Roboboat 2025: 'Mandakini Zenith' Technical Design Report

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***Abstract*—This paper explains the strategy for developing the Mandakini Zenith boat to complete all 2025 International Roboboat Competition (IRC) missions. Development is carried out in control algorithms, fusion sensors, hull types, frame design, and object detection. Testing from the development is carried out by experimental methods, simulations, and direct testing on the lake. Based on the results of the tests and simulations that have been carried out, Mandakini Zenith is considered capable of completing all missions in IRC 2025.**

***Keywords*—ASV, ROS, round hull, sensor fusion, LiDAR, GPS**

I. COMPETITION STRATEGY

A. General Strategy

This year, Mandakini Zenith (2025) uses a modular system like its predecessors Mandakini Catra (2023) and Mandakini Hydra (2024) to facilitate travel and mobility [1]. This year's development is focused on the hull type, a combination of object detection algorithms with LiDAR sensors, azimuth propulsion, power monitoring, and object delivery mission mechanisms.

The hull is a round type, considering better stability [2]. The composition of the composite material used is not much different from the Mandakini Hydra because the composition is good in terms of weight and strength [1]. To improve the ability to complete missions, a combination of YOLOv4 object detection and LiDAR is used as an avoidance sensor called a fusion sensor [3].

As an evaluation from 2024, the team added a component box to separate the main component from the power component placed on the front of the boat to make it easier to perform power maintenance and reduce signal interference in the Global Positioning System (GPS). Additionally, the team increased the frame height to prevent water from entering the component box.

B. Task Completion Strategy

At the 2025 International Roboboat Competition (IRC), Mandakini Zenith is designed to complete all missions in the sequence of mission completion, as shown in Figure 1.

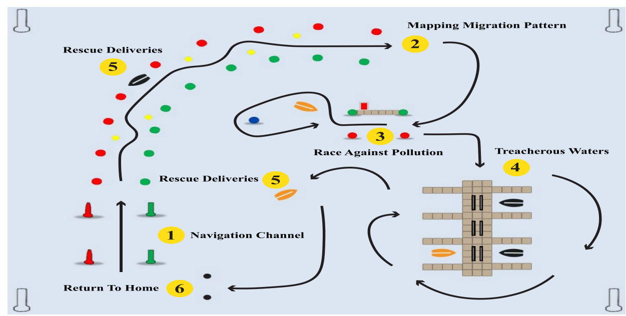


Figure 1. Autonomy Challenge Task [4].

The top priorities to complete are the Navigation Channel, Mapping Migration Patterns, Race Against Pollution, and Return to Home missions. Treacherous Waters will be the second priority, and Rescue Deliveries will be the third priority.

Before initiating the mission, all sensors on the boat are activated and connected to a computer system. The data collected by the sensors is transmitted to the mini-PC for processing. The processed data is then sent to the microcontroller, which controls the supporting components responsible for executing each mission. Figure 2 illustrates the diagram of Mandakini Zenith's autonomous control and navigation system.

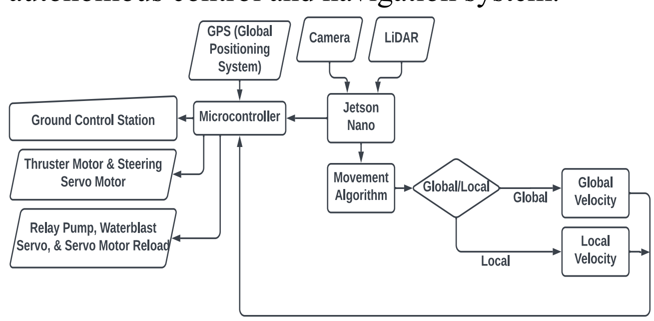


Figure 2. Control and Navigation System Diagram on Mandakini Zenith.

1) Navigation Channel

The team developed a stable navigation system using waypoints for the entrance gate buoy. It implemented the detection of the exit gate buoy through four defined Regions of Interest (ROIs), called conditioning areas, to prevent collisions. These ROIs guide navigation by determining the boat's response based on the position of the buoys relative to its current location, ensuring precise and adaptive maneuvers. Additionally, LiDAR is employed to detect objects when the camera cannot do so, enabling the boat to navigate through the buoys optimally.

2) Mapping Migration Patterns

In the Mapping Migration Patterns mission, the team developed navigation similar to the Navigation Channel, utilizing eight ROIs to estimate the distance and position of the buoys. The team also added an algorithm to calculate the number of yellow buoys according to the second method in the reporting guidelines, with the results directly displayed on the Ground Control Station (GCS) operator's screen for easy monitoring and verification [4].

3) Treacherous Waters

Mandakini Zenith uses waypoints to approach the docking area and detect objects based on a detection model trained according to the guidebook. The boat searches for an empty docking space with a suitable object, avoiding other boats if the space is already filled. LiDAR detects empty dock areas, steers the boat without striking the wall, and stops the boat movement when reaching the correct position.

4) Race Against Pollution

The team uses the waypoint at the entrance gate to guide the boat's movement. After stopping at the holding bay, the camera scans and monitors the light panel until it turns green. Once detected, the boat proceeds to a waypoint near the blue buoy, maneuvers around the buoy, and returns to the gate following the designated route. As in the second mission, the team also added an algorithm to avoid black buoys (oil spills).

5) Rescue Deliveries

In the Rescue Deliveries mission, the team used object tracking to find the coordinate value of the object in the camera. Then, the value is converted to the Pulse Width Modulation (PWM) value. This value was sent to the microcontroller to trigger the actuator to hit the target as detected.

6) Return to Home

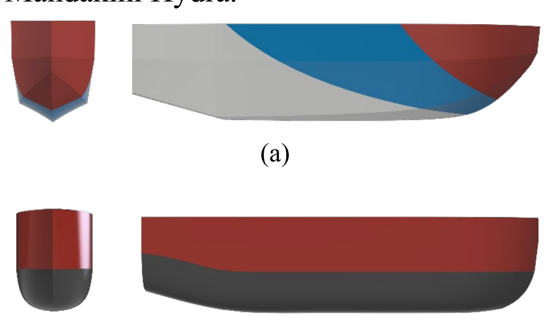
In the Return to Home mission, Mandakini Zenith saves the starting point coordinates to ensure the boat returns accurately after completing all missions. The team also developed a black buoy detection program so that the boat could precisely recognize and pass the buoys.

II. Design Strategy

A. Hull and Frame Design

This year, the Mandakini Zenith hull is a round, semicircular, or curved displacement hull that prioritizes buoyancy [2]. The team uses a round hull because it is stable and can slide smoothly on the water. In addition, round hulls are very suitable for boats that move at low speeds and carry heavy loads [5]. Furthermore, the team continues to implement a catamaran hull to further enhance boat’s stability and performance in withstanding wave impacts [6].

The dimensions and composition of the composite material used in the Mandakini Zenith hull are similar to those of the previous boat, as they are deemed optimal. The hull is made from a mixture of polyester resin and aerosil, reinforced by three additional layers of fiberglass. Figure 3 compares the hull shapes of the Mandakini Zenith and Mandakini Hydra.

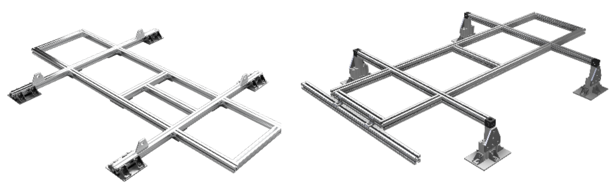


(a)

(b)

Figure 3. (a) Hull Mandakini Hydra (2024); (b) Hull Mandakini Zenith (2025).

The Mandakini Zenith has a different frame shape this year. There are additional elbow-shaped masts at all four ends of the frame, so it is higher than the previous boat. This is because of the evaluation from last year, where waves that are too high can reach the top of the component box and endanger the safety of the electronic components inside. The difference between the Mandakini Zenith and Mandakini Hydra frames is shown in Figure 4.

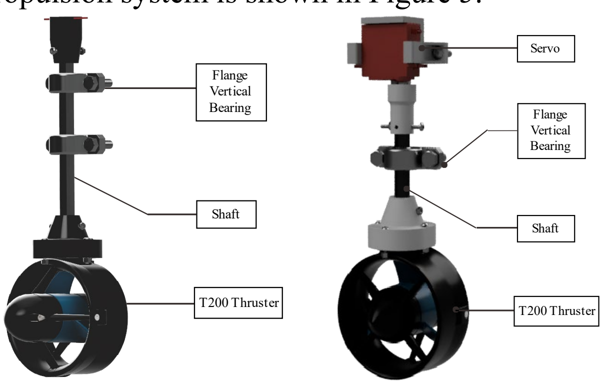


(a) (b)

Figure 4. (a) Mandakini Hydra Frame (2024); (b) Mandakini Zenith Frame (2025).

B. Propulsion

Mandakini Zenith uses a T200 thruster that is azimuth-mounted in the stern of the boat. Each T200 thruster is mounted on a 15 mm diameter aluminum shaft connected to a servo motor. To increase the effectiveness of the propulsion system, the shaft is connected directly to the servo motor using only one bearing flange [7]. The thruster's position is also closer to the hull, increasing thrust efficiency (Appendix I). The CAD of the propulsion system is shown in Figure 5.



(a) (b)

Figure 5. (a) Mandakini Hydra Propulsion (2024); (b) Mandakini Zenith Propulsion (2025).

C. Controls System

The team used Pixhawk Cube Orange to control the boat's motion system with a PWM signal, where commands for the boat's movement were received from a computer. In addition, the team also uses GPS to determine the boat's position based on longitude and latitude coordinates as a reference for movement according to the trajectory.

This year, the team developed a method of controlling the boat by integrating the Robot Operating System (ROS) and MAVLink for command delivery. ROS offers a service-based approach that supports distributed system development [8]. Thus, this modification provides a significant advantage in developing, troubleshooting, and simulating the boat's movements. This approach makes the control system more flexible and efficient than previous methods that relied solely on pyMAVLink.

Using ROS, boat control becomes more efficient and easier to develop because it allows the simultaneous integration of various data sources, such as cameras, LiDAR, and Pixhawk. This facilitates faster and more accurate information processing for optimal boat navigation and control.

The team also implemented Proportional Integral Derivative (PID) control and adjusted the ground speed and steering rate according to each mission's needs. This implementation is optimized to achieve more accurate maneuvers and fulfill each mission's specific requirements.

D. Object Detection

The YOLO algorithm can process images in a single pass, which makes it very efficient in detecting objects in real-time. The Darknet framework also allows for flexible configurations such as grid size settings and bounding boxes, which are very useful in situations requiring high speed and accuracy [9]. The detection result of the YOLOv4 algorithm is shown in Figure 6.

Figure 6. Detection Result YOLOv4.

Object detection speed and accuracy are essential to developing a boat maneuver against an object. YOLO Darknet provides significant advantages in both aspects, allowing Mandakini Zenith to respond to obstacles faster and more precisely than the MobileNetv2 SSD used in the Mandakini Hydra (2024).

E. Communication

Previous year, the communication system used a Wi-Fi adapter for communication between the boat and the GCS but faced signal interference, which resulted in high latency and disrupted the smooth operation of the boat. To improve the reliability of the communication connection, the team implemented a point-to-point protocol, connecting Wi-Fi devices with directional antennas on the ground and omnidirectional dual-band antennas on the boat. The omnidirectional dual-band antenna offers the advantage of producing a stable radiation pattern across the entire operating frequency band, thus supporting a more reliable connection [10].

F. Electrical System

Mandakini Zenith's electrical system utilizes a power distribution box with two terminal blocks and a DC-to-DC converter to distribute power to the main box (Pixhawk, Jetson, Telemetry, etc.). The propulsion system uses power directly from a separate Li-Po battery. The team also added a voltage sensor to determine the battery voltage left on the boat. The voltage sensor is connected to the Arduino to transmit the battery voltage data to the Pixhawk. The diagram of Mandakini Zenith's electrical system can be seen in Figure 7.

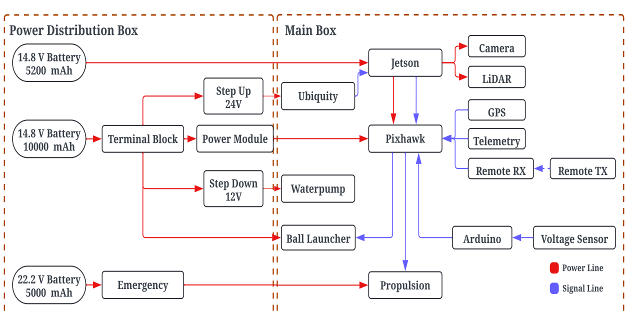


Figure 7. Electrical System Diagram of Mandakini Zenith.

As for the emergency system, Mandakini Zenith still uses the same emergency scheme as last year because it is considered adequate in its use as a boat security system. This emergency is custom-made, and the propulsion system can be turned off in an emergency through a push button or a remote switch. The overall diagram of the Mandakini Zenith's electrical system can be seen in Appendix E.

G. Object and Water Delivery Mechanism

The object delivery mission uses a flywheel-based mechanism with a launch mechanism of two rubber wheels rotating in opposite directions to throw the ball. The reload system features a queue and release mechanism, employing three servo motors to manually load three balls before use, and one additional servo motor for the release function, integrated with the launcher. The design of this system is shown in Figure 8.

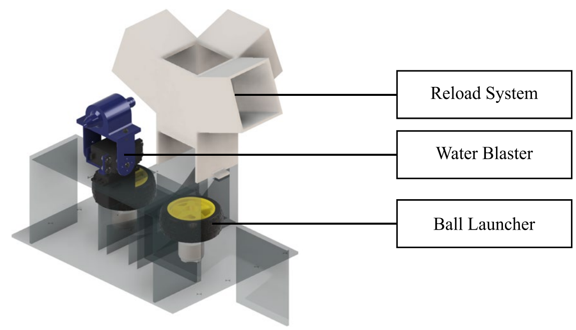


Figure 8. CAD Object Delivery and Water Delivery.

Mandakini Zenith uses the exact water delivery mechanism as Mandakini Hydra (2024) because the system is considered adequate to complete the mission.

III. TESTING STRATEGY

A. Hull and Frame Simulation

The Mandakini Zenith hull has been simulated using ANSYS Aqwa and Maxsurf Stability to ensure optimal performance during missions.

The team conducted simulations in ANSYS Aqwa to determine the Mandakini Zenith hull's Response Amplitude Operator (RAO). RAO refers to the movement of a floating boat within six degrees of freedom due to hydrodynamic wave excitation [11]. Table 1 compares the RAO simulation of Mandakini Zenith and Mandakini Hydra using a frequency of 3.691 rad/s.

Table 1. RAO Simulation Results.

Type	Roll RAO	Heave RAO	Pitch RAO
Mandakini Zenith	0.7612	0.9654	0.7790
Mandakini Hydra	0.7630	0.9656	0.7913

Based on Table 1, the values for roll, heave, and pitch at a wave frequency of 3.691 rad/s, with a head wave of 180º for pitch and heave and 90º for roll, are better for the round hull than for the V hull. Following the RAO simulation, a stability simulation was conducted. The results of the stability simulation are shown in Figure 9.

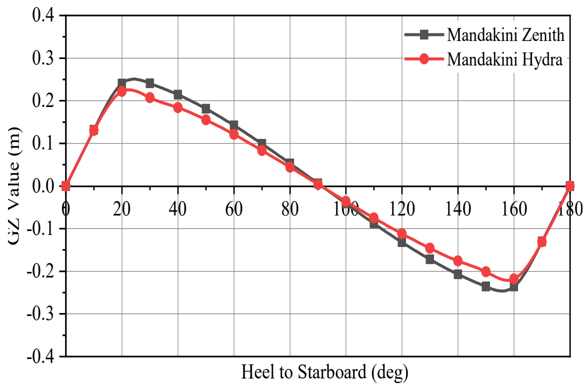


Figure 9. Stability Simulation Results.

Stability refers to the ability of a boat to return to its original position after an external impact [12]. Based on Figure 9, the Mandakini Zenith has a maximum GZ Arm at an angle of 30° of 0.241 m, while the maximum value of the GZ Arm Mandakini Hydra at 20° is 0.222 m. At the maximum value, the difference in the value of the GZ Arm is 0.019 m, and at an angle of 30°, the difference in the value of the GZ Arm is 0.034 m.

Mandakini Zenith's frame was analyzed using Fusion 360 software. The analysis method used is static stress simulation by applying an axial load evenly on the entire upper surface of the frame of 60 N, which is the estimated weight of the total components. Table 2 compares the frame simulation results of the Mandakini Hydra and Mandakini Zenith.

Table 2. Frame Simulation Results.

Type	Reaction Force (N)	Von Mises Stress (MPa)	Yield Strength (MPa)
Mandakini Hydra (2024)	1354.136	9.497	290
Mandakini Zenith (2025)	22059.875	5.362	290

The results in Table 2 show that this year's reaction force value is more prominent, indicating a better force distribution. In addition, the von Mises stress value is smaller, so it has a larger margin of safety [13]. More complete results can be seen in Appendix H.

B. *Communication Testing*

The team conducted the test by placing the vessel 100 m from the GCS to measure the communication latency. The results of the latency measurement are presented in Figure 10.

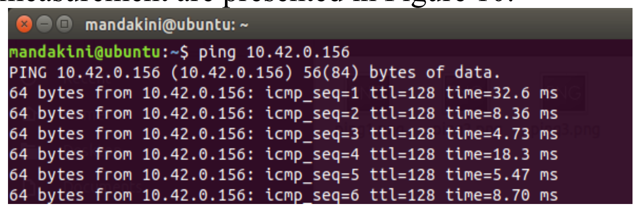


Figure 10. Latency Testing Results.

Figure 10 shows the results of the communication test between GCS and the boat, which are entirely satisfactory. The team's network testing obtained a latency value of 4 – 32 ms. Based on these values, it can reduce the potential for lagging and lost connections during boat monitoring [14].

C. *LiDAR Testing*

LiDAR testing is carried out directly by testing the accuracy of the LiDAR by comparing the LiDAR value with the actual distance. This test was carried out ten times using ten variations of the actual distance in the 10 cm - 100 cm range, with an interval of 10 cm. The results of the LiDAR accuracy test are shown in Figure 11.

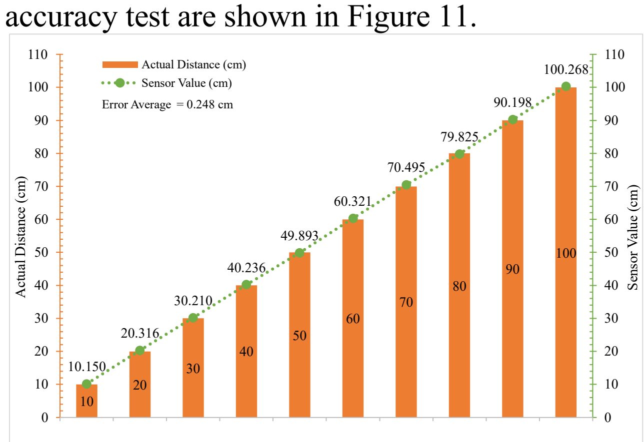


Figure 11. LiDAR Testing Results.

Based on the test results, the average error value between the actual distance and the sensor value is 0.248 cm. To overcome this error, adjustments have been made to the detection program to change the error value in the detection results.

D. *Object Detection*

Various architectural models have been used to develop object detection using the Jetson Nano. Table 3 presents the test results of these models.

Table 3. Architecture Models Test Results.

Model Architecture	Framework	mAP	FPS
Mobilenet_v1 TRT	Pytorch	0.351	27.7
Mobilenet_v2 TRT	Pytorch	0.376	42.0
YOLOv4	Darknet	0.895	23.0

Based on the test results, YOLOv4 was chosen because it has a higher mean Average Precision (mAP) value than other models, which reaches 89.5%. A high mAP value indicates better accuracy in detecting and classifying objects [15]. Although the other two models have higher FPS values, accuracy is more important. Thus, YOLOv4 provides the best balance between high accuracy and real-time performance, making it an ideal choice for completing all missions.

E. *Safety and Power Durability*

The boat's safety tests include the emergency remote switch, signal loss failsafe, and physical switch, which successfully shut down the propulsion while the boat is in operation. The relay endurance was tested to withstand the current to the propulsion system.

Power durability tests indicate that the boat can complete the mission within 40 minutes. The boat utilizes various batteries for propulsion, control systems, and the Jetson module. The safe voltage limit for each battery cell is 3.7V. With the throttle set at 60%, 10 mission repetitions reduced the voltage from 4.20V to 3.7V, with an average completion time of 4 minutes.

F. *Object Delivery*

Object delivery uses a flywheel-based system, where two wheels rotate opposite directions to launch the ball. The test uses a 6 cm diameter wheel and a 1400 kV motor, with three PWM signal-controlled motor speed variations, to determine the maximum distance, as shown in Table 4.

Table 4. Object Delivery Testing Results.

Motor (PWM)	Result (meter)	Vibration status
1100	0.6	Stable
1200	1.0	Stable
1250	1.4	Unstable

The results of this test prove that the motor's speed can affect the ball's distance and provide vibration. The PWM value 1200 was chosen to complete the Object Delivery mission because it provides sufficient distance with stable vibration.

IV. Conclusion

The Mandakini Zenith is designed as a modular boat that prioritizes efficiency, stability, and ease of maintenance. Significant improvements to the propulsion system are made with a new azimuth configuration, ROS-based control integration for adaptive navigation, and point-to-point communication protocols that ensure a stable connection during operation. The development of the flywheel system on the object delivery mission and the XY robot arm mechanism for water delivery provides high accuracy in the implementation of the Rescue Deliveries mission. A better RAO value compared to the Mandakini Hydra showed an increase in the boat's stability. In contrast, the GZ stability test at 30° resulted in a maximum value of 0.241 m, which was higher than its predecessor.

Extensive testing on navigation, control, and object detection systems proved a 51.9% increase in accuracy through the YOLOv4 model, which provides the best balance between precision and real-time performance. The optimal PWM value on object delivery testing ensures efficient launch with stable vibration. Overall, Mandakini Zenith's design improved reliability and efficiency, preparing the boat to effectively complete the entire mission of the competition.

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Appendix A: Component Specifications and Bill of Material

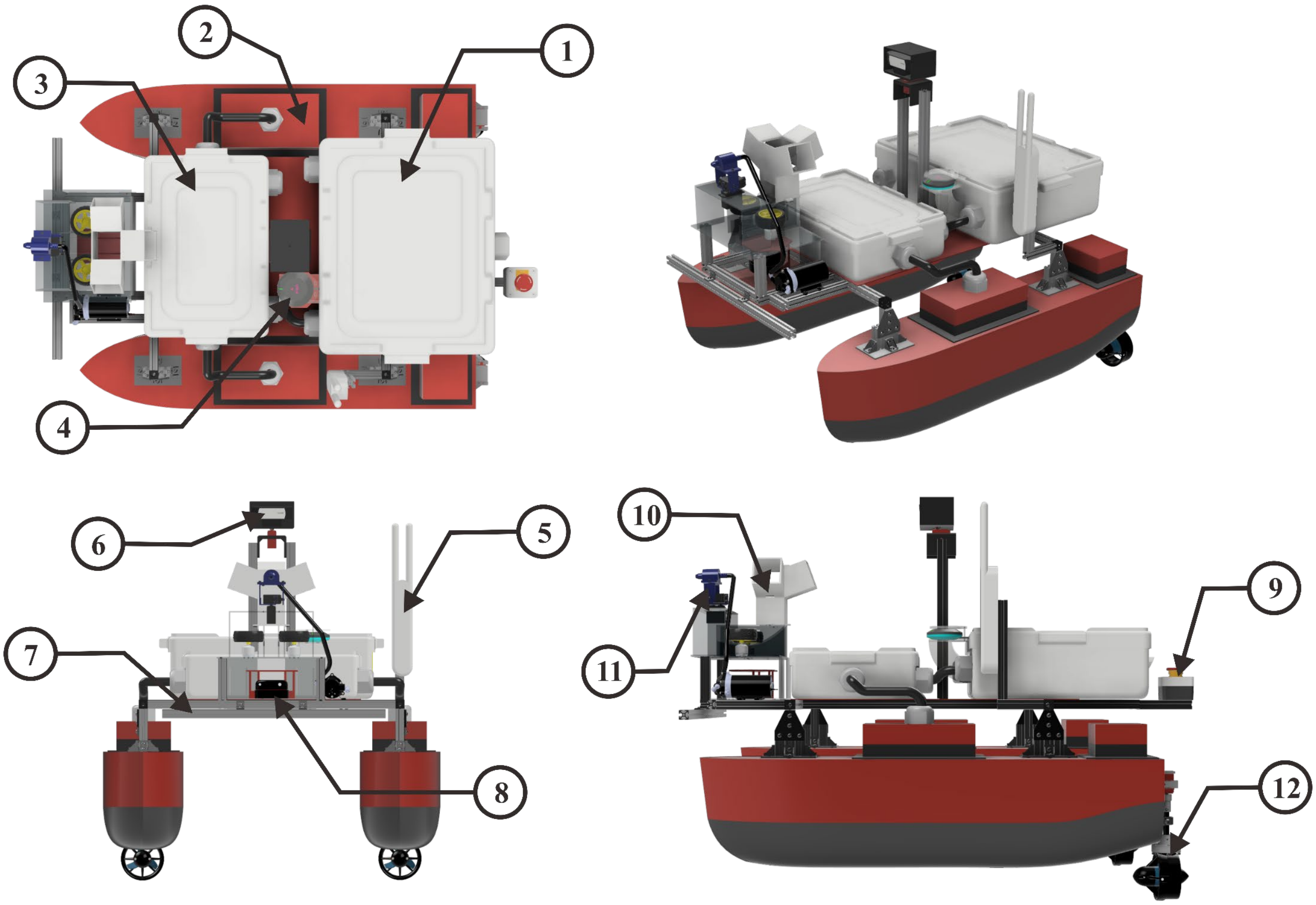
Table A-1. Component specifications and bill of material

Components	**Vendor**	**Model/Type**	**Specs**	**Custon/Purchased**	**Cost**	**Year of Purchase**
ASV Hull	"Hand Made With Fiberglass"	Catamaran Symmetric	3 Layers of Fiber Glass, LOA:90 Beam:28 Depth:22.	Custom	$75	2024
Frame	Alumunium	Aluminium 2014-T4	Yield Strength = 290 MPa Density = 2.800E-06 kg/mm^3	Custom	$29	2024
Waterproof Connectors	N/A	N/A	N/A	N/A	N/A	N/A
Propulsion	Blue Robotics	T200	https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster-r2-rp/	Awarded	-	2023
Power System	Multiple	Li-Po Battery, Terminal Blocks, Converter DC	2x4P 60A Terminal Block	Purchased	$9	2023
Propulsion	Gens Ace	Li-Po Battery	5 Ah, 75C, 25.2 V	Purchased	$100	2024
Control	Tattu	Li-Po Battery	10 Ah 25C, 16.8 V	Purchased	$125	2023
Mini PC	Tattu	Li-Po Battery	5.2 Ah 35C, 16.8 V	Purchased	$69	2024
GCS	Tattu	Li-Po Battery	5.2 Ah 35C, 16.8 V	Purchased	$69	2024
Motor Controls	Blue Robotics	Basic ESC 30 A	30 A, 25 V Max	Awarded	-	2023
CPU	Nvidia Developer	Jetson Nano	https://www.seeedstudio.com/Jetson-10-1-H0-p-5335.html	Purchased	$400	2023
Radio Telemetry	Custom 3DR Robotic	3DR Radio Telemetry	915 MHz, -121dBm, 100mW	Custom	$126	2024
Communication	Ubiquiti	Unifi AC Mesh UAP-AC-M	https://techspecs.ui.com/unifi/wifi/uap-ac-mesh	Purchased	$160	2024
GPS and Compass	Matek	M10 L4 3100	https://www.mateksys.com/?portfolio=m10-l4-3100	Purchased	$120	2023
Internal Compass	Cubepilot	Cube Orange	https://docs.px4.io/main/en/flight_controller/cubepilot_cube_orange.html	Purchased	$320	2023
Inertial Measurement Unit (IMU)	Cubepilot	Cube Orange	https://docs.px4.io/main/en/flight_controller/cubepilot_cube_orange.html	Purchased	$320	2023
Doppler Velocity Logger (DVL)	N/A	N/A	N/A	N/A	N/A	N/A
LiDAR	RPLiDAR	A2M12	https://www.slamtec.com/en/Lidar/a2	Purchased	$190	2024

Camera(s)	Logiteh	C922 Pro	https://www.logitech.com/id-id/products/webcams/c922-pro-stream-webcam.960-001090.html?srsltid=AfmBOopRGTdmKkU7OEIA8GQa1kc88I-IShpktvBEmAjGbZbY1eKxR-hJ	Purchased	$82	2024
Water Blast Pump	Sakai	N/A	12 V 3 A	Purchased	$20	2023
Microcontroller	Arduino	Arduino Nano	https://store-usa.arduino.cc/products/arduino-nano?srsltid=AfmBOopvDSQBWgWdCZ6LSxcbLllDnBT5U7PDLa9kBatBX9-xAyqzIELX	Purchased	$24.90	2023
Object Delivery Reload	Tower Pro	Tower Pro SG90	Operating Volt = 4.8 V (1.8 kg/cm) Dimensions 22.2 × 11.8 × 31 mm Weight = 9g	Purchased	$2	2024
Emergency Relay	HKE	CMA31C	Voltage = 12 V Max Current = 40 A	Purchased	$6	2023
Manual Operation	FLYSKY	FSIA6B	https://www.flysky-cn.com/fsi6	Custom Firmware	$30	2022
Hydrophones	N/A	N/A	N/A	N/A	N/A	N/A
Algorithms	Bengawan UV	Custom	N/A	Custom	N/A	N/A
Vision	N/A	OpenCV, YOLOv4 Darknet	N/A	Custom	N/A	N/A
Localization and Mapping	Bengawan UV	Custom Sensor Fusion	N/A	N/A	N/A	N/A
Autonomy	Bengawan UV	Custom Bug Algorithm	N/A	Custom	N/A	N/A
Open Source Software	N/A	ROS, OpenCV, Ubuntu18.04, YOLOv4, Mision Planner, U-Center	N/A	N/A	N/A	N/A
Engineering Simulation and Design Software	Autodesk	Fusion 360	N/A	Free Student License	N/A	N/A
Navigation Simulation Software	Ardupilot	Mission Planner	N/A	Opensource License	N/A	N/A
Design Software	Maxsurf	Maxsurf Modeller	N/A	Collaboration Lcense	N/A	N/A
Engineering Simulation Software	ANSYS Inc.	Ansys Aqwa	N/A	Faculty License	N/A	N/A

Appendix B: Mechanical Design

A. Assembly Design



B. Disassembly Design

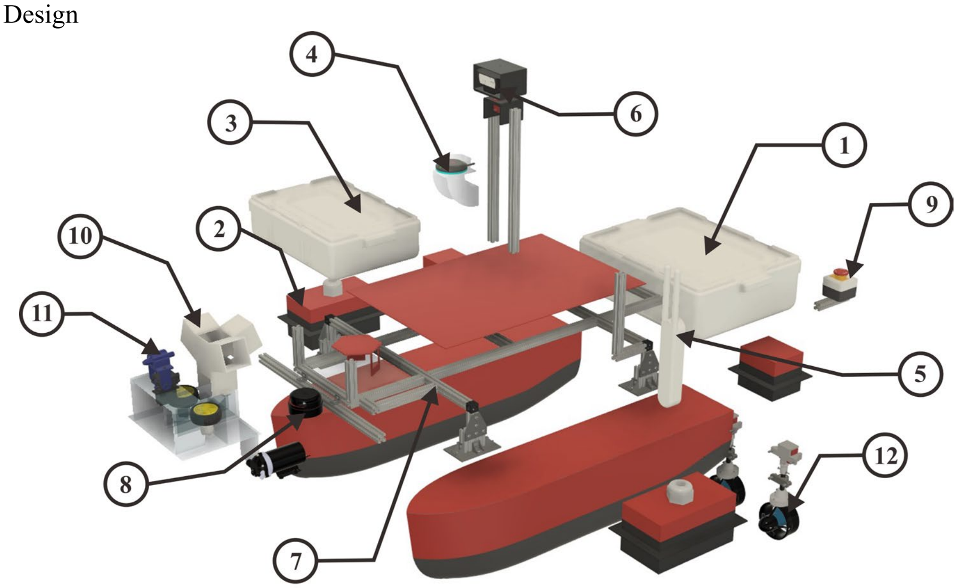


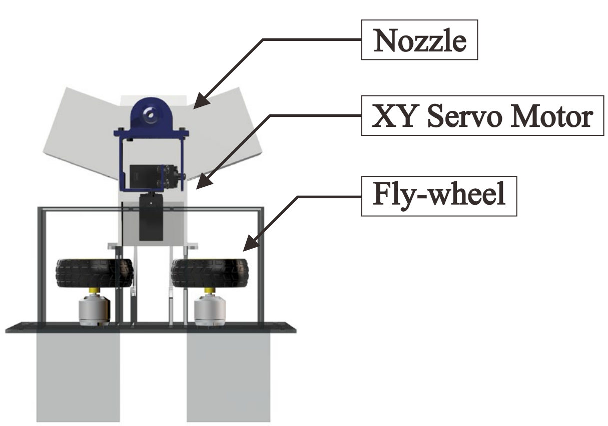
Table B-1. Mandakini Zenith Part Lists

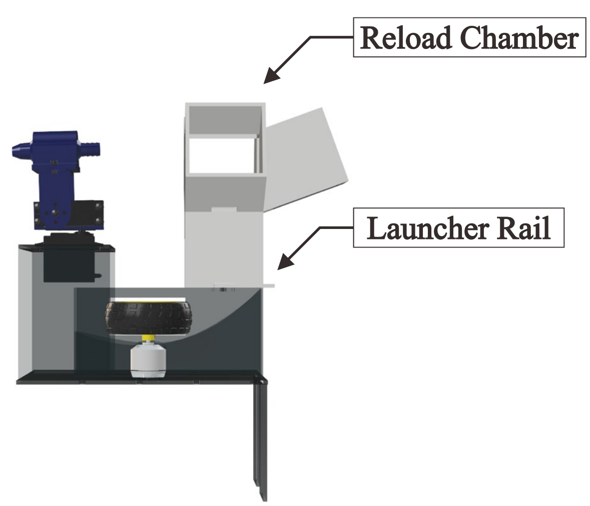
Item	Part Name	Qty.
1	Main Box	1
2	Battery Box	2
3	Power Distribution Box	1
4	GPS	1
5	Router	1
6	Camera	1
7	Aluminium Profile 2020	31
8	LiDAR	1
9	Emergency Button	1
10	Ball Launcher	1
11	Water Blaster	1
12	T200 Thruster	2

Table B-2. Mandakini Zenith Principal Dimension

No.	Parameters	Value
1	Length Overall (LOA)	0.92 m
2	Beam Overall (B_{OA})	0.73 m
3	Demihull Beam (B)	0.18 m
4	Depth (D)	0.22 m
5	Draft (D_{WL})	0.12 m
6	Displacement	30.19 kg
7	Length Waterline (L_{WL})	0.907 m
8	Demihull Spacing (S)	0.55 m
9	Block Coefficient (C_B)	0.752
10	Wetted Area	0.62 m^2

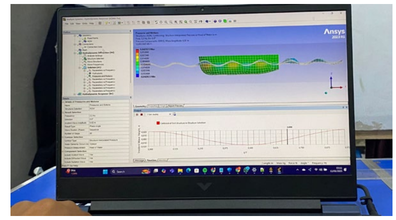
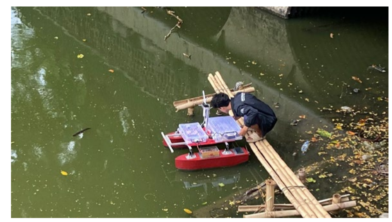
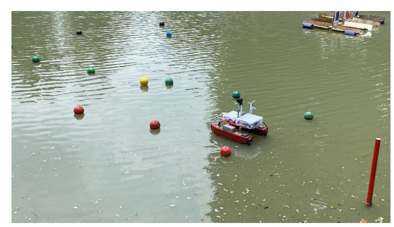
C. Ball Launcher and WaterDelivery Design

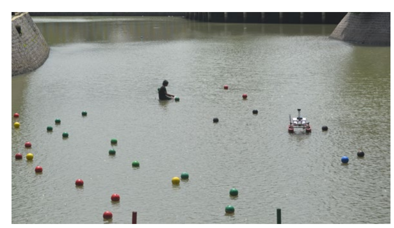




APPENDIX C: TEST PLAN AND DOCUMENTATION

Table C-1 Test Plan Details

Date	Target	Result	Location	Documentation
09/23/24 – 09/28/24	1. Object Detection Algorithm Decision 2. FPS and mAP Checking 3. Simulation of Stability, RAO, and Resistance using ANSYS Aqwa and ANSYS Fluent	Obtained the YOLOv4 algorithm with 64.4% mAP and achieved results in stability, RAO, and resistance.	Bengawan UV Workshop	
08/01/24 – 08/05/24	1. Bouyayncy test 2. Propulsion test 3. Maneuver test	Mandakini Zenith can float safely, the propulsion generates a thrust of 13 kg, and vessel can maneuver well.	Universitas Sebelas Maret Lake Facility	
08/07/24 – 08/12/24	1. Navigation system simulation testing 2. PID Simulation	Obtained the PID values to be used for Mandakini Zenith.	Bengawan UV Workshop	
08/14/24 – 08/19/24	Navigation Channel and Mapping migration patterns mission testing	1. The program implemented on Mandakini Zenith successfully executed motion commands during the Navigation Channel mission. 2. Mandakini Zenith effectively detected ball obstacles and completed Mapping migration patterns mission.	Bengawan UV Workshop	
08/28/24 – 11/02/24	LiDAR testing for treacherous waters mission	Mandakini Zenith is able to measure the distance to the docking area with precision.	Bengawan UV Workshop	

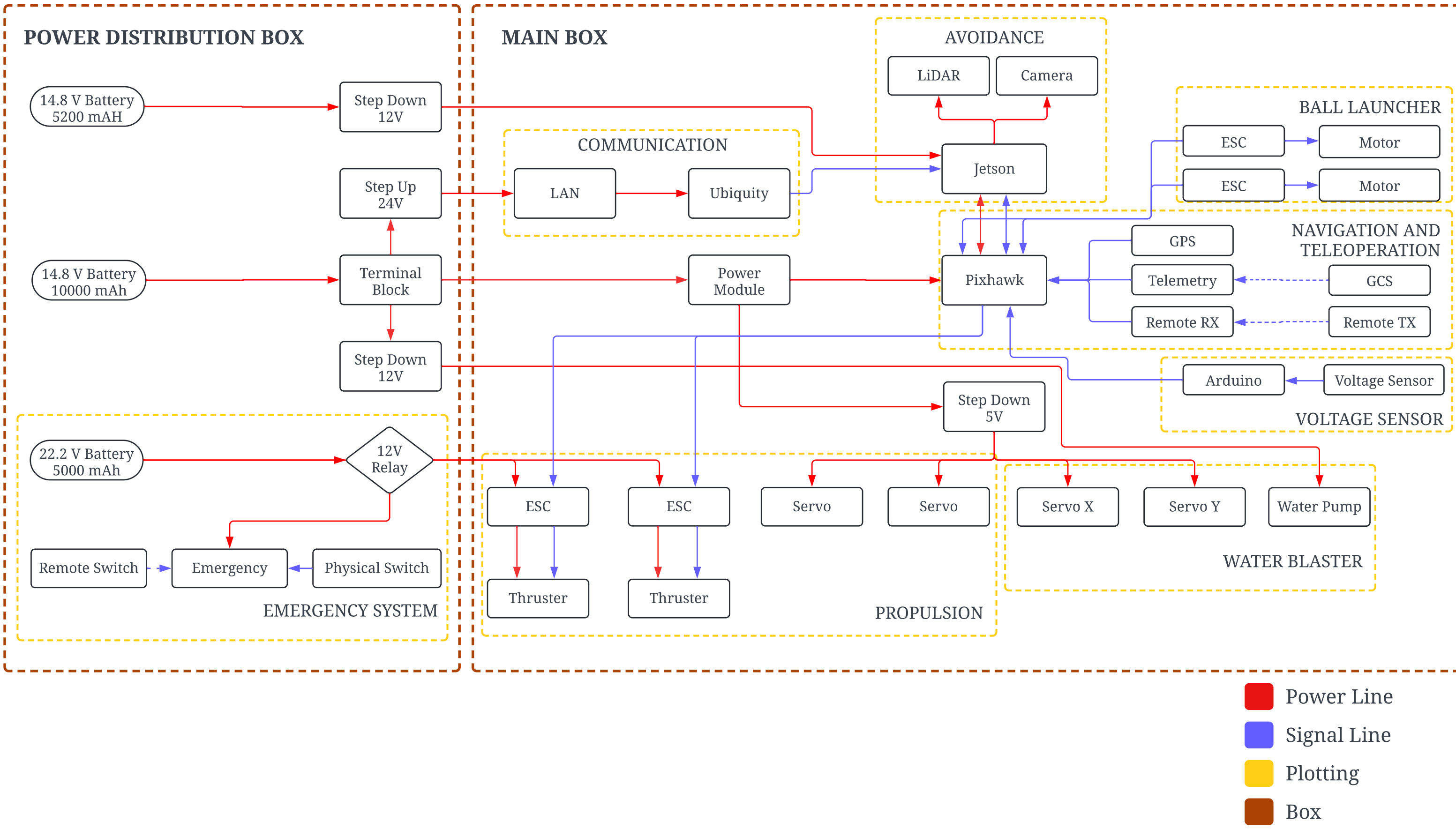
11/04/24 – 11/16/24	Treacherous waters mission testing	Mandakini Zenith entered the right docking area with precision.	Universitas Sebelas Maret Lake Facility	
11/18/24 – 11/23/24	1. Testing the X-axis camera servo mechanism. 2. Simulation of Race against pollution mission	1. The camera servo can move to assist the camera in monitoring the light panel located beside the vessel. 2. The object detection system can accurately detect the light panel and black buoys.	Bengawan UV Workshop	
11/25/24 – 12/07/24	Race against pollution mission testing	1. Mandakini Zenith is able to stop at the holding bay and move when the light panel turns green. 2. Mandakini Zenith is capable of navigating around the blue buoy and avoiding the black buoys.	Universitas Sebelas Maret Lake Facility	
12/09/24 – 12/22/24	Testing object and water delivery mechanism and Rescue Deliveries mission testing	Mandakini Zenith is capable of detecting the orange and black vessels and delivering water or a racquetball based on the detected vessel at a distance of approximately 2 meters.	Universitas Sebelas Maret Lake Facility	
01/06/25 – 01/18/25	Full mission testing and simulation	Improving obstacle detection and PID variables is essential to ensure the mission runs optimally.	Bengawan UV Workshop and Universitas Sebelas Maret Lake Facility	

APPENDIX D: RISK MANAGEMENT

Table D-1 Risk Management

No	Risk	Cause	Impact	Impact Level	Probablity	Mitigation Plan	Responsibility
1	Overheating Component	Failing Cooling System	Damaging Component	High	Medium	a. Performe routine cooling system maintenance b. Spare cooling fan	Mechanic Electronics Team
2	Hull Leaking	Hits obstacles	increase the weight of the boat and cause it to sink	High	Low	a. Perfome routine hull check after in-water testing b. Patch the leak as soon as possible	Design Manufacture Team
3	Communcation Failure	Signal interfrence or faulty connectors	Loss of control and monitoring the ASV	High	High	a. Preparing backup system b. Ensure connectors are in good condition	Mechanics Electronics Teams
4	Power Consiumption problem	Bad battery condition, overloaded components	Sudden system shutdown	High	Medium	a. Using higher capacity battery b. Real-time monitoring battery condition	Mechanics Electronics Team
5	Object Detection Inacurracy	Bad camera lighting and bad models trained	ASV cannot performe mission	High	High	a. Using camera filter lens b. Adjusting contrast and brightnessw	Programming Team
6	Navigation and control inacurracy	Electromagnetic Field Interference at sensor, bad connectors, and suboptimal parameters tuning	ASV cannot go to the commanded location	High	High	a. Using electromagnetic shielding b. Comparing simulation parameters with real condition	Programming and Mechanics Electronics Team
7	Trash stuck in the motor impellers	Dirty environment (Sebelas Maret University Lake)	Reduce performance and motor damage	Medium	Medium	a. Covers the thruster b. Performe routine motor maintenance	Mechanics Electronics Team
8	Failure in ball-launching and reload mechanism	Shaking of the ASV, inacurracy timing control	Ball is not launched as intended	High	Low	a. Prepare spare components b. Tuning control parameter	Mechanics Electronics and Programming Team
9	Failure in water blaster system	Hose placement error by ASV Movements and water pum problems	Water is not supplied to the nozzle	High	Low	a. Prepare spare water pump b. Fixed hose placement and length	Mechanics Electronics Team
10	Radio Transmitter signal loss	Low battery in the transmitter	ASV cannot be rescued by manual operator	High	Low	a. Performe routine check battery capacity b. Spare battery for remote control	Driver
11	Weather constraints during testing	Rain	Testing delays and invalid result of testing	High	Medium	a. Monitor weather forecast before testing b. Allocate backup time for testing	Head of Technical

APPENDIX E: ELECTRICAL DIAGRAM AND EMERGENCY SYSTEM



APPENDIX F: ANSYS AQWA SIMULATION

1. Ansys Aqwa Simulation Mandakini Zenith (2025)
   Environment
   Wave Amplitude: 0.02 m
   Wave Frequency: 2.2 Hz
   Wave Direction: 180°

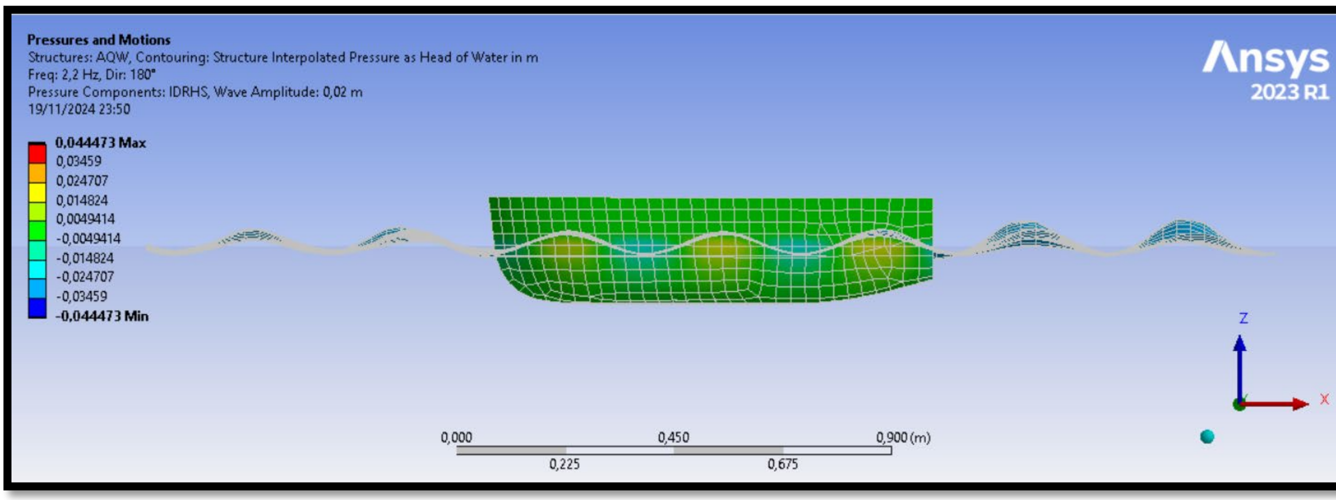


Figure F-1. Ansys Aqwa Simulation Mandakini Zenith

2. Ansys Aqwa Simulation Mandakini Hydra (2024)
   Environment
   Wave Amplitude: 0.02 m
   Wave Frequency: 2.2 Hz
   Wave Direction: 180°

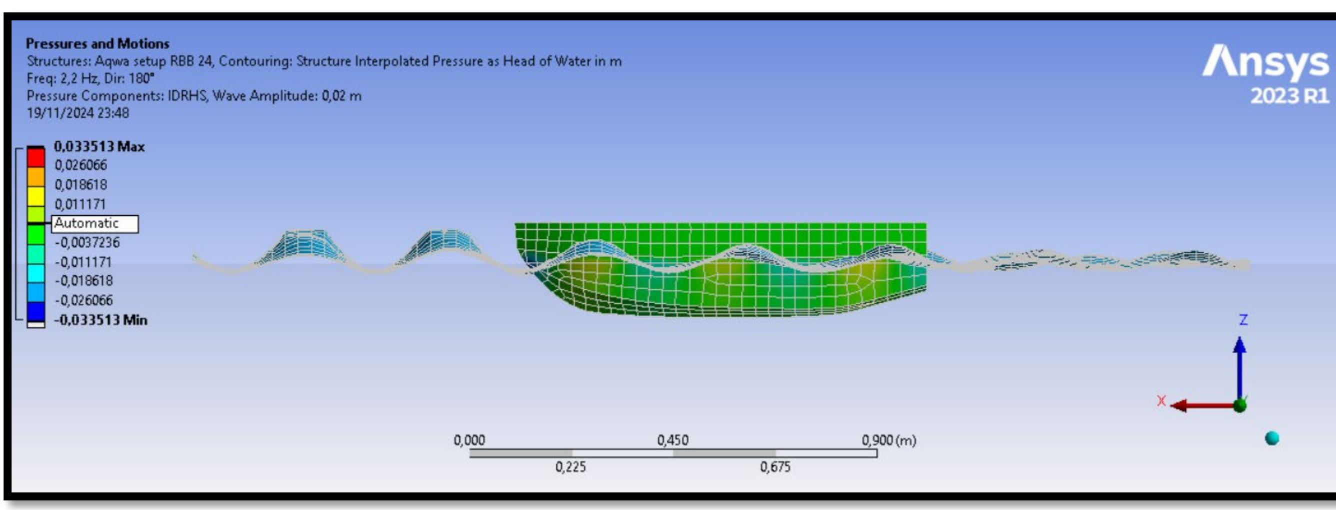


Figure F-2. Ansys Aqwa Simulation Mandakini Hydra

Wave Frequency – RAO Position

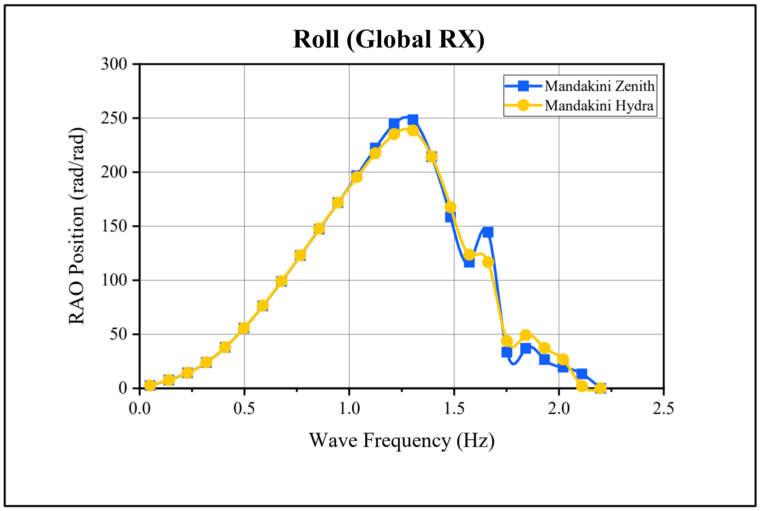


Figure F-3 Roll Result

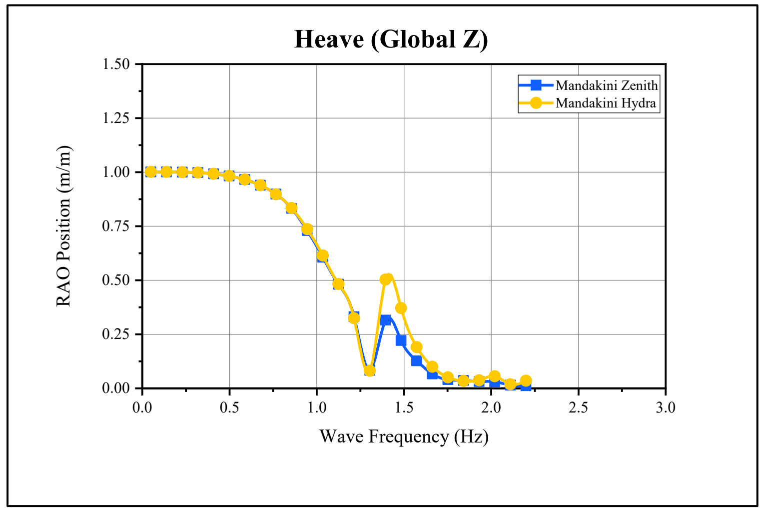


Figure F-4. Heave Result

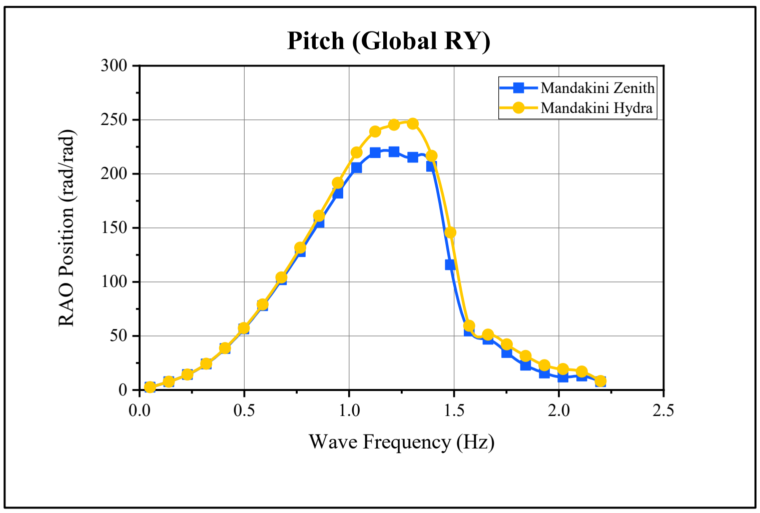


Figure F-5. Pitch Result

APPENDIX G: STABILITY SIMULATION

Table G-1. Stability Simulation Result

Heel to Starboard (deg)	GZ Value (m)	
	Mandakini Zenith	**Mandakini Hydra**
0	0	0
10	0.132	0.13
20	0.24	0.222
30	0.241	0.207
40	0.214	0.184
50	0.181	0.155
60	0.142	0.121
70	0.099	0.083
80	0.053	0.044
90	0.006	0.004
100	-0.041	-0.036
110	-0.088	-0.075
120	-0.132	-0.112
130	-0.172	-0.146
140	-0.207	-0.176
150	-0.236	-0.201
160	-0.236	-0.218
170	-0.13	-0.131
180	0	0

APPENDIX H: FRAME SIMULATION

1. Fusion 360 Simulation Static Stress
   Material Type: Aluminium 2014-T4
   Material Properties:
      Yield Strength = 290 MPa
      Density = 2.800E-06 kg/mm^3

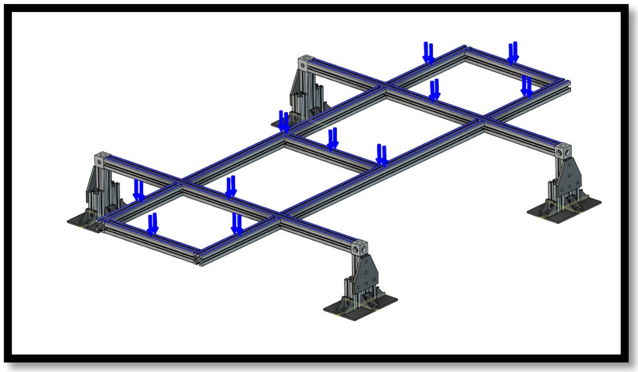


Figure H-1. Axial Force

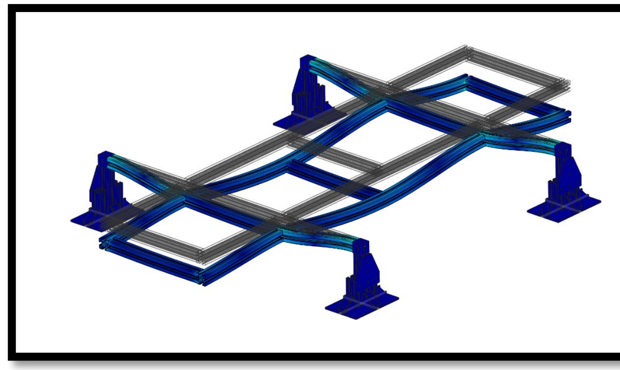


Figure H-2. Von Mises stress

Table H-1. Frame Simulation Results

Parameter	**Value**	
	Minimum	**Maximum**
Axial Force	0	60 N
Reaction Force	0	22059.875 N
Von Mises Stress	0	5.532 MPa
1st Principal Stress	-1.356 MPa	6.155 MPa
3rd Principal Stress	-4.814 MPa	1.29 MPa

Safety Factor:

$$Safety\ Factor\ = \frac{\sigma_y}{\sigma_{vm}}$$

$$Safety\ Factor\ = \frac{290\ MPa}{6.155\ MPa} \approx 47$$

APPENDIX I: THRUST CALCULATION

Thrust Power T200 @16 V:

Full Throttle FWD/REV Thrust @ Nominal (16 V)	5.25 / 4.1 kg f	11.6 / 9.0 lb f

$$T_{max,\ FWD} = 5.25 \times 2 = 10.5\ kg\ f$$
$$T_{max,\ REV} = 4.1 \times 2 = 8.2\ kg\ f$$

Thrust Power T200 @20 V:

Full Throttle FWD/REV Thrust @ Maximum (20 V)	6.7 / 5.05 kg f	14.8 / 11.1 lb f

$$T_{max,\ FWD} = 6.7 \times 2 = 13.4\ kg\ f$$
$$T_{max\ REV} = 5.05 \times 2 = 10.1\ kg\ f$$

Maximum forward thrust using T200 @16 V recorded at Mandakini Hydra (2024):

$$10.2/2 = 5.1 \text{ kg f per thruster}$$
$$\eta = \frac{5.1}{5.25} \approx 97.1\%$$

Maximum forward thrust using T200 @ 20 V recorded at Mandakini Zenith (2025):

$$13.1/2 = 6.55 \text{ kg f per thruster}$$
$$\eta = \frac{6.55}{6.7} \approx 97.7\%$$

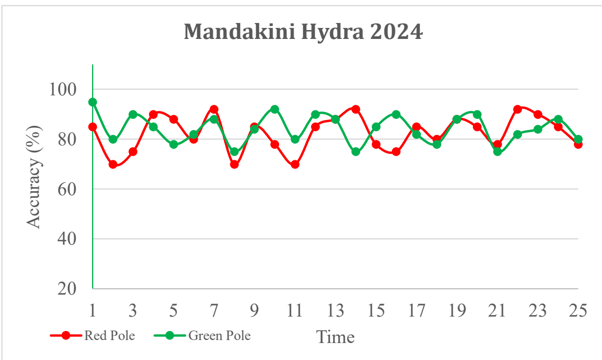
T	=	Thrust
T_{max}	=	Max Thrust
η	=	Efficiency

By raising the thrusters closer to the hull, the reduction in hull resistance can improve thrust efficiency.

APPENDIX J: OBJECT DETECTION AND COMPUTER VISION TESTING

Figure J-1. Mandakini Hydra 2024

Figure J-2. Mandakini Zenith 2025



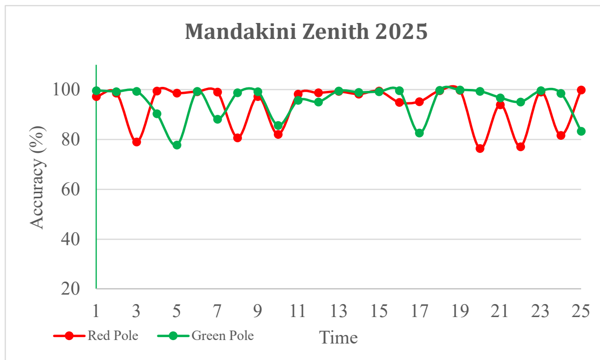


Figure J-3. Accuracy of Object Detection to Pole