RoboBoat 2025: Environmental Monitoring: Guardians of the Waters

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Technical Design Report
UPRM RoboBoat Team: AquamaRUM

Abstract

AquamaRUM was initially designed for the 2024 RoboBoat International Competition and further enhanced for the 2025 RoboBoat International Competition. Designed with a focus on modularity and adaptability, AquamaRUM features fiberglass hulls that provide stability, an optimized power management system and navigation algorithms powered by YOLOv8’s object detection system. This design and system architecture closely aligns to the team’s competition strategy targeting Autonomous Navigation, leading to key implementations such as in-house behavior trees. The testing phase allowed the team to fine-tune hardware components, optimize navigation algorithms, and ensure seamless integration of all subsystems. The lessons learned from the 2024 competition and the integration of upgrades underscore AquamaRUM’s potential for success in the 2025 Competition.

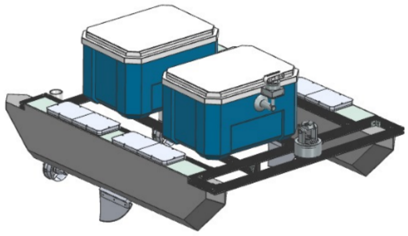

Figure 1: AquamaRUM CAD Render

I. Competition Goals and Strategy

A. General Strategy

The UPRM RoboBoat Team’s strategy for the competition focuses on prioritizing the navigation tasks, as they are fundamental to demonstrating AquamaRUM’s core capabilities while maximizing points. The primary objectives include navigating the ***Navigation Channel***, successfully completing ***Follow the Path***, ***Speed Challenge*** and the ***Water Delivery*** part of **Task 5**, demonstrating precise maneuvering, decision-making and consistent performance through robust control algorithms. Secondary objectives focus on advanced tasks, including ***Docking***, and the ***Object Delivery*** part of Task 5. The decision to enhance AquamaRUM’s design from the 2024 competition, rather than designing and manufacturing a new boat, allowed the team to focus on refining software systems and enhancing testing workflows, ensuring continuous in-water trials throughout the semester.

B. Task Breakdown

Task 1 - Navigation Channel: To autonomously navigate through two pairs of red and green buoys, buoy detection and path planning techniques are employed. First, AquamaRUM identifies buoys by shape and color. After the pair of buoys has been identified, the midpoint between them is calculated and the vessel is instructed to move continuously through it.

Task 2 - Mapping Migration Patterns (Follow the Path): AquamaRUM’s navigation strategy mirrors the principles of the Navigation Channel. The Autonomous Surface Vehicle (ASV) is programmed to identify a buoy gate and maintain continuous movement through it while executing a parallel decision tree combined with obstacle avoidance algorithms. The vision system dynamically processes visual data: upon detecting a yellow buoy, the ASV executes an avoidance maneuver and increments a counter for yellow buoys. If a stationary vessel is identified, the ASV switches to a decision tree specific to handling stationary vessels. Once no further gates are detected, the ASV communicates with the Ground Control Station (GCS) and displays the yellow buoy count on the interface.

Task 3 - Treacherous Waters (Docking): The approach for this task consists of maneuvering into a dock marked with the correct color or shape by evaluating docks and bypassing the occupied ones. This ability relies on the computer vision model trained to identify shapes and colors that provide accuracy and high adaptability.

Task 4 - Race Against Pollution (Speed Challenge): AquamaRUM begins by locating the first set of gates, calculating the midpoint, and moving near it while passing through the gate, marking the location as "home." The onboard camera, mounted on a custom turret, then rotates to monitor a light panel, awaiting a green signal. Once detected, the ASV advances until it identifies the blue buoy, executing a parallel decision tree alongside obstacle avoidance algorithms. Black buoys trigger avoidance maneuvers, while stationary vessels engage specific decision trees. Upon detecting the blue buoy, the ASV calculates three target points—right, behind, and left of the buoy—and sequentially navigates to each. After completing these maneuvers, the ASV returns to its "home" location, ensuring precise execution of the task.

Task 5 - Rescue Deliveries (Object and Water Delivery):

Water Delivery: During this task, AquamaRUM will identify and approach the *orange vessels* in the course. After the ASV accurately aligns with the vessel's black triangles using its vision system, the onboard computer will activate the Water Gun System. The ASV will release water streams for predetermined intervals, adjusting length based on its distance to the target while maintaining stability for accuracy.

Object Delivery: In this task, similarly to the *Water Delivery* approach, AquamaRUM will use its vision system and approach the *black vessels* on the course. The ASV will align with the black cross shapes on the vessels and maintain stability. Once the targets are assessed, the Ball Launcher System will fire pre-loaded racquetballs with varying force based on the final distance.

Task 6 - Return to Home: To return to the designated location, the ASV navigates to a previously recorded coordinate, saved prior to entering the navigation channel. During this return, the ASV's vision system is configured to disregard all detected buoys while executing obstacle avoidance algorithms to ensure safe traversal. The ASV proceeds until it identifies and reaches the black gate, marking the completion of the return sequence.

II. Design Strategy

The design of the ASV remains mainly unchanged from the previous iterations, maintaining its proven framework. However, key adjustments were incorporated based on the valuable lessons learned from last year's competition. These refinements address specific challenges encountered such as fine-tuning the decision tree algorithms for better path planning, improving boat stability, water proofing and upgrading battery monitoring systems. These changes aim to build upon the ASV's established strengths while addressing areas for improvement to achieve greater performance and reliability.

A. Mechanical Design

1. Propulsion System

The ASV is equipped with two T200 thrusters from Blue Robotics, chosen for their reliability and performance. As shown in Appendix H the thrust is 9.9lb, while the drag force is only 3.1lb, in, this allows for optimal power usage, flexibility in adjusting speeds, and the ability to experiment with different accelerations.

To address ergonomic issues encountered during the assembly process, a new mechanism inspired by a hinge was developed for the thruster mount. This design eliminates the need to disassemble the mount during transportation.

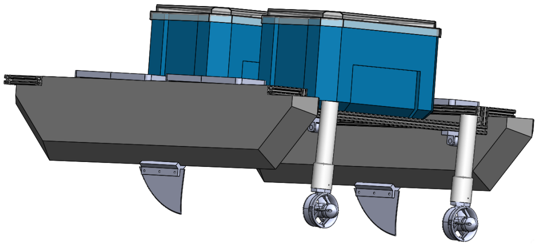

Figure 2. Thruster Configuration

2. Vessel arrangements

The hulls, connected by an aluminum extrusion 43” × 36” frame, are 4 feet long and 4 inches wide. This arrangement provides a 28-inch gap between them, granting enough room for the components to be placed between them. The frame supports two component boxes: the heavier battery box, positioned toward the rear to balance the load, and the navigation box, placed closer to the center of gravity to optimize accuracy. For the hull design, two key ratios were considered: the Hull Fineness Ratio (HFR) and the Hull Centerline Beam to Waterline Length (BCL/LWL), both of which help balance the tradeoffs between stability and maneuverability. The HFR is calculated by dividing the hull length by beam width, resulting in a 10:1 ratio typical for cruising catamarans (8-12:1). The BCL/LWL ratio is based on the waterline for the ASV weighing around 40lb, yielding a ratio of approximately 0.7, with 0.5-0.6 being ideal for cruising catamarans, where a higher ratio emphasizes stability.

3. Waterproofing

Past iterations of the design faced water leakage issues due to the hull lids. To resolve this, the team developed a new lid design incorporating O-rings to create a watertight seal. The new design was inspired by those used in advanced boats, ensuring improved reliability. The lids were designed to effectively block water from entering, addressing the waterproofing requirements caused by the frame attachment points.

4. Directional control

To improve directional control, the lateral forces experienced by the ASV due to interactions with wind and water were analyzed. Based on the calculations shown in Appendix G, stabilization fins were designed to counteract these forces and enhance stability. The fins were positioned at the center of the vessel, as the majority of the lateral forces occurred in this area. These fins were custom-designed and manufactured using 3D printing technology, with PLA chosen as the material due to its affordability and accessibility, aligning with the project constraints. Each fin has an area of 0.16 ft^2, a dimension determined after thorough calculations. This size was selected because the lateral forces vary by velocity, and the chosen area allows the boat to withstand a wider range of conditions effectively.

B. Electrical System

1. Thruster Battery Pack:

The propulsion system, utilizing Blue Robotics T200 thrusters, requires a battery capable of sustaining full-throttle operation while providing sufficient energy to power the vessel throughout the duration of the complete course or challenge. Currently, the power system includes two Zeee batteries (one intended for redundancy), configured in a 4S1P arrangement to deliver 14.8V with a capacity of 10Ah.

2. System Battery Pack:

The team has acquired two 7,000mAh 77.7Wh 11.1V Gens Ace battery packs. By connecting them in parallel the system will achieve a total capacity of 14,000mAh to supply power to the 12V components via a fuse block. Based on calculations, the system consumes 65.6Wh with all components running at maximum power. Therefore, the system can operate at full power for 1.5 hours while retaining 37% of the battery capacity.

3. Kill Switch:

In addition to the physical kill switch, the vessel is equipped with a wireless kill switch integrated with one of the remote controller's switches. During testing conducted at full throttle, the activation of the wireless kill switch resulted in an immediate shutdown, effectively cutting power from the thrusters.

4. Battery Telemetry:

Batteries in use are equipped with a Bluetooth-enabled monitoring device connected via the cell balancer port. This setup enables accurate real-time monitoring of the battery, both during in-water operations and when the system is inactive.

C. Software Architecture

1. Navigation and Control Algorithms

AquamaRUM's navigation and control systems ensure reliable task execution using a robust Python-based tech stack. The architecture comprises two subsystems: vision and control. The control system communicates with the Ground Control Station (GCS) to publish telemetry and system status, manages the ASV's operational status, interfaces with the flight controller, and initiates movement subprocesses. The ASV operates in two modes: AI/Pathfinding and Missions. Pathfinding mode uses dynamic decision trees, implemented with Python's Py-Trees library, to generate navigation commands based on vision pipeline data. These customizable trees are task-specific and modular. Missions' mode executes preloaded instructions in a custom scripting language designed for the vessel's operations.

2. AI and Computer Vision

The AI and computer vision systems use a vision pipeline for object detection. Data from a RealSense D435 camera is processed by an in-house-trained YOLOv8 model to identify specific object segments. The system minimizes processing overhead by sending frames at a specific rate. Outputs include object type, color, and radial coordinates, enabling real-time navigation.

3. Network System

AquamaRUM's networking infrastructure ensures reliable ASV-GCS communication using a Wi-Fi network enhanced with 5G extenders for extended range and high-speed data transmission. Configurable parameters, like channel width adjustments, mitigate interference, while the extenders' modes—router, repeater, and access point—offer versatility for various mission needs.

4. Ground Control Operations

The Ground Control Station (GCS) connects to the ASV via SSH over a network link provided by an onboard antenna, allowing remote management of vision and control processes. The GCS provides access to dynamic persistence data, such as buoy counts and confirmed objects, tailored to the active decision tree. This ensures the operator and system have critical information for effective decision-making and monitoring.

D. Special Task Modules

For the Task-Specific Challenges this year's objective was to design and implement mechatronic systems to improve the ASV's performance. Based on previous competition experiences, the focus was placed on developing semi-automatic modules, controlled via On/Off Pulse Width Modulation (PWM) signals. The approach prioritized simple design concepts for initial iterations, even if it possessed limited operational windows. Detailed design decisions, analysis calculations, specifications, and prior design iterations are documented in Appendix D.

1. Water Delivery Mechanism

For the Water Delivery portion of the Task 5, a turret design was chosen as the optimal solution to accurately hit the targets, as shown in Figure 3. Once the vision system detects the triangular shape, it triggers a subroutine on the microcontroller to spray water within the designated area. The turret oscillates within a 135 º range, while the voltage input to the submersible pump is controlled to manipulate the water gun's range, ensuring coverage of the entire area (maximum range of 16ft). The fixed spraying method allows the ASV to cover a wide area for approximately 30 seconds, prioritizing covering a wide area over accuracy. This is done to compensate for in-water conditions like drifting or incorrect data from the initial detection point.

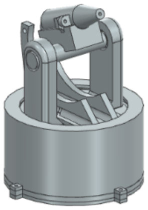

Figure 3: 2nd Generation Water Gun Module

2. Object Delivery Mechanism

For Object Delivery in Task 5 a similar approach was taken to the water gun module as for the current iteration of launcher is a static design with a manual setup for aiming. A sling shot mechanism with industrial rubber bands #64 was chosen over a tennis ball launcher approach since only three racquetballs can be preloaded. A two-gear system is in charge of reeling back the rubber bands via a rail. The release is done by spinning the DC motor in another direction through the L298N H-Bridge module. Furthermore, a servomotor in the top part of the module will control the in-feed of racquetballs.

3. Camera Turret Mechanism

The camera turret module, shown in Figure 4, was developed similarly to that of the Water Gun module to aid the ASV in Task 4 by providing the camera the ability to rotate 90º degrees to the right or left. This expands the field of vision, allowing the ASV to detect the light panel from either side to perform the speed challenge without compromising the starting position. Similarly to the design of the water gun this module contains a Buna O-ring on the rotating shaft for waterproofing, protecting the internal MicroServo-SG90.

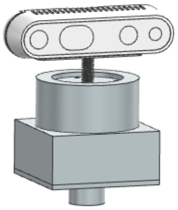

Figure 4: 1st Generation Camera Turret Module

4. Interior Data Panel

To continuously monitor and provide real-time feedback on temperature and humidity levels within the ASV's software component box, temperature and humidity sensors will be strategically placed inside the enclosure. An LCD display will be mounted on a casing attached to the transparent lid, enabling clear visibility of the data. This setup aims to record these metrics for testing and analysis, enhancing component protection and assessing other relevant environmental factors.

III. Testing Strategy

A. Testing Framework

The testing framework focuses on two main objectives: ensuring waterproofing and enhancing directional control. Waterproofing tests evaluate the vessel's ability to maintain a watertight seal at varying speeds in a controlled environment, allowing the team to identify any leakage issues. For directional control, the testing integrates computational fluid dynamics (CFD) analysis with velocity-based trials. The vessel navigates the pool at different speeds while the stabilization fins are monitored for their effectiveness in maintaining stability and minimizing lateral forces.

B. Simulations

AquamaRUM's simulation framework refines pathfinding algorithms without physical deployment. The environment replicates key subsystems like the vision pipeline and flight controller. Ardupilot SITL simulates vehicle dynamics, while a custom vision simulator creates buoy arrangements based on relative coordinates. The simulator's lightweight design enables rapid testing and iteration, ensuring seamless transitions from virtual to real-world testing. Additionally, the team is developing a Gazebo environment to expand testing capabilities, allowing for more detailed and realistic simulations of the ASV's interactions with its surroundings.

C. Field Testing

1. Waypoint Tracking

Waypoint tracking tests evaluate AquamaRUM's ability to navigate predefined paths in controlled environments. These tests focus on accuracy, stability, and responsiveness to real-time conditions. Metrics include waypoint precision, path stability, and control adjustments.

2. Obstacle Avoidance

Obstacle avoidance tests assess AquamaRUM's capability to detect and navigate around obstacles in real-time scenarios. These tests involve placing various objects in the vehicle's path to evaluate its detection algorithms and pathfinding systems. Key metrics include the accuracy of obstacle detection, the system's ability to adjust its route dynamically, and the responsiveness of the control algorithms. These tests aim to confirm AquamaRUM's reliability and adaptability in challenging, dynamic environments.

3. Test Locations and Logistics:

Testing is conducted in a pool and at the beach to evaluate the ASV's performance. The pool provides a controlled environment for waterproofing, buoy detection, and navigation trials with minimal external disturbances. The beach allows for open water testing to assess pathfinding, stability, and adaptability in real-world conditions.

4. Endurance Testing:

The vessel has a total runtime of 1.5 hours with all systems operating at maximum power. During the Challenge course, the thrusters run intermittently at 50%-70% throttle. Calculations in Appendix C estimate the thrusters' total runtime to be approximately one hour.

IV. Conclusion

AquamaRUM was originally designed for the 2024 competition, but with the enhancements made for the 2025 iteration, it is now optimized for this year's challenges. The team's competition strategy focuses on navigation tasks ensuring that the design of the hulls and control systems fully support these objectives. Testing in controlled environments, including the pool and sea, has been crucial in refining the ASV's performance. Key takeaways from the project include the importance of careful task selection, iterative design, and real-world testing to achieve a high-performance system. Looking ahead, future iterations will focus on further refining the autonomy system for increased precision, enhancing the robustness of the control algorithms, and expanding the ASV's capabilities to tackle even more complex tasks.

V. Acknowledgments

The creation of AquamaRUM has been made possible through the dedication of our remarkable team and the generous support of our sponsors. We extend our heartfelt appreciation to each team member for their work and commitment which has been instrumental in every phase of AquamaRUM's development. We acknowledge our previous advisor, Dr. Ruben Diaz, as well as our current advisor, Dr. Juan Patarroyo, for their invaluable guidance and mentorship, critical to the project's success. Special thanks to our sponsors, Boeing, Lockheed Martin, and GM, for their generous financial contributions that significantly enhanced the project.

VI. References

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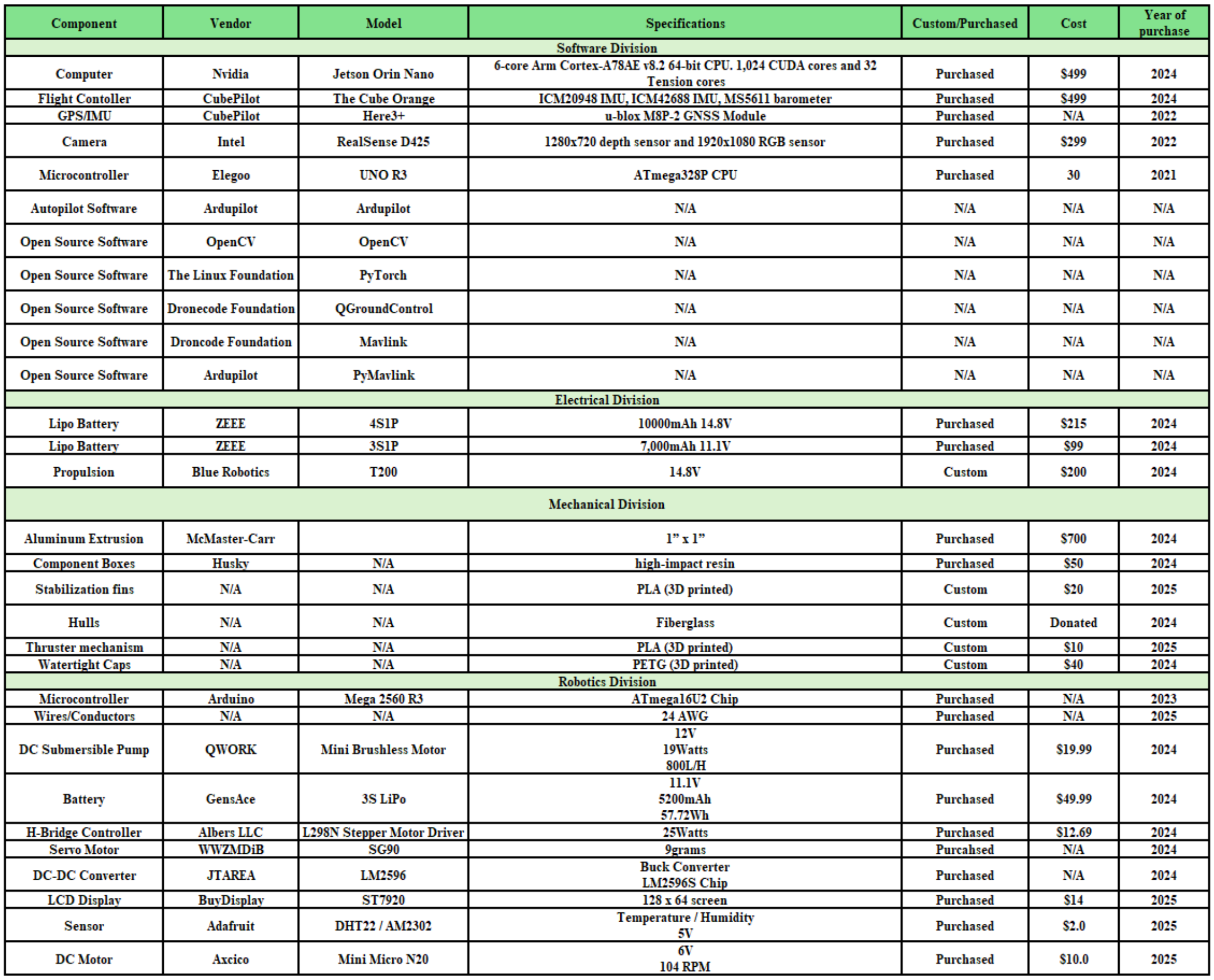
VII. Appendices

Appendix A. Component List



Component	Vendor	Model	Specifications	Custom/Purchased	Cost	Year of purchase
Software Division						
Computer	Nvidia	Jetson Orin Nano	6-core Arm Cortex-A78AE v8.2 64-bit CPU. 1,024 CUDA cores and 32 Tension cores	Purchased	$499	2024
Flight Contoller	CubePilot	The Cube Orange	ICM20948 IMU, ICM42688 IMU, MS5611 barometer	Purchased	$499	2024
GPS/IMU	CubePilot	Here3+	u-blox M8P-2 GNSS Module	Purchased	N/A	2022
Camera	Intel	RealSense D425	1280x720 depth sensor and 1920x1080 RGB sensor	Purchased	$299	2022
Microcontroller	Elegoo	UNO R3	ATmega328P CPU	Purchased	30	2021
Autopilot Software	Ardupilot	Ardupilot	N/A	N/A	N/A	N/A
Open Source Software	OpenCV	OpenCV	N/A	N/A	N/A	N/A
Open Source Software	The Linux Foundation	PyTorch	N/A	N/A	N/A	N/A
Open Source Software	Dronecode Foundation	QGroundControl	N/A	N/A	N/A	N/A
Open Source Software	Droncode Foundation	Mavlink	N/A	N/A	N/A	N/A
Open Source Software	Ardupilot	PyMavlink	N/A	N/A	N/A	N/A
Electrical Division						
Lipo Battery	ZEEE	4S1P	10000mAh 14.8V	Purchased	$215	2024
Lipo Battery	ZEEE	3S1P	7,000mAh 11.1V	Purchased	$99	2024
Propulsion	Blue Robotics	T200	14.8V	Custom	$200	2024
Mechanical Division						
Aluminum Extrusion	McMaster-Carr		1" x 1"	Purchased	$700	2024
Component Boxes	Husky	N/A	high-impact resin	Purchased	$50	2024
Stabilization fins	N/A	N/A	PLA (3D printed)	Custom	$20	2025
Hulls	N/A	N/A	Fiberglass	Custom	Donated	2024
Thruster mechanism	N/A	N/A	PLA (3D printed)	Custom	$10	2025
Watertight Caps	N/A	N/A	PETG (3D printed)	Custom	$40	2024
Robotics Division						
Microcontroller	Arduino	Mega 2560 R3	ATmega16U2 Chip	Purchased	N/A	2023
Wires/Conductors	N/A	N/A	24 AWG	Purchased	N/A	2025
DC Submersible Pump	QWORK	Mini Brushless Motor	12V 19Watts 800L/H	Purchased	$19.99	2024
Battery	GensAce	3S LiPo	11.1V 5200mAh 57.72Wh	Purchased	$49.99	2024
H-Bridge Controller	Albers LLC	L298N Stepper Motor Driver	25Watts	Purchased	$12.69	2024
Servo Motor	WWZMDiB	SG90	9grams	Purcahsed	N/A	2024
DC-DC Converter	JTAREA	LM2596	Buck Converter LM2596S Chip	Purchased	N/A	2024
LCD Display	BuyDisplay	ST7920	128 x 64 screen	Purchased	$14	2025
Sensor	Adafruit	DHT22 / AM2302	Temperature / Humidity 5V	Purchased	$2.0	2025
DC Motor	Axcico	Mini Micro N20	6V 104 RPM	Purchased	$10.0	2025

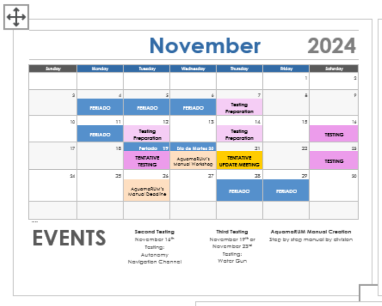
Appendix B. Testing plan

I. Scope

The scope of this testing plan encompasses addressing critical design and performance issues identified in previous competition analyses, alongside advancing the functionality of the vessel through software improvements. Key areas of focus include:

1. **Hull Integrity**:
    - Redesigning the hull covers to eliminate leakage issues by replacing the gasket seal with an O-ring, ensuring a reliable and watertight seal.
2. **Stability Enhancements**:
    - Implementing stabilizing fins on the boat's hulls to counteract lateral forces caused by water currents, wind, or their combination, thereby improving the vessel's operational stability.
3. **Battery Monitoring System**:
    - Integrating a Bluetooth-enabled battery monitoring system to provide real-time updates on battery levels via a mobile device, ensuring effective power management during on-water operations.
4. **Software Optimization**:
    - Enhancing the software systems to improve overall performance, including more efficient buoy detection, path-planning algorithms, and real-time data analysis.
    - Refining system integration between sensors, control systems, and decision-making frameworks to ensure seamless operation and reliable task execution during competitions.

II. Schedule



November 2024

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
					1	2
3	4 FERIADO	5 FERIADO	6 FERIADO	7 Testing Preparation	8	9
10	11 FERIADO	12 Testing Preparation	13	14 Testing Preparation	15	16 TESTING
17	18	Feriado 19 TENTATIVE TESTING	Día de Martes 20 AquamaRUM's Manual Workshop	21 TENTATIVE UPDATE MEETING	22	23 TESTING
24	25	26 AquamaRUM's Manual Deadline	27	28 FERIADO	29 FERIADO	30

EVENTS

Second Testing
November 16th
Testing:
Autonomy
Navigation Channel

Third Testing
November 19th or
November 23rd
Testing:
Water Gun

AquamaRUM Manual Creation
Step by step manual by division

December 2024

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6 ULTIMO DIA DE CLASES	7 TENTATIVE TESTING
8	9	10 Periodo	11 de	12 Examenes	13 Finales	14
15	16	17 Deliverables	18 Registration Deadline	19 Creation	20	21
22	23	24	25	26	27	28
29	30	31				

EVENTS

December 7th
Last testing for 2024 Semester

Deliverables
Start the Development of Deliverables during Winter Break

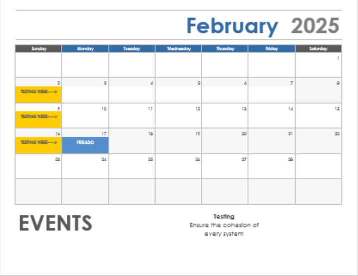
January 2025

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1	2	3	4
5	6	7	8	9	10	11
12	13	14 Comienzo de Clases	15	16 Deliverables Development	17	18
19	20 FERIADO Event Submissions	21 Dia de Lunes	22	23 Deliverables Development	24	25
26	27 Deliverables Deadline	28	29	30	31	

EVENTS

January 20: Event Submissions
Team Member Registration
Team Demographics
Merchandise Order
Vehicle Information
On-Site Requirements

January 27: Design Documentation
Website
Technical Design Report
Team Video
Community & Outreach (optional)



February 2025

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2 TESTING WEEK---->	3	4	5	6	7	8
9 TESTING WEEK---->	10	11	12	13	14	15
16 TESTING WEEK---->	17 FERIADO	18	19	20	21	22
23	24	25	26	27	28	

EVENTS

Testing
Ensure the cohesion of every system

March 2025

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1	2 Prepare AquamaRUM for shipping	3 Batteries Need to be Shipped	4 Prepare AquamaRUM for shipping	5	1
2	3 FERIADO	4 Robo	5 Boat	6 International	7 Competition	8 2025
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

EVENTS

Shipment of Batteries
Batteries that need to be shipped are shipped on Wednesday before the competition.

Shipping Preparation Week
Make sure everything is packed and ready for shipping.

Competition
SHOWTIME!

III. Environment

Testing environments are carefully selected to evaluate the ASV's performance under both controlled and real-world conditions:

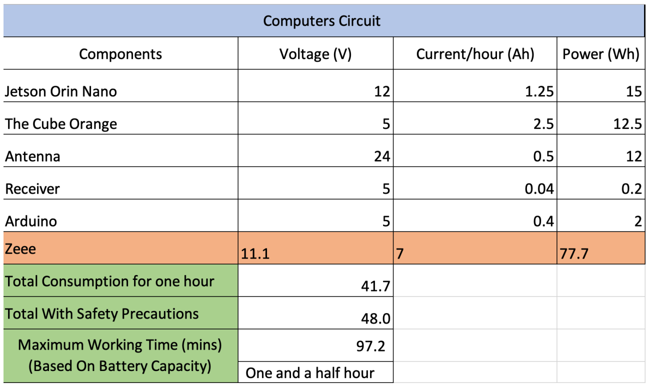
1. **Pool Testing:**
    - Conducted in a controlled environment to focus on waterproofing, buoy detection, and navigation trials with minimal external disturbances.
    - Provides an ideal setting for validating sensor accuracy, software algorithms, and the integrity of hardware components.
2. **Beach Testing:**
    - Performed in open water to assess the ASV's pathfinding, stability, and adaptability to real-world conditions such as waves, wind, and currents.
    - Offers a realistic environment to test the robustness of the ASV's systems under dynamic and unpredictable external forces.

IV. Risk Management

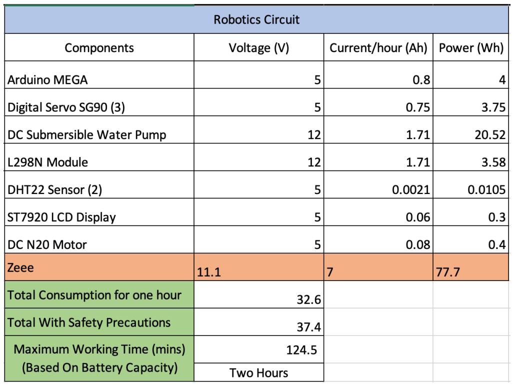
1. **Testing Environment Risks:**
    - **Pool Testing:**
        - Risk: Potential for inaccurate results due to the controlled nature of the environment.
        - Mitigation: Use the pool as a preliminary testing stage and follow up with open water trials to validate results.
    - **Beach Testing:**
        - Risk: Exposure to adverse weather conditions or strong currents may damage the ASV.
        - Mitigation: Monitor weather conditions, test in manageable environments, and implement recovery protocols in case of equipment failure.
2. **System Performance Risks:**
    - **Waterproofing Failures:**
        - Risk: Leaks in the hull during pool or beach testing.
        - Mitigation: Implement rigorous pre-testing inspections and maintain redundancy of upgraded O-ring seals.
    - **Instability in Open Water:**
        - Risk: Lateral forces from waves and wind affecting stability.
        - Mitigation: Conduct iterative testing of the stabilizing fins and adjust their design as needed based on performance data.
3. **Operational Risks:**
    - **Software Malfunctions:**
        - Risk: Errors in buoy detection or path-planning during testing.
        - Mitigation: Conduct simulations and in-pool validation before progressing to beach testing.
    - **Battery Monitoring:**
        - Risk: Uncertainty in battery levels during extended testing sessions.
        - Mitigation: Utilize the Bluetooth-enabled monitoring system to track battery percentage in real time.

By leveraging these controlled and open water testing environments, along with comprehensive risk management strategies, the ASV is systematically refined to perform reliably in competition and real-world scenarios.

Appendix C. Power Consumption Calculations

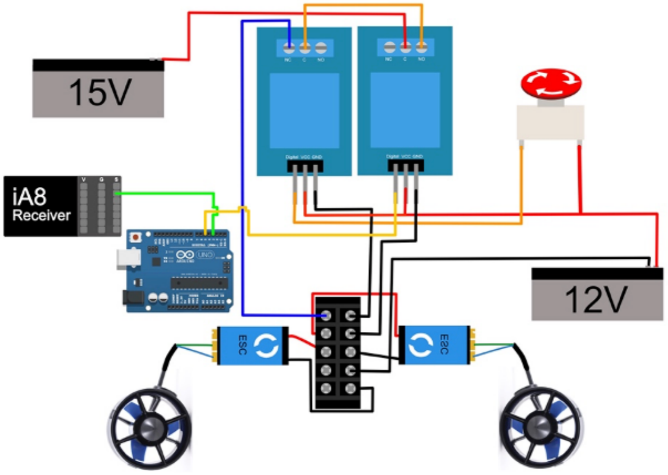


Computers Circuit			
Components	Voltage (V)	Current/hour (Ah)	Power (Wh)
Jetson Orin Nano	12	1.25	15
The Cube Orange	5	2.5	12.5
Antenna	24	0.5	12
Receiver	5	0.04	0.2
Arduino	5	0.4	2
Zeee	11.1	7	77.7
Total Consumption for one hour	41.7		
Total With Safety Precautions	48.0		
Maximum Working Time (mins) (Based On Battery Capacity)	97.2		
	One and a half hour		

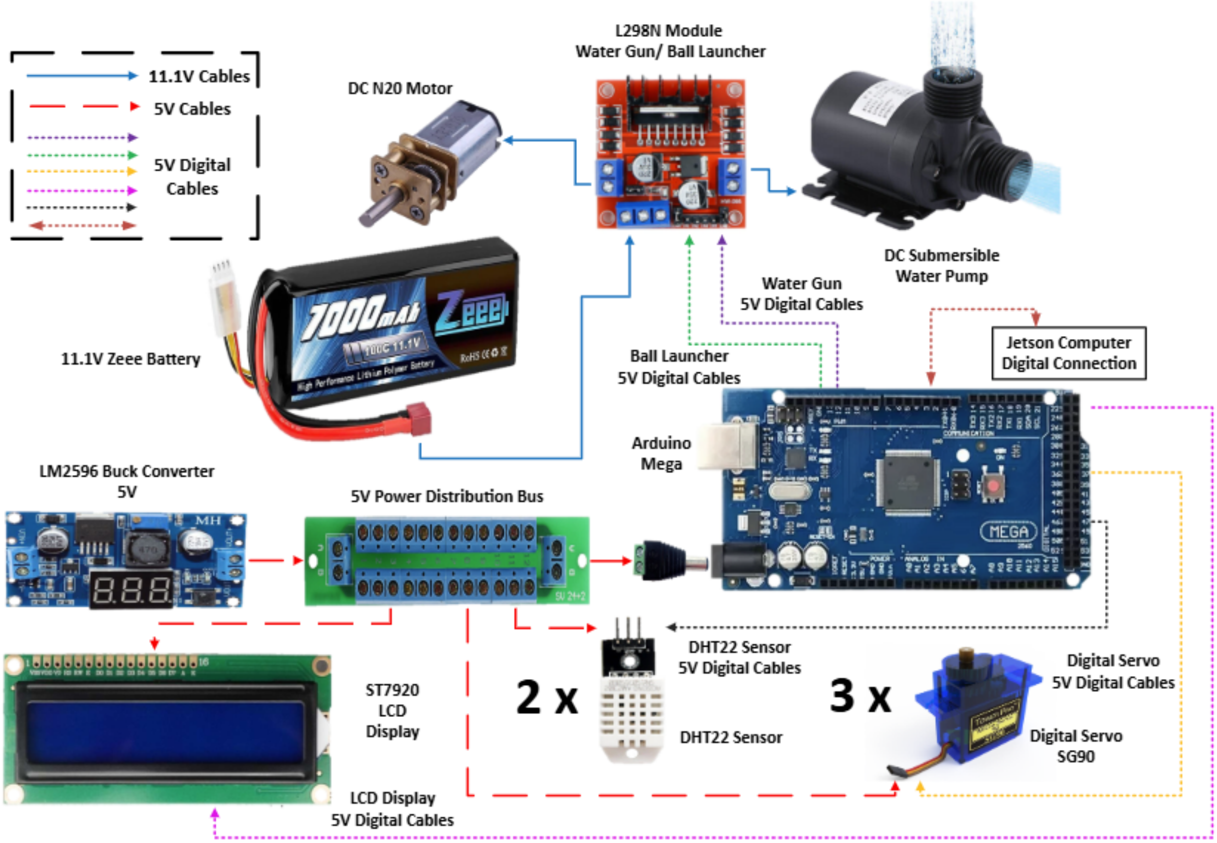


Robotics Circuit			
Components	Voltage (V)	Current/hour (Ah)	Power (Wh)
Arduino MEGA	5	0.8	4
Digital Servo SG90 (3)	5	0.75	3.75
DC Submersible Water Pump	12	1.71	20.52
L298N Module	12	1.71	3.58
DHT22 Sensor (2)	5	0.0021	0.0105
ST7920 LCD Display	5	0.06	0.3
DC N20 Motor	5	0.08	0.4
Zeee	11.1	7	77.7
Total Consumption for one hour	32.6		
Total With Safety Precautions	37.4		
Maximum Working Time (mins) (Based On Battery Capacity)	124.5		
	Two Hours		

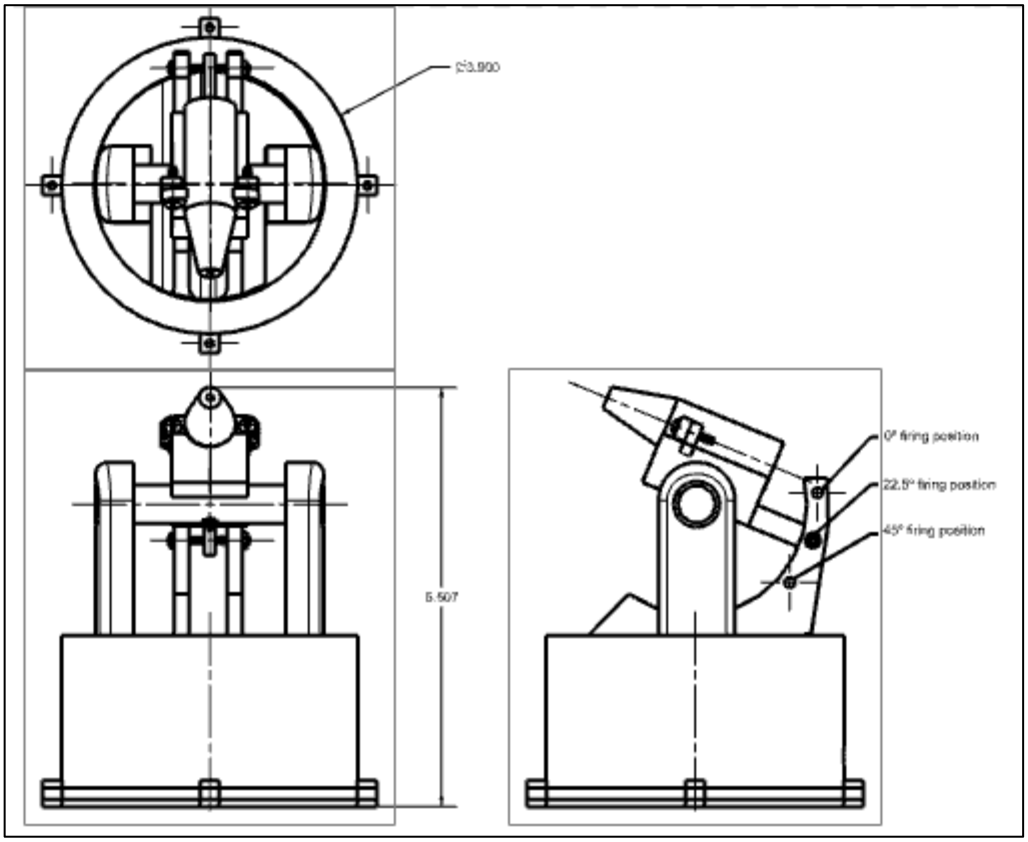
Appendix D. Technical Drawings



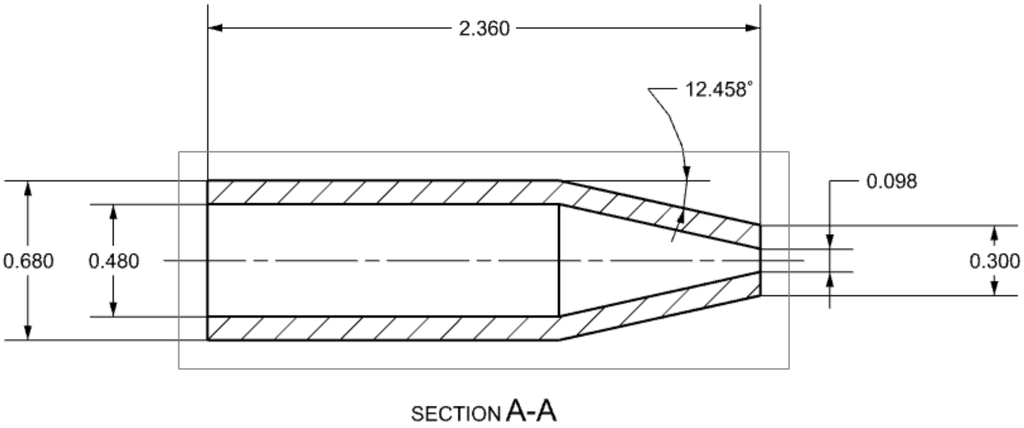
Kill Switch Circuit



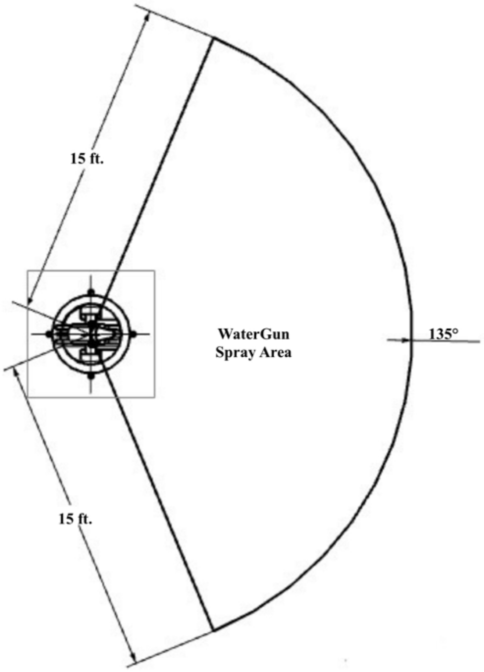
Delivery Systems Schematic



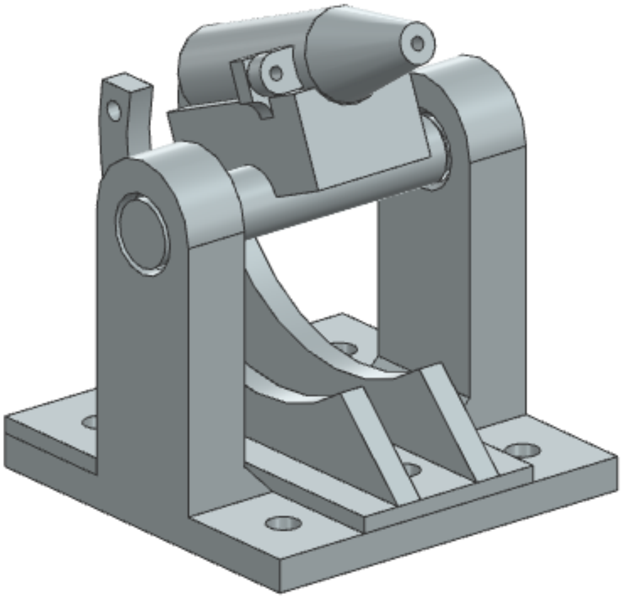
General Dimension for Water Gun Module



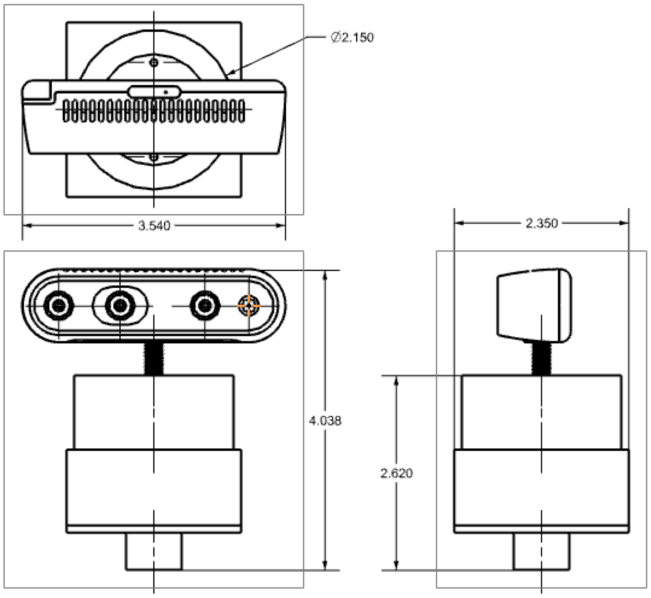
Water Gun Nozzle Cross Section



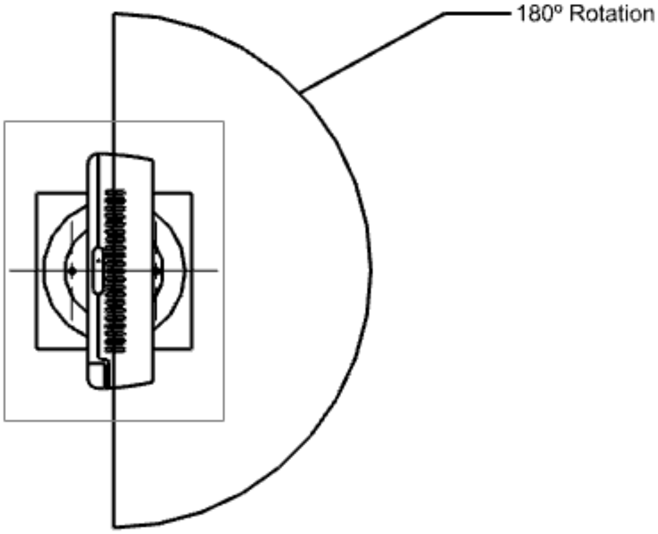
Water Gun Operating Range



1st Generation Water Gun Module



General Camera Turret Dimensions



Camera Turret Area of Rotation

Appendix E. Water Gun O-Ring Calculations

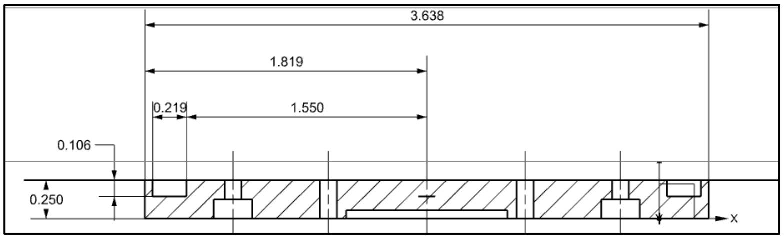
Calculations for Oil Resistant Soft Buna-N O-ring [234 O-ring 3”ID x 3-¼” OD x 1/8” thickness]
-In the case for a moving aO-ring seal it was found that a Dynamic of 10- 20 % compression was recommended, along with a compression factor range of 1.5-2.0.

- 0.15 = dynamic compression

Groove Depth = 1/8 in * (1-0.15) = 0.106in

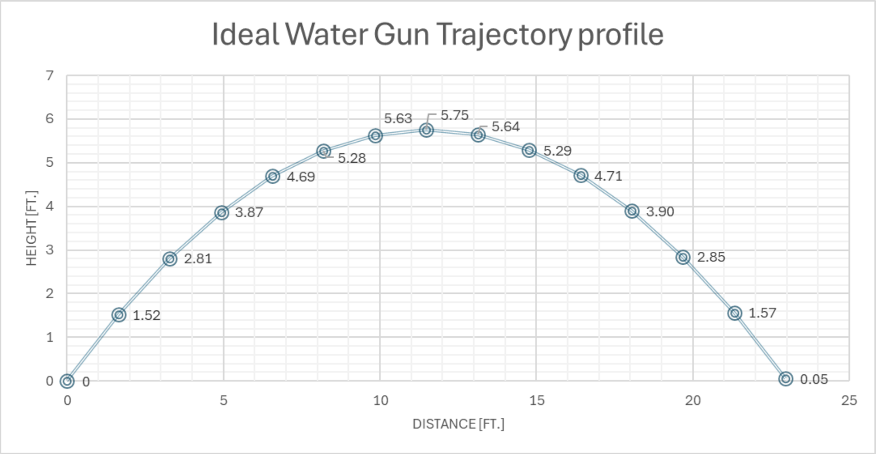
- 1.75 = compression factor

Groove Width = 1/8 * (1.75) = 0.219in



Water Gun Rotation Base O-ring cross section

Appendix F. Ideal Water Gun Calculations and Testing Data



Ideal Water Gun Trajectory

Preliminary analysis for the water gun module with previously shown water gun nozzle dimensions and a submersible pump with a flow rate of 210 GPH resulted in the following trajectory profile.

Water Gun Module Testing Data:

Pulse Width Modulation Signal (PWM)	Range [ft.]
255	14-15
125	7-8
90	<1

After the manufacturing of the first water gun module testing was conducted to verify the analysis conducted and correlate PWM signals to distances. The L298N H-bridge motor driver carries some downside where some power is lost when driving the motor and with a battery pack powering the driver of approximately 11.1V. The submersible water pump which is rated for 12V never truly reaches maximum operating capacity so the comparisons can truly be compared with the ideal data.

Appendix G. Stabilization Fins Calculations

Variables:

$$C_d = 1.0\ (Drag\ coeficcient\ of\ component\ boxes)$$

$$v_a = 26.4\frac{ft}{s}\ (wind\ speed)$$

$$A_s = 1.61\ ft^2\ (\ Component\ Box\ Side\ Area)$$

$$\rho_a = density\ of\ air$$

$$F_a = 0.5 * C_d * v_a^2 * \rho_a * A_s = 1.33\ lb_f$$

$$v = \ velocity\ of\ the\ ASV$$

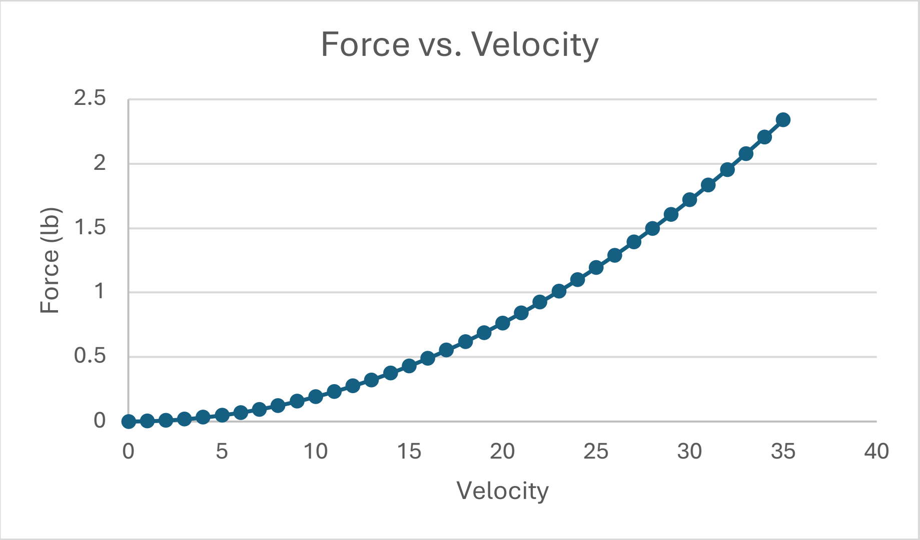
$$F_w = 0.930 lb_f\ (Lateral\ force\ caused\ by\ water)$$

$$C_l = 0.2$$

$$F_L = F_w + F_a = 2.26 lb_f$$

$$\rho_w = density\ of\ water$$

$$A_f = \frac{F_L}{0.5 * \ \rho_w * v^2 * C_L} \approx 0.12\ ft^2$$



Variation of Force with Velocity

Appendix H. Propulsion and Buoyancy

Propulsion Calculations

Variables

$$C_d \approx 0.02$$
$$A = 0.1574\, ft^2 (Area\ of\ contact)$$
$$F_T = 9.9 lb_f\ (Thrust)$$
$$F_d = 0.5 * C_d * A * v^2 * \rho = 3.1 lb_f (Drag\ force)$$
$$9.9 lb_f > 3.1 lb_f$$

Buoyancy Calculations

Variables

$$V_d = 0.357 ft^3 (Volume\ displaced)$$
$$\rho = 62.4\ lb_f/ft^3$$
$$F_b = \rho * V_d * g \approx 22.2\ lb_f (Buoyancy\ force\ of\ each\ hull)$$