They will undergo safety training led by senior members. This fosters technical proficiency and independence while instilling a sense of commitment to our mission and safety standards. After the training period, they are divided into 3 different departments that leverage their expertise to advance ROV development. The ROV department creates everything that is needed for the ROV, this department includes multiple sectors like mechanical, hardware, software. The Mechanical department creates computer-aided design (CAD) files for the ROV



Figure 28: Our team's project management Gantt chart

5.4. Resources, Procedures, and Protocols:

To ensure timely project execution and foster interdepartmental collaboration, iEngineering conducts weekly meetings on Wednesday. Each department leader shares their

respective progress updates and solves challenges faced, enhancing transparency and teamwork. Additionally, integration of specialised tools supports department-specific needs. For instance, Arduino is used for software code within the breadboard which controls the float and ROV. The software department also leverages GitHub for efficient code management and change tracking. Apart from team correspondence protocols, environmental sustainability is another core pillar of iEngineering mission. Our team uses biodegradable materials which are derived from natural materials, we reduce our environmental footprint, aligning with our dedication to marine conservation. These integrated tools and practices promote effective collaboration, scalability, and sustainable progress.

6. Accounting

6.1. Budget

iEngineering’s 2026 season was funded primarily through St. Stephen’s College. By reusing proven components from the 2025 ROV, the team redirected the majority of its budget toward new structural materials, cameras, and the float subsystem.

New Purchases

Item	Qty	Unit (USD)	Total (USD)
PETG filament (1 kg)	5	25	125
Acrylic 5 mm 400×600	5	10	51
AHD 720p camera	4	13	51
IR camera (1080p)	1	13	13
Epoxy / adhesives	—	—	19
Float subsystem	—	—	103
New subtotal			362

Figure 29: Purchases chart 1

Reused from 2025 (HK\$0 actual cost)

Item		Qty	Orig. year
BLDC thrusters		8	2023/2024
Basic ESCs (30 A)		8	2023/2024
Pixhawk		1	2023/2024
Raspberry Pi		1	2023/2024
Newton Gripper		1	2024/2025

Electronics cylinder		1	2024/2025
Servo motors		2	2025/2026
SP13/SP21 connectors		—	2025/2026
Tether cable + joystick		—	2025/2026

Figure 30: Reused material chart

Total actual expenditure for the 2026 season: approximately HK\$2,825. All reused items were inspected and bench-tested before integration. We noticed that many materials such as connectors, electronic devices and 3D printing filaments are not completely used up. In order to save materials, we reuse them this year.

Travel Expenses

The 2026 MATE ROV World Championship will be held in St. John’s, Newfoundland and Labrador, Canada. Since the competition requires international travel from Hong Kong to Canada, the travel budget includes round-trip airfare, accommodation, meals, local transportation, travel documentation, insurance, baggage and equipment-related costs, and contingency. Based on our current estimate, each attending person will require approximately **USD 5,128**. For **24 team members and 3 supervising teachers**, the total estimated travel expense is approximately **USD 138,462**.

Item	Cost (USD)
Round-trip airfare: Hong Kong → St. John’s	72693
Accommodation	14539
Meals	11077
local transportation	3461
Travel documents, insurance, and SIM cards	4154
Baggage and equipment-related transport	6,923

Competition registration / administration share	1731
Contingency	23884
Total travel estimate	≈138462

Figure 31: Travel expenses chart

6.2. Cost Projection

The table below estimates what it would cost a new team to build Aphex from scratch at current retail prices, ignoring reuse and donations. All figures are in USD (1 USD ≈ 7.8 HKD). Labour costs are excluded.

Item	Qty	Unit (USD)	Total (USD)
T200 thrusters	8	231	1,846
Basic ESC R3	8	40	318
Newton gripper	1	923	923
Pixhawk 6C	1	200	200
Raspberry Pi 5	1	87	87
NiMH cells (1.2 V)	10	6	64
AHD cameras	4	13	51
IR camera	1	13	13
Servo motors	2	26	51
SP13/SP21 connectors	6	6	38
PETG filament (1 kg)	5	25	125
Acrylic 5 mm sheets	5	10	51
Epoxy / adhesives	—	—	19
Float subsystem	—	—	103
Tether cable	1	38	38
Cylinder enclosure	1	64	64
Joystick controller	1	38	38
Contingency (~10%)	—	—	451
Grand total			4,444

Figure 32: Purchases chart 2

Our actual spend of approximately HK\$2,825 is roughly 8% of the projected full-build cost, demonstrating the significant cost savings achieved by reusing proven components from the 2025 ROV. The largest individual items in a from-scratch build would be the thrusters (42%) and the Newton gripper (21%), both of which were carried over at zero cost this season.

6.3. Build vs. Buy, New vs. Used

iEngineering follows a clear rule for deciding whether to build a component in-house or purchase it off the shelf: we buy where commercial products offer proven reliability,

safety certification, or performance that we cannot practically replicate, and we build in-house where custom geometry, rapid iteration, or significant cost savings are available. The same logic applies to the choice between new and reused hardware—any component that remains within its expected service life and passes inspection is carried over to reduce both cost and environmental impact.

Purchased (Buy) components

Thrusters (8× BLDC)

Buy. Commercial underwater BLDC thrusters are pressure-rated, dynamically balanced, and cheaper than any in-house equivalent once custom sealing is accounted for. Developing our own would offer no performance benefit and carry significant reliability risk.

Electronic Speed Controllers (ESCs)

Buy. Off-the-shelf bidirectional ESCs with specialised firmware provide instantaneous forward/reverse thrust and are impractical to replicate as a student project.

Pixhawk Flight Controller

Buy. The Pixhawk is an industry-standard autopilot with a mature ArduSub firmware stack that would be impossible to reproduce in-house within a season.

Raspberry Pi Companion Computer

Buy. Readily available, well-documented, and cheaper than any custom single-board computer we could assemble.

Automotive AHD Cameras (×4)

Buy. Modified commercial reversing cameras are inherently waterproof, low-latency, and

extremely cost-effective compared with designing our own housings and image pipelines.

IR Camera (1080p)

Buy. Commercial IR modules provide reliable low-light imaging at a fraction of the cost of a custom solution.

SP13 / SP21 IP68

waterproof connectors Buy. Certified aviation connectors are safety-critical; any in-house waterproofing would introduce an unacceptable risk of water ingress.

Tether Cable and Ethernet Backbone

Buy. Standard Cat5e/Cat6 cable meets the bandwidth requirement at minimal cost

LIEYING QFS0030/360 IP68 Rotary Servo

Buy. Its intrinsic IP68 rating removes the need for a custom pressure housing, and its 5 V operation integrates directly with our existing step-down converters.

General-purpose Robotic Claw

Buy (reused from 2025). Our primary manipulator for routine mission tasks is the Blue Robotics Newton Subsea Gripper, a proven IP-rated commercial unit delivering 97 N tip / 124 N mid-jaw grip force, a 0.62 m jaw opening, and a 300 m depth rating. The same unit was carried over from the 2025 ROV after inspection and servicing, eliminating both development risk and repurchase cost.

NiMH Battery Pack (float)

Buy. Commercial cells provide predictable capacity and safety characteristics; in-house cell assembly would be a fire risk.

In-house (Build) Components

Acrylic box-frame Chassis

Build. No commercial frame matches the custom geometry required for our integrated manipulator bay and standardised M3 mounting grid. Laser-cut acrylic is cheap, fast to iterate, and fully recyclable.

Main Electronics Enclosure

Build. The consolidated single-cylinder enclosure is designed around our specific Centre of Gravity strategy and component layout, which no off-the-shelf housing accommodates.

Thruster Shrouds

Build. 3D-printed in PETG to enforce the MATE 5 mm finger-gap safety rule. No commercial shroud fits our thrusters, and in-house printing allows rapid redesign when failures occur.

1080° Rotating Claw (spinning-task manipulator)

Build. A dedicated second manipulator is purpose-built for the Holyrood subsea observatory biofouling task, where three full rotations of the observatory's inner mechanism are required. It is driven by the purchased LIEYING IP68 rotary servo but the mechanical interface, gripper tolerances, and mounting are all custom-designed to engage the simulated observatory props reliably.

Float (non-ROV device)

Build. A custom syringe-and-lead-screw ballast mechanism housed in a reinforced pipe; no commercial equivalent exists at the scale required for the MATE float task.

Epoxy-potted Electronics Shells

Build. 3D-printed PETG shells filled with epoxy protect sensitive electronics from water ingress and vibration at negligible cost.

Pilot-station Control Box

Build. Tailored to our specific surface-side wiring and tether interface so that the pilot has a single, organised interface during operation.

New vs. Used

To reduce cost and waste, iEngineering inspects and reuses any component from the 2025 ROV that remains within its expected service life. For the 2026 build, the following items were carried over and re-validated before integration: the eight BLDC thrusters and their ESCs, the Pixhawk flight controller, the Raspberry Pi companion computer, the Blue Robotics Newton Subsea Gripper, the SP-series waterproof connectors, the tether cable, and the surface-station joystick. Each reused item was bench-tested under load and inspected for corrosion or mechanical wear before being cleared for the new vehicle. All custom-fabricated structural components—the acrylic chassis, the integrated electronics enclosure, the custom 1080° spinning-task claw, and the thruster shrouds—were built new for 2026 to match the updated box-like architecture, while consumables such as PETG filament, acrylic sheets, fasteners, epoxy, and the float's NiMH cells were purchased new.

7. Appendix

7.1. Safety Checklist

Safety Checklists for Construction and Operation

Construction

- ☐ Ensure machinery and tools are in good condition before use
- ☐ Wear suitable protective equipment
- ☐ Shut down electronic appliances that are not in use
- ☐ Perform soldering or other practices that involve toxic gas in a well-ventilated area
- ☐ Return all tools to designated areas after use
- ☐ Use reusable or recycled materials for ROV components
- ☐ Store batteries in designated fireproof containers

Operation — Pre-deployment

- ☐ All electronics connections are secured, correctly connected, and non-exposed
- ☐ Screw caps on all cameras are secured
- ☐ Cables and tethers are properly tightened
- ☐ Manipulators are all properly mounted and secured onto the ROV
- ☐ No damage in ROV frame
- ☐ Tether is laid out neatly without knots or tangles
- ☐ Surface station tether strain relief is connected; tether Ethernet and power are connected
- ☐ Surface station is stable and on a level surface
- ☐ Deck area is clear of clutter and tripping hazards
- ☐ Thrusters free from obstruction
- ☐ All members wearing appropriate and safe attire
- ☐ Verify no microplastics or debris are shed into the pool
- ☐ Confirm post-operation cleanup plan

Operation — Power-up

- ☐ Control Box is receiving 12 V nominal
- ☐ Verify camera connection to the Control Box is stable
- ☐ Perform thruster test; joystick movements correspond with thruster activity
- ☐ Test any electrical manipulators that require pilot control

Operation — Deployment

- ☐ Verify no excess bubbles are coming out
- ☐ Clear signal communication established:
 - “Kill” — when power needs to be cut off
 - “Contact” — before touching Aphex
 - “Launch” — when Aphex is ready to be operated underwater
 - “Power on” — before turning on Aphex
- ☐ Appropriate length of tether is released into water to prevent pull on ROV or entanglement

Camera Feed

- ☐ Pilot calls out “Kill” and powers down the ROV
- ☐ Crew members retrieve ROV via tether to shore
- ☐ Begin troubleshooting process until communication is restored
- ☐ Document the cause of failure and the implemented repair method

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