RoboBoat 2025: Technical Design Report SimLE SeaSentinel Team

Igor Rusiecki, Cezary Wieczorkowski, Tomasz Ujazdowski, Patryk Martyniak, Sergiusz Pyskowacki, Paulina Prudel, Piotr Stroiński, Filip Jaworski, Jakub Link, Tomasz Lisowski, Marcel Skierkowski, Wojciech Miłosz, Wiktor Sieklicki
Gdańsk University of Technology, Poland, Gdańsk

***Abstract*—This report discusses the strategy of a SimLE SeaSentinel Team for RoboBoat 2025 and the design of our system. The system consists of an Autonomous Surface Vehicle (ASV) named ASV Zimorodek (ang. *Kingfisher*) and Ground Segment. In our work, we adhere to systems engineering principles. We used V-model to organize the development process our vehicle. ASV Zimorodek will be a modular, easily transportable, mostly 3D printed catamaran. The propulsion system consisting of four thrusters will provide us with omnidirectional movement capabilities. In addition, we will equip our ASV with Special Operations Modules (SOMs) to exectute Task 5. All modules within our boat will communicate with each other via an Ethernet network. Computer vision will rely solely on OAK-D LR stereo camera. As a basis of our software system architecture, we decided to utilize Robot Operating System 2 (ROS2). We will maintain communication with our ASV with the help of three different radio links. Apart from the boat, we also decided to improve our Operator Control Station (OCS) by developing a custom application based on Rviz to enhance ASv-Operator interface. In addition, we developed a Crawler Rover for Autonomous Boat testing (CRAB), a robot that allows to test our algorithms on land without the need of taking our boat to the water. Combined with other, used by our team in the past testing methods it greatly improved both the quality and quantity of conducted tests.**

***Index Terms*—autonomous surface vehicle, robot operating system, behavioural trees, omnidirectional propulsion, RoboBoat**

ACRONYMS AND ABBREVIATIONS

ASV Autonomous Surface Vehicle
ConOps Concept of Operations
DMS Decision-Making System
ESC Electronic Speed Controller
FB Fuse Board
OCS Operator Control Station
PCB Printed Circuit Board
PM Power Manager
ROS2 Robot Operating System 2
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).

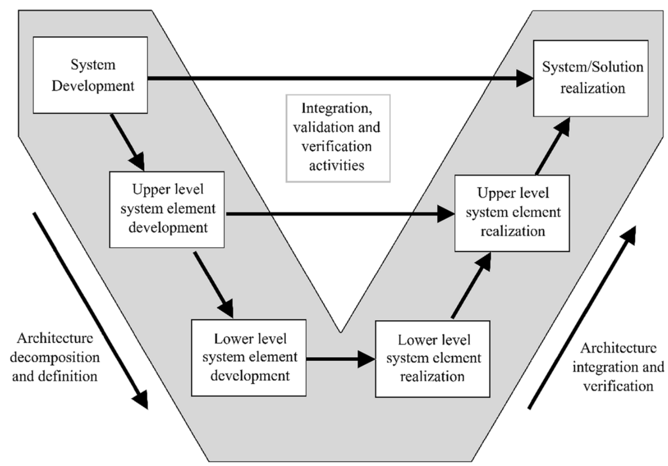

Fig. 1: V-model from INCOSE [2]

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

- **Lessons Learned** - RoboBoat 2024 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 veri ed 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 justi cation 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 speci c 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 Gdańsk to improve the aesthetics of our design and create concept arts (see Fig. 2) that inspire engineers during the design phase. Most subsystems nished this phase and passed the Preliminary Design Review (PDR) in December.

Design – At this stage, the nal technical documentation has been created, which enabled the production of models and prototypes rst, and subsequently the nal product. Calculations, cost estimates, bills of materials, justi cations for the selection of key dimensions and tolerances, as well as photos of the nal models were all documented. The nal design of the majority of subsystems was approved during the Critical Design Review (CDR) in late December and early January.

Manufacturing - Our last year's experiences convinced us that manufacturing components from berglass is both resource and labor-intensive. For this reason, we decided to utilize primarily 3D printing during ASV Zimorodek'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.

Veri cation - 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 veri ed. Veri cation even on very early stages of the project is also a key feature on V-model. In the SRD, four different veri cation methods have been distinguished: review, inspection, analysis, and test. More than one veri cation method can be assigned to a selected requirement. The document used to track the status of ongoing veri cations is the Veri cation Control Document (VCD). The last stage before system deployment is the Acceptance Review (AR) planned for mid-February.

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

Each subsystem has been described in a separate document named Subsystem Design De nition (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, speci es which documents must be delivered during a given review.

B. Course Strategy

During RoboBoat 2025 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.

First, the most basic, mandatory task that our ASV needs to complete is Task 1 - Navigation Channel. Behavior tree for this task can be simpli ed to the following steps:

As long as the ASV hasn't passed 2 gates:

- Find the 2 nearest different large markers (forming a gate).
- Designate a waypoint located just beyond the gate.
- Move to a designated waypoint.
- Repeat for the next gate.

Task completed.

After completing the rst task, the ASV will search for the pair of green and red small buoys, which will indicate the beginning of Task 2 – Mapping Migration Patterns (Follow the Patch). Our vehicle will conduct the following decision-making process:

As long as the buoys are visible in front of the boat:

- Find the 2 nearest different buoys.
- Designate a waypoint located just beyond the buoys. The route is planned to avoid the yellow buoys (ASV will be suggested to move to the nearest unobstructed area).

Task completed.

During Task 3 – Treacherous Waters (Docking) our ASV will first circle the entire dock and register a sign marking every spot as well as every boat 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 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 4 – Race Against Pollution (Speed Challenge) is probably the most complex of the tasks. First, our vehicle will detect the starting area by finding the closest gate of the holding bay. After entering the starting area, ASV's position will be saved in its memory. At the same time, our boat will turn in place to locate a blue buoy and designate 3 waypoints around it. Next, the ASV will turn in place to detect the LED light. When the light turns green, ASV Zimorodek will proceed to previously designated waypoints around the blue buoy. After that, the ASV will return to the previously saved waypoint inside the starting area. If an obstacle is detected on the vehicle's path, the Decision-Making System (DMS) will designate a waypoint to the right of it that will temporarily override other waypoints.

Our team has made a decision that our ASV will not conduct activities related to Task 5 – Rescue Deliveries (Object and Water Delivery) while performing other tasks. Instead, ASV Zimorodek will execute Task 5 separately from other tasks, after completing Tasks 1-4. Although less time-efficient, such an approach allowed for a great reduction in the complexity of our behavior trees. Autonomy Challenge has been divided into 6 well-defined, smaller missions each with a separate behavior tree, instead of one, great behavior tree for an entire mission. Such a structure will be easier to modify and debug during the competition. ASV will detect black and yellow boats while performing other tasks, save their position in its memory, and then use that data to return to them to deliver either a racquetball or a steady stream of water to all detected targets, which will constitute task completion.

Task 6 - Return to Home is the last task on the entire course. Our plan for this task is to use the proximity of Task 6 to Task 1. Before entering the Navigation Channel, our ASV will take a look around itself in order to locate black buoys from Task 6. Their position will be saved in the vehicle's memory and serve as a reference point when designating the last waypoints to which ASV Zimorodek will move during Autonomy Challenge.

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 first design dilemma for this work package was the selection of the general layout and hull concept. The options considered included: catamaran, trimaran, monohull, barge, SWATH, and hovercraft. Guided by criteria such as stability, steadiness, maneuverability, and hydrodynamic resistance, it was decided that ASV Zimorodek would be a catamaran.

One of the issues with the project's previous iteration, ASV Rybitwa, was its high susceptibility to pitching caused by relatively large waves present during the RoboBoat 2024 competition. This had a negative effect on the stereo camera's ability to correctly estimate the distance between detected objects and the ASV. Therefore, one of the main criteria for selecting the float shape concept was the hull's ability to pierce through waves rather than climb over them and then leap off the crests. For this reason, the decision was made to design a hull with a bow inspired by the X-BOW® [6] solution developed by Ulstein. The characteristic inverted bow of this solution reduces the amplitude and acceleration of hull pitching when operating in high waves.

Thanks to our cooperation with KSTO KORAB, the possibility arose to cheaply 3D print the floats out of PLA+. 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 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. 3.

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 hull design was connecting the catamaran's two floats. The team chose to build a frame using 15x15 mm MakerBeam XL [7] aluminum profiles. The superstructure and deck, which holds Special Operations Module (SOM), are attached directly to the frame with screws. Thanks to the unique MakerBeam 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, even when SOM is not installed.

Fig. 3: Bow segment during 3D printing

Fig. 4: An assembly of ASV Zimorodek with Battery Boxes and ESC Boxes in oats, and without yet integrated bridge for the camera

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, as shown in Fig. 4. This allows the team to experimentally determine the optimal settings based on the ASV's con guration and mission conditions. The walls of the superstructure will be made from PET-G using 3D printing technology, while the oor and cover will be made from foam PVC sheets, valued for their low weight and high stiffness. The entire structure will be painted.

B. Propulsion

Similarly to our previous vessel, ASV Zimorodek will be equipped with a differential thrust propulsion system using four Blue Robotics T200 Thrusters [8]. Their con guration (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 2024 our team decided to change the angle between thrusters and ASV's center line from 45° to 30° in order to increase the resultant thrust force directed along this axis.

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

C. Water Gun

The Water Gun is a very simple SOM consisting of a diaphragm pump, a hose, and a nozzle which angle relative to the deck can be manually adjusted by the operator from 0° to 90° before launching the vehicle. This parameter is provided by the operator to the ASV 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 xed position relative to the target with high precision.

D. Racquetball Delivery Module

A key aspect of Task 5 is that the racquetball does not need to hit the banner located on the black boat. No penalty points for physical contact between the ASV and the target boat are given. Therefore, it is suf cient for the vehicle to approach the black boat as closely as possible and then gently deliver the ball onto its deck. That is why this SOM will be equipped with three barrels with a spring and a racquetball in each of them. The operator tensions all the springs on land, which are then released one by one by the ASV.

E. System Bus

Just like our previous vehicle, ASV Zimorodek uses an Ethernet-based network. The centralized switch as shown in Appendix D handles all network communication. Ethernet's exibility 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

Electrical system architecture (see Appendix D) developed by our team a year ago proved to be effective and reliable. However, this year, our goal was to make it more space-ef cient. To achieve this, we partnered with Central Point to help us deploy redesigned circuitry on a PCB (see Appendix E). The electrical system consists of three separate integrated PCB modules, Power Manager (PM), Fuse Board (FB), and a module dedicated to SOM. PM is a module that controls the power onboard. It also monitors battery voltage, current, and temperature. This module also facilitates local and remote shutdown functions. FB distributes ad switches the power to all onboard modules. Each circuit is protected by a fuse.

G. Computer Vision

OAK-D cameras, mounted on our previous vehicles, failed to provide suf cient precision for detecting distant objects. For this reason, a decision was made to switch to the OAK-D LR [11] camera that addresses this issue with its ability to measure depth with high accuracy up to 30 meters. Additionally, it is fully compatible with the previous system, requiring only minor code modi cations to integrate seamlessly.

The OAK-D LR features a Vision Processing Unit (VPU) that processes RGB image data internally using the YOLOv8n [12] neural network model. The depth information is calculated by the stereo cameras, which signi cantly reduces the computational load on the SBC - Nvidia Jetson Orin NX 16GB. The processed data, including object detections and RGB images, is sent to the SBC for further processing and to the Operator Control Station (OCS) for visualization purposes (Fig. 5).

To train the YOLOv8n 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 Robo ow platform were used. This strategy allowed us to validate the model using data tailored to our speci c camera, accounting for its unique physical properties that in uence image quality and dynamics.

Furthermore, the implementation of classical data augmentation methods, including rotation, mirror ips, 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 prede ned messages, and each node can read, write, or perform both operations within the communication structure. This modular design allows for ef cient data handling and robust interaction between system components. As shown in Fig. 5, the architecture consists of four main components: VPU, DMS, Vehicle Control Unit (VCU), and OCS.

The VCU is managed by a PX4 controller [9] 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" (see Fig. 5).

The DMS serves as the central processing unit for autonomous navigation. It receives detections from the VPU and vehicle status data from the VCU. Behavior trees [16] are implemented within this component to analyze the input and decide on the next waypoint, ensuring ef cient decision-making based on the boat's surroundings. In general, behavior trees are hierarchical structures that represent a set of prede ned scenarios for an agent's (in this case, an ASV's) responses to external stimuli detected and identi ed in its environment. In the proposed system, a primary tree (see Fig 6) oversees data collection and task switching, while each competition task is represented as an independent tree sharing a common set of conditions and actions.

Fig. 5: ASV Zimorodek's Software Architecture

Fig. 6: Behavioral Tree Structure

I. Telemetry and Remote Shutdown

The communication system with the ASV during the previous year's competition demonstrated satisfactory performance. Consequently, no signi cant 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. In addition, LoRa modules were incorporated to facilitate an emergency shutdown mechanism. These modules can be con gured to operate on either the

868 MHz or 915 MHz frequency bands, enabling compliance with regulatory requirements in both 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. This year, to enhance the team's ability to monitor and interpret data collected from the ASV, an additional application was developed. This application not only improves video streaming but also provides a more intuitive visualization of key data, such as the ASV's orientation relative to true north and its resultant velocity vector. The application leverages the Rviz [20] interface to aggregate and display this information in a clear and accessible manner. Furthermore, the tool enables the assignment of specific data to individual operators, which is expected to improve ASV control and performance during competition. 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 depicted on Fig. 7: 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 F.

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 2024, ASV Rybitwa, serves as a testing platform used to test for example GPS modules, communication links and behaviour 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. Because of that we did not need to develop a new controller for CRAB but instead we could simply adjust a controller used on our boat. Batteries, SBC, VCU and camera are also the same as on ASV Zimorodek. This platform allows our team to test behaviour trees on a mock-up of Autonomy Challenge setup on the parking lot next to our workshop.

To make testing even more convenient for our team members, we created a simulation using the Gazebo [21] platform, the expansive PX4 [9] ecosystem, and easily accessible docker containers [22]. This approach significantly accelerates and simplifies the process of testing and debugging our software. It has demonstrated its effectiveness in the development of behaviour trees, navigation strategies, and the integration of ROS2 with PX4. Furthermore, it is invaluable in generating synthetic data for neural network training. Such data enables us to train YOLOv8 to identify objects not previously present in the competition or those difficult to procure.

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. Test results are recorded and attached in a subsystem design document.

Fig. 7: Testing methods utilized by SimLE SeaSentinel Team

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Appendix A
ConOps - ASV25

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, which we are preparing for the RoboBoat 2025 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, two vehicles have been built: ASV Perkoz and ASV Rybitwa. Both were 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 and participation in the RoboBoat 2025 competition. To accomplish the mission, the construction of the vehicle must be completed no later than February 25, 2025. It is also assumed that the SeaSentinel Program will continue its activities after RoboBoat 2025, participating in subsequent editions of the competition or other initiatives aimed at students interested in autonomous maritime vehicles. ASV Zimorodek is expected to be capable of completing all tasks during RoboBoat 2025.

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 2025 competition.

Preliminary course layout for the RoboBoat 2025 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 de nes 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 oats, 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.
- Modi ed Cyber Deck.
- Custom ASV-Operator Interface App
- Modi ed 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 2025 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 2024 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 2025. 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 is supposed to be capable of performing all tasks during the RoboBoat 2025 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 CapabilitiesBelow 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 2025.

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 March. During this time of year, air temperatures range from 10°C (mornings and nights) to 27°C (clear, windless days).

Note: Despite the organizers' announcements, the competition date is subject to change. In 2022, it was held in June, in 2023 in March, and in 2024 in February.

Air temperatures in February: 8–20°C
Air temperatures in June: 18–38°C

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 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 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 and ASV Rybitwa.

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 speci c 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 oating dock or a ramp, depending on the presumed cause of the loss of control.
If towing to a oating 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 nals. 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 con guration.
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 scienti c aspects of the project.

1) Environmental Impacts: The operation of the system has a very limited impact on the natural environment. The only signi cant 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 is expected to elevate the SeaSentinel Program to an entirely new level of professionalism. We hope that the system will be used not only for RoboBoat 2025 but also for RoboBoat 2026 and potentially for the Njord competition. This will help reduce the program's operating costs in the future and simplify the generational transition when the current Manager steps down. The new Manager's task will not be to build a new system—a daunting challenge—but rather to modify the existing one. However, this approach may lead to a reduced demand for team members specializing in hull design. This carries the risk of losing key competencies, which could negatively affect the team's performance in the 2026/2027 season. Even if a decision is made in 2025 to upgrade ASV Zimorodek to the ASV Zimorodek II standard rather than building a new system, the team members specializing in hull design and construction should be engaged to preserve and develop these skills within the team. We believe that the quality of ASV Zimorodek will help attract more sponsors from both the private and public sectors.

3) Scientific and Technical Impacts: Although ASV Zimorodek 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, technologies will be utilized with which team members either have no experience or limited familiarity. This primarily includes designing and manufacturing PCB boards and producing complex-shaped parts from laminates.

To mitigate these risks, we have established 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 boards.

2) Risk of Propeller Blade Breakage: During the RoboBoat 2024 competition, there were two incidents where propeller blades broke during operation, rendering the propulsion system inoperable. In ASV Rybitwa, replacing a propeller on land took more than 15 minutes. As a result, due to time constraints, the system was inoperative during two of the three final round attempts.

To address this risk, ASV Zimorodek will be designed to allow for faster propeller replacement. Additionally, the production of custom, more durable propellers is being considered.

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. The decision on whether funding will be granted will be made in mid-May 2024. Until then, the level of funding remains uncertain.

To mitigate this risk, we are seeking private sector sponsors willing to support the project financially or materially.

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. 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 and RoboBoat 2024, 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 - ASV25

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	
Veri cation Control Document			X	X	X	X
Cost Estimate Report				X	X	
Subsystem Design De nition				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 - ASV25

Appendix D
System Details

A. Power distribution system

B. Telemetry system

C. System Bus

D. Thrusters con guration

APPENDIX E
ELECTRICAL SCHEMATICS

A. Power Manager

B. Fuse Board

C. Special Operations Module Board

APPENDIX F
TEST PLAN & RESULTS

A. Testing scope

Every formulated requirement can be veri ed 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 oat	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 oats. 3) Attach the straps to the handheld scale. 4) Two people lift the ASV and read the scale's measurement.	Feb 13th, 2025		Igor Rusiecki
F1.1	To oat	REQ-008	The oats must be watertight.	1) Fully submerge the oats. 2) Observe for air bubbles coming out of the oats.	Feb 6th, 2025		Igor Rusiecki
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.	Feb 13th, 2025		Igor Rusiecki
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.	Feb 6th, 2025		Igor Rusiecki

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-013	The ASV must ensure that the wave reaching the hull oats 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 in uencing 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.	Feb 13th, 2025		Igor Rusiecki
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 in uencing 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.	Feb 13th, 2025		Igor Rusiecki
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.	Feb 6th, 2025		Igor Rusiecki
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		Igor Rusiecki
F1.3	To maintain a xed position relative to the seabed	REQ-018	The ASV must be capable of maintaining a xed 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		Igor Rusiecki

Function ID	2nd level function	REQ ID	Requirement	Test description	Planned test date	Real test date	Person approving test results
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.	Feb 3rd, 2025		Cezary Wieczorkowski
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, 2025		Cezary Wieczorkowski
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.	Feb 15th, 2025		Cezary Wieczorkowski
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.	Feb 15th, 2025		Cezary Wieczorkowski
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.	Feb 16th, 2025		Cezary Wieczorkowski
F3.1	To deliver a steady stream of water	REQ-031	The WG must ensure a constant ow 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 ow in the system.	Feb 20th, 2025		Igor Rusiecki
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.	Feb 20th, 2025		Igor Rusiecki
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.	Feb 20th, 2025		Igor Rusiecki
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.			
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 dif culty and accesability of the BRB	Feb 16th, 2025		Cezary Wieczorkowski
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.	Feb 21st, 2025		Patryk Martyniak

Function ID	2nd level function	REQ ID	Requirement	Test description	Planned test date	Real test date	Person approving test results
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.	Feb 21st, 2025		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.	Feb 9th, 2025		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.	Feb 21st, 2025		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.	Feb 21st, 2025		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.	Feb 21st, 2025		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.	Feb 21st, 2025		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.	Feb 21st, 2025		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.	Feb 21st, 2025		Patryk Martyniak
F5.2	To interface with Operator	REQ-048	The OCS must allow the operator to remotely make changes to the con guration 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.	Feb 21st, 2025		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 con rmation from the ASV. 3) Receive con rmation from the ASV that it reached the waypoint.	Feb 1st, 2025		Marcel Skierkowski
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.	Feb 1st, 2025		Marcel Skierkowski
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.	Feb 22nd, 2025		Marcel Skierkowski
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 eld 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.	Feb 22nd, 2025		Marcel Skierkowski
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 eld 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.	Feb 22nd, 2025		Marcel Skierkowski

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.	Feb 1st, 2025		Marcel Skierkowski
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.	Feb 3rd, 2025		Marcel Skierkowski
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 eld of view.	1) Deploy the ASV on the water and put some objects in its eld of view. 2) Compare the number of detected objects with the true number of course objects.	Feb 22nd, 2025		Marcel Skierkowski
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 eld of view. 2) Identify false detections by using map of the competition course and video recordings from ASV.	Feb 22nd, 2025		Marcel Skierkowski
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 eld of view. 2) Compare assigned labels to human-assigned ones	Feb 22nd, 2025		Marcel Skierkowski
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.	Feb 1st, 2025		Marcel Skierkowski
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.	Feb 22nd, 2025		Marcel Skierkowski
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.	Feb 24th, 2025		Igor Rusiecki
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.	Feb 24th, 2025		Igor Rusiecki
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 re command. 3) Observe the RDM. 4) Repreat two times.	Feb 24th, 2025		Igor Rusiecki
F4.1	To deliver racquetballs to anchored, black boats	REQ-075	The RDM must not ll with water during rainfall.	1) Place RDM under o shower. 2) Slightly turn on the water and aim at the RDM from the top.	Feb 24th, 2025		Igor Rusiecki
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.	Feb 24th, 2025		Igor Rusiecki
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.	Feb 22nd, 2025		Igor Rusiecki
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.	Feb 16th, 2025		Igor Rusiecki