The Orca by UM::Autonomy
RoboBoat 2025: Technical Design Report

Ben Bruick, Sparsh Bahadur, Archita Saraiya, Jackson Donaldson, Gordon Fream, Alice Ivanitskiy, Eeshwar Krishnan, Lani Quach, Lucas Mitsch, Ben Schattinger, Aayush Shah, Siming Tang, Georgia Zender

UM::Autonomy, University of Michigan College of Engineering, Ann Arbor, MI, USA
Submitted January 27, 2025

1. Abstract

UM::Autonomy's 2025 RoboBoat entry, *The Orca*, is a redesigned autonomous vessel informed by two seasons of experience with our previous vessel, The Phoenix. Driven by competition requirements for precise Navigation and Docking, and mindful of specialized hardware for tasks like Rescue Delivery, we focused on creating a robust new platform. Our X-Bow hull, adapted from offshore service vessels, improves seakeeping and maneuverability, while consolidated electrical systems enhance reliability. We also added wind compensation and transitioned to ROS 2 for better fault tolerance real-world conditions. These mechanical, electrical, and software improvements provide a flexible foundation for advanced autonomous maritime operations. This technical design report outlines our integrated competition strategy, design rationale, and rigorous testing methodologies that validate The Orca's capabilities for RoboBoat 2025.

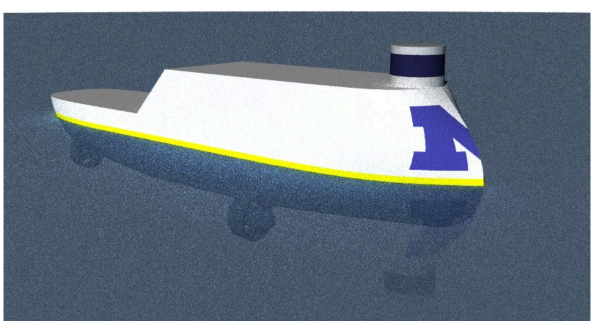


Figure 1. "The Orca" Render

2. Technical Content

2.1 Competition Strategy

After two seasons with The Phoenix, our RoboBoat 2025 strategy emphasizes enhancing Navigation (Tasks 1, 2, 4, and 6) and Docking (Task 3) while assigning lower priority to Rescue Delivery (Task 5). This decision reflects the specialized hardware requirements of Rescue Delivery and our focus on constructing a new vessel, The Orca.

Our overarching goal is to strengthen and refine our software in anticipation of The Orca's debut. Through lessons in controls, construction strategies, and maintainability, we aim to develop modular, maintainable designs and follow best engineering practices. These include verifying all changes through rigorous testing and choosing simpler systems than previous seasons.

Over the last two years, we have observed hardware constraints limiting our software's performance. Addressing these constraints is a core principle in our current strategy, guiding us to build a new vessel with improved reliability and maneuverability. As a result, we are investing in The Orca's design and construction to raise our overall software capabilities and establish a more capable platform for repeatable results across all key tasks at RoboBoat 2025.

2.1.1 Task-by-Task Strategic Breakdown

For the autonomous navigation necessary for all of the tasks in this year's competition, the team chose the systems logic in Figure 2.

Figure 2. AI Team Systems Architecture

This modular approach allows for parallel development while abstracting away parts of the challenges. This provides added redundancy for changes in competition challenges and lets the team test each system individually as a module, which increases overall reliability.

When approaching a challenge, the Perception team uses a camera and the YOLOv8 deep learning model to identify buoys by shape and color, taking advantage of its high accuracy and retraining capability. A Velodyne LiDAR with ~2 cm accuracy measures distances, and any detected objects are "mapped" so the vessel can navigate around buoys no longer in the camera's field of view. Once Perception provides a buoy location, Task Planning generates a waypoint between the nearest red and green buoys and then sends it to Navigation. By grouping every two buoys into a gate, the team creates a general framework for all navigation tasks, which differ only in how these gates are arranged.

2.1.1.1 Navigation Channel

For the Navigation Channel task, Task Planning instructs the vessel to move continuously through the first pair of buoys, as seen in Fig. 3.

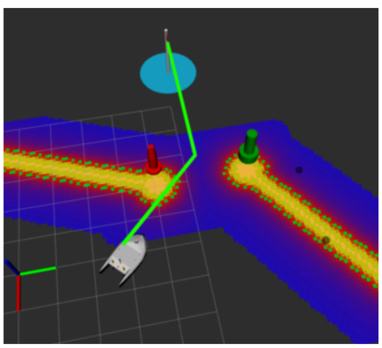


Figure 3. Navigation A Algorithm Path in RViz*

Once Perception algorithms detect the second pair of buoys, the continuous movement is preempted, and the vessel is commanded to go within the gates.

2.1.1.2 Follow the Path

To complete the Follow the Path task, Task Planning identifies the furthest red and green buoys that form a gate, creates a waypoint between them, and repeats this process until no more buoys remain. Each waypoint is then sent to Navigation, which uses an A* algorithm to generate an optimal path from the vessel's current location. This algorithm accounts for the vessel's dynamics and places high-cost zones on either side of the gates to ensure it travels between the buoys. As a result, the vessel receives reliable, accurate routes to follow.

The vessel executes this route with a PID (Proportional-Integral-Derivative) control algorithm guided by the VectorNav VN-300 sensor, which provides precise pose data. When turning, the difference between the present heading and the path is treated as an error, and thruster commands correct the course accordingly. The path also dictates velocity and acceleration, so the vessel compensates for wind and waves while staying on track. The team adopted PID for its simplicity and maintainability compared to the steeper learning curve of previous LQR (Linear–Quadratic Regulator) algorithms.

2.1.1.3 Docking

For Docking, the team must identify each dock's color and shape and the markers belonging to vessels occupying the bays. Once the banner of an open dock is located using computer vision, a plane is fitted using LiDAR data to determine its normal vector. Task Planning then lines up the vessel along this vector. The Navigation and Controls systems then operate to move the vessel to the desired location, reversing into the corresponding dock.

2.1.1.4 Speed Challenge

For the Speed Challenge task, Task Planning first sets a waypoint to the blue buoy. After the camera detects a change in color from the light panel, the algorithm sends the vessel forward until it detects the blue buoy, then circles it using Navigation's path planning algorithm. The vessel is then sent back to the entrance of the challenge.

2.1.1.5 Object and Water Delivery

For the Advanced Capabilities challenges, the team has taken the approach of aiming the delivery mechanisms instead of aiming the entire vessel. Our strategy for the water and object delivery vessels remains the same. The boat will approach the floating Vessels and maintain a set distance to avoid collision. Then, it will rotate the launching turret to face the targets and either launch the balls or fire the water cannon. Using a rotating turret will help avoid difficulties in stationkeeping. This will also allow the vessel to find routes alongside the Delivery Vessels and continue moving along the path while firing the projectiles.

2.1.1.6 Return to Home

The vessel records its location before attempting any tasks to complete the Return to Home task. After completing all other tasks, the vessel approaches the starting location until it observes the black buoys that mark the challenge.

2.2 Design Strategy

2.2.1 Mechanical Design Strategy

After competing with The Phoenix in 2023 and 2024, the Mechanical subteam leveraged their experiences to design and manufacture a new vessel, The Orca. The primary design underwent key revisions, notably transitioning from a trimaran hull to a single, X-Bow hull form. This decision prioritized optimizing maneuverability, speed, and wave resistance.

The inspiration for the X-Bow design came from North Sea offshore service vessels, which first applied this strategy. Developed by Ulstein in the early 2000s, the X-Bow concept has proven effective in challenging sea conditions [1]. These vessels demonstrated superior seakeeping, reduced pitch motions, and improved fuel efficiency in rough seas [2][3]. This reduction in pitch motion is crucial for maintaining stable sensor readings and improving overall performance in varied sea states.

The hull form's ability to cut through waves rather than ride over them can improve efficiency and reduce power usage. Additionally, the single-hull design allows for tighter turning radii and more precise control, addressing challenges faced with the previous trimaran design. While the team focused on implementing these design changes, all advanced capabilities development proceeded in parallel and was tested independently, which allowed for simultaneous progress on multiple fronts.

2.2.1.1 Vessel Arrangements and Materials

While the trimaran provided ample deck space and trim stability, it proved difficult to maneuver through buoys and dock precisely. The new hull measures 4-feet in length with an 11.5-inch beam. To compensate for reduced stability in a monohull, the design includes a wider beam and provisions for small, articulating outriggers, deployable when extra stability is needed, as seen in Figure 4.

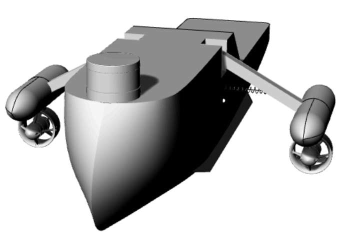


Figure 4. The Orca with Outriggers

In constructing this new hull form, the team chose carbon fiber for its exceptional strength-to-weight ratio, stiffness, and corrosion resistance. This material creates a robust, lightweight structure necessary for high speed and dependable hydrodynamic performance under load. Carbon fiber can be layered strategically where greater reinforcement is required, and its non-corrosive nature is necessary for durability. Though more expensive and fabrication-intensive than alternatives, these drawbacks are outweighed by carbon fiber's significant performance gains.

2.2.1.2 Propulsion

The Orca's propulsion system has been redesigned to optimize maneuverability. As seen in Appendix C.3, we've adopted a dual-thruster setup mounted vertically on the hulls. This configuration places two Blue Robotics T500 thrusters at the maximum distance from the vessel's center of floatation, creating a larger moment arm. This improves the vessel's roll stability and allows for a tighter turn radius. We've implemented differential thrust for steering, allowing higher forward speeds.

2.2.1.4 Manufacturing Process

The Orca’s manufacturing process was refined to streamline production while preserving complex hull geometries. By directly 3D-printing the female mold in sections using a large-format PLA printer, we eliminated the need for a male plug and significantly reduced production time. Initially, concerns arose about the mold’s ability to withstand vacuum bagging pressures. To resolve this, our team conducted small-scale experiments evaluating pressure distribution and structural factors, eventually identifying the optimal combination of exterior wall thickness, infill percentage, and material usage to prevent shattering.

Once printed, each mold section is sanded to remove layer lines, followed by applying a mold release agent to enable smooth part removal. We then lay carbon fiber sheets into the mold halves and use a vacuum-assisted wet layup for better resin penetration and compaction, resulting in a strong, lightweight hull.

After curing, the two halves are bonded using flanges integrated into the mold design, forming a watertight seal and maintaining the X-bow geometry. This process merges 3D printing’s flexibility with carbon fiber's strength, delivering a high-performance hull tailored to our requirements.

2.2.1.5 Projectile & Water Delivery Hardware

The main objectives for Rescue Delivery were to enable independent aiming and maintain consistent launch or spray distance. The team's approach uses planetary gear assembly on a slip ring, providing infinite rotation and supporting all electrical components. A secondary gear, powered by a motor mounted on the vessel, delivers directional control. Both the platform and gear are 3D-printed in PLA for a lightweight build and ease of replacement. The launching mechanism uses a 3D-printed tube preloaded with racquetballs, a flywheel, and a 45° upward curvature to maximize distance. Meanwhile, the water delivery system employs a self-priming 12V pump that draws from a 15 fl oz reservoir, removing the need for filtration and simplifying slip-ring mounting. Flow rate calculations (Appendix E) informed the choice of a 2.5 mm 3D-printed nozzle for an estimated 2.6 m range, with the reservoir holding 15 fl oz (1 lb) of water and providing ~18 seconds of continuous firing.

2.2.2 Electrical Design Strategy

The Electrical Team's priority was to enhance subsystem resilience by standardizing connectors and designs, thereby reducing downtime for repairs and modifications. Centralized power management and continuous logging replaced the previously distributed approach, enabling more robust diagnostics. This transition was facilitated by unified hardware choices, including a shift from STM32 microcontrollers to easier-to-use Raspberry Pi Picos. Standardizing voltage requirements at common 12V and 5V levels further simplified power distribution. The team adopted a CANbus system to increase fault tolerance and monitoring depth, incorporating sensors for battery status and leak detection. Eliminating unnecessary components also reduced the system footprint, resulting in a smaller electrical enclosure than last season's.

2.2.2.1 PCB Design and Improvements

Building on our custom PCB work from 2024, the team expanded the number of boards on the vessel to enhance monitoring throughout each subsystem. Each subsystem now houses a Raspberry Pi Pico–based PCB that handles current, voltage, and thermal monitoring, along with other key metrics transmitted over a CAN bus. Though physically larger than prior designs, these updated boards are more straightforward to repair, standardize, and prototype.

The PCB manufacturing process was also revised to increase resilience in challenging conditions. While the high-temperature, high-mix solder used in 2024 improved vibration resistance, it reduced protection against accidental water entry. To address this, the team applied a 75 µm epoxy layer that maintains board rework ability while significantly increasing resistance to shorts. Schematics can be found in Appendix G.

2.2.2.2 Improved motor controllers

Our existing thruster motor controllers only support a single PWM input, preventing us from receiving sensor feedback such as thermal data or power usage. This limitation also restricts control to duty cycle commands, which lack the necessary precision. As a result, we're exploring Odrive S1 motor controllers, which can provide real-time telemetry, including thermal conditions and current draw, and allow precise velocity or torque control. Moreover, these controllers communicate over CAN bus, simplifying wiring and offering robust two-way data transfer.

2.2.4 Software Design Strategy

The Artificial Intelligence (AI) team focused on increasing reliability and enhancing performance. Infrastructure upgrades extended the lifespan of the codebase while optimizing performance across a broader range of scenarios.

2.2.4.1 ROS 2 Conversion

Previously, we have used the latest distribution of ROS 1 as our middleware. This distribution, ROS Noetic, will reach its end-of-life in May of 2025, so our AI team spent the first semester of this year converting to ROS 2 Humble. Transitioning to ROS 2 has extended the lifespan of our codebase and offers many improvements over ROS 1. Key advancements include increased scalability, cross-platform capability, and updates to related tools. However, we have experienced issues with ROS 2's network layer, which utilizes DDS using FastRTPS. We've discovered that any intermittent fault in WiFi significantly disrupts camera and LiDAR telemetry. We have switched to an alternative DDS implementation, Cyclone, that has fewer issues.

2.2.4.2 Wind Correction

Last year's competition revealed that strong winds could blow the vessel off course, forcing a slow recovery to the intended heading. To address this for 2025, we introduced a constant wind in our simulation platform to replicate real-world effects and test how quickly the vessel could return to its trajectory. We then added a wind corrective factor in the control loop: after each update, the predicted vessel position is compared with the GPS-reported location, and the difference is stored. That difference becomes a corrective input, allowing the vessel to compensate for wind and current.

2.2.4.3 CV Training with Generated Images

We adopted a novel approach to enhance our vision model by adding computer-generated images to our dataset. We utilized our 3D model of the RoboBoat competition inside Blender to render hundreds of images that mirror real-world conditions. This method provided us with a diverse range of perspectives and scenarios, allowing our model to generalize more effectively to new data. Additionally, this method allows us to generate images in different weather conditions, lighting, object positioning, and background complexity, ultimately leading to improvements in the model's accuracy and robustness. The next step for this project is to begin integrating generative-AI-created images, which would remove the need to make environments by hand.

Figure 5. Sample Blender-Generated Image of Buoys from Training Corpus

2.3 Testing Strategy

Design validation through rigorous testing remains crucial to UM::Autonomy's success, as demonstrated by over 100 hours of in-water trials. Typically, the team has limited itself to controlled indoor environments, but outdoor testing took place at a small pond on campus for the first time in two seasons. This additional venue provided more variable conditions for evaluating both hardware and software. At the same time, the Marine Hydrodynamics Laboratory (MHL) continued to serve as our primary location for weekly in-water testing, beginning in early September and continuing to RoboBoat 2025 in March.

In-water testing is essential for validating AI subteams. For Perception, it ensures robustness against real-world lighting and environmental conditions. For Navigation and Controls, it verifies the accuracy of the costmap and planned paths with realistic vessel dynamics. For Task Planning, it facilitates testing of complete multi-task functionality. When in-water testing is unavailable, simulation in Gazebo allows subteams to refine code and validate algorithms before bench or in-water verification.

2.3.1 Simulator Testing

The team ran extensive simulations in Gazebo to ensure AI modules were thoroughly tested before in-water testing. These simulations replicated vessel movement and task scenarios for all aspects of the code, including complex challenges like Water Delivery by generating a simulated water stream. This approach allowed subteams to validate their progress continuously without waiting for scheduled in-water sessions.

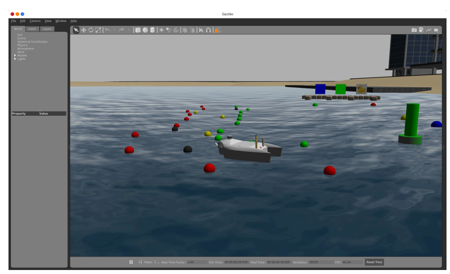


Figure 6. Testing AI Pipeline for "Follow the Path"

The simulator also helps decouple processes, as AI subteams can test independently. Though the simulator is an idealized environment and thus lacks the randomness of in-water testing, it allows us to validate logic quickly and remotely.

Surge and sway parameters were calculated using Prelimina.com and the equations in Appendix F. Prelimina provided surge resistance values at various speeds, which were fitted to a function (Figure F1), and hand calculations using a 0.9 drag coefficient helped approximate sway resistance from velocity^2. A prismatic coefficient of 0.7188 was derived from Rhino3D [4].

2.3.2 In-Water Testing

The team meets for in-water testing at the Marine Hydrodynamics Laboratory (MHL) every Sunday, increasing to twice a week as competition approaches. Centering our workflow around regular testing allows for continuous iteration and progress toward in-water sprint goals.

In addition to MHL testing, the team conducted outdoor testing at the Earl V. Moore Pond. This provided an opportunity to evaluate the navigation channel and test hardware and software in a less controlled environment. Outdoor testing requires significantly more preparation and safety measures, including additional equipment setup, environmental assessments, and contingency planning. The procedure and testing guidelines for both MHL and outdoor testing are detailed in Appendix A.

Figure 7. Testing Navigation Channel Outdoors

2.3.3 Dry Testing

Dry testing complemented in-water sessions, particularly on weekdays when the MHL was unavailable. The Perception team could assess CV and Deep Learning algorithms by mounting cameras on the vessel and placing target objects in a workspace. Similarly, Controls tested rotation commands on land while connected to the base station to verify thruster response before attempting full-scale water trials.

2.3.4 Indoor Positioning

GPS signals are accessible within the MHL, so we explored alternatives to the sonar-based Marvelmind system, which suffered echo interference from concrete walls. Ultra-wideband (UWB) time-of-flight transceivers combined with an intersection-of-spheres positioning algorithm offered improved precision and fewer tracking losses. This UWB-based approach has proven more robust for maintaining reliable positional data during MHL testing.

3. Conclusion

In preparing for RoboBoat 2025, UM::Autonomy has advanced its vessel with The Orca, integrating a ROS 2-based architecture, an X-Bow hull, and a refined electrical system for stability, reliability, and fault tolerance. Rigorous weekly testing at MHL and expanded outdoor trials confirmed measurable gains in maneuverability and robustness compared to The Phoenix, with improved handling in cross-wind scenarios and more consistent docking performance. These results validate our design decisions and highlight the synergy between hardware, software, and controls. Moving forward, The Orca will serve as a flexible test platform for iterative enhancements in marine autonomy, ensuring we remain well-positioned for ongoing successes at RoboBoat and beyond.

4. Acknowledgements

UM::Autonomy would first like to thank corporate sponsors for their assistance with design and funding. We extend a special thanks to Ford Motor Company, Boeing, APTIV, Northrop Grumman, Raytheon, and Siemens for their support. In addition, UM::Autonomy would like to thank university sponsors for their assistance. With the constraint of not being able to test outside in the Michigan winters, the team would like to thank the MHL staff, Jason Bundhoff and Nicole Cheesman, for generously allowing us to test the vessel and for allowing us to store our vessel and equipment in the MHL.

Furthermore, the subteam leads are grateful to Dr. David Singer and Dr. Maani Ghaffari for their considerable leadership guidance and advice. The AI subteams are also grateful to post-doctoral scholar Dr. Junwoo Jang for helping to overcome many software issues. Mariah Fiumara, Katelyn Killewald, and Devon Vaughn have also immensely helped the team through the challenges of student organization management. Their guidance and support have been instrumental in the project.

The existence and success of our team depend on the incredible support of the University of Michigan, our advisor, our committed alumni, and our industry sponsors. Special thanks to the Wilson Student Team Project Center staff and teams for training our members to use equipment and machinery safely and effectively.

5. References

[1] Ulstein, “Statements from X-BOW Users,” *Ulstein*, 2018. https://ulstein.com/innovations/statements-from-x-bow-users.

[2] S. Chen, B. Zou, C. Han, and S. Yan, “Comparative Study on Added Resistance and Seakeeping Performance of X-Bow and Wave-Piercing Monohull in Regular Head Waves,” *Journal of Marine Science and Engineering*, vol. 10, no. 6, p. 813, Jun. 2022, doi: https://doi.org/10.3390/jmse10060813.

[3] Abolfath Askarian Khoob, Majid Askari Sayar, Karim Akbari Vakilabadi, and H. Ghassemi, “Experimental Study of the Heave and Pitch Motions of an Inverted Bow Hull,” *Journal of ETA Maritime Science*, vol. 11, no. 2, pp. 119–126, May 2023, doi: https://doi.org/10.4274/jems.2023.28291.

[4] Orca3D, “Basic Hydrostatics & Stability,” *Orca3D, LLC*, 2025. https://orca3d.com/pages/hydrostatics-stability.

Appendix A: Testing Plan

I. Scope

The team created testing goals based on different components. The team tested the electrical systems on the old vessel individually, and then moved on to testing each individual AI subteam. The team tested CV and LIDAR intermittently while testing other subsystems of the vessel.

II. Schedule

In August, the officers drafted a timeline for the season's workflow. This timeline was discretized into biweekly segments, where at the end of every two weeks, using Agile methodologies, a measurable sprint goal could be tested either in-water, in-sim, or via bench testing. This timeline is seen in Figure A1.

This season, the team had the opportunity to have an in-water testing slot reserved for 4 hours every Sunday during the Fall 2024 semester. In the Winter 2025 semester, we reserved a 3-hour slot every Wednesday and retained our 4-hour slots on Sundays. Each semester is about a ~16-week period. This meant that every team meeting would be followed by a testing session, where subteams could use the time to gather data. While time for development was also a part of the schedule, this open availability made it possible to facilitate testing frequently.

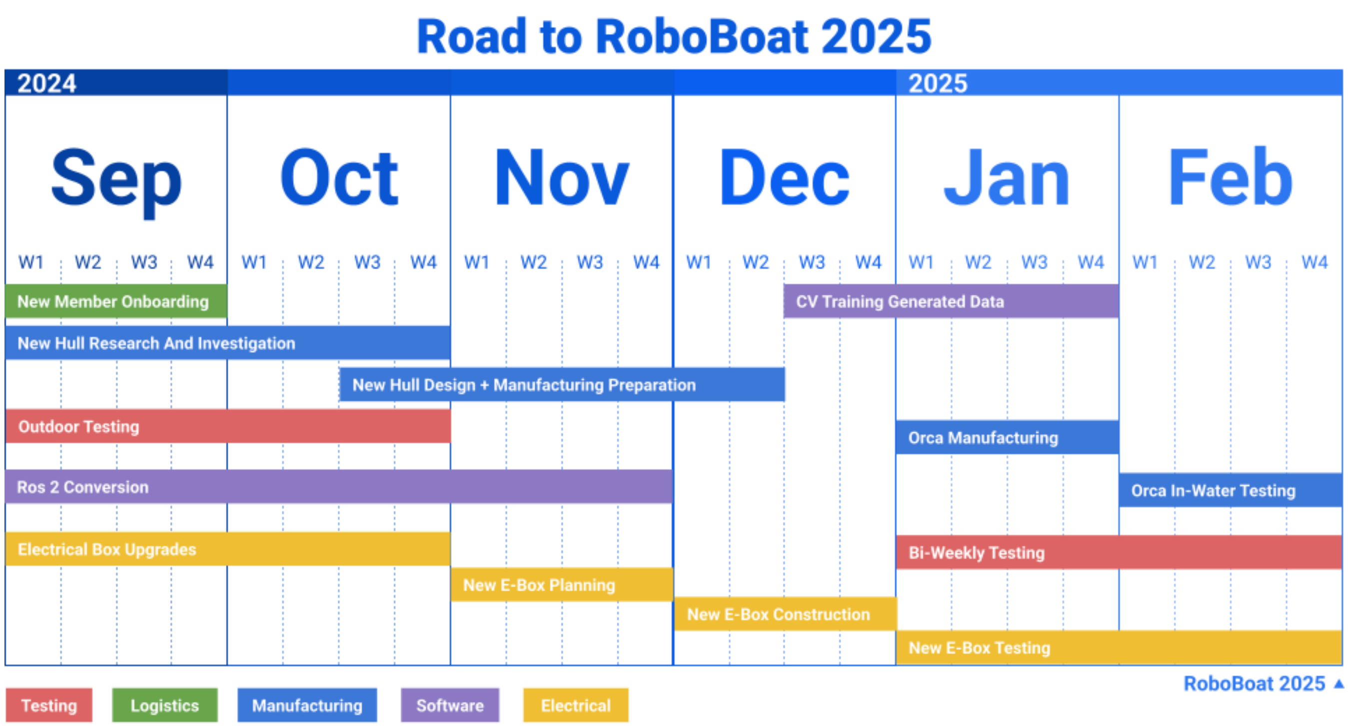


Figure A1. Testing Timeline

III. Resources & Tools

The testing hardware the team employed in recreating the test environment is included below. All the buoys and docks shown below were anchored and placed in the tow tanks for CV and task planning testing.

Challenge	Item	Description	Model	Height Above Water	Base Diameter	Quantity Needed	Unit Price	Total Price
Navigation Channel	Port Marker Buoy (Red)	Taylor Made Sur-Mark Buoy	950410	39 in	18 in	2	$330.00	$660.00
	Starboard Marker Buoy (Green)	Taylor Made Sur-Mark Buoy	950400	39 in	18 in	2	$330.00	$660.00
Follow The Path	Gate Buoy (Red)	Polyform	A-0	6 in	8	5	$42.00	$210.00
	Gate Buoy (Green)	Polyform	A-0	6 in	8	7	$42.00	$294.00
	Obstacle Buoy (Yellow)	Polyform	A-0	6 in	8	4	$42.00	$168.00
	Obstacle Buoy (Black)	Polyform	A-0	6 in	8	4	$42.00	$168.00
Docking	Floating Dock (Beige)	40 in. "Baby" Ez Dock				0	$656.00	$0.00
	Color Display	Vinyl Banner 2ft X 2ft				3	$12.00	$36.00
	Tines	Pvc Pipes, White				4	$10.69	$42.76
Speed Challenge	Gate Buoy (Red)	Polyform	A-2	12 in	14.5 in	1	$76.13	$76.13
	Gate Buoy (Green)	Polyform	A-2	12 in	14.5 in	1	$76.13	$76.13
	Gate Buoy (Blue)	Polyform	A-2	12 in	14.5 in	1	$76.13	$76.13
	Gate Buoy (Yellow)	Polyform	A-2	12 in	14.5 in	1	$76.13	$76.13

Figure A2. Testing Hardware

In addition, measurement equipment, such as a tension gauge, was used to obtain physical metrics from the system, such as thrust-weight calculations. The indoor GPS equipment, as described in the GPS and IMU testing strategy section, was used to simulate running outdoors.

IV. Environment

The vessel mounted on its stand was used as the dry testing environment with a significant amount of empty space in front of the camera for the vessel.

The team's AI lead developed the in-simulation testing environment. Using CAD models of the boat, a physically accurate model ensures that similar behavior is experienced in simulation as on real hardware. An entire competition field was also created, using 3D models created in-house and from others, including the SimLE: SeaSentinel team's published models and the Open Source Robotics Foundation's models of Nathan Benderson Park. This provides context as to exactly how the competition runs—because everything from the sandy beach to buildings to every object the boat interacts with is simulated, members can complete a full competition run from putting the boat in the water to completing every task.

The University of Michigan's Marine Hydrodynamics Laboratory Towing Tank Basin and Earl V. Moore Building Pond were the in-water testing environments. The tow tank is a long hallway with water in the middle and a beach area for team members to get the vessel into the water. Buoys of varying sizes can be added to the tank. The MarvelMind Indoor GPS was mounted in the environment to provide position information. The Moore pond is a 3000 sq m. pond on the edge of North Campus with a maximum depth of 10 ft. Buoys can be added to the pond with a kayak.

V. *Risk Management*

While the MHL is a vital resource for testing, it can also be hazardous. The facility is over 100 years old, and the team must understand the risks involved in using the lab and what safety protocol must be followed. The tank is 10-15 feet deep, consists of exposed electrical channels, and has many moving parts, such as a sub-carriage that travels the length of the tow tank and is unlocked and moved by foot.

To mitigate these risks, the team worked with the MHL to coordinate a training session in the fall with all of its members. This included being debriefed on the safety protocol in the lab, what precautions must be taken, and what to do when something goes wrong. At the end of the session, members were provided with card access to the tank area, which was instrumental in allowing the team to test in water frequently.

Before each session, the team sought MHL approval and provided four trained members' names as those who would oversee the team's safety. Each of these members had a role and a responsibility to the team to employ and assist everyone in employing safe practices while also being ready to act in the event of an emergency. These four roles and their detailed descriptions are given below. With these roles and the safety briefing for all attending members, the team is happy to report that there were no injuries in testing.

- Person Responsible: Usually the team president, the person responsible is the contact point between the MHL and the team. They are responsible for ensuring that all relevant paperwork has been completed, submitted, and accepted. The PR is also responsible for providing the necessary safety personnel and equipment for safe operation within the MHL. The PR is also the liable party for any incidents during the group's visit to the MHL.
- Safety Officer: This person is responsible for ensuring all relevant safety equipment and practices are present, properly utilized, and followed at all times. The SO is also responsible for briefing all of the group's personnel on relevant safety procedures before the visit and making sure that the personnel are stationed in a manner that allows for expedient action in case of emergency.
- Designated Caller: Responsible for maintaining a means of contacting outside emergency personnel during the group's entire time at the MHL. They are responsible for knowing the emergency contact numbers, such as UM DPSS, in case of emergency. The DC also coordinates with the Designated Runner on where to meet outside emergency personnel.
- Designated Runner: The DR is responsible for knowing all the relevant entrances/exits to all spaces during the group's visit to the MHL. They are responsible for knowing where to meet emergency personnel best and how to direct them to the MHL.

To extend our testing beyond the MHL, the team also conducts autonomous boat trials at the pond outside the Moore building. While this outdoor environment poses different risks than the MHL, the same four key roles (Person Responsible, Safety Officer, Designated Caller, and Designated Runner) still apply. The outdoor safety plan emphasizes personal protective equipment, robust emergency stop mechanisms, and thorough pre-test readiness checks. Weather conditions are continuously monitored to ensure testing only proceeds under safe conditions, and any presence of wildlife or bystanders prompts immediate postponement. A first aid kit and throw rope remain onsite for emergency use, and all activities strictly follow leave-no-trace principles to minimize environmental impact. Should any incident occur, testing ceases at once, and the team activates its emergency protocols, including notification of appropriate authorities. Following these guidelines, the team safeguards personnel, equipment, and local ecosystems while conducting autonomous boat trials at the pond.

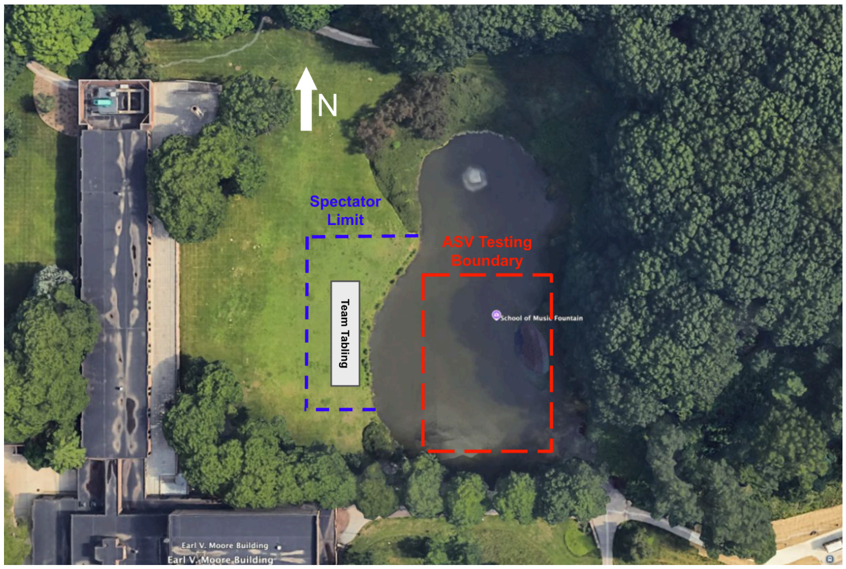


Figure A3. Outdoor Testing Layout from Safety Plan

VI. Results

Through the weekly testing sessions, the team obtained valuable information primarily used to update software for Nav/Controls and CV continuously. Each MHL testing session had a group get specific testing accomplished within that session. They were able to use immediate data to modify and improve in order to achieve the group's goal. The ROS bags of the connected onboard sensors and the data they published to their respective ROS topics were collected. They could be "replayed" to have data for the other subteams that could not be in the water testing. Outdoor testing was essential to validate software for actual GPS usage, especially with replacement drivers due to the ROS 2 upgrade.

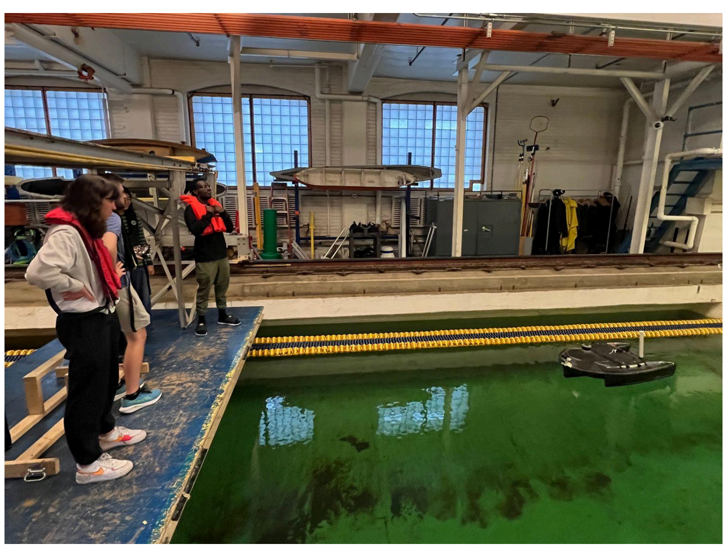


Figure A4. Testing at the MHL

Appendix B: Parts List

	Vendor	Model/Type	Specs	Custom/ Purchased	Cost ($)	Year of Purchase
ASV Hull Form/Platform	UM::Autonomy	Monohull X-Bow	Carbon Fiber	Custom	1045	2025
Waterproof Connectors	Multiple	Deutsch DT Connectors	N/A	Purchased	47	2023
Propulsion	Blue Robotics	T500	43.5 A Max @ 24 V	Purchased	690	2023
Power System	Multiple	LiPo Battery, ATX Power Splitter & Adapter	20 Ah @ 26 V Max	Custom	400	2023
Motor Controls	Blue Robotics	Basic ESC 500	50A Rating	Purchased	95	2023
CPU	Amazon	Beelink Mini PC SEi12	Intel 12th Gen Core i5-12450H	Purchased	200	2023
Teleoperation	Amazon	X8R Receiver	8-Channel	Purchased	40	2024
Inertial Measurement Unit (IMU)	VectorNav	VectorNav	VN-300	Purchased	5000	2019
Camera(s)	Best Buy	Logitech C920 Webcam	1080p	Purchased	70	2024
Wind Speed Sensor	Amazon	CALT - YGC-FS	5V DC Supply, 0-5V Output, 0-45m/s Range	Purchased	70	2025
Wind Direction Sensor	Amazon	Yosoo - Anemometer Wind Meter	1-5V Output, 360-Degree Measurement	Purchased	45	2025
Water Pump	Amazon	Hyuduo Electric Diaphragm Pump	Self-Priming, 12 V DC, 1.5 L/min flow rate, 2m Max Lift Height	Purchased	11	2025
Algorithms	UM::Autonomy	PID Control Loop		Custom		
Vision	N/A	OpenCV, Yolov8 Deep Learning Model		Custom		
Localization and Mapping	UM::Autonomy	Custom Sensor Fusion Algorithm		Custom		
Autonomy	UM::Autonomy	A* Algorithm		Custom		
Open Source Software	N/A	ROS 2, OpenCV, Ubuntu, YOLOv8		Custom		

Figure B1. Components List

Appendix C: Hull Calculations

C.1 Weights & Centers

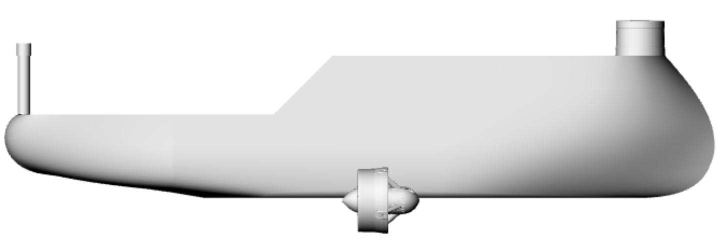
	Weight, total (lbF)	x Location, aft of FP (in)	y Location, offset from BSL (in)	z Location, off CL (in)	W*x	W*y	W*z
Carbon Fiber	18.3	26.42	5.44	0	483.49	99.55	0
Electrical Box	10.8	23.83	9.25	0	257.36	99.90	0
Velodyne	1.8	6.06	13.08	0	10.91	23.54	0
E-Stop	1.0	54.83	7.07	0	54.83	7.07	0
Rocket	1.2	56.77	9.92	0	68.12	11.90	0
Water Gun	2.0	44.00	9.25	0	88.00	18.50	0
T500	5.9	27.38	-0.13	0	161.54	-0.77	0
Battery	5.0	27.00	1.00	0	135.00	5.00	0
TOTAL	**46.0**				**1259.25**	**264.70**	**0**
					LCG (in)	**VCG (in)**	**TCG (in)**
					27.37	**5.75**	**0**

C.2 Trim & Stability

Condition	Sinkage (in)	Trim (deg)	Heel (deg)	LCB (in)	TCB (in)	VCG (in)	GMt (in)
Neutral	-3.66	1.27	0	27.21	0.9	1.68	-0.61*

*Stability analysis was done without outriggers or ballast. Negative GMt suggests an unstable vessel and the necessity of methods to improve transverse stability.

C.3 Hull Renders



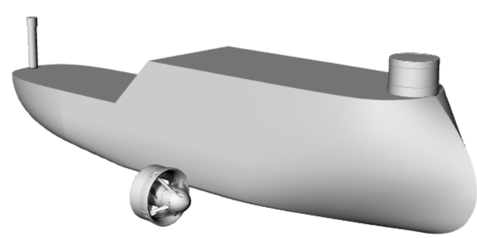


Figure C1. The Orca Hull Renders With Thruster Placement

Appendix D: Propulsion Trade Study Calculations

1.0 T200 and T500 Thrust:

T200 @ 20 V

Full Throttle FWD/REV Thrust @ Maximum (20v)	6.7/5.05 kg f	14.8/11.1 lb f

T500 @ 24 V

Full Throttle FWD/REV Thrust @ Maximum (24v)	16.1/10.5 kg f	35.5/23.2 lb f

$T_{tot,\,500,\,FWD} = 35.5 \bullet 2 = 71.0\ lbf$

$T_{tot,\,500,\,REV} = 23.2 \bullet 2 = 46.4\ lbf$

$T_{tot,\,200,\,FWD} = 14.8 \bullet 4 = 59.2\ lbf$

$T_{tot,\,200,\,FWD} = 11.11 \bullet 4 = 44.44\ lbf$

Maximum $T_{tot,\,500,\,FWD}$ recorded at 2023 RoboBoat Competition: $24.0\ /\ 2 = 12\ lb\ ft$ per thruster.

Prop ventilation in 2023 - resulting in 66% loss in thrust.

With lowered thrusters, assuming this is improved to being just 16% more efficient.

$T_{tot,\,500,\,FWD} = 35.5 \bullet 2 \bullet 0.50 = 35.5\ lbf$

Improves thrust by 11.5 lbf immediately.

Appendix E: Water Gun Calculations

Parameters:
Pump: Hyuduo Electric Diaphragm Pump (Amazon)
Output Rate: 1.5-2.0 L/min (2.5e-5 m^3/s)
Voltage: 12V
Tubing: 1/4" ID x 3/8" OD
Water Reservoir: 15 fl oz (1 lb of water, 0.444 L)

Calculations:
Given the need for horizontal distance, we elected to mount the nozzle at a 45° angle for maximum distance, and we ran calculations to determine the necessary nozzle size to achieve our desired distances.

1. **Nozzle Area & Exit Velocity**

   $$A = \pi(\frac{d}{2})^2$$

   $$v_{exit,\, ideal} = \frac{Q}{A}$$

2. **Projectile Motion**

   $$v_x = v\, cos(45),\ v_y = v\, sin(45)$$

   $$x(t) = v_x t,\ y(t) = v_y t - \frac{1}{2}gt^2$$

   $$T = \frac{2v_y}{g} = \frac{2v\, sin(45)}{g}$$

   $$x_{max} = \frac{v^2}{g},\ y_{max} = \frac{v^2}{4g}$$

3. **Reservoir Depletion Time**

   $T = \frac{0.444L}{1.5\ L/min} = 17.7\ s$ firing time.

Using Python, we ran a series of calculations on a range of Nozzle sizes from 0.25” (6.35mm) to 2.25 mm. We concluded that a nozzle diameter of 2.5mm is ideal, as a firing distance of 2.6 m (8.5 ft) was sufficient. Defects in 3D printing at this scale can create turbulence and reduce exit velocity.

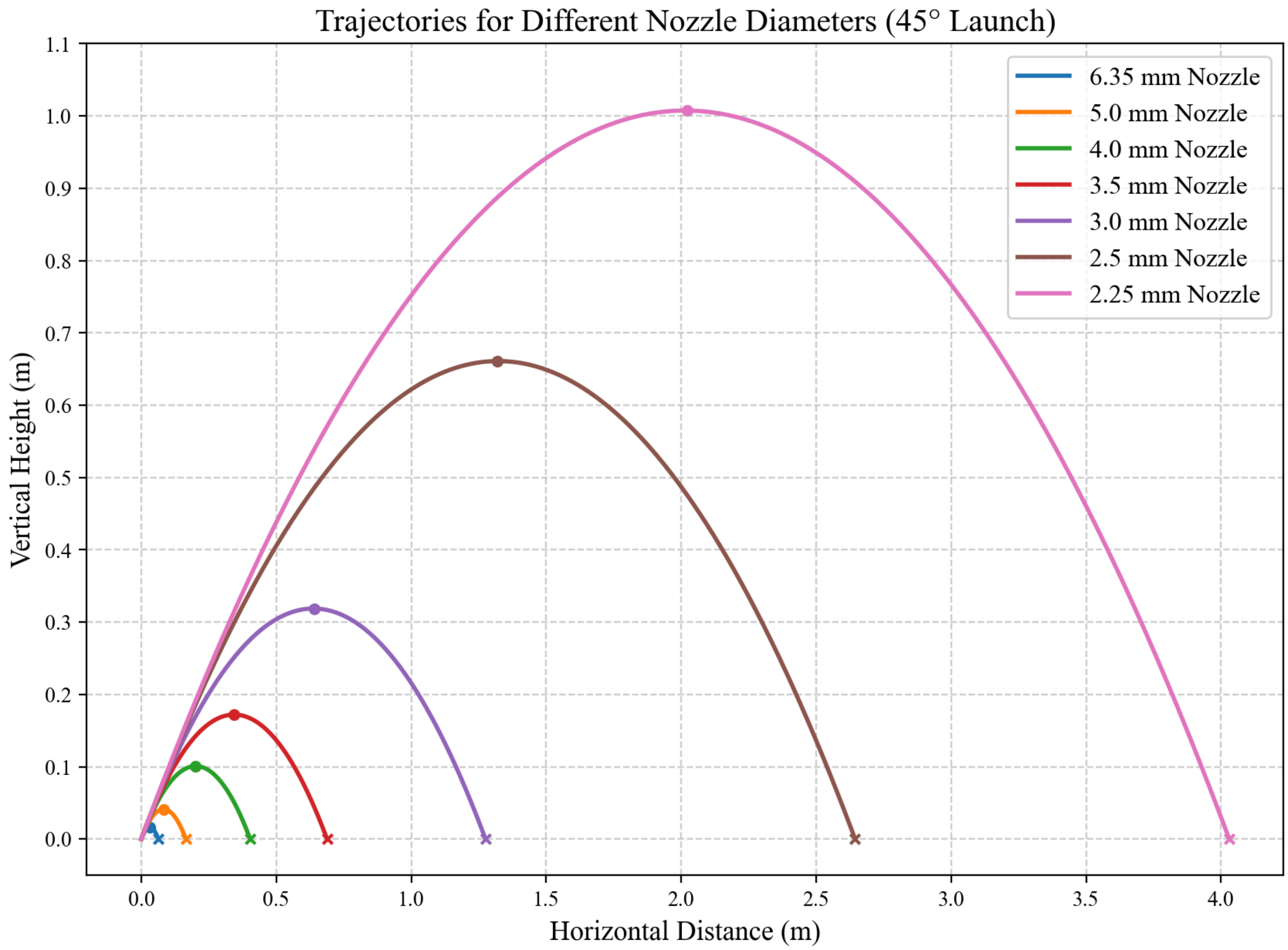


Figure E1. Water Pump Output Distances Based on Nozzle Diameter

Nozzle Diameter (mm)	Exit Velocity (m/s)	Range (m)	Max Height (m)
6.35	0.789	0.064	0.016
5.00	1.273	0.165	0.041
4.00	1.989	0.403	0.101
3.50	2.598	0.688	0.172
3.00	3.537	1.275	0.319
2.50	5.093	2.644	0.661
2.25	6.288	4.030	1.007

Figure E2. Water Jet Calculations at 45° Launch for Varying Nozzle Diameters

Appendix F: Simulator Physical Parameters Calculations

m/s	N
0	0
0.33333	0.62854
0.66666	2.2
1	4.544
1.3333	7.60356
1.666	11.325
2	15.67
2.334	20.63
2.6667	26.1736
3	33.248

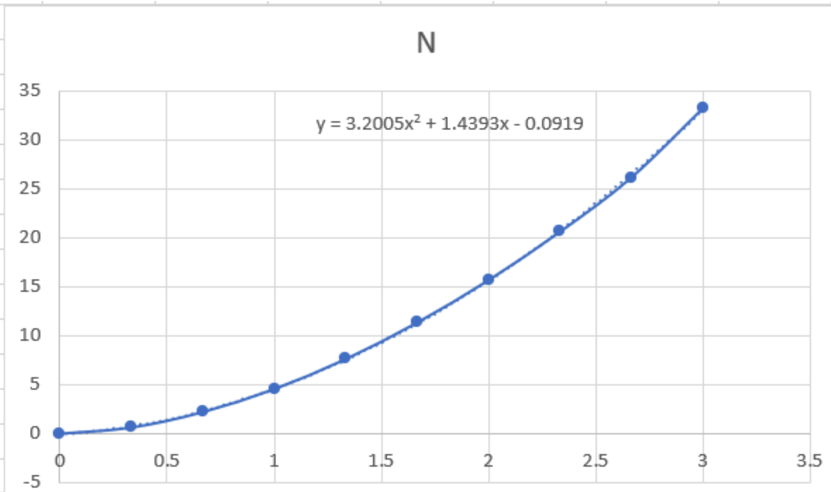


Figure F1. Resistance vs. Speed

$F_{surge} = 3.2005v^2 + 1.4393v$ [Ns/m]

Appendix F.2

$F_{sway} = C_D * 0.5 * \rho_{seawater} * v^2 * (C_{prism})$

$C_{prism} = V_{hull} / (A_{max} * L_{pp}) = 0.005m^3 / (0.03129m^2 * 1.1176m) = 0.14298$

$C_D \approx 0.9$

$\rho_{seawater} = 1026\ kg/m^3$

$F_{sway} = 0.9 * 0.5 * 1026 * v^2 * 0.14298 = 66.01v^2$ [Ns/m]

Appendix G: Electrical Schematics

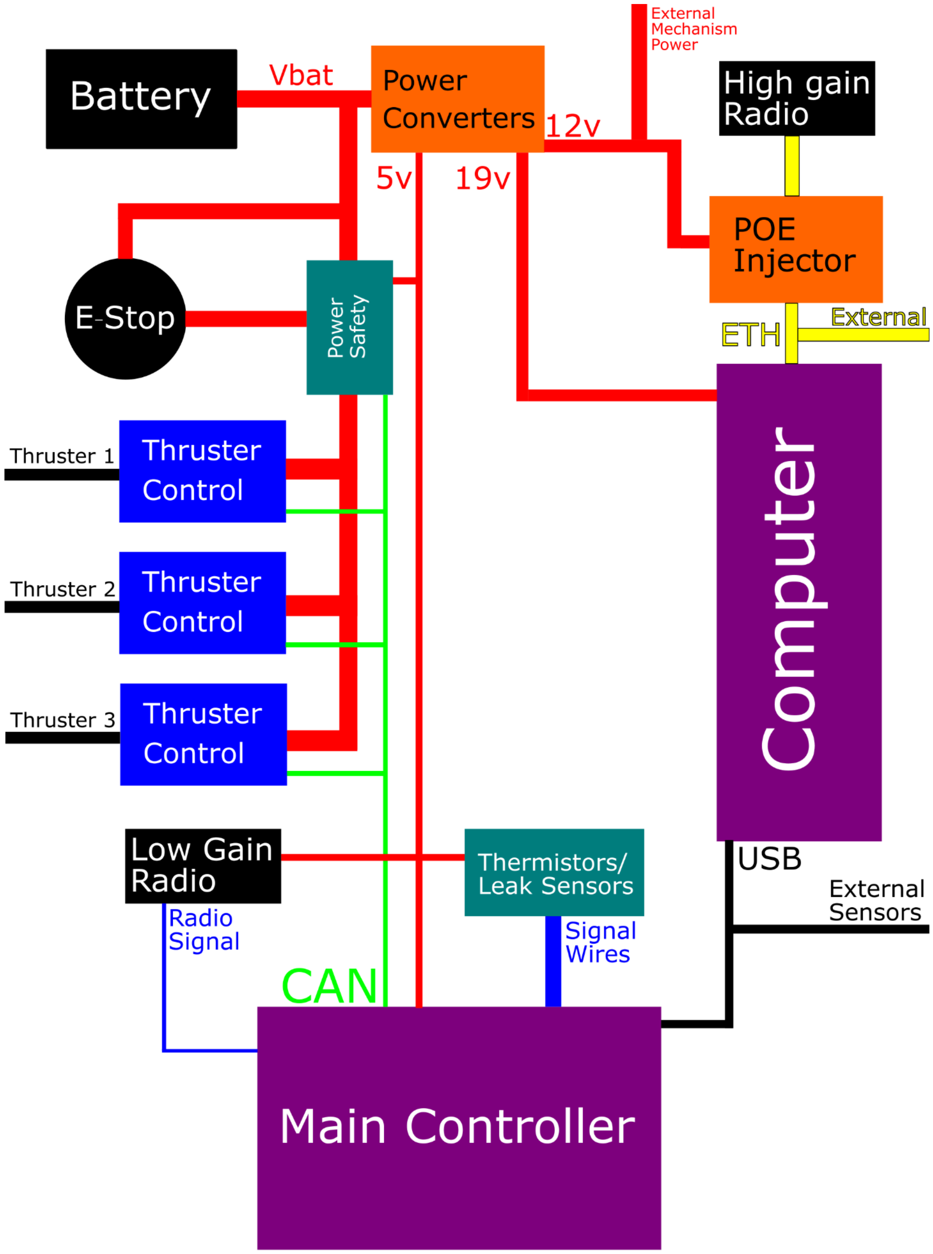


Figure G1. High-Level Boat Wiring Diagram

Figure G1 depicts the central electrical diagram of critical systems. The core systems are split up into thruster control, managed by a power safety relay system; the main controller, which operates the low-gain radio meant for remote e-stop and control, as well as the thruster controllers; and the main computer, which operates the software and high-gain radio for base station communication.

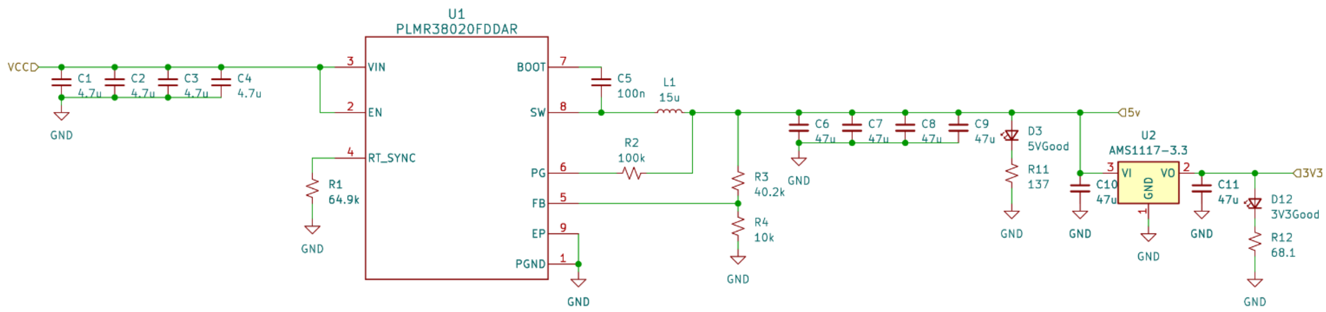


Figure G2. Power Regulation Circuit

A 15-30V into 5V output buck regulator with a 5V power good LED, feeding into a 5V to 3.3V Linear Dropout Regulator with a 3.3V power good LED.

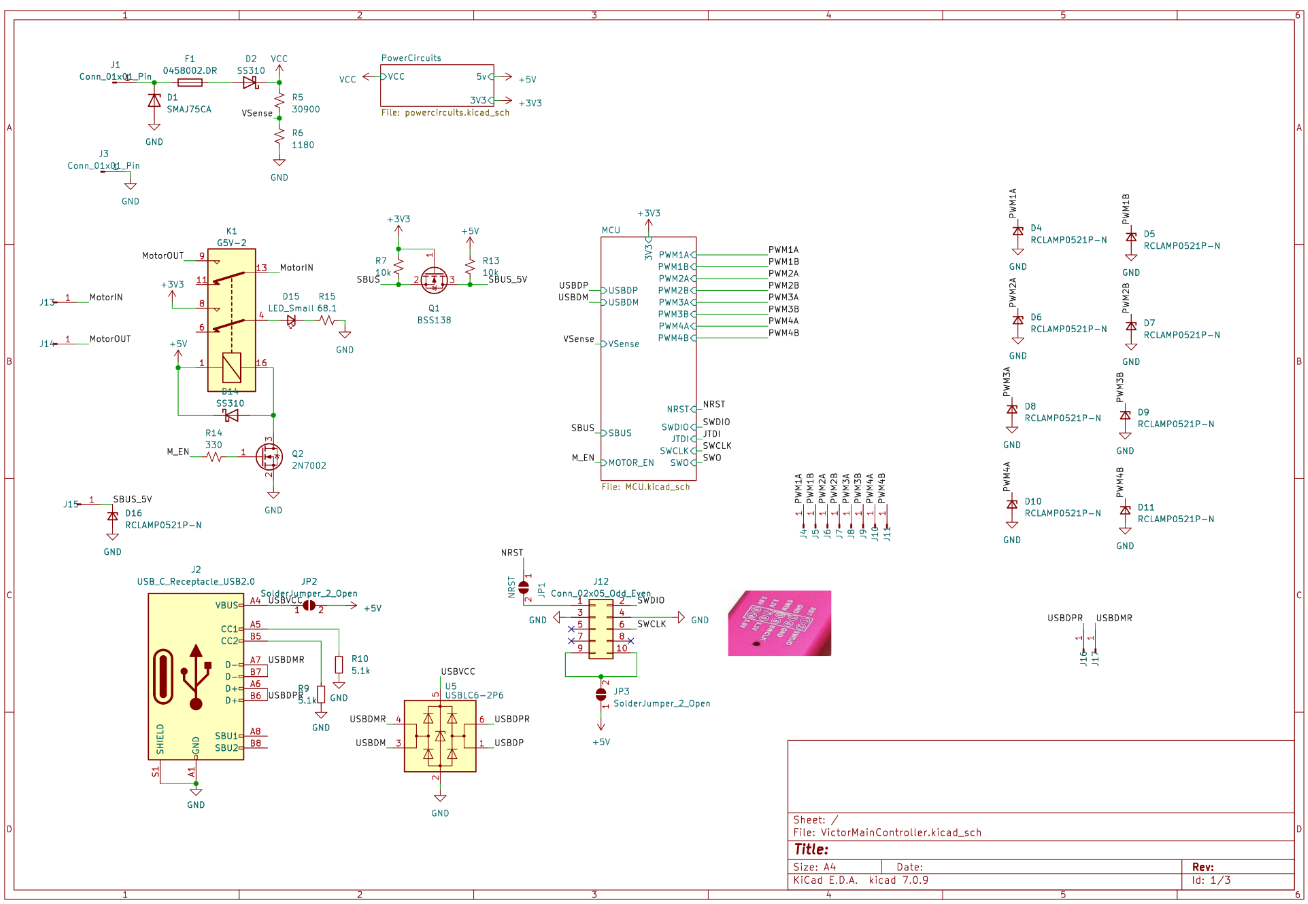


Figure G3. Speed Controller

Figure G3 depicts a high-level diagram of the speed controller. It contains a relay for switching a signal on and off, an input power fuse and reverse polarity protection, a USB-C port for communication, and JTAG, debug, and GPIO breakouts for the PWM signals. Included are the two sub-sheets for power regulation and the microcontroller.

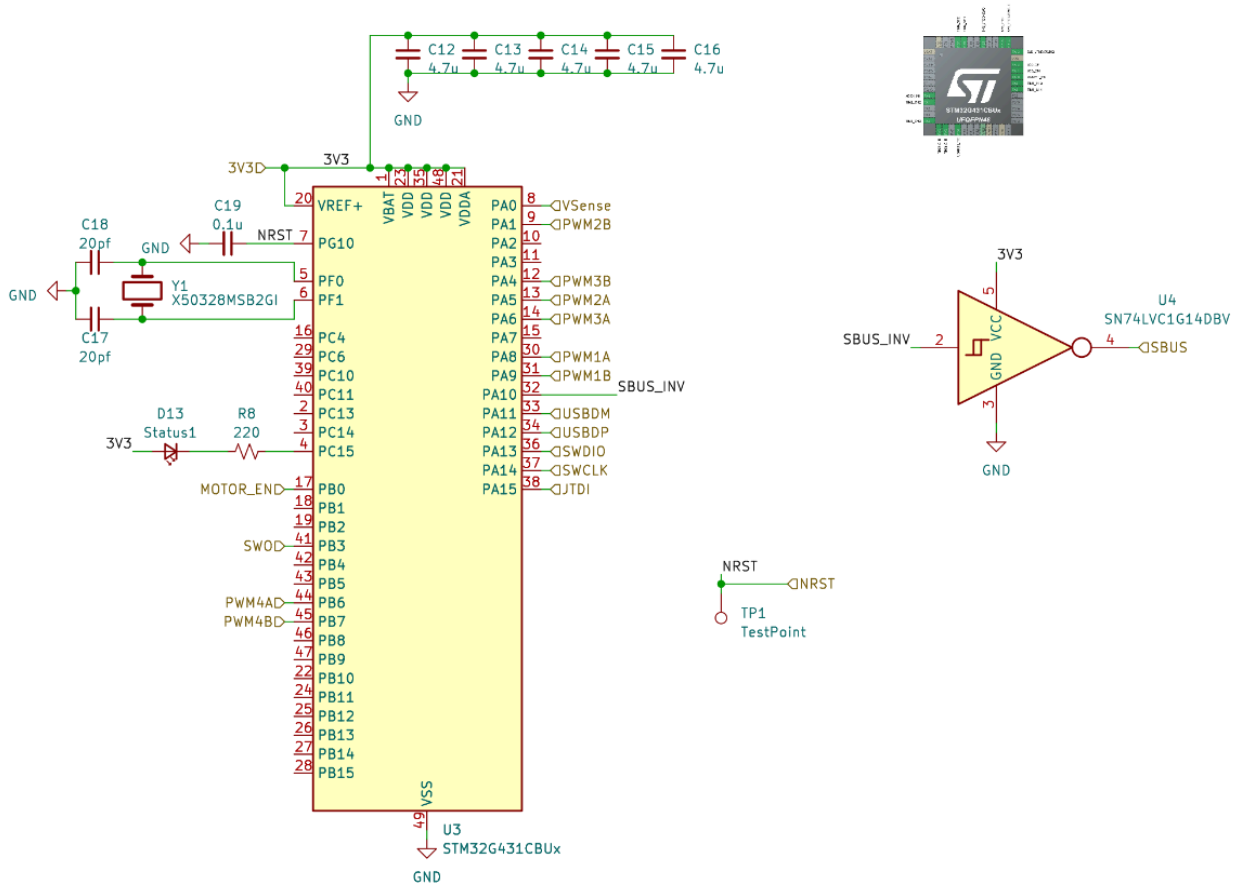


Figure G4. Boat's Main Microcontroller

The boat's main microcontroller pinout contains a Sbus inverter, crystal oscillator, and status LED. The design is based around an STM32G431CBU6, with the pinout in the top right corner.