How to Scale-Down a WAM-V platform for RoboBoat

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Abstract — Team Minion developed a brand-new vessel named Mini-Minion following reworked and optimized Competition, Design, and Testing Strategies. The Competition Strategy called for retaining the proven hardware architecture used by Team Minion for RobotX, but at one-fourth scale to compete in RoboBoat. This strategy also meant all software modules used for RobotX could be directly applied to complete RoboBoat tasks. To maximize hardware familiarity, the Design Strategy is oriented around "mimicking" the on-water behavior of the WAM-V platform. The design process was executed through three design sub-teams working in coordination on different parts of the design process. The process went through requirements generation, decision making, Preliminary and Technical Design Reviews (TDR/PDR), prototyping, and ultimately testing. Due to the development of a new platform in a condensed timeline, an expedited Testing Strategy was implemented that allowed simulation testing of tasks, while the platform underwent hardware changes and calibration. This process allowed for rapid tuning of systems to ensure reliability and robustness. These strategies led the team to create a highly competitive USV, eager to take on the most advanced autonomous challenges.

I. TEAM MINION

Team Minion is an interdisciplinary team comprised of Embry-Riddle Aeronautical University (ERAU) undergraduate and graduate volunteers, senior design students, and research students. The team has competed at RobotX for over a decade but formally took over as ERAU's RoboBoat team in December 2024 [3]. As such, Team Minion seeks to balance competing in multiple competitions while addressing the academic and research needs of its members. Its 2026 RoboBoat entry, Mini-Minion, is therefore designed as a roughly one-quarter scale version of the 16 ft WAM-V vehicle, which has competed in RobotX since 2014. The resulting RoboBoat Uncrewed Surface Vessel (USV), called Mini-Minion, is 4 ft long & weighs approximately 85 lbs. The Mini-Minion platform is primarily designed by a group of senior capstone design students, while the platform software leverages graduate student expertise and Team Minion institutional knowledge from competing in RobotX. This paper will highlight how the competition, design, and testing strategy for Mini-Minion have led to a unique vehicle design that will be highly competitive at the 2026 RoboBoat competition.

II. COMPETITION STRATEGY

Team Minion will compete this year with a brand-new vessel that was developed for the RoboBoat 2026 competition and is shown in Figure 1.

Figure 1: Mini-Minion Design

To develop this system, the team followed a multi-year, multi-competition strategy initiated after RobotX 2024 that builds on the team experience, as shown in Figure 2. This approach emphasizes using each competition as a milestone to further train the team members and advance its system capabilities, culminating in a competitive entry into the 2026 RoboBoat competition.
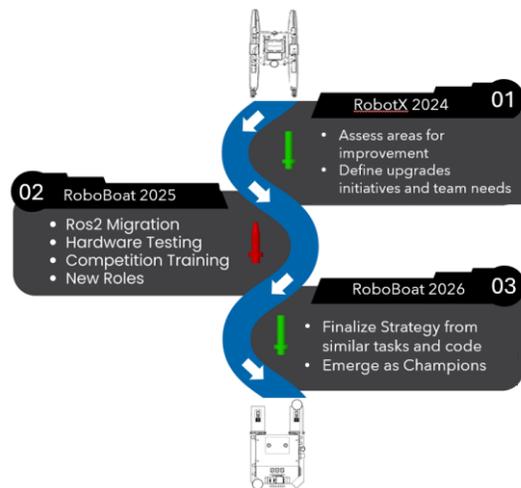

Figure 2: Path to RoboBoat 2026 Success

Because the Mini-Minion platform was designed and built within a five-month timeframe in 2025-2026, only

one month was reserved for on-water software testing. Consequently, tasks were prioritized according to Team Minion's demonstrated capabilities in prior competitions.

A. System Features and Capabilities

Due to the significant development effort required to design a new vessel for the 2026 competition, Team Minion's strategy focused on leveraging prior RobotX competition successes. The system builds on previously validated motion behaviors such as station keeping, defined as maintaining position and orientation under environmental disturbances, and path planning, defined as generating smooth and constrained trajectories through task environments. The navigation capabilities, summarized in Table 1, establish the foundational motion framework, while the perception capabilities presented in Table 2 provide a global representation of the environment that has proven effective for reliable object localization, boundary detection, and classification.
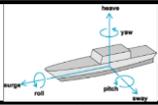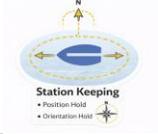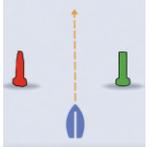
Table 1: Navigation Capabilities/Features

Capability	Description	Figure
[1] 3-DOF Control	Independent control of surge, sway, and yaw for precise maneuvering	
[2] Station Keeping	Maintains position and orientation during sensing and task execution	
[3] Path Following	Smooth waypoint-based navigation through gates and constrained channels	

Table 2: Perception features

Capability	Description	Illustration
[1] Object Localization & Boundary Detection	Detects objects and course boundaries (no color)	
[2] Object Identification	Classifies buoys, vessels, and targets	
[3] Color Classification	Identifies object color for task logic	

Table 3 outlines additional system-level capabilities that had to be newly developed or significantly refined to support 2026 task-specific behavior. These behaviors can be integrated into the Table 1 and Table 2 features but require significant new development and are thus considered less reliable for 2026 competition.

Table 3: Special System Features

Capability	Description
[1] Payload Deployment	Executes task-specific payload actions (ball launcher and water cannon) for supply drop. Includes safe actuation logic (arming conditions + command gating) to prevent accidental firing during transit.
[2] Audible Signal Detection	Detects and interprets the course audible cue and converts it into task logic ("one blast" vs "two blasts") to carry out the correct mission.
[3] Communications + Heartbeat Reporting	Maintains a continuous status/heartbeat to judges/RC system that reports vehicle state: position, heading, and system health.

The navigation, perception, and special system capabilities described in the prior tables were developed specifically for integrating task-level execution. Navigation capabilities provide the basic steps for maneuvering, station keeping, and constrained path following, while perception capabilities enable environmental awareness through object detection, boundary recognition, and color classification [17].

B. Mapping Capabilities to Tasks

After identifying the list of system features, these features are mapped to the requirements of 2026 competition tasks. Table 4 summarizes how these capabilities correspond to competition tasks, demonstrating that a deliberate combination of navigation control, perception inputs, and system-level functionality supports each task. Furthermore, it shows which tasks require new features and how many different features working in combination to achieve the maximum level of capability the 2026 team is seeking to achieve.

Table 4: Capability to task mapping

Task	Navigation	Perception	Special	Max Achievable Capability Level
Evac	T1.3	T2.1, T2.2	T3.3	Core
Debris Clearance	T1.3	T2.1, T2.2, T2.3	T3.3	Disruptive
ER Sprint	T1.3	T2.1, T2.2, T2.3	T3.3	Disruptive
Supply Drop	T1.2	T2.1, T2.2,	T3.1, T3.3	Core
Marina	T1.3, T1.1	T2.1, T2.3	T3.3	Advanced
Comms	N/A	N/A	T3.3	N/A
Harbor Signal	T1.3	N/A	T3.2, T3.3	N/A

Note: Refer T1.3 as Table 1 Row 3

C. Task Completion

According to the RoboBoat qualification requirements, the team must complete two core tasks, two advanced tasks, two tasks consecutively, and transmit an informational heartbeat to qualify for the semi-finals. Based on Mini-Minion's available navigation, perception, and special system capabilities summarized in Table 4, the team established a task prioritization strategy shown in Table 5 to guide autonomous execution. Mini-Minion identifies tasks within line-of-sight using perception system outputs. The vehicle prioritizes completing the nearest feasible task first and, once a task is selected, commits to execution without deviation until completion. If a detected task has already been completed, it is automatically skipped to avoid redundant actions. Tasks are executed in the predefined priority order to maximize scoring potential and ensure qualification objectives are met. A search routine is employed to locate objectives, when no tasks are available for execution.

Table 5: Task Prioritization and Capability Matrix with special focus placed on most achievable tasks

Task	Task Capability Completion Level	Prioritization Level
Debris Clearance	Advanced	High
ER Sprint	Advanced	High
Evac	Core	High
Marina	Core	High
Supply Drop	Core	Low
Harbor Signal	N/A	Very Low

The tasks highlighted in Table 5 will be completed to qualify for semi-finals and were selected to have the highest chances of success based on the Table 4 analysis. Supply Drop is labeled as "Low" priority because the systems needed to execute the tasks have been prototyped but are untested as of this report. Furthermore, Harbor Signal is a Very Low priority as these features are still in the design stage. This table does not include the communication task, as task communication is intertwined in all tasks and will be completed by Team Minion.

I. DESIGN STRATEGY

The success of Mini-Minion's competition strategy is highly dependent on building a RoboBoat vehicle that performs in the same manner as its RobotX vehicle, Minion. This allows for the direct application a 10-year codebase, significantly reducing the time needed for software testing. Furthermore, the team sought to intelligently reuse resources from the 2025 vehicle to stretch its budget.

D. Project Management

To systematically achieve this goal, three sub-teams for system design were formed. The stability team focused on the hull and propulsion systems, the deck team focused on the electronics and their enclosure, while the third team, dubbed Sensors and Sub-Systems (S&S), focused on platform sensing, communications, and support systems. Each team followed a requirements-driven design process to develop the 2026 version of Mini-Minion. The team goal was to make an RC capable boat by Thanksgiving with an autonomous boat by January 14, to allow for on-water testing before completion of the team video [15].

Team Minion had a budget of $3500 USD for platform hardware. The team lead oversaw purchases below $100 while our faculty advisor oversaw purchases over $100. During the development of Mini-Minion, formal progress updates were held every 3-4 weeks with our team advisor. These updates were used to get feedback so that each team could adjust designs and approaches.

E. Requirements Generation

Historically, Team Minion has held post-competition debriefs to capture system failures, inconveniences, etc., for the following year's USV. From the 2025 debrief, Team Minion generated many requirements, such as an external low-battery voltage indicator, while the 2026 RoboBoat Handbook and research objectives of Team Minion also led to several team requirements. Furthermore, these requirements match the Competition Strategy, by ensuring the new USV "mimics" the RobotX WAM-V, which in turn allows all RobotX algorithms to be used on the RoboBoat USV. Once the three teams drafted their requirements, they were reviewed and critiqued by senior team members and supporting faculty advisors, resulting in the requirements shown in Appendix F. Once the requirements were finalized, the team could then move forward to the design phase.

F. Decision-making

Formal decision matrices were used in cases where multiple viable options existed, and the tradeoffs were not immediately clear. For example, a decision matrix was used to compare deck materials using criteria such as cost, weight, and manufacturing time, given physically testing each option was not feasible (see Appendix D Table D.1, and Appendix C Table G.1). Computational analysis was then used to size options before committing to hardware, such as MATLAB scripts to calculate buoyancy for different pontoon and pod shapes, areas, and dimensions. Additional tools such as ANSYS and SOLIDWORKS were used to analyze part strength prior to manufacturing (see Appendix A Fig. 9 - 11). When analytical methods were insufficient, physical testing was used to define constraints and guide decisions, including adhesive testing to determine compatibility with structural foam and TPU/PETG pontoon and pod shells, as well as comparative water launcher nozzle testing based on spray

distance and spray angle to verify that imposed system requirements could be met.

The final decision-making tool was the use of the PDR/TDRs (Preliminary / Technical Design Reviews) throughout the design process. During these reviews, the team presented design ideas, choices, and decisions to team members, graduate student leadership, and faculty advisors. Review feedback was incorporated into revised analyses and design changes as needed, ensuring all final design decisions were well justified before fabrication.

G. USV Design

The outcome of this process was a USV geared towards maintaining mechanical familiarity within Team Minion's WAM-V platform.

1) Hulls

Inspired by Minion, the team preserved the functional pontoon and articulating pod concept of the WAM-V while modifying the cross-section toward a semi-displacement hull, retaining the "walking" stability mechanism. TPU was selected for the pontoon shells to provide impact damping, while PETG was used for the pod shells to rigidly mount the thrusters inside of a glued-in Schedule 40 PVC pipe. All cross-sections were designed to fit on a standard 256×256 mm print bed with appropriate body slices for ease of production, then joined using tongue-and-groove features that also formed epoxy channels. Shown in Figure 3, shaped foamboard infill resides inside the printed shells with layered external coats for a durable, clean finish.
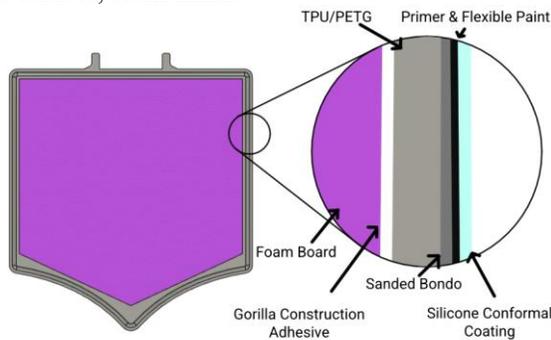

Figure 3: Diagram of the Layers of the Pod/Pontoons

Finally, aluminum extrusions and a custom pinned hinge were added for structural integration as visible in Figure 4.

Figure 4: Pontoon with labeled extrusions.

2) Propulsion

The articulating pods house the thruster group. Each side is comprised of one azimuth servo and two T200 thrusters for independently paired steering on each pod. Each assembly is held in place by two clamping collars that ride on thrust bearings mated to the hull body. By bolstering the thrust output with two motors, each capable of 180-degree azimuth control and 59.2 lbf maximum thrust. This structure provides the platform with holonomic movement. The pods can rotate about the draft line ±10°, allowing the thrusters to remain in the water under choppy conditions (see Figure 5).
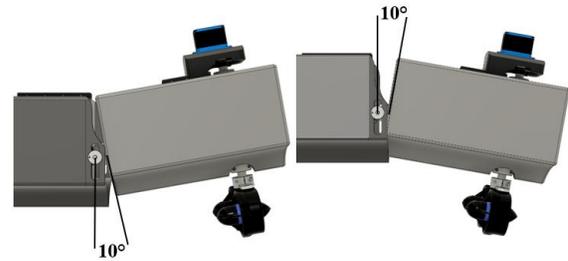

Figure 5: Pod Articulation Up (on left) and Down (on right)

3) Power and Communications

Mini-Minion uses two 18 V lithium-ion drill battery packs in parallel, selected for their rugged construction, high current capability, simple charging interface, commercial availability, and proven reliability in harsh, vibration-prone environments. Power distribution Figure 6 is handled through a custom PCB which provides monitoring and remote control of the emergency e-stop, allowing quick shutdown of all external actuators like the thrusters, servos, and delivery systems. The thrusters are connected directly to the 18 V battery rail, while all other subsystems are regulated through 5 V, 12 V, and 19 V rails. All components are fuse-protected.
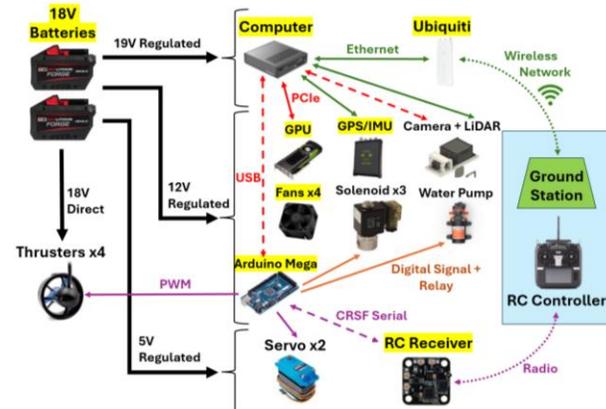

Figure 6: System diagram of Mini-Minion. Shows power distribution and communication relationships between components. Highlighted components are in the Deck. Components in the blue rectangle are external to Mini-Minion.

3.1) Power Analysis

Based on the selected onboard computing, sensing, actuation, and delivery components, a system-level power analysis was performed to quantify total electrical demand, expected runtime, and current loads. Power

requirements were driven primarily by azimuth motor control, onboard computation, and delivery system actuation. Using component datasheets and measured operating characteristics, the power architecture was evaluated to ensure that voltage regulation, current capacity, and energy storage were sufficient to support continuous operation. From this analysis, Mini-Minion was predicted to achieve an approximate runtime of 66 minutes under nominal operating conditions (see Appendix C).

4) Deck Enclosure

The waterproof deck protects the ASV's internal electronics while providing mounting surfaces for external sensors and actuators. The final deck structure weighs approximately 5 lbs, which is 1/3rd the weight of the alternatives. To meet ASV mass and strength requirements, the deck enclosure walls are made with lightweight, aircraft-grade aluminum honeycomb panels bonded with epoxy resin and reinforced by carbon-fiber [6]. External electrical components are mounted to rails along the sides of the deck and atop the deck bow wall. The deck has one large removable lid for access to electronics, and three panels on the deck's bow and stern walls to mount quick-release electrical connectors. The removable lid and all connector panels are sealed to an IP66 standard, while each electrical connector meets IP67 standards. The four ventilation ducts (two inlets and two exhausts) are designed to eliminate water ingress while maximizing airflow.

4.1) Heat Dissipation

Based on the system power analysis, Mini-Minion exhibits an average internal heat generation of approximately 92.5 W. Using a volumetric airflow formulation of the specific heat equation, internal deck temperature was evaluated as a function of airflow, with results summarized in Appendix C. The analysis predicts a steady-state internal temperature of approximately 36 °C when using two small server fans, which remains well below the 50 °C maximum operating temperature of the onboard batteries [12]. To account for airflow losses due to venting restrictions and internal flow resistance, the final design incorporates four fans arranged as two intake and two exhaust units. Detailed thermal modeling, airflow assumptions, and validation plots are provided in Appendix C.

H. USV Support Systems

In addition to the USV design, the team completed the design of two lower-priority support systems: a water cannon and a ball launcher. The water cannon system utilizes a 12 V SEAFLO 21 water pump, 3/8 inch tubing, a 3D printed PETG mounting bracket for tubing support & structural stability, and a resin printed universal barb fitting and nozzle assembly for sealing reliability & precision [1]. The universal barb fitting is seated inside the tubing to enable rapid nozzle changes, while the nozzle threads into the top of the barb fitting, allowing for quick iteration and controlled spray characteristics.

The water cannon was designed and evaluated specifically to satisfy the functional requirements of the RoboBoat 2026 Supply Drop task (Task 3.2.4), which requires the ASV to deliver a continuous and visible stream of water to a target vessel for a minimum duration [2]. System performance was verified through bench testing, which confirmed the ability to produce a steady and repeatable water stream to approximately 10 feet. Additional design details and validation results for the water cannon system and the port-side mounting configuration are shown in Figure 6, in Appendix D.

For the ball launcher the team evaluated four pressurized system options, summarized in Appendix D Table D.1. After comparison, our 25g CO2 cartridge configuration was selected due to its low mass and compatibility with existing pressurized launch systems. For comparison, commercially reliable systems CryoFX & ConfettiVibe utilize 5 lb CO2 tanks at pressures near 150 psi and can launch t-shirts approximately 60 feet & balls 200 feet [13], [14]. Using the known molar mass of CO2 and published shot counts for these systems, an analysis was performed to estimate gas usage per launch and relate these results to a single 25 g cartridge operating at 850 psi for 70 °F. This analysis shows that a 25g CO2 cartridge contains sufficient gas to support one full power launch, defined as maintaining an exit pressure of approximately 100 psi. This required pressure threshold was determined through MATLAB-based projectile simulations and experimental reference data obtained from the legacy RobotX pneumatic ball launcher system. It defines the pressure regime & baseline required to satisfy the RoboBoat 2026 Supply Drop task requirements. This indicates a credible likelihood of successful task execution while acknowledging that additional cartridge specific testing is required to fully characterize efficiency losses and repeatability. The full design of the ball launcher is shown in Figure 7 below.
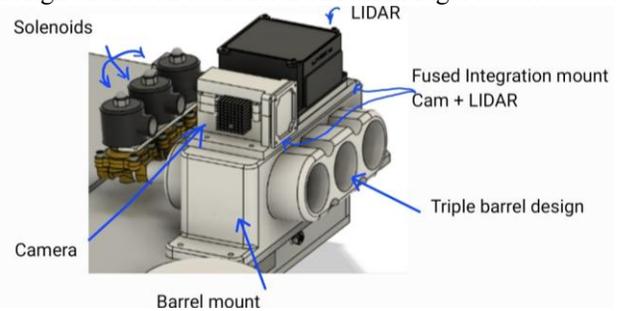

Figure 7: Ball launcher system

II. TESTING STRATEGY

As the boat hardware neared completion, team personnel were re-organized into separate teams that supported system software and hardware testing. These

Teams were Calibration, Tasking, and Testing. The responsibilities of each team are detailed below in Table 6. Furthermore, hardware and software can be tested in parallel, a Gazebo-based simulation of Mini-Minion and a 2026 RoboBoat course was created to test tasking logic.

Table 6: Testing Strategy Sub-Team Divisions

Team	Responsibilities	Key Objectives	Reporting
Calibration	Hardware setup, signal configuration, component and task validation	Verify all subsystems are communicating correctly and executing the intended commands	Reviews test results and communicates issues to the Tasking Team
Tasking	Develop/tune autonomy & task logic	Define command and data pathways	Notifies Testing Team: new software for testing
Testing	Weekly programmed functions of USV in both manual and autonomous modes	Continuously monitor the health of the USV and log crucial data	Test results and data to Calibration Team for analysis

I.   Hardware Strategy

All hardware systems were verified through a staged testing process to ensure safe operation and reliable performance prior to competition. Computer-aided analysis using Fusion 360, ANSYS, and SolidWorks was first utilized to evaluate form, fit, and function before fabrication. Proof-of-concept prototypes were then used to experimentally validate key design assumptions and finalize major design decisions. Next, bench testing was performed on all major subsystems to verify control logic, electrical performance, and mechanical limits in a controlled environment. Identified failure points were addressed through design iterations and retested until acceptable performance was achieved.

After subsystem validation, in-lab integration testing confirmed communication and functional compatibility between newly installed components and existing onboard systems. Once integrated, on-water testing was conducted weekly using structured test plans with defined objectives and success criteria. All on-water testing required a minimum safety team consisting of an RC operator, two in-water safety observers, and a ground-station operator. Each test began with a standardized startup sequence to ensure all systems are operating as normal. After baseline functions were verified, new test programs were executed, recorded, and evaluated against the intended outcomes.

Once the system was ready for software testing, hardware tests were also completed to optimize system performance. For example, the platform is designed with an adjustable mounting location for the arches to the pontoons, and flotation pods to the back of the pontoons.

This allowed the team to adjust the platform center of gravity and motor pod draft after all components were in their final place. These built in adjustments also allow for additional optimizations in system hardware as the platform is used for future competitions, which may require changes in platform payload.

J.   Software Strategy

The software used on this vessel was designed to perform all competition tasks and objectives in a safe, efficient, and robust manner. To ensure this, all software was rigorously tuned and tested. This began by integrating existing code from the RobotX Minion to control Mini-Minion's sub-systems. This includes sensor and command inputs to build world maps, monitor position in space, and control thruster commands and autonomous functions. Task Programming uses base code functions and sensor input information to accomplish a desired outcome based on what task the USV is expected to perform. Virtual Testing was performed using Gazebo to test new autonomous programs and functions in a controlled environment (See Figure 8).

Figure 8: Gazebo Simulation of Evac, Debris Clearance, ER Sprint & Navigate the Marina [19]

Tuning of the software was conducted based on the desired outcomes of continuous simulation testing. After building confidence in a virtual test platform, the software was loaded onto the vessel for weekly on-water testing. Reliability of the software was established through repeated testing in both virtual and on-water operations, ensuring the robustness of the developed code.

III.   ACKNOWLEDGEMENTS

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Appendix A
Test Plan and Results

Mini-Minion USV Test Plan

Test Description

The following test plan documents the procedures used to verify the safe operation, electrical integrity, communication reliability, perception functionality, and basic task-relevant performance of the Mini-Minion USV prior to on-water testing. Testing was conducted to ensure all onboard systems were energized safely, responded correctly to control commands, produced valid perception outputs, and could be shut down immediately under emergency conditions. The procedures outlined below reflect the actual commissioning and validation steps performed on the Mini-Minion platform.

Test Objectives

- Verify safe system startup and shutdown procedures
- Confirm proper voltage regulation and power distribution
- Validate communication links between onboard computers, controllers, and peripherals
- Ensure emergency stop systems function correctly in both physical and remote modes
- Confirm correct command routing and low-power actuation of propulsion systems
- Validate perception system outputs required for autonomous task execution
- Establish baseline operational readiness prior to full autonomy testing

Safety Considerations

Potential hazards during testing include rotating motors, electrical shock, unintended actuation, pressurized systems, and pinch points. To mitigate these risks, testing was performed using a staged enablement process with propulsion and delivery systems disabled until all electrical, communication, and perception checks were complete. Both physical and remote emergency stop systems were tested prior to enabling any motor outputs.

Test Procedure

1. System Power-Up and Safety Verification

1. Batteries were connected to the system with all actuators disabled.
2. The main kill switch was engaged to energize the electrical system.
3. Voltage levels on all regulated rails were verified to be within acceptable limits.
4. Communication links between the onboard computer, microcontrollers, and peripheral devices were confirmed.
5. Physical and remote emergency stop systems were tested to ensure immediate shutdown capability.

2. Incremental System Bring-Up

1. Each subsystem was powered individually to verify correct operation prior to integration.
2. Voltage stability and communication status were rechecked after each subsystem was enabled.
3. Dangerous components, including thrusters, motors, and payload actuators, remained disabled during this phase.

3. Propulsion and Control Validation

1. After all safety checks were completed, propulsion systems were enabled at reduced power.
2. Low-speed motor commands were issued to confirm correct command routing and motor response.
3. Basic maneuver commands were tested to ensure proper directional control in surge, sway, and yaw.
4. System telemetry was monitored throughout testing to confirm stable electrical and control behavior.

4. Emergency Shutdown Testing

1. Physical emergency stop was triggered to verify immediate system shutdown.
2. Remote emergency stop was triggered to confirm redundant safety functionality.
3. System recovery procedures were verified following emergency stop activation.

5. Perception System Validation (Camera and LiDAR)

1. Onboard camera systems were tested to verify object localization and boundary detection of course elements.
2. Object identification was validated by correctly detecting buoys, vessels, and task-specific targets.
3. Color classification was verified by distinguishing red, green, and yellow markers used for navigation logic and task execution.
4. LiDAR sensing was evaluated to confirm accurate distance measurements to static obstacles and structural features at ranges relevant to docking, station keeping, and constrained navigation.
5. Distance readings were cross-checked against known reference points to ensure reliability for autonomous maneuvering and collision avoidance.
6. Perception outputs were confirmed to be correctly ingested by autonomy logic for downstream navigation and task selection.

6. Task-Level Autonomous Behavior Verification

1. Waypoint-based navigation was tested to validate smooth path following through constrained channels.
2. Station keeping behavior was verified by holding position within a defined tolerance relative to detected targets.
3. Controlled approach maneuvers were executed to confirm proper alignment with task elements such as docking structures or supply drop targets.
4. Autonomous task selection logic was exercised by identifying the nearest feasible task based on perception outputs and executing it without deviation once initiated.

5. When no immediately completable task was detected, a search routine was verified to re-acquire targets using perception feedback.

Team Responsibilities

Testing activities were coordinated across the Calibration, Tasking, and Testing sub-teams as defined in Table 6.

- **Calibration Team**
  - Verified hardware setup, signal configuration, voltage levels, and component operation
  - Validated sensor outputs and perception system calibration
- **Tasking Team**
  - Developed and validated autonomy logic, command routing, and task execution pathways
- **Testing Team**
  - Conducted functional testing in both manual and autonomous modes
  - Monitored system health, telemetry, and data logging during all test phases

Deliverables

- Verified system startup and shutdown sequence
- Confirmed voltage regulation and power distribution integrity
- Validated communication links and command routing
- Demonstrated functional emergency stop capability
- Established baseline propulsion functionality at reduced power
- Verified camera and LiDAR perception outputs for autonomous navigation
- Confirmed task-level autonomous behaviors aligned with competition requirements

Appendix B
Stability Team

The stability portion of this vessel is comprised of the pontoons, articulating pods, thruster group, and suspension. Essentially everything below the deck falls under this category.

A.   Hull Material and Functional Design

Opting for a semi displacement hull, both the pontoons and pods are 3D printed with TPU and PETG, respectively, to achieve a complex profile. Choosing TPU for the pontoons enables collision damping, especially at the bow, whereas utilizing PETG for the articulating pods allows for rigid mounting and force translation from the thrust. The pods themselves are designed to mimic the articulating pod group of 'Minion', the RobotX USV that our team has historically competed with to enable optimal thruster depth at all times. The range of motion is ±10 degrees about the hinge connecting the pod to the pontoons, see Figure B.1 below.

Figure B. 1: Pod Articulation.

Note the gaps between the pod and pontoon in Figure B.1 above. As a calibration technique, spacers are glued to the rear face of the pontoon, preventing the pods from rotating beyond the 10-degree limit.

B.   Profile Simulations

The bow of the pontoons raised questions about drag, and how the profile impacted power consumption and water cutting capability. Considering these concerns, the SolidWorks Flow Simulation tool was used to perform a CFD analysis. First, the draft line defines the air to water boundary, see Figure B.2.
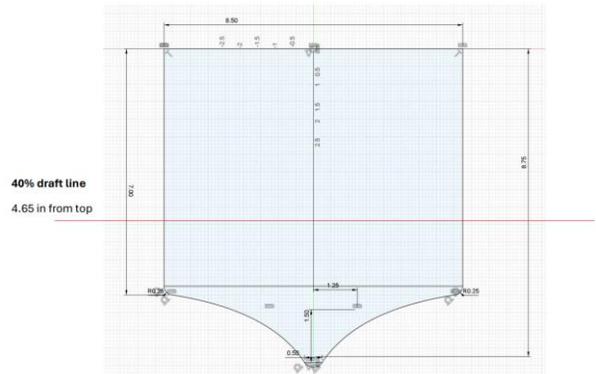

Figure B. 2: 40% draft line: air to water boundary.

Other initial conditions: pontoon only, 1.5 m/s air and water speeds (~1.3 m/s real estimated), and no gravity as we are only concerned with the front profile. As a result, the profile displayed minimal pressure and shear stress impacts; +1.2 kPa max and +4.3 Pa max, respectively.
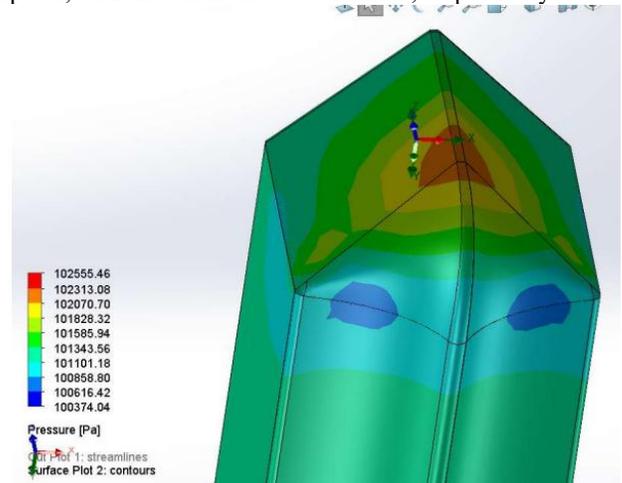

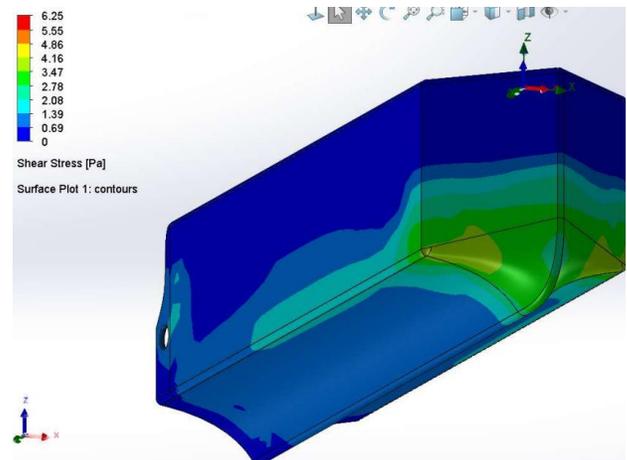*Figure B. 3: SolidWorks CFD Surface Pressure Plot.*

Figure B. 4: SolidWorks CFD Shear Stress Plot.

Furthermore, just as a visualization tool, flow vectors and flow trajectories were also observed.
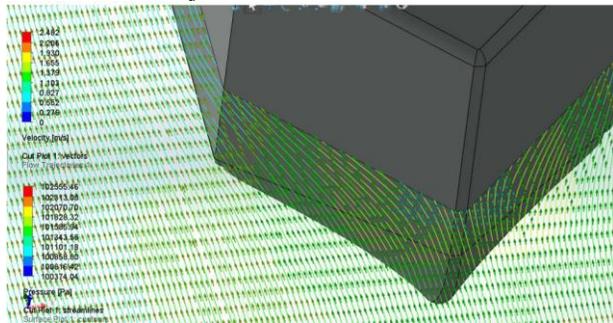

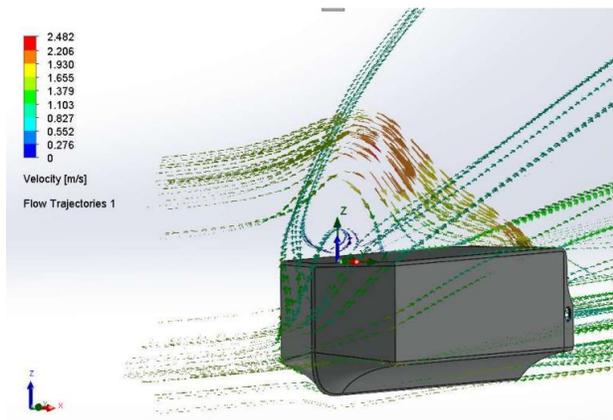*Figure B. 5: SolidWorks CFD Flow Vectors and Streamlines.*

Figure B. 6: SolidWorks CFD Flow Trajectories.

Because of how minimal the shear stress and surface pressures were, the initially designed profile was not discarded or modified.

C.   Thruster Group

Two T200 thrusters are attached to the bottom of an 11.7" 6063 anodized aluminum tube via a custom aluminum bracket manufactured in-house at ERAU. The tube, or shaft, acts as a guide for the 3-phase insulated thruster cables, where, above the pods, they exit and run up the suspension towards the rear of the deck with the servo harness. Furthermore, the tube is retained by two white acetal washdown clamping shaft collars, which ride axially on thrust bearings to reduce friction. The thrust bearings themselves are dry running, made with a mixture of plastics. A schedule 40 ¾" PVC tube retains the aluminum shaft for added thrust support and rigidity, glued to the PETG pod body with PVC primer and cement to ensure a chemical weld.[16]
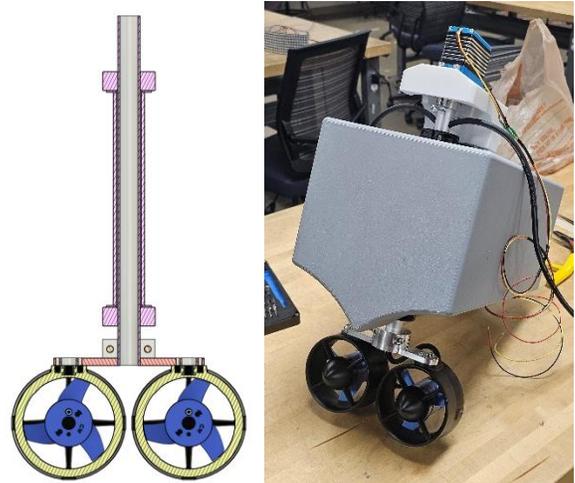

Figure B. 7: Thruster Group

The servo subgroup illustrated above actuates the thrusters ±90 degrees from center, permitting various thrust vector combinations. The mechanism for interconnecting the servo horn to the shaft is another custom flanged shaft collar manufactured in-house. And for stowing the vessel, or if actuation capabilities are lost, a threaded locking bolt may be installed through the aluminum shaft into the PETG servo mount for retention.

The intentions behind independently paired thruster control are complex, but enable extensive research behind thrust vector control, such as holonomic movement. Not only can this vessel control thrust azimuth in a paired configuration, but we can also implement four separate PWM signals, one for each thruster, broadening the range of capabilities for thrust control.

For extra caution, Ansys was utilized to perform an analysis on the custom thruster bracket by distributing the maximum T200 thrust of 14.8 lbf (x2) to the 8 mounting holes on each end, shown in Figures B.9-B.11.

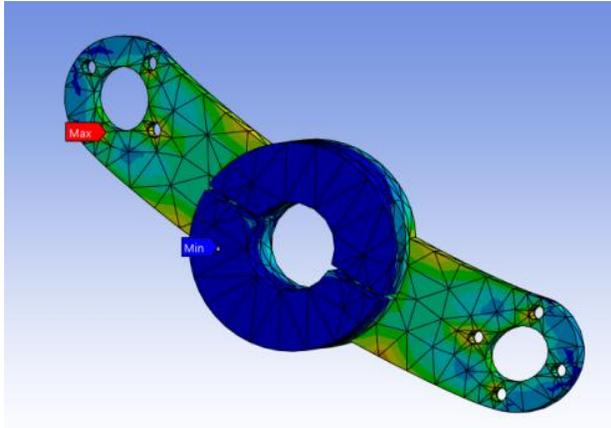*Figure B. 8: Custom dual-thruster bracket*

Figure B. 9: Thruster bracket Ansys stress analysis (max 3.32 MPa, 81.2 FoS).
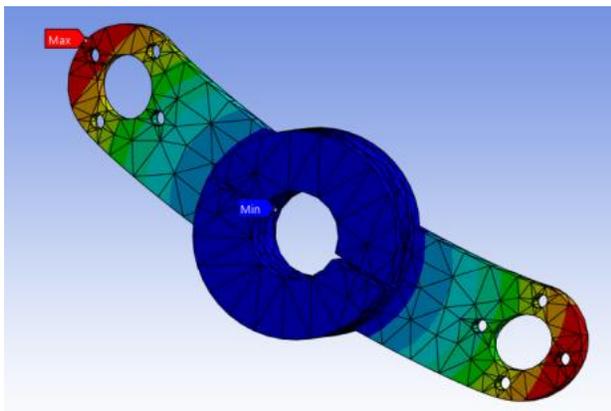

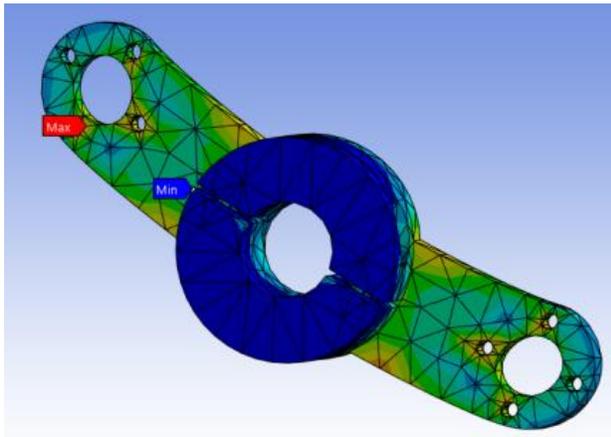*Figure B. 10: Thruster bracket Ansys deformation analysis (max 0.004 mm).*

Figure B. 11: Thruster bracket Ansys strain analysis (max 0.000047882 m/m, see below for FoS).

Regarding strain, assuming a Young's Modulus of $E = 70\ GPa$ (0.02% offset),

$$\varepsilon_y = \frac{\sigma_y}{E} = \frac{270}{70000} = 0.0039$$

$$FoS = \frac{0.0039}{0.000047882} = 81.4$$

Needless to say, the bracket exceeds the thrust requirements 80-fold and the initial design was retained.

D.   Buoyancy

An initial vessel weight of 100 lbs. was assumed, and the target draft was 40% by volume. Later, a real weight estimate of 85 lbs. was identified after much of the vessel design was drafted. Using brackish water density of 63 $\frac{lb}{ft^3}$, and the initially calculated pontoon and pod volumes, we can identify if we meet those requirements [7]:

$$V_{pontoon} = 1919\ in^3$$
$$V_{pod} = 789\ in^3$$
$$V_{total} = 2708\ in^3 = 1.567\ ft^3$$
$$1.567\ ft^3 \times 63\frac{lb}{ft^3} = 98.7\ lb$$

At 100% draft, the hulls could hold up to 197.4 lb. Now at 40% draft:

$$0.4 \times 1.567\ ft^3 = 0.6268\ ft^3$$
$$\rightarrow 0.6268\ ft^3 \times 63\frac{lb}{ft^3} = 39.4\ lb$$

At 40% draft, our total weight supported is 78.9 lbs., just 6.1 lb. under our target. Although our target was 40% draft, it may realistically rise towards 45%. This was an acceptable number for us to move forward towards the manufacturing stage.

E.   Critical Angles

Due to the lack of extreme water conditions, the primary goal was to ensure that the boat had a righting moment at 45 degrees. Testing of this for pitch was performed by rotating a plane 45 degrees in CAD in each direction and performing center of buoyancy calculations to determine its position relative to the center of mass. Simple trigonometry calculations were performed to determine if the center of mass crosses over the center of buoyancy. Because of how center of buoyancies move when a body rotates in water, the pitch angle present in the following figure is not its max roll angle, but simply proof that there is a righting moment at 45 degrees of pitch (which is proven by the angle between the location of the center of buoyancy at 45 degrees of tilt and center of mass exceeding 45 degrees). In both directions, the boat was shown to effectively maintain righting moment at 45 degrees.
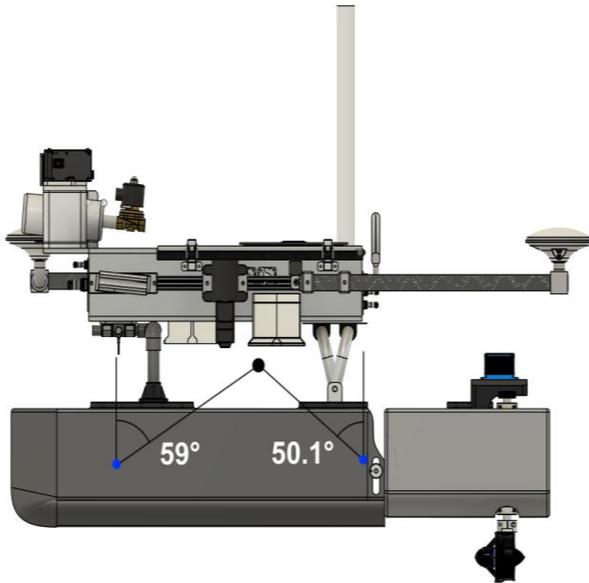
Figure B. 12: Visualization of CB and CM Locations for Pitch.

Note how the angles between the center of buoyancies when the boat is pitched at 45 degrees and the center of mass does not fall under 45 degrees.

Boat roll angle was calculated by finding the position of the center of buoyancy of each pontoon and pod and determining the angle between it and the center of mass.
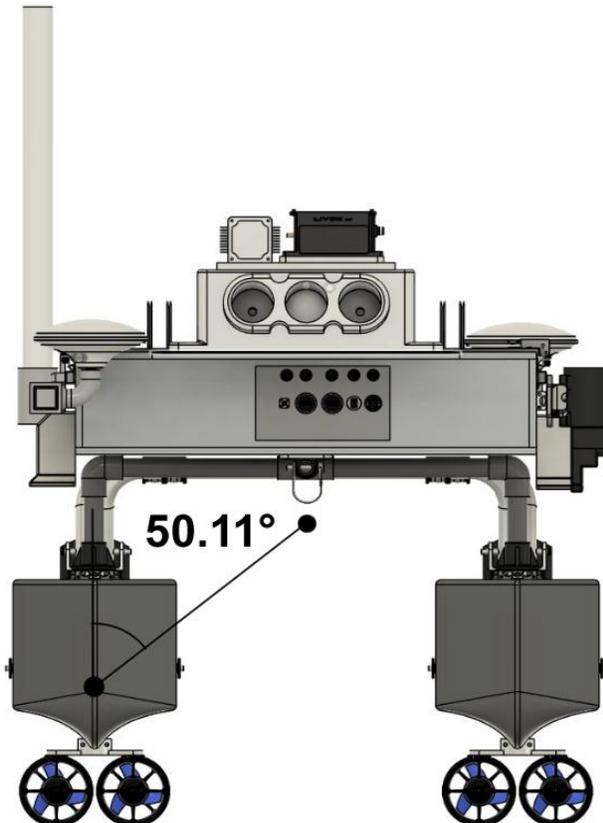

Figure B. 13: Visualization of CB and CM Locations for Roll.

Note our center of mass is very slightly off center, so this calculation was performed on the least stable side. Unlike pitching, the roll angle should be more accurate to what will be the actual max angle as the center of buoyancies will not significantly shift in the bow to starboard axis.

F. *Suspension Group*

Because this is a catamaran vessel, achieving the 'walking' effect requires a dynamic suspension. The dynamic suspension consists of an articulating arch and two cantilever suspension arms. The arch is made up of a singular aluminum beam bent to shape with a central spherical joint, interfacing with the deck, and two fabricated clevis joints on either end. These clevis joints are connected to the cantilever suspension arms via a spherical joint mounted on each arm. These suspension arm assemblies pivot about a fixed joint on each pontoon and are dampened by an adjustable shock within the suspension arm. All components of this system are calibrated to mitigate leveling disturbances while damping rougher water conditions. See Figure B.14 below.

Figure B. 14: Dynamic Suspension Group.

In the event of a failure with the dynamic suspension, a static PVC suspension has been created. This suspension lacks the ability to perform the same 'walking' maneuver as the dynamic suspension; however, it has fewer moving parts making a reliable backup. See Figure B.15 below.
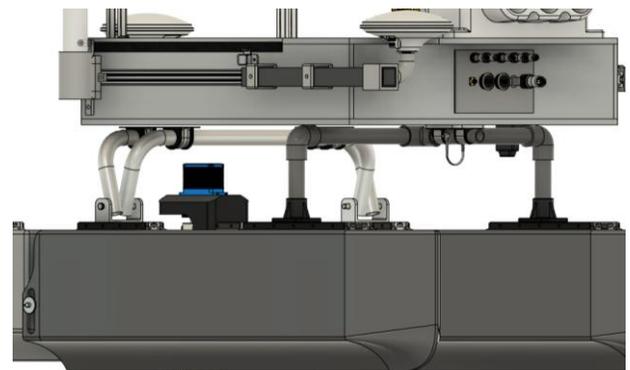

Figure B. 15: Static Suspension Group.

Note the pin where the front PVC suspension attaches to the deck to prevent articulation.

As PVC does not provide the same structural stability as aluminum, additional Ansys calculations were performed to ensure failure would not occur. In the simulation, a minimum and maximum stress of 1.35Pa and .82Mpa were measured which resulted in a factor of safety of ~17.
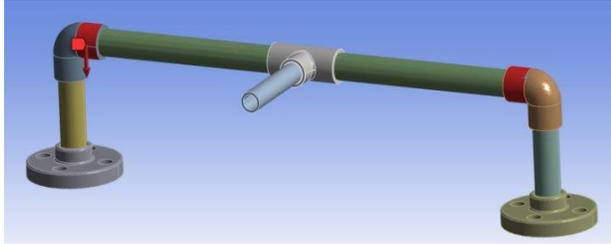
Figure B. 16: Static PVC Suspension Ansys Load Points.
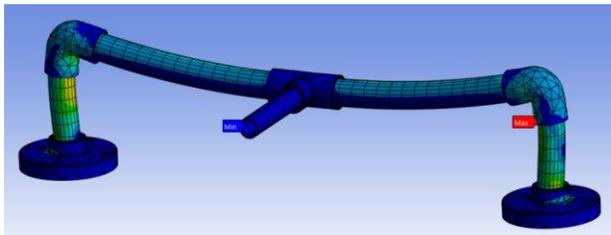
Figure B. 17: Static PVC Suspension Ansys Deflection.

G.   Finishing

Because the team opted to 3D-print all hulls on this vessel, ensuring proper seals are pivotal in preventing any moisture from entering infill cavities (or the hull in general). Furthermore, because the pontoons are made of TPU, a flexible material, the finish must be ductile as well. To achieve a smooth finish, the team started with a thick Bondo layer to fill all gaps and weak areas from the slicer geometry. Upon sanding this down with up to 400 grit paper, the hulls were primed, and wet-sanded up to 2000 grit to prevent an 'orange peel' finish. Next, a flexible spray paint coating was applied 3 times, along with a silicone conformal coating ensuring a smooth, consistent, watertight finish.

Appendix C

Deck Team

The Deck is a waterproof enclosure for all the electronics and sensors for Mini-Minion. It contains the power system and provides various mounting points for delivery systems and sensors.

A. Power Analysis

The objective of this power analysis is to determine the operating voltages and power of all required components for Mini-Minion, select power components for rated amperage, select e-stop components for amperage, calculate runtime, and calculate expected heat generation.

Power consuming components for motor control, sensors, and delivery systems are listed in Table C.1. Operating voltage, current, and power are found in data sheets or testing from external sources. Nominal voltages are selected for each power consuming component based on their shared ranges. In the end, three regulated nominal voltages were chosen: 5V, 12V, and 19V.

Power Consuming Components	Quantity	Operating Voltage	Nominal Voltage	Peak Current (A)	Continuous Current (A)	Peak Power (W)	Continuous Power (W)
Minisforum MS-01-US w/Core i9 13900H	1	19	19.00	6.32	1.42	120.00	27.00
Ubiquiti Prism AC	1	18-26	19.00	0.47	0.47	8.50	8.97
T200 - Blue Robotics Thrusters	4	18	18.00	112.88	14.40	2031.84	259.20
Arduino Mega 2560 Rev3	1	7-12	12.00	0.50	0.20	6.00	2.40
Livox HAP LiDAR	1	9-18	12.00	2.17	1.00	26.00	12.00
SEAFLO 21 Water Pump	1	12-24	12.00	4.00	0.00	48.00	25.00
USB30-IMX490-GW5400-GMSL2-120H Camera	1	9-19	12.00	0.26	0.18	3.17	2.11
Nvidia Quadro M6000 24Gb	1	12	12.00	20.83	1.67	250.00	20.00
2H012-016 High Pressure Solenoid Valve	3	10.8-13.2	12.00	5.00	0.00	0.00	60.00
GPS/IMU Javad DELTA-DI GNSS Receiver	1	4.5-40	12.00	0.56	0.38	6.72	4.50
Arctic 6k RPM Server Fans	4	12	12.00	0.40	0.40	4.80	4.80
D845WP - Monster Torque Servo	2	4.8-7.4	5.00	12.34	2.25	61.70	11.25
DBR4 Dual Band Xrossband Gemini ExpressLRS Receiver	1	4.5-8.4	5.00	0.50	0.10	2.50	0.50
5V Relay (Normally Open)	4	5	5.00	0.02	0.00	0.10	0.00

Table C. 1: Power consuming components of Mini-Minion. Note that the 5V relays are powered through the Arduino and the DBR4 is powered through the custom E-Stop PCB.

The continuous power draw of the T200 thrusters was estimated using Team Minion's 2025 RoboBoat vessel as reference [4]. Continuous power draw of Mini-Minion's four T200 thrusters through match the old vessel's maximum thruster. To achieve an equivalent thrust of 6.5kgf, Mini-Minion draws 14.40A, half of the old vessel's ~30A [8]. The continuous power draw of the Minisforum computer was assumed to be the idle power draw of the computer [9].

With the regulated voltages selected for the components, it is now possible to determine the current drawing through each regulator. Since the thrusters take power straight from the batteries, its amperage will be examined through the electronic speed controllers (ESCs). As shown in Table C.2, continuous currents are relatively manageable through each device, however the peak currents do raise concerns. Especially for the e-stop system, since whatever relay or relays are chosen must be capable of stopping current flow over 100 A.

Power Transfer Components	Continuous Current (A)	Peak Current (A)
Basic ESC from Blue Robotics	14.40	112.88
Voltage Regulator 19V (15A)	1.89	6.79
Voltage Regulator 12V (30A)	4.03	33.72
Voltage Regulator 5V (15A)	2.25	12.34

Table C. 2: Continuous and peak amperage flowing through the regulators or ESCs.

To stop all actuators on Mini-Minion, two relays will be utilized. One 150A rated contactor relay will stop the thrusters and the servos, and one 40A solid state relay will stop the delivery systems. A second relay is used because other components that do not need to be shut down during e-stop also rely on 12V. The servo's voltage regulator only powers the servos, so it is viable to place that regulator on the thruster's relay as well. Both relays operate on battery voltage. The power requirements for these relays will now be accounted for in Table C.3:

Power Consuming Components	Quantity	Operating Voltage	Nominal Voltage	Peak Current (A)	Continuous Current (A)	Peak Power (W)	Continuous Power (W)
150A Max Contactor Relay	1	12-24	18.00	3.80	0.10	68.40	1.80
40A Max Solid State Relay	1	5-60	18.00	0.02	0.01	0.27	0.20

Table C. 3: Motor relay and delivery system relay power requirements are accounted for.

The figures in Table C.1 and C.3 do not tell the full story of how much power consuming components are used. For example, the thrusters have a peak power draw of 2031.84W but using that statistic is not accurate for predicting the total runtime of Mini-Minion. Therefore, component duty cycles must be considered.

Duty cycle durations are estimated per component given the competition tasks at hand. Component power draw can be categorized in 3 different modes: ON, OFF, and PEAK. ON is when a component is continuously drawing power. OFF is when a component is not being used. PEAK is when a component may see an unpredictable power spike. Each of these modes is a certain percentage of their component's total runtime (one competition attempt). Average power is a weighted average between the power modes and their corresponding draws.

Component Duty Cycles *(considering a 30-minute runtime as reference)*	Time ON (%)	ON State (W)	Time OFF (%)	Time PEAK (%)	PEAK Power (W)	Average Power (W)
Minisforum MS-01-US w/Core i9 13900H	96%	27.00	1%	3%	120.00	29.52
Ubiquiti Prism AC	90%	8.97	10%	0%	8.50	8.08
T200 - Blue Robotics Thrusters	80%	259.20	20%	0%	2031.84	207.36
150A Max Contactor Relay	100%	1.80	0%	0%	68.40	1.80
40A Max Solid State Relay	100%	0.20	0%	0%	0.27	0.20
Arduino Mega 2560 Rev3	100%	2.40	0%	0%	6.00	2.40
Livox HAP LiDAR	90%	12.00	10%	0%	26.00	10.80
SEAFLO 21 Water Pump	3%	25.00	97%	0%	48.00	0.75
USB30-IMX490-GW5400-GMSL2-120H Camera	90%	2.11	10%	0%	3.17	1.90
Nvidia Quadro M6000 24Gb	96%	20.00	1%	3%	250.00	26.70
2H012-016 High Pressure Solenoid Valve	1%	60.00	99%	0%	0.00	0.60
GPS/IMU Javad DELTA-DI GNSS Receiver	90%	4.50	10%	0%	6.72	4.05
Arctic 6k RPM Server Fans	100%	4.80	0%	0%	4.80	4.80
D845WP - Monster Torque Servo	80%	11.25	20%	0%	61.70	9.00
DBR4 Dual Band ExpressLRS Receiver	100%	0.50	0%	0%	2.50	0.50
5V Relay (Normally Open)	1%	0.25	99%	0%	0.10	0.00

Table C. 4: Component Duty Cycles are considered to get an average power draw of each component. Note that average power does not necessarily mean a component is continuously drawing power. Average power is a quantity used purely for runtime duration calc

There are a few notable assumptions made to determine the percentage time of each of the power draw modes:

1. Assuming that autonomy mode will be on for 90% of the duty cycle, components critical to autonomy will be ON for 90% as well (LiDAR, Camera, & GPS).
2. The Minisforum computer is always on standby for autonomy, so OFF percent is expected to be minimal.
3. Thrusters and Servos will be ON during autonomy mode and RC mode. However, a significant amount of OFF time is expected for Thrusters and Servos to account for drifting in the water, remaining stationary, or standing by.
4. Software blocks will be placed on the thrusters to ensure that peak wattage is never encountered.

Efficiency of the electrical system can be estimated through the power losses of the power transfer components, much like seen in Table C.2.

The voltage regulators and ESCs should contribute to power loss based on their efficiency and what power flows through them. Regulators were assumed to have 95% efficiency based on their listings. The ESCs, which also consider inefficiencies from the thrusters themselves, were assumed to have 85% efficiency. An additional miscellaneous efficiency loss is applied to the electrical system as a whole at 90%. Additional efficiency losses can come from wires, connectors, and unpredictable component behavior. After efficiencies, Mini-Minion average power draw is 389.15W.

Power Losses	Efficiency	Average Power Thru from Figure C.1 (W)	Power Lost (W)	Power After Losses (W)
Basic ESC from Blue Robotics	0.85	207.36	36.59	243.95
Voltage Regulator 19V (15A)	0.95	37.60	1.98	39.57
Voltage Regulator 12V (30A)	0.95	52.00	2.74	54.74
Voltage Regulator 5V (15A)	0.95	9.00	0.47	9.47
	Misc. Efficiency	**Total Power (W)**	**Total Power Lost (W)**	**Total Power After Losses (W)**
Miscellaneous Efficiency Losses	0.9	350.24	38.92	389.15

Table C. 5: Efficiency losses throughout the electrical system. Note that the 150A thruster relay and the 40A delivery system relay are not directly connected to power transfer components.

We had 4 total M18 12Ah Milwaukee drill batteries [12], giving the possible battery configurations of 1, 2, and 4. A configuration of 3 is not being considered due to the impracticalities of having only one extra battery in case all batteries need to be changed. Ultimately, a 2-battery configuration was selected for the ample runtime of 66.61 minutes and for the additional benefit of battery hot-swapping. Two extra batteries can now be charged up and available at any time to replace drained batteries, keeping Mini-Minion continuously running for longer test sessions.

Power Storage Configurations	Quantity	Nominal (V)	Capacity (Ah)	Energy Stored (Wh)	RUNTIME (min)
1 Battery Config	1	18	12	216	33.30
2 Battery Config	2	18	24	432	66.61
4 Battery Config	4	18	48	864	133.21

Table C. 6: Battery configuration and their runtimes.

Note that the Milwaukee M18 12Ah batteries have chemistry that supports the peak amperage possible from the electronics on board: 170.07 A. Keep in mind that this amperage is nearly improbable. Max amperage to be pulled from the batteries will more likely be ~120 A (approximately the current draw when operating all thrusters at full throttle), [18].
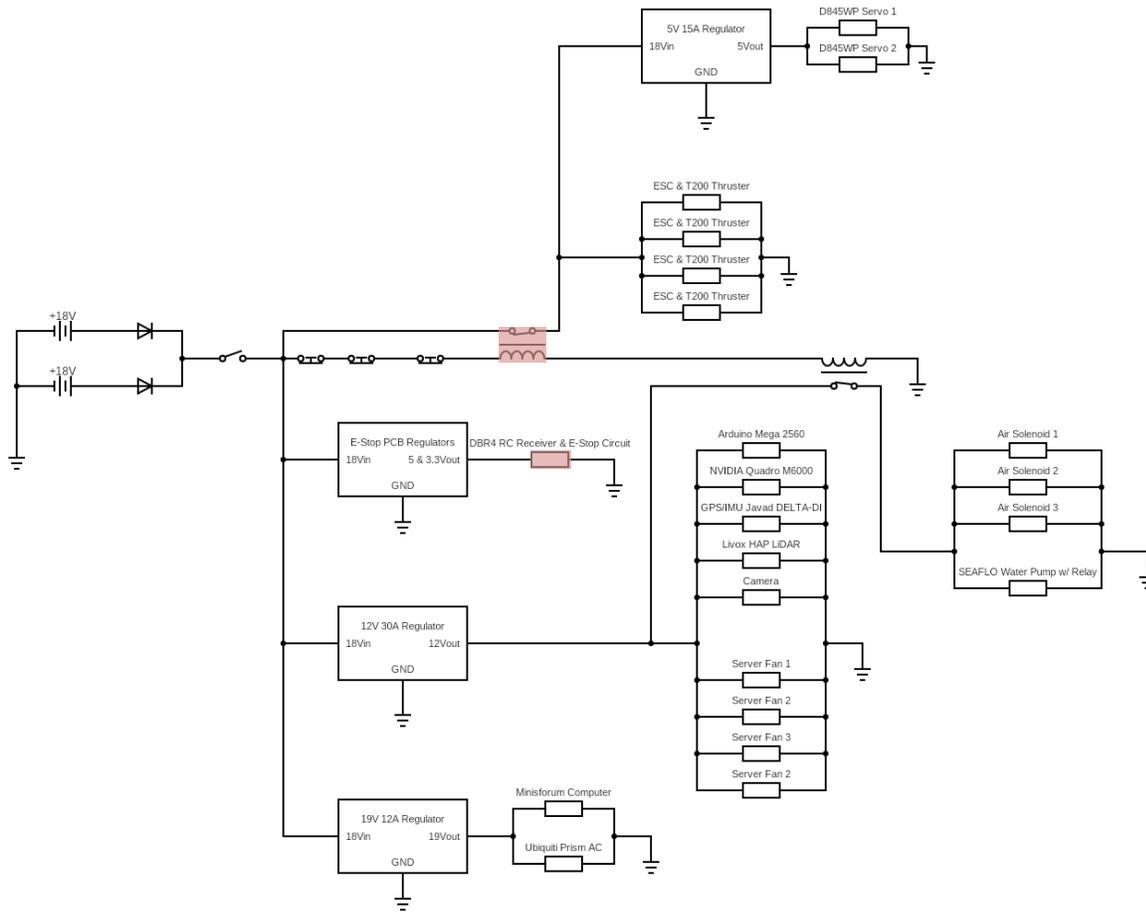
B. *Power Circuit*

Figure C. 1: Power circuit for Mini-Minion. Components are depicted as resistors. The orange normally open button corresponds to the wire e-stop activation. The orange resistor is the custom E-Stop PCB.

C. *Heat Dissipation*

All internal components and power lost due to inefficiency from the voltage regulators contribute to heat generation in the deck. Since power draw of internal components is known and power lost due to inefficiencies have been calculated, expected heat generated inside the deck can be summed up:

Internal Component	Average Power from Duty Cycle Calculation (W)
Minisforum MS-01-US w/Core i9 13900H	29.52
Ubiquiti Prism AC	8.08
150A 900VDC max contactor relay	1.80
40A 5-60VDC max solid-state relay	0.20
Arduino Mega 2560 Rev3	2.40
Nvidia Quadro M6000 24Gb	26.70
GPS/IMU Javad DELTA-DI GNSS Receiver	4.05
Arctic 6k RPM Server Fans	4.80
DBR4 Dual Band Xross Gemini ExpressLRS Receiver	0.50
5V Relays (Normally Open)	0.003
Total	**78.05**

Table C. 7: Internal components and their average power.

Internal Component	Efficiency	Power Thru (W)	Power Lost (W)
Voltage Regulator 19V (15A)	0.95	37.87	1.99
Voltage Regulator 12V (30A)	0.95	78.39	4.13
Voltage Regulator 5V (15A)	0.95	11.41	0.60
		Total	**5.19**

Table C. 8: Power lost and, therefore, released into the deck from the voltage regulators.

Total power inside the deck is 83.23W. Tacking on a 90% efficiency loss to account for unpredicted heat from wires or other sources gets 92.48W of total heat generation.

Mini-Minion will primarily rely on continuously running fans for heat dissipation. To determine the number of fans required, a simple derivation starting from the specific heat equation can be done [5]:

$$Q = mc\Delta T$$

Q is heat energy, m is mass, c is specific heat capacity, and ΔT is the change in temperature [7]. Dividing both sides by time converts the equation into rates:

$$\frac{Q}{t} = \frac{m}{t}c\Delta T$$
$$\dot{Q} = \dot{m}c\Delta T$$

$\dot{Q}$ is heat energy over time, and $\dot{m}$ is mass over time. Convert mass over time into density and volume over time:

$$\dot{Q} = \rho \dot{V} c\Delta T$$

ΔT is the difference in temperature between ambient and internal deck temperature:

$$\dot{Q} = \rho \dot{V} c(T_{internal} - T_{ambient})$$

Solving for $\dot{V}$ gets the following reciprocal function:

$$\dot{V} = \frac{\dot{Q}}{\rho c(T_{internal} - T_{ambient})}$$

The relationship between $\dot{V}$ and $T_{internal}$ can be graphed, giving a clear correlation for what volume air flow we would need given an internal deck temperature. The following quantities were assumed for generating Figure C.3 [11]:

$$\dot{Q} = 92.5 \text{ W}$$
$$T_{ambient} = 25°C \ (298 \text{ K})$$
$$\rho_{air} = 1.3 \left[\frac{\text{kg}}{\text{m}^3}\right]$$
$$c = 1\left[\frac{\text{kJ}}{\text{kg*K}}\right]$$
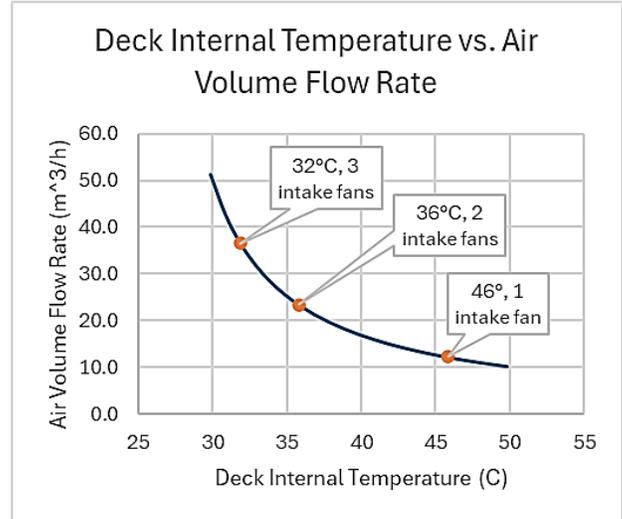$$\dot{V}_{one \ fan} = 12 \left[\frac{\text{m}^3}{\text{hr}}\right]$$

Figure C. 2: A reciprocal proportionality is observed between internal deck temperature and air volume flow rate.

The maximum internal deck temperature is 50°C, which is the maximum operating temperature of the batteries [12]. To be comfortably below that temperature, 2 intake fans are required, generating a combined airflow rate of 24 $\left[\frac{\text{m}^3}{\text{hr}}\right]$. However, it is not expected that we would get this airflow from the fans, as the air vents will restrict the airflow. To make up for this, 4 fans are used in total: 2 intake and 2 exhaust. Having fans on the inlets and outlets of the deck should allow us to get the airflow we need.

D. Air Vent Design

Mini-Minion's air vents were guided by several factors: splash-proofing, airflow, and size. The air vents had to let air flow freely in and out of the deck enclosure while confidently keeping water out and taking up an inoffensive amount of space.

A vertically stacked fin "maze" system was devised for splash-proofing. Other orientations for the fin "maze" were ruled out due to pockets where water can pool were formed. The quantity and dimensions of the fins had a direct influence on the airflow or air resistance of the vents. Multiple 2-fin and 3-fin configurations were tested qualitatively, with 2-fin having the best airflow.

The total size of the vents was constrained by the fans and the location of the vents. 40mm server fans were selected for their high static-pressure, designed to handle restricted airflow conditions. Slower 6000RPM versions of the server fans were used to keep power draw low and for safety, as high RPM server fans can easily cause harm.

Their small cross section also minimized the hole size required to be cut in the deck enclosure panels.

Whether the vents are located internally or externally will determine how much space there will be to work with for the vent size. While externally mounting the vents would give the vents the most room to increase airflow, there were too many extra considerations to make external vents "outdoors" proof. Since the vents will be printed out of PTEG, extensive waterproofing surface finishes much like what the motor pods have would need to be done to prevent water seeping into the vent structure in the event of rain or washing after Mini-Minion deployments. Additionally, the vent will have to be sturdy enough to handle impacts or bumping. Therefore, it was decided to place the vents internally in an essentially controlled environment, simplifying the considerations required for the vent design. Since the vents are already designed vertically, the footprint of the vents inside the deck enclosure is small enough to not be invasive to electrical system or internal components.
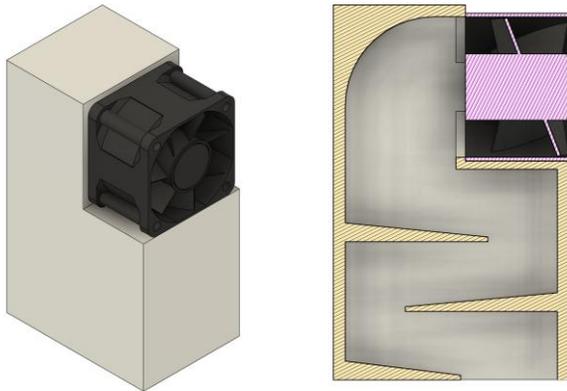

Figure C. 3: Iso view and cross-section view of the 3-fin air vent to be located inside the deck enclosure. Small cutouts at the base of the deck allow the vents to draw air in or out.

Silicone secures and seals the air vents to the base plate, and epoxy seals the edges of the exposed honeycomb at the vent cutouts. A hydrophobic mesh is also placed externally on the deck enclosure covering the vent cutout to make the vents as splash proof as possible. However, airflow tests for the mesh have yet to be done.

E.   Internal Layout

The internal layout of the deck is arranged considering where each component connects to, how much heat it generates, and how much it weighs. Fans intakes are on starboard side and fan exhausts are on the port side. The computer and graphics card are oriented to assist in the starboard-to-port air flow.
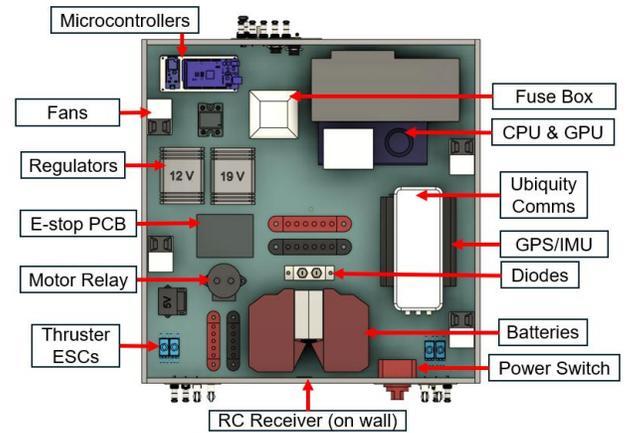

Figure C. 4: Internal Layout of the deck. The top is the bow of the Mini-Minion.

F.   Lid Sealing

The enclosure lid provides access to all internal components. C-Channel edge trims create a flat, even surface on the exposed end of the honeycomb panels. Silicone seal strips on the lid are pressed down with locking latches on the port and starboard sides.
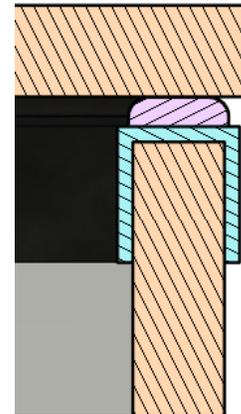

Figure C. 5: Cross section shows the C-channel in cyan and the silicon gasket in purple.

G.   Deck Material and Selection

The deck material is an important choice as it needs to be lightweight, waterproof, less insulative, without breaking the bank.

Criteria	Grade	Weight	Honeycomb Panel Glass Epoxy Skin Aluminum Core		Foam Epoxy Skin		5052 Aluminum Panel		Fiberglass (Fabric) Polyester Laminate		Marine Grade Plywood with Epoxy Skin		Polycarb Enclosure (28" x 20" x 7.3") w/ Aluminum mounting	
			Measure	Score	Measure	Score	Measure	Score	Measure	Score	Measure	Score	Measure	Score
Weight [lbs]	10 = Light 5 = Medium 1 = Heavy	25%	2.38 lbs for base plate	8	7.8 lbs/ft^3 **1.13 lbs for base plate**	9	2.24lb/ft^2; **10.45lbs for base plate**	3	95 lb/ft^3 *0.08 ft^3 = **7.4 lb for 0.2" baseplate**	6	9.5 lbs for base plate	5	Whole Box=15.72lbs; 1.5ft of extrusion=0.82lbs ; total structure=16.5lbs	6
Strength [psi]	10 = Strong 5 = Medium 1 = Weak	25%	S_y= 1.6 kpsi; 0.375" thick n=2.53	2	S_y = 20.6 kpsi	7	5052 (for marine; 0.16" thick; deflection = 0.137"; n = 8.19; S_y = 28 kpsi	8	**Anisotropic** : S_c (x,y) = (30,15) kpsi Flex modulus (x,y) = (1600 800) kpsi	9	S_y = 7.25 kpsi	4	Box: S.y = 11.09 kpsi, for 24"x28"x0.177" plate N=3.97	6
Corrosion Resistance (water)	10 = High 5 = Medium 1 = Low	15%	Epoxy skin prevents corrosion	8	Depends on the type of foam. Epoxy skin has high corr res	8	Excellent corrosive resistance, used for marine commonly	8	High corrosion resistant resins available	8	Epoxy Skin has high corrosion resistance	8	No worries for the box, aluminum choice is important though	8
Cost [$/ft^2]	10 = Cheap 5 = Medium 1 = Expensive	5%	$20.43 per sqr ft	5	?	5	$39.84 per sqr ft	4	$9/sq ft	9	$5 persqr ft (wood)	10	box is ~$275, aluminum extrusions are $9.33/ft	7
Manufacturability	10 = Easy 5 = Medium 1 = Difficult	20%	Commercially available. Precicion cuts, epoxy seals. SDS req	7	Not commericaly available. Make in house.	5	need extra consideration for box edges	7	Many materials. SDS applications (takes time)	4	Easy but takes time to dry resin. SDS for resins	5	off the shelf box, recommended to put all connectors at the top and front.	10
Thermal conductivity [Btu-in/hr-ft^2-ºF]	10 = High 5 = Medium 1 = Low	10%	k = 61	6	k=4.69	4	k= 960	9	k=4	3	k=0.8	1	heat resistance material, heat deflection temp=138C; k is unknown	3
	Totals:	100%	5.95		6.85		6.45		6.5		5.05		6.85	

Table G.1: Decision matrix comparing multiple materials for, weight, strength, corrosion resistance, cost, upkeep, and thermal conductivity.

Appendix D

Sensors and Integration

A) Mounting System Design

Integration of all external components and sensors to the deck was vital to efficient telemetry and activation. Mini-Minion's external mounting system was designed to allow for modular positioning and ease of adaptation/modification. Along both port and starboard sides of Mini-Minion Aluminum T-Slot Rails are epoxied to the side faces as shown in Figure D.1.
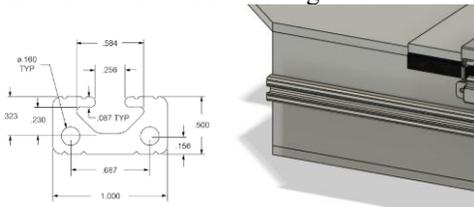

Figure D.1 Aluminum T-Slot rail dimensions and placement on deck face

These rails will allow for easy attachment of additional sensors/components if needed. All mounts are made to be secured via screw and T-nut.

B) Ball Launcher System

a. General Design Concept

The ball launcher design was inspired by RobotX Minion's ball launcher design, Figure D.2: Legacy pneumatic ball launcher assembly used for pressure and range validation.
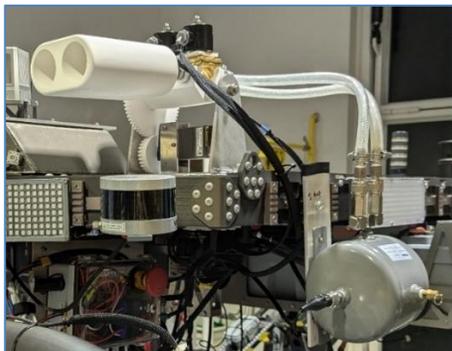

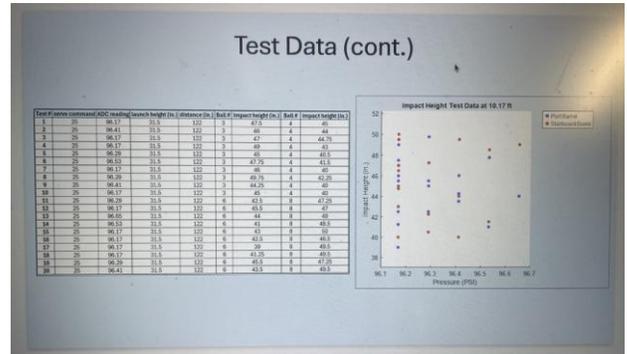*Figure D.2: Legacy pneumatic ball launcher assembly used for pressure and range validation*

Figure D.3: Legacy RobotX test data table and projectile trajectory plot used for MATLAB validation (25° simulation and 5° in-house launch).

It was a Pneumatic system consisting of a VIAIR air compressor, a 3L air reservoir, and U.S Solid Solenoids. This system was proven to work in the past, with the 3L reservoir pressurized to 90 psi and shooting up to 10 ft. In addition, it was designed to be able to adjust the trajectory angle by a servo for adjustable distances. However, this design, if designed to meet task requirements, would be very heavy, weighing in at about 26 lbs. It would weigh over 20 lbs even without the servo and mounting frame. Adjustments were made to reduce weight and improve performance. A large portion of the system's weight was due to the air compressor and 3L reservoir. The simplest solution is to reduce reservoir size, which requires an increase in pressure according to Boyle's Law and Ideal Gas Law:

$$P_1 * V_1 = P_2 * V_2 \qquad [1]$$
$$PV = nRT \qquad [2]$$

Unfortunately, this raised major issues. To meet the same output pressure of the previous system, the new reservoir would need to store pressures > 500 psi. Most reservoirs smaller than 3L can't handle that much pressure. Even if they could, most commercially bought portable air compressors can only pressurize up to 200 psi. Most importantly, the old system's solenoids had a maximum operating pressure of 124 psi. So many things need to change.

As a result, the air compressor and large reservoir were replaced with compact 25 g CO_2 cartridges, each storing gas at an internal pressure of approximately 850 psi at 70 F. To evaluate whether a cartridge based system could plausibly support a launch event, a first order gas availability analysis was performed using molar quantities. Two commercially available pneumatic launcher systems were referenced, both of which use 5 lb CO_2 tanks and are capable of launching projectiles or payloads on the order of 60 to over 100 feet at operating pressures between 100 and 150 psi.

Expressing gas availability in moles allows a direct comparison between these validated systems and the proposed design, independent of tank size or geometry. Using the molar mass of CO2, the total number of moles contained in a 5 lb tank was computed and divided by the reported number of launches to estimate the molar consumption per shot. This value was then compared against the number of moles available in a single 25 g cartridge. This analysis provides a conservative feasibility check showing that the proposed system operates within the same order of magnitude as existing validated systems. When combined with prior projectile motion simulations and experimental results included elsewhere in the appendix, this analysis supports the conclusion that the cartridge based launcher is physically plausible and merits further experimental validation.

$$m = 5x453.6 = 2268g$$
$$n_{total,\,5lb} = \frac{2268}{44} = 51.5\ mol$$
$$n_{shot} = \frac{51.5}{50} = 1.03\ \frac{mol}{shot}$$
$$n_{shot} = \frac{51.5}{100} = 0.515\ \frac{mol}{shot}$$
$$n_{25g} = \frac{25}{44} = 0.57\ mol$$
$$shots = \frac{0.57}{1.0} = 0.6\ shots$$
$$shots = \frac{0.57}{0.5} = 1.1\ shots$$

We also replaced the solenoids with ones that are rated to have a maximum operating pressure of 1000 psi. [10] This new ball launcher system, including all adapters and safety valves, reduced the launcher system's weight by > 50%, weighing only 8 lbs.

Figure D.4 CO2 Cartridge Design Setup

b.   Barrel Design

The barrel design hasn't changed much from the RobotX Minion design. A couple of modifications were made to make it more efficient and meet task requirements. Old design had only two unified barrels and a flat internal face at the base of the barrel, shown in Figure D.5.
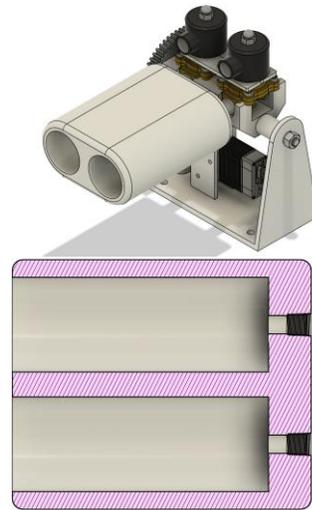

Figure D.5 RobotX Minion (Old) Barrel Design

The new barrel now consists of three unified barrels, to meet task requirements, and as seen in Figure D.6, has a concave internal base face to match the curvature of the racquetball.
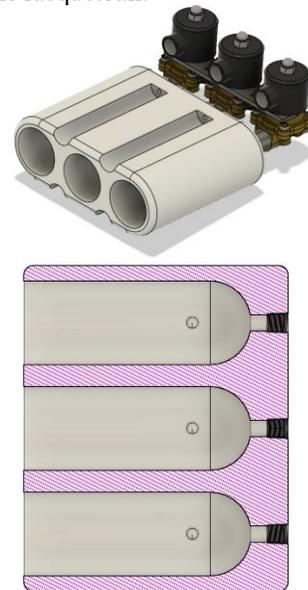

Figure D.6 Mini-Minion (New) Barrel Design

In addition, a 0.04-inch extruded nub was added near the base of the barrel to prevent the ball from excessive movement within the barrel during runs. All modifications decrease initial pressure loss, allowing for more consistent shots.

c.   Mount Design

The mounting system is unique for Mini-minion. It is a permanent mount, designed to only allow the barrel to be attached from one direction, and holds the barrel securely in place with screws due to ball launcher recoil.
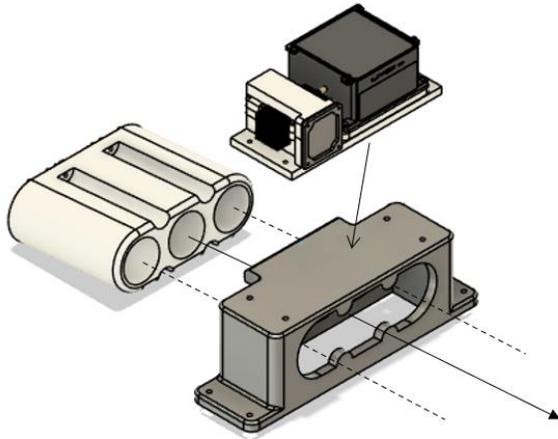
Figure D.7: Exploded view of updated ball launcher mount showing attachment to perception system platform.

This mount also acts as a raised platform for the perception system mount. The mount is designed for easy replacement of the barrel or perception components.

d. Testing/Results

The MATLAB trajectory plot represents the simulated data from the original air compressor launcher setup, used to determine required firing pressures and angles before switching to the CO2-based design. This simulation modeled projectile motion at 25 degrees to validate the pressure-to-range relationship for a 10-foot target. The data table corresponds to legacy RoboBoat launcher results showing consistent launches around 96 psi, confirming that a 10-foot delivery distance aligns with the Object Delivery task's requirements. These results served as a baseline for modeling the CO2 replacement system, ensuring the smaller cartridge setup could achieve the same pressure range and trajectory.

The MATLAB simulation was also used to replicate our in-house testing conditions, where a 5-degree firing angle from a 35-inch launcher height was physically verified to hit a target 10 feet away. These results, combined with projectile motion equations, confirmed that the theoretical pressure curve matches the real launcher's output behavior. The CO2 system, when operating at 850 psi with a 0.05 L cartridge and 4 L chamber, produces equivalent launch pressures of around 85–100 psi, matching the model. This conclusion is supported by the decision matrix results, where the CO2 design scored higher due to its reduced weight, improved efficiency, and identical pressure capability. Together, the MATLAB analysis and comparison data confirm that the CO2-based launcher maintains the original system's range and performance while optimizing for RoboBoat competition constraints.

Table D.1: Decision matrix comparing legacy air-compressor system and CO_2 single-use design for weight, cost, upkeep, and integration.

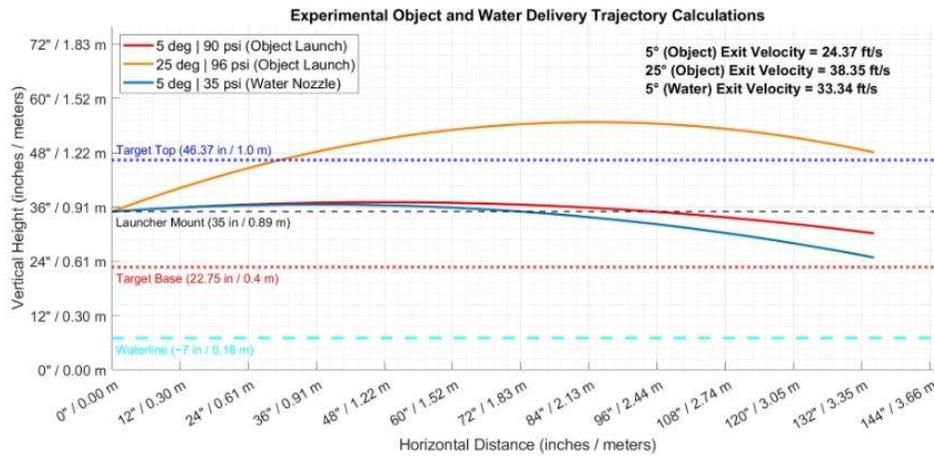|	Viability	Cost	Weight	Upkeep	Integration	SCORE
Air Compressor + Tank (Old Design)	Y	7	6	7	10	7
Air Compressor (external) + 3 Tank (180 psi) (Individual)	N	0	0	0	0	0
CO2 Single-Use Air Tank Ammo	Y	7	10	7	6	8
Single Large Multi Shot Tank	Y	7	5	6	5	6

Figure D.8: MATLAB trajectory comparison showing simulated projectile motion for 25 deg (object launch), 5 deg (object launch), and 5 deg (water nozzle) configurations.
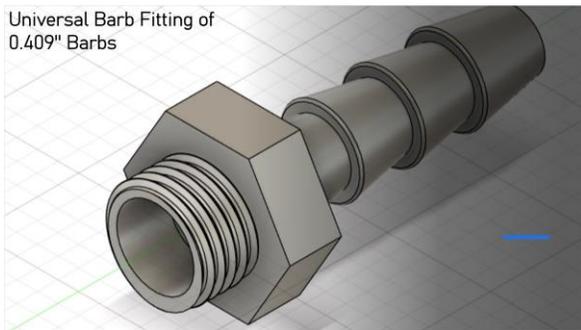
C) Water Cannon System
    a. General Design Concept

Figure D.9: Universal 3D-printed barbed fitting used to interface SEAFLO pump and nozzle tubing
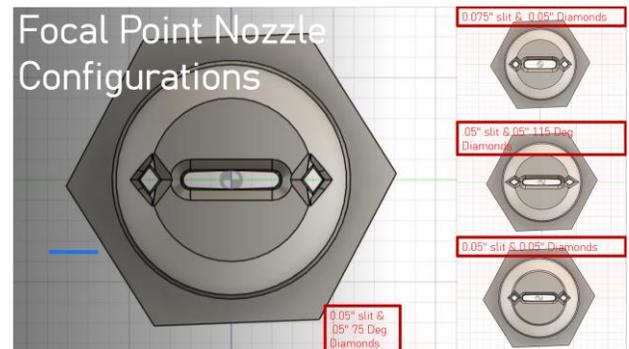
b. Nozzle Design

Figure D.10: Focal point nozzle configurations featuring slit and diamond geometries for converging spray patterns
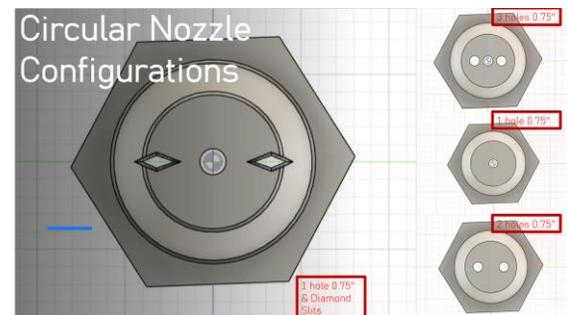
Figure D.11: Circular nozzle configurations in single, double, and triple-hole arrangements for controlled fan spread.

The water delivery system was developed to complete the target-hitting task using a compact and efficient design. The SEAFLO 5V 2A pump was selected for its lightweight construction and reliability under constant use. To enable rapid testing and modular setup, a universal 3D-printed barbed fitting was created to attach to the pump outlet. This allowed for quick swapping between different nozzle designs to compare performance and spray patterns. All nozzles and fittings were printed in fire resin to handle sunlight exposure and provide sufficient strength for repeated testing. The overall goal was to consistently hit targets from a distance of at least 10 feet, exceeding the 6-foot average achieved by other competitors in previous competitions.

Eight nozzle configurations were created and tested, divided into two main categories: circular and focal point designs. The circular designs used 0.075 inch holes in single, double, and triple layouts, along with one that included additional diamond slits. The focal point nozzles used narrow slits with side diamonds at different angles to control how the spray converged or fanned out. These designs were evaluated for range, spread, and visibility of spray to identify the best options for consistent, visible, and precise water delivery.

Table D.2: Water cannon decision matrix comparing nozzle configurations based on range, stability, and visibility performance.

Nozzle Config.	Type	Hole/Slit Size (inch)	Spread (degrees)	Distance (feet)	Notes
1 Hole	Circular	0.075	3–5	10	**Chosen Design**
2 Holes	Circular	0.075	3–5	~12	
3 Holes	Circular	0.075	5–10	~9	
0.075" Hole + 0.05" Diamond Slits	Circular	0.075	3–5	10	**Chosen Design**
0.050" Slit + 0.050" Diamonds	Focal Point	0.05	5–10	8–10	
0.050" Slit + 0.050 Diamonds, 75 degrees	Focal Point	0.05	15–30	~6	
0.050" Slit + 0.050" Diamonds 115 degrees	Focal Point	0.05	3	~5	
0.075" Slit + 0.050" Diamonds	Focal Point	0.075	8–10	~8	

The single-hole and single-hole-with-slits designs were chosen as the final configurations due to their consistent range and stable fan spread. Both achieved the required 10-foot reach and produced a visually clear fan of water, improving accuracy and confirmation of target hits.
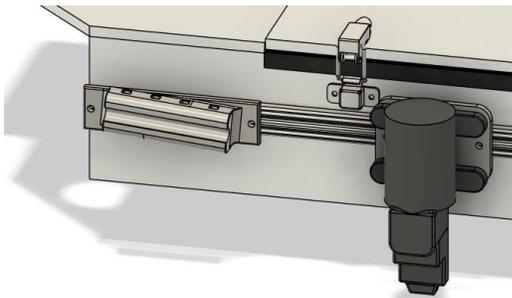
c.   Mount Design

Figure D.12: 3D model of SEAFLO pump mounting assembly attached to T-slot rail for adjustable nozzle alignment and maintenance access.

The mounting system for the water delivery setup uses T-slot rails that run around the perimeter of the boat. This setup provides flexibility for adjusting nozzle positioning and alignment during testing. The SEAFLO pump is secured to a 3D-printed plate that slides along the T-slot rail, allowing the team to fine-tune the aim angle or swap components without full disassembly. The left side of the pump connects to the nozzle assembly, which fires at a fixed 5-degree upward angle toward the target. Both inlet and outlet lines use 3/8 inch tubing, with the right side feeding down the pontoon into the water to supply the pump. This modular design makes the system adaptable for real-time calibration and consistent field use.

d.   Testing/Results

Table D.3: Water cannon decision matrix for selected nozzles.

Nozzle Config.	Type	Hole/Slit Size (inch)	Spread (degrees)	Distance (feet)	Notes
1 Hole	Circular	0.075	3–5	10	**Chosen Design**
0.075" Hole + 0.05" Diamond Slits	Circular	0.075	3–5	10	**Chosen Design**

After completing the tests, the single-hole and single-hole-with-slits nozzles proved to be the most effective configurations. These produced a stable fan

pattern between 5 and 10 degrees while maintaining a consistent 10-foot range. The spray was visibly defined, allowing both the operator and judges to clearly verify target hits. Other nozzle designs were functional but either

lacked sufficient range or created too wide of a spread to stay consistent. Based on these results, the chosen nozzles offered the best balance of range, visibility, and control, making them ideal for the RoboBoat competition environment.

Real-time testing data from these two nozzle configurations was then used to develop and validate the MATLAB trajectory model shown above. The measured output pressure, launch angle, and observed range were input into the simulation to recreate the SEAFLO pump's 5V 2A performance under real conditions. In the MATLAB plot, the blue curve represents the predicted water stream path fired at a 5-degree angle from a launcher height of 35 inches. The trajectory aligns closely with physical testing, showing the water reaching the 10-foot target zone. Reference lines for the launcher mount, target base, and waterline confirm that the simulation accurately replicates the observed spray path, verifying that the selected nozzle design provides reliable, consistent coverage at the required distance.

D) Perception System

A USB30-IMX490-GW5400-GMSL2-120H Camera and a Livox HAP LiDAR make up the perception system. Used to detect and classify objects for specific tasks [20], [21]. The perception system mount is 3D printed from PETG and holds both the Camera and HAP LiDAR together for ease of calibration. Both components are secured to the mount by screws. The mount has a picture frame design that secures plexiglass to the mount to prevent water from reaching the camera lens. The mount attaches to the ball launcher barrel mount to be raised for better perceptive distance.
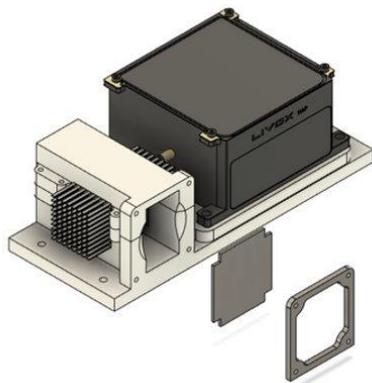

Figure D.13: Perception Mount Exploded View

E) GNSS Antenna

The GPS-702-GGL Antenna was chosen to pair with the JAVAD GNSS GPS. Two GPS Antennas were required to be distanced by 1 meter apart for accurate location readings. To meet this requirement the GPS antennas are extended past the bow face by 5 inches and extended past the stern face by 18 inches.
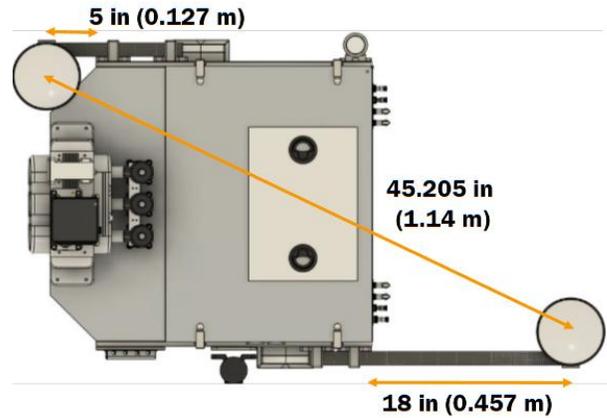

Figure D.14: GPS Antenna Separation Distance

The diagonal distance between each GPS antenna is 45.2 in (1.14 meters), meeting the 1-meter requirements.

Its mounting system comprises three parts: a rail mount, a square 30 mm x 30 mm x 3 mm carbon fiber tube, and a mount to attach the antenna to the carbon fiber tube, as shown in Figure D.15: GPS Antenna Mount Design.
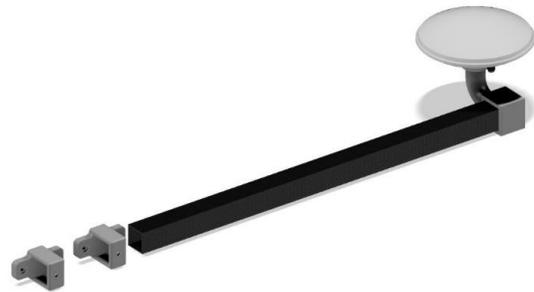
Figure D.15: GPS Antenna Mount Design

The GPS rail mount and GPS tube mount are 3D printed from PETG.

F) Ubiquiti Antenna

The Ubiquiti Prism Antenna was chosen to be able to send heartbeat data signals to judges as per competition requirements. Its mount is 3D printed from PETG. The antenna is located on the starboard side of the deck near the rear for clear signal communication, shown in Figure D.16.

Figure D.16: Ubiquiti Antenna Mount Design and Deck Location

G) *LED Beacon*
   a. *Component Description*

Figure D.17: Exploded view and Assembled View of LED antenna assembly showing component stack, fasteners, and wiring layout for modular installation.

The LED Antenna Mount was designed to house the upper LED matrix and control electronics in a compact and maintainable setup. The pink portion represents the LED panel, while the green block inside is the SAMD21 board, which was selected over the Mega due to its higher clock speed and faster data handling for LED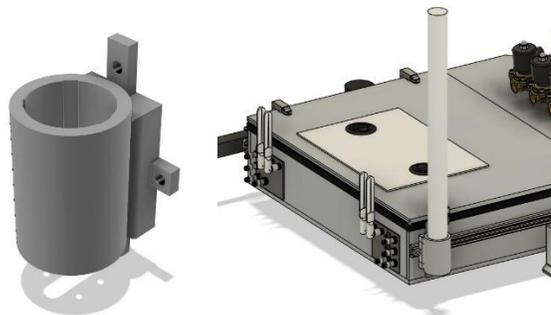 animations. The entire system is built around a 36-inch PVC pipe that was cut down into a 28-inch assembly, then split into two sections measuring 16.25 inches and 11.75 inches.

The 11.75 inch top section holds the LED panel, SAMD21 board, and LED Antenna Cap. This section can be detached for quick access to internal components or replacement. The 16.25-inch lower section is permanently fixed to the boat's side using epoxy for structural integrity. A set of IP67-rated Nilight connectors run up through this section, providing waterproof signal and power connections to the LED assembly.
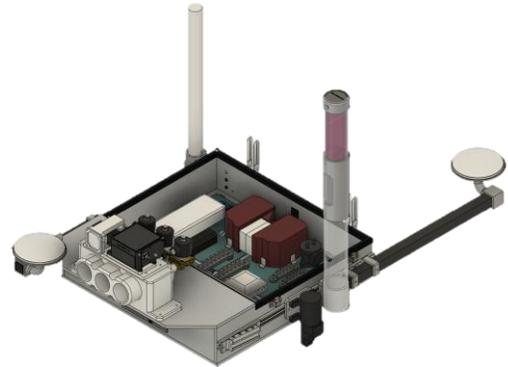
b. *Mount design*

Figure D.18: Full boat system view highlighting antenna placement, LED matrix positioning, and sensor layout along the port and starboard rails.

The mount design connects directly into the T-slot rail system that runs along the side of the boat, giving it modular flexibility. The lower section of the pipe is anchored to a 3D-printed coupler, which connects the two PVC segments. This coupler is secured using trailer pins and cotter pins, allowing the upper LED section to be quickly removed for transport or maintenance without disturbing the lower mount. The entire assembly can be repositioned along the T-slot rails to optimize visibility or adjust height if needed.

Positioning the mount near the upper corner of the boat ensures the LEDs remain visible from all directions during competition, even with the taller antennas or HAPD module nearby. If the overall height needs to be reduced during inspections, the taller antennas can be removed while keeping the LED assembly intact.

H) *Connector Panels*

All external electrical connections are connected to the deck via connector panels located on the bow and stern panel faces. The connector panels are made of ¼" plexiglass for ease of connector adaptation and is epoxied to hole cutouts in the deck. Each panel consists of various connectors depending on component location, is designed for optimal cable management, and has extra surface area for additional connector attachment when necessary. The bow connector panel consisted of 2-pin and 3 pin connectors, USB, HDMI, Fakraz connector, and a 12 pin Aviation Connector, shown in Figure D.19.

Figure D.19: Bow Electronics Connector Panel
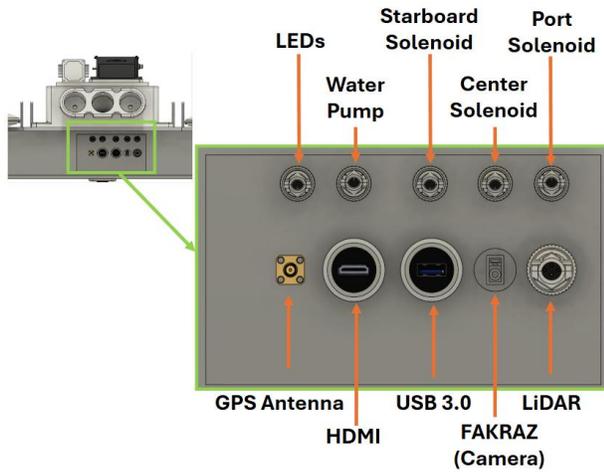
There are two connector panels on the stern face, housing 3-pin connectors and coaxial SMA connectors, shown in Figure D.20.
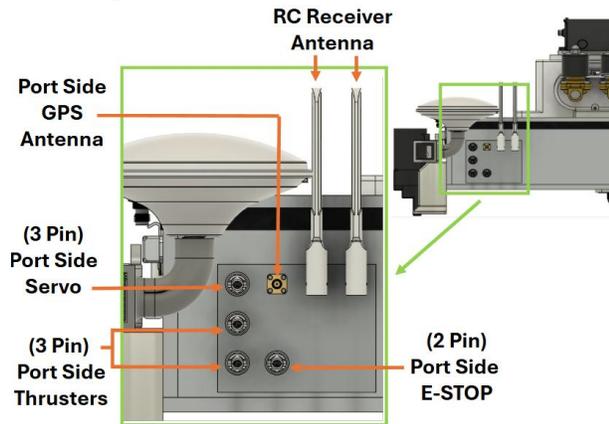

Figure D.20: Stern Port Side Electronics Connector Panel

All connector types are shown below:

Table D. 4: Connector Type Table

Connector Type	Images
2-Pin	
3-Pin	
SMA	
USB	
HDMI	
FAKRAZ	
12-Pin	

Appendix E

Automation and Preliminary Testing Methods

A) Communication Protocol

To facilitate fast and reliable serial communication between a computer running ROS 2 and an Arduino, a communication protocol is implemented to define strict packet guidelines between each system. This ensures error-free data exchange while maintaining high speed and reliability.

Message Start	Communication Protocol Sensor and Subsystems		Version: Date:	A:2 11/23/2025
1001100000001100	**Command Name**	**ID**	**Size**	**Description**
	Open Solenoids, A-C	0xA1	1 byte	Opens Solenoids 1,2,3
	Close Solenoids, A-C	0xA2	1 byte	Closes Solenoids 1,2,3
	Thruster A PWM write	0xC1	2 byte uint16_t	PWM (1000-2000)
	Thruster B PWM write	0xC2	2 byte uint16_t	PWM (1000-2000)
The following data is sent to the Arduino from the Computer	Thruster C PWM write	0xC3	2 byte uint16_t	PWM (1000-2000)
	Thruster D PWM write	0xC4	2 byte uint16_t	PWM (1000-2000)
	Thruster AB PWM write	0xC5	2 byte uint16_t	PWM (1000-2000)
	Thruster CD PWM write	0xC6	2 byte uint16_t	PWM (1000-2000)
	Servo A Angle write	0xD0	1 byte	Servo Angle 0-181
	Servo B Angle write	0xD1	1 byte	Servo Angle 0-181
	Wireless E-Stop	0xE1	1 byte	Trigger E-Stop
Message Start	Communication Protocol Sensor and Subsystems		Version: Date:	A:2 11/23/2025
1001100000001100	**Command Name**	**ID**	**Size**	**Description**
	Solenoid A State	0xA1	1 byte	State Closed/Open (0/1)
	Solenoid B State	0xA1	1 byte	State Closed/Open (0/1)
	Solenoid C State	0xA1	1 byte	State Closed/Open (0/1)
	Thruster A PWM read	0xC1	2 byte uint16_t	PWM (1000-2000)
	Thruster B PWM read	0xC1	2 byte uint16_t	PWM (1000-2000)
The following data is sent to the Computer from the Arduino	Thruster C PWM read	0xC1	2 byte uint16_t	PWM (1000-2000)
	Thruster D PWM read	0xC1	2 byte uint16_t	PWM (1000-2000)
	Servo A Angle read	0xD1	1 byte	Servo Angle 0-181
	Servo B Angle read	0xD1	1 byte	Servo Angle 0-181
	Battery Voltage read	0xB1	4 byte float	Reads Arduino Voltage
	Physical E-Stop State	0xE1	1 byte	reads the current physical E-Stop state
	Wireless E-Stop State	0xE2	1 byte	reads the current wireless E-Stop state

Figure E.1 Communication Protocol

The protocol shown in Figure E.1 defines a master code that must be read first. If the master code is not received, all subsequent bytes are ignored. If the master code is correctly received, the next field read is the Command ID, formatted in hexadecimal, which identifies the system being interacted with. Finally, the expected packet data size is read, and the variable corresponding to the Command ID is updated accordingly.

B) Remote Control

Utilizing CRSF communication allows transmitting remote-controller data up to 16 unique channels. Each channel is then designated for a particular system that corresponds to the Command ID identified in the protocol and can be individually monitored or controlled with analog PWM signals. In this setup, a

Radiomaster DBR4 Dual-Band Express LRS receiver receives commands from a Radiomaster TX16S transmitter.

The receiver outputs CRSF data using a high-speed UART interface. The DBR4 TX line is connected directly to the Arduino Mega RX1 pin (pin 19), with shared 5 V power and ground, allowing the Arduino to continuously decode channel values and interact with connected devices based on the operator's inputs.
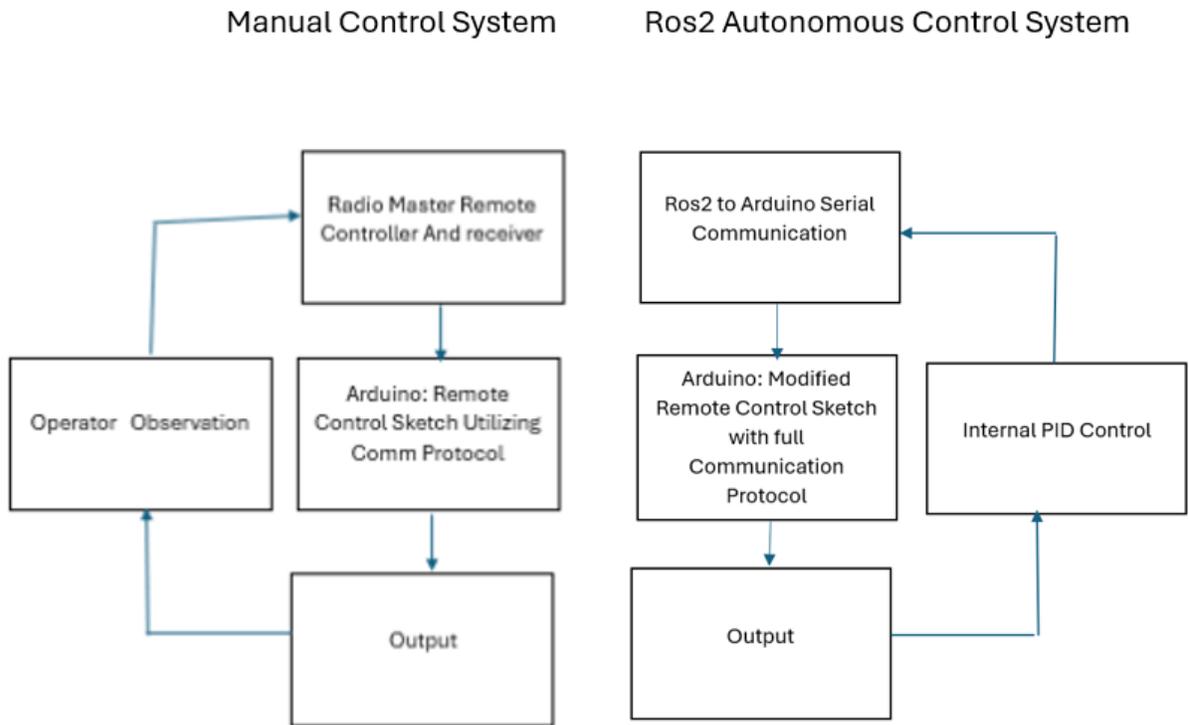

Figure E.2 Communication Protocol Flow Chart
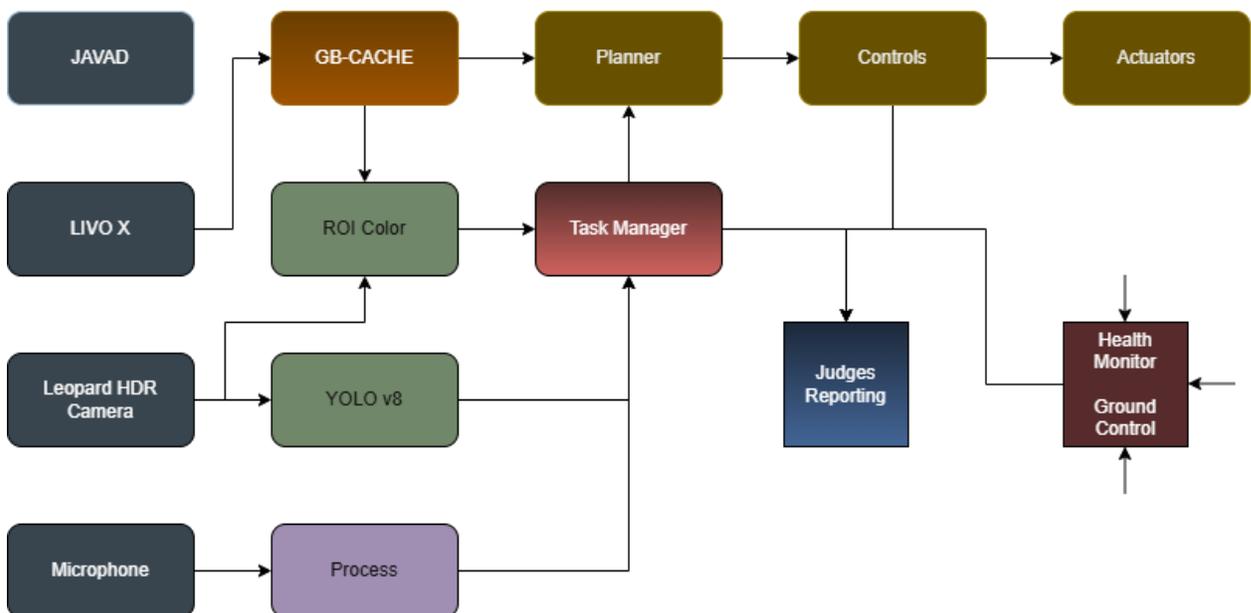
C) Mini-Minion Robot Architecture

Figure E.3 Mini-Minion Robot Architecture Flow Chart

Appendix F
Team Minion Requirements

Definitions Table:

Term	Definition
Design	Covers requirements governing configuration, placement, integration & use of defined components.
Safety	Covers requirements ensuring compliance with standards & protection of personnel, equipment, & environment.
Performance	Covers requirements defining functional outcomes, scoring tasks, & operational accuracy per RoboBoat rules.
Physical	Covers size, weight buoyancy & mounting requirements that affect structural limits.
Perception & Delivery Payload	Consisting of the Livox HAP LiDAR, USB30-IMX490-GW5400-GMSL2-120H camera, Javad TR-3S DUO GNSS (dual antenna GPS/IMU), ball launcher, water cannon, and associated components.
Camera	USB30-IMX490-GW5400-GMSL2-120H sensor used for visual detection of navigation channels and task objects.
LiDAR	Livox HAP (TX) sensor used for range and object detection.
GNSS	Javad TR-3S DUO GNSS dual antenna GPS/IMU module used for position and heading.
Comms	Ubiquiti Prism AC radio communication system used for shore communication.
Computer	Minisforum SM-01-US onboard computer with Intel i9-13900H, Ubuntu Jammy, and ROS2 Humble.
Subsystem	Refers specifically to the Perception & Delivery Payload.
Deck	The flat top surface of the ASV hull. The elevated structure and assembly to which components from *Appendix 1* shall be either externally mounted or internally protected.
Position-Sensitive Electronics	Components whose accuracy or functionality depend on a fixed orientation/placement (e.g., camera, LiDAR, GNSS, comms antenna).
ASV	Autonomous surface vehicle (Entire Boat)

Design Section: DSN-#	Requirement
DSN-1	The **Perception & Delivery Payload** shall include the following components: **LiDAR, Camera, GNSS, Comms, Onboard Computer, Ball Launcher, and Water Cannon**.
DSN-2	The **camera** and **LiDAR** shall be mounted at a height suitable for navigation channel and task object detection, not exceeding 3 inches above **deck**.
DSN-3	The **GNSS** shall be mounted at a height not exceeding 3 inches above **deck.**
DSN-4	The **Comms** shall meet IEC 61000-4 EMC/EMI standards to tolerate electromagnetic interference from neighboring components.
DSN-5	The **Perception & Delivery Payload** shall mount rigidly to the ASV hull.
DSN-6	The **Perception & Delivery Payload** software shall interface with the **computer** on the ASV.
DSN-7	**Position-sensitive electronics** shall be mounted using vibration-tolerant fixtures in accordance with manufacturer recommendations.
DSN-8	The entire **subsystem** and all components shall be mounted to the **deck**.
DSN-9	All required and sourced equipment shall be incorporated into the **subsystem** design.
DSN-10	The **GNSS** shall maintain positional accuracy in open-sky conditions per manufacturer specifications.
DSN-11	The **comms** system shall maintain ≥90% link reliability under line-of-sight conditions.
DSN-12	The **LiDAR** shall maintain calibration within manufacturer angular tolerance during operation.
DSN-13	All structural materials shall meet ASTM B117 standards.
DSN-14	All systems below the instrumentation **deck** shall be IP67 compliant.
DSN-15	The **ASV** shall have 2 stern-mounted thrusters on each pontoon.
DSN-16	The **deck** height shall be dimensioned such that there is sufficient space for all sensors and **deck** components in and on the **deck**. (we should reference the tallest component)
DSN-17	The **deck** elevation from water level shall be such that the pontoons and motors have the necessary clearance to properly function.

DSN-18	The **deck** width and length shall be less than the robot system's overall width and length.
DSN-19	The **deck** shall interface with the base by suspension arms in the front, with additional support near the stern.
DSN-20	The **deck** shall interface with the base by suspension arms in the front, with additional support near the stern.
DSN-21	The **deck** shall rigidly interface with the racquetball launcher and water cannon assembly.
DSN-22	The **deck** shall be within 10 degrees pitch relative to the waterline in still waters.
DSN-23	The **deck** shall support the mass and dimensions of all components listed in *Appendix 1*.
DSN-24	All components and systems listed in *Appendix 1* shall be securely fastened on or inside the **deck**.
DSN-25	The combined mass of the **deck** structure and its components, as listed in *Appendix 1*, shall not exceed 50lbs.
DSN-26	The **deck** system and all exposed components shall be dust and water tolerant to a minimum standard of IP66.
DSN-27	The system shall be powered by one to four M18 Batteries.
DSN-28	The **deck** and entire system shall use the components listed in *Appendix 2 (required components)*.

Safety Section: SAF-#	Requirement
SAF-1	All subsystem wiring shall comply with IPC/WHMA-A-620 (Class 2 or better).
SAF-2	Subsystem wiring shall be secured (clamps/strain relief), insulated (heat-shrink or equivalent), and routed separately from high-current propulsion wiring.
SAF-3	Sharp edges and exposed moving parts shall be covered or shrouded to meet IEC 60529 IP2X (finger-safe).
SAF-4	The launcher and water cannon shall not discharge upon any failsafe condition (kill switch, signal loss, or system fault).
SAF-5	Pressurized components of subsystem shall operate strictly within manufacturer specifications.
SAF-6	Environment-exposed components of subsystem shall meet IEC 60529 IP65 (rain and dust protection) or higher.
SAF-7	Subsystems shall tolerate vibration per IEC 60068-2-6.
SAF-8	Components of ASV shall withstand wind gusts up to 10 m/s (~20 kt) in accordance with IEC 60721-3-2 Class 2M3.
SAF-9	Components of subsystem shall operate within ambient temperatures of 35 °F to 100 °F ($\approx$ 2–38 °C) per IEC 60068-2-1/-2.
SAF-10	The ASV shall comply with all rules in the RoboBoat 2026 Handbook.
SAF-11	The ASV shall be light enough for two people to carry it without injury as outlined by OSHA ASH Act Section 5(a)(1).
SAF-12	Batteries shall be handled in accordance with the manufacturer's safety and disposal guidelines.
SAF-13	No system on the ASV shall exceed 60 Vdc.

Performance Section: PERF-#	Requirement
PERF-1	The **subsystem** shall locate orange vessels (with black triangles) and black vessels with ≥90% detection accuracy.
PERF-2	The **subsystem** shall deliver racquetballs to black vessels (hit plus signs or inside hull) in accordance with RoboBoat Handbook §3.2.5 Rescue Deliveries.
PERF-3	The **perception & delivery payload** shall be preloaded with no more than 3 racquetballs without reloading during a scoring run**.**
PERF-4	The **perception & delivery payload** shall fire balls independently and sequentially, not simultaneously.
PERF-5	The **subsystem** shall be capable of scoring on each delivery task (water and ball) per RoboBoat Handbook §3.2.5.
PERF-6	The **perception & delivery payload** shall project a visible stream ≥2 m onto the black triangle target for ≥3 seconds, per RoboBoat Handbook §3.2.5.
PERF-7	The **perception & delivery payload** shall initiate firing from a distance ≤10 ft (≈3.05 m).
PERF-8	The **perception & delivery payload** shall not exceed 100 mph (~161 km/h) launch velocity for safety.
PERF-9	The **subsystem** shall log each ball delivery event (launch initiation, current target) for post-run verification.
PERF-10	The **ASV** shall be positively buoyant at all orientations.
PERF-11	The **ASV** shall be capable of independent thruster-paired steering.
PERF-12	The draft of the pontoons shall be 40% +/- 10% by volume in still waters.
PERF-13	The **ASV** shall have a suspension group capable of damping rough water conditions.
PERF-14	The **ASV** shall consist of remote control between manual and autonomous operation modes.
PERF-15	All Radio Frequency (RF) equipment shall be operated within the rules and regulations of the United States of America.
PERF-16	The **ASV** shall consist of an onboard **computer** capable of operating all autonomy functions.

Deck Systems and Components

System	Components
Projectile Systems	Water Cannon, Water Pump, Hoses, Hose Nozzle
Racquetball Launcher	Racquetballs, Launcher Assembly, Air Compressor, Air Tank
Sensing System	LiDAR Sensor, Camera, GPS, IMU
Power System	Batteries (≤4), Voltage Regulators, Motor Controllers (ESCs ×4), E-Stop & Relays, Fuses, Wires
Computational System	Computer, Data Cables
Communications System	Antennas, Wiring

Physical Section: PHYS-#	Requirement
PHYS-1	The **ASV** shall be scaled down dimensionally to 25% +/- 20% the size of the Minion designed by ERAU (Daytona Beach).
PHYS-2	The **ASV** shall maintain the pontoon and articulated pod layout of the ERAU Minion platform.
PHYS-3	The **ASV** shall weigh less than 100 lbs.
PHYS-4	The **Perception & Delivery Payload** shall weigh no more than 25 lbs. in total.
PHYS-5	The **ASV** shall fit within a standard doorway as outlined by the ADA in Section 404.