Crusader, Ekko, and Græy: A Three-Domain Autonomous System of Systems for the 2026 Maritime RobotX Challenge

Chase Chen (Co-lead), Chris Martin (Co-lead), Colin Szeto (Co-lead), Dhruv Choudhary, Dominick Cardella, Nico Katz, Ruth Tu, Stephen Liu, Thejas Vakamudi

***Abstract*—** Team Inspiration approaches the 2026 Maritime RobotX Challenge with three autonomous platforms comprising four vehicles: the Uncrewed Surface Vehicle, Crusader, previously developed for RoboBoat; the Uncrewed Underwater Vehicle, Græy, developed for RoboSub; and two Uncrewed Aerial Vehicles, Don and Ekko. Rather than developing each vehicle as an independent system, our approach emphasizes reusable core capabilities that can be deployed across platforms and combined to execute multiple mission tasks.

To accelerate development, improve reliability, and simplify field operations, we aligned mechanical, electrical, and software architectures across the vehicles wherever practical. A dedicated ground station provides a common framework for vehicle monitoring, command and control, mission management, and data visualization, while standardized vehicle–human interfaces support testing, debugging, and operational readiness. This architecture enables the reuse of tools, software components, and workflows while preserving the ability of each vehicle to operate independently.

This paper presents our capability-driven strategy for this competition and our objectives for the Disruptive tier. It describes the key architectural and design decisions for each vehicle, the four-link communication architecture connecting the multi-vehicle system, and a systematic testing strategy spanning component, vehicle, system, and multi-vehicle levels. The development and validation process is supported by extensive water testing, flight testing, and software-in-the-loop simulation of mission logic and multi-vehicle behaviors. Together, these elements form an integrated three-domain autonomous system of systems designed to provide reusable autonomy capabilities, operational flexibility, and robust execution across the RobotX 2026 mission set.

I. COMPETITION STRATEGY

A. Strategic Vision

Team Inspiration is a community-based organization of nineteen members ranging from middle school students to experienced industry professionals. The team operates with a diverse range of technical backgrounds, varying levels of experience, non-overlapping schedules, and annual membership turnover. Consequently, a strategy that relies on a small number of specialists possessing critical system knowledge is neither scalable nor sustainable. Instead, our strategy emphasizes modular, reusable capabilities that can be developed collaboratively, documented systematically, and applied across multiple vehicles and mission tasks.

Our development strategy builds these capabilities incrementally through participation in other RoboNation competitions, including RoboBoat and RoboSub, as well as through volunteer participation in the Student Unmanned Aerial Systems (SUAS) competition. These activities provide opportunities to develop and validate individual autonomy capabilities, including vehicle control, perception, navigation, communications, and mission planning, before integrating them into the multi-domain architecture required by RobotX [1]. This approach reduces integration risk while allowing software, hardware, operational practices, and lessons learned to be transferred between platforms.

For RobotX 2026, the team is pursuing the Disruptive tier across all available tasks [2]. Our strategy is therefore not based on optimizing a single vehicle or mission capability, but on building a robust three-domain system of

systems in which capabilities developed for one platform can be reused and extended across the Uncrewed Surface Vehicle (USV), Uncrewed Underwater Vehicle (UUV), and Uncrewed Aerial Vehicles (UAVs). This capability-driven approach enables the team to maximize the value of its limited development resources while maintaining independent vehicle operation and progressively increasing the level of multi-vehicle collaboration.

B. Capability-to-Task Alignment

There are overlapping capabilities between each task, as shown in the matrix below:

TABLE I. Capability-to-Task Matrix (Task 1 ~ Task 4)

Capability	T1	T2	T3	T4
Mission element mapping and state estimation	yes	yes	yes	—
Surface–air communication relay	yes	yes	yes	—
Magnetic probe on an underwater target	—	yes	—	—
Two-color flash sequence decode	—	yes	yes	—
RoboCommand report and acknowledgement	yes	yes	yes	yes
Break off, transit, loiter, resume	—	—	—	yes

The team first identified the core capabilities required across the competition tasks. We then prioritized the capabilities that could be reused across multiple tasks and vehicles. By focusing development on these high-value, transferable capabilities first, we maximize the impact of our limited resources and enable the team to pursue the Disruptive tier.

This capability-based approach also determines our development order. Vehicle-to-vehicle and Operator Control Station (OCS) communications are developed first because they support nearly every task and enable multi-vehicle operations. In contrast, task-specific capabilities, such as the magnetic probe required for only one task, are developed later.

C. Mission Procedures

Task 1 — Safe Passage. The UAV maps the ten buoys at 20 m altitude, descends to 10 m to determine their light states, and transmits buoy identifiers, positions, and states to the USV. The USV independently detects buoy positions using camera and LiDAR, while retaining the UAV-provided light states. This redundant perception architecture maintains reliable obstacle avoidance despite degraded communications or UAV localization errors. The USV and UAV then execute a coordinated gate sequence using an arrival/acknowledgment handshake. If a light state changes, the UAV searches outward toward the exit gate to reacquire the updated location. The task concludes with coordinated exit maneuvers by both vehicles.

Task 2 — Infrastructure Survey and Repair. The UAV detects damaged pipeline indicators and transmits their GPS coordinates to the UUV. The UUV uses GPS for surface transit to the target. During UUV submersion the Doppler Velocity Log (DVL) is used for navigation when the GPS becomes obstructed by surface waves or other errors. After acquiring the pipeline with its downward camera and scanning sonar, the UUV uses computer vision to localize and navigate to the damaged node. Pixel-to-meter calibration provides the positioning required to actuate the repair magnet. While the UUV operates underwater, the UAV lands and powers down its motors to conserve energy. The UUV subsequently surfaces and transmits the observed pipeline color sequence to the USV acting as a relay to transmit information to the UAV, which uses the information to deliver the corresponding payload.

Task 3 — Coordinated Logistics. The USV combines GPS waypoints and computer vision to locate and approach the docking structure. Camera and LiDAR are used to identify the designated docking bay and guide lateral alignment. After docking, the USV identifies the target window, aligns its water nozzle, and extinguishes the simulated fire. It then decodes the resulting color sequence and transmits it to

the UAV. The UAV, which remains landed with motors disarmed during the USV operation, uses the received sequence to select and deliver the corresponding payload.

Task 4 — Dynamic Incident Response. A common incident-response behavior is implemented across all three vehicle types, with the required response varying by competition tier. The behavior supports three primary responses: breaking off and loitering at a designated position, replanning around a static keep-out region, and maintaining separation from a reported moving object. Dynamic GPS geofencing provides the mechanism for modifying the active mission. The response is implemented as a leaf node in the vehicle behavior trees [3], allowing it to interrupt the current mission and return control when the incident is resolved.

II. DESIGN STRATEGY

The team created requirement lists for individual vehicles at the beginning of the season to drive our design decisions. See Appendix F for more information.

Three properties guide the design across all three vehicles:

- **Commonality:** Knowledge and capabilities developed on one vehicle can be transferred to the others.
- **Validation:** Capabilities are tested and proven on the vehicles before being implemented in competition.
- **Modularity:** Complex capabilities are broken down into simple, independently testable modules, enabling easier debugging and parallel development.

Commonality ensures streamline training of members as the system architectures are similar, reducing overhead and mechanical spares required. Even with members spanning middle school to industry professionals, someone who learns one vehicle can work on any of them. That argument drove mechanical and electrical choices as much as software ones, and it is why a Pixhawk-class autopilot running ArduPilot sits on all three vehicles.

All three vehicles share similar safety architecture. A radio-control transmitter on its own independent link with a trusted remote-kill. Upon transmitter kill action, a relay cuts power to the actuators and motors while keeping the sensors and computer running.

A. Uncrewed Surface Vessel — Crusader

1) Control system: We moved from a custom Teensy stack to a Pixhawk running ArduRover in an omnidirectional four-thruster configuration. The move collapsed three control stacks into one firmware family, provided software-in-the-loop (SITL) simulation for the boat, and connected us to an established tuning workflow.

2) Perception and sensor placement: Crusader is equipped with a long-baseline stereo camera and a 360° LiDAR to provide real-time perception and obstacle avoidance. The perception system is designed to provide continuous coverage around the vehicle, allowing Crusader to detect obstacles early and react to them while maintaining autonomous navigation. To address the limitations of camera-only perception at close range, the LiDAR was deliberately mounted upside down to extend coverage into the blind spot beneath the camera's field of view. The resulting sensor Vertical Field of View (VFOV) coverage is shown in Fig. 1.



Fig. 1. LiDar and Camera VFOV coverage visualization.

With the LiDAR mounted 0.28 m above the waterline, its −7° to 52° VFOV allows it to detect Task 1 buoys, which are approximately 0.25 m tall. More importantly, Crusader operates with an average pitch-up angle of approximately

7° at cruise, creating a 1.02 m blind spot in front of the vehicle when relying solely on the camera. By complementing the camera with the downward-facing LiDAR, this blind spot is reduced to approximately 0.2 m in front of the vehicle. This configuration provides overlapping perception between the two sensors while maintaining close-range coverage, giving the obstacle avoidance system sufficient visibility to detect and respond to objects directly in Crusader's path.

3) Object detection: Object detection is performed through two complementary perception layers: LiDAR and camera-based detection. The team utilizes the OAK-D LR's stereo capability to obtain 3D spatial information for mission elements, providing both object detection and range estimation. For Task 1 buoys, we employ a two-stage detection pipeline to improve robustness. The first stage uses YOLO26 to detect and classify buoys based on their overall geometry and appearance, while the second stage analyzes the beacon region to determine its color and other task-specific characteristics.

Separating general buoy detection from fine-grained classification reduces the complexity of each detection task and allows the system to remain robust under variations in lighting, viewing angle, and distance. The LiDAR layer complements camera-based detection by providing independent 3D obstacle detection and close-range coverage, enabling the perception system to maintain reliable spatial awareness during autonomous navigation.



Fig. 2. Task 1 buoy mapping

B. Uncrewed Aerial Vehicle — Ekko

Ekko replaced Don, a 650 mm aircraft with 14-inch propellers. Ekko's 760 mm frame and 16-inch propellers give 31% more disc area, cutting ideal hover power by about 12% at equal thrust; the change was driven by endurance, payload delivery in Tasks 2 and 3, and persistent station-keeping in Task 1. Don remains in service as a test bench.

Both aircraft share motors and autopilot family, but the larger disc moves the hover point, so Ekko carries its own tune. Table II compares the two on lift margin, endurance, vibration and wind tolerance.

TABLE II. DON AND EKKO COMPARED

Metric	Don	Ekko
Hover vibration, X/Y/Z RMS	6.5 m/s² worst axis (after mount fix)	5.7 / 8.0 / 14.8 m/s²
Clipping events per flight	Not recorded	0
Thrust-to-weight at operating mass	Estimated 2.2	2.57 at 4.65 kg (2.72 at 4.4 kg)
Maximum take-off mass	4.6 kg provisional	5.98 kg
Endurance, own pack (with gripper)	12 min declared	20 min projected (22 without gripper)
Behavior in wind	Not measured (interim 6 m/s sustained, 8 m/s gust)	8 m/s sustained, 11 m/s gust declared; holds station to ~14.6 m/s

Ekko carries a nadir-pointing SIYI A8 mini gimbal camera and, for Tasks 2 and 3, a magnetic gripper. Safety authority stays on the autopilot rather than the companion computer. The geofence, a polygon with a 12 m ceiling, is stored in the autopilot; its 2 m margin stops every climb at the 10 m working altitude, and a breach triggers return to launch. We are using 12 m geofence altitude for most testing, but will adjust it to 22 m for buoy mapping on Task 1. Position targets from the Jetson are forwarded only while the autopilot reports GUIDED mode, armed, inside the fence and below the ceiling, and autonomy starts only on the safety pilot's switch. A failed companion computer can therefore stop a mission but cannot fly the

aircraft anywhere unsafe, which lets mission software change without re-verifying flight safety.

Ekko's key Task 1 output is each buoy's light state, visible only from above. Detections are projected onto the water using the pose and gimbal angles stamped on each frame, and each state is decided over at least 4 s of observation. In five park runs all ten state decisions were correct, with buoy-to-buoy distances repeating within $\pm$0.16 m (Fig. 3). For Tasks 2 and 3, a servo-switched magnetic gripper picks up a tin by landing on it, before activating the servo.



Fig. 3. Buoy mapping at the park test site: detected buoy positions and decided light states.

C. Uncrewed Underwater Vehicle — Græy

1) Dual battery system: Græy is equipped with a dual battery system to isolate actuators from sensors. When testing, we found that activating the kill switch caused a voltage drop which shut down the main computer, because capacitance on the thruster branch pulled the shared rail down. The fix was two power paths: one battery for thrusters, one for everything else. A recoverability property in our design philosophy came directly from a bench failure.

2) Untethered UUV: Græy operates without a tether, freeing Task 2 from tether length and from Crusader's position, enabling parallel execution of Task 2 and Task 3. Because Græy has no tether, losing it does not end the run: a disabled UUV is recovered manually while Crusader continues autonomously. A tethered UUV would pull the USV into manual control along with it and end the autonomous attempt. The cost is the loss of a guaranteed high-bandwidth link, which we mitigated with an acoustic link between Græy and Crusader.

3) Navigation: A DVL gives velocity over ground, a VectorNav AHRS provides attitude reference, and a barometer gives depth, fused in the autopilot's estimator. During our testing, we observed substantial localization drift. The mitigation is to use a GPS to correct its localization when Græy surfaces to report.

4) Underwater object detection: Græy has a Ping360 scanning sonar along with forward and downward-facing cameras as its primary perception sensors. We understand that camera performance may degrade in turbid water. In such conditions, the Ping360 will provide object detection information and allow Græy to continue detecting the pipeline structure when the camera alone can't complete the mission. The externally mounted cameras were chosen for the environment, trading additional penetrators and external cabling for one less layer between camera lenses and object. See Fig. 4 for example of sonar image from Ping360.

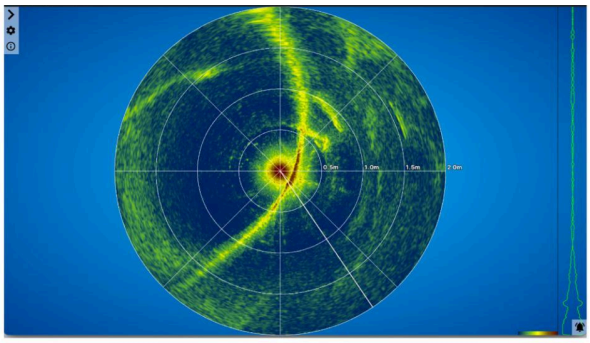


Fig. 4. Ping360 scanning sonar image.

5) Lessons carried into the build: Græy was flooded in July 2026, a week after the RoboSub competition. The team used this rebuild as an opportunity to add upgrades and improvements to Græy. First, we cleaned up Græy's hardware, replacing zinc-coated fasteners with corrosion-resistant stainless steel and organizing the main enclosure's wiring. The team then added a GPS system for accurately navigating to the buoys above the pipeline, an RFD900ux as a communication system when surfaced, and an 8 by 8 pixel LED matrix as a visual indicator for the vehicle's control state along with a voltage

divider for sensing when the kill switch has been activated.

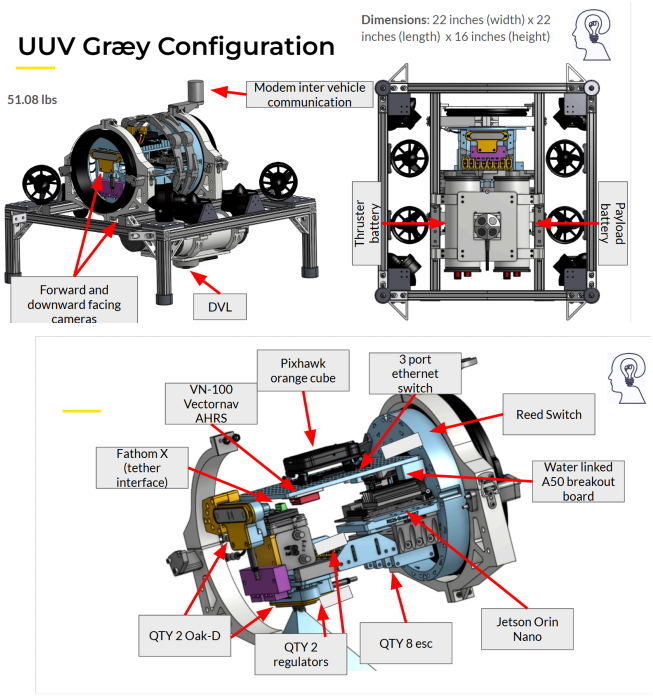


Fig. 5. External sensors (upper left), dual battery system (upper right), internal electronics (bottom) on Græy.

D. Communications Architecture

The team built four links to carry the system. A 920-925 MHz telemetry radio carries the USV–UAV and UAV-ground-station conversation, because their handshake must survive beyond line-of-sight Wi-Fi range. A directional 5 GHz link carries high-rate traffic between USV and ground station, including video and sensor views for debugging. A 2.4Ghz link between each pilot and vehicle for manual operation. An acoustic modem reaches Græy submerged. See Fig. 6 for our communication architecture.

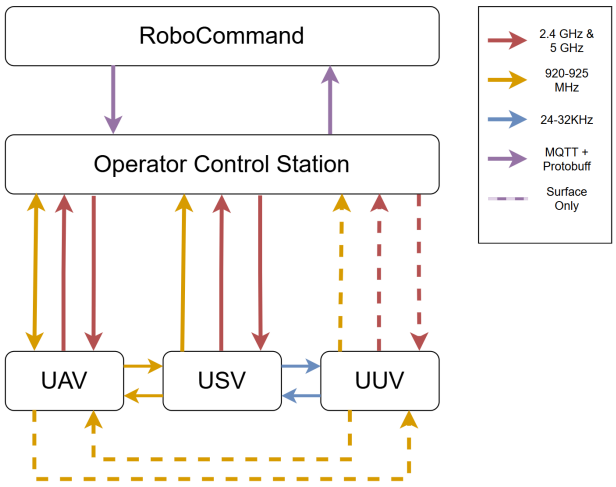


Fig. 6. Communication Architecture

1) 920-925MHz link: The UAV and USV have RFD900ux modems to communicate during collaborative missions. An additional modem will be used on the ground station to receive UAV telemetry. The UAV has the modem connected directly to its Pixhawk flight controller, and the USV has the modem connected directly to its Jetson. Custom messages (e.g., buoy colors and positions) are sent using the MAVLink Tunnel protocol. This allows us to send custom messages through UAV's Pixhawk without getting filtered by Ardupilot.



Fig. 7. A screenshot of QGroundControl has the USV and UAV connected to the ground station.

2) 2.4 GHz & 5 GHz link: We continue to use a competition-proven 5 GHz link from RoboBoat between our ground station and USV. The strong AirMax 5 GHz link gives us reliability, but also adds complexity to our inter-vehicle communication design because regular Wi-Fi cards cannot join AirMax. To achieve reliable vehicle operation, each is controlled via a transmitter receiver operating at 2.4 GHz.

3) 24-32 KHz link: An acoustic modem will be used between the UUV and USV when the UUV submerges underwater to execute a task. With a limited data rate of approximately 600 bps, this link carries critical heartbeat information as well as fully custom binary inter-vehicle messages to complete the missions.

E. Software

All three platforms share a common software architecture so that capabilities developed on one vehicle can be transferred to the others with minimal rework. At the same time, each vehicle is designed to operate independently. This modular approach allows the team to test one, two, or all three vehicles depending on the mission.

Besides a centralized ground station application that interfaces with all vehicles and RoboCommand, the team developed an individual User Interface (UI) for each vehicle to give operators and developers direct access to vehicle status, sensor data, system parameters, and mission controls during testing. This accelerates our development process by minimizing the need to interface with terminals for simple tasks like tuning parameters.

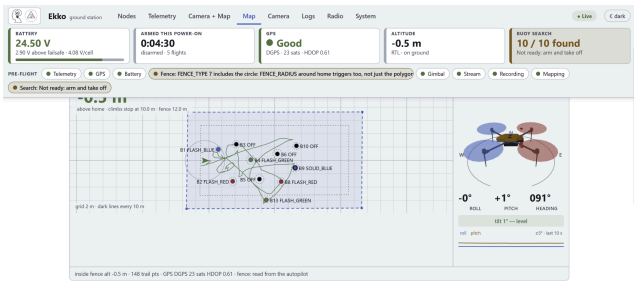


Fig. 8. Ekko's UI for viewing mapping result

Mission logic is implemented using behavior trees, allowing similar actions to be reused across different missions and vehicles. Compared with a traditional Finite-State Machine (FSM), behavior trees provide a more flexible structure for dynamic mission planning. An FSM generally requires explicitly defined transitions between states, which can become difficult to manage when a vehicle needs to interrupt its current mission and respond to an unexpected or higher-priority event. In contrast, behavior trees can continuously evaluate conditions and priorities, allowing an urgent action to take control when its conditions are met and then return to the previous mission once the event is resolved. This makes the mission logic better suited for autonomous vehicles operating in environments where conditions can change during execution. Fig. 9 shows an example behavior tree structure for Task 1.

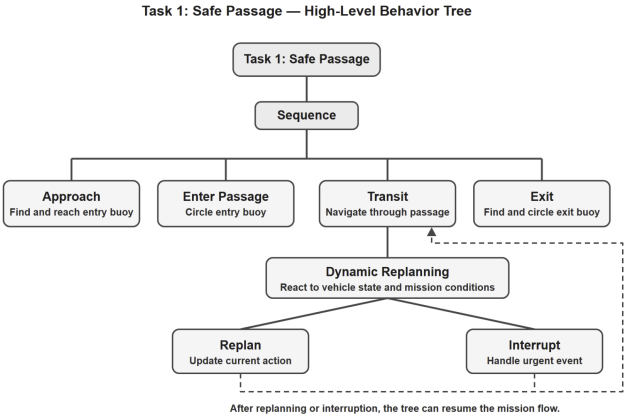


Fig. 9. High level behavior tree visualization for Task 1

Perception follows a common structure of detection, classification, and temporal decision-making. Crusader applies this structure to its stereo camera for surface-object detection, while Ekko uses the same approach on its gimbal camera for buoy mapping. Græy uses models developed through the same data collection, labelling, and training pipeline. All three vehicles use the same code to interpret colored light signals, where the signal state over time is more important than a single observation.

By sharing these common patterns, tools, and development processes while keeping each implementation modular, we can transfer proven

capabilities between platforms without forcing all three vehicles into an identical software stack.

III. TESTING STRATEGY

A. The Testing Ladder

The team utilized the systems engineering process throughout our testing, deriving action items and test cases from complex mission requirements, guiding our testing strategy.

Component tests are conducted to ensure reliability and functionality of individual features before integration into the overall system. Components include mechanical, electrical, and modularized software functions like object detection and payload actuation.

System testing is performed to verify mission capabilities involving multiple components. Subsystem testing includes testing isolated maneuvers of the overall approach such as UUV perception, localization and interaction with an LED box on the pipeline.

System testing includes all the capability for a platform to complete a task. Vehicles are evaluated on their completion of the tasks.

Each testing stage is carried out at a site chosen for cost and what it can verify. A lab pool allows daily subsystem testing of Crusader and Græy, including Græy's interaction with a pipeline LED box. Ekko is tested in an open park, where crashes are recoverable and buoys can be placed by hand at known positions to score the aircraft's map. Capabilities are proven at the park and pool before we advance to the local reservoir, whose open water best approximates the competition course.

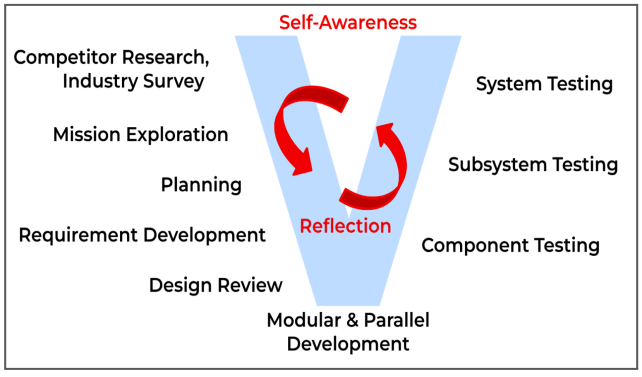


Fig. 10. Systems engineering V shape diagram.

B. Component Testing

Component testing is conducted to ensure individual components behave as expected before being integrated into the system.

For example, after we flooded our UUV Græy, we cleaned each component with isopropyl alcohol and conducted component testing on them. Because we had a flood, the UUV enclosure was opened frequently due to unexpected electrical failures in the thrusters. We located the root cause of the failures: low soldering quality and a lack of strain relief on the cables. We quickly applied changes based on the component testing results, and our system has remained reliable ever since.

C. System Testing

We have accumulated more than twenty hours of water testing on the current systems and eight hours of flight time. Access to a local reservoir is sustained through community relationships. The system launches and operates with two people, which is what makes weekly testing possible.

Land and pool testing are used for smaller tests or when the reservoir is unavailable.

D. System of Systems Testing

Rigorous test planning is conducted to ensure streamlined operations during multi-vehicle operation. Dry runs of multi-vehicle operations expose edge cases not foreseen in individual system operations. For example, we found that low altitude hovering of the UAV pushes buoys around due to downwash, thus introducing variables for USV navigation.

E. Verification Path to Competition

Shipping four vehicles to an unfamiliar venue introduces environmental and logistical differences that cannot be fully reproduced during local testing. Our verification plan addresses these differences through local testing, simulation where applicable, and on-site validation.

- **Environment:** Differences in altitude and air density affect thrust and

efficiency, while water density affects buoyancy and vehicle waterline. We will adjust vehicles' parameters and validate their performance on-site.

- **Perception:** Competition lighting may introduce glare, reflections, and motion blur not present in our local testing. We will test perception across varied lighting conditions at different times of the day and tune the system on-site.
- **Communications:** Local radio regulations and radio frequency (RF) traffic around the arena may differ from our test environment. We will verify our frequency configuration with Singapore authority and teams. We will test the complete communication network robustness before facing the complex radio environment at competition.
- **Logistics:** Battery transportation and local availability narrowed the selection. The team is actively communicating with local vendors and teams to ensure availability for our vehicles.

F. Simulation

The team uses SITL to learn vehicle behavior under different control modes and test high level mission behavior without physical dependency of a venue as big as a lake. Also utilizing SITL, we are simulating every mission before we actually attempt them. This is to confirm that the movement of our vehicles will work as intended in autonomous modes before we ever arm them. We simulated vehicle behavior by executing the behavior tree mission logic in SITL, see Fig. 11. The team also utilized VRX with Gazebo and Simulink to aid our UAV testing. See more details in Appendix E.

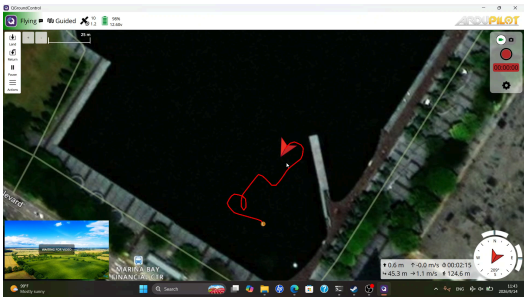


Fig. 11. Simulated Task 1 execution at Singapore in SITL.

IV. ACKNOWLEDGEMENTS

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Appendix A

Component	Vendor	Model/ Type	Specs	Custom/ Purchased	Cost	Year of Purchase
UUV Hull Form/ Platform (Frame, Waterproof Housing)	80/20 Inc.	1010 aluminum extrusion	Weight: 25 oz Size: 22 in x 7.9 in	Purchased and machined in lab	$234	2019
	ePlastics	Acrylic tube, 8 in. series	Size: 8” diameter	Donated	$343	2019
Waterproof Connectors	Blue Trail Engineering	10 cobalt series dummy plug 10 cobalt series locking sleeve 4 cobalt series cable termina-tion kit	https://www.bluetrailengineering.com/product-page/cobalt-series-dummy-plug https://www.bluetrailengineering.com/product-page/removable-cobalt-locking-sleeve https://www.bluetrailengineering.com/product-page/cable-termination-kit	Purchased	$201	2020
	Blue Robotics	1 7.5mm HC Wetlink penetrator	https://bluerobotics.com/store/cables-connectors/penetrators/wlp-vp/		$12	
Inter Vehicle Communica-tion	Succorfish	Delphis V3.3	https://succorfish.com/wp-content/uploads/2023/01/DELPHIS-Data-Sheet_V9_3.2.pdf	*Donated by a sponsor*	*Donated by a sponsor*	2023
	RFD	RFD900ux	https://irlock.com/products/rfd900ux-modem-bundle?variant=32295861026867	Purchased	$ 262.40	2024

Inter Vehicle Communica-tion (continued)	UniFi	airMAX Bullet AC IP67	Size 190 x 46Ø mm, 5 GHz frequency band, Mass 190 grams, 300 Mbps Throughout	Legacy	$129	2024
	HolyBro	SiK Telemetry Radio V3	Size 28 x 53 x 10.7mm, Mass 23.5 grams, Frequency 433MHz	Purchased	$59	2026
Propulsion	Blue Robotics	T200 thrusters	Full Throttle FWD/REV Thrust @ Maximum (20 V) https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster-r2-rp/	Legacy	$200 apiece	2019
	Blue Robotics	T200 propellers	Max thrust: 49.82 N	Legacy	Included with thrusters	2019
Power System (Battery, Converter, Regulator)	Blue Robotics	Lithium-Ion Battery	4s 14.8V 15.6 Ah	Legacy	Legacy	2019
	Blue Robotics	5V, 6A power supply	5V, 6A	Legacy	Came with BlueROV setup; Legacy	2019
	Mouser	Murata MYBSS05 4R6EBF	54V Power supply https://tinyurl.com/inspirationRegulator	Purchased	$22	2023
	AliExpress	100A Ideal Diode	100A Ideal diode	Purchased	$72	2023
	Custom	Unified Power Controller	Three: 12V 3A, 5V 3A, 3.3V 1.2A Power supplies	Custom	$400	2023
	Amazon	DROK Buck Converter 12v to 5v	Input 12V, Output 5V, Mass 22 grams,	Legacy	$14	2025

Motor Control	Blue Robotics	Basic ESC	30A brushless ESC https://bluerobotics.com/store/thrusters/speed-controllers/besc30-r3/	Legacy	$36 each	2019
	Lumenier	ELITE PRO 60A 2-6S AM32 4-in-1 ESC	Size 43 x 46 x 9 mm, Mounting Holes 30.5 x 30.5 mm, Mass 27 grams 60 A	Purchased	$119	2026
	Holybro	Tekko32 F4 Metal 4in1 65A ESC	Size 43 x 44 mm, Mounting Holes M4 30.5x30.5mm, Mass 15.8 grams, 65 A	Purchased	$95	2026
Motor Control (continued)	Pololu	Micro Maestro 6-Channel	Size 1.20” x 0.85”, 33-100 Hz pulse rate (configurable), Mass 3 grams,	Legacy	$28	2024
Button	McMaster-Carr	Emergency Stop Enclosed Push-Button Switch	Size 2.875” x 2.875” x 1.876”, 2.5 A 24 V (DC)	Legacy	$73	2024
Reed Switch	Amazon	NO/NC Black Magnetic Switch	Size 5.51 x 4.33 x 0.43 inches, Max 0.5 A 100 V (DC)	Legacy	$10	2021
Barometer	Blue Robotics	Bar High-Resolution Depth/Pressure Sensors	Operating Pressure 0-30 bar, Operating Depth 0–295.6 m, Absolute Accuracy 0 to 45°C: ±200 mbar (204 cm in freshwater) -20 to 85°C: ± 400 mbar (409 cm in freshwater)	Legacy	$85	2019
CPU (4x)	Nvidia	Nvidia Jetson Orin Nano	1.4 GHZ clock speed 4 GB RAM	Purchased	$400 each (On all vehicles)	2021

Teleopera-tion	Blue Robotics	Fathom-X and Fathom-X Tether Interface (FXTI)	Communication: USB 2.0, Ethernet 10/100	Legacy	Installed	2023
Flight Controller	Pixhawk Cube Orange+	Invensense ® MPU 6000 3-axis acceler-ometer/ gyroscope	32-bit ARM Cortex M4 core with FPU 168 MHz/256 KB RAM/2 MB Flash 32-bit failsafe co-processor	Legacy	$501	2019, 2022
	Dampener	XTORI Pixhawk dampener	Materials: plastic and rubber Weight: 17 g	Legacy	$8	2021
Internal Measuring Unit (IMU)	VectorNav	VN-100	5°/hr Gyro In-Run Bias, Accelerometer Range 16g, Power 200 mW	Legacy	$950	2019
Doppler Velocity Log (DVL)	WaterLinked	A50	Velocity Range: ±3.75 m/s Long Term Accuracy: ±1.01% https://waterlinked.com/web/content/15701?unique=b4aef6d930bbb256c64bae4e0ead8c56661bf12f0	Purchased	$5990	2020
Cameras	Luxonis	OAK-D	12 MP Resolution 60 FPS max frame rate Focus (Full Frame): 60cm - ∞	Purchased	$ 329	2024
	SIYI	A8 mini Gimbal Camera	Size 55x55x70 mm, Mass 95 grams, 4K Max Resolution, Max 25 FPS, Gimbal Angular	Purchased	$253	2026

			Vibration Range ±0.01°, Gimbal Pitch Angle 135° ± 45°, Gimbal Roll Angle 30° ± 30°, Gimbal Pitch Yaw 160° ± 160°			
Hydro-phones	Custom	Hydro-phone Circuit	100kHz sample rate for DTOA analysis. Variable gain control. 1-40kHz frequency lock range. Sub-watt and sub-degree precision under ideal conditions.	Legacy	$315	2020
	Aquarian Audio & Scientific	AS-1 Hydro-phone	Linear range: 1Hz to 100kHz ±2dB Horizontal Directivity (20kHz): ±0.2dB Horizontal Directivity (100kHz): ±1dB Vertical Directivity (20kHz): ±1dB Vertical Directivity (100kHz): +6dB -11dB https://www.aquarianaudio.com/as-1-hydrophone.html	Legacy	$413	2019
Water Pump	Bayite	12V DC Fresh Water Diaphragm Pump	Mass 1.5 lbs, Size 6” x 4” x 2.2”, Flow Rate 4 liters per minute	Legacy	$20	2025
Vision	Custom	Open Computer Vision	Color isolation, binary thresholding, contour approximation, erosion and dilation, area thresholding, and Contrast Limited Adaptive Histogram Equalization (CLAHE)		Free/ Open Source	2019

	Ultralytics	YOLO	YOLO26		Free	2026
Localization and Mapping	In-house	Custom	DVL, Hydrophones, CV		Free	2021
Mission Planner	In-house	Custom	Mission planner		Free	2024
Open Source Software	Open- Source (n/a)	OpenCV, Robot Operating System, Python, C++, Linux	Computer Vision, Inter-process communication, programming, computer operating system		Free	2019
UAV Frame (Don)	RobotShop	Tarot IRON MAN 650 Folding Carbon Fiber Quadcopter Frame	Mass 476 grams Diagonal Length 650mm	Purchased	$150	2026
UAV Propellers (Don)	SpeedyFPV	14x5.5 Carbon Fiber Propeller T-Style Set (2x CW / 2x CCW)	Set of 4 propellers 2 CW, 2 CCW Diameter 14” Pitch 5.5” Mass (Each) 20 grams Shaft Diameter 4mm	Purchased	$20	2026
UAV Frame (Ekko)	AliExpress	9IMOD IDF-17 inch FPV Frame	Mass 84 grams Size 70x50x31 (mm) Diagonal Length 760mm	Purchased	$70	2026
UAV Propellers (Ekko)	SpeedyFPV	16x5.5 Carbon Fiber Propeller T-Style Set (2x CW / 2x CCW)	Set of 4 propellers 2 CW, 2 CCW Diameter 16” Pitch 5.5” Mass (Each) 20 grams Shaft Diameter 4mm	Purchased	$30	2026
GNSS	HolyBro	Micro M9N GPS	Size 34 x 28 x 11mm, Mass 16 grams, Accuracy 1.5m CEP, Frequency Band GPS	Purchased	$40	2026

			L1, Update Rate 25 Hz			
	Septentrio	Mosaic-G5 P8	Frequency Band GPS L1, Horizontal RTK 0.6cm, Vertical RTK 1cm, 100Hz Update Rate, Mass 2.2 grams, Size 22.8 x 16.4 x 2.4 mm	Purchased	$1000	2026
	GNSS Store	Multiband RTK GNSS Active Quad Helix Antenna	Size 59.7 x Ø27.5mm, Mass 18 grams, Frequency Band GPS L1, Frequency 1550-1610 MHz	Purchased	$80	2026
	Beitian	Beitian GNSS Module BT-982G1	Size 66 x 48 x 10.8mm, Update Rate 20Hz, Mass 18 grams	Legacy	$176	2025
ASV Hull Form/Platform (Frame, Waterproof Housing)	80/20 Inc.	1010 aluminum extrusion	Weight: 25 oz Size:115 in	Purchased and machined in the lab	$234.73	2019
	Lowe’s	FOAMULAR NGX F-250 Unfaced Polystyrene Board Insulation	R-10, 2-in x 4-ft x 8-ft	Purchased	$51.98	2023
	Home Depot	Maple Plywood, ⅛ in. series	Thickness: ⅛”	Purchased	$23.99	2024
	Fibre Glast Developments Corp.	1.5 Oz Chopped Strand Mat	Quantity: 2 Length: 5 yards Width: 38 In	Purchased	$93.90	2023
	Sunrez Composites	7315 Polyester Resin	Quantity: 3 gallons	Donated	$320	2023

	Fibre Glast Developments Corp.	2 oz Fiberglass Fabric	Quantity: 2 Length: 3 yards Width: 38 In	Purchased	$49.90	2023
	McMaster-Carr	1016N215 Cable Entry Panels	Supported cable diameter: 0.22”	Purchased	$25.95	2023
	MAKERELE	Cord Grip Cable Glands Kit	1/4”, 3/8”, 1/2”, 3/4”, 1”, 1-1/4” https://www.amazon.com/gp/product/B08R86BHBC/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&th=1	Purchased	$24.99	2023
Water Cannon	Bayite	12V DC Fresh Water Pressure Diaphragm Pump	https://www.amazon.com/gp/product/B01N75ZIXF/ref=ppx_yo_dt_b_asin_title_o00_s00?ie=UTF8&psc=1	Purchased	$20.99	2024
	Eastrans	3/8" ID x 10 Ft High-Pressure Braided Clear PVC Vinyl Tubing	https://www.amazon.com/gp/product/B07MTYMW13/ref=ppx_yo_dt_b_asin_title_o00_s00?ie=UTF8&psc=1	Purchased	$12.99	2024
	Everbilt	1/2 - 1-1/4 in. Stainless Steel Hose Clamp	https://www.homedepot.com/p/Everbilt-1-2-1-1-4-in-Stainless-Steel-Hose-Clamp-6712595/202309385	Purchased	$2.18	2024
Propulsion	Blue Robotics	T200 thrusters	Full Throttle FWD/REV Thrust @ Maximum (20 V): 6.7/5.05 kg f https://bluerobotics.com/store/thrusters/t100	Purchased	$200 apiece $230 apiece	2019, 2025

			-t200-thrusters/t200-thruster-r2-rp/			
	ELEGOO	Elegoo UNO R3	https://a.co/d/c9i5BFC	Purchased	$15.99	2024
Motor Control	Blue Robotics	Basic ESC	30A brushless ESC https://bluerobotics.com/store/thrusters/speed-controllers/besc30-r3/	Purchased	$36 apiece $40 apiece	2019 2025
	Teensy	Teensy 4.1	https://www.sparkfun.com/teensy-4-1.html	Purchased	$31.50	2025
Power System (Battery, Converter, Regulator)	Blue Robotics	Lithium-Ion Battery	4S 14.8V 18 Ah	Purchased	$425	2019
	Circuit Breaker	200 Amp Circuit Breaker with Manual Reset 12V	https://a.co/d/h648Kfr	Purchased	$29.99	2025
	Push-Button Switch	Emergency Stop Enclosed Push-Button Switch	https://www.mcmaster.com/6785k21/	Purchased	$69.69	2025
	ElecDirect	200A Manual Reset Type 3 Surface Mount	https://www.elecdirect.com/fuse-holders-circuit-breakers/circuit-breakers/200a-high-amp-manual-reset-type-3-surface-mount-12-42-volts	Purchased	$29.95	2023
	Pololu	RC Switch with Omron Relay	https://www.pololu.com/product/2804/specs	Purchased	$12.95	2023
	AEDIKO	DC 5V Relay Module 2	https://a.co/d/5N9Z85c	Purchased	$8.99	2025

		Channel Relay Board with Optocoupler Support High or Low Level Trigger				
	iRhapsody	4 Pin High Current Relay	120A, 12V	Purchased	$11.99	2023
	McMaster-Carr	7060K16 Insulated Quick-Disconnect Terminals	https://www.mcmaster.com/7060K16/	Purchased	$16.36 per 100 pieces	2024
	McMaster-Carr	7113K612 Ring Terminals	https://www.mcmaster.com/7113K612/	Purchased	$13.74 per 50 pieces	2024
	McMaster-Carr	69145K218 Spade Terminals	https://www.mcmaster.com/69145k218/	Purchased	$14.74 per 50 pieces	2024
	TKDMR	Battery Cable Ends Ring Terminals Connectors Tubing	https://a.co/d/5omEFDm	Purchased	$13.59	2025
Actuator Control	HUAREW	PCA9685 16 Channel PWM Servo Driver Board 12-bit IIC Interface Module Compatible with Arduino and	https://a.co/d/3V12mrF	Purchased	$12.95 per 2 pieces	2025

		Raspberry Pi				
DC-DC Converter	Cllena	Buck/Boost Converter	DC 8V-40V to 12V 10A	Purchased	$29.99	2023
	Matek Systems	Buck/Boost Converter	4A/5-12V and 4A/5V	Legacy		2021
	DROK	Buck converter	12v to 5v	Purchased	$9.99	2025
PoE Switch	Linovision	5 Ports DC12-48V Input Full Gigabit with Voltage Booster	5 Ports Full Gigabit POE Switch with DC12V ~ DC48V Input and Voltage Booster,Total IEEE802.3at POE Power Budget 120W | LINOVISION US Store	Purchased	$109	2023 2025
CPU	Nvidia	NVIDIA Jetson Xavier NX	https://developer.nvidia.com/embedded/learn/get-started-jetson-xavier-nx-devkit	Purchased	$399	2021
CPU	Nvidia	NVIDIA Jetson Orin Nano	https://www.nvidia.com/en-us/autonomous-machines/embedded-systems/jetson-orin/nano-super-developer-kit/	Purchased	$249	2025
Teleoperation	Ubiquiti	airMAX Bullet AC IP67	Communication: GbE, PoE UISP airMAX Bullet AC Dual-Band IP67 Radio - Ubiquiti Store United States	Purchased	$129.00 apiece	2023
	Alfa	AOA-2458-79AF Antenna	https://www.alfa.com.tw/products/aoa-2458-79af?variant=3647396	Purchased	$24.46 apiece	2023

			2332232			
	Ubiquiti	Instant Outdoor PoE Converter	https://store.ui.com/us/en/category/all-accessory-tech/products/instant-802-3af-outdoor-gigabit-poe-converter	Purchased	$21.00	2023
	RadioMaster	ER6 ExpressLRS PWM receiver	https://www.tekrc.eu/shop/receivers/expresslrs/radiomaster-er6-expresslrs-pwm-receiver-6-channels/	Purchased	$31.60	2023
	Flysky	FS-iA6B Receiver Radiomaster ER6	https://www.amazon.com/FS-iA6B-Receiver-6-Channel-Compatible-Transmitter/dp/B09STCQCCF/ https://a.co/d/aUiDuj5	Purchased	$18.49 $39.99	2023 2025
	Pololu	4-Channel RC Servo Multiplexer	https://www.pololu.com/product/2806	Purchased	$12.95	2023
Perception	Livox	Mid-360	Specs - Mid-360 LiDAR Sensor - Livox (livoxtech.com)	Purchased	$749	2023
Inertial Measurement Unit (IMU)	Adafruit	BNO085	https://www.ceva-ip.com/wp-content/uploads/BNO080_085-Product-Brief.pdf	Purchased	$24.95	2024
Camera	Luxonis	OAK-D LR	Resolution: 2.3MP (1920x1200) Frame Rate: 60 FPS max rate Focus: M12 FF (45cm - ∞) https://shop.luxonis.com/products/oak-d-lr	Purchased	$350.00 (50% discount)	2024 2025

Localization and Mapping	Beitian	UM982 GNSS Module Model BT-982K1	https://store.beitian.com/products/beitian-built-in-zed-f9p-navigation-surveying-positioning-precision-agriculture-centimeter-level-rtk-gnss-module	Purchased	$200.88	2023
	Beitien	High Precision Provides Stability And Reliability External Dish	https://store.beitian.com/products/beitian-high-gain-high-precision-gnss-antenna-provide-stability-and-reliability-gnss-signal-for-positioning-applications-bt-800s?variant=50615537369375	Purchased	$40.88 apiece	2025
	U-blox	ANN-MB series L1/L2 GNSS antennae (2x)\	https://content.u-blox.com/sites/default/files/documents/ANN-MB_DataSheet_UBX-18049862.pdf	Purchased	$60.00 apiece	2023
Vision	Custom	Open Computer Vision	Color isolation, binary thresholding, contour approximation, erosion and dilation, area thresholding, and Contrast Limited Adaptive Histogram Equalization (CLAHE)		Free/ Open Source	2019
	Ultralytics	YOLOv8	Real-time object detection and inference https://docs.ultralytics.com/models/yolov8/		Free/Open Source	2022

Autonomy	In-house	Custom (Python)	Object detection integration, mission planning, waypoint navigation		Free	2024
Open-Source Software	Open-Source (N/A)	OpenCV, Python, C++, Linux	Computer Vision, Inter-process communication, programming, and computer operating systems	Custom	Free	2024

Appendix B — Software Architecture Diagrams

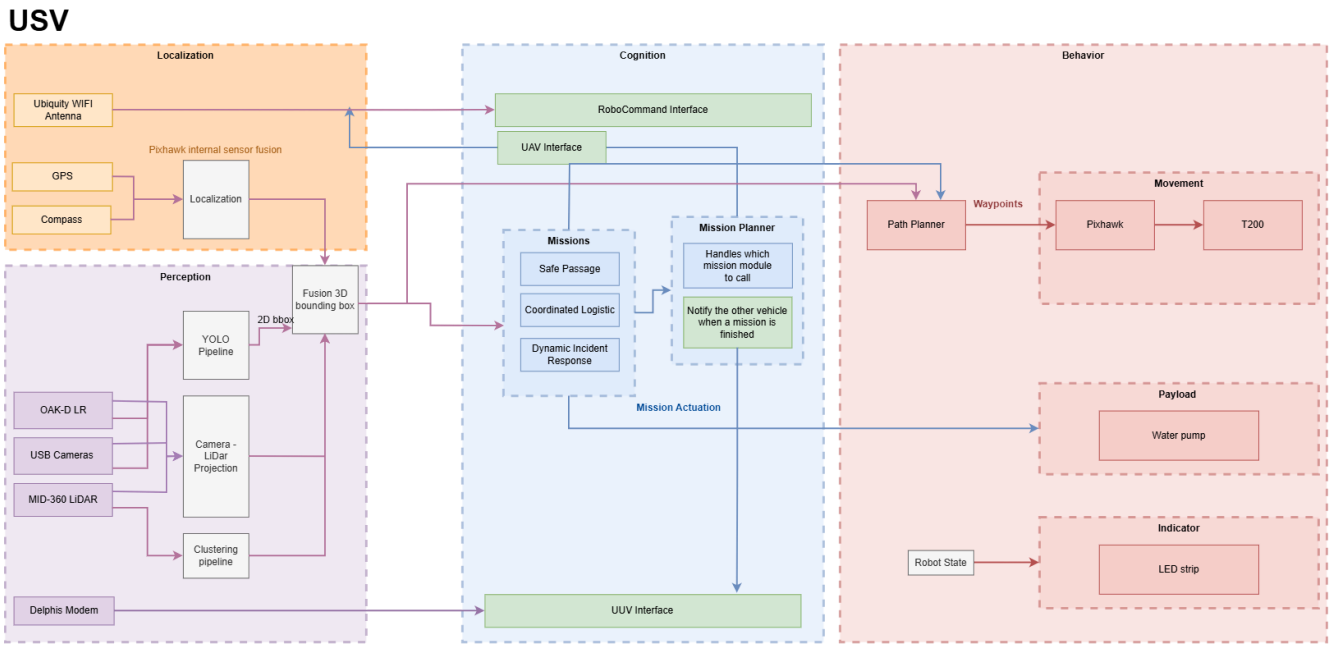


Fig. 12. USV Software Architecture

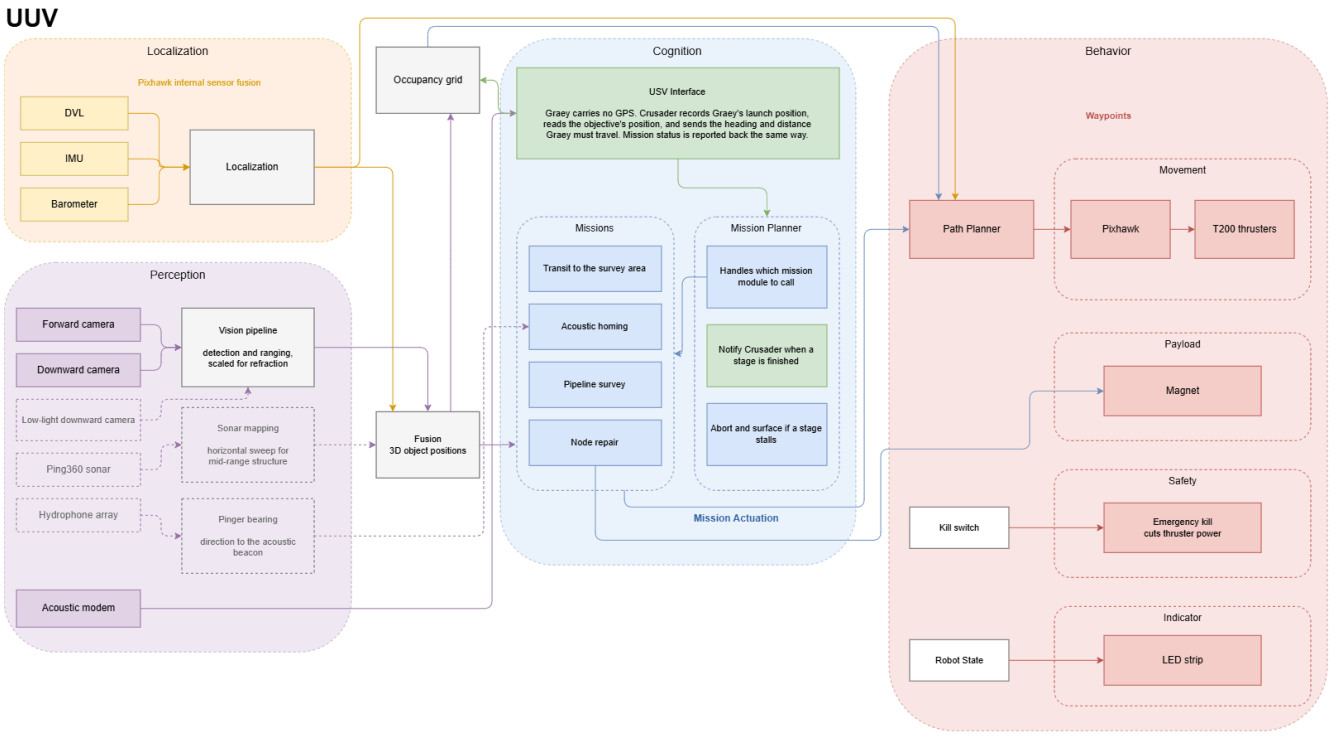


Fig. 13. UUV Software Architecture

UAV

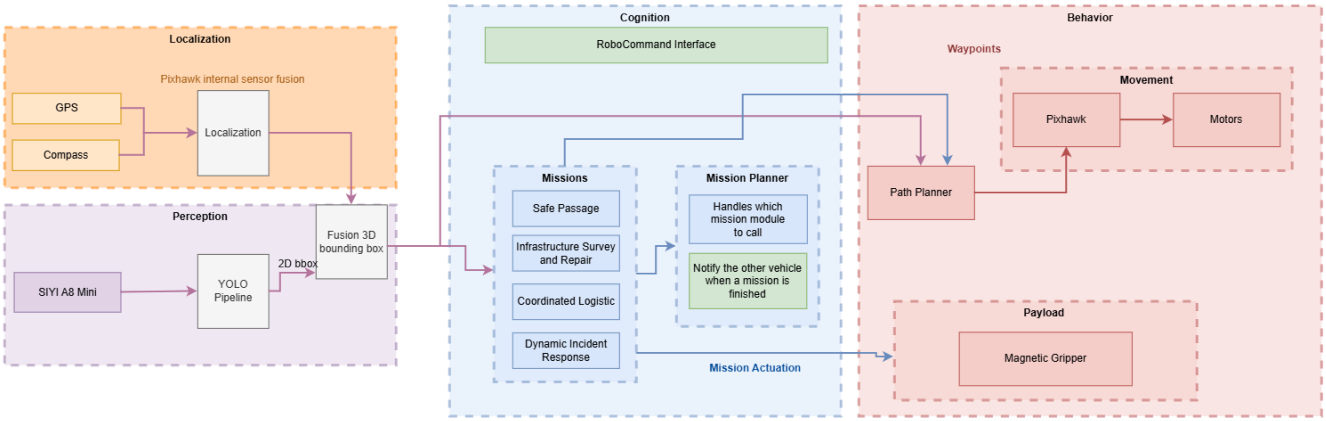


Fig. 14. UAV Software Architecture

Appendix C — Electrical Architecture Diagrams

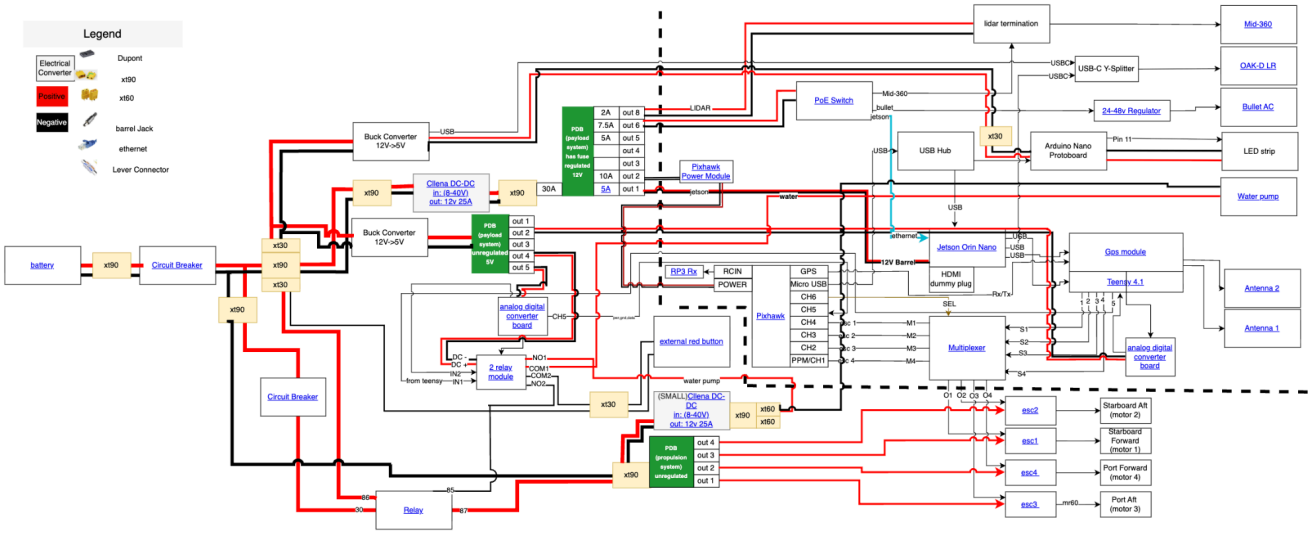


Fig. 15. USV Electrical Architecture

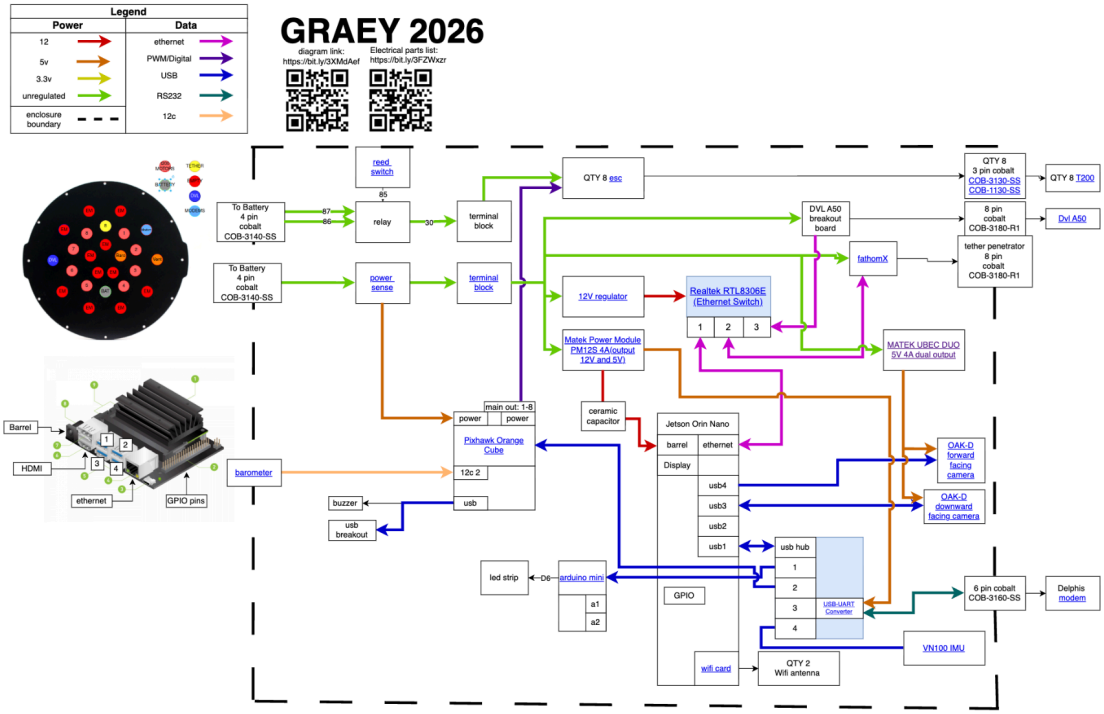


Fig. 16. UUV Electrical Architecture

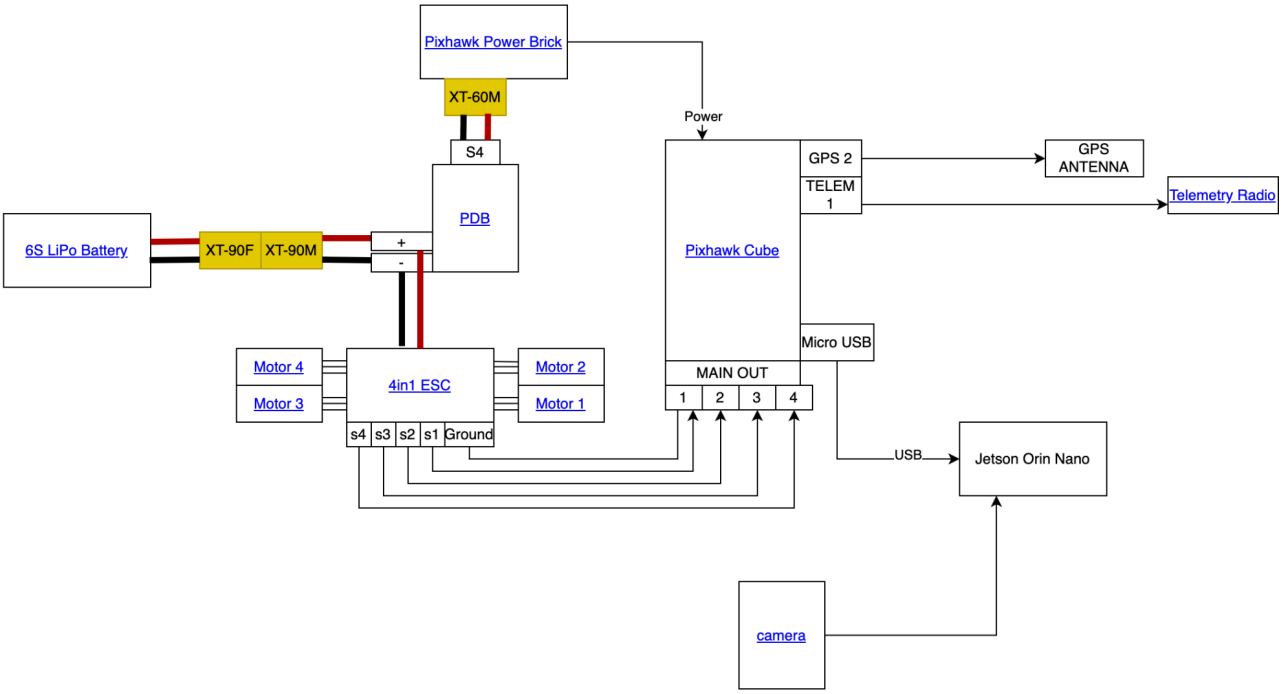


Fig. 17. UAV Electrical Architecture

Appendix D — Test plan

<table>
<tr><td colspan="4" rowspan="2">Crusader ASV prequalification</td><td>Approval Authority</td><td colspan="3">Position</td></tr>
<tr><td>Chris Martin Colin Szeto</td><td colspan="3">Team Leads</td></tr>
<tr><td colspan="2">Date: 2026-07-19</td><td colspan="5">Mission Title: Prequalification Crusader v2</td></tr>
<tr><td colspan="2">Test #: 1</td><td colspan="3">Location: Lake Miramar
WW72+G2G, San Diego, CA 92131</td><td colspan="2">Risk: Low</td></tr>
<tr><td colspan="2">Software Version: ROS2 Humble</td><td colspan="3">Hardware Sensors Mounted:
GPS, ELRS receiver, Bullet, Oak-D LR camera</td><td colspan="2">Hardware Sensors Used:
GPS, Oak-D LR camera</td></tr>
<tr><td colspan="7">Scope: <u>Primary:</u> Prequalification maneuver of Crusader v2
<u>Secondary:</u>
<u>Tertiary:</u>
<u>Quaternary:</u></td></tr>
<tr><td colspan="2" rowspan="2">Roles</td><td colspan="2" rowspan="2">Walkie Talkies/ Cell Phones</td><td colspan="3">Times</td></tr>
<tr><td>Event</td><td>Time</td><td>Actual</td></tr>
<tr><td>Test Conductor</td><td>Chris Martin</td><td>Ground</td><td></td><td>Packup</td><td>Day before</td><td>Day before</td></tr>
<tr><td>Boat Launcher</td><td>Brandon Tran</td><td>Pool Deck</td><td></td><td>Go to Lake</td><td>12:00 pm</td><td>~12:30pm</td></tr>
<tr><td>Ground Control</td><td>Chris Martin</td><td>Chase Boat</td><td></td><td>Test</td><td>12:30 pm</td><td>~13:30pm</td></tr>
<tr><td>Data Collector</td><td>Chris Martin</td><td>Tether</td><td></td><td>Cleanup</td><td>14:30</td><td>~16:15pm</td></tr>
<tr><td>Photographer</td><td>Dominick Cardella</td><td></td><td></td><td>Leave Lake</td><td>15:00</td><td>~16:30pm</td></tr>
<tr><td>Safety Checker/QA</td><td>Chris Martin</td><td></td><td></td><td>Put Away</td><td>15:30</td><td>~17:00pm</td></tr>
<tr><td>Remote Control</td><td></td><td></td><td></td><td>Hot Wash</td><td>16:00</td><td></td></tr>
</table>

Status			
Weather	GO	GO/NO GO	
Boat	GO	GO/NO GO	
Attendance	**Test Notes**		
	Resources Needed: **Environment:** 2 red buoys, 2 green buoys, QTY 4 rope, QTY 4 weights **Expected Results:** Crusader go to waypoints and pass the nav channel **Prerequisites:** Make sure GPS are working and can get heading **Test procedure:** Run script with models trained on the buoys, crusader autonomously navigates through the buoys Use RC control to survey and mark waypoints, then go to them using mission planner Show the controller in manual mode Be recording the entire time, ensure that we say “auto auto” and show there is no human operation with the controller **Risk Management:** Do not run thrusters on dry land for more than 5-10 seconds. Be sure all screws are secure and the electrical box and cable glands are sealed completely.		

#	**Validation Step Description**	**Expected Result**	**Pass/Fail**	
1	Test run gate mission in Bravo	Pass the gate	Pass	
2	Test run gate mission in Bravo	Pass the gate	Pass	
3	Test run gate mission in Bravo	Pass the gate	Pass	
4				
5				
…				



Fig. 18. Test site at Lake Miramar

Item #	Time	zone	
1		B	Deploy kayak + buoys + weights (dropping off with van)
2		A	Set up base station, antenna, battery and inverter, chairs, ensure SSH connection with Crusader v2
3		A > B	Transport crusader v2 down the flight of stairs to the boat ramp
4		B	Rc crusader into position
5		B	Mission execution (autonomous mode)
6		B	Manual waypoints,

Appendix E — SITL simulation

A. Simulation

1) SITL

The test strategy runs every UAV perception and navigation capability in a full software-in-the-loop (SITL) environment before lake time: ArduPilot SITL [4] flies an iris-class UAV in Gazebo Harmonic [5] over an animated VRX ocean [6], on the same MAVLink/ROS 2 Humble [7] stack as the real Pixhawk, with the flight code, buoy detector, and course scripts unmodified from the field build. The test plan exercises three ground-truth courses with known buoy layouts built to RobotX 2026 task specs—a 3-gate-pair Safe Passage channel (Task 1), a 7-buoy open-water lawnmower survey (surface-marker search for Task 2), and a 4-gate-pair dogleg with a 90° heading change—scored automatically against Gazebo ground truth.

The detector's YOLOv11n [8] weights are fine-tuned on auto-labeled captures augmented with Gaussian blur, random-angle motion blur, three glare hotspots, and pixel noise to match real nadir-camera degradation in flight, with the train/validation split fixed before augmentation so no source frame leaks across sets. Before flight, the resulting weights must clear a 5-step validation test plan: held-out mAP50, per-class precision and recall, a synthetic noise-injection stress test, and a train/validation overfit check. The current weights pass all five, reaching mAP50 0.994, recall 1.000, and precision 0.941 held-out, retaining full detection rate under the noise stress test with a healthy (non-diverging) overfit check.

2) False-Positive Filter Testing

Three candidate reject-only shape filters were tested against the held-out set (Table III). An aspect-ratio gate and a fixed-altitude size gate were both rejected—the ratio ranges overlap directly, and the size gate collapsed recall to 0.396 as capture distance varies—so a circularity gate was adopted instead (default 0.5): the only one of the three that gained precision at zero recall cost. Auditing the residual false positives against known Safe Passage gate geometry confirmed the rest are genuine detector confusions, and caught one real gate pair the auto-labeler had missed entirely—two buoys sitting 2.68 m apart against a true 2.5 m gate spacing—correcting measured precision from 0.931 to 0.950.

TABLE III. FALSE-POSITIVE GATE TEST RESULTS, HELD-OUT VALIDATION SET

Gate	Result
Aspect ratio	Rejected: TP ratio (up to 1.62) overlaps FP ratio (1.02–1.59)
Size @ fixed altitude	Rejected: recall 1.000 → 0.396
Circularity ≥ 0.5	Adopted: recall unchanged at 1.000, precision 0.941 → 0.950 post-audit
Track confirmation	Built, synthetic-tested; default off pending live tuning

3) Simulink Sensor-Injection Testing

Since Gazebo's simulated sensors are noise-free, the test plan adds MATLAB Simulink models (Navigation Toolbox gpsSensor [9]) that generate GPS, rangefinder, and optical-flow noise, each mode-switched at runtime across RTK-fixed, RTK-float, DGPS, and standard-GPS quality tiers (Fig. 19). Each model closes the loop directly into ArduPilot's own EKF over MAVLink (GPS_INPUT, DISTANCE_SENSOR, OPTICAL_FLOW) instead of only comparing noise offline, so the same navigation solution that flies at competition is what gets tested. All three were verified on live SITL Course 1 flights rather than open-loop simulation alone: the GPS path tracked a ~50 m flight to within 0.4% of true distance flown, and

EKF fusion measured 3.5× more accurate than the raw, unfiltered GPS signal. A RobotX-specific extension models GPS multipath/occlusion degradation near buoys and gates (the core hazard in Safe Passage [2]), showing roughly 23× worse horizontal accuracy within 8 m of a buoy than in open water (Fig. 20), which the team uses to pressure-test gate-approach control logic before real water time.

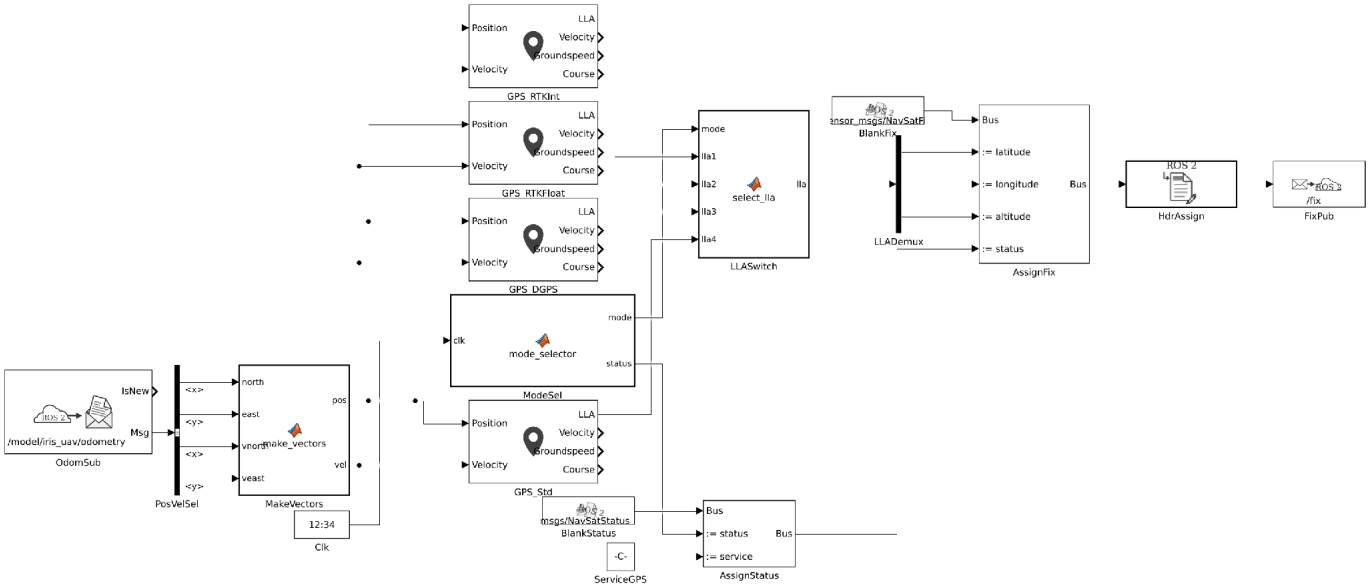


Fig. 19. Simulink GPS sensor-injection model. Mode-switched RTK-fixed, RTK-float, DGPS, and standard-GPS gpsSensor blocks [9] publish /gps (sensor_msgs/NavSatFix); fix_to_gps_input.py relays that fix into ArduPilot's EKF as MAVLink GPS_INPUT [4].

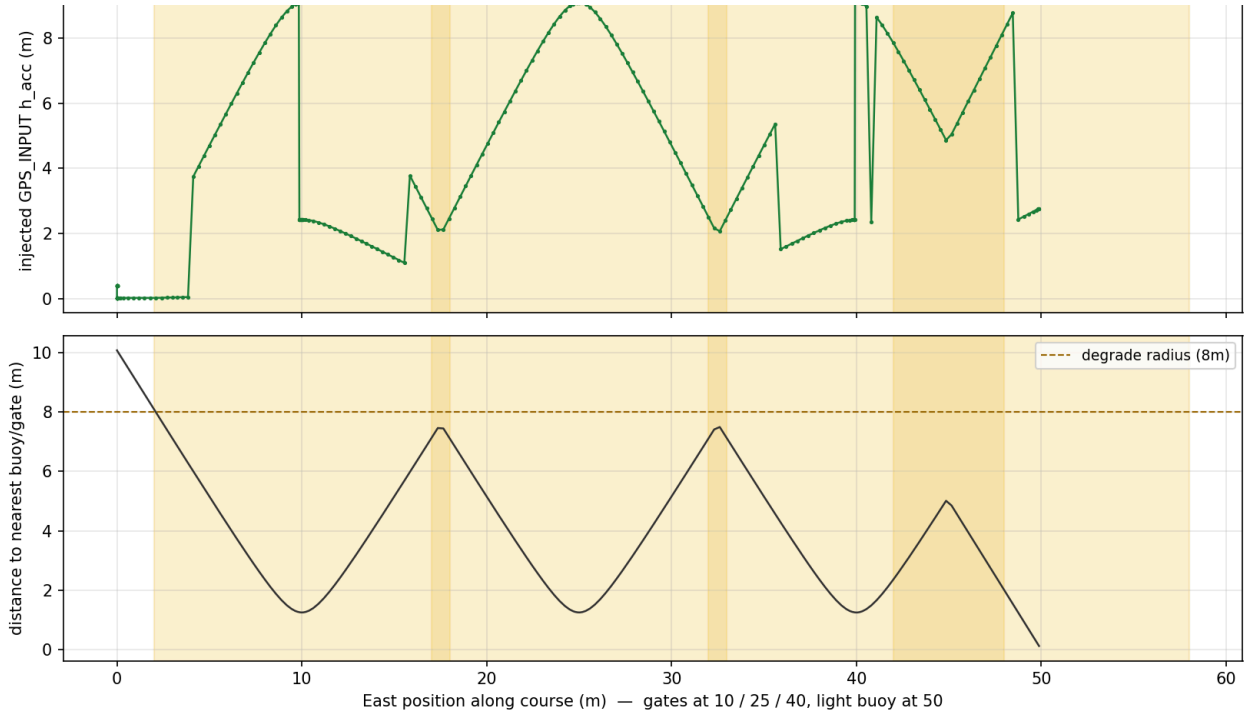


Fig. 20. Live SITL Course 1 verification of buoy-proximity GPS degradation: injected horizontal accuracy (h_acc) rises within an 8 m radius of gates/light buoy (shaded), yielding ~23× worse accuracy near structures than in open water—used to stress Safe Passage gate-approach control before lake time

Appendix F — Vehicle Requirement Spreadsheet

Below are our UAV requirements, exemplifying our vehicle requirements

UAV mechanical requirements

Source: RoboNation Maritime RobotX Challenge 2026 Team Handbook. Type M = explicit handbook mandate, D = derived from a scored mission-task capability or team decision.

Req ID	Requirement (shall statement)	Type	Tier	Source (RobotX 2026 Handbook)	Verif. Method	Verification Event	Evidence Artifact
UAV-MEC-001	The UAV shall have a maximum all up flying weight of 7.0 kg (15.43 lb) or lower, in the configuration presented for flight.	M	ALL	5.3.3 UAV General Req	T	UAV Safety Check / airworthiness inspection	Mass budget spreadsheet + scale ticket at inspection
UAV-MEC-002	The mass budget shall hold at least 10% margin below the 7 kg limit at design freeze, to absorb payload, wiring and mounting growth.	D	ALL	Team - design margin	A	Design review	Mass budget with line-item margin column
UAV-MEC-003	The UAV shall provide a mount point for the water-activated emergency safety light supplied on site by competition organisers, fitted without tools and without significant CG shift.	M	ALL, POR	5.3.3; 3.2.1 Static Safety Inspection	I,D	UAV Safety Check	Mount drawing + fitted photo; CG check with light installed
UAV-MEC-004	The UAV shall float in fresh	M	ALL, POR	5.3.3 UAV Safety	T	Float test; UAV Safety Check	Float test video with all payloads and batteries

	water after an unpowered water landing, remaining afloat long enough for recovery by support craft.			Systems			fitted, timed to 15 min minimum
UAV-MEC-005	Flotation shall be verified with every payload configuration the UAV will fly, including with a resource tin retained.	D	ALL	Team - derived from 5.3.3	T	Float test	Float test record per configuration
UAV-MEC-006	Batteries shall be mounted so they can be removed and replaced without any airframe deconstruction, using a quick-release retention method.	M	ALL	5.3.3 UAV General Req	I,D	UAV Safety Check	Battery bay photos; timed swap demonstration
UAV-MEC-007	All flight batteries shall be brightly colored, preferably wrapped in bright colored tape, for identification after a crash.	M	ALL	5.3.3 UAV General Req	I	UAV Safety Check	Photo of the labelled pack set
UAV-MEC-008	The UAV shall be capable of heavier-than-air free flight with no tether or other ground encumbrance.	M	ALL	5.3.3 UAV General Req	D	UAV Safety Check; practice flights	Untethered flight video
UAV-MEC-009	The UAV shall have a static thrust to weight ratio greater than 2:1 at maximum all up weight, in Singapore sea level ambient	D	ALL	Team design requirement DSN-A-1	T,A	Thrust stand test; design review	Thrust stand data at flight voltage + margin calculation

	conditions.						
UAV-MEC-010	Motor, ESC and avionics cooling shall be achieved using forward flight airflow and propeller downwash, without dependence on auxiliary fans.	D	ALL	Team design requirement DSN-A-2	T	Thermal test	Logged motor and ESC temperatures over a full-duration mission profile
UAV-MEC-011	All sharp, pointy, moving or sensitive parts shall be covered and clearly marked.	M	ALL	5.3 General System Req #6	I	UAV Safety Check	Guard and label photo set
UAV-MEC-012	Propellers and other moving parts shall be guarded to the standard required by the safety inspector for aerial systems.	D	ALL	5.3 General System Req #6; 5.2.1	I	UAV Safety Check	Guard design + fitted photos
UAV-MEC-013	All externally mounted equipment shall be secured such that it cannot detach in flight or on landing.	M	ALL	5.3 General System Req; 3.2.1	I,T	UAV Safety Check	Fastener torque record; vibration/shake test record
UAV-MEC-014	No materials shall be released by the UAV into the waters of the operating area, other than an intentional payload delivery onto a competition platform.	M	ALL	5.3 General System Req #7	I,A	Design review; UAV Safety Check	Consumables and release-path declaration
UAV-MEC-015	The payload mechanism shall retain the resource tin under all flight and manoeuvring loads and shall	D	ADV, DISR	Task 2 - 3.3.3; Task 3 - 3.3.4	T	Bench test; flight test	Retention load test; 20-cycle release reliability record

	release only on command, failing to the retained state on power or signal loss.						
UAV-MEC-016	The payload mechanism shall accept the competition resource tin and place or drop it inside a 60-70 cm diameter circle on a 2 m square floating platform.	D	ADV, DISR	Task 2 - 3.3.3; Task 3 - 3.3.4	T	Flight test	Delivery accuracy record over 20 or more attempts
UAV-MEC-017	The UAV shall be hand-carried to and from the launch and recovery area in a safe-to-handle state by no more than two people.	M	ALL	6.4.3 Vehicle Deployment and Recovery	D	Practice sessions	Carry and handling demonstration
UAV-MEC-018	The airframe, motor mounts, wiring and battery retention shall pass the on-site airworthiness safety inspection.	M	ALL	3.2.1 UAV Airworthiness Safety Inspection	I	UAV Safety Check	Pre-inspection self-audit against the published checklist
UAV-MEC-019	Airframe hardware, fasteners and exposed structure shall resist salt spray and 80-92% relative humidity for the duration of the event.	D	ALL	Team - environment	A,I	Design review	Materials list with corrosion assessment
UAV-MEC-020	Landing gear shall support landing on grass and on a pontoon deck, and shall not compromise the flotation	D	ALL	Team - operations	T	Landing tests	Landing test record on both surfaces

	requirement.						
UAV-MEC-021	Spare propellers, motors and at least one complete spare airframe-critical fastener set shall be carried on site.	D	ALL	Team - operations	I	Check-in	Spares inventory

UAV software requirements

Type M = explicit handbook mandate, D = derived from a scored mission-task capability or team decision [2].

Req ID	Requirement (shall statement)	Type	Tier	Source (RobotX 2026 Handbook)	Verif. Method	Verification Event	Evidence Artifact
ASV-SWA-001	The USV shall be capable of operating as a fully autonomous system, sensing and maneuvering using on-board resources or in collaboration with other systems that are themselves operating autonomously.	M	ALL	5.3 General System Req #4, #4.1	D	PoR video; qualifying and scored runs	Autonomy architecture description (TDR); run logs
ASV-SWA-002	While in autonomous mode, the USV shall share sensor or control information only with other systems that are also operating in autonomous mode.	M	ALL	5.3 General System Req #4.2	A,I	Design review; post-run log review	Comms state machine showing mode gating; run logs
ASV-SWA-003	The remote controller and Operator Control Station shall not be used while the USV is in autonomous mode.	M	ALL	5.3 General System Req #4.3	D	Scored runs (judge observation)	Hands-off demonstration; OCS input lockout design
ASV-SWA-004	The USV software shall maintain an	M	ALL	5.3.1; 3.1.2	T,D	Static Safety Inspection; PoR video	Mode state machine diagram; transition test matrix

	explicit mode state (autonomous / manual / killed) and drive the visual feedback system from the true system state.						
ASV-SWA-005	The USV shall be switched to autonomous mode to initiate the start of any collaborative autonomous run on the course.	M	ALL	3.3 Mission Task Descriptions	D	Scored runs	Run start checklist
ASV-SWA-006	The USV shall autonomously detect and avoid obstacles, treating every course element as an object to be avoided or approached safely; additional obstacle buoys may be placed anywhere in the operating areas.	M	ALL	3.3.1 Cross-cutting Tasks	T,D	Team test; qualifying and scored runs	Obstacle avoidance test matrix; miss-distance logs
ASV-SWA-007	The USV shall remain inside course boundaries and shall not entangle, drag, push or damage course elements; violation terminates the run.	M	ALL	5.1 Team Rules #11	D	Scored runs	Geofence implementation; boundary margin analysis
ASV-SWA-008	In a fully autonomous run the USV shall start 3 m behind the gate and pass through	M	POR	3.1.2 USV Proof of Readiness Criteria	D	PoR video (due 31 Aug 2026)	Continuous unedited <=5 min video, English, team name at start

	both sets of gates without striking any buoys, demonstrating good autonomous control throughout.						
ASV-SWA-009	The USV shall detect, localise and classify light beacons in five states - OFF, flashing RED, flashing GREEN, flashing BLUE, steady BLUE - and report the classified buoys and the transit start and end points.	M	CORE	3.3.2 Task 1 Core	T,D	Team test with replica beacons; scored run	Beacon classifier evaluation set; confusion matrix
ASV-SWA-010	The USV shall circle the ENTRY buoy (flashing BLUE) clockwise before transiting the buoy field, and circle the EXIT buoy (steady BLUE) counter-clockwise on completion.	M	CORE	3.3.2 Task 1 Core	D	Scored run	Circling manoeuvre behavior; run track plot
ASV-SWA-011	During Task 1 transit the USV shall pass flashing RED beacons on its starboard side and flashing GREEN beacons on its port side.	M	CORE	3.3.2 Task 1 Core	D	Scored run	Path planner constraint implementation; run track plot
ASV-SWA-012	The USV shall discriminate	D	CORE	Derived from 3.3.2	T	Bench and on-water test	Camera exposure/shutter analysis; flicker

	flashing (1 s on / 1 s off) from steady illumination, at the frame rates and exposure settings used by its perception stack.						discrimination test
ASV-SWA-013	The USV shall plan and execute a safe transit using ENTRY, EXIT, RED and GREEN marker data supplied by the UAV, without detecting the safe route itself.	M	ADV	3.3.2 Task 1 Advanced	D	Scored run	Shared-data path planner; inter-vehicle message log
ASV-SWA-014	The USV shall accept and act on route updates from the UAV during transit, replanning in real time when the safe passage changes.	M	DISR	3.3.2 Task 1 Disruptive	D	Scored run	Replanning behavior; timestamped re-tasking log
ASV-SWA-015	The USV shall identify and localise the GREEN color indicator, or localise the active acoustic pinger, and communicate the survey start point to the UUV.	M	CORE	3.3.3 Task 2 - USV capabilities	D	Scored run	Indicator detection; start-point message log
ASV-SWA-016	The USV shall locate the floating docking platform, identify the bay marked by a GREEN color indicator, and	M	CORE	3.3.4 Task 3 Core	D	Team test on replica; scored run	Docking approach controller; success-rate test data

	fully dock in that bay.						
ASV-SWA-017	On successful docking the USV shall report the docking event to RoboCommand and stand by for tasking.	M	CORE	3.3.4 Task 3 Core	D	Scored run	RoboCommand message log
ASV-SWA-018	The USV shall detect which of the two 25 cm windows shows the RED light, deliver water into that window until the light turns GREEN, and detect the GREEN transition (held 5 s).	M	CORE	3.3.4 Task 3 Core	T,D	Team test on replica structure; scored run	Window detection; aim/spray control; closed-loop detection test
ASV-SWA-019	The UAV shall specify for which task it is executing the resource delivery in order to be eligible to score points for the Advanced and Disruptive tiers.	M	ADV	3.3.4 Task 3 Advanced	T,D	Scored run	RoboCommand message log
ASV-SWA-020	The USV shall decode the single-color flashing resource request (1 s on / 1 s off for 60 s, RED / GREEN / BLUE), relay the delivery destination to the UAV, and report it to RoboCommand.	M	ADV	3.3.4 Task 3 Advanced	T,D	Team test; scored run	color-sequence decoder test set; relay + report logs

ASV-SWA-021	The USV shall decode the two-color sequence (color 1 for 1 s, off 1 s, color 2 for 1 s, off 2 s, repeating for 60 s) identifying both the required resource and the delivery bay, report the detected pattern to RoboCommand and relay it to the UAV.	M	DISR	3.3.4 Task 3 Disruptive	T,D	Team test; scored run	Two-color sequence decoder; synchronisation test
ASV-SWA-022	On a RoboCommand assistance request for the surface domain, the USV shall acknowledge receipt and intent, break off its current task, transit to the specified GPS position, loiter, report readiness, and resume normal operations after clearance.	M	CORE	3.3.5 Task 4 Core	D	Scored run	Re-tasking behavior; full message exchange log
ASV-SWA-023	On a RoboCommand static keep-out area broadcast affecting the surface domain, the USV shall acknowledge and avoid the area for the remainder of the run or until an All Clear is	M	ADV	3.3.5 Task 4 Advanced	D	Scored run	Dynamic geofence insertion; acknowledgement log

	received and acknowledged, while continuing its mission.						
ASV-SWA-024	On a RoboCommand moving-object report (GPS position, heading, speed, system type), the USV shall avoid approaching within 10 m of the object based on its current and projected track.	M	DISR	3.3.5 Task 4 Disruptive	D	Scored run	Virtual-target tracker; closest-point-of-approach log
ASV-SWA-025	The USV mission executive shall be able to interleave, suspend and resume tasks so the SoS can execute a continuous mission in the finals rounds.	D	ALL	Derived from 3.3.1 Dynamic Adaptability; Intro (finals require all capabilities)	D	Integrated rehearsal; finals run	Mission executive design (TDR); full-mission rehearsal log
ASV-SWA-026	The USV shall log vehicle data sufficient to substantiate inter-vehicle communication and cueing to judges after a run.	M	ADV, DISR	5.3 Multi-Vehicle Ops #8.2	I	Post-run judge review	Timestamped, human-readable run logs and a log-reading guide
ASV-SWA-027	The USV shall support a safe transition from autonomous to manual control so it can be piloted back to the dock or launch area.	M	ALL	5.3 Manual Control #1	T,D	Static Safety Inspection; on-water test	Mode transition test; recovery procedure

ASV-SWA-028	After an emergency stop is reset, the USV software shall not automatically resume propulsion; re-initialisation shall require deliberate operator action with course manager permission.	M	ALL	5.2.3; 5.3.1	T	Static Safety Inspection	Power-on state machine; kill-reset test log
ASV-SWA-029	color classification shall be robust to the specified course palette under Singapore outdoor lighting: background grey #CCCED0, red #E8282B, green #089404, blue #0072CE.	D	CORE,ADV,DISR	Derived from 3.3.3 platform color table	T	Outdoor test across lighting conditions	color calibration data; classifier performance vs time of day
ASV-SWA-030	The USV shall maintain position or station-keep as required to complete docked operations and any loiter tasking.	D	CORE	Derived from 3.3.4; 3.3.5	T	Team test; scored run	Station-keeping controller; hold-accuracy test data

UAV electrical requirements

Type M = explicit handbook mandate, D = derived from a scored mission-task capability or team decision [2].

Req ID	Requirement (shall statement)	Type	Tier	Source (RobotX 2026 Handbook)	Verif. Method	Verification Event	Evidence Artifact
ASV-ELE-001	The USV shall use battery-powered electrical systems only.	M	ALL	5.3 Overall Power Requirements #1	I	Static Safety Inspection	Power architecture block diagram
ASV-ELE-002	All batteries shall be sealed to reduce the hazard from acid or caustic electrolytes.	M	ALL	5.3 Overall Power Requirements #1.1	I	Static Safety Inspection	Battery datasheets
ASV-ELE-003	The open-circuit voltage of any battery or battery system shall not exceed 60 Vdc.	M	ALL	5.3 Overall Power Requirements #1.2	I,T	Static Safety Inspection	Pack configuration calc (cells in series x max cell V); measured OCV
ASV-ELE-004	Li-Po battery packs shall use cell-level safety and balancing circuits.	M	ALL	5.2.2 Battery Safety Requirements #5	I	Static Safety Inspection; battery brief	BMS specification and wiring diagram
ASV-ELE-005	The team shall submit battery specifications, MSDS and manufacturer disposal procedures for all batteries, and keep hard copies in Team Village at all times.	M	ALL	5.2.2 #2, #3	I	Event submission; on-site check	Battery document binder
ASV-ELE-006	The team shall bring LiPo-safe bags adequate for all lithium batteries used, available at both the competition site and the hotel.	M	ALL	5.2.2 #4	I	On-site check	Bag inventory list
ASV-ELE-007	All batteries shall be shipped in accordance with applicable HAZMAT shipping regulations for their weight and type.	M	ALL	5.2.2 #6	I	Pre-travel	Shipping declaration / carrier paperwork
ASV-ELE-008	Batteries shall be inspected daily for swelling, heat, leaking, venting, burning or other irregularities, and any affected pack removed from use and reported to	M	ALL	5.2.2 #9, #11	I	Daily on-site	Battery inspection log

	RoboNation.						
ASV-ELE-009	A team member shall be present at all times while batteries are charging.	M	ALL	5.2.2 #10	I	Daily on-site	Charging watch roster
ASV-ELE-010	The USV shall have sufficient stored energy to complete a full scored run without a battery change, since batteries may not be changed while the system is in the water.	D	ALL	Derived from 5.2.2 #14	A,T	Endurance test	endurance test log
ASV-ELE-011	The USV shall have at least one hard-wired on-board emergency stop that instantaneously disconnects power from all propulsion systems and actuators. It need not kill the onboard computer.	M	ALL,POR	5.2.3; 5.3.1	I,T	Static Safety Inspection; PoR video	E-stop schematic; contactor part spec; functional test video
ASV-ELE-012	Both emergency stop systems shall be fail-safe: if any part of the system fails, or the battery dies or is removed, the vehicle shall enter emergency stop.	M	ALL,POR	5.2.3	T	Static Safety Inspection (incl. remote battery removal test)	Controls schematic; test procedure and results
ASV-ELE-013	The on-board emergency stop shall latch: quick to actuate but requiring intentional effort to reset (press-to-activate / twist-or-pull-to-reset, or magnetic). Power to propulsion and actuators shall not be restorable until the switch is reset and the course manager grants permission.	M	ALL,POR	5.2.3	I,T	Static Safety Inspection	POR video
ASV-ELE-014	On reactivation after a kill, the USV shall return to a safe state with propellers not spinning.	M	ALL,POR	5.3.1	I,T	Static Safety Inspection	POR video
ASV-ELE-015	The USV shall have a portable, handheld wireless emergency stop that disconnects power from propulsion and actuators in under 2 seconds when activated, or when power/battery is	M	ALL,POR	5.2.3; 5.3.1	I,T	Static Safety Inspection; PoR video	Timed latency test data, PoR video

	removed from the transmitter.						
ASV-ELE-016	The wireless emergency stop shall operate on its own frequency and its own link, independent of all other vehicle links.	M	ALL	5.2.3	I,A	Static Safety Inspection	Frequency plan showing E-stop link isolated
ASV-ELE-017	The wireless emergency stop shall not be a laptop, tablet or phone.	M	ALL	5.2.3	I	Static Safety Inspection	RC controls diagram
ASV-ELE-018	On loss of connection to the remote kill switch (power loss or out of range), the USV shall default to a state with power disconnected from all motors and actuators.	M	ALL,POR	5.3.1; 5.3 Manual Control #2	T	Static Safety Inspection, PoR video	Range-out and transmitter-off test log (PoR video showcasing heartbeat loss)
ASV-ELE-019	The team shall produce drawings detailing how the kill switches are wired into the system, for Proof of Readiness submission.	M	POR	3.1.2 USV Proof of Readiness Criteria	I	PoR file upload (due 31 Aug 2026)	Kill-switch wiring drawing (PDF)
ASV-ELE-020	The USV shall carry a visual feedback system displaying at least three states - RED, YELLOW, GREEN - with 360-degree daylight visibility at approximately 100 m, indicating the operational mode of the system.	M	ALL,POR	5.3.1 Visual Feedback System	I,D	Static Safety Inspection; PoR video	Lumen/beam analysis; 100 m daylight visibility test
ASV-ELE-021	When the kill switch is activated, the on-board state indicator shall change to solid RED.	M	ALL,POR	5.3.1	T	Static Safety Inspection; PoR video	Kill-to-indicator test video
ASV-ELE-022	The indicator color shall correspond to the vehicle mode per the handbook state table (autonomous / manual / killed).	M	ALL,POR	5.3.1 (state table figure)	I,T	Static Safety Inspection; PoR video	Mode-to-color mapping table in TDR
ASV-ELE-023	The USV shall be tele-operable from a dedicated remote controller unit not used for any other purpose. A laptop shall not be used as the manual control station.	M	ALL,POR	5.3 Manual Control #1, #3; 5.3.1	I,D	Static Safety Inspection; PoR video	RC hardware spec; functional block diagram showing laptop independence

ASV-E LE-024	On loss of the remote control link, or if the controller is turned off or loses power, all propulsion systems and actuators shall be automatically commanded to 0% thrust or an OFF state.	M	ALL	5.3 Manual Control #2, #4; 5.3.1	I,D,T	Static Safety Inspection	Failsafe configuration screenshot; link-loss test log
ASV-E LE-025	All RF equipment shall be operated within the rules and regulations of Singapore, including frequency, transmit power and antenna height.	M	ALL	5.2 Safety Requirements #1	A,I	Design review; on-site check	Frequency plan mapped to IMDA-permitted bands and power limits
ASV-E LE-026	The USV power system shall comply with the safety rules and regulations of both Singapore and the team's home country.	M	ALL	5.2 Safety Requirements #2	A,I	Design review	Compliance statement in TDR
ASV-E LE-027	The team shall produce a functional block diagram and photographs of the R/C manual control approach demonstrating operation independent of a laptop connection.	M	POR	3.1.2 USV Proof of Readiness Criteria	I	PoR file upload (due 31 Aug 2026)	RC functional block diagram (PoR)
ASV-E LE-028	The water delivery subsystem pump, valve and flow control electronics shall be powered within the vehicle power budget without browning out propulsion or compute.	D	CORE	Derived from 3.3.4 Task 3	A,T	Bench test; integrated run	Transient load test; bus voltage trace during spray
ASV-E LE-029	If the USV performs acoustic pinger localisation to cue the UUV, its receiver shall cover 25-40 kHz with at least 2 kHz channel discrimination.	D	CORE	Derived from 3.3.3 Task 2; 3.5.4 Acoustic Pingers	T	Team test; scored run	Hydrophone array spec; bearing accuracy test
ASV-E LE-030	The USV shall provide sufficient compute and sensing power headroom to run perception, planning and RoboCommand reporting concurrently for a full run.	D	ALL	Derived from 3.3.1; 3.4	A,T	Endurance test	Compute power budget; thermal soak test in ambient tropical conditions

UAV communication requirements

Type M = explicit handbook mandate, D = derived from a scored mission-task capability or team decision[2].

Req ID	Requirement (shall statement)	Type	Tier	Source (RobotX 2026 Handbook)	Verif. Method	Verification Event	Evidence Artifact
UAV-COM-001	The UAV shall transmit the telemetry messages required by Section 3.4, without which it will not be permitted to operate during the competition.	M	ALL	5.3.3 UAV General Req; 3.4	T	Scored run	RoboCommand transmission log
UAV-COM-002	UAV status reports shall reach RoboCommand over the team's hard-wired RJ-45 connection from the Operator Control Station.	M	ALL	3.4 Communications Protocol	T	Integration test	End-to-end message delivery capture
UAV-COM-003	Status messages shall be encoded as Protocol Buffers using the RoboNation-supplied .proto definition compiled with protocol.	M	ALL	3.4 Communications Protocol	T	Integration test	Encoded message capture validated against the schema
UAV-COM-004	The UAV shall have its own dedicated remote controller, not shared with any other vehicle and not used for any other purpose.	M	ALL, POR	5.3.3; 5.3 Manual Control Req #3	I	UAV Safety Check	Photo of the dedicated transmitter
UAV-COM-005	The UAV control link and any remote safe-state link shall operate on separate frequencies and links.	M	ALL	5.2.3 Kill Switch Req; 5.3 General Safety	I,A	UAV Safety Check	RF plan showing separate links
UAV-COM-006	All RF hardware carried or operated for the UAV shall comply with Singapore IMDA rules and with United States FCC rules.	M	ALL	5.2 Safety Req #1; 5.1	A,I	Pre-travel audit	RF compliance audit covering control, telemetry and video links
UAV-COM-007	The team shall post its inter-vehicle	M	ALL	5.3 Multi-Vehic	I	Pre-competition	Forum post record

	communication method and frequencies on the RobotX Technical Forum channel.			le Operations #8			
UAV-COM-008	Judges shall be notified in advance of any inter-vehicle communication behavior, and post-run vehicle logs shall be presented as supporting evidence.	M	ADV,DISR	5.3 Multi-Vehicle Operations #8b	I,D	Scored run	Advance notification + exported logs
UAV-COM-009	UUV to UAV messaging shall be relayed via the USV; the UAV shall not attempt to address the UUV directly while it is submerged.	D	ADV,DISR	Task 2 - 3.3.3; team architecture	T	Integration test	End-to-end relay test record
UAV-COM-010	The message interface between the UAV and the USV shall be defined and version-controlled before integration testing begins.	D	ADV	Team - integration	I	Design review	Interface control document in version control
UAV-COM-011	The control and telemetry links shall be demonstrated at the maximum operating range plus margin, over water.	D	ALL	Team - operations	T	Flight test	Range test with link quality and packet loss record
UAV-COM-012	Loss of the telemetry link shall not by itself trigger a change of flight mode; control link loss and telemetry link loss shall be handled separately.	D	ALL	Team - safety	T	Fault injection test	Independent link-loss test record
UAV-COM-013	Communication hardware and antenna condition shall be verified as part of the pre-flight checklist for every flight.	D	ALL	Team - operations	I	Pre-launch (every flight)	Signed pre-flight checklist
UAV-COM-014	The UAV shall not interfere with other teams' RF systems during operation.	M	ALL	5.1; 5.2 Safety Req #1	A	Design review	Frequency coordination record

UAV-COM-015	Spare antennas, RF cabling and a spare receiver shall be carried on site.	D	ALL	Team - operations	I	Check-in	Spares inventory

UAV pilot and regulatory requirements

Type M = explicit handbook mandate, D = derived from a scored mission-task capability or team decision [2].

Req ID	Requirement (shall statement)	Type	Tier	Source (RobotX 2026 Handbook)	Verif. Method	Verification Event	Evidence Artifact
UAV-REG-001	The team shall have at least one licensed UAV pilot for the airframe flown at the competition, and should have a second licensed pilot available.	M	ALL	5.3.3 UAV Pilot Req	I	Pre-competition	Pilot licence documentation
UAV-REG-002	Pilots shall pass a theory test and a practical piloting test administered by event organisers in country prior to the competition.	M	ALL	5.3.3 UAV Pilot Req; 1.5 Schedule	D	In-country pilot tests	Pass certificates
UAV-REG-003	Nominated pilots shall arrive in Singapore with enough margin ahead of the in-country pilot tests to account for travel disruption.	D	ALL	Team - operations	I	Pre-travel	Booked itinerary
UAV-REG-004	The nominated pilots shall log regular practice flight time on the competition airframe in manual mode ahead of the tests.	D	ALL	Team - operations	I	Practice sessions	Pilot flight log with hours by month
UAV-REG-005	A dedicated, licensed safety pilot shall be assigned and available to take over any UAV operating in the air, via its dedicated remote controller.	M	ALL	5.3.3 UAV Manual Control Systems	I,D	UAV Safety Check; every flight	Named safety pilot per run in the run plan
UAV-REG-006	Only licensed pilots shall operate UAVs during the competition.	M	ALL	5.3.3 UAV General Req	I	Every flight	Run log naming the operating pilot
UAV-REG-007	The UAV shall meet all requirements mandated by the Civil Aviation Authority of Singapore, with compliance	M	ALL ,POR	5.3.3 UAV General Req; 3.2.1	I,A	PoR submission; UAV Safety Check	CAAS compliance package

	evidence collected in the UAV Proof of Readiness and UAV Safety Check.						
UAV-REG-008	The team shall submit its technical data package as early as possible to allow feedback and modification ahead of airworthiness certification.	M	POR	5.3.3 Airworthiness note	I	PoR submission window	Submitted technical data package + organiser response
UAV-REG-009	The UAV and its pilots shall pass the UAV and Pilot Proof of Readiness submission before the vehicle is eligible to deploy at competition.	M	POR	3.1.4 UAV and Pilot PoR Criteria	I,D	PoR submission	Accepted PoR submission
UAV-REG-010	The UAV shall pass the on-site airworthiness safety inspection before being cleared for flight.	M	ALL	3.2.1 UAV Airworthiness Safety Inspection	I,D	UAV Safety Check	Completed inspection checklist
UAV-REG-011	The UAV shall not exceed 60 m above mean sea level, or the current CAAS-defined ceiling if it changes before the event.	M	ALL	5.3.3 UAV General Req	T	Flight test	Altitude limit parameter record + breach test
UAV-REG-012	The team shall confirm and satisfy any CAAS operator registration, permit or third-party liability insurance requirement applicable to visiting operators.	D	ALL	Team - regulatory diligence	I	Pre-travel	Registration, permit and insurance documentation
UAV-REG-013	Import and customs clearance for the UAV airframe and its batteries into Singapore shall be arranged ahead of shipping.	D	ALL	6.4.2 Shipping; team - logistics	I	Pre-travel	Shipping plan + customs documentation
UAV-REG-014	The team shall re-check the handbook change log before each design review and before travel, and update this matrix accordingly.	D	ALL	Team - configuration control	I	Each design review	Dated change-log review note in this workbook

UAV Verification events in chronological order

When	Event	What must be ready
31 Aug 2026	Proof of Readiness - mandatory systems	Criteria for the UAV are not published yet (GAP-U01). Expect at minimum: technical data package for CAAS airworthiness review, safety systems evidence, and pilot licensing status. Video format rules follow 3.1.1 - max 5 minutes, continuous, no cuts, school and team name stated.
23 Sep 2026	Design Documentation + Event submissions	Technical Design Report; team website; intro video; vehicle information; battery specs, MSDS and disposal procedures; shipping plan.
12 Oct 2026	Proof of Readiness - optional third system	Applies if the UAV is the team's third domain rather than its second.
TBA Nov 2026	UAV pilot tests (in country)	Theory test and practical piloting test administered by event organisers. Nominated pilots must be in the country. A first-attempt failure removes that student from flying during the competition.
08 Nov 2026	Team check-in and orientation	At least one representative present, or the team may not deploy.
09-11 Nov 2026	UAV Safety Check and airworthiness inspection	Size and weight limits; propellers, motor mounts, airframe and wiring integrity; battery security and capacity; all subsystems secured; autonomous flight control disconnect to manual mode; emergency light mount points and compatibility.
Each launch	Weight measurement and pre-flight checks	All up flying weight verified at safety inspection; emergency light activation demonstrated prior to each launch.
09-11 Nov 2026	System Assessment (180 pts)	30-minute judged inspection of the System of Systems: technical design 45%, innovation 30%, craftsmanship 25%.
12-13 Nov 2026	Scoring rounds	UAV tasking in Task 1 (Advanced, Disruptive), Task 2 (Advanced, Disruptive), Task 3 (Advanced, Disruptive) and Task 4 (all tiers).