The Orca 2.0 by UM::Autonomy
RoboBoat 2026: Technical Design Report

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1. Abstract

UM::Autonomy's 2026 RoboBoat entry, The Orca 2.0, is an improved iteration of the 2025 vessel, *The Orca*, and is designed to address roll stability issues observed during last year's competition. The hull was modified with a wider beam and a fin keel while retaining the successful X-Bow geometry from the previous year. The new Orca 2.0 vessel measures 5.25 ft in length with a 15-inch beam. This year's competition focus is on the Navigation Channel and Docking challenges, with continued development of Supply Drop and Harbor Alert.

The software team implemented a hybrid A* path-planning algorithm for smoother navigation and introduced a waypoint queue to enable continuous motion between waypoints. To support these navigation updates, we also upgraded the camera and LiDAR to make perception more reliable in real-world conditions. For advanced capabilities, the ball launcher was relocated inside the hull to lower the center of gravity and eliminate previous listing issues. The hull manufacturing processes were also improved by transitioning from a 3D-printed mold technique to CNC-machined high-density foam molds, resulting in improved surface finish and reduced fabrication time. With over 100 hours of simulation and outdoor testing, these improvements produced a more stable and reliable vessel for RoboBoat 2026.

Figure 1. "The Orca 2.0" Render

2. Technical Content

2.1 Competition Strategy

Our RoboBoat 2026 strategy builds on what we learned from the original Orca at RoboBoat 2025, where roll instability and autonomy limitations reduced overall reliability. In response, we developed Orca 2.0, a refined version of the platform paired with software updates designed to produce more consistent behavior on the water. Key improvements focus on perception reliability, path planning, and maneuvering constraints that became clear during Follow the Path.

This year we prioritize Navigation Channel (Task 2) and Docking (Task 5) as our primary objectives, while continuing development of Supply Drop (Task 4) and Harbor Alert (Task 6). These priorities reflect a deliberate trade-off: rather than spreading effort across every task, we spent the majority of our development time improving software reliability and the remaining time on hardware refinements and integration. The specialized hardware for Supply Drop and Harbor Alert was built modularly so progress can happen in parallel without risking core navigation performance. This approach trades some high-ceiling points from advanced tasks for a higher probability of completing the fundamental challenges that drive overall scoring, based on what limited us in 2025.

2.1.1 Task-by-Task Strategic Breakdown

For core autonomous navigation across all tasks in this year's competition, the team uses the system logic shown in Figure 2. This modular design allows parallel development and makes it easier to swap task-specific logic as challenges change. It also enables module-level testing, which improves overall reliability.

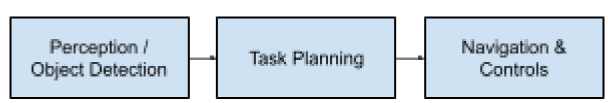

Figure 2. AI Team Systems Architecture

When approaching a challenge, the Perception team uses a camera and the YOLOv11 deep learning model to identify buoys by shape and color, taking advantage of its high accuracy and retraining capability. An LSLiDAR C32 with a measurement accuracy of ~3 cm 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 Evacuation Route & Return (Entry & Exit Gates)

For the Evacuation Route and Return task, Computer Vision uses the camera and LiDAR data to detect the first two cylindrical buoys. Task Planning then instructs the vessel to move continuously through that first pair of buoys, as seen in Fig. 3.

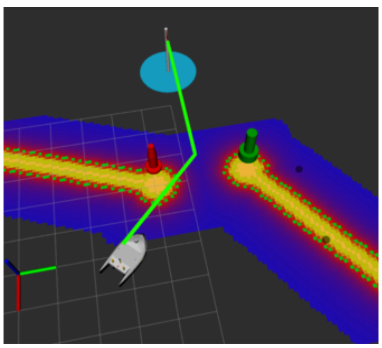

Figure 3 Navigation A Algorithm Path in RViz*

2.1.1.2 Debris Clearance (Nav Channel)

For the Navigation Channel task, Task Planning identifies red and green buoys and uses their positions to generate a spline interpolation through the gates. This produces curved waypoints that are stored for return navigation at the end of the task.

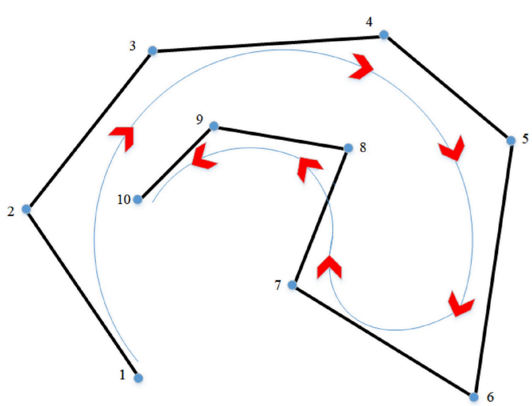

Figure 4. Spline Algorithm Diagram

Each waypoint is sent to Navigation, which uses the hybrid A* planner (smac_planner) to generate a feasible path from the vessel's current location. We chose hybrid A* over our older A* planner because it respects the boat's turning limits and avoids sharp turns the boat cannot execute. This directly targets the 'stop-and-go' and wide-turn failure modes we saw in 2025 when navigating long gate sequences.

Navigation then provides a tracked reference path and target velocities to Controls. Using the VectorNav VN-300 pose estimate, we compute heading and cross-track error relative to the reference path and convert them into differential thrust commands through a PID controller. We chose PID over our previous LQR because it is simpler to tune and maintain while still meeting our tracking accuracy needs under wind and small waves.

Once the vessel detects a red or green color indicator, it stores its location. When there are no more gates to pass through, it will circle the location of the green color indicator, and after it has done that and seen a red color indicator, it will retrace its steps to go back to the beginning of the Navigation Channel task, following the spline points in reverse.

2.1.1.3 Emergency Response Sprint (Speed Challenge)

During earlier tasks, the vessel stores the speed color indicator buoy's position as soon as it detects the yellow buoy, so Sprint starts with a known target instead of a search. It navigates back to that cached location until it reaches the start red/green pair of buoys, drives forward until it reaches the color indicator, and then circles left on green and right on red while avoiding black buoy debris using the costmap.

2.1.1.4 Supply Drop (Object Delivery)

The vessel will keep any supply drop boats in memory while doing tasks and will go back to perform their respective behaviors of water shooting or ball shooting after each task is finished. As a part of our competition strategy, we will initially only attempt one of each color and switch to attempting all supply drops if we are quickly and consistently doing all tasks.

Because the water blast is fixed at the bow and the ball blast is fixed on the vessel's side, the task planning team orients the boat to position each device.

2.1.1.5 Navigate the Marina (Docking)

For Docking, the team must identify each dock's numbers, color indicators, and boat locations. Task Planning will remember which direction the

ASV entered the marina from and store its position. It will then scan left and right to gather computer vision data. 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, and the Navigation and Controls systems operate to move the vessel to the desired location, parking in the corresponding dock.

2.1.1.6 Harbor Alert

The vessel continuously listens for the harbor alert tone and will interrupt its current task while saving state (location and current progress) when the signal is heard. To process the audio signal, we apply a Hanning window to the audio stream and compute a Discrete Fourier Transform [2], which gives a spectrum of frequency magnitudes. We check whether the designated frequency of 600, 800, or 1000 Hz is in this spectrum and at a large enough magnitude. If so, we start tracking the length of time that this frequency persists for. If this matches either of the signal patterns, it gets sent to Task Planning. Task Planning will proceed to stop the current task, making note of the location and task progress at this point, and set course toward the location corresponding to the signal pattern.

2.2. Design Strategy

2.2.1 Mechanical Design Strategy

The mechanical design of Orca 2.0 was driven by three primary objectives:

(1) Improve roll stability to stabilize perception
(2) Increase internal volume and modularity to support sensors and ACT components
(3) Improve manufacturing quality and speed

Our RoboBoat 2025 results showed that roll motion directly reduced autonomous reliability. When the hull rolled in real water conditions, the camera view and sensor returns became less consistent, which led to less stable detections and harder planning through gates. Since perception reliability affects every task, improving stability became a top mechanical priority for Orca 2.0. As a result, this year's hull updates focused on roll stability and mass distribution so the boat provides a steadier platform for sensors and more repeatable autonomous behavior.

The X-Bow geometry was retained due to its demonstrated ability to reduce pitch motion and improve controllability in rough water conditions. Inspired by North Sea offshore service vessels, the X-Bow allows for precise motion control and improved wave-piercing behavior. [3] [4] [5] However, analysis of in-water testing data motivated an increased hull beam and the addition of a fin keel to improve roll stability and righting moment [6] [7]. These changes reduced roll amplitudes and provided a more stable sensing platform, directly impacting our camera performance and perception consistency.

Increasing the beam increased the vessel's righting moment, reducing roll amplitudes and providing a more stable platform for the sensors. The fin keel introduced additional hydrodynamic resistance to roll motion and improved dynamic stability. Together, these changes improved both passive stability and controllability during navigation tasks.

2.2.1.1 Vessel Arrangements and Materials

As a redesign of the Orca, the Orca 2.0 keeps many of the same internal components and arrangements. Key changes focus on improving stability and making integration and maintenance easier. The new hull measures 5.25 ft in length with a 15-inch beam, a scaled and widened version of the previous vessel.

Internal component placement was redesigned to lower the center of gravity and improve mass distribution. Heavy components such as batteries, propulsion, and ACT components were moved closer to the bottom of the hull and onto the longitudinal centerline. This placement reduces roll inertia and improves recovery from environmental disturbances.

Advanced-capability hardware, including the ball launcher and water delivery mechanisms, was moved inside the hull to lower the center of gravity and eliminate asymmetric loading that previously caused listing behavior. Internal placement also improves protection from environmental exposure and simplifies wiring integration. These mechanisms and their supporting electronics were mounted on a modular platform to speed up maintenance and keep attachments secure.

Carbon fiber composite was selected for material due to its high stiffness-to-weight ratio and ability to locally reinforce high-load regions such as thruster mounts and the keel. Maintaining low structural mass supports improved stability and higher payload capacity without displacing the vessel significantly.

Critical sensors were mounted on the upper deck to reduce occlusion and maximize field of view. At the bow, the LiDAR, camera, and GPS are stacked vertically to improve visibility and reduce mutual interference, supporting more consistent perception.

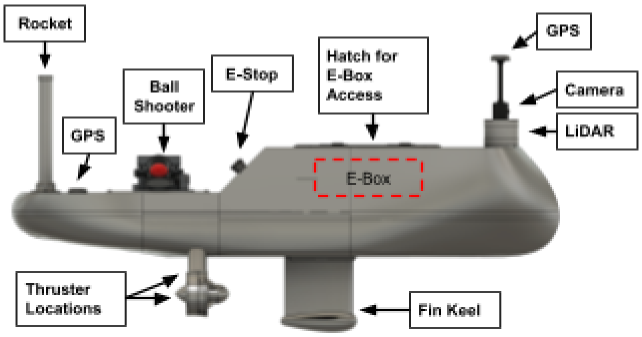

Figure 5: Vessel Arrangement Diagram

2.2.1.2 Propulsion

Orca 2.0 uses the same dual-thruster, differential-thrust propulsion concept as the original Orca, but with two changes to improve low-speed control and reduce ventilation. The Orca 2.0 has thrusters placed further aft at 73.5° from horizontal to create a larger moment arm and increase maneuverability. The thrusters also utilize 3D-printed PLA mounts to increase the depth of the thrusters in the water. This helps to place the center of gravity of the vessel lower, as well as reduce cavitation. The Orca 2.0 utilizes a parallel Blue Robotics T500 thruster setup that allows for differential thrust steering and has maneuverability as described in Appendix C.3.

2.2.1.3 Manufacturing Process

Hull molds were produced using CNC-machined high-density polyurethane tooling board rather than the segmented 3D-printed mold used in the previous year. This transition was made to improve the surface finish, dimensional repeatability, and left–right symmetry between the two hull halves. Using Rhino and Fusion to generate toolpaths, we machined the port and starboard half-hull molds on a ShopBot, which eliminated the need to print, bond, and fair multiple mold sections and resulted in more consistent left–right geometry.

After the CNC process, each mold was coated with multiple layers of a Duratec Primer using a spray gun. This was then followed by sanding with progressively finer grit sandpaper and further coating with mold release and PVA film to ensure smooth part removal. For the epoxy resin saturation, a combination of wet layups and vacuum bagging processes was used. Placing the saturated carbon fiber fabric into the mold and applying vacuum pressure ensured proper positioning while removing excess resin and trapped air. After curing, the port and starboard sections of the hull were joined and bonded to ensure a watertight seal along the centerline, creating a high-performance X-bow hull.

2.2.1.4 Projectile Hardware

To address the listing observed during the 2025 competition, the advanced capabilities team redesigned the projectile hardware with a focus on lowering the vessel's center of gravity. The object delivery mechanism was moved to within the hull, which greatly reduced the tipping moment compared to the previous year's designs. This design improves roll stability while maintaining reliable projectile delivery by feeding the balls to a spinning flywheel at a controlled velocity. The system uses a lightweight, 3D-printed PLA structure and a statically mounted launch direction, reducing mechanical complexity while supporting consistent, repeatable performance.

2.2.1.5 Water Delivery Hardware

To complete the Water Delivery task, the advanced capabilities team designed a water pump system fed from a small water tank inside the boat, which helped deliver water while bypassing the need for a filtration system and additional components needed if lake water was used as feedstock. From iterations and testing, the team decided on a 2 mm diameter 3D-printed nozzle. From testing, we calculated that at an angle of 45 degrees, the nozzle was able to spray the water at a distance of around 80 inches. For this year's challenge, up to three vessels will need to be hit with water for at least three seconds each. To meet these requirements, testing was conducted with the tank, and the ideal nozzle size was determined from initial tests and calculations presented in Appendix C.4.

2.2.2 Electrical Design Strategy

The Electrical Team prioritized two design constraints for the E-Box this year: size and simplicity. The goal was to reduce the overall size while creating a wiring layout that could be easily understood by both Electrical and non-Electrical team members, improving troubleshooting and maintenance. To achieve this, custom PCBs were designed to replace bulky off-the-shelf components from last year's E-Box, reducing size and also improving heat dissipation.

Simplifying the wiring was also a major focus, as previous designs had limited documentation and cluttered wiring connections. New wiring diagrams were created to clearly show all module connections without opening the E-Box, and cable routing was cleaned up to match these diagrams. Finally, due to an updated camera, the wiring was upgraded from USB to Ethernet, requiring updates to the E-Box to support the new interface.

2.2.2.1 PCB Design and Improvements

To reduce the size and complexity of our electrical system, we replaced the bulky bus bar connections with a custom PCB-based architecture that integrates power distribution directly onto the boards. This reduced the internal wiring needed, which improved routing efficiency to each module and produced a more compact and organized layout that is easier to wire and less prone to loose connections.

In addition to the refined power layout, we introduced three specialized motor control boards to manage the servos for the water delivery mechanism. Because the system utilizes three different motor types, these dedicated boards ensure that each component receives the exact power and signal it needs for smooth operation. This modular approach allows the electrical box to communicate more effectively with the peripheral hardware, improving the overall responsiveness of the components and making future maintenance much simpler and faster, especially at competition, where time is critical.

2.2.3 Software Design Strategy

The software team focused on improving reliability across all of our systems this year. Our priorities were upgrading computer vision hardware, building an onboard memory system to track detected objects, and making waypoint navigation faster and smoother.

2.2.3.1 Improved Hardware

Roboboat 2025 revealed three reliability issues with our perception hardware:

(1) Condensation on the camera lens
(2) Inconsistent LiDAR returns for medium-distance objects
(3) Narrow field of view that limited how much of the environment we could observe at once

To address these issues, we replaced our previous webcam with an IP67 Ethernet camera to improve image stability across changing lighting conditions and reduce dropouts. We also upgraded to a 32-beam LiDAR, which provided denser point returns and improved ranging while reducing water-surface noise. Together, these changes increased the number of usable detections available to Task Planning and Navigation and improved robustness during turns and cluttered scenes.

2.2.3.2 Object Mapping

During the 2025 Follow the Path task, Task Planning sometimes created waypoints between the wrong red/green buoy pairs because both sides of the gate were not always visible in the same camera frame. We also ran into cases where the boat narrowly missed a waypoint and failed to progress, since the previous logic required reaching the exact point before continuing. Because Debris Clearance uses a similar buoy layout, these were important issues to resolve.

To address this, we added an onboard memory system that stores buoy locations in a 2D grid, including object type and coordinates. This allows buoys to remain usable even after leaving the camera field of view, and the stored object locations also feed Navigation's costmap for obstacle avoidance. For Debris Clearance, we fit splines through the red and green buoy lines and generate a centerline spline that produces smooth mid-gate waypoints. If the boat misses a waypoint, we redirect to the nearest point on the spline instead of backtracking, which keeps motion continuous.

2.2.3.3 Waypoint Navigation

In previous years, we generated paths with a custom A* planner and published waypoints one at a time from Task Planning. In gate-heavy tasks, this caused a repeated stop-and-go pattern since after reaching a waypoint, the boat would briefly pause while waiting for the next waypoint to be published, which made navigation slow and choppy.

To eliminate those failure modes, we updated both the planner and the waypoint interface. We replaced the old planner with hybrid A* using smac_planner [1], which explicitly considers the boat's kinematics (including minimum turning radius) and therefore avoids sharp turns the vessel cannot execute. Planner parameters were tuned in simulation and then refined during in-water testing using measured speed and turning limits, with a focus on maintaining efficient paths while still clearing obstacles such as black buoys. At the same time, Task Planning now publishes a continuously updateable queue of waypoints rather than a single waypoint, allowing Navigation to plan ahead and transition smoothly between gates without stopping, while still supporting mid-task replanning when the course geometry changes. Finally, we corrected the waypoint acceptance logic so the boat targets the center of each waypoint region instead of stopping at the edge, improving precision and overall consistency.

2.3 Testing Strategy

Testing is central to validating Orca 2.0, supported by over 100 hours of combined in-water trials and simulation. Because facility access varies throughout the year, we used both indoor and outdoor sites when available, and we relied on simulation when water time was limited. In-water testing is still the most important step for validating the full autonomy stack, since it exposes Perception to real lighting and reflections, verifies Navigation and Controls on realistic vessel dynamics and obstacle layouts, and allows Task Planning to run complete multi-task sequences end-to-end.

To make testing efficient, we split validation into simulation, dry/bench tests (on the stand), and in-water trials, since each catches different failures. Simulation in Gazebo helps us find logic and planning bugs quickly and reproduce issues consistently before moving to hardware. Bench testing de-risks wiring, sensors, and bring-up safely. In-water trials then validate the integrated system under wind, glare, reflections, and interference that cannot be reproduced indoors. Testing details are further laid out in Appendix A.

2.3.1 Simulator Testing

The team ran extensive simulations in Gazebo to test AI modules before in-water sessions. These simulations replicated vessel motion and task scenarios across the autonomy stack, including advanced behaviors like Water Delivery by generating a simulated water stream. This let subteams validate logic, perception outputs, planning behavior, and control responses repeatedly without waiting for limited water time, which helped catch regressions early and kept development moving in parallel.

While simulation is still more idealized than real water and lacks the full randomness of wind, glare, and waves, it was valuable for fast iteration, remote development, and reproducing bugs consistently. To keep the workflow accessible across student hardware, team members used different simulator front ends depending on their system: ARM-based Apple Mac systems commonly used a Foxglove-hosted workflow, while x86-based Windows and Linux systems used the Gazebo application.

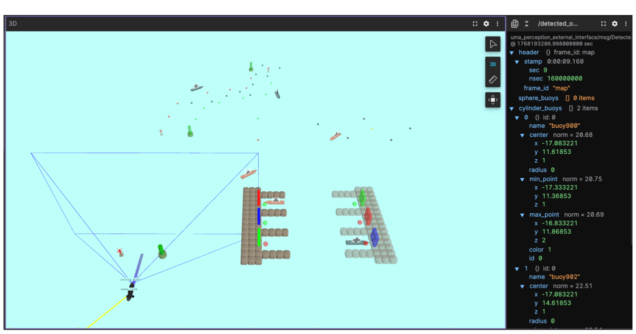

Figure 6: Foxglove simulator

2.3.2 In-Water Testing

The renovation of the Marine Hydrodynamics Laboratory (MHL) made in-water testing more difficult for us in 2025. Instead, we conducted outdoor testing once every two weeks at the Earl V. Moore Pond in the fall. This testing site requires significantly more preparation and safety measures, including additional equipment setup, environmental assessments, and contingency planning. Despite these challenges, this workflow allowed for continuous iteration and progress toward in-water sprint goals. In 2026, weekly testing at the MHL resumed, quickly expanding to twice a week in preparation for competition.

3. Conclusion

UM::Autonomy set out to fix the stability problems that hurt us at RoboBoat 2025, and stability testing confirmed that our redesign worked. The Orca 2.0 now has a positive GMt compared to the negative value we measured on the original Orca. The wider beam and fin keel made a noticeable difference during in-water testing, and the switch to CNC-machined molds cut down our manufacturing time significantly. On the software side, the waypoint queue and hybrid A* improvements have made navigation smoother in simulation and early water tests. As we head into competition, we feel confident that Orca 2.0 gives us a more reliable platform to build on for future years.

4. Acknowledgments

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5. References

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Appendix A: Testing Plan

A.1. Scope

The purpose of testing for *The Orca 2.0* focuses on verifying the functionality, reliability, and integration of all the sub-systems prior to competition. Testing goals included validation of individual subsystems and full systems tests in realistic competition environments.

The AI subteams conducted testing of their algorithms in their simulator to evaluate the success of their navigation, sensing and decision making algorithms before testing on water. Components testing with the electrical team ensured that sensors were properly calibrated and connected along with properly interfacing with software and hardware components. Subsystem and full system testing was performed in in-water trials at university-approved locations to assess the autonomous behavior of the vessel in real-world conditions.

The mechanical teams' testing focused on vessel stability, including stability testing of the original Orca to inform *The Orca 2.0's* redesign as well as future in water testing of the completed vessel. The ACT subteam supported testing through validating the design through CAD modeling as well as regular iterative prototyping of the ball shooter and water delivery mechanisms.

Testing did not include testing in extreme environmental conditions or fully replicate competition scenarios or layouts. Design changes noted from testing were incorporated into the final vessel design.

A.2. Schedule

In order to ensure our team stayed on track and that technical decisions were made with support from testing, our team made a schedule to plan out both when testing was critical and when other tasks needed to be completed in order to allow for meaningful and successful testing.

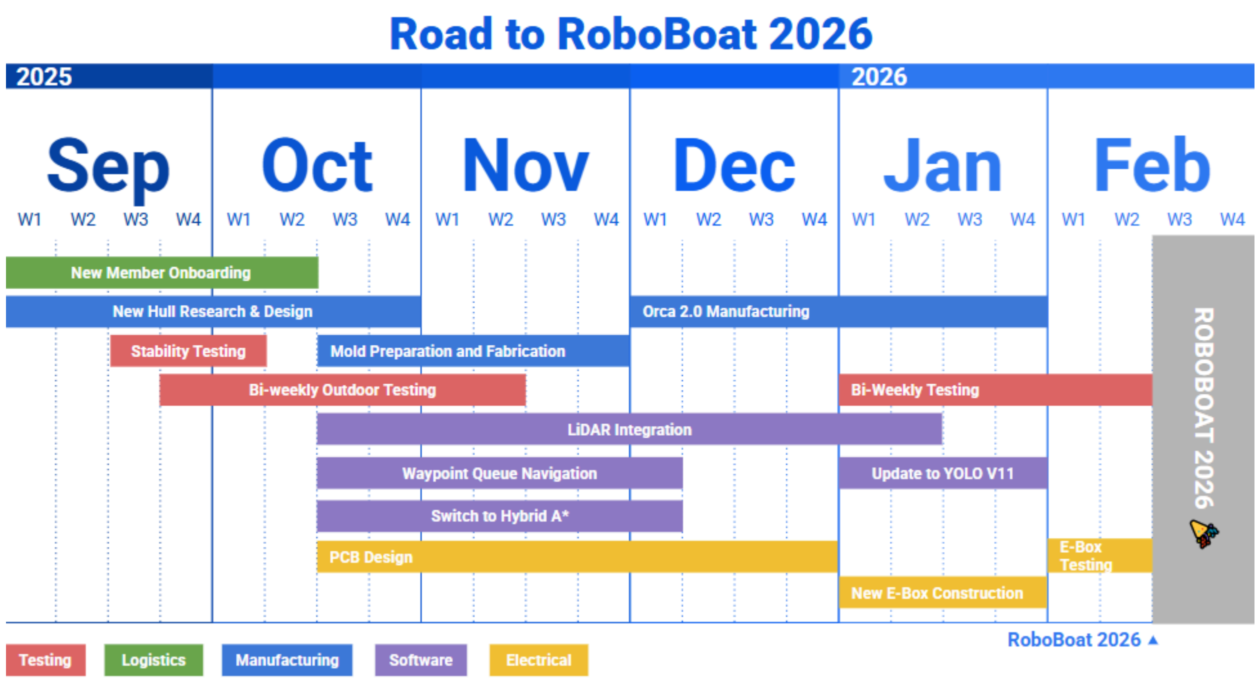


Figure A1. Testing and team timeline

A.3 Tools & Resources

Challenge	Item	Description	Model	Height above Water	Base Diameter	Quantity Needed	Unit Price	Total Price
Multiple	Color Indicators	3D Printed with the provided Roboboat STL files and Red, Green, and White PCTG.		5.2 in	5in	1		
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) I		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
	Number 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) I		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
Stability Testing	Rail	Aluminum	Thorlabs RLA 450/M			1	$142.36	$142.36
	Rail Slider	Aluminum	Thorlabs RC2/M			1	36.56	36.56
	Scale					1		
	10g Weights	Steel				10	$40.69	$40.69
	Angle Reader		Klein Tools Digital Angle Reader			1	$34.95	$34.95

Figure A2. Testing Hardware

In addition to the tools above, various measurement equipment was used to obtain physical metrics from the system, such as thrust-weight calculations.

A.4 Environment

For simulation testing, the AI team used our 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.

For our dry testing our vessel was mounted on its stand in a large empty space in order to allow the LiDAR and camera to have ample space for computer vision testing and to create a safe environment for the people and surroundings in case of any faults. This allowed our team to test motors, sensors and other components before testing in water.

The University of Michigan's Marine Hydrodynamics Laboratory Towing Tank Basin which is traditionally used by our team was under construction for the majority of the year, only opening up in the second semester. 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 Earl V.Moore Building Pond was the in-water testing environment used to test our boat on the water for the majority of the year, both due to the tow tank being out of operation as well as outdoor testing providing our team with a realistic environment, simulating waves, sunlight, and wind. 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.

The stability testing conducted by our team was done in the smaller Wind wave tanks in the University of Michigan's Marine Hydrodynamics Laboratory. This 35 foot long tank provided our team the space to conduct stability testing with our vessel and find what key changes needed to be done to the vessel to mitigate roll.

A.5 Risk Management

For our dry testing, our team ensured that proper fire safety equipment was nearby in our team space and followed proper PPE rules in our team project space.

For the outdoor testing conducted at Moore Pond, our team made sure to ensure both our own safety as well as consider the safety of the environment around us. Our team created four key roles to ensure proper protocol would be followed in case of emergency. For each testing session we had a team lead assigned to one of each of the roles as described below:

- Person Responsible: Usually the team president, the person responsible is the contact point between the University 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 at Moore Pond. The PR is also the liable party for any incidents during the group's visit to the pond.

- 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 pond. 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 emergency personnel.

- Designated Runner: The DR is responsible for knowing all the relevant entrances/exits to all spaces during the group’s visit to Moore pond. They are responsible for knowing where to meet emergency personnel best and how to direct them to the Pond due to its location being offroad.

Along with the roles above, our team also created an outdoor safety plan that 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.

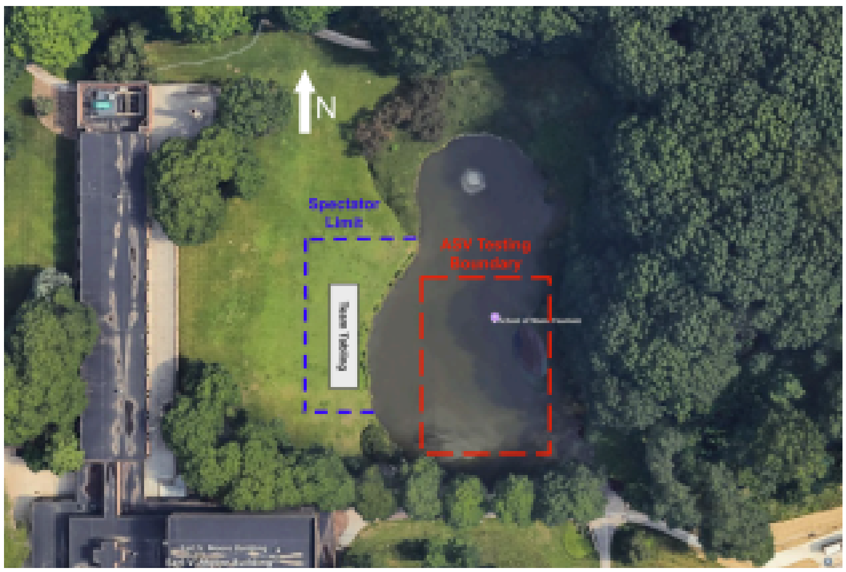


Figure A3. Outdoor Testing Layout from Safety Plan

Our team prioritized the safety of surrounding personnel and minimized environmental and public disturbances during all testing activities. Equipment and cables were kept clear of nearby walkways, noise levels were maintained at low decibel levels, and care was taken to avoid disturbing local wildlife. The vessel wake was kept to a minimum, and all equipment and materials were properly removed and disposed of following each testing session

A.6 Software Testing Results

Through the weekly testing sessions, the team obtained valuable information primarily used to update software for Nav/Controls and CV continuously. Each 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 changes and hardware upgrades.

A.7 Stability Testing Results

Stability testing validated that The Orca 2.0 corrected the roll-stability deficiency seen in The Orca. Orca 2.0 exhibited positive GMt while the original Orca measured negative GMt, indicating a transition from unstable to stable small-angle roll behavior. This improvement is consistent with the design changes intended to increase righting moment and add roll-resisting hydrodynamic damping.

Results of Stability testing are further depicted in Appendix C.2

Appendix B: Components List

	Vendor	Model/Type	Specs	Custom/ Purchased	Cost ($)	Year of Purchase
ASV Hull Form/Platform	Fibre Glast	Monohull X-Bow	Carbon Fiber	Custom	2,653.76	2026
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	BOSGAME Intel Mini PC i5 12600H(12C/20T, up to 4.5GHz) 32GB DDR4 512GB NVMe SSD, Dual LAN Mini Computer s for Office & Business, Triple Display, WiFi 6E, Bluetooth 5.2	Intel 12th Gen Core i5-12450H	Purchased	399	2025
Teleoperation	Amazon	X8R Receiver	8-Channel	Purchased	40	2024
Inertial Measurement Unit (IMU)	VectorNav	VectorNav	VN-300	Purchased	5000	2019
Camera(s)	e-con Systems	RouteCAM_CU22_IP67 - Outdoor Lowlight GigE HDR Camera	HD @ 60 fps & Full HD @ 60 fps, waterproof	Purchased	329	2025
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		PID Control Loop	N/A	Custom		
Vision	N/A	OpenCV, Yolov11 Deep Learning Model	N/A	Custom		
Localization and Mapping		UM::Autonomy Custom Sensor Fusion Algorithm	N/A	Custom		

Autonomy	UM::Autonomy		N/A	Custom		
Open Source Software	N/A	ROS 2, OpenCV, Ubuntu, YOLOv11	N/A	Custom		

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 Hull	22.3	30.3	8.3	0	675.7	185.2	0
Pegboard	3.3	25.4	1.0	0	83.8	3.3	0
Electrical Box	10.8	24.50	5.2	0	264.4	56.2	0
Velodyne	1.8	6.4	13.7	0	11.5	24.7	0
E-Stop	1.0	36.9	10.2	0	36.9	10.2	0
Rocket	1.2	60.1	12.5	0	72.1	15.0	0
Deck Hatch	1.9	21.6	13.1	0	41.0	24.9	0
Water Pump System	0.3	4.2	3.7	0	1.3	1.1	0
Ball Launch System	3.5	49.9	5.2	0	174.7	18.2	0
T500 x2	5.9	40.3	-0.5	0	237.8	-3.0	0
Battery	5.0	29.7	3.9	0	148.5	19.5	0
TOTAL	**57.0**				**1747.9**	**355.23**	**0**

LCG (in)	VCG (in)	TCG (in)
30.66	**6.23**	**0**

C.2 Stability Testing

C.2.1 2025 ORCA Trim & Stability - Software Analysis

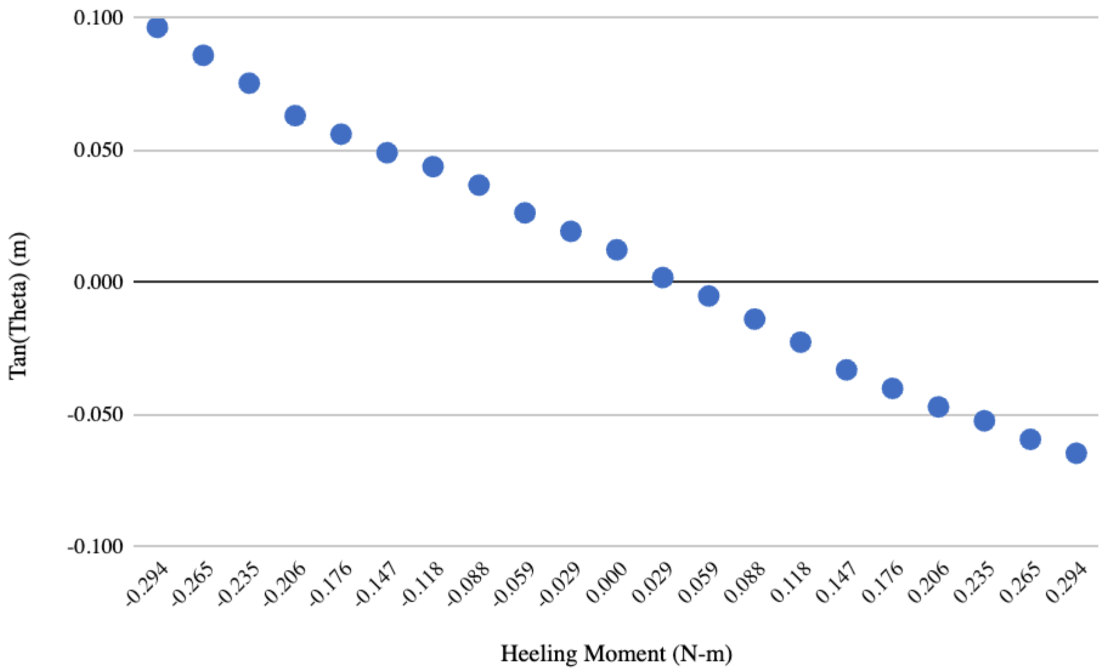
Condition	Sinkage (in)	Trim (deg)	Heel (deg)	LCB (in)	TCB (in)	VCG (in)	GMt (in)
Neutral	-3.66	1.27	0	27.21	0.9	1.68	-0.61*

The hull of the original Orca (without outriggers or ballast) had a negative GMt. This suggests an unstable vessel.

C.2.2 Physical GMt Testing Analysis

To determine and verify the GMT of the original Orca with all of its components, an inclining experiment was conducted in the Marine Hydrodynamics Laboratory's Wind-Wave Tank. Below is the analysis and results.

GZ v Theta for Orca



Results

Total Calculted GM (m)	Total Calculted KG (m ABL)	STDV of KG (m)	KG without Heeling Ballast and Rail (m ABL)	Corrected KG with Heave Staff (m ABL)
-0.008	0.162	0.013	0.160	0.160

This confirms that the Orca (2025) had a negative GM.

C.2.3 2026 ORCA 2.0 Trim & Stability - Software Analysis

Condition	Sinkage (in)	Trim (deg)	Heel (deg)	LCB (in)	TCB (in)	VCG (in)	GMt (in)
Neutral	-0.02	0.32	0.16	2.55	0.12	0.52	0.19

GMt should be in a preferred range of 2-3in for resistance wind heeling and dynamic stability in waves*
Calculations were run without fin keels, so vessel with the addition of fin keels should have an improved GMt **

C.3 Propulsion Calculations

T500 @ 24 V

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

$$T_{tot,\,500,\,FWD} = 35.5 \bullet 2 = 71\ lbf$$

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

Maximum $T_{tot,\,500,\,FWD}$ recorded at 2025 RoboBoat Competition:$24.0\ /\ 2\ = 12\ lbft\ per\ thruster$

C.4 Water Cannon Testing & Calculations

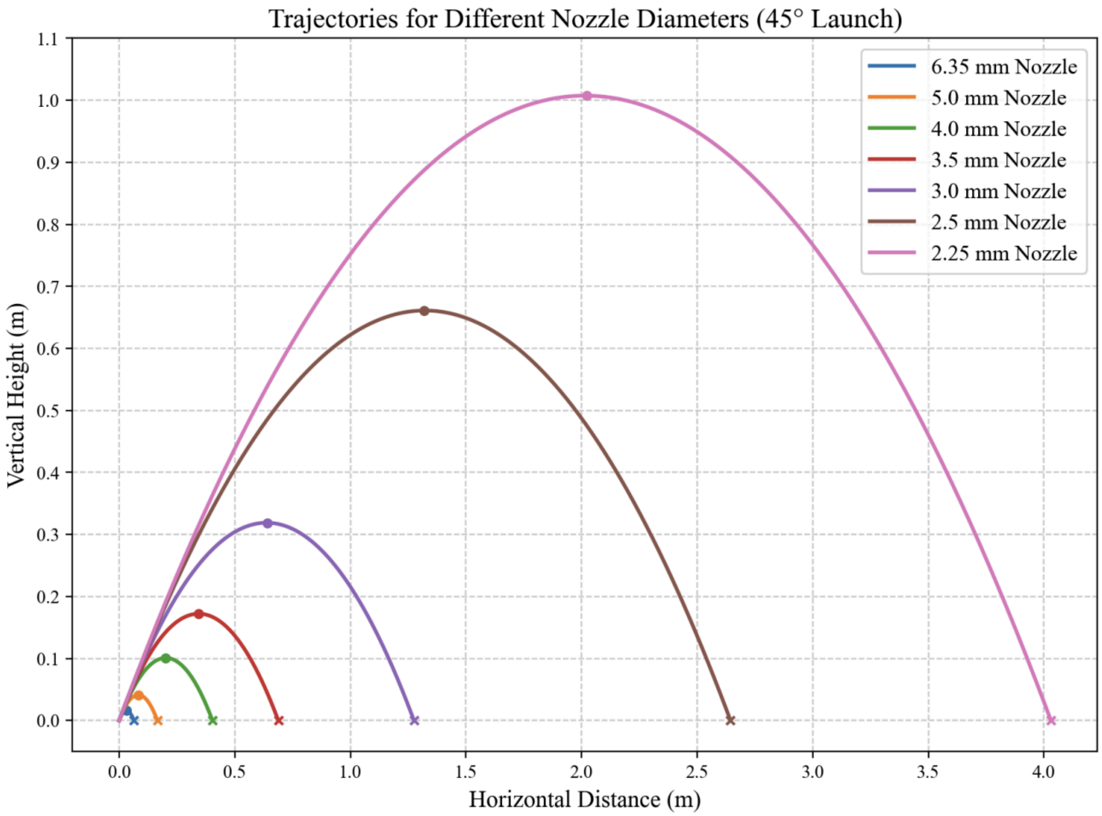
Parameters:
Pump: Hyuduo Electric Diaphragm Pump (Amazon)
Output Rate: 1.5-2.0 L/min (2.5e-5 m^3/s)
Voltage: 12V
Tubing: 1/4" ID x 3/8" OD
Water Reservoir: 15 fl oz (1 lb of water, 0.444 L)

Calculations:
To maximize the distance of the water being shot, we mount our nozzle at 45°. We used this value for calculations to determine the ideal nozzle size for the necessary trajectory.

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

After doing these theoretical calculations, we experimented with 3d printing a few different variations of nozzles to see what would work the best. From these experiments, we determined that a 2mm nozzle to maximize the distance that our water shooter sprays.

Below are calculations from python on nozzles ranging from 6.35mm down to 2.25mm.


Trajectories for Different Nozzle Diameters (45° Launch)
6.35 mm Nozzle
5.0 mm Nozzle
4.0 mm Nozzle
3.5 mm Nozzle
3.0 mm Nozzle
2.5 mm Nozzle
2.25 mm Nozzle
Vertical Height (m)
Horizontal Distance (m)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

Appendix D: Electrical System Overview

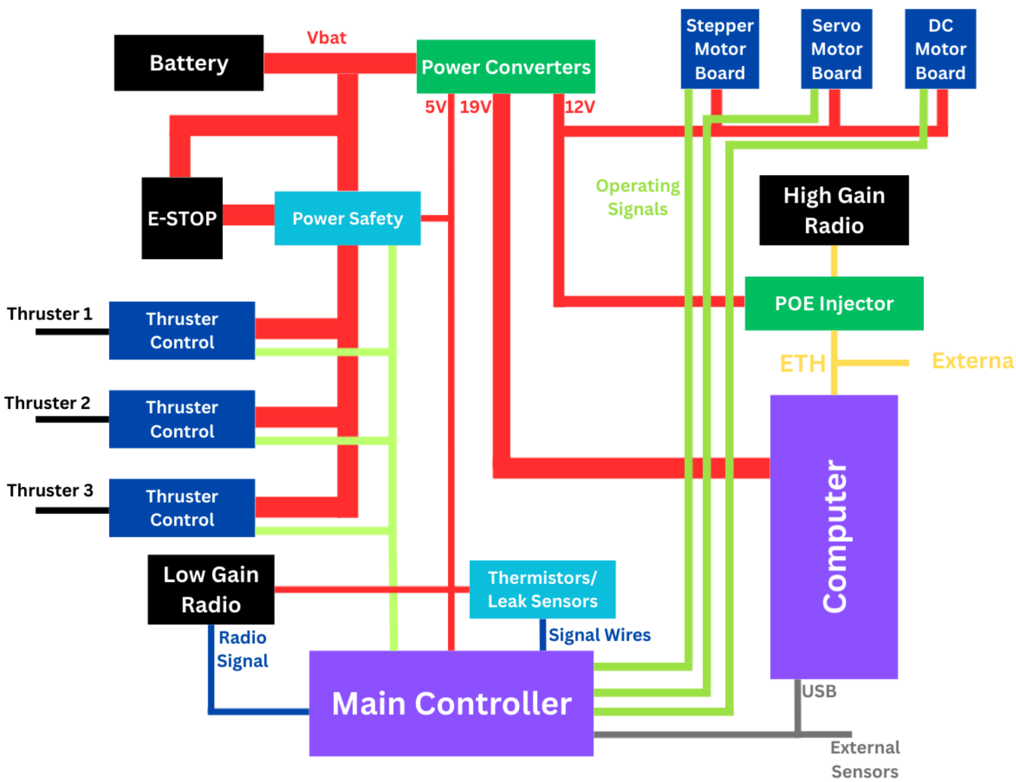


Figure D1. Electrical system overview

Figure D1 details the overarching construction of the electrical system, which can be broken up into 3 groups, power, computing, and outputs. The power aspect runs from the battery through the converters to supply each system with the necessary supply voltage. On the computing side, we run everything from the main controller to the computer to achieve a central processing network. Both of these subsystems provide the necessary resources to run the thrusters and servo motors in the required fashion.

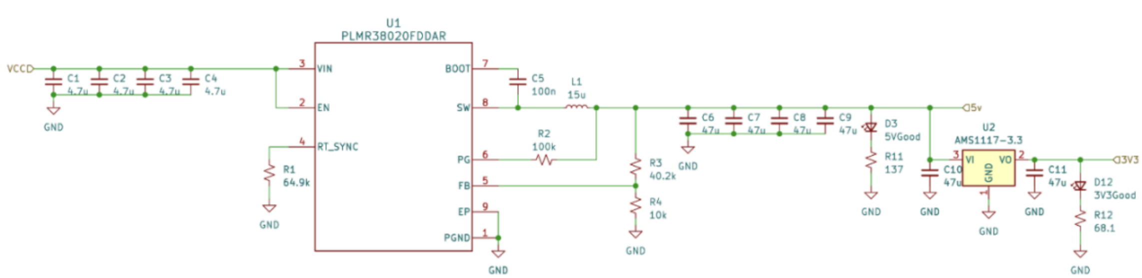


Figure D2. Power Regulation Circuit

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.

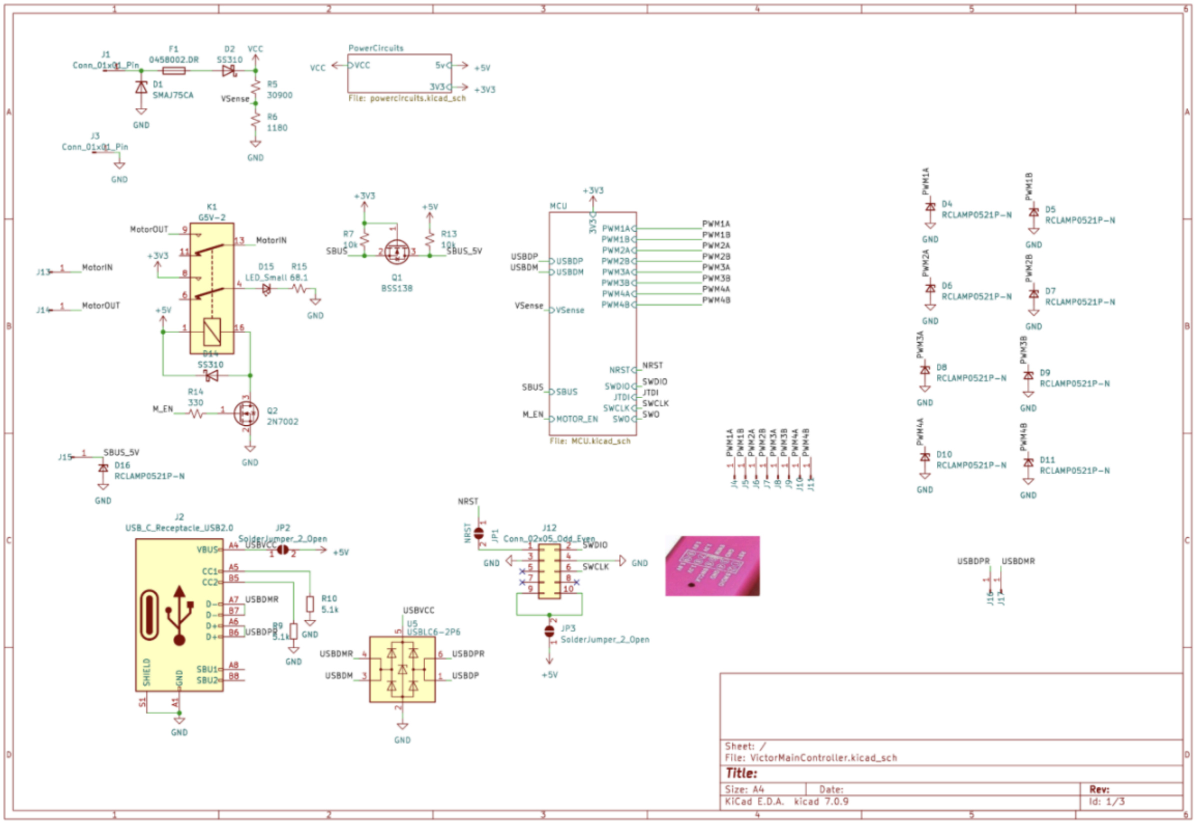


Figure D3 Speed controller

Figure D3 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.

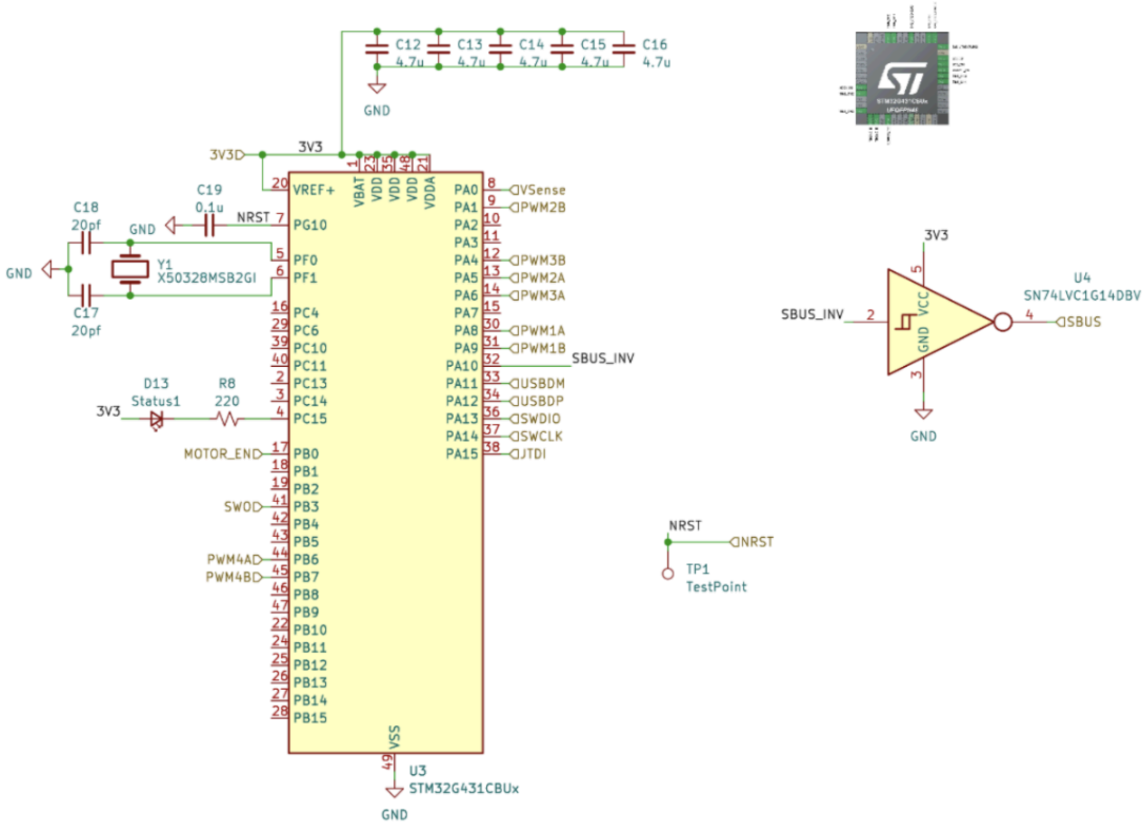


Figure D4. Boat's Main Microcontroller

Figure D4 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.

Appendix E: Cost of Hull Manufacturing

Product	Vendor	Product ID	Cost	Use
Duratec Grey surfacing Primer	Fiber Glast	707-002	$154.45	Finish mold
Duratec Hardener	Fiber Glast	707-002	Comes with hardener	Mix into duratec to finish mold
Duratec Thinner	Fiber Glast	39UCEG	$80.00	Mix into duratec to finish mold
Acetone	Aramsco	1684-6368	$10.03	Clean spray gun after spraying duratec
Isopropyl alcohol	ForPro		$9.79	clean and prep molds to be sprayed with duratec
Gram Scale	BOMATA		$33.88	Accurately measure ratios of duratec and thinner + hardener to ensure optimal results
Sandpaper	BOSCHCRAFT		$11.99	Sand molds to enable adhesion
Brown Butchers paper	Home Depot		$4.98	Protect work surfaces during duratec spraying
Measuring cups	Technoglow	M02-SMC-4P CS	$12.00	Accurately measure ratios of duratec and thinner + hardener to ensure optimal results
Painters Tape	Home Depot		$8.00	Required for vacuum bagging process

Vacuum Sealant Tape	Fiber Glast	AT200Y	$11.28	Required for vacuum bagging process
Epoxy	Fiber Glast	2001	$185.35	Saturated into carbon fiber to provide structure to hull
Epoxy Hardener	Fiber Glast	2001	$61.75	Hardens the epoxy into a stiff product
Carbon Fiber	Fiber Glast	1069-C	$548.80	Primary element of carbon fiber layup; hull material
Release Film	Fiber Glast	200	$26.73	Required for vacuum bagging process
Fluffy breather/bleeder	Fiber Glast	579-A	$30.85	Required for vacuum bagging process
Vacuum Bag	Fiber Glast	M13-5737	$49.50	Required for vacuum bagging process
Large Silicone Sheet	INFIONE		$130.00	Protective to entire work surface and does not stick to resin
Mold Release	Fiber Glast	119-A	$28.79	Allow resin & carbon fiber to release from mold
High Density Foam	RAMPF Group	08-0160-204	$1,574.80	Material to CNC mold
CNC Drill Bit	MSC	87829859	$92.12	Drill bit for CNCing HDF
		Total	**$3,065.09**	

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

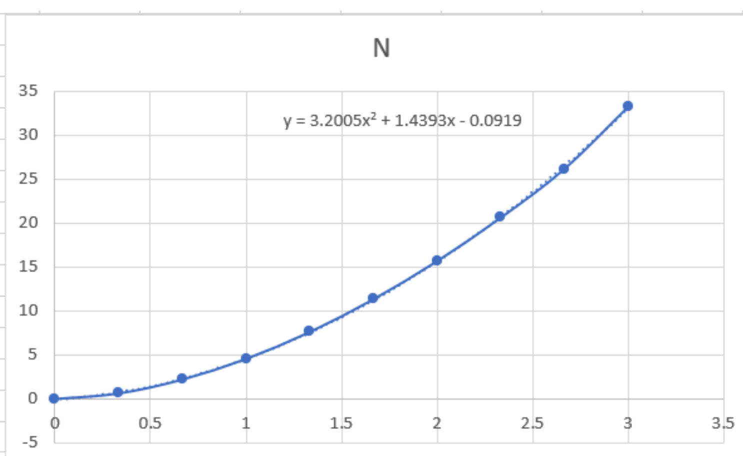


Figure F1. Resistance vs. Speed

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

Appendix F.2

$F_{sway} = C_D * .5 * \rho_{seawater} * v^2 * (C_{prism})$

$C_{prism} = V_{hull} / (A_{max} * L_{pp}) = .005m^3 / (.03129m^2 * 1.1176m) = .14298$

$C_D \approx .9$

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

$F_{sway} = .9 * .5 * 1026 * v^2 * .14298 = 66.01v^2$ [Ns/m]