RoboBoat 2026: Technical Design Report SimLE SeaSentinel Team

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***Abstract*—This report presents the strategy of the SimLE SeaSentinel Team for RoboBoat 2026 and the design of the system. The system is composed of an Autonomous Surface Vehicle (ASV) designated ASV Zimorodek II (Kingfisher II) and the Ground Segment (GS). In this project, the principles of systems engineering have been followed, and the V-model has been employed to organise the development process of the vehicle. In the present year, the emphasis was directed towards the enhancement of the preceding iteration of the unit, as opposed to the conception of an entirely novel platform. The ASV Zimorodek II represents an iteration of the Zimorodek, developed in the 2025/2026 period. The vehicle retains its modularity, ease of transport, and predominantly 3D-printed components. The propulsion system, comprising four thrusters arranged in an X-configuration, enables omnidirectional movement capabilities. It has been established that all modules within the vessel communicate via an Ethernet network. Situational awareness is based on an OAK-D LR stereo camera. The software system architecture is based on Robot Operating System 2 (ROS2). Maintenance of communication with the ASV is facilitated by means of three discrete radio links. The navigation system of ASV Zimorodek II is built on an advanced potential field-based algorithm for object mapping and clustering, enabling task recognition and collision avoidance, supported by Rapidly-exploring Random Tree* (RRT*).**

***Index Terms*—autonomous surface vehicle, robot operating system, collision avoidance, omnidirectional propulsion, RoboBoat**

Acronyms and Abbreviations

ASV Autonomous Surface Vehicle
ConOps Concept of Operations
BMS Battery Management System
DMS Decision-Making System
FB Fuse Board
OCS Operator Control Station
PM Power Manager
SBC Single Board Computer
SOM Special Operations Module
VCU Vehicle Control Unit
VPU Vision Processing Unit

I. Competition Goals

A. General Strategy

"Complicated" is a word that probably serves as a good description of every project aiming to develop an autonomous vehicle of any sort. As technology progresses, humanity's endeavors become more and more complex. That is why a new field of engineering began to emerge in the United States during the Second World War - Systems Engineering [1]. One of many tools and processes developed in this field is a V-model (see Fig. 1).

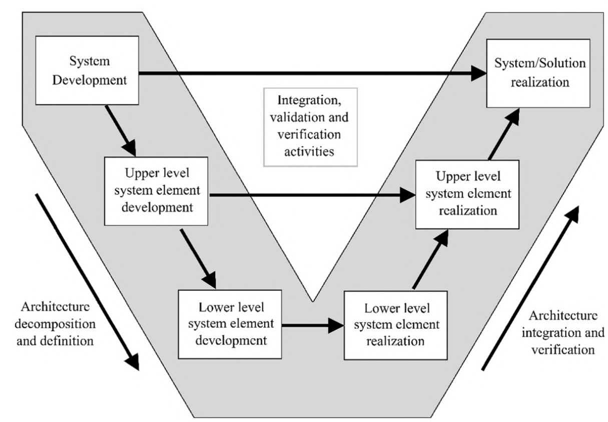

Fig. 1: V-model from INCOSE [2]

The development process of Autonomous Surface Vehicle (ASV) Zimorodek II has been organized following the principles of the V model and can be divided into subsequent phases:

- **Lessons Learned** – RoboBoat 2025 has been a great learning experience for our team. All team members shared their opinions and feedback regarding both the system and team performance. These conclusions were later organized and written down in a document that became a reference point for decisions made during the next phases. It also became a basis for an After Action Report that was presented to stakeholders.
- **Concept of Operations** – Lessons Learned document and Task Ideas were a starting point for our team when we formulated a comprehensive Concept of Operations (ConOps) for our system (see Appendix A). The overall structure of the document has been based on an outline published by NASA [3]. ConOps contains information about the goals and tasks of the designed system, the scope of the project, a description of the environment in which the system will operate, as well as an outline of the course of the mission, highlighting the processes and activities the system must perform to achieve the

mission's objectives. This document also presents a high-level architecture of the system. The ConOps is a key tool in the process of onboarding new team members to the project, as well as during communication with stakeholders and explaining the purpose and context of the entire project. Its contents were verified during the Mission Design Review (MDR) in May and the Preliminary Requirements Review (PRR) in July.

- **Requirements** – Functions and course of the mission described in ConOps allowed us to formulate two sets of requirements for our system: functional and operational. All of these requirements have been written down in a System Requirements Document (SRD). As stated in law no. 13 from Akin's Laws of Spacecraft Design: "Design is based on requirements. There's no justification for designing something one bit "better" than the requirements dictate." [4] Requirements provide engineers with fundamental guidelines on what to design and how to design it. We passed PRR in July and System Requirements Review (SRR) in November.
- **Concept** – In October, we began working on concepts of various subsystems within our vehicle. Some decisions regarding the selection of specific solutions from various alternatives were made at this stage. Such decision-making processes have been documented in Trade-off Reports, organized according to Annex L of the ECSS-E-ST-10C Rev.1 standard [5]. We continue to cooperate with KNW "Proces" from Beautiful Arts Academy in Gdańnsk to improve the aesthetics of our design and create concept arts (see Fig. 2) that inspire engineers during the design phase. Most subsystems finished this phase and passed the Preliminary Design Review (PDR) in December.
- **Design** – At this stage, the final technical documentation has been created, which enabled the production of models and prototypes first, and subsequently the final product. Calculations, cost estimates, bills of materials, justifications for the selection of key dimensions and tolerances, as well as photos of the final models were all documented. The final design of the majority of subsystems was approved during the Critical Design Review (CDR) in late December and early January.

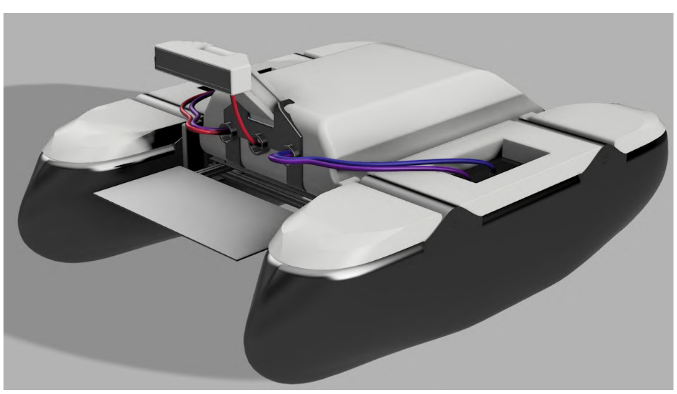

Fig. 2: Concept art by Aleksander Kwiek from KNW "Proces"

- **Manufacturing** – Our last year's experiences convinced us that manufacturing components using 3D printing both resource and labor efficient. For this reason, we decided to utilize primarily 3D printing during ASV Zimorodek II's production. Not only the superstructure of our boat will be 3D printed but also its hull. Another important milestone for our team was entering a partnership with CentralPoint and Forelectronic which allowed us to consult the design of our Printed Circuit Board (PCB) and manufacture it for free. We also continue to cooperate with AQ Wiring STG who provide us with electrical components free of charge.
- **Verification** – Developing and approving a list of functions and requirements for the designed solution would be pointless if compliance of the design with these requirements was not verified. Verification even on very early stages of the project is also a key feature on V-model. In the SRD, four different verification methods have been distinguished: review, inspection, analysis, and test. More than one verification method can be assigned to a selected requirement. The document used to track the status of ongoing verifications is the Verification Control Document (VCD). The last stage before system deployment is the Acceptance Review (AR) planned for mid-February.

Each subsystem has been described in a separate document named Subsystem Design Definition (SDD) that comprises the following sections: Requirements, Research, Concept, Design, Manufacturing, Testing and Quality Control, and Final Conclusions. Interfaces between particular subsystems are tracked in the Interface Control Document (ICD). Document Delivery Matrix, shown in Appendix B, specifies which documents must be delivered during a given review.

B. *Course Strategy*

During RoboBoat 2026 our team aims to approach all tasks during Autonomy Challenge. For every task, the ASV's motion control will be based on computer vision and the decision-making process will be supported by a behavior tree.

The most basic mandatory task for the ASV is **Task 1 — Evacuation Route & Return**. The ASV completes this task iteratively by passing through two gates: it identifies the two nearest distinct large markers, stores their positions, sets a waypoint just beyond the gate, and navigates toward it until both gates are traversed. After finishing all the tasks, the ASV establishes a shortest possible path to return through gates from the other side. Upon completion of the first task, the ASV will search for the pair of green and red small buoys, which will indicate the entrance to **Task 2 – Debris Clearance**. Maneuvering our ASV inside a designated corridor and also in an open space requires high precision. The corridor segment contains custom triangulation of visible buoys, allowing easy maintenance of the optimal path. When data is insufficient to calculate a goal point, ASV enters a search protocol and utilize every available anchor point to re-establish its course. Maneuvering inside obstacle-rich open space to the light beacons is handled by close-range Rapidly-exploring Random Tree Star (RRT*) algorithm, ensuring collision-free trajectory. Finally, the ASV initiates the last phase, changing trajectory from the light beacon back to the starting point.

The execution of **Task 3 – Emergency Response Sprint (Speed Challenge)** relies on situational awareness. The ASV first detects the start gate (green and red buoys) or the yellow buoy, while continuously identifying the light color that determines circling direction. After reaching the gate, the ASV circles the yellow buoy using four planned waypoints if its position is known; otherwise, it performs up to three exploratory scouting maneuvers to acquire it. The waypoint order depends on the detected light color. Once completed, the ASV returns through the gate and exits the area, using A* algorithm.

ASV Zimorodek II will execute **Task 4 – Supply Drop (Object and Water Delivery)** separately from other tasks, after completing Tasks 1-3, 5 and probably 6. The ASV will detect black and yellow boats while performing other tasks using their banners, save their position in its memory, and then use that data to find the best two candidates to supply drop in both categories based on distance to the ASV, nearest neighbor and number of obstacles on the straight path from the ASV to the vessel. The ASV then takes up a safe position with its heading facing the centroid of the vessel's potential field and turns on auto-positioning. This mode automatically moves the ASV so the detected boat's banner remains in the center of the RGB camera lens within ≈ 0.5 meters distance. The ASV then delivers either a racquetball or a steady stream of water. Supplying both targets will constitute task completion.

Task 5 – Navigate the Marina (docking) our ASV will first swim next to every slip and register numbers and color indicators marking every spot as well as every vessel anchored inside of it. This data will be used to determine in which spot our ASV should dock. It will also be utilized when executing Task 5. Two waypoints will be designated: inside the dock and 3 m in front of it. At first, ASV Zimorodek II will move to the waypoint outside the dock, then proceed to the one in the dock, stay there for about 5 seconds, and then move back to the waypoint outside which will constitute task completion.

Task 6 – Harbor Alert begins with a sound signal that is captured by the onboard microphone. The sampled signal undergoes amplitude and frequency analysis, and the results determine the navigation point to which the ASV will proceed. Next, two scenarios are considered. In the first scenario, the ASV has already completed the task in which the destination buoy was positioned. The buoy's coordinates are stored in onboard memory and the ASV can navigate to it using the shortest possible path. The second scenario, takes into the consideration that the buoy's location is unknown. In this case, the ASV positions itself near the estimated task area and then proceeds to search for the buoy.

II. Design Strategy

In this section, we aim to provide an overview of the design of particular subsystems and the rationale behind it. The decomposition of our system into subsystems can be found in Product Breakdown Structure (PBS) in Appendix C. Detailed descriptions of some of the components have not been mentioned in this report to emphasize our design's creative aspects.

A. Mechanical Structure

The primary challenge for this year's development phase was enhancing the vessel's seakeeping capabilities. Based on the previous year's trade-off report, which identified the catamaran as the optimal configuration, it was decided to retain this hull concept. Consequently, the improvement of seakeeping qualities was pursued through the optimization of the bow shape. The bow designs considered included: wave-piercing, axe-bow, and X-bow. The selection was guided by criteria such as seakeeping, calm water resistance, slamming reduction, and added resistance in waves.

The analysis supported the continuation of the bow design inspired by the Ulstein X-BOW® solution. The focus remained on further mitigating pitching motions to ensure an more stable platform for the camera systems. To achieve this, the hull length was increased by 15 cm, and Computational Fluid Dynamics (CFD) was employed to optimize the geometry. A comparison between the new hull geometry and last year's ASV revealed a reduction in calm water resistance of nearly 26%.

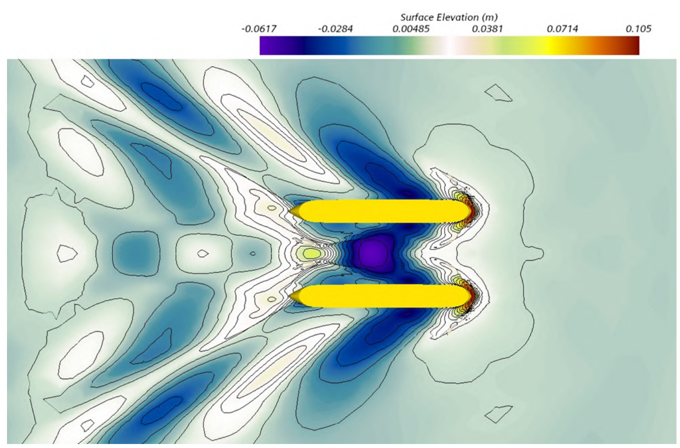

Fig. 3: CFD analysis results for ASV Zimorodek II

To validate the CFD analysis results, a physical experiment was conducted in a towing tank using the ASV Zimorodek. The tests showed a discrepancy of only 3.4%, which is considered a highly satisfactory result. Strip theory was utilized for seakeeping analysis, demonstrating significant improvement by reducing motion and acceleration values for pitch, heave, and roll in 10 cm waves. The most notable performance gain was achieved in pitch accelerations, with values reduced by as much as 40%. Thanks to our cooperation with EXCENTO, the possibility arose to cheaply 3D print the floats out of PET-G. This material is characterized by low shrinkage, high rigidity, and good adhesion to the printer bed, making it an optimal choice for large prints. After printing the hull segments, they

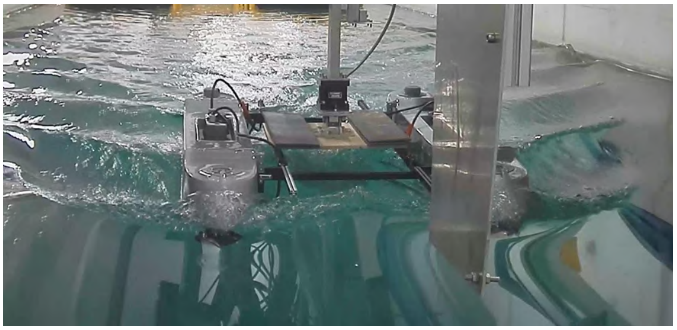

Fig. 4: ASV Zimorodek during towing tank tests

were filled with low-expansion closed-cell foam to ensure buoyancy even in the event of outer hull's puncture. Hull's segments were then glued together, sanded, and painted. The process of printing a hull segment is illustrated in Fig. 5.

Fig. 5: Bow segment on 3D printer

At a very early stage of the concept phase, a decision was made to relocate the batteries and Electronic Speed Controller (ESC) from the superstructure to the floats. This approach aims to lower the center of gravity of the ASV, thereby improving its stability properties. An additional advantage of this solution is the increased distance between the ESCs, which generate significant electromagnetic interference, and components sensitive to such interference (e.g., the GPS antenna).

Another key aspect of the hull design was the connection between the catamaran's two pontoons. The team decided to construct a frame using 20x20 mm V-Slot aluminum profiles, replacing last year's 15x15 mm MakerBeam. This change was implemented to improve structural rigidity and ensure better stability under dynamic loads. . The superstructure and deck, which holds Special Operations Module (SOM), are attached

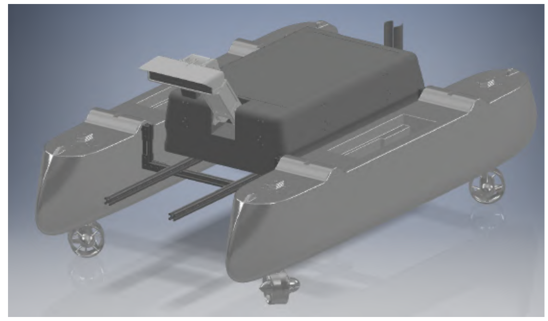

Fig. 6: An assembly of ASV Zimorodek II with modules for Battery Boxes and ESC Boxes in floats, and with integrated extending bridge for the camera

directly to the frame with screws. Thanks to the unique V-Slot profile design, both the superstructure and deck can be moved along the vehicle's Center Line and also up and down, enabling proper weight balance and preventing unwanted trim.

The stereo camera is mounted in a particularly creative way. Its height and tilt angle relative to the deck can be adjusted using two joints and an , as shown in Fig. 6. This allows the team to experimentally determine the optimal settings based on the ASV's configuration and mission conditions. The walls of the superstructure will be made from PET-G using 3D printing technology, while the floor and cover will be made from foam PVC sheets, valued for their low weight and high stiffness.

B. Propulsion

Similarly to our previous vessels, ASV Zimorodek II will be equipped with a differential thrust propulsion system using four Blue Robotics T200 Thrusters [8]. Their configuration (see Appendix D) provides our vehicle with omnidirectional movement capabilities and substantial dynamic positioning capabilities which is crucial when performing Task 5. After testing this setup during RoboBoat 2025 our team decided to leave the angle between thrusters and ASV's center line at 30° in order to increase the resultant thrust force directed along this axis.

To maximize operational efficiency, a new quick-release mechanism was implemented for the thruster columns. This mechanism drastically cuts ASV assembly time and allows for rapid swaps in the event of thruster failure. The same design philosophy was extended to the camera mounting system.

To control this propulsion setup, we are using our custom controller based on PX4 autopilot firmware [9]. We have been improving this controller for the past year to increase its stability and utilize the full potential of our thruster configuration.

C. Water Gun

The Water Gun is a very simple SOM consisting of a diaphragm pump, a hose, and a nozzle which angle can be manually adjusted by the operator from 0° to 90° before launching the vehicle. This parameter is configured before switching to autonomous mode and is used to calculate the effective watering range. The propulsion system and advanced stereo camera enable our boat to maintain a fixed position relative to the target with high precision.

D. Racquetball Delivery Module

The Racquetball Delivery Module comprises a rotating magazine equipped with a release latch capable of indexing three racquetballs, feeding them into a flywheel mechanism. This launcher utilizes two counter-rotating wheels to accelerate and project the balls.

E. System Bus

Just like our previous vehicle, ASV Zimorodek II uses an Ethernet-based network. The centralized switch as shown in Appendix D handles all network communication. Ethernet's flexibility and widespread adoption allow us to utilize one network for high and low-throughput devices such as stereo vision camera and power monitoring modules, as well as integrate new devices into the existing infrastructure. We also decided to keep using micro-Ros protocol [10]. Its key advantage is a seamless integration of our custom embedded software with Robot Operating System 2 (ROS2) applications running on the Single Board Computer (SBC). By utilizing this proven solution, we were able to focus our efforts on further improvements in its stability and reliability.

F. Electrical System

The electrical system architecture (see Appendix D) remained largely unchanged as the system proved to be both effective and reliable. This year we renewed our partnership with Central Point to help us improve designed system on custom PCBs (see Appendix E). The electrical system consists of five separate integrated PCB modules, Power Manager (PM), Fuse Board (FB), Battery Management System (BMS), with one per battery box, and a module dedicated to SOM.

The Power Manager (PM) controls onboard power distribution, monitors component temperatures, manages the remote shutdown capability and passes the telemetry data to the onboard network. The Fuse Board (FB) distributes and switches the power to all onboard modules via dedicated fuses.

The new (BMS) modules were designed to enhance operational safety and reduce deployment time. Last year's design required opening the watertight battery boxes for every charging cycle. This year, we designed a circuit that allows us to charge and monitor battery boxes without a need to compromise the watertight seal. The system monitors individual cell voltages and balances them accordingly. Additionally, we track temperatures and system errors, transmitting all data to the ground segment during operations.

G. Computer Vision

OAK-D LR cameras [11], mounted on our previous vehicles, proved to be sufficient for 10 meters depth measurements.

The OAK-D LR features a Vision Processing Unit (VPU) that processes RGB image data internally using the YOLOv11m [12] neural network model. This model is used for coarse object detection. For banner classification, we use ResNet-18 [23]: YOLOv11 detects the general banner class, while ResNet differentiates geometric shapes and numbers. The light beacon is treated as a banner with a rhombus shape. Once the position of the figure is detected in the captured frame, the pixels above it are assumed to originate from the LED light. Based on the dominant color in this region, the beacon is classified as either red or green.

The depth information is calculated by the SBC - Nvidia Jetson Orin NX 16GB, as it allows us to adapt the stereo-depth algorithm to our use case. The processed data, including object detections and RGB images, is sent to the SBC for further processing and to the Operator Control Station (OCS), where each operator connected to it has access to the ASV's perception of the environment via Rviz2 simulation [20].

To train the YOLOv11m model, we utilized a combination of datasets. Validation was performed using data collected during previous RoboBoat competitions, which was annotated in the YOLO [14] format. For training and testing, publicly available datasets [15] from the Roboflow platform were used. This strategy allowed us to validate the model using data tailored to our specific camera, accounting for its unique physical properties that influence image quality and dynamics.

Furthermore, the implementation of classical data augmentation methods, including rotation, mirror flips, and color intensity adjustments, has led to an enhancement in the model's accuracy, particularly in detecting black buoys, a previously challenging task.

H. Autonomous Navigation Software Architecture

The architecture of our system is based on ROS2, which enables the operation of parallel nodes that communicate through topics. These topics facilitate the exchange of predefined messages, and each node can read, write, or perform both operations within the communication structure. This modular design allows for efficient data handling and robust interaction between system components. The architecture consists of four main components: VPU, Decision-Making System (DMS), Vehicle Control Unit (VCU), and OCS.

The VCU is managed by our own PX4 controller [9] dedicated for omnidirectional boats, running on Pixhawk 6X device, which is responsible for position and attitude determination with the use of an Inertial Measurement Unit and GPS RTK as well as low-level communication with the boat's thrusters. We send control signals, such as waypoints and speed commands, to the VCU, which then translates these signals into precise commands for thrusters. This includes managing the calibration of PID controllers to ensure smooth and accurate movement. The VCU also sends back essential data, such as the current position and orientation of the boat, under the signal "vehicle status".

The DMS serves as the central processing unit for autonomous navigation, receiving detections from the VPU and vehicle status data from the VCU. A behavior tree methodology [16] is used as the core decision-making framework, enabling structured and modular mission decomposition. In the proposed system, a primary tree manages data collection and task switching, while each competition task is implemented as an independent tree sharing common conditions and actions.

In local path-planning algorithms, a mapping procedure based on the artificial potential field method was employed, supported by clustering algorithms for grouping objects detected by the onboard camera. Furthermore, a map-rendering approach was implemented in areas where obstacles were detected, thereby mitigating the disadvantages associated with grid-based representations. The resulting map structure of detected objects forms the basis for navigation and collision avoidance algorithms like RRT* and A*. (see Appendix F)

I. Telemetry and Remote Shutdown

The communication system with the ASV during the previous year's competition demonstrated satisfactory performance. Consequently, no significant changes were introduced to the communication architecture (see Appendix D) of the vessel. A 2.4 GHz link that utlizes ELRS protocol [17] was used for manual control, while a 5 GHz link was utilized for autopilot telemetry and video transmission. We retained the same 5 GHz radio hardware from the previous year so we could utilize Mikrotik's proprietary Nv2 protocol [18] that proved to be very stable and reliable. For the remote shutdown capability we use last year's LoRa modules. These modules can be configured to operate on either the 868 MHz or 915 MHz frequency bands, enabling compliance with regulatory requirements in both the EU and the USA. To mitigate the risk of unintentional shutdowns caused by communication errors or interference, a simple protocol was implemented. This protocol incorporates Cyclic Redundancy Check and requires acknowledgment of received messages to ensure reliability.

J. Ground Segment

Ground Segment of our system consists of the OCS and logistical equipment like carts, crates and tools. The core of our OCS is a protective case [19] nicknamed *Football* or *Cyber Deck*. It integrates Remote Shutdown, basic telemetry data display, power supply and connectors for antennas and laptops. No significant changes were made to the software application; we continue to utilize the Rviz interface for video streaming, detection map visualization and monitoring other ASV parameters. The application effectively aggregates and displays this information in a clear and accessible manner. Diagrams portraying the elements of OCS can be found in Appendix A.

III. Testing Strategy

Test are a vital part of the development process and must be performed either on system, subsystem, or component level. Most of the time our team will use one of these four methods: live tests on the water, live tests on the ground, tests in simulated environment, individual component test. Details regarding conducted tests can be found in Appendix H.

The most reliable and comprehensive method of verification of our system are obviously live tests on the water. Only then is the subject to unpredictable elements like animals, sunlight, or interference. Vehicle developed by our team for RoboBoat 2025, the ASV Zimorodek, serves as a testing platform used to test for example GPS modules, communication links and behavior trees. It is not only the system that is put to the test when the vehicle operates on the water but also the team. Frequent live tests helped our team master procedures related to preparing our ASV for launch. However, transporting the vehicle from our workshop to the shipyard, where live tests on the water are being conducted, together with all necessary equipment is a major logistical challenge that requires at least one day of preparations. That is why our team decided to develop the Crawler Rover for Autonomous Boat testing (CRAB). It is a robot with the same omnidirectional movement capabilities as our ASV. This platform allows our team to test behavior trees on a mock-up of tasks setup on the parking lot next to our workshop. To make testing more convenient for our team members, we developed a second simulation based on Rviz2 [20]. Compared to the Gazebo-based simulation used in the previous year [21], this solution allows us to observe in real time exactly what the vehicle perceives, shown as a map of the environment, including the ASV marker with its current heading and setpoint, detected objects represented by unique markers, and the artificial potential fields of these objects computed from a cost grid generated during object discovery. The Gazebo platform [21], together with the extensive PX4 ecosystem [9] and easily accessible Docker containers [22], is used to realistically simulate the environmental conditions encountered during real-world tests, such as wind, waves and drift, from the operator's perspective, while also serving as the primary environment for system-level testing, debugging, development of the decision system, and ROS2–PX4 integration. Testing individual hardware modules is firstly done in the lab. Those tests mostly include basic electrical and functional testing using standard equipment such as multimeters and oscilloscopes. The test results are recorded and attached into a subsystem design document (see Appendix G).

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REFERENCES

[1] K. J. Schlager, *Systems engineering - key to modern development*, IRE Transactions on Engineering Management, vol. EM-3, no. 3, p. 64-66, July 1956

[2] Walden D, Roedler G, Forsberg K, Hamelin R, Shortell TM (2015) *Systems engineering handbook: a guide for system life cycle processes and activities*. Wiley, New York

[3] NASA, Appendix S Concept of Operations Annotated Outline, June 26, 2023. https://www.nasa.gov/reference/appendix-s-concept-of-operations-annotated-outline/. [Accesed on: Januray 25, 2025].

[4] Akin's Laws of Spacecraft Design, retrieved from https://spacecraft.ssl.umd.edu/akins_laws.html

[5] ESA Requirements and Standards Division, Space engineering. System engineering general requirements., Noordwijk, 2017.

[6] X-BOW®, retrieved from https://ulstein.com/innovations/x-bow

[7] V-Slot 20x20 mm, retrieved from https://vslot-poland.com/

[8] T200 Thruster: ROV thruster for marine robotics propulsion, retrieved from https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster-r2-rp/.

[9] Open Source Autopilot for Drones - PX4 Autopilot, retrieved from https://px4.io/.

[10] Micro ROS overview, retrieved from https://micro.ros.org/docs/overview/features/

[11] OAK-D LR — DepthAI Hardware Documentation 1.0.0 documentation, retrieved from http://docs.luxonis.com/projects/hardware/en/latest/pages/BW1098OAK.html

[12] Ullah, Chuang, et al. *Real-Time Aerial Object Detection via YOLOv11 with Coordinate Attention Enhancement.* Proceedings Of The 2025 3rd International Conference On Machine Learning And Pattern Recognition. pp. 22-27 (2025), https://doi.org/10.1145/3760678.3760682

[13] Jetson AGX Orin for Next-Gen Robotics, retrieved from https://www.nvidia.com/en-us/autonomous-machines/embedded-systems/jetson-orin/

[14] Redmon, Joseph, et al. *You only look once: Unified, real-time object detection.* Proceedings of the IEEE conference on computer vision and pattern recognition. 2016.

[15] FINAL2024ROBOTx Computer Vision Projecthttps://universe.roboflow.com/gtmrg/final2024robotx

[16] BehaviorTree/BehaviorTree.CPP: Library in C++, retrieved from http://github.com/BehaviorTree/BehaviorTree.CPP

[17] ExpreLRS protocol overview, retrieved from https://www.expresslrs.org/

[18] Mikrotik's Nv2 protocol user manual, retrieved from https://wiki.mikrotik.com/wiki/Manual:Nv2

[19] Protective cases used https://www.auer-packaging.com/us/en/Protective-cases-Pro/CP-4316.html

[20] Rviz overview, retrieved from http://wiki.ros.org/rviz

[21] Gazebo showcase, retrieved from https://gazebosim.org/showcase

[22] Docker overview. Available online: https://docs.docker.com/get-started/overview/

[23] ResNet-18 overview. Available online: https://blog.roboflow.com/resnet-18/

APPENDIX A
CONOPS - ASV26

A. *Introduction*

The following section provides information about the SeaSentinel Program, under which the project is implemented, as well as the main objectives and assumptions of the project.

1) Project Description: Autonomous vehicles are one of the primary directions of development in the maritime industry in the 21st century. The SeaSentinel Program aims to educate students of Gdańsk University of Technology in the field of autonomous vehicles. This goal is realized through the construction and development of Autonomous Surface Vehicle (ASV) technologies. The latest project of our team is a vehicle named ASV Zimorodek II, which we are preparing for the RoboBoat 2026 competition.

Background

Since the beginning of the SeaSentinel Program (November 2021), over 100 students have participated. Two master's theses and one conference paper have been produced based on the work conducted. So far, three vehicles have been built: ASV Perkoz, ASV Rybitwa and ASV Zimorodek. Each was designed for participation in the RoboBoat competition, achieving 9th and 7th places in consecutive editions of the event. Due to issues with ASV Rybitwa, including buoyancy, rigidity of the superstructure, total weight, stability, and accurate range estimation of detected objects (detailed in Lessons Learned), the decision was made to build a new vehicle named ASV Zimorodek. Its goal is to achieve a top-ranking position at RoboBoat 2025.

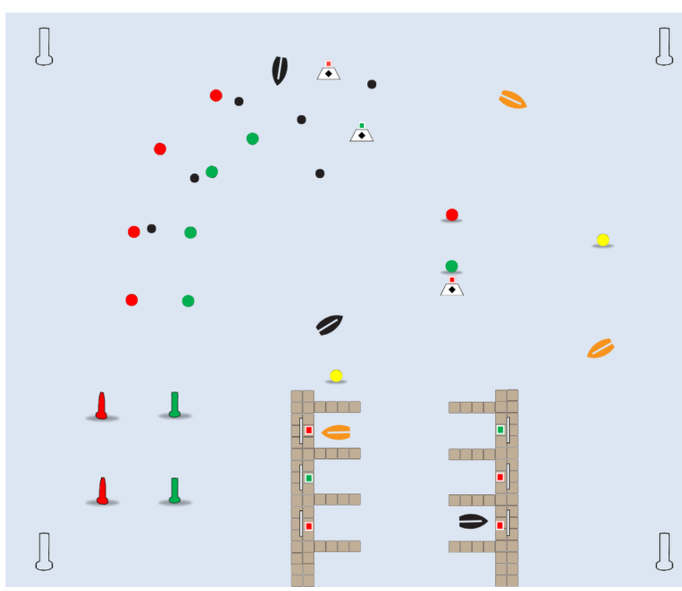
Assumptions and Constraints

One of the key assumptions of both the project and the entire Program is the expectation that the broadly understood autonomous vehicles industry will continue to grow steadily over the next several years. Consequently, there will be an increasing demand for engineers with experience in such platforms and those who possess mental frameworks enabling them to develop innovative solutions in this specialized field of science and technology. It is assumed that adequate funding for the program will be secured, enabling both the construction of ASV Zimorodek II and participation in the RoboBoat 2026 competition. To accomplish the mission, the construction of the vehicle must be completed no later than February 12, 2026. It is also assumed that the SeaSentinel Program will continue its activities after RoboBoat 2026, participating in subsequent editions of the competition or other initiatives aimed at students interested in autonomous maritime vehicles. ASV Zimorodek II is expected to be capable of completing all tasks during RoboBoat 2026.

2) Overview of the Envisioned System: The following section provides a summary containing the most important information necessary to understand the project. A more detailed description will be provided in the section "Description of Envisioned System".

Overview

The primary function of the system is to navigate water surfaces either remotely or autonomously, avoid obstacles, and perform tasks outlined by the organizers of the RoboBoat 2026 competition.

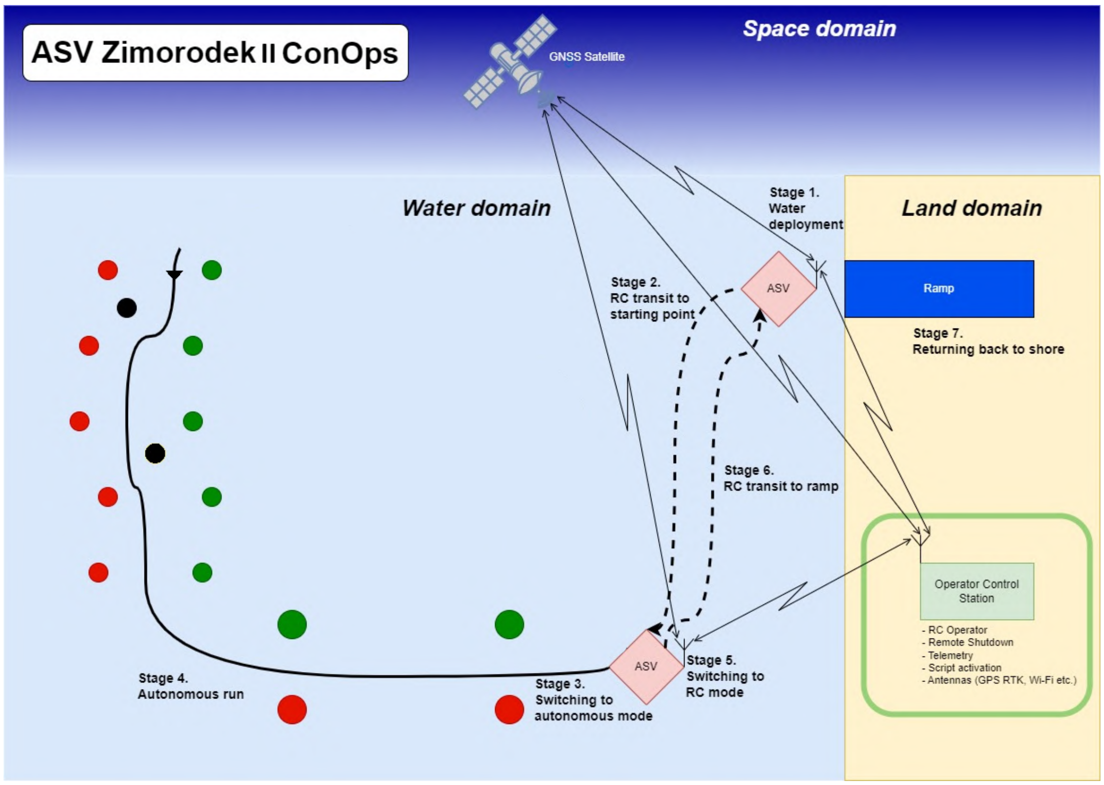


Preliminary course layout for the RoboBoat 2026 qualification round

Tasks include: navigating a designated waterway, avoiding and counting obstacles, starting in response to a light signal, docking, and shooting water or balls at a target.

The system comprises the following components:

- Autonomous Surface Vehicle (ASV) – Capable of remote operation for reaching the starting position and autonomous operation for completing the mission.
- Ground Segment (GS) – Includes all system elements that remain onshore while the ASV performs its mission.
- Operator Control Station (OCS) – A mobile control station set up in a tent provided by the competition organizers. It integrates antennas, Remote Shutdown, and operator terminals via the Cyber Deck.
- Cart – A key tool for logistics and operations, used for transporting the ASV to the launch site and other equipment such as supply crates.

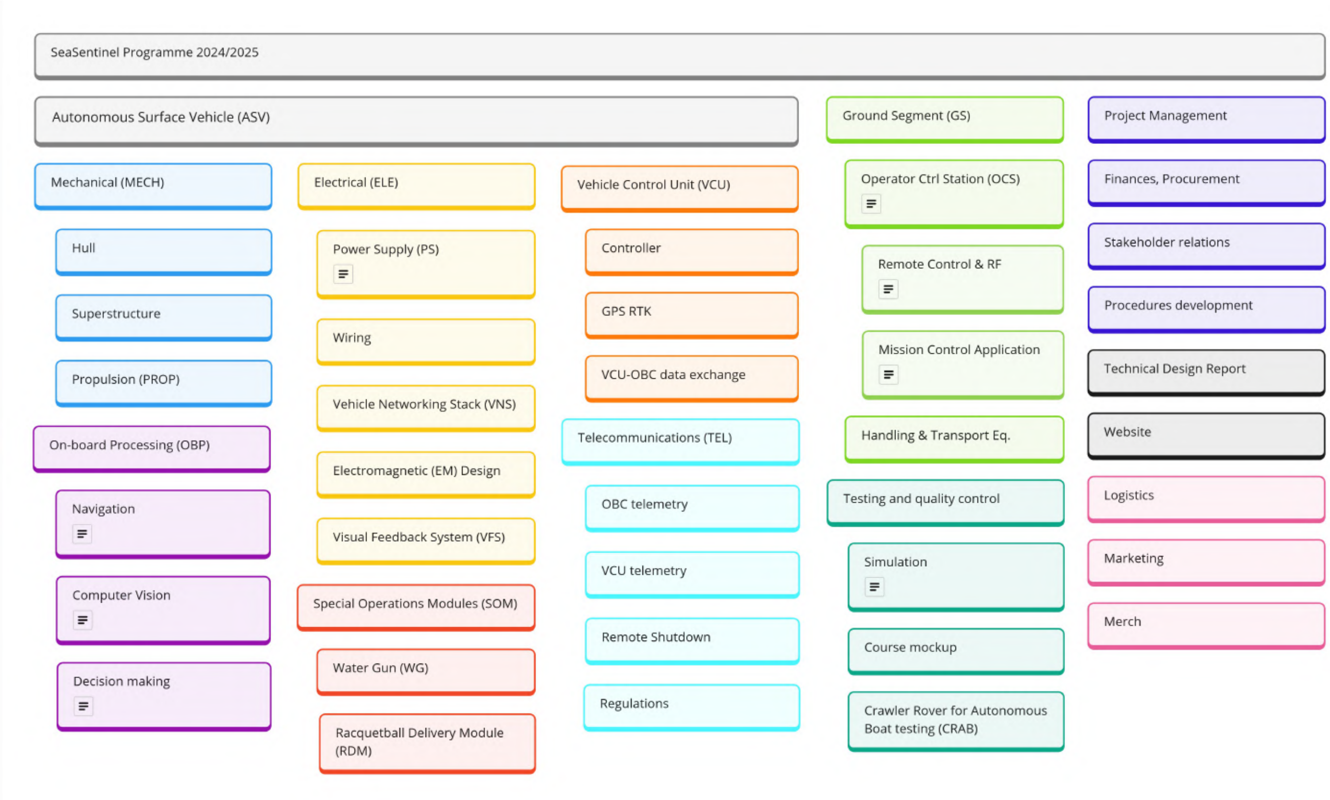


Operational View with mission stages

System Scope

This is a collection of all actions, processes, products, and results that must be completed for the project to be completed according to the requirements and assumptions. The scope of the project clearly defines what will be included in the project and what will not, which is crucial to managing the expectations of the stakeholders. It also prevents the phenomenon of scope creep, which is a common cause of project delays and budget overruns. The project includes:

- A new ASV - The floats, deck, and superstructure will be built from scratch. For power and control systems, ready-made market components will be used when possible to limit the scope of the work and reduce risk. Components from previous generations (Perkoz and Rybitwa) could be reused if feasible, including cameras, thrusters, Vehicle Control Unit, On-Board Computer, and fuse terminal.
- Modified Cyber Deck.
- Custom ASV-Operator Interface App
- Modified Cart - Adjustments will be made if required during the design process.
- Special Operations Module (SOM) - A module or modules designed and installed on the ASV to perform additional tasks (beyond navigation) in the RoboBoat 2026 competition. Tasks include shooting water at a banner on a moored boat and delivering balls to moored boats.
- Crawler Rover for Autonomous Boat testing (CRAB) - A robot controlled in a similar way as the ASV which will allow the team to test their algorithms on land.



Work Breakdown Structure

B. *Reference documents*

- Team Handbook
- RoboBoat 2025 Lessons Learned

C. *Description of Envisioned System*

This section provides a detailed description of the target system and its operations, as outlined in the subsections below.

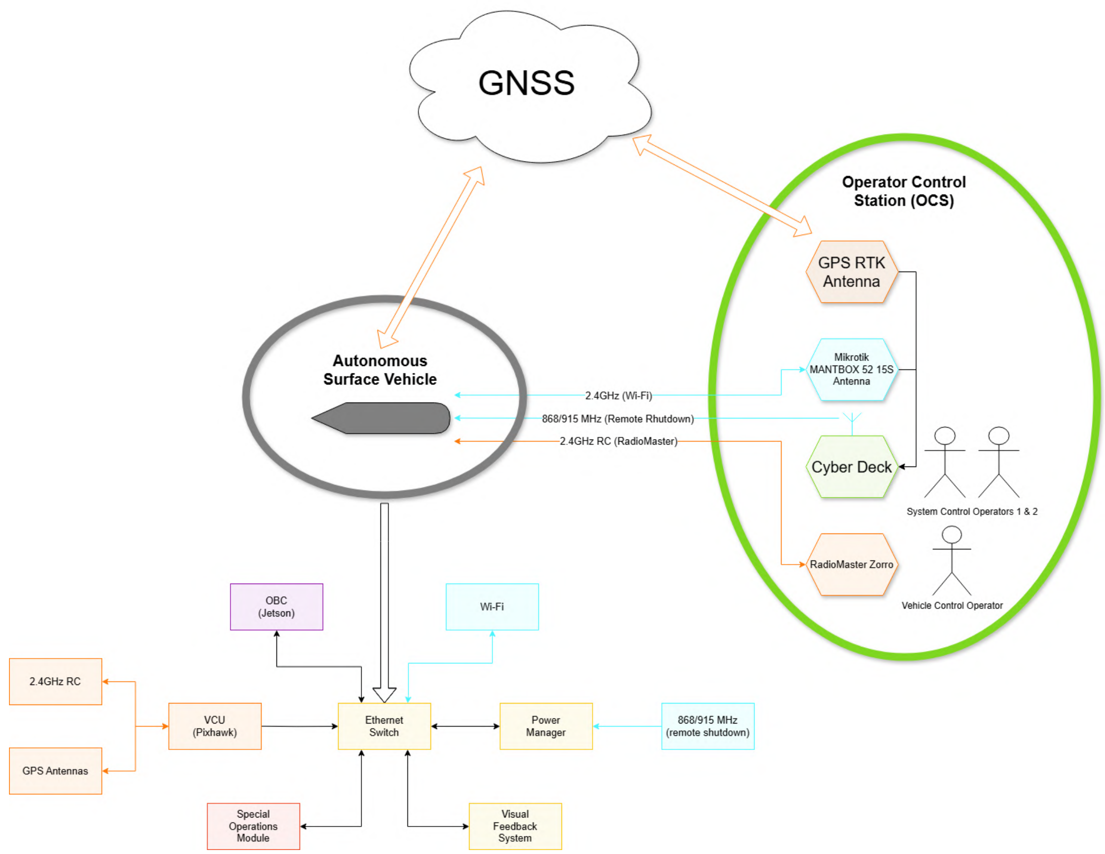
1) Needs, Goals and Objectives of Envisioned System: The system fully aligns with the requirements of RoboBoat 2026. This means meeting the demands set by the competition organizers (see Team Handbook). The primary goal is to win the competition. The system must be transported as luggage from Gdańsk to Sarasota, Florida, where the competition takes place, and then brought back. To maximize points, as many competition tasks as possible must be completed. The ASV Zimorodek II is supposed to be capable of performing all tasks during the RoboBoat 2026 competition.

2) Overview of System and Key Elements: The system integrates two domains: land and water.

- Land Domain - The team's operational area, including the competition venue and hotel vicinity. Activities here include storing, repairing, modifying, transporting, and controlling the system.
- Water Domain - The competition area where the ASV will operate and where tasks prepared by the competition organizers will take place.

The system includes:

- Autonomous Surface Vehicle (ASV): The primary operational component for performing tasks autonomously on water. The new ASV, named Zimorodek, will independently collect data about its condition and surroundings to make task-related decisions.
- Ground Segment (GS): All elements remaining on land while the ASV is operational on water.
  - Operator Control Station (OCS): A mobile control and monitoring station set up in the competition tent. Components include:
    * GPS RTK Antenna: Ensures accurate position estimation.
    * Cyber Deck: Integrates functions such as an antenna, Remote Shutdown, cable organization, and telemetry data display.



System components and data links

- ∗ RadioMaster Zorro: Remote control equipment for the ASV.
- ∗ Wi-Fi Antenna: Provides vehicle connectivity and telemetry data reception.
- – Cart and crates: Used for transporting the ASV to the launch site and other operational logistics.

3) Interfaces: This section outlines the system's interfaces with external systems outside the project's scope. Additionally, it covers the high-level interfaces among the primary components anticipated within the system.

- GPS System - The vehicle is equipped with a GPS receiver to determine its global position, which communicates with satellites in the GPS system. Position data is sent to the Vehicle Control Unit (VCU).
- Power Network - The OCS is powered from the national power grid via a power supply that produces the required DC voltage. The grid also powers the onboard battery charger.
- Interfaces Between ASV and OCS - A radio link connects the ASV and OCS. Operators access resources via laptops, monitor onboard computer data, and configure it remotely. An RC apparatus enables manual control of the ASV through communication with the onboard VCU.

4) Modes of Operations: The system operates in four primary modes:

- RC Mode (Remote Control): In this mode, the ASV is controlled by the operator using a remote control device.
- Automatic Mode (Path Following): In this mode, the vehicle moves between waypoints designated on an electronic map by the operator.
- Autonomous Mode: In this mode, the ASV independently collects information from its surroundings, analyzes it, and based on this analysis, decides where to navigate and what actions to perform.
- Emergency Mode: The vehicle enters this mode when the operator presses the Remote Shutdown button. In this mode, power is cut off to all actuators, but the On-Board Computer (OBC) and Vehicle Control Unit (VCU) remain operational.

The above modes can be further characterized with the following distinction:

- Competition Modes: These are characterized by a constant connection to the OBC and mandatory activation of the Remote Shutdown feature, as required by competition regulations.
- Non-Competition Modes**:** These allow for disabling certain features that are unnecessary during testing, such as the Remote Shutdown. Alternatively, the OBC may not be connected at all when operating exclusively in RC mode.

5) Proposed Capabilities: Below is the function tree of the entire system, which forms the basis for the requirements. The system must fulfill these functions to be able to perform all tasks during RoboBoat 2026.

Function tree

D. Physical Environment

The environment in which our system will operate can be divided into two categories: during the competition and outside the competition.

1) During the Competition: The competition takes place in Nathan Benderson Park in Sarasota, Florida. This is a former open-pit mine that has been flooded with freshwater. The water is murky, and the bottom is covered with numerous algae. Near the shore, the algae are tall enough to be visible to the naked eye, reaching almost the water's surface. The local fauna includes small fish, alligators, snakes, and predatory birds (herons, eagles, etc.). The competition takes place in February. During this time of year, air temperatures range from 10°C (mornings and nights) to 24°C (clear, windless days).

During the winter period (February–March), wind speeds regularly reach 4–5 on the Beaufort scale. Wave heights on the pond can reach up to 30–35 cm. Rainfall is rare but intense. Dense fog often occurs in the mornings.

2) Outside the Competition: In Poland, the system is most often tested at the Gdańsk Imperial Shipyard. The water in the basin is freshwater and polluted. Since the tests take place on a slipway oriented SW–NE, the water surface is sheltered from wind, and even in strong winds, wave heights do not exceed 10 cm. The bottom is concrete, so algae are practically absent. The fauna is limited to seagulls and small fish. Tests are conducted year-round as long as the water is not frozen. The temperature range in Gdańsk throughout the year is approximately -5°C to 28°C. Rainfall is frequent and generally moderate in intensity. During winter, snowfall may occur.

E. Support Environment

The support environment for the system can again be divided into two main categories: during the competition and outside the competition.

1) During the Competition: In the USA, the team has access to tools and parts brought from Poland, as well as the possibility of purchasing items locally in stores such as Lowe's or Home Depot (provided they are not too expensive). It is also possible to borrow tools and parts from other teams. On-site, the system is assembled, and the team has the capability to repair and/or modify it, e.g., by changing the configuration of task modules or building new subsystems (such as the Boat Swell Survival Kit or a water cannon for ASV Rybitwa). It should be noted that during the competition, the team's ability to manufacture components independently is limited to using ready-made parts and subassemblies (e.g., beams, flat bars, electronic modules) due to the lack of tools such as 3D printers, milling machines, lathes, etc.

2) Outside the Competition: The experiences gained from the competition will help determine whether ASV Zimorodek II will be further developed and upgraded or if a new vehicle will be built. In the event of a decision to build a new vehicle, ASV Zimorodek II would serve as a testing platform, and eventually, some of its components would be cannibalized and installed on the new vehicle. The same approach was successfully applied to ASV Perkoz, ASV Rybitwa and ASV Zimorodek.

F. 6.0 Operational Scenarios

This section examines key scenarios for the system's functioning under nominal and off-nominal conditions. Details regarding particular tasks can be found in Team Handbook.

1) Nominal Conditions - NCC-01: The progression of the practical part of the competition (Autonomy Challenge) can be divided into the following phases:

- Phase I - Arrival at the hotel in Sarasota and system assembly.
- Phase II - System tests in the hotel pool.
- Phase III - Qualifications:
  - Safety Check (details in Team Handbook),
  - Entering the water,
  - Setting up the OCS in the designated tent,
  - Transporting the boat from the pit box to the weighing station (boat + cart),
  - Transporting the boat from the weighing station to the ramp,
  - Establishing communication between the OCS and the ASV,
  - Testing Remote Shutdown and E-Stop,
  - Launching the ASV,
  - Thrust test,
  - Weighing the trolley,
  - Navigating remotely to the designated zone,
  - Informing judges about the attempt to qualify for a specific task,
  - Positioning the boat before the task,
  - Switching to autonomous mode,
  - Performing the task,
  - Switching back to remote mode,

  - Returning to the ramp,
  - Removing the ASV from the water and returning to the pit box,
  - Packing up the OCS and returning to the pit box.
- **Phase IV** - Finals:
  - Entering the water,
  - Setting up the OCS in the designated tent,
  - Transporting the boat from the pit box to the weighing station (boat + cart),
  - Transporting the boat from the weighing station to the ramp,
  - Establishing communication between the OCS and the ASV,
  - Testing Remote Shutdown and E-Stop,
  - Launching the ASV,
  - Thrust test,
  - Weighing the trolley,
  - Navigating remotely to the starting point of the course (2 meters before Task 1),
  - Switching to autonomous mode,
  - Performing the tasks,
  - Switching back to remote mode,
  - Returning to the ramp,
  - Removing the ASV from the water and returning to the pit box,
  - Packing up the OCS and returning to the pit box.

2) Off-Nominal Conditions: Below are several cases where a condition occurs that causes the system to operate differently than normal. These include failures, reduced performance, unexpected environmental conditions, or operator errors (Off-Nominal Conditions Case - ONCC).

ONCC-01

In this case, control over the ASV on the water is lost. The scenario in this situation proceeds as follows:

- Remotely shut down the ASV using Remote Shutdown.
- Notify the Course Manager about the loss of control over the ASV and request towing by a kayaker.
- Decide whether to tow the ASV to a floating dock or a ramp, depending on the presumed cause of the loss of control.
- If towing to a floating dock is chosen, only one person may be present on the dock to physically access the vehicle.
- If towing to a ramp is chosen, the scenario proceeds analogously to nominal conditions after removing the ASV from the water.

ONCC-02

In this case, one of the thrusters is damaged, and it cannot be repaired before entering the water during the finals. Before launching the ASV, the following steps must be taken:

- If one of the front thrusters is damaged, the operator disables both front thrusters at the PX4 level. Similarly, if one of the rear thrusters is damaged, both rear thrusters are disabled.
- The operator enters new PID controller settings, predetermined for this thruster configuration.
- The rest of the scenario proceeds as in nominal conditions.

G. Impact Considerations

This section describes the potential impact of the system, both positive and negative, on the natural environment, the organizational structure, and the scientific aspects of the project.

1) Environmental Impacts: The operation of the system has a very limited impact on the natural environment. The only significant risk is associated with the lithium-polymer batteries used. Improper handling of these batteries can lead to self-ignition during operation or charging, which is accompanied by the release of toxic fumes. The disposal of batteries at the end of their life cycle also presents a challenge.

We mitigate these risks by:

- following appropriate procedures for battery usage, reducing the risk of failure;
- storing batteries in suitable containers (Li-Po Guards) to limit the consequences of potential failures;
- disposing of batteries at dedicated facilities to ensure they are recycled.

2) Organizational Impacts: The construction of ASV Zimorodek II represents an evolutionary step from a previous design. Given the last year's satisfactory performance in both the mechanical and electrical subsystems, we plan to enter the ASV in additional competitions this year. To preserve team capabilities in hull design and electrical development as well as manufacturing the decision was made to redesign all component with needed changes and guide new members through the process. We believe that the quality of ASV Zimorodek II will help attract more sponsors from both the private and public sectors.

3) Scientific and Technical Impacts: Although ASV Zimorodek II itself is not revolutionary in terms of autonomous vehicles, the project as a whole has significant potential for publishing articles in areas such as the application of ROS2. It is also possible to transport research payloads in dedicated modules designed for this purpose. Another valuable outcome of the project is the skills and competencies acquired by team members, which add significant value to their educational process.

*H. **Risks and Potential Issues***

The following section describes the risks and potential problems associated with the development and use of the system.

1) Risks Related to Implementing New Technologies: During the project development, the same technologies were utilized as for the development of ASV Zimorodek. For this reason the design risk was significantly lower than in the previous ASV. However for manufacturing and expertise reasons we continued our cooperation with Sportis S.A. for the design and production of the hull and are in discussions with Forelectronic and CentralPoint, companies specializing in PCB fabrication.

2) Risk of Propeller Blade Breakage: During the RoboBoat 2024 competition, we encountered two incidents in which propeller blades fractured during operation, rendering the propulsion system inoperable. In contrast, the 2025 season saw no propeller failures. However, the ASV Rybitwa design highlighted a critical maintenance inefficiency: replacing a propeller on land required over 15 minutes. Consequently, due to these strict time constraints, the vessel was unable to deploy for two of the three final round attempts.

To address this risk, ASV Zimorodek II will be designed to allow faster propeller replacement.

The ASV Zimorodek introduced a new design based on swappable propeller columns; however, its performance did not yield a satisfactory improvement over the ASV Rybitwa. Consequently, the ASV Zimorodek II features a refined design that meets the target swap time.

3) Bus Factor: Every organization faces the risk of the so-called Bus Factor. In student projects, members may leave or reduce their involvement not only due to unforeseen events but primarily due to the workload associated with their studies. This is particularly evident during the summer and winter exam sessions.

We address this issue in two ways. First, team leaders have designated deputies who are prepared to lead the team in case of their unavailability. Second, for tasks involving critical components, we use a system analogous to Battle Buddies or Pair Programming. Each task is assigned to a pair of members, often pairing a more experienced member with a newcomer to help them learn and acquire key competencies.

4) Funding Risks: The annual cost of running the program is approximately 175,000 PLN, with the primary sponsor being the Student Government of Gdańsk University of Technology. To mitigate the risk of relying on a sole sponsor, we are seeking private sector sponsors willing to support the project financially or materially.

In September, we received a key decision from the Ministry of Science and Higher Education granting us funding under the 'FERS' project. These funds will be dedicated to the strategic development of the SimLE SeaSentinel team's competencies and the execution of our mission to the international competitions.

5) Risk of Missing Tools or Components During Packing: The entire system must be disassembled, packed, transported to the USA as checked baggage, and then reassembled on-site. This also necessitates bringing essential tools and spare parts. Failing to pack a required component or tool could lead to significant expenses for purchasing or fabricating parts on-site or could jeopardize the mission's success.

To minimize this risk, we follow procedures such as creating critical components lists and packing checklists.

6) Risk of System Damage During Transportation: During the return from RoboBoat 2023, two thruster columns made using 3D printing technology were damaged during air transport. Additionally, during transport to RoboBoat 2024, one of the superstructure walls cracked. For the RoboBoat 2025 the superstructure cover was cracked. Fortunately, none of these damages impacted the mission's outcome. To address this risk, components must be designed to withstand mishandling by airport baggage handlers and better secured during packing.

7) Health Risks During Travel: During RoboBoat 2023, RoboBoat 2024 and RoboBoat 2025, team members experienced cases of colds. Lack of sleep, stress, fatigue, and a diet low in vitamin C reduce immune resistance, often resulting in headaches, sore throats, and runny noses, and in extreme cases, high fever.

The second most common cause of team member unavailability is dehydration. Even in winter, Florida can be very hot, and the workload during the competition often leads to forgetting to stay hydrated. Symptoms of dehydration include a drastic drop in mood, increased fatigue, drowsiness, and headaches, potentially sidelining a team member for an evening.

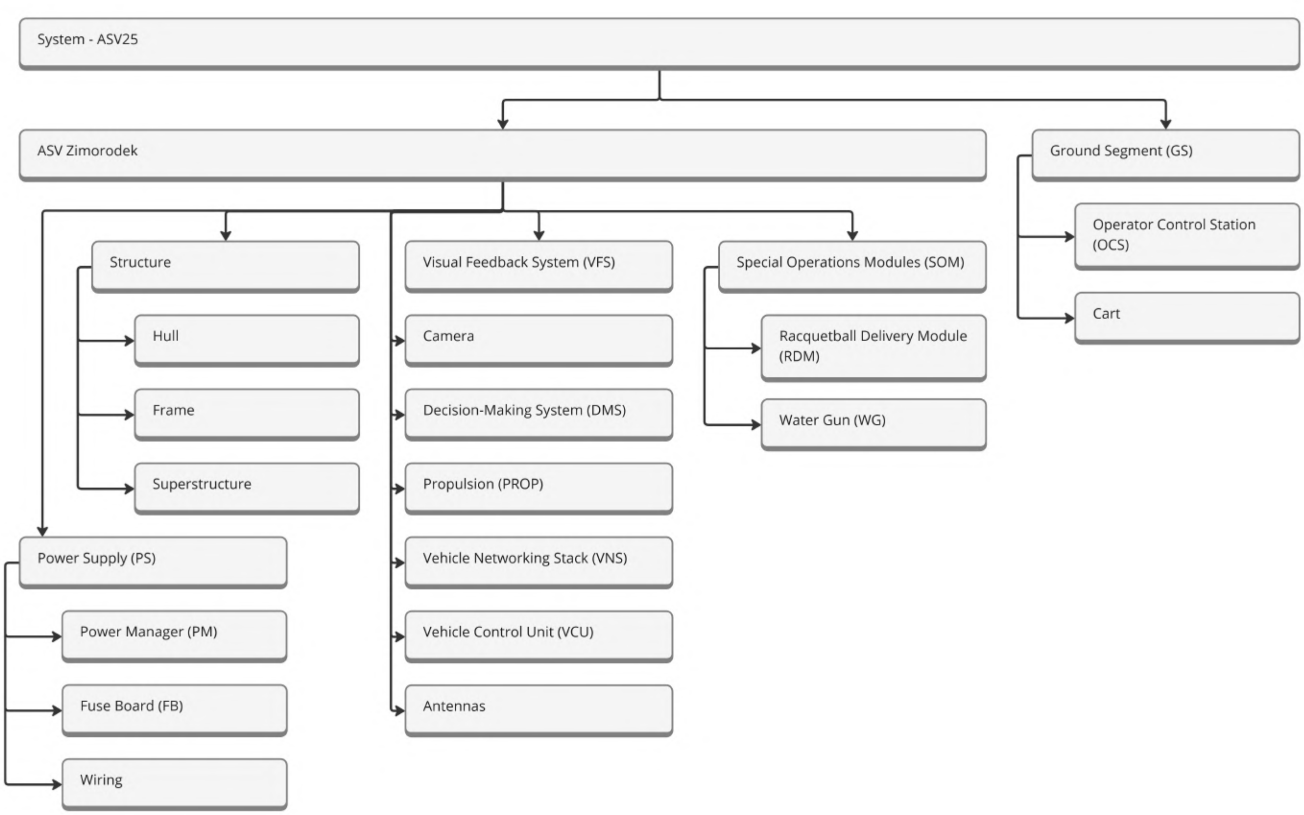
The third issue negatively affecting health, mood, and productivity is sunburn and overheating, most often caused by not using sunscreen or appropriate clothing (mainly hats).

Appendix B
Document Delivery Matrix - ASV26

Document name/Review	MDR	PRR	SRR	PDR	CDR	AR
Mission Description Document (ConOps)	X [1]	X				
Work Breakdown Structure	X	X	X			
Schedule	X	X	X	X	X	
Function tree		X	X	X		
System Requirements Document		X	X	X		
Interface Control Document			X	X	X	
Verification Control Document			X	X	X	X
Cost Estimate Report				X	X	
Subsystem Design Definition				X [2]	X [3]	X [4]
Test Plan					X	X

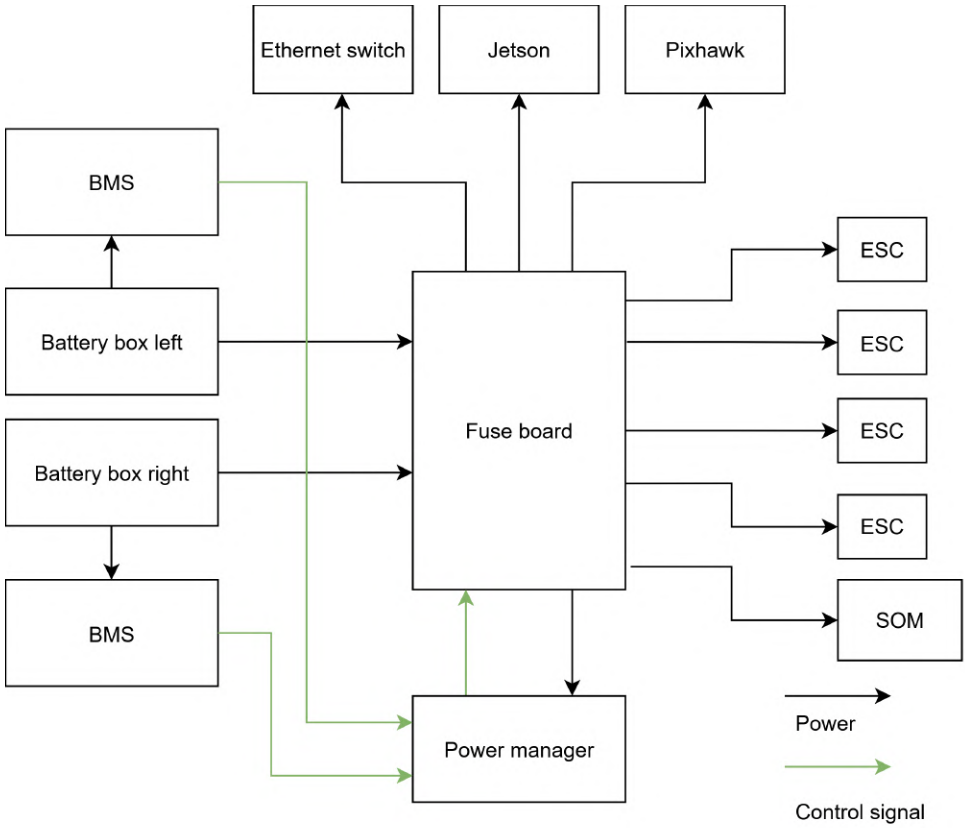
[1] without Function tree
[2] up to Concept section
[3] up to Design section
[4] up to Testing and Quality Control section

Appendix C
Product Breakdown Structure - ASV26

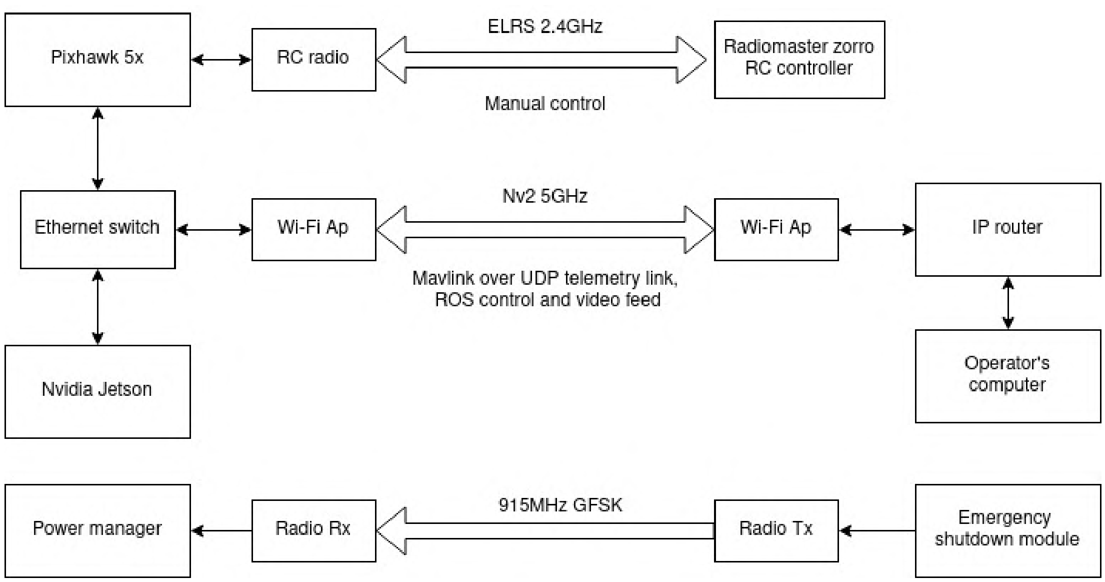


Appendix D
System Details

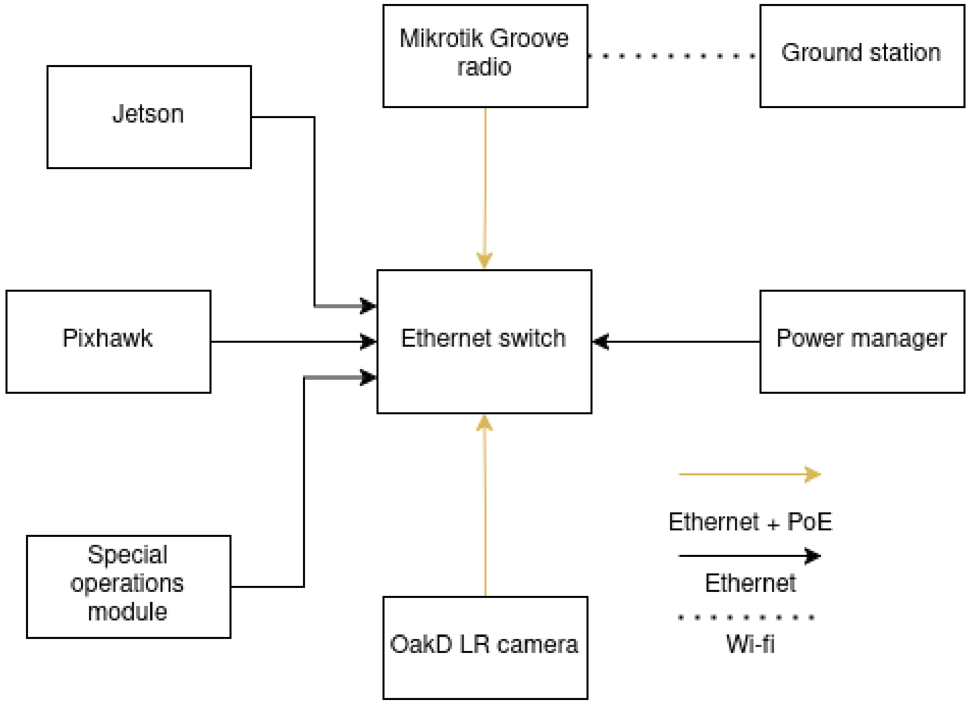
A. Power distribution system



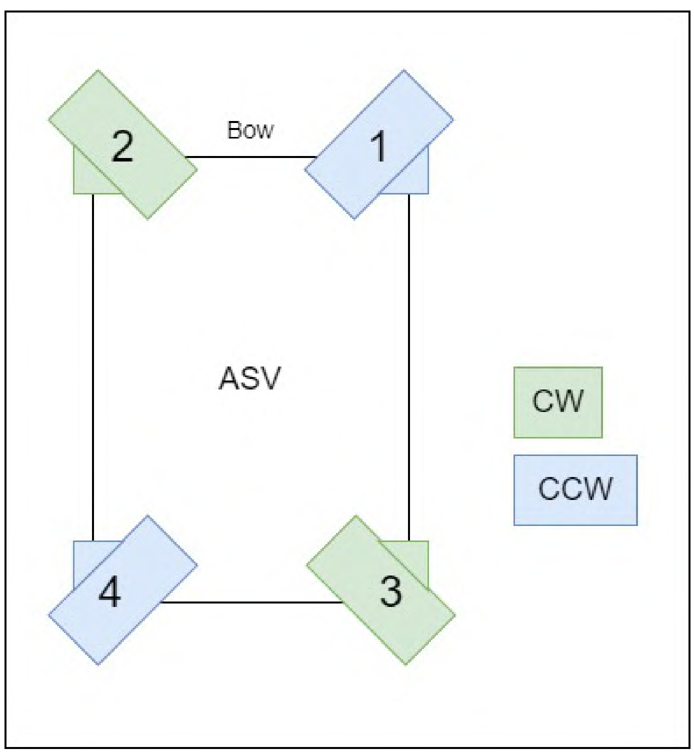
B. Telemetry system



C. System Bus

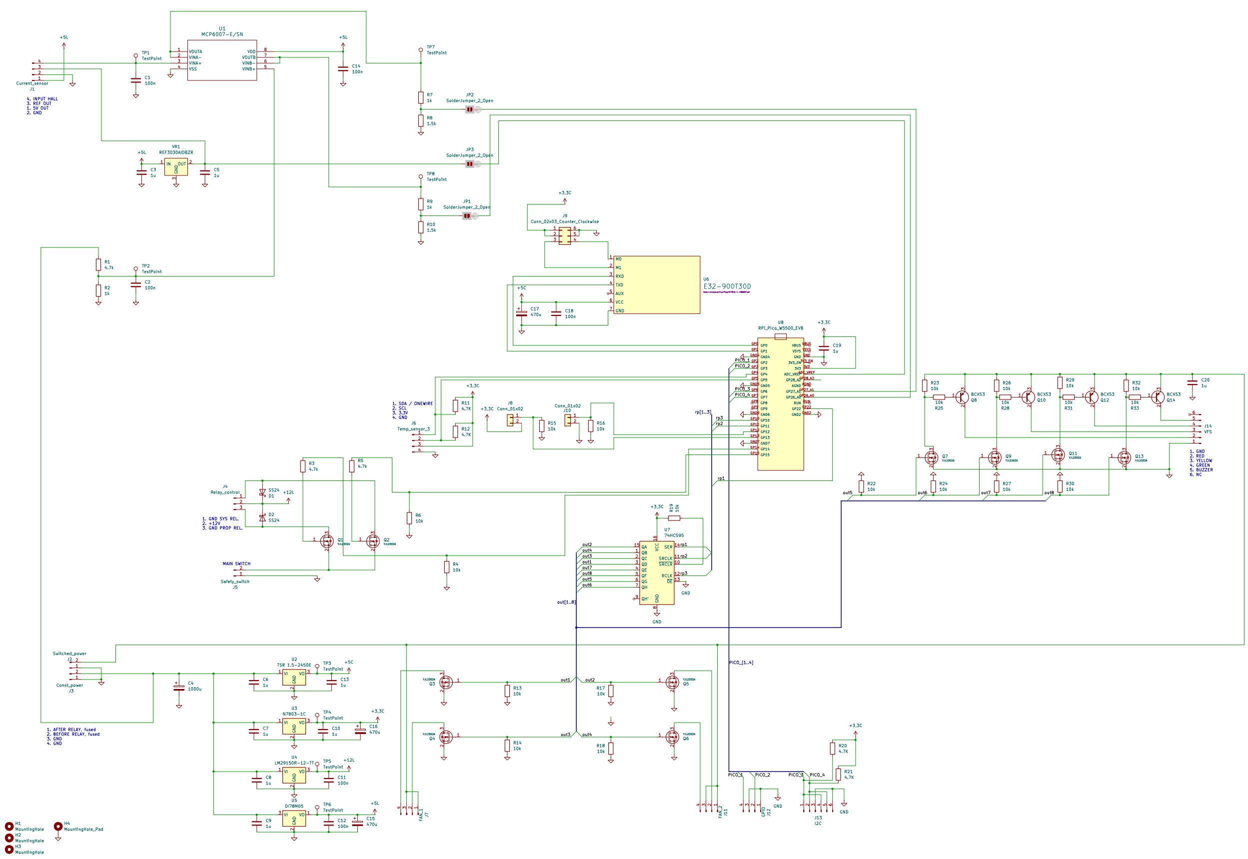


D. Thrusters configuration

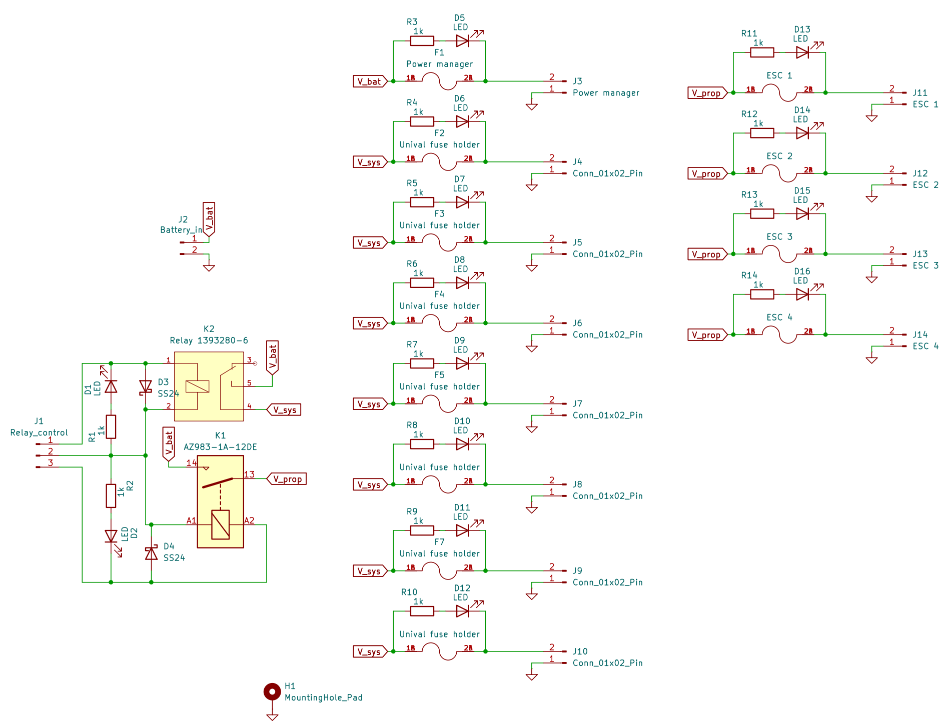


Appendix E
Electrical schematics

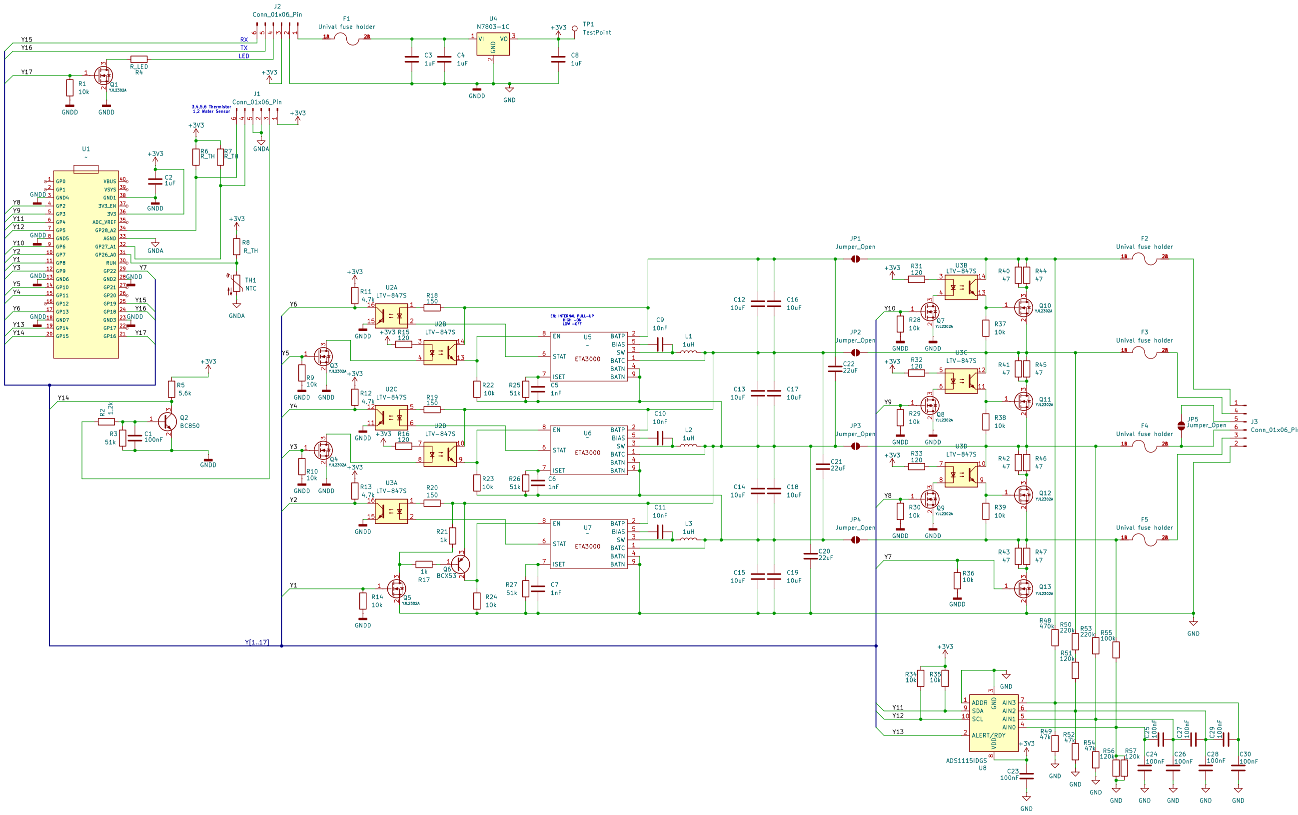
A. Power Manager



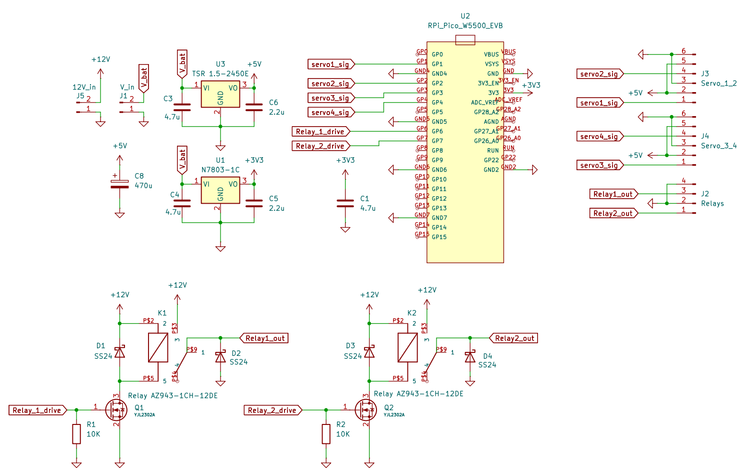
B. Fuse Board



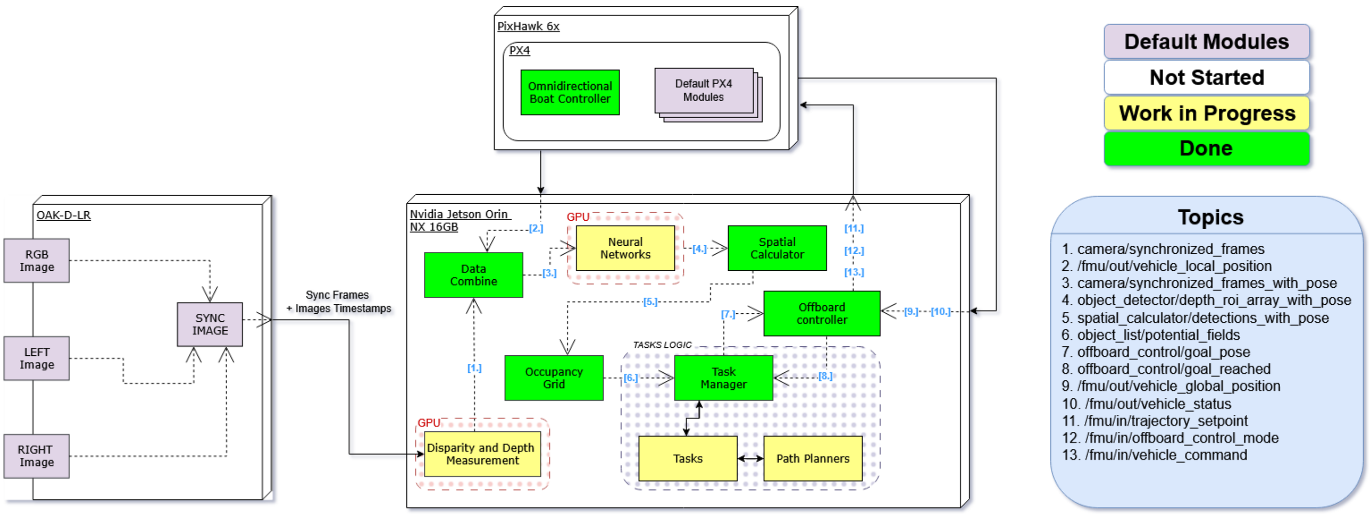
C. Battery Management System



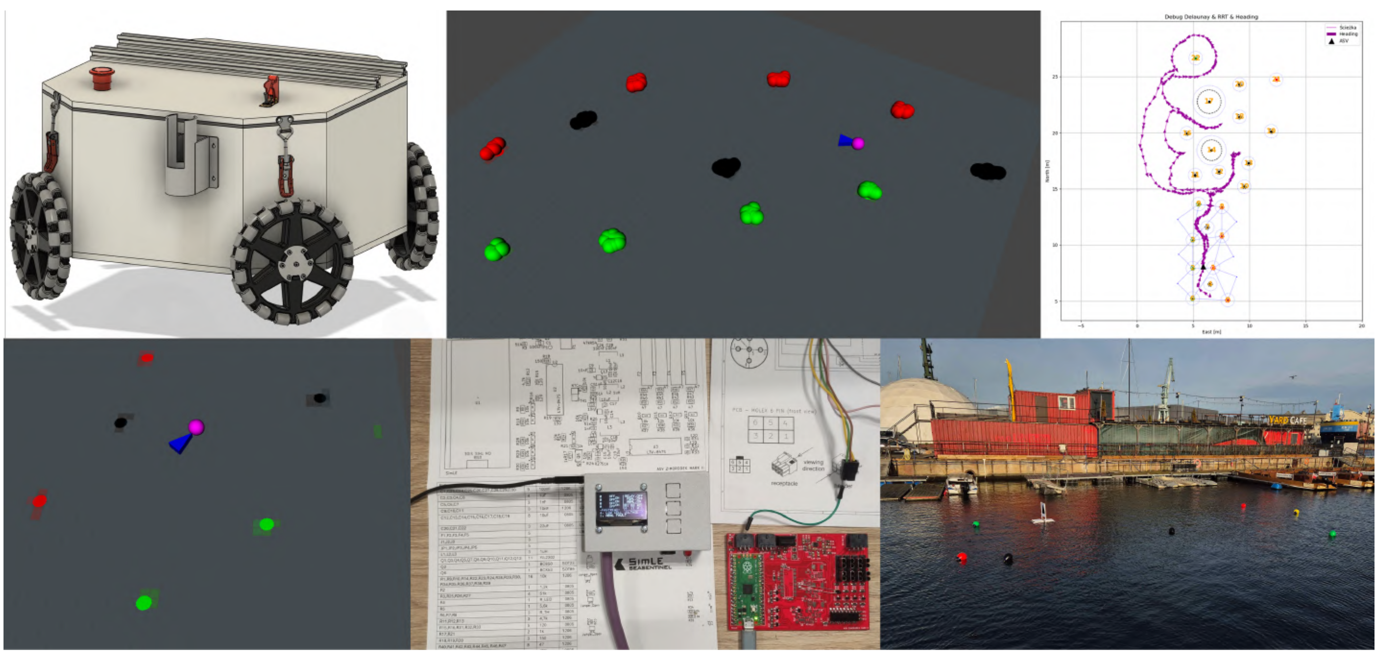
D. Special Operations Module Board



Appendix F
Autonomous Navigation Software Architecture



Appendix G
Testing methods utilized by SimLE SeaSentinel Team



APPENDIX H
TEST PLAN & RESULTS

A. Testing scope

Every formulated requirement can be verified either during a Review, an Analysis, an Inspection or a Test. For those requirements that will be tested, a following Test Plan was created.

Function ID	2nd level function	REQ ID	Requirement	Test description	Planned test date	Real test date	Person approving test results
F1.1	To float	REQ-001	The ASV should have a mass of no more than 30kg.	1) Place the transport straps on the cart. 2) Position the ASV on the cart so that the transport straps are underneath the floats. 3) Attach the straps to the handheld scale. 4) Two people lift the ASV and read the scale's measurement.	Jan 13th, 2026		Piotr Stroiński
F1.1	To float	REQ-008	The floats must be watertight.	1) Fully submerge the floats. 2) Observe for air bubbles coming out of the floats.	Jan 6th, 2026		Piotr Stroiński
F1.2	To move on the water surface	REQ-011	The ASV must be capable of moving on the water surface at a speed of no less than 2 knots, with wind force up to 4B from any direction.	1) Establish two measuring points and measure distance between. First measuring point must be at least 3 meters away from ASV's starting point. 2) Launch ASV in towing tank and enter RC mode.	Jan 13th, 2026		Piotr Stroiński
F1.2	To move on the water surface	REQ-012	The ASV should be directionally stable.	1) Balast the hull to simulate the mass and the center of gravity of the entire ASV. 2) Attach the hull to the towing carriage. 3) Tow the hull in a straight line at a constant speed. 4) Measure the model's yaw (rotational movement around the vertical axis) and any lateral deviations from the intended straight path. 5) Analyze collected data to determine the model's tendency to maintain or deviate from the straight course. A directionally stable ship will show minimal deviation, while an unstable one will exhibit increasing divergence from the straight path.	Jan 6th, 2026		Piotr Stroiński
F1.2	To move on the water surface	REQ-013	The ASV must ensure that the wave reaching the hull floats causes a trim in the direction of travel not greater than 3 degrees, with wind speeds up to 4B from any direction and with the ASV speed of 2 knots.	Since it is waves, not wind that are a primary factor influencing the hull's pitching, test will be conducted in towing tank only. 1) Establish two measuring points and measure distance between. First measuring point must be at least 3 metres away from ASV's starting point. 2) Launch ASV in towing tank and enter RC mode. 3) Steer the ASV in a straight line with maximum power with no waves in the tank. 4) Measure the time it takes for the ASV to move from one measuring point to another. 5) Observe and record hull's pitching. 6) Steer the ASV in a straight line with maximum power through 30cm-high waves in the tank. 7) Measure the time it takes for the ASV to move from one measuring point to another. 8) Observe and record hull's pitching. 9) Collect IMU data from the test. 10) Analyze recorded videos and data collected from IMU.	Jan 13th, 2026		Piotr Stroiński
F1.2	To move on the water surface	REQ-014	The ASV must ensure that when traveling in the opposite direction to the wave direction, the hull's pitching occurs with an angular acceleration not greater than X rad/s², with wind speeds up to 4B from any direction and with the ASV speed of 2 knots.	We are unable to calculate or estimate desired value of property in question. Futher research regarding the effects of pitching acceleration on detection capabilities of VPU is needed. All we know for now is that we want to minimize it. For this reason test results will be subject to team's intuitive evaluation. Since it is waves, not wind that are a primary factor influencing the 1) Establish two measuring points and measure distance between. First measuring point must be at least 3 metres away from ASV's starting point. 2) Launch ASV in towing tank and enter RC mode. 3) Steer the ASV in a straight line with maximum power with no waves in the tank. 4) Measure the time it takes for the ASV to move from one measuring point to another. 5) Observe and record hull's pitching. 6) Steer the ASV in a straight line with maximum power through 30cm-high waves in the tank. 7) Measure the time it takes for the ASV to move from one measuring point to another. 8) Observe and record hull's pitching. 9) Collect IMU data from te test. 10) Analyze recorded videos and data collected from IMU.	Jan 13th, 2026		Piotr Stroiński

Function ID	2nd level function	REQ ID	Requirement	Test description	Planned test date	Real test date	Person approving test results
F1.2	To move on the water surface	REQ-015	The critical angle of the ASV must not be less than 30°.	1) Balast the hull to simulate the mass and the center of gravity of the entire ASV. 2) Gradually increase the heel angle until the hull overturns.	Jan 6th, 2026		Piotr Stroiński
F1.2	To move on the water surface	REQ-017	The propulsion system must be capable of generating a turning moment, with no translation and a wind force of 4B from any direction.	1) Launch the ASV in the shipyard. 2) Set a waypoint for the ASV and a command to hold position when it reaches it. 3) Set heading north, wait for approx. 2 minutes, repeat for east south and west 4) Observe and record the ASV for the duration of the turn 5) Collect GPS data from the test 6) Analyze recorded video and collected data	Subject to weather forecast		Piotr Stroiński
F1.3	To maintain a fixed position relative to the seabed	REQ-018	The ASV must be capable of maintaining a fixed geographic position with an accuracy of +/- 0.1 m, with a wind force of 4B from any direction.	If the weather allows to test the ASV during 4B wind strength: 1) Launch the ASV in the shipyard. 2) Set a waypoint for the ASV and a command to hold position when it reaches it 3) Observe and record the ASV for approx. 3 minutes. 4) Collect GPS data from the test. 5) Analyze recorded video and collected data. If the weather does not allow to test the ASV during 4B wind strength: 1) Attatch one end of the rope the to ASV and leave the other in Operator's hands. 2) Launch the ASV in the shipyard. 3) Set a waypoint for the ASV and a command to hold position when it reaches it. 4) Pull the rope. 5) Observe and record the ASV for approx. 3 minutes. 6) Collect GPS data from the test. 7) Analyze recorded video and collected data.	Subject to weather forecast		Piotr Stroiński
F2.2	Not to overload	REQ-022	The electrical circuits must be protected against overload and short circuits.	1) Power on the ASV. 2) Attach an electronic load to the tested circuit. 3) Increase the current drawn by the load above the circuit's rated current. 4) Observe if the power to the circuit is disconnected.	Jan 3rd, 2026		Wojciech Miłosz
F2.3	Fail safe - to deactivate when conncection is lost	REQ-026	The ASV must shut down the propellers when it loses communication with the OCS.	1) Launch the ASV in the shipyard. 2) Set waypoints for ASV to follow. 3) Disconnect power from the OCS to stop communication. 4) Observe the ASV's behavior.	Feb 15th, 2026		Wojciech Miłosz
F2.4	To deactivate remotely	REQ-027	After pressing Remote Shutdown, only the motor power section must be disconnected from the power source.	1) Power on the ASV. 2) Using RC mode turn on thrusters. 3) Press the Remote Shutdown button. 4) Check if power is being delivered to SBC. 5) Check if power is being delivered to thrusters.	Jan 15th, 2026		Wojciech Miłosz
F2.5	To deactivate locally	REQ-028	After pressing Local Shutdown, all components should be disconnected from the power source.	1) Power on the ASV. 2) Using RC mode turn on thrusters. 3) Press the Local Shutdown button. 4) Check voltage after Fuse Board.	Jan 15th, 2026		Wojciech Miłosz
F2.6	To stay active when grid power is lost	REQ-029	The battery should provide emergency power to the OCS for at least 6 hours after the loss of power from the grid.	1) Deploy OCS. 2) Observe power demand over 6h. 3) Check battery charge.	Jan 16th, 2026		Wojciech Miłosz
F3.1	To deliver a steady stream of water	REQ-031	The WG must ensure a constant flow of water in the system.	1) Connect power to the WG. 2) Submerge the intake line. 3) Turn on the pump/s. 4) Observe water flow in the system.	Jan 20th, 2026		Piotr Stroiński
F3.1	To deliver a steady stream of water	REQ-032	The WG must continuously deliver a steady stream of water for no less than 10 seconds.	1) Connect power to the WG. 2) Submerge the intake line. 3) Turn on the pump/s more than 10 second. 4) Observe the module.	Jan 20th, 2026		Piotr Stroiński
F3.2	To hit the target with water	REQ-033	The WG must generate a water stream that reaches a target located 2.5 meters from the bow of the ASV and at a height of 1.2 meters.	1) Place WG in a secure position. 2) Place a target approx. 1.2 meter above WDS level and 2.5 meters away. 3) Power on the WG. 4) Correct the shooting angle of the WG if the shot misses. 5) Observe and record the module and the stream of water.	Jan 20th, 2026		Piotr Stroiński
F3.2	To hit the target with water	REQ-034	The ASV must hit a target with a diameter of 1.2 meters using the water stream.	Unable to construct Autonomy Challenge mock-up on time.			
F3.2	To hit the target with water	REQ-034	The WG must continuously hit the target for at least 5 seconds.	Unable to construct Autonomy Challenge mock-up on time.			

Function ID	2nd level function	REQ ID	Requirement	Test description	Planned test date	Real test date	Person approving test results
F5.1	To interface with Competition Staff	REQ-037	The ASV must have a switch located in a position that allows local shutdown using a paddle.	1) Power on the ASV. 2) Hit the Local Shutdown button with a paddle. 3) Analize the difficulty and accesability of the BRB	Jan 16th, 2026		Wojciech Miłosz
F5.2	To interface with Operator	REQ-038	The OCS must provide the capability to send commands to the SBC.	1) Power on the ASV and the OCS. 2) Connect computer to network. 3) Launch ROS2 publisher node. 4) Observe ASV response.	Jan 21st, 2026		Patryk Martyniak
F5.2	To interface with Operator	REQ-039	The OCS must continuously display the voltage of the ASV's batteries.	1) Power on the ASV and the OCS. 2) Measure battery voltage with a multimeter. 3) Compare the measured value with value displayed on the OCS.	Jan 21st, 2026		Patryk Martyniak
F5.2	To interface with Operator	REQ-040	The OCS must provide the capability to view live footage from the cameras.	1) Power on the ASV and the OCS. 2) Connect computer to network. 3) Observe camera stream on the OCS.	Jan 9th, 2026		Patryk Martyniak
F5.2	To interface with Operator	REQ-041	TThe OCS must provide the capability to view the ASV's orientation relative to the north.	1) Power on the ASV and the OCS. 2) Change ASV orientation by turning the cart. 3) Compare orientation displayed on the OCS to the actual orientation.	Jan 21st, 2026		Patryk Martyniak
F5.2	To interface with Operator	REQ-042	The OCS should provide the capability to view the thrust vector of each propeller in real time.	1) Power on the ASV and the OCS. 2) Use RC mode to vary the thrust of each thruster form 0 to 100 3) Observe thrust vector values displayed on the OCS.	Jan 21st, 2026		Patryk Martyniak
F5.2	To interface with Operator	REQ-043	The OCS should provide the capability to view the resultant thrust vector of the propellers.	1) Power on the ASV and the OCS. 2) Use RC mode to vary the thrust form 0 to 100 3) Observe resultant thrust vector value displayed on the OCS.	Jan 21st, 2026		Patryk Martyniak
F5.2	To interface with Operator	REQ-044	The OCS must provide the operator with the ability to select which data collected from the ASV to view at any given moment.	1) Power on the ASV and the OCS. 2) Choose parameters to be displayed on the OCS. 3) Observe if choosen parameters are displayed correctly.	Jan 21st, 2026		Patryk Martyniak
F5.2	To interface with Operator	REQ-046	The OCS should continuously display information about the system's operating mode (RC, automatic, autonomous).	1) Power on the ASV and the OCS. 2) Connect to the ASV with QgroundControll. 3) Change ASV operating modes to: RC, auto, autonomus. 4) Observe value displayed on the OCS.	Jan 21st, 2026		Patryk Martyniak
F5.2	To interface with Operator	REQ-047	The OCS must provide the operator with control over the propellers.	1) Launch the ASV on the water and power on the OCS. 2) Use the RC remote to actuate the thrusters. 3) Observe if ASV is moving correctly.	Jan 21st, 2026		Patryk Martyniak
F5.2	To interface with Operator	REQ-048	The OCS must allow the operator to remotely make changes to the configuration of the OBC and VCU.	1) Power on the ASV and the OCS. 2) Try accessing the VCU parameters using QgroundControll app. 3) Try accessing OBC through an SSH connection.	Jan 21st, 2026		Patryk Martyniak
F6.1	To follow waypoints set by Operator	REQ-054	The control system should allow the ASV to approach the target point with accuracy limited only by the precision of the ASV's geographic position determination.	1) Launch the ASV on the water. 2) Set a waypoint and wait for confirmation from the ASV. 3) Receive confirmation from the ASV that it reached the waypoint.	Jan 4st, 2026		Filip Jaworski
F6.2	To be able to independently make a decision based on data collected by on-boad sensors only	REQ-055	In autonomous mode, the ASV should avoid obstacles with a clearance of at least 0.1 m.	1) Launch the ASV on the water and put an obstacle in front of the ASV. 2) Save GPS values of the obstacle. 3) Set a waypoint behind the obstacle. 4) Observe if the required distance between ASV and the obstacle is preserved by comparing GPS values of ASV and the obstacle.	Jan 4st, 2026		Filip Jaworski
F6.2	To be able to independently make a decision based on data collected by on-boad sensors only	REQ-057	The ASV can record and store the positions of previously detected objects in its memory.	1) Launch the ASV on the water and put 5 objects in different positions. 2) Send rotation command to the ASV. 3) Observe if new objects with their position values are added to the object list.	Jan 22nd, 2026		Filip Jaworski
F6.2	To be able to independently make a decision based on data collected by on-boad sensors only	REQ-058	If an object that was saved in the ASV's memory disappears from its field of view and then reappears, the ASV should recognize it as an object that was previously detected, not a new one.	1) Launch the ASV on the water in front of an object that will be stored in the object list. 2) Change ASV position by setting a waypoint. 3) Rotate ASV, so that it detects the known object. 4) Check if the object appeared as a new object in the object list.	Jan 22nd, 2026		Filip Jaworski
F6.2	To be able to independently make a decision based on data collected by on-boad sensors only	REQ-059	If an object that was saved in the ASV's memory appears in its field of view and the ASV is closer to the object than during the previous measurement, the ASV should overwrite/correct the recorded position of the object.	1) Launch the ASV on the water in front of an object that will be stored in the object list. 2) Change ASV position by setting a waypoint closer to the object. 3) Observe if position values of the known object have been changed.	Jan 22nd, 2026		Filip Jaworski

Function ID	2nd level function	REQ ID	Requirement	Test description	Planned test date	Real test date	Person approving test results
F6.2	To be able to independently make a decision based on data collected by on-boad sensors only	REQ-060	The ASV must correctly identify the stage of the mission.	1) Deploy ASV on the water and put objects needed to complete the task. 2) Assign task to the ASV. 3) See if ASV sends the message about task completion. 4) Observe the current mission of the ASV.	Jan 4st, 2026		Filip Jaworski
F6.2	To be able to independently make a decision based on data collected by on-boad sensors only	REQ-061	The ASV must calculate the position of the detected object with an accuracy of 1 meter at a distance of up to 20 meters from the object.	1) Deploy the ASV on land. 2) Place a red buoy 20 meters in front of the ASV. 3) Observe the distance to the object reported by the ASV.	Jan 3rd, 2026		Filip Jaworski
F6.2	To be able to independently make a decision based on data collected by on-boad sensors only	REQ-062	The ASV must correctly detect at least 85% of the objects that are part of the competition course and are within its field of view.	1) Deploy the ASV on the water and put some objects in its field of view. 2) Compare the number of detected objects with the true number of course objects.	Jan 22nd, 2026		Filip Jaworski
F6.2	To be able to independently make a decision based on data collected by on-boad sensors only	REQ-063	False detections of objects that are part of the competition course must account for less than 15% of all detections.	1) Deploy the ASV on the water and put some objects in its field of view. 2) Identify false detections by using map of the competition course and video recordings from ASV.	Jan 22nd, 2026		Filip Jaworski
F6.2	To be able to independently make a decision based on data collected by on-boad sensors only	REQ-064	Among the correctly detected objects that are part of the competition course, the ASV must correctly identify at least 90% of them.	1) Deploy the ASV on the water and put some objects in its field of view. 2) Compare assigned labels to human-assigned ones	Jan 22nd, 2026		Filip Jaworski
F6.3	To establish its geographical position	REQ-065	The ASV should receive data about its current geographic position with an accuracy of +/- 0.1 meters.	1) Deploy the ASV on land on a cart. 2) Note current geographic position reported by the ASV. 3) Move the ASV by 1 meter to the north. 4) Note geographic position reported by the ASV. 5) Calculate the difference between two recorded positions. 6) See if the result is within +/- 0.1m of the traveled distance.	Jan 4st, 2026		Filip Jaworski
F6.4	To independently control actuators	REQ-067	The control system must be stable.	1) Deploy the ASV. 2) Launch a a waypoint mission. 3) Observe if the ASV reaches the waypoint without oscilating and overshooting.	Jan 22nd, 2026		Filip Jaworski
F7.1	To enable quick module exchange	REQ-069	The assembly and disassembly of modules must not take longer than 40 seconds.	Team members will assemble and disassemble modules. Meanwhile another team member will measure time passed.	Jan 24th, 2026		Piotr Stroiński
F4.1	To deliver racquetballs to anchored, black boats	REQ-073	The RDM must deliver the ball at a distance of at least 20 cm from the tip of the bow and at a height of 20 cm above the water surface.	1) Mount RDM in a secure place. 2) Record a video of racquetball release. 3) Analyze the video and racquetball's point of impact.	Jan 24th, 2026		Piotr Stroiński
F4.1	To deliver racquetballs to anchored, black boats	REQ-074	The RDM must be capable of releasing the balls one at a time.	1) Mount RDM in a secure place. 2) Send a single fire command. 3) Observe the RDM. 4) Repreat two times.	Jan 24th, 2026		Piotr Stroiński
F4.1	To deliver racquetballs to anchored, black boats	REQ-075	The RDM must not fill with water during rainfall.	1) Place RDM under o shower. 2) Slightly turn on the water and aim at the RDM from the top.	Jan 24th, 2026		Piotr Stroiński
F5.2	To interface with Operator	REQ-080	The ASV must provide the operator with the ability to connect to the OBC via a cable without the need to open the superstructure or hull of the ASV.	1) Power up the ASV. 2) Connect a laptop to an outside ethernet port on the ASV hull. 3) Try accessing the OBC through an SSH connection. 4) Observe if connection is successful.	Jan 24th, 2026		Piotr Stroiński
N/A	N/A	REQ-111	The power system should allow the ASV to operate under standard conditions for at least one hour.	1) Deploy the ASV. Perform waypoint missions for an hour. 2) Observe if ASV stays powered on the entire time.	Jan 22nd, 2026		Piotr Stroiński
N/A	N/A	REQ-112	Replacing a single propeller must take a team of at least 3 people no longer than 5 minutes.	1) Assemble a team of 3 people. 2) Aproach the ASV safely. 3) Attempt to change propeller. 4) Record the time it takes to change it.	Jan 16th, 2026		Piotr Stroiński

B. Schedule

The production phase of ASV Zimorodek II will end in the second half of January and this when we will begin to conduct various tests on system and subsystem levels. Minor tests on the component level began in December. Software and behavior trees are tested during live tests on the water at least twice a month. With increasing intensity before competition.

C. Environment

Tests that require water but do not require GPS signal are performed at the towing tank facility at Gdańsk University of Technology. Live tests in the water are conducted at Imperial Shipyard. Water at this location is a seawater which prevents it from freezing as easily as freshwater ponds. It is very important since most of the tests take plane in winter as shown on Fig. 12 (see below). Tests on land, with the use of CRAB take place on the parking lot, next to our team's workshop.

Tests at Imperial Shipyard in January

D. Results

Results of every test are written down in a separate document and are later a basis for assigning a Compliance Status (Compliant, Partially Compliant, Non-compliant) to a given requirement in Verification Control Document.