

2026 MATE ROV COMPETITION ♦ RANGER CLASS

THE ORCAS

TECHNICAL DOCUMENTATION



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Rohan Mishra	Documentation Lead, Marketing Lead
Daksh Singh	Chief Technological Officer, Finance Lead
Udheer Vasudevan	Head of Safety, Machining Specialist
Manveen Singh	NRD Hardware
Ayansh Paliwal	Head of Software, Camera Vision Lead
Aarav Shah	NRD Software
Tanmay Namburi	3D Design Lead

Organization	Unaffiliated (Multi-School Team)
Location	Bangalore, Karnataka, India
Schools	NPS, Inventure Academy, Greenwood High, Primus Public School, TISB
Mentors	Piyush Kore (Coach), Vasudevan Visvanathan, Nitesh Varshney (Additional Mentor), Rishi Patchigolla (Mentor)

Table of Contents

THE ORCAS		2026 MATE ROV • Technical Documentation
I.	Abstract	3
II.	Project Management	3–5
	A. Company Profile	3
	B. Schedule	4
	C. Resource Management	4–5
III.	Design Rationale	5–10
	A. Overall Vehicle Design	5–6
	B. Step-by-Step Design Process	6–7
	C. Design Trade-Offs	7
IV.	Innovation	8–9
V.	Problem Solving	9–10
VI.	Systems Approach	10–11
VII.	Vehicle Structure	11–13
VIII.	Vehicle Systems	13–14
IX.	Electrical System	14–16
X.	Control System	16–17
XI.	Propulsion	17–18
XII.	Buoyancy & Ballast	18–19
XIII.	Payload & Tools	19–20
XIV.	Build vs Buy, New vs Used	20–21
XV.	System Integration Diagram	22
XVI.	Safety	23–24
XVII.	Testing & Troubleshooting	24–25
XVIII.	Budget & Cost Accounting	25–27
XIX.	Discretionary Points	27
XX.	Acknowledgements & References	28

1 ABSTRACT

The Orcas is a student-led engineering team based in Bangalore, India. The team consists of ten students from multiple schools who share a passion for underwater robotics, engineering, and hands-on problem solving. ORCA Mark I is the team's entry for the 2026 MATE ROV Ranger Class Competition. The ROV was designed with a strong focus on stability, modularity, and reliability during underwater missions. Its structure combines precision-cut acrylic sheets with PVC components to create a lightweight frame that is durable and easy to modify during testing. The ROV uses a Pixhawk flight controller along with a six-thruster vectored propulsion system to achieve stable movement in multiple directions underwater. Neutral buoyancy is achieved using ballast, buoyancy foam, and repeated pool testing. ORCA Mark I is equipped with a dual-camera imaging system: one front-facing camera assists with navigation, while the second is positioned toward the arm and hook system to improve manipulation accuracy. The vehicle was developed through repeated prototyping, testing, and redesign. This document outlines the design, construction, control systems, and engineering decisions behind ORCA Mark I.

2 PROJECT MANAGEMENT

A. Company Profile

ORCAS is a student-led underwater robotics team focused on designing reliable and efficient ROV systems for the MATE ROV Competition. The team consists of nine members from seven different schools specializing in mechanical engineering, electrical systems, software development, operations engineering, and business management. The team structure was divided into three major departments: Software Development, Hardware Engineering, and Business & Documentation. This division allowed responsibilities to be distributed efficiently while ensuring that every subsystem could be developed simultaneously throughout the season.

Software Department

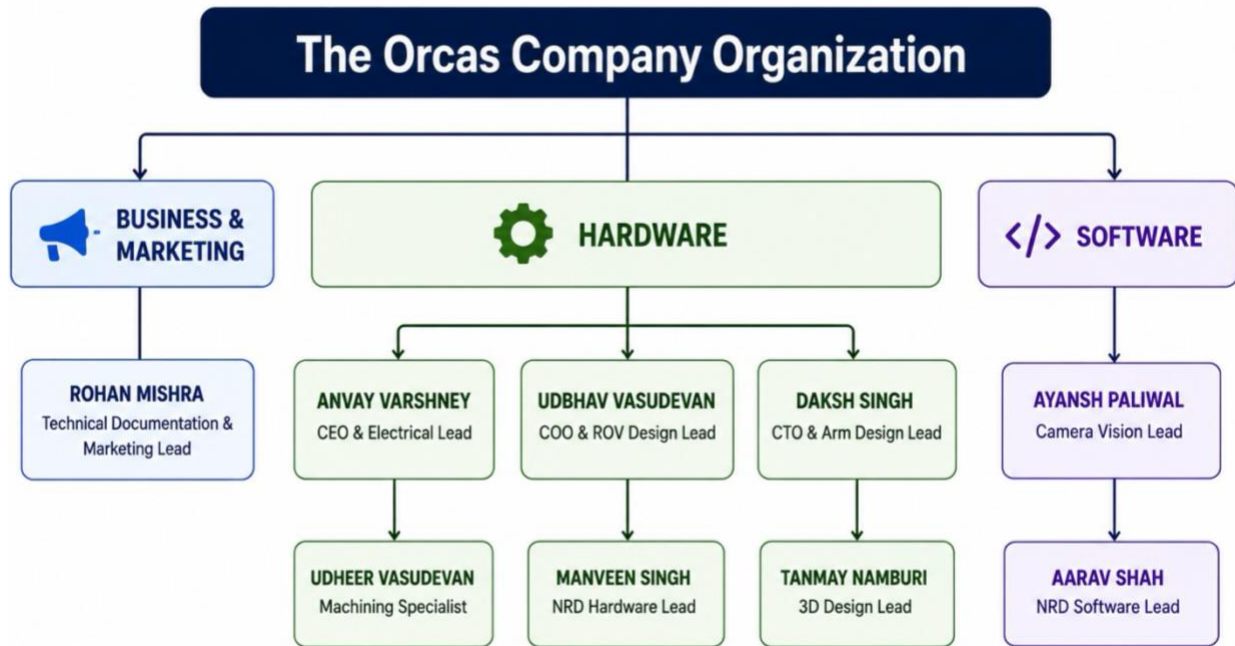
The Software Department was led by Ayansh Paliwal, Head of Software Development. He was selected for this role due to his proficiency in programming languages such as Python, Java, and C++. This year's MATE ROV competition involved several computer-vision-based tasks, including measuring coral garden dimensions, determining iceberg height, and identifying different crab species automatically. These tasks required strong programming and image-processing capabilities, making him highly suited for the role.

Hardware Department

The Hardware Department was responsible for frame design, electrical integration, buoyancy systems, and subsystem manufacturing. Anvay Varshney served as CEO and Electrical Systems Lead due to his strong leadership abilities and experience with hardware systems and fabrication. Udbhav Vasudevan served as the COO and ROV Design Lead. Udbhav also serves as the primary pilot for Orca. Tanmay served as the 3D Design Lead developing all custom 3D-printed components using Fusion 360, Blender, and Onshape. Udheer Vasudevan served as Head of Safety and Machining Specialist. Manveen Singh led buoyancy and hardware implementation, while Arav Shah assisted with subsystem integration.

Business & Documentation

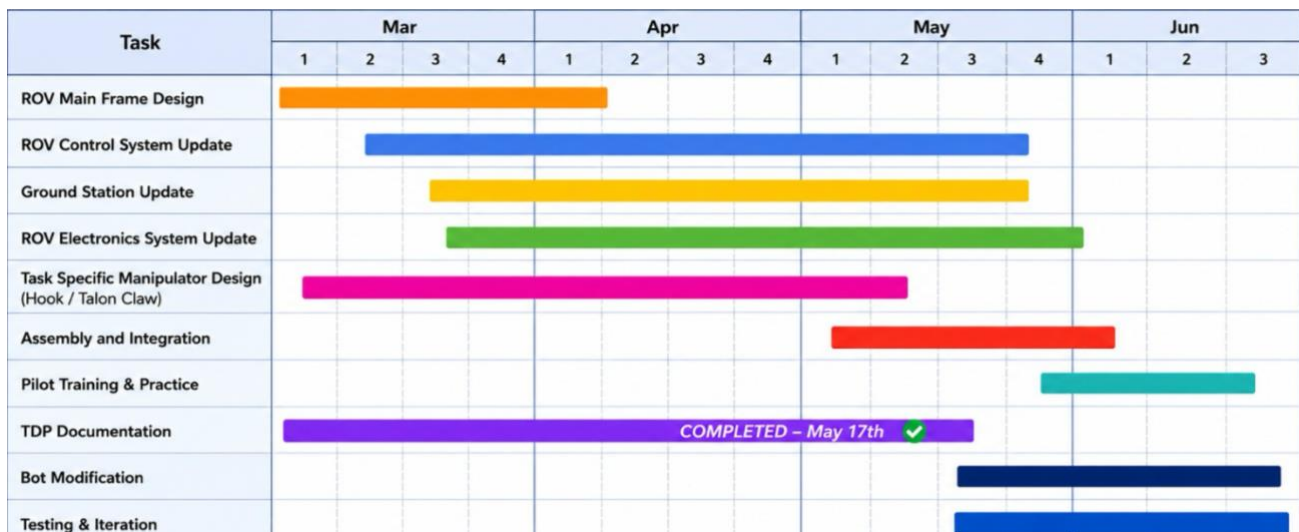
The Business and Documentation Department was led by Daksh Singh (CTO&CFO) and Rohan Mishra (Documentation Lead). Daksh was responsible for budgeting, accounting, cost optimization, and technical documentation while continuously identifying cost-effective alternatives. Rohan assisted with report writing and technical documentation throughout the season.



B. Schedule

A complete development timeline and Gantt chart were created to organize the season into major phases including brainstorming, CAD development, manufacturing, subsystem integration, waterproofing, testing, troubleshooting, and driver practice. The schedule was updated continuously throughout development to accommodate redesigns, testing feedback, and failures.

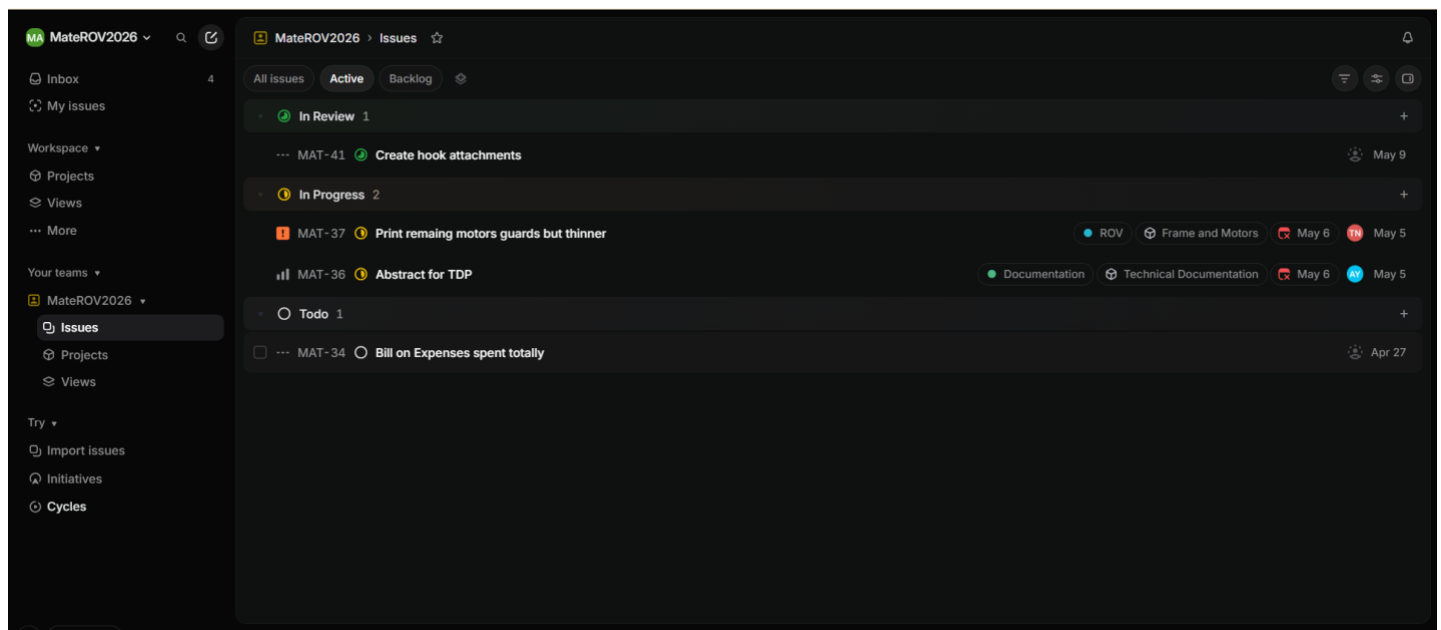
The initial phase focused on brainstorming and subsystem research. The team researched different propulsion layouts, waterproofing methods, frame geometries, manipulator designs, and control-system architectures. Multiple subsystem concepts were discussed collectively before the final design direction was selected. Following subsystem research, the team transitioned into CAD development and subsystem prototyping involving frame modeling, 3D printing, waterproofing experiments, propulsion testing, and tether development. Final weeks before competition was dedicated to pool testing, troubleshooting, subsystem optimization, and pilot practice.



C. Resource Management

The team carefully managed resources including tools, spare parts, electrical components, and budgeting throughout development. All components and engineering tasks were cataloged using the project-management platform Linear. Linear allowed the team to create engineering tasks, assign responsibilities, establish deadlines, and track subsystem progress efficiently. Since the team consisted of members from seven different schools, centralized task management was essential to ensure that all members remained updated on development progress and individual responsibilities.

Daily meetings were conducted where members discussed completed work, subsystem issues, design changes, and implementation challenges. This ensured continuous communication between departments and allowed engineering decisions to be reviewed properly before implementation. All tools and fabrication equipment were systematically organized after each work session to improve operational efficiency during future build sessions.



Budget management was overseen by the CTO, Daksh Singh, who ensured that the project remained within budget while prioritizing in-house manufacturing whenever possible. For example, instead of purchasing commercial T200 thrusters costing approximately \$200 USD, the team used locally sourced 5010 360KV BLDC motors costing approximately \$15 USD while still achieving comparable thrust performance. Previously purchased cameras were also reused because they continued to meet mission requirements. Travel expenses and subsystem procurement were also tracked throughout development.

Several operational protocols were implemented during testing. A dedicated tether operator ensured that the tether remained untangled during operation, as tether-related failures could significantly impact maneuverability and subsystem reliability. Pre-dive and post-dive safety checklists were conducted before and after every pool test to verify waterproofing, tether integrity, buoyancy, and electrical safety. During early pool testing, the team observed that tether drag caused rotational instability and shifted the vehicle balance rearward. Additional pool-noodle foam was added to rebalance the vehicle and improve underwater stability, demonstrating the team's systematic engineering problem-solving process.

THE ORCAS		2026 MATE ROV • Technical Documentation
Protocol	Implementation	
Daily Standups	Members discussed progress, blockers, and next steps each session	
Linear Task Board	All engineering tasks tracked with deadlines and assignees (used by MATE 2025 winners)	
Tether Operator	Dedicated member ensured tether remained untangled during all pool operations	
Safety Checklists	Pre-dive and post-dive verification conducted before/after every test	
Tool Organization	All fabrication equipment systematically organized after each session	

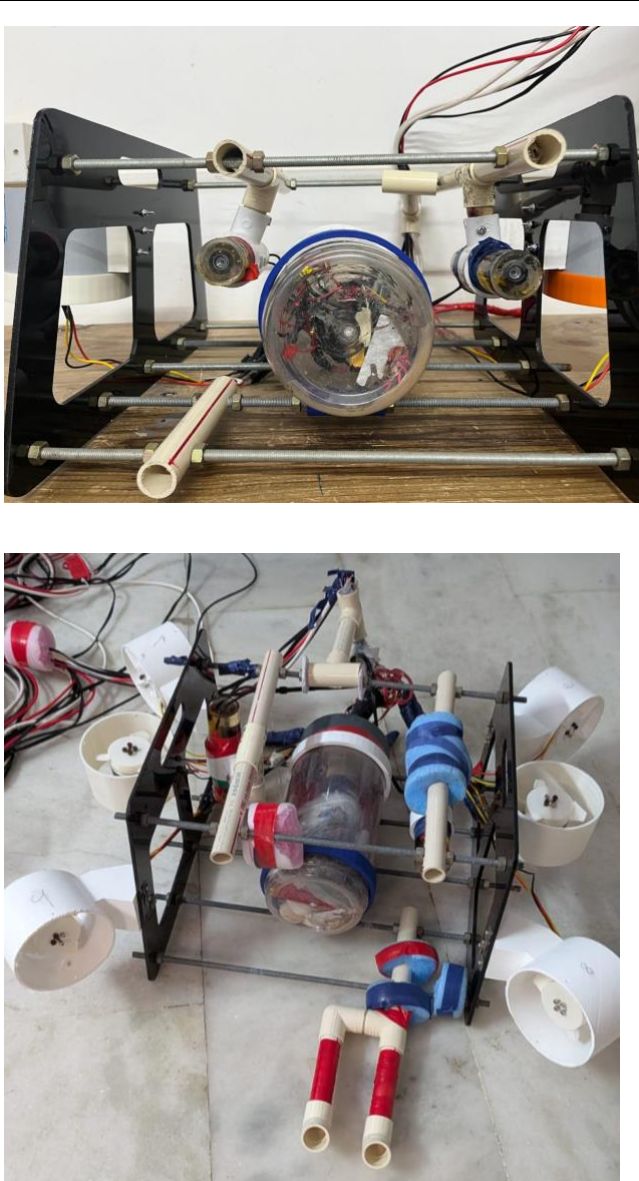
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ENGINEERING DESIGN RATIONALE

A. Overall Vehicle Design

The main vehicle philosophy of ORCA Mark I was to create an ROV that was compact and maneuverable, stable during manipulation tasks, modular for maintenance, and lightweight for transport. The vehicle was designed around modularity and maneuverability to allow rapid maintenance while maintaining precise control during mission tasks. The overall design focused on balancing subsystem integration, maneuverability, stability, and cost efficiency while ensuring that the vehicle could complete all mission requirements effectively.

The vehicle uses a trapezoidal acrylic frame design. The trapezoidal geometry provided a wider front section for payload placement, manipulator operation, and improved camera visibility, while the narrower rear section reduced drag and improved maneuverability underwater. Acrylic was selected because it is lightweight, inexpensive, locally available, and easy to machine. However, acrylic is more susceptible to cracking compared to HDPE. To compensate, large structural cut-outs were incorporated into the frame to reduce stress concentration while lowering overall vehicle weight.

The frame structure is connected using seven metal threaded rods, with two rods on the upper section and five on the lower section. This threaded-rod architecture significantly improved modularity — components could easily slide onto the rods and be repositioned without requiring structural redesign. The frame width could also be adjusted depending on subsystem requirements.



THE ORCAS		2026 MATE ROV • Technical Documentation
Specification	Detail	
Dimensions	310 mm × 400 mm × 260 mm	
Frame Material	Precision-cut acrylic + PVC hybrid	
Propulsion	6× 5010 360kV BLDC motors, vectored layout	
Control	Pixhawk FC + FS-i6S RC Transmitter/Receiver	
Cameras	2× (forward navigation + manipulator)	
Manipulators	PVC safety hook + dual-servo clamp arm + backup screw-mechanism arm	
Tether	20 m, 10 wires (6 PWM + 2 camera + 2 servo)	
Buoyancy	Pool-noodle foam + rock ballast, tool-free adjustment	
Waterproofing	Dual O-ring capsule + 4-layer tether seal	
Electrical Protection	8 fuses (25A main + 25A capsule + 6×3A ESC)	

The waterproof electronics capsule was positioned near the vehicle’s center of mass to improve balance, turning stability, and camera visibility. The vehicle uses two cameras: one forward-facing camera for navigation and maneuvering, and a second camera aimed toward the manipulator and safety hook. The tether exit point was positioned near the rear centerline, so tether drag forces aligned with the primary vehicle axis, reducing unwanted yaw moments. A tether strain-relief system was also implemented to ensure that external pulling forces would not damage the internal wiring of the capsule.

For propulsion, the team transitioned from the previous orthogonal thruster layout to a vectored configuration. The orthogonal layout required more motors while still producing lower thrust efficiency. The final vectored design used four horizontal thrusters positioned at 45-degree angles and two vertical thrusters for depth control. This configuration allowed the vehicle to move forward, backward, vertically, laterally, and rotate efficiently while maintaining precise maneuverability during mission tasks.

B. Step-by-Step Planning & Design Process

Initially, the team planned to continue using the orthogonal thruster configuration from the previous season. However, testing and analysis revealed that the orthogonal system required more motors while still producing lower thrust efficiency and maneuverability compared to a vectored configuration. As a result, the final propulsion configuration transitioned to a vectored layout because it provided improved lateral maneuverability and more efficient thrust distribution.

The team also evaluated both brushed DC motors and BLDC motors. Although brushed DC motors were simpler to integrate and easier to waterproof, testing demonstrated that they did not provide sufficient thrust for mission requirements. BLDC motors provided substantially greater performance; however, they required onboard ESCs, creating the challenge of underwater waterproofing. Despite this added engineering complexity, BLDC motors were selected because their thrust efficiency and maneuverability advantages significantly improved overall vehicle performance.

To reduce tether size and improve efficiency, the ESCs were mounted onboard inside a waterproof electronics capsule. Initially, the team attempted to waterproof the capsule using only epoxy sealing methods similar to those used for the cameras. However, prolonged underwater testing revealed micro-leaks around the cable exit points. The final waterproofing solution combined dual O-rings, epoxy sealing, PVC cable penetrations, and silicone-assisted sealing. Overnight underwater testing exceeding fourteen hours confirmed complete waterproof integrity of the final capsule design.

The team also tested multiple propeller designs and propeller sizes to determine the most efficient configuration. Initial joint-style propeller concepts were abandoned after testing showed lower thrust

efficiency. Propeller testing demonstrated that larger propeller diameters produced improved thrust output, leading the team to select a 12 cm propeller configuration for the final propulsion system.

CRITERIA	BRUSHED DC MOTORS	BLDC MOTORS
 Integration Complexity	• Simpler to integrate	• More complex due to ESC requirements
 Waterproofing	• Easier to waterproof	• ESCs required additional underwater waterproofing
 Thrust Output	• Insufficient thrust during testing	• Provided substantially greater thrust
 Efficiency	• Lower efficiency	• Higher thrust efficiency
 Maneuverability	• Limited maneuverability	• Improved maneuverability
 Control System	• Direct motor control	• Requires onboard Electronic Speed Controllers (ESCs)
 Suitability for Mission Requirements	• Did not meet mission performance needs	• Met mission performance requirements
 Final Decision	✗ Rejected	✓ Selected

C. Design Trade-Offs

Several engineering trade-offs were evaluated throughout development. Acrylic was selected for the frame because it was inexpensive and lightweight; however, acrylic is more susceptible to cracking compared to HDPE. To compensate, large structural cut-outs were incorporated to reduce stress concentration while lowering overall vehicle weight. For propulsion, brushed DC motors were easier to waterproof and simpler to control, but produced insufficient thrust. BLDC motors provided greater efficiency but required onboard ESC integration and complex waterproofing. The tether was also redesigned — during the previous season it contained over twenty wires, making it rigid and difficult to maneuver. By moving ESCs onboard, the number of tether wires was reduced significantly, improving flexibility and reducing drag.

Decision	Benefit Gained	Trade-Off Accepted
PVC hook & camera mounts	Easily modified and adjusted during testing	Risk of joints loosening — checked before every run
Precision-cut acrylic frame	Lightweight, transparent; weight savings and visibility	More brittle than PVC/HDPE; lower impact resistance
Wired tether (reduced to 10 wires)	Eliminated signal loss risk; improved flexibility	Tangling risk — tether mounted at top rear to trail cleanly
M-seal for joints & cameras	Strong, fully waterproof permanent bond	Sets permanently; repositioning during field testing is difficult
Vectored 6-thruster layout	Superior maneuverability across all axes	Lower peak thrust in single direction; complex tuning required
BLDC over brushed DC motors	Significantly greater thrust and efficiency	Requires onboard ESCs; harder waterproofing challenge
In-house capsule (\$2) vs commercial (\$200)	99% cost reduction; local manufacturing	More R&D time for waterproofing iteration needed
Onboard ESCs (reduced tether wires)	Improved tether flexibility and reduced drag	Required waterproof capsule engineering challenge

4 INNOVATION

Modular Subsystem Architecture

One of the primary innovations implemented in ORCA Mark I was its modular subsystem architecture. PVC mounting systems were integrated throughout the vehicle, allowing cameras, safety hooks, and tools to be repositioned rapidly without modifying the primary frame structure. This simplified maintenance, subsystem upgrades, and future modifications. The PVC mounting systems also allowed the camera orientation and manipulator placement to be adjusted easily depending on mission requirements and testing feedback.

The threaded-rod chassis system also significantly improved modularity. Components could easily slide along the rods and be repositioned depending on subsystem requirements, while the frame width could be adjusted whenever necessary. This allowed rapid subsystem reconfiguration without requiring complete frame redesign or additional manufacturing. The modular architecture also simplified maintenance because damaged or redesigned subsystems could be replaced individually without rebuilding the entire frame.

In-House Waterproof Electronics Capsule

Another major innovation was the development of a fully in-house waterproof electronics capsule. Commercial underwater capsules typically cost approximately \$200 USD; however, the team developed a locally sourced waterproof capsule using a plastic housing combined with dual O-rings, epoxy, PVC cable penetrations, and silicone sealing. This significantly reduced costs while maintaining reliable underwater performance. Additionally, replacement capsules could be manufactured locally within two days if damage occurred, eliminating the need to wait for international shipping.

Custom In-House Thrusters

The team also developed custom in-house thrusters instead of purchasing commercial T200 or T400 systems. Locally sourced 5010 360KV BLDC motors costing approximately \$15 USD each were waterproofed using epoxy, hot glue, and waterproof heat-shrink tubing. Custom motor guards and mounts were designed and manufactured using 3D printing, allowing complete control over thruster orientation, propeller size, and subsystem integration while significantly reducing propulsion costs. This also allowed the team to optimize the propulsion layout specifically for their vehicle.



Cost Comparison: In-House vs Commercial

Component	Commercial Cost	Our Cost	Savings
Waterproof Capsule	\$200	\$2	\$198 (99%)
6× Thrusters	\$1,200	\$90	\$1,110 (92.5%)
Servo Waterproofing (2×)	\$100	\$8	\$92 (92%)
Total Propulsion + Capsule	\$1,500	\$100	\$1,400 (93%)

5 PROBLEM SOLVING

The team followed a structured engineering problem-solving methodology throughout development. Whenever a subsystem challenge was identified, the lead member responsible for that subsystem first researched multiple possible solutions and developed several design concepts. These concepts were based on previous competition experience, online research, mentor feedback, and subsystem requirements.

The proposed concepts were then presented to the entire team, where the advantages, disadvantages, manufacturability, subsystem compatibility, and cost of each design were discussed collectively. After narrowing the concepts down to the strongest options, the designs were reviewed with mentors, whose engineering experience provided valuable feedback regarding practical implementation, subsystem reliability, and underwater performance.

Finally, prototype designs were manufactured and rigorously tested. If prototype testing failed to meet mission or safety requirements, the design process was repeated iteratively until acceptable subsystem performance was achieved. This engineering workflow was used throughout the season during propulsion development, waterproofing development, manipulator design, and subsystem integration.

Stage	Action	Details
1	Research	Lead member independently researched 3–4 alternatives, documenting cost, operating principle, and known limitations
2	Trade Study	Full team evaluated candidates against cost, reliability, build time, and mission suitability to produce a data-driven ranking
3	Mentor Review	Top options reviewed with mentors whose multi-year ROV experience identified failure modes not captured by trade study
4	Prototype & Test	Chosen design prototyped, pool-tested, and refined with results logged for future reference; iterated until acceptable

One major example of this process was the manipulator system. Initially, the vehicle used only a stationary safety hook; however, testing revealed that many mission tasks could not be completed efficiently using a fixed hook alone. Multiple claw and manipulator concepts were researched, discussed, prototyped, and tested before the final hook-talon hybrid design was selected. The final manipulator significantly improved object interaction capability while still retaining the original safety hook as a backup recovery mechanism.



Engineering decisions were validated through testing and subsystem comparisons whenever possible. Different propulsion layouts, waterproofing methods, propeller geometries, manipulator designs, and tether configurations were tested before final subsystem selection. The team prioritized testing-based decision-making rather than selecting designs solely based on assumptions or theoretical performance. Waterproofing systems also underwent extensive testing — initially the capsule was waterproofed using only epoxy sealing, but prolonged underwater testing revealed micro-leaks. After evaluating different methods, silicone-assisted sealing combined with dual O-rings provided substantially greater reliability. Overnight testing exceeding fourteen hours confirmed the final design.

6 SYSTEMS APPROACH

ORCA Mark I was designed as an integrated system rather than a collection of independent subsystems. Subsystem placement and configuration were continuously evaluated based on their effects on vehicle stability, maneuverability, visibility, electrical reliability, and operational efficiency. Every subsystem was designed while considering how it would interact with the other systems onboard the vehicle.

The waterproof electronics capsule was positioned near the vehicle's center of mass to improve balance, turning performance, and overall stability. Positioning the capsule centrally also prevented excessive obstruction of either camera's field of view while improving weight distribution throughout the frame. Since BLDC motors required onboard ESCs to reduce tether size, waterproofing the capsule became a critical subsystem integration challenge that directly affected propulsion, tether management, buoyancy, and electrical reliability.

The vehicle uses a dual-camera arrangement where each camera performs a dedicated function. The forward-facing camera provides environmental awareness and navigation visibility, while the secondary camera focuses directly on the manipulator workspace for precise object interaction. Separating these functions improved operator situational awareness and reduced the difficulty of completing precise manipulation tasks. PVC mounting systems allowed cameras and tools to be repositioned rapidly without disturbing the electrical subsystem. The six-thruster vectored propulsion system was positioned carefully to avoid obstructing camera visibility while still maintaining balanced thrust distribution. The tether exit point was positioned near the rear centerline so tether drag aligned with the primary vehicle axis, reducing unwanted yaw moments. Pool-noodle foam and rock ballast were designed to be adjustable between testing.

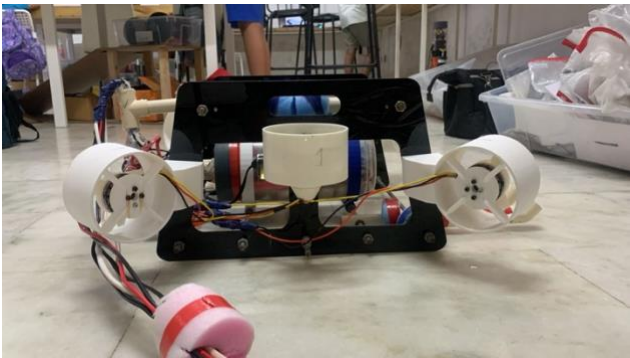
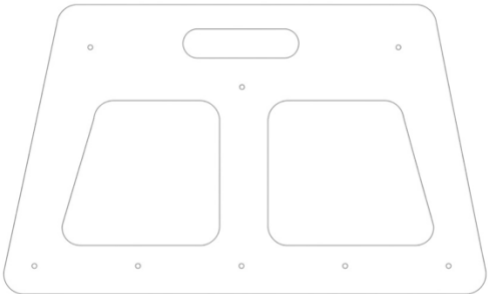
Subsystem	Integration Design
Capsule Placement	Positioned at vehicle's longitudinal centre of mass for stability, turning, and camera visibility
Dual-Camera Layout	Forward camera for navigation; secondary camera angled at manipulator workspace for precise object interaction
PVC Mount System	Cameras and tools repositioned rapidly without disturbing electrical subsystem or requiring structural changes
Chassis Architecture	Steel-rod spine adjustable in width; components added/removed without fabricating new frame
Thruster Array	Six-thruster vectored array positioned clear of camera sight lines; balanced thrust distribution
Electrical Protection	Eight-fuse isolation network prevents single fault from cascading to other subsystems
Tether Exit	Top rear position so cable drag aligns with primary vehicle axis, reducing yaw moments
Buoyancy System	Pool-noodle foam and rock ballast adjustable without tools between runs

7 VEHICLE STRUCTURE

The frame of ORCA Mark I was designed to balance structural rigidity, modularity, maneuverability, lightweight construction, and cost efficiency. The vehicle uses a trapezoidal acrylic frame design. The trapezoidal geometry was selected because it provided a wider front section for payload placement, manipulator operation, and improved camera visibility, while the narrower rear section reduced drag and improved maneuverability underwater.

Acrylic was selected as the primary frame material because it is lightweight, inexpensive, locally available, and easy to machine. Compared to HDPE or aluminum, acrylic significantly reduced manufacturing costs while still providing sufficient structural rigidity for underwater operation. However, acrylic is more susceptible to cracking compared to HDPE. To compensate, large structural cut-outs were incorporated into the frame to reduce stress concentration while lowering overall vehicle weight and improving water flow through the structure.

The frame structure is connected using seven metal threaded rods, with two rods on the upper section and five on the lower section. This threaded-rod architecture significantly improved modularity and subsystem integration. Components could easily slide onto the rods and be repositioned without requiring structural redesign. The width could also be adjusted whenever necessary. The modular structure simplified maintenance because damaged components could be replaced individually without rebuilding the entire frame.



Material Comparison

Property	Acrylic ✓	PVC	HDPE	Aluminium	3D Print (PETG)
Cost	Low ✓	Low	Medium	High	Low
Weight	Light ✓	Light	Medium	Heavy	Light
Customizability	High ✓	Medium	Low	Low	Highest
Durability	Medium	High	High	High	Medium
Machinability	High ✓	High	Medium	Medium	N/A (printed)
Transparency	Yes ✓	No	No	No	Translucent

The waterproof electronics capsule was positioned near the center of mass to improve turning stability, buoyancy balance, and subsystem symmetry. The compact structural arrangement maintained balanced maneuverability while ensuring all major subsystems remained easily accessible. The frame was also

designed to support rapid subsystem mounting using PVC attachment systems and 3D-printed mounts. Cameras, safety hooks, manipulator systems, and buoyancy components could be repositioned quickly depending on mission requirements and testing feedback.

Capsule Waterproofing

The primary electronics capsule uses a double O-ring sealing system to minimize water ingress risk. This dual-seal configuration provides redundancy. The tether entry point is reinforced with a four-layer waterproofing structure:

Layer	Function
Rubber seal	Creates initial flexible seal around the tether entry
Epoxy resin	Rigidly secures and insulates the tether entry point
Marine-grade clay	Strengthens waterproofing and fills micro-gaps
Silicone sealant	Removes water channels between individual wires

Connection Waterproofing: All exposed and soldered wire connections were individually waterproofed using heat-shrink tubing (primary insulation), hot glue (additional waterproof barrier), and insulating tape (external protection and durability).

8

VEHICLE SYSTEMS

Component selection was driven by the key lesson of the prior year: insufficient thrust and limited maneuverability. Every decision this year balanced performance improvement against cost.

The propulsion system used locally sourced 5010 360KV BLDC motors instead of expensive commercial thrusters such as T200 systems. These motors cost approximately \$15 USD each while still providing strong thrust performance. Custom 3D-printed motor guards and mounts were manufactured in-house, allowing thruster orientation and propeller geometry to be optimized easily depending on subsystem requirements. Previously purchased cameras from the previous season were reused because they remained reliable and continued to meet mission requirements. Reusing the cameras reduced subsystem costs while simplifying electrical integration. The dual-camera system was designed so that one camera focused primarily on navigation while the second focused on the manipulator workspace. To minimize voltage drop across the 15-meter tether, 16 AWG power wires were selected after testing demonstrated only approximately 0.1 V of voltage drop. CAT cables were selected for signal transmission because testing confirmed reliable communication over long distances.

The electronics capsule was developed in-house instead of using expensive commercial underwater housings. A locally sourced plastic container combined with epoxy, silicone, PVC cable penetrations, and dual O-rings provided reliable waterproofing while significantly reducing cost and improving repairability. PVC was selected for mounting systems because it is lightweight, inexpensive, waterproof, and easy to modify.

Design Evolution

Initially, the vehicle used only a stationary safety hook for payload interaction. However, testing revealed that several mission tasks could not be completed efficiently using a fixed hook alone. Multiple manipulator concepts were evaluated before the final hook-talon hybrid design was selected. The propulsion system also evolved from orthogonal to vectored layout. The waterproofing system underwent several design revisions — initially epoxy-only, then evolving to the final silicone-assisted multi-layer system after prolonged testing revealed micro-leaks.

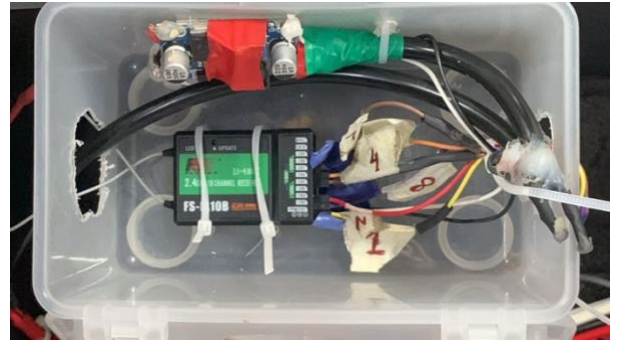
9 ELECTRICAL SYSTEM

The electrical system of ORCA Mark I was divided into three primary power subsystems: (1) Camera and monitor systems, (2) Radio receiver and control electronics, (3) Main propulsion and ROV power systems. This separation improved subsystem organization and simplified troubleshooting by ensuring that failures in one subsystem would not directly affect the others.

The vehicle uses a Pixhawk flight controller integrated with six ESCs housed inside the waterproof electronics capsule. Power entering the capsule is distributed across six independent ESC channels responsible for controlling the BLDC propulsion system. The radio receiver communicates directly with the Pixhawk, while ESC signal wires and servo control wires are routed internally through the flight controller. The radio receiver and servos operate at 5V, while the Pixhawk and ESC systems operate at 12V. Since the ESCs already provided a regulated 5V output, this simplified power distribution.

To minimize voltage drop across the 15-meter tether, 16 AWG power wires were selected after testing demonstrated only approximately 0.1V of voltage drop over the entire tether length. CAT cables were selected for signal transmission because testing confirmed reliable communication over long distances while maintaining lightweight tether construction.

The electrical system incorporates eight fuses for subsystem protection. A primary 25A fuse protects the overall power system, while an additional 25A fuse protects the internal capsule electronics. Each ESC channel is individually protected using 3A fuses to prevent electrical failures from cascading throughout the system. This fuse isolation architecture significantly improved electrical safety and subsystem reliability during operation and testing.



Waterproof Electronics Capsule

Because BLDC motors required onboard ESCs to reduce tether complexity, the team developed a fully waterproof onboard electronics capsule. Waterproofing the capsule became one of the most important engineering challenges during development because the internal electronics needed to remain completely isolated from water during prolonged underwater operation.

The capsule used a threaded plastic container fitted with dual O-rings to prevent water ingress through the lid. A PVC cable channel was integrated into the rear section to route tether wires internally. The cable penetrations were filled using epoxy adhesive, while silicone sealant was applied externally to improve waterproof reliability. Combining multiple sealing methods significantly improved overall reliability.

Initially, the capsule was waterproofed using only epoxy sealing methods similar to those used for the cameras. However, prolonged underwater testing revealed micro-leaks around the cable exit points. After extensive troubleshooting and testing of different sealing methods, silicone-assisted sealing provided

substantially greater waterproof reliability and became the final solution. The completed capsule remained fully waterproof during overnight underwater testing exceeding fourteen hours, confirming the effectiveness of the final design. Since the capsule was manufactured using inexpensive locally sourced materials, replacement capsules could also be manufactured rapidly if subsystem damage occurred.

10 CONTROL SYSTEM

ORCA Mark I uses a **HARDWARE-based control system.**

Pilot commands are generated by physical RC hardware and a Pixhawk flight controller rather than custom application software.

The control system uses an FS-i6S radio transmitter paired with a FlySky radio receiver. This system was selected because similar control architectures are commonly used in drone systems, making the controls intuitive for the pilot, who already possessed prior drone piloting experience. Using a familiar controller layout significantly reduced pilot learning time and improved overall maneuverability.

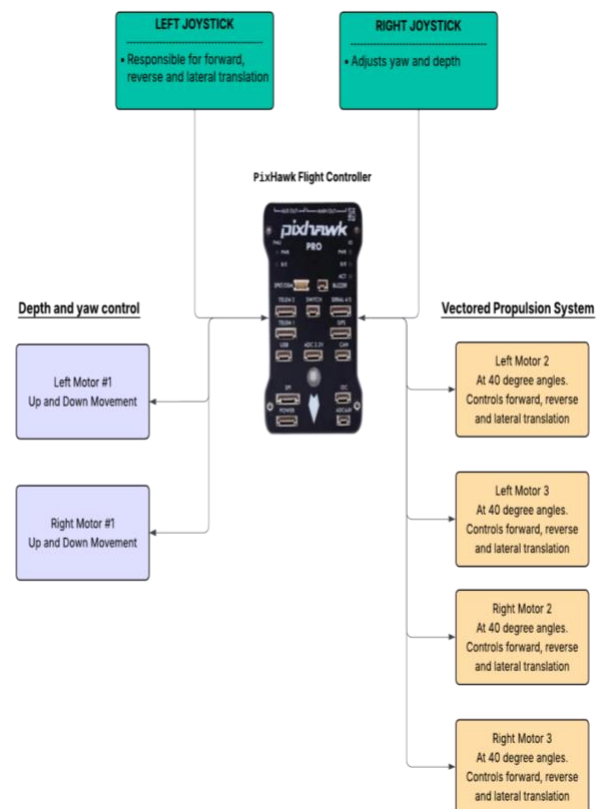
The right joystick controls forward, backward, and turning movement, while the left joystick controls vertical motion and lateral strafing. Additional buttons were assigned for manipulator operation. Input signals from the radio receiver are transmitted directly to the Pixhawk flight controller, which processes the commands and distributes output signals to the propulsion and manipulator systems.

The Pixhawk was selected because it includes built-in gyroscopic stabilization, acceleration sensing, and vectored-thruster configuration support. The Pixhawk also supports the BlueROV2 vectored-thruster configuration, simplifying implementation of the vectored propulsion system.

Initially, testing was performed using only the FlySky radio system without a dedicated flight controller. However, testing revealed that proper vectored-thruster mixing and lateral movement were not achievable reliably without a flight controller. The Pixhawk solved these issues while improving stability, control precision, and pilot usability.

Software System Design

Camera feeds were converted into USB-compatible video streams that could be processed directly through software systems. This allowed implementation of computer-vision-based mission tasks including coral measurement, iceberg analysis, and crab identification. The Pixhawk's built-in stabilization systems also improved operational usability by maintaining stable vehicle orientation during precision tasks.



11 PROPULSION

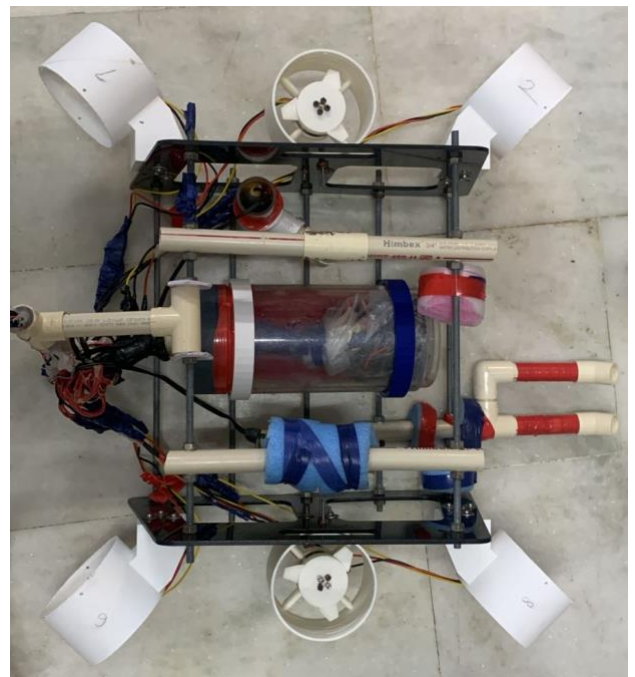
During the previous competition season, the team used an orthogonal thruster configuration. Although the orthogonal layout was mechanically simpler, it required a larger number of thrusters while still producing lower maneuverability and thrust efficiency. Based on testing and operational experience, the team transitioned to a vectored propulsion configuration for ORCA Mark I.

The propulsion system uses six thrusters in total. Four horizontal thrusters are mounted at 45-degree angles in a vectored configuration, while two vertical thrusters control depth. The vectored configuration allowed forward, backward, turning, lateral “crab” movement, and precise station-keeping while maintaining efficient propulsion performance. The 45-degree orientation provided an effective balance between forward thrust and lateral maneuverability, especially important during precision manipulation tasks.

The horizontal thrusters were positioned carefully to maintain balanced thrust distribution while avoiding obstruction of cameras and manipulator workspace. The two dedicated vertical thrusters improved depth control and vertical maneuverability.

Multiple propulsion systems were evaluated. Brushed DC motors were initially considered because they were easier to waterproof and simpler to control. However, testing demonstrated that brushed motors produced insufficient thrust. BLDC motors provided significantly greater efficiency but introduced waterproofing complexity. Despite added challenges, BLDC motors were selected because performance advantages outweighed complexity.

The team selected locally sourced 5010 360KV BLDC motors costing approximately \$15 USD each instead of commercial T200 systems at \$200 each, saving \$1,110 total. Extensive propeller testing demonstrated that larger diameters produced improved thrust, leading to a 12 cm propeller configuration as the optimal balance between thrust generation, efficiency, and motor loading.



12 BUOYANCY & BALLAST

The buoyancy system was designed to maintain near-neutral buoyancy while improving vehicle stability during manipulation tasks. Maintaining proper buoyancy was essential because it reduced the load on the propulsion system and improved maneuverability during precise underwater operations. The buoyancy system was also designed to remain adjustable so that changes in payload or subsystem configuration could be compensated easily during testing and operation.

Pool-noodle foam was used as the primary buoyancy material because it is lightweight, inexpensive, waterproof, and easy to modify during testing. Rock ballast was added to the lower section of the vehicle to lower the center of mass and improve roll stability underwater. Positioning the buoyancy foam above the frame while placing ballast below the vehicle created separation between the center of buoyancy and center of mass, improving passive stability and reducing unwanted rolling during operation.

Because the waterproof electronics capsule introduced trapped internal air and additional buoyancy, ballast adjustments were required during testing to rebalance the vehicle properly. The buoyancy system was designed for rapid adjustment between testing sessions, allowing foam and ballast to be repositioned easily without requiring major structural modifications.

During early testing, tether drag caused the rear section of the vehicle to sink slightly and introduced rotational instability. Additional buoyancy foam was added to rebalance the ROV and improve underwater stability. This demonstrated how buoyancy tuning and subsystem balancing were continuously adjusted throughout testing to improve overall operational performance.

13 PAYLOAD & TOOLS

Camera System

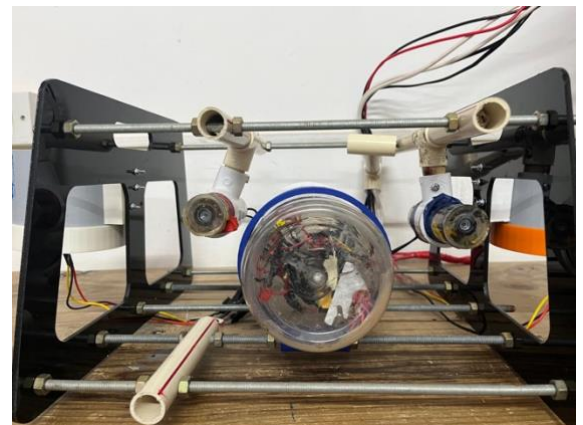
The vehicle uses a dual-camera system to separate navigation and manipulation tasks. One forward-facing camera was positioned to provide wide environmental visibility and improve pilot navigation. The second camera was directed toward the manipulator workspace to improve visibility during close-range object interaction. Separating these functions significantly improved operator situational awareness and reduced task completion difficulty. The cameras were mounted using adjustable PVC supports, allowing positions and viewing angles to be modified rapidly.

Safety Hook

Custom PVC safety-hook at the front for underwater object manipulation and backup recovery. Lightweight, durable, simple design with few moving parts to reduce failure risk. The hook can lift, pull, reposition, or grab objects underwater.

Clamp Arm & Backup Manipulator

Primary manipulator is a versatile clamp arm driven by two servos — one for rotation and one for claw open/close. Backup: custom screw-mechanism clamp arm built entirely in-house from a motor-and-screw mechanism, delivering precise linear jaw motion at a fraction of commercial cost. PVC was selected as primary material because it is lightweight, inexpensive, waterproof, and easy to manufacture. Multiple manipulator concepts were researched and tested before the final hook-talon hybrid design was selected.



Option	Type / Description	Pros	Cons	Our Choice
Option A: Hook / Talon Claw <i>(Selected)</i> 	Curved claw that hooks onto objects instead of fully enclosing them.	• Strong grip on irregular objects • Works well underwater • Simple design	• Poor precision handling • Can damage fragile objects • Not ideal for flat items	✓
Option B: Three-Finger Claw 	Three-finger claw that provides a more stable grip from three directions.	• Better grip stability • Handles round / uneven objects • Balanced force distribution	• More complex mechanism • Higher cost and weight • Harder to waterproof	—
Option C: Adaptive / Soft Gripper 	Soft gripper that adapts to the shape of objects using flexible fingers.	• Excellent for fragile objects • Adapts to shapes • Safe interaction	• Lower gripping force • Slower response • Difficult manufacturing	—

14 BUILD VS BUY, NEW VS USED

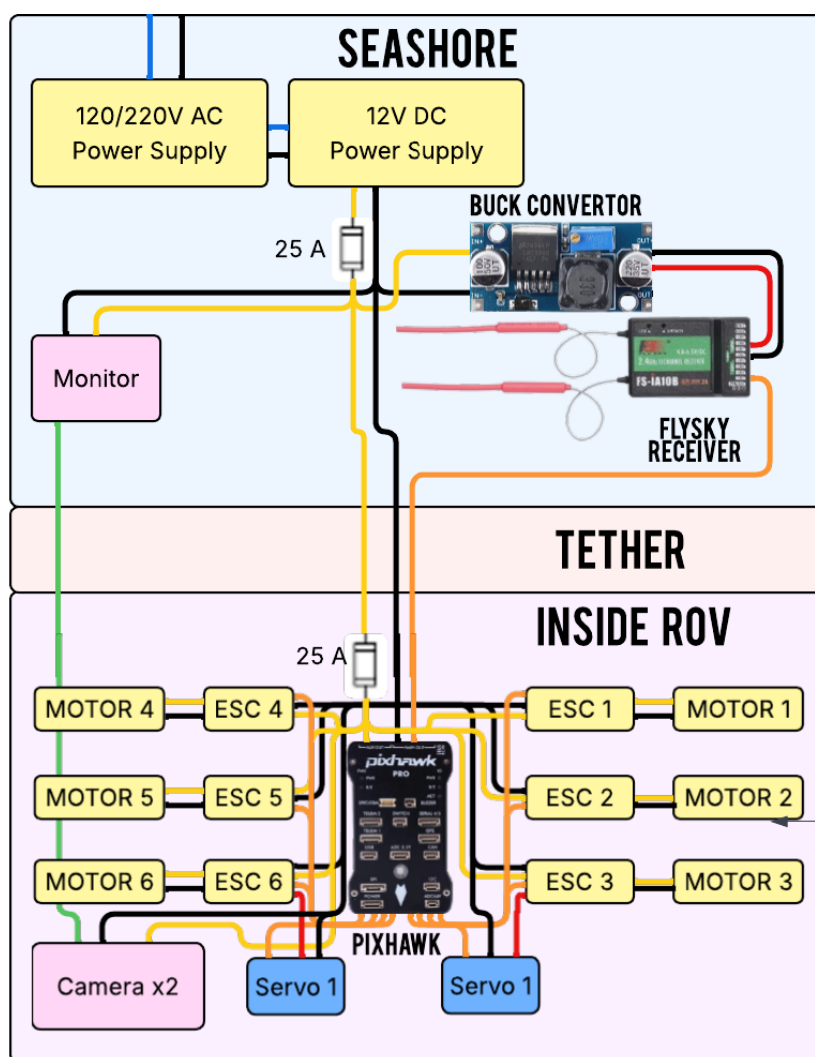
The team prioritized in-house manufacturing whenever possible to reduce overall costs and improve subsystem customization. Commercial underwater capsules and thrusters were considered during development; however, their costs were significantly higher than the team budget allowed. Instead, the team developed a fully in-house waterproof electronics capsule and custom propulsion system using locally sourced materials and components. This significantly reduced overall subsystem cost while still maintaining reliable operational performance.

Manufacturing components internally also allowed rapid iteration and customization based on testing feedback. Custom 3D-printed motor guards, tether mounts, capsule mounts, and subsystem brackets were developed specifically for the vehicle architecture rather than relying on fixed commercial designs. The locally sourced waterproof capsule reduced enclosure cost from approximately \$200 USD to approximately \$2 USD while still providing reliable waterproof performance after extensive testing.

Previously purchased cameras from the previous competition season were reused because testing confirmed that they continued to meet current mission requirements reliably. Reusing the cameras reduced subsystem costs while simplifying electrical integration since the team was already familiar with their waterproofing systems, mounting methods, and electrical requirements. Several subsystem concepts from the previous season were also reused and improved. The original safety hook concept was retained as a backup while a more advanced manipulator system was added. The propulsion system transitioned from orthogonal to vectored, the tether was simplified, and the vehicle adopted onboard ESC integration.

Decision	Components	Rationale / Benefit
Build	Custom PVC hook, backup screw-mechanism clamp arm, electronics capsule, servo waterproofing, 3D-printed motor guards	Full control over material, dimensions, actuation; far cheaper than commercial alternatives; rapid local iteration
Buy	BLDC thrusters, tether wire, Pixhawk FC, ESCs, RC transmitter, acrylic sheets, steel rods	Sourced from kit or local suppliers where in-house fabrication was impractical; precise electrical/mechanical specs required
Reuse	Imaging system (2× cameras), Pixhawk FC, servos, video system, brushed DC motors	Sustainable engineering; all reused parts re-validated and confirmed to meet current mission requirements

15 SYSTEM INTEGRATION DIAGRAM (SID)



16 SAFETY

The development and deployment of the ORCA Mark I prioritized safety across all phases. Our risk-mitigation strategy covers **personnel, equipment, and operational safety**.

Safety Domain	Rationale & Measures
Personnel	Mandatory PPE (goggles, gloves) during wiring, cutting, and soldering; technical briefings on safe handling of electronic components and tools.
Equipment	An eight-fuse protection system, waterproof enclosures for all electronics, and strain reliefs on the tether and cables to prevent damage or disconnection.
Operational	Pre-dive and post-dive checklists verified before and after every mission; continuous voltage and current monitoring with a hardwired multimeter.

◆ Vehicle-Specific Safety Features

- An eight-fuse system isolating the vehicle from damage caused by a single short circuit.
- All high-current power lines insulated, clearly labeled, and individually fused.
- Shielded propellers and rounded frame edges to reduce physical risk during manual handling.
- Waterproof enclosures and tether strain relief preventing electrical and mechanical failure underwater.

◆ Construction Phase Safety Checklist

#	Safety Item Description	Done
1	PPE (gloves and goggles) worn while soldering, cutting, or drilling	☐
2	Mentor supervision ensured for all high-risk tool use	☐
5	Fuses (25 A and 3 A) installed in control box to prevent overcurrent damage	☐
6	All electrical components sealed in waterproof enclosures and wires labelled	☐
7	Strain relief applied to all external cables, especially the tether	☐
8	Control box tested with multimeter before integration	☐

◆ Pre-Dive (Operation) Safety Checklist

#	Pre-Dive Verification Item	Done
1	SMP working and giving enough voltage	☐
2	All fuses checked for continuity	☐
3	All thrusters tested for direction and responsiveness	☐
4	Front and manipulator cameras confirmed operational	☐
5	Hook and arm servos tested for range and control	☐
6	Tether inspected for wear, twists, or loose connectors	☐
7	Emergency shut-off mechanism confirmed functional	☐
8	Joystick control interface tested and responsive	☐
9	Waterproof seals on all electronics enclosures verified	☐

◆ Post-Dive (Operation) Safety Checklist

#	Post-Dive Verification Item	Done
1	Visual inspection of ROV for leaks, damage, or loose joints	☐
2	All moving parts lubricated if needed	☐
3	Any faults or irregularities logged in the troubleshooting document	☐
4	ROV dried and stored in a safe, dry location	☐
5	All tools cleaned and returned to storage	☐
6	Team debrief conducted to share observations and learning	☐

17 TESTING AND TROUBLESHOOTING

The team implemented a rigorous testing and troubleshooting framework built around incremental verification. Core components — thrusters, motor drivers, and the controller — were unit-tested before integration into larger subsystems, and each subsystem was verified independently before the full vehicle was assembled and run. Testing in increments meant that when a fault appeared, it could be traced to a small, recently changed part of the system rather than searched for across the entire vehicle.

◆ Systematic Testing Procedures

Component validation: each thruster was water-tested for balance and direction; cameras were evaluated both dry and submerged to confirm focus, field of view, and a watertight enclosure.

Integration testing: once components passed individual checks, assemblies were screened for electrical conflicts, shorts, loose connections, and communication latency before being mounted on the vehicle.

Mission simulation: the custom hook and clamp arm were subjected to repeated stability and strength tests using props that imitated the actual mission objects, so performance was measured under realistic conditions.

Rapid iteration: 3-D printing was used to quickly produce and test parts, allowing competing design options to be built, compared, and refined within a single session before a final version was committed.

Full-vehicle pool runs: after integration, the complete ROV was run through practice mission sequences to verify handling, buoyancy, and tooling under operational conditions.

◆ Troubleshooting & Fault Diagnosis

When a fault appeared, the team followed a structured diagnostic process rather than changing parts at random:

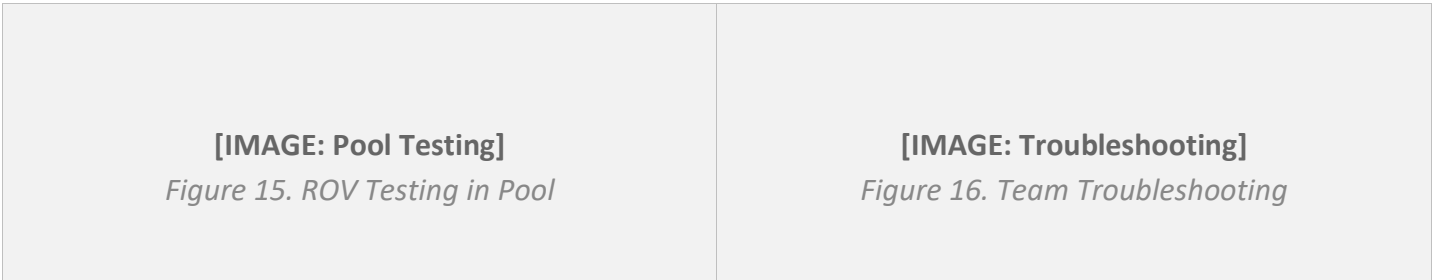
Multi-faceted diagnosis: visual inspection for physical damage, multimeter checks for electrical continuity and shorts, and serial-monitor debugging for code-related issues.

Subsystem isolation: suspect subsystems were isolated and swapped with known-good backups to localize a fault quickly and confirm the cause.

Documentation: all major fixes and modifications were recorded in a shared troubleshooting log, which prevented repeat errors and kept the whole team informed of the vehicle’s current state.

◆ Representative Issues Resolved

Problem	Cause	Solution	Result
Water leakage near tether entry	Cable movement weakened the seal	Added 4-layer waterproofing	No leakage in 24-hr submerged test
ROV tilting underwater	Uneven buoyancy distribution	Repositioned ballast and foam	Improved stability
Tether drag on vehicle	Tether weight pulling the ROV	Added buoyancy-foam sections	Reduced tether strain



18

BUDGET AND COST ACCOUNTING

The team treated budgeting and cost accounting as two distinct activities: a **Budget** — a category-level projection made at the start of the project — and a **Project Costing** — the actual accounting of income, donations, and expenditure. All figures are in USD as required by the competition.

◆ Project Budget (Projected at Project Start)

Company name: **The Orcas** Reporting period: **15-04-2026 to 16-05-2026**

THE ORCAS			2026 MATE ROV • Technical Documentation	
Category	Type	Description	Projected	Budgeted
Hardware	Purchased	Steel rods (7 units) — frame	\$35.00	\$36.00
	Purchased	3× plastic housing systems	\$4.00	\$4.00
	Purchased	Acrylic sheets (2 ft × 2 ft)	\$19.00	\$19.00
Electronics	Purchased	Tether (20 metres)	\$26.00	\$26.00
	Purchased	360kV 5010 BLDC motors (6 units)	\$94.00	\$94.00
	Purchased	ESCs (6 units) — thruster control	\$38.00	\$38.00
	Re-used	2× brushed DC motors (profiling float)	\$50.00	—
	Re-used	Servos (2 units) — manipulator arm	\$2.00	—
	Re-used	Pixhawk RC flight controller	\$63.00	—
	Re-used	Video system (30 metres)	\$37.00	—
Sensors	Re-used	2× cameras — imaging system	\$210.00	—
Travel	Purchased	8 tickets to World Championship (Canada)	\$16,000.00	\$16,000.00
	Purchased	Accommodations	\$6000	\$6000
	Purchased	Food	\$500	\$500

Total Income: \$3,000.00 | Total Expenses (market value): \$27,078.00 | Total Expenses (purchased only): \$22,717.00 | Fundraising Still Needed: \$19,717.00

Purchased — items bought new or services paid for. Re-used — items purchased in previous years; amounts shown at current market value. Re-used items carry \$0 cash outlay this year and are excluded from the Budgeted Value column.

◆ Project Costing

Company name: **The Orcas** Reporting period: **15-04-2026 to 16-05-2026**

Date	Type	Category	Item	Description	Amount	Balance
15-04-2026	Cash	General	Parent sponsorship	Team contributions	+\$3,000	\$3,000
Apr 2026	Purch.	Hardware	Steel rods (7)	Frame construction	−\$36	\$2,964
Apr 2026	Purch.	Hardware	Plastic housing (3×)	Frame components	−\$4	\$2,960
Apr 2026	Purch.	Hardware	Acrylic sheets	2 ft × 2 ft — frame	−\$19	\$2,941
Apr 2026	Purch.	Electronics	Tether (20 m)	Thruster/signal connections	−\$26	\$2,915
Apr 2026	Purch.	Electronics	5010 motors (6×)	360kV BLDC — propulsion	−\$94	\$2,821
Apr 2026	Purch.	Electronics	ESCs (6×)	Thruster speed controllers	−\$38	\$2,783

THE ORCAS				2026 MATE ROV • Technical Documentation		
Apr 2026	Reuse	Electronics	DC motors (2×)	Profiling float — carried over	\$50*	\$2,783
Apr 2026	Reuse	Electronics	Servos (2×)	Manipulator — carried over	\$2*	\$2,783
Apr 2026	Reuse	Electronics	Pixhawk FC	RC FC — carried over	\$63*	\$2,783
Apr 2026	Reuse	Electronics	Video system	Camera feed — carried over	\$37*	\$2,783
Apr 2026	Reuse	Sensors	Cameras (2×)	Imaging — carried over	\$210*	\$2,783
May 2026	Purch.	Travel(Food + Accommodation)	8 tickets Canada	World Championship travel	−\$12,000	−\$13,217

Total Raised: \$3,000 | Total Spent (purchased): \$22,717 | Total Re-used (market value): \$362 | Final Balance: −\$19,717

** Re-used items are listed at current market value per MATE rules. They carry \$0 cash outlay this year and do not affect the running balance. To combat this shortfall, The Orcas is actively seeking sponsorship from robotics companies worldwide, including Oceaneering India.*

19 DISCRETIONARY ENGINEERING HIGHLIGHTS

The team wishes to highlight the following original engineering work for discretionary consideration. Each represents a system where the team went beyond standard practice to produce something genuinely innovative or remarkably well-manufactured for a student team:

Custom backup screw-mechanism clamp arm.

Designed and fabricated entirely in-house from a motor-and-screw mechanism, this original tool delivers precise object control at a fraction of the cost of a commercial jointed arm. The screw converts rotary motor output into the linear jaw motion, providing a strong and repeatable grip without complex linkages.

Four-stage layered waterproofing system.

A purpose-developed rubber–epoxy–marine-clay–silicone tether-entry seal. Each layer addresses a different failure mode: the rubber gasket handles flex, the epoxy rigidly secures the entry point, marine clay fills micro-gaps, and silicone closes the water channels between individual wires. The completed assembly withstood a 24-hour submerged test with zero leakage.

Tether-relief structure.

A custom movable PVC bracket mounted at the rear of the vehicle that manages the tether exit angle, distributing the cable’s mechanical load across the bracket rather than concentrating it on the internal wire connections. Designed, prototyped, and installed in a single test session after a cable-stress failure was diagnosed.

Design philosophy: Every system on ORCA Mark I was built to be repaired in the field. From the tool-free ballast to the modular camera mounts to the accessible electrical enclosure, the team consistently chose designs that could be fixed in the next pool session rather than requiring days of workshop time. This discipline — building for serviceability from day one — is one of the most significant practical achievements of the 2026 build.

20 ACKNOWLEDGEMENTS & REFERENCES**◆ Acknowledgements**

- The parents of The Orcas, for sponsoring and supporting the team.
- Yolabs Organization, for providing valuable equipment and resources.
- The online MATE ROV community and open-source engineering resources that supported our research and development.
- Lasya Vasudevan, for assistance during fabrication.

◆ References

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- LightBurn Software Documentation (docs.lightburnsoftware.com)
- Vectored Propulsion System — research paper (PMC)
- Pixhawk Flight Controller Documentation (docs.px4.io)
- Tinkercad — 3D design platform (tinkercad.com)