RoboBoat 2026: 'Mandakini Raiden' Technical Design Report

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***Abstract*—This report presents Mandakini Raiden, an autonomous surface vehicle strategically designed for the RoboBoat 2026 "Storm Response" theme. The competition strategy directly shaped critical engineering decisions: a flared flat-hull catamaran addresses wave-handling challenges, epoxy-resin VIP manufacturing reduces weight while enhancing maneuverability, and RTK-GPS integration achieves centimeter-level positioning for precise navigation. The system architecture systematically links task requirements to technical implementations: YOLO-LiDAR sensor fusion enables adaptive waypoint generation and obstacle avoidance, coordinate transformation supports dynamic maneuvering in Emergency Response Sprint, and FSM-based control with fused camera-LiDAR manages autonomous docking in Navigate the Marina, both at Disruptive level. A multi-stage testing strategy progressively validates the design from component-level verification through SITL simulation and off-water integration to on-water autonomous operation. This systematic linkage between competition objectives, engineering decisions, and validation methodology positions Mandakini Raiden for comprehensive RoboBoat 2026 task readiness.**

***Keywords*—Autonomous Surface Vehicle (ASV), RoboBoat 2026, Hull Design, RTK-GPS Navigation, Sensor Fusion, Object Detection, Vacuum Infusion Process (VIP)**

I. Competition Strategy

A. General Strategy

The 2026 RoboBoat competition theme was "Storm Response," leading the team to develop Mandakini Raiden (Fig. 1). The boat resulted from an iterative design process, with ongoing enhancements to the hull and structure, manufacturing techniques, perception and navigation systems, and the integration of a high-accuracy Real-Time Kinematic (RTK) and Global Positioning System (GPS). Due to budget constraints, the team opted to deploy a single boat instead of multiple platforms, while optimizing it to be versatile enough for various competition tasks. To ensure strong overall performance, the team aimed for the Disruptive level on Tasks 3 and 5, the Advanced level on Tasks 2 and 4, and the Core level on Tasks 1 and 6. For Task 6, the focus was on minimal completion to keep the system simple and avoid unnecessary complexity.

Fig. 1. 3D design of Mandakini Raiden

The evaluation of Mandakini Zenith (2025) showed that the boat had difficulty handling waves [1]. To address this issue, Mandakini Raiden (2026) adopts a flared flat hull design to reduce water resistance. Flat hulls are less stable than round hulls; however, this was compensated for by increasing the hull beam [2]. The team also reduced weight through material selection and manufacturing process optimization. Mandakini Raiden was constructed using epoxy resin and the Vacuum Infusion Process (VIP). Epoxy resin enhances interlayer bonding, while vacuum infusion minimizes air voids and optimizes the fiber-to-resin ratio [3], [4]. These changes result in a lighter hull with enhanced maneuverability.

For the perception and navigation system, the team employs a sensor fusion strategy that integrates YOLO-based object detection with LiDAR data [5]. This system was enhanced by tuning configurations and implementing pre-processing steps such as spatial filtering and logical refinements in data combination. The sensor fusion outputs support the navigation system in generating adaptive local waypoints and enhancing obstacle avoidance. Evaluations from the previous year led to the addition of RTK-GPS integration, which reduces signal interference and boosts the positional accuracy of the boat.

B. Task Completion Strategy

The Task Completion Strategy defines how Mandakini Raiden executes each competition task in a structured and reliable manner by integrating perception, navigation, and control systems. Task sequencing and prioritization are applied to ensure mandatory missions are completed efficiently while maintaining system robustness under dynamic environmental conditions. The sequence of task completion can be seen in Fig. 2.

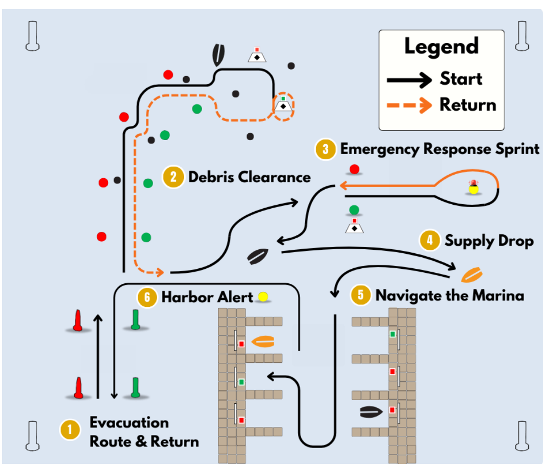


Fig. 2. RoboBoat 2026 Autonomy Challenge Task [6]

*1) **Evacuation Route, Debris Clearance**:* Mandakini Raiden must complete the Evacuation Route before starting any other task. After finishing this mandatory task, it moves on to the Debris Clearance task. Both tasks use a combination of the Braitenberg algorithm and midpoint navigation [7].

$$e = \frac{2P_x - W}{W} \tag{1}$$

$$V_{steer} = K \times e \tag{2}$$

The system calculates the midpoint between each pair of buoys or poles (P_x, P_y). This midpoint is divided by the frame width (W) to produce an error value (e), as shown in eq. (1). The error value is then multiplied by a gain (K) to determine the steering speed (V_{steer}) (eq. (2)) for visualization, see Fig. 3.

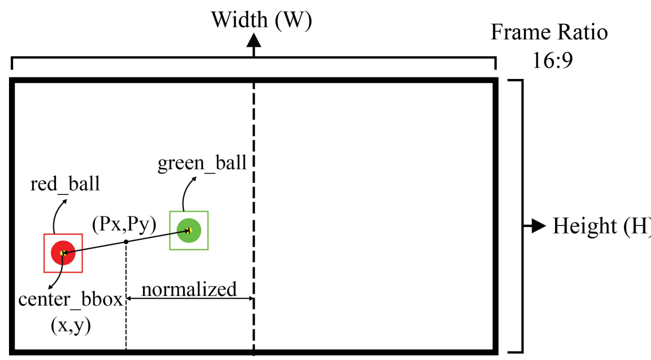


Fig. 3. Visualization of how to get (V_{steer}).

In the Debris Clearance task, the team added an algorithm that converts detected objects in the camera frame into real-world coordinates. Using these coordinates, Mandakini Raiden identifies the positions of the red and green indicators and sets waypoints to navigate around the green indicator. Subsequently, the team targeted Core and Advance capability levels.

*2) **Emergency Response Sprint**:* To complete the Emergency Response Sprint at Disruptive capability level, Mandakini Raiden transforms the positions of the color indicator and the yellow buoy within the frame into real-world coordinates. Color of the indicator determines the maneuver's direction relative to the yellow buoy, with red for counterclockwise (CCW) routes and green for clockwise (CW) routes. The system then generates three waypoints surrounding the yellow buoy while enabling real-time obstacle avoidance.

*3) **Supply Drop**:* In the Supply Drop task, Mandakini Raiden detects the target and converts its coordinates into Pulse Width Modulation (PWM) signals to control the servo and shooter motor. Water is delivered immediately when an orange boat is detected, while targets on black boats are stored and executed after all main tasks are completed. This task targets the Core capability level.

*4) **Navigate the Marina**:* To manage the Navigate the Marina task, the team used a Finite State Machine (FSM) to simplify control [8]. The task consists of three phases: `SCAN`, `NAVIGATE`, and `DOCK`. Mandakini Raiden identifies the target dock in `SCAN`, approaches it in `NAVIGATE`, and docks using fused camera and LiDAR data in `DOCK`. This task targets the Disruptive capability level.

*5) **Harbor Alert**:* Harbor Alert is the final task and is targeted at the Core capability level. The task uses an omnidirectional microphone combined with an interrupt-based algorithm to detect buzzer signals while other tasks are running [9]. The system tracks task progress, and the collected audio data are processed to determine the required task.

*6) **Communications & Reporting**:* Mandakini Raiden implements the RoboBoat 2026 standardized communication protocol to enable real-time task status reporting. A heartbeat service collects mission data from ROS topics, reformats it into Protocol Buffers, and transmits it to the RoboCommand server via the Operator Control Station (OCS) over an Ethernet connection.

II. Design Strategy

A. Hull Design and Manufacture

Mandakini Raiden employs a flat-bottomed catamaran hull designed to optimize buoyancy distribution and enhance initial stability [10]. Several hull configurations were evaluated, including round-hull catamarans and flared flat-bottom designs. Although round-hull catamarans offer smoother roll behavior, their lower initial stability makes them less suitable for high-wave conditions [11]. The flat-bottom configuration provides faster recovery after wave-induced disturbances, while flared sides improve wave resistance by deflecting water away from the deck [11], [12]. This design achieves a stable, efficient, and maneuverable platform with sufficient load-carrying capacity, leading to the selection of a flared flat-bottom catamaran as the optimal hull form. Simulation results for the two hull configurations are provided in Appendix F and Appendix G.

The hull dimensions were retained from the previous design, as they met operational requirements. The structure employs a fiberglass-reinforced polyester composite fabricated via vacuum resin infusion to ensure consistent geometry between both hulls. A comparison between the Mandakini Raiden and Mandakini Zenith hull designs is presented in Fig. 4.

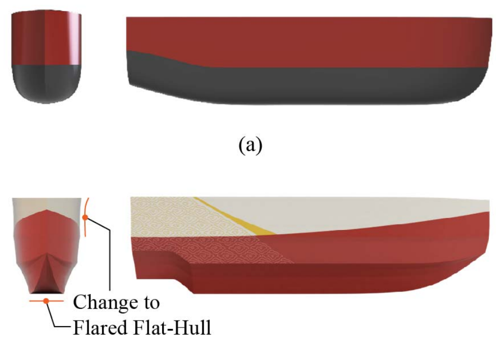


Fig. 4. (a) Hull design of Mandakini Zenith (2025); (b) Hull design of Mandakini Raiden (2026)

B. Propulsion

Mandakini Raiden uses a pair of T200 thrusters mounted in a semi-azimuth configuration at the stern. Each thruster is installed on a 15 mm aluminum shaft embedded in the lower hull and mechanically coupled to an internal servo motor. A direct mechanical transmission supported by a single flange bearing is employed to prevent water ingress. The thrusters re mounted on the hull bottom to reduce hydrodynamic losses and improve thrust efficiency and maneuverability [13]. The propulsion system design is illustrated in Fig. 5.

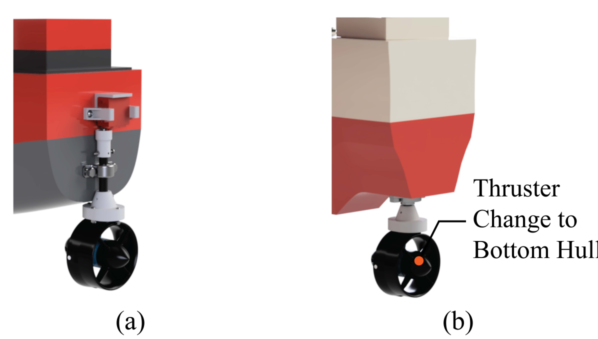


Fig. 5. (a) Propulsion design of Mandakini Zenith (2025); (b) Propulsion design of Mandakini Raiden (2026)

C. System Architecture

The system architecture of Mandakini Raiden is designed as a modular control framework that separates high-level decision-making from low-level actuation. The Robot Operating System (ROS) running on the Jetson Nano functions as the main processing unit, handling visual perception using YOLOv4-Tiny, executing task logic through the Task Controller, and computing navigation commands in the Algorithm module [14]. Motion commands are then transmitted via the MAVLink protocol to the Cube Orange for execution by the actuators. As shown in Fig. 6, this modular architecture enables real-time data synchronization with the Ground Control Station (GCS) for monitoring and control.

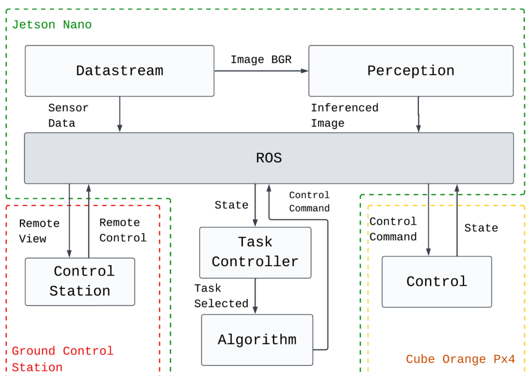


Fig. 6. System architecture of Mandakini Raiden

D. Object Detection

Based on performance evaluations from the previous year and the current system tests on the NVIDIA Jetson Nano, a comparison was conducted to balance detection accuracy and processing speed [1]. The system used YOLOv4 at 608×608 in 2025, while the current implementation adopts YOLOv4-Tiny at 640×352, which is deployed using TensorRT for optimized inference on the Jetson Nano GPU [15], [16]. This change results in a decrease in mAP@0.5 from 84.41% to 81.69%, or an absolute reduction of 2.72%. However, the inference speed improves significantly from 5–6 Frames Per Second (FPS) to 29–32 FPS, providing an increase of approximately 25 FPS, which is close to a fivefold improvement. This trade-off is considered acceptable for real-time autonomous operations, where higher frame rates and system responsiveness are more critical [17]. More recent YOLO implementations, such as those provided by Ultralytics, were not adopted due to the limited computational resources of the Jetson Nano and potential compatibility issues related to Python dependencies, CUDA versions, and runtime stability [18]. The detection results produced by YOLOv4-Tiny are illustrated in Fig. 7, while detailed quantitative comparisons are provided in Appendix K.

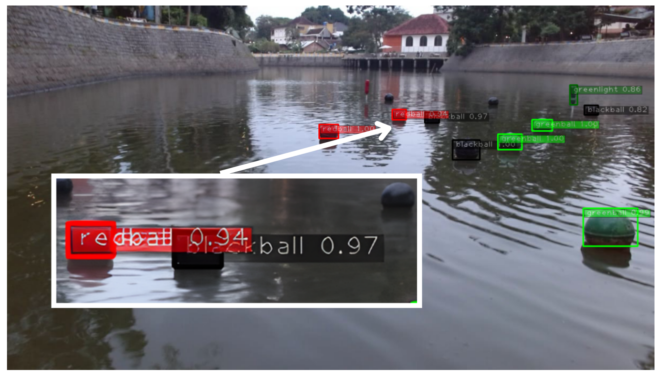


Fig. 7. The result of object detection by YOLOv4-Tiny

E. Communication

To address latency spikes caused by signal interference in the Ubiquiti UAP-ACM - Totolink CP350 (Ubiquiti as access point and Totolink as receiver) communication system the previous year, the team optimized the frequency and bandwidth spectrum by selecting cleaner channels and adjusting bandwidth [1]. Based on the test data in Appendix L, this strategy has been shown to significantly reduce latency by 45% and minimize frequency interference between teams. As a result, the stability of control and the reliability of real-time data exchange between Mandakini Raiden and the GCS can be guaranteed.

F. Electrical System

Electrical system of Mandakini Raiden is based on a power distribution box consisting of a terminal block and DC converter, which supplies power to the Control Box components, including the Pixhawk, Jetson, telemetry module, and emergency system, as well as to the relay and ESC used for the Supply Drop tasks. The propulsion system is powered independently by a separate Li-Po battery. In addition, a voltage sensor is installed to monitor the remaining onboard battery voltage. This sensor is connected to the Arduino, which transmits the voltage data to the Pixhawk. An overview of Mandakini Raiden's electrical system is presented in Fig. 8.

For the emergency system, Mandakini Raiden retains the same emergency scheme used in the previous year, as it has proven to be an effective safety mechanism [1]. In the current design, a visual indicator in the form of a light has been added to signal the Mandakini Raiden operational status. The custom-built emergency system is capable of cutting off the propulsion system during emergency situations, either via a physical push button or a remote switch. The complete electrical diagram of Mandakini Raiden is provided in Appendix E.

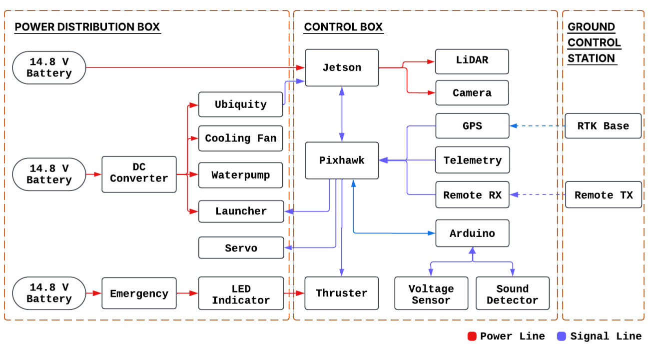


Fig. 8. Electrical system diagram of Mandakini Raiden

G. Global Positioning System

The positional adjustment performance of Mandakini Zenith was suboptimal, indicating reduced GPS accuracy under challenging navigation conditions [1]. Factors such as electromagnetic interference and adverse weather increase signal noise, leading to position instability and deviations from the intended task trajectory. To address these limitations, the team implemented GPS integration with RTK base stations in the current system. RTK significantly enhances positioning accuracy, minimizes drift, and provides real-time corrections in high-interference environments [19]. This integration improves navigation stability, increases resilience to interference, and enhances the overall reliability of GPS-based navigation during task execution. The results of the GPS performance test are provided in Appendix M.

H. Supply Drop Mechanism

For the Object Delivery task, the team implemented a flywheel-based launch mechanism using two rubber wheels rotating in opposite directions to launch the ball. The reload system employs a queue-and-release mechanism in which two micro servos are used to manually load up to three balls prior to operation, while a single servo motor integrated with the launcher controls ball discharge. For the Water Delivery task, an 80 psi pressurized water pump is used in combination with a nozzle actuated by a single-axis servo motor, allowing precise directional control of the water stream toward the target. The Supply Drop mechanism of Mandakini Raiden is presented in Fig. 9.

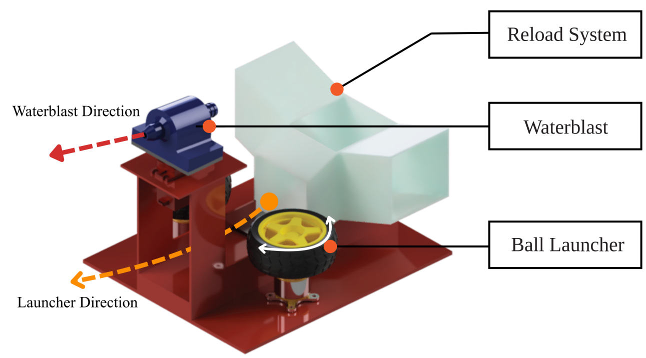


Fig. 9. Supply drop mechanism of Mandakini Raiden

I. Harbor Alert Detection

For the Harbor Alert task, the team employed an omnidirectional microphone integrated with a MAX4466 preamplifier to amplify analog audio signals [20]. The microphone captures the sound frequency, after which the signal is amplified and stabilized by the MAX4466 before being transmitted to the Arduino as an analog input. The microcontroller processes the audio data to identify the sound frequency, and the resulting information is then forwarded to the Jetson to execute the task algorithm. The results of the sound detection performance test are provided in Appendix N.

III. Testing Strategy

Given the short development timeline (October to February) and the gradual release of competition regulations, the team implemented a parallel, phased testing strategy (Fig. 10). This approach improves time efficiency by allowing algorithm verification and component validation to proceed concurrently with construction and hardware integration of Mandakini Raiden. The overall testing methodology is divided into four main phases: **Component and Vision Testing**, **Simulation and Logic Testing**, **Off-water Testing**, and **On-water Testing**. For the detailed overview of this workflow, see the test plan in Appendix C.

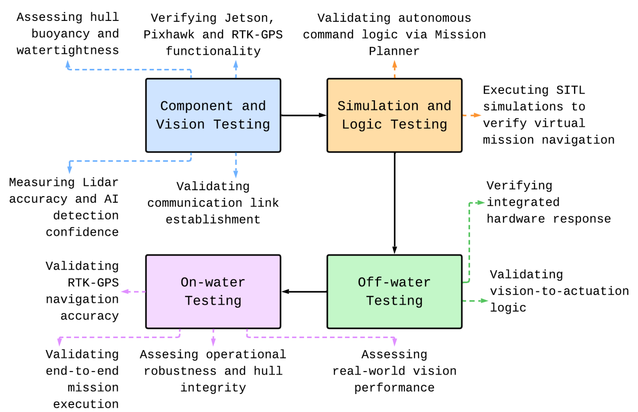


Fig. 10. Testing scope and objectives of Mandakini Raiden

*1) **Component and Vision Testing**:* Component and vision testing aim to verify the functionality of hardware components, vision model outputs, and overall system performance in real-world conditions. All team members conduct testing once individual components are available or after the vision model has been trained. A test is successful when hardware, sensors, and actuators function correctly, and the vision system delivers consistent, reliable detection results. Components tested include the hull, Jetson Nano, LiDAR, propulsion system, and emergency system. Data from this stage serve as benchmarks to establish baseline parameters for motion algorithm of the Mandakini Raiden.

*2) **Simulation and Logic Testing**:* Simulation and logic testing verify that the task algorithm functions according to the Task Completion Strategy. This step confirms the core algorithm works error-free before on-water testing, allowing subsequent testing to be more focused on tuning algorithm parameters. Conducted by the Programming Team using the SITL Mission Planner, these tests monitor the state of Mandakini Raiden during program execution. The phase is successful when all task states run correctly within the SITL environment.

*3) **Off-water Testing**:* Off-water testing is conducted by the Mechanics and Programming Team in an open workshop after full system installation and prior to on-water deployment. This phase verifies that the integrated system and GCS communication operate correctly and that operational state transitions conform to the validated SITL logic. The test is considered successful when state transitions are consistent with simulation results, actuators respond as commanded, and GCS communication remains stable.

*4) **On-water Testing**:* The on-water testing phase is conducted in a lake environment with full team supervision and is performed only after the system has passed off-water verification. Any hardware modification requires repeating off-water testing to ensure system integrity. This phase aims to evaluate system robustness under dynamic environmental conditions and to validate task execution algorithms. On-water testing is considered successful when Mandakini Raiden autonomously completes all tasks while maintaining stable control without manual intervention.

ACKNOWLEDGMENT

We sincerely thank all parties who participated and supported us, enabling this research to proceed smoothly. Our deepest appreciation goes to:

1) Universitas Sebelas Maret for funding and for providing essential facilities that supported the development, integration, and testing of this project.
2) Laboratory of Automation, Laboratory of Design and Computational Mechanics, and Laboratory of Computer for their technical support, guidance, and access to laboratory resources.
3) Software developers and technology providers who offer student licenses, enabling the team to utilize professional engineering, simulation, and development tools essential for the successful completion of this project.

References

[1] A. R. F. Azka, A. P. Haryadi, A. F. Lusiana, D. N. Moko, E. B. Nugroho, F. U. Halima, F. V. Anjarwati, F. A. Mulya, G. Haqqani, H. H. Mafasa, M. R. Bramantyo, M. T. N. Hidayat, N. A. A. Ningrum, P. R. Tumanggor, P. R. Anugrah, R. A. P. Wibawa, R. M. Noorathaya, S. K. Fitriani, and W. O. S. P. R. Tonga, "Roboboat 2025: 'mandakini zenith' technical design report," Bengawan UV Universitas Sebelas Maret, Tech. Rep., 1 2025.

[2] S. C. Misra, *Design principles of ships and marine structures*. CRC Press, 2015.

[3] S. G. Maxineasa and N. Taranu, "Life cycle analysis of strengthening concrete beams with frp," *Eco-efficient Repair and Rehabilitation of Concrete Infrastructures*, pp. 673–721, 1 2018. [Online]. Available: https://www.sciencedirect.com/science/chapter/edited-volume/abs/pii/B9780081021811000241?via%3Dihub

[4] H. Awais, Y. Nawab, A. Amjad, A. Anjang, H. M. Akil, and M. S. Z. Abidin, "Environmental benign natural fibre reinforced thermoplastic composites: A review," *Composites Part C: Open Access*, vol. 4, p. 100082, 3 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2666682020300827?via%3Dihub

[5] Z. Shi, Z. Bai, K. Yi, B. Qiu, X. Dong, Q. Wang, C. Jiang, X. Zhang, and X. Huang, "Vision and 2d lidar fusion-based navigation line extraction for autonomous agricultural robots in dense pomegranate orchards," *Sensors*, vol. 25, no. 17, 2025. [Online]. Available: https://www.mdpi.com/1424-8220/25/17/5432

[6] Roboboat, "Section 3: Autonomy challenge — roboboat 2026 team handbook," 12 2026. [Online]. Available: https://robonation.gitbook.io/roboboat-resources/section-3-autonomy-challenge

[7] X. Yang, R. V. Patel, and M. Moallem, "A fuzzy-braitenberg navigation strategy for differential drive mobile robots11this research was supported in part by the national sciences and engineering research council (nserc) of canada under grants rgpini345 and rgpin227612, and the canada foundation for innovation under the new opportunities program." *IFAC Proceedings Volumes*, vol. 37, pp. 97–102, 2004. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S147466701731087X

[8] M. Steinbrink, P. Koch, S. May, B. Jung, and M. Schmidpeter, "State machine for arbitrary robots for exploration and inspection tasks," in *ACM International Conference Proceeding Series*, 2020.

[9] G. Herberich, B. Schlich, C. Weise, and T. Noll, "Proving correctness of an efficient abstraction for interrupt handling," *Electronic Notes in Theoretical Computer Science*, vol. 217, pp. 133–150, 7 2008. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1571066108003897?pes=vor&utm_source=mendeley&getft_integrator=mendeley

[10] A. Pranata, A. R. Prabowo, J. M. Sohn, T. Tuswan, R. Samad, M. Jurkovič, O. Melnyk, T. Muttaqie, and N. Muhayat, "Mechanical design of engineered-curved patrol boat hull based on the geometric parameters and hydrodynamic criteria," vol. 12, 2025. [Online]. Available: https://doi.org/10.1515/cls-2025-0041

[11] A. Prabowo, E. Martono, T. Muttaqie, Tuswan, and D. Bae, "Effect of hull design variations on the resistance profile and wave pattern: A case study of the patrol boat vessel," *Journal of Engineering Science and Technology*, vol. 17, pp. 106–126, 2 2022.

[12] S. X. Bu, J. Lu, and M. Gu, "Study on the effects of radiation and diffraction forces on roll restoring arm with flared and tumblehome vessels," *Ocean Engineering*, vol. 239, p. 109777, 11 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0029801821011434?via%3Dihub

[13] N. Bulten and P. Stoltenkamp, "Full scale thruster-hull interaction improvement revealed with cfd analysis," in *International Conference on Offshore Mechanics and Arctic Engineering*, vol. 55430. American Society of Mechanical Engineers, 2013, p. V009T12A017.

[14] A. O. Prasad, P. Mishra, U. Jain, A. Pandey, A. Sinha, A. S. Yadav, R. Kumar, A. Sharma, G. Kumar, K. Hazim Salem, A. Sharma, and A. K. Dixit, "Design and development of software stack of an autonomous vehicle using robot operating system," *Robotics and Autonomous Systems*, vol. 161, p. 104340, 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0921889022002299

[15] A. Bochkovskiy, C.-Y. Wang, and H.-Y. M. Liao, "Yolov4: Optimal speed and accuracy of object detection," *arXiv preprint arXiv:2004.10934*, 2020.

[16] T. P. Swaminathan, C. Silver, T. Akilan, and J. Kumar, "Benchmarking deep learning models on nvidia jetson nano for real-time systems: An empirical investigation," *Procedia Computer Science*, vol. 260, pp. 906–913, 2025.

[17] X. Chen, "Object detection in autonomous driving: Advances in computer vision techniques," in *ITM Web of Conferences*, vol. 78. EDP Sciences, 2025, p. 03017. [Online]. Available: https://doi.org/10.1051/itmconf/20257803017

[18] Ultralytics, "Quickstart ultralytics," 1 2026. [Online]. Available: https://docs.ultralytics.com/quickstart/

[19] A. Pirti, "Performance analysis of the real time kinematic gps (rtk gps) technique in a highway project (stake-out)," *Survey Review*, vol. 39, pp. 43–53, 2007.

[20] J. Suo, Y. Liu, C. Wu, M. Chen, Q. Huang, Y. Liu, K. Yao, Y. Chen, Q. Pan, and X. Chang, "A wide-bandwidth nanocomposite-sensor integrated smart mask for tracking multi-phase respiratory activities for covid-19 endemic," *medRxiv*, pp. 2022–2023, 2022.

Appendix A: Component Specifications and Bill of Material

Table A-1. Component Specifications and Bill of Material

Component	Vendor	Model/Type	Specs	Custom/ Purchased	Cost	Year of Purchase
ASV Hull	"Hand Made With Fiberglass"	Catamaran Symmetric	5 Layers of Fiber Glass, LOA:94 Beam:18 Depth:25.	Custom	$85	2025
Frame	Alumunium	Aluminium 2014-T4	Yield Strength = 290 MPa Density = 2.800E-06 kg/mm^3	Custom	$50	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, Konverter DC	2x4P 60A Terminal Block	Purchased	$9	2023
Batteries	Ovonic	Li-Po Battery	5.3 Ah, 50C, 25.2 V	Purchased	$100	2025
	Tattu	Li-Po Battery	10 Ah 25C, 16.8 V	Purchased	$125	2023
	Tattu	Li-Po Battery	5.2 Ah 35C, 16.8 V	Purchased	$69	2024
	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	Holybro	H-RTK F9P GNSS	https://holybro.com/products/h-rtk-f9p-gnss-series?srsltid=AfmBOoqrFjBuDoqyBBdWcYilEYQDrNTWBQV-cQ3Efc_1UTGbCIg_l6zY	Purchased	$296	2025
RTK Base	Holybro	H-RTK F9P Base	https://holybro.com/products/h-rtk-f9p-gnss-series?variant=41466787201213	Purchased	$325	2025
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

Component	Vendor	Model/Type	Specs	Custom/ Purchased	Cost	Year of Purchase
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	Taffware	N/A	12 V 2 A	Purchased	$10	2025
Microcontroller	Arduino	Arduino Nano	https://store-usa.arduino.cc/products/arduino-nano?srsltid=AfmBOopvDSQBWgWdCZ6LSxcbLlIDnBT5U7PDLa9kBatBX9-xAyqzIELX	Purchased	$24.90	2023
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, Maxsurf Stability	N/A	Free Student Lcense	N/A	N/A

Component	Vendor	Model/Type	Specs	Custom/ Purchased	Cost	Year of Purchase
Engineering Simulation Software	ANSYS Inc.	Ansys Aqwa, Ansys Resistance	N/A	Free Student License	N/A	N/A

APPENDIX B: MECHANICAL DESIGN

A. Assembly Design

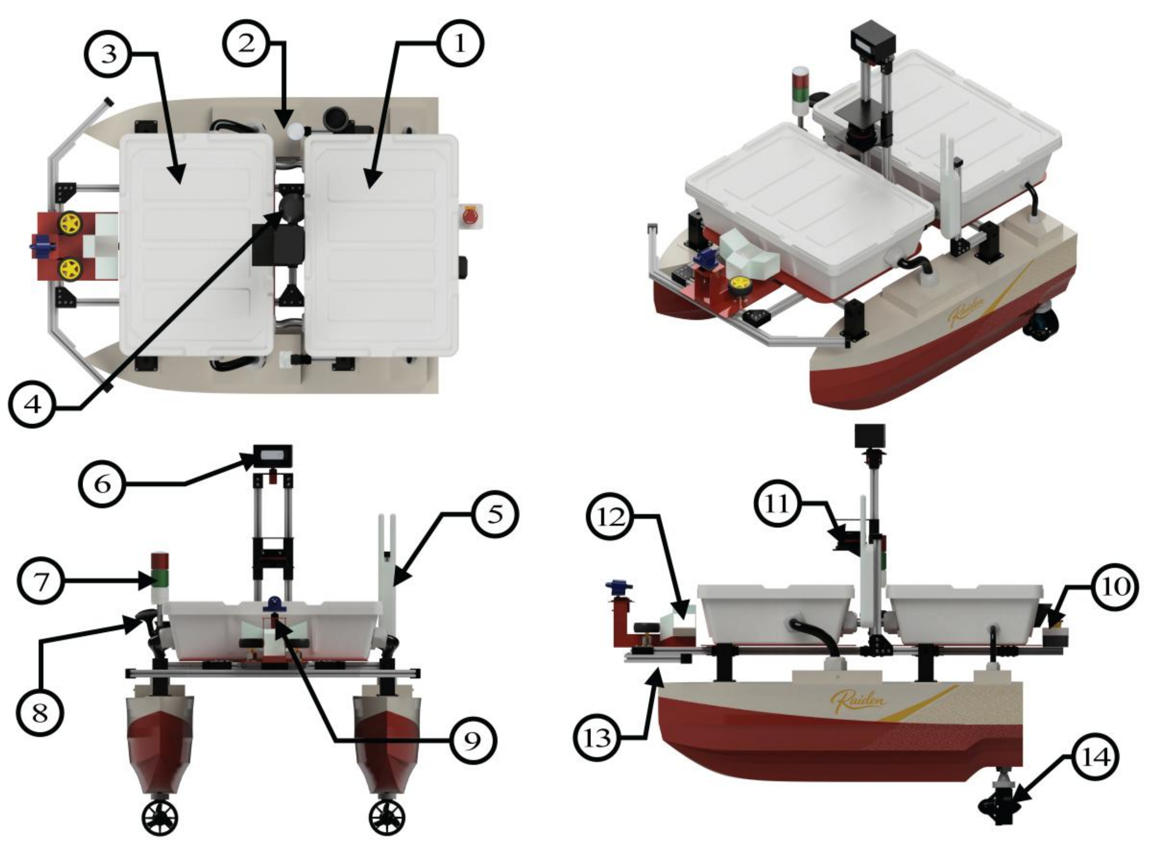


Fig. B-1. Assembly design of Mandakini Raiden

B. Disassembly Design

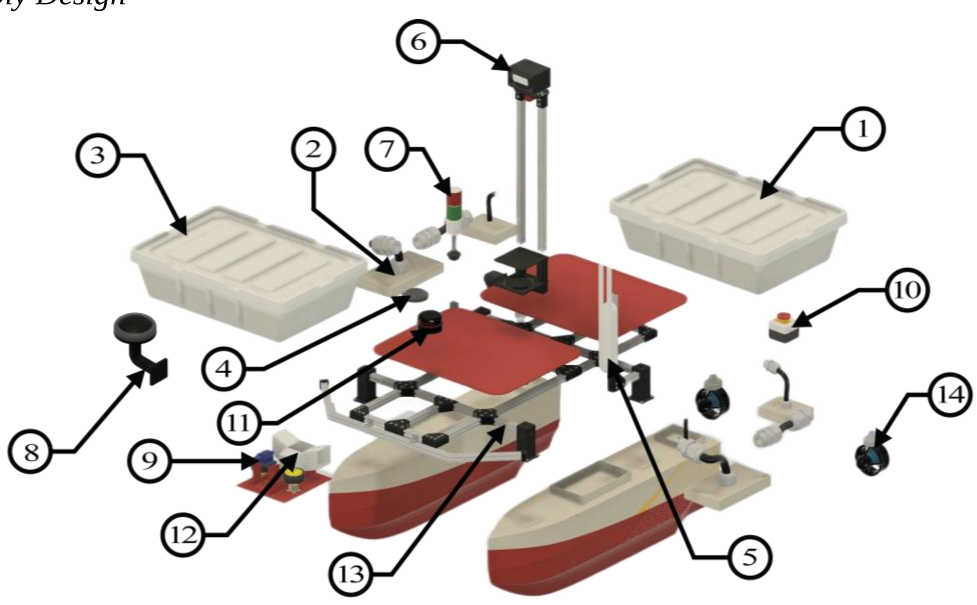


Fig. B-2. Disassembly design of Mandakini Raiden

Table B-1. Mandakini Raiden Part Lists Refer to Fig B-1 and B-2

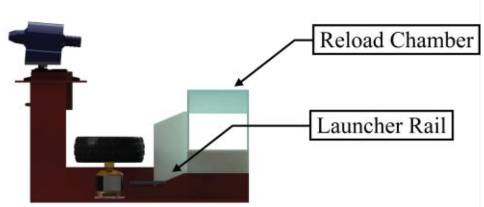
Item Number	Part Name	Quantity
1	Power Distribution Box	1
2	Battery Box	2
3	Control Box	1
4	GPS	1
5	Router	1
6	Camera	1
7	Indicator Lamp	1
8	Microphone	1
9	Water Blaster	1
10	Emergency Button	1
11	LiDAR	1
12	Ball Launcher	1
13	Aluminium Profile 2020	22
14	T200 Thruster	2

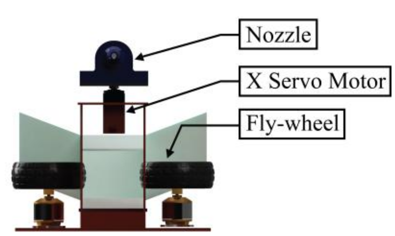
C. *Hull Specifications*

Table B-2. Mandakini Raiden Principal Dimension

Parameters	Value
Length Overall (LOA)	0.94 m
Beam Overall (B_{OA})	0.78 m
Demihull Beam (B)	0.18 m
Depth (D)	0.25 m
Draft (D_{WL})	0.12 m
Displacement	23.87 kg
Length Waterline (L_{WL})	0.93 m
Demihull Spacing (S)	0.6 m
Block Coefficient (C_B)	0.628
Wetted Area	0.579 m^2

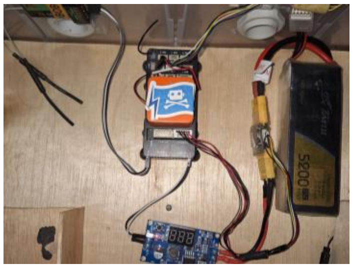
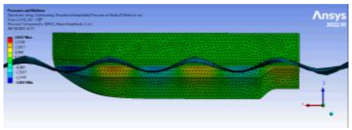
D. *Ball Launcher and Water Delivery Design*



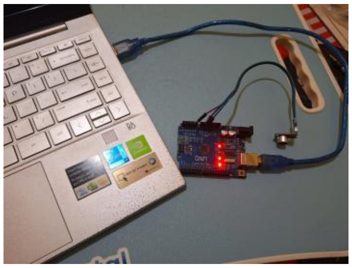
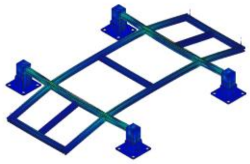


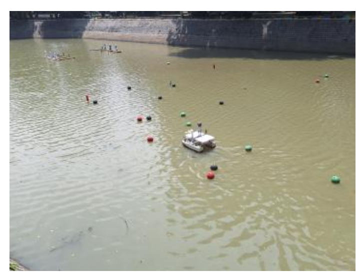
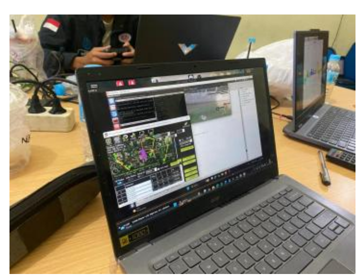
APPENDIX C: TEST PLAN AND DOCUMENTATION

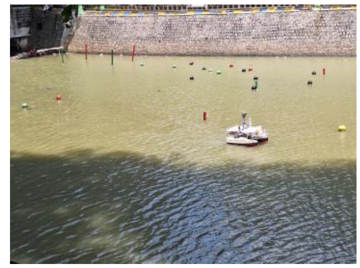
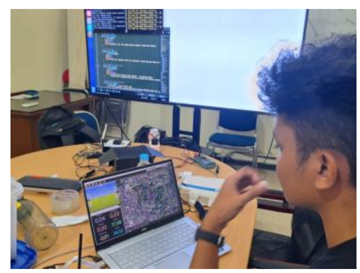
Table C-1. Test Plan and Documentation

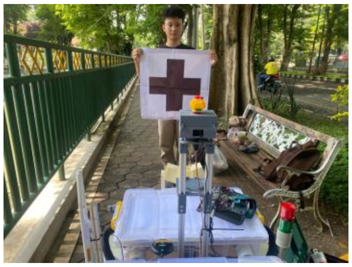
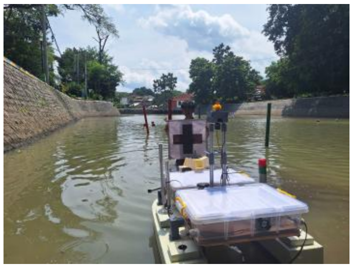
Date	Requirement	Test Description	Type of Testing	Division In-Charge	Documentation
Nov, Week 1	The Jetson can turn on and operate normally.	1) Checking the physical condition and power connection of the Jetson. 2) Turn on Jetson and verify the system boot process. 3) Observes the stability of the operating system while running. 4) Verify the I/O port function and GPU acceleration (CUDA).	Component and Vision Testing	Programming Team	
	Pixhawk can light up well and receive signals well.	1) Connect the Battery to the power module and wait for pixhawk to turn on 2) Once turned on, connect the BEC 5V to the power rails 3) Check the Pixhawk pin voltage 4) Connect the actuator (Servo) for signal testing 5) Set the maximum and minimum values of servo 6) Pixhawk can receive signals well	Component and Vision Testing	Mechanic Electronics Team	
	Receiver can receive the signal from the Transmitter.	1) Turn on the Pixhawk by connecting the battery to the power module 2) Connect the Jumper Cable from the Receiver to the Pixhawk 3) Turn on the Transmitter 4) Binding Transmitter with Receiver	Component and Vision Testing	Mechanic Electronics Team	
	Mandakini Raiden has good stability and weighs under 30kg.	1) Simulation of Stability, RAO, and Resistance using ANSYS Aqwa and ANSYS Fluent 2) Achieved results in stability, RAO, and resistance.	Component and Vision Testing	Design Manufacture Team	
	Lidar can accurately obtain distance data.	1) Turns on and initializes the LiDAR sensor. 2) Verify the LiDAR connection with Jetson. 3) Observing distance data generated by LiDAR. 4) Compare distance reading results with actual distance.	Component and Vision Testing	Programming Team	

Date	Requirement	Test Description	Type of Testing	Division In-Charge	Documentation
	The object detection model is able to detect with a confidence value of >= 0.75.	1) Connect the camera to the Jetson. 2) Run an object detection program. 3) Observe the results of model detection and the resulting confidence value.	Component and Vision Testing	Programming Team	
	Ubiquiti can turn on and become an AP by connecting to Jetson.	1) Turn on ubiquiti and then plug it into jetson. 2) Set ubiquiti as jetson AP. 3) Set ubiquiti to spread its SSID. 4) Observe and test AP connections.	Component and Vision Testing	Programming Team	
	Totolink became Ubiquti's AP repeater.	1) Turn on Totolink and then connect it to your computer. 2) Set Totolink to be a ubiquiti AP repeater. 3) Observe and test Totolink's connection with Ubiquiti AP.	Component and Vision Testing	Programming Team	
	Jetson and Ground Control Station Computers can exchange information data with each other.	1) Turn on and then connect the AP to the jetson via the RJ45 cable. 2) Turn on the Totolink router and then connect the ground control station (GCS) computer to the repeater via wireless. 3) Ping between jetson and computer (GCS). 4) Observe the connection between gcs and jetson.	Component and Vision Testing	Programming Team	
Nov, Week 2	Mandakini Raiden can maneuver well.	1) Connect the servo signal to the pixhawk 2) Set the midpoint of the PWM servo propulsion system 3) Set the maximum and minimum values of PWM 4) Connect the pixhawk with the Remote set the channel so the servo can move 5) Observe the motion of servo	Component and Vision Testing	Mechanic Electronics Team	

Date	Requirement	Test Description	Type of Testing	Division In-Charge	Documentation
	Thruster works well.	1) Connect the thruster to the ESC 2) Connect the ESC signal to pixhawk 3) Move the thruster from the remote 4) Observe the movement of the thruster 5) Thrusters can provide thrust for the Mandakini Raiden well	Component and Vision Testing	Mechanic Electronics Team	
	Sensor can detect the frequency of reference frequency	1) Setup the Arduino and the sensor 2) Wire the sensor and Arduino board correctly 3) Write the code on Arduino IDE 4) Upload the code to Arduino board 5) Check the serial monitor for the output	Component and Vision Testing	Mechanic Electronics Team	
Nov, Week 3	Ensures the frame can withstand a load of 60 Newtons.	1) Import the frame model into Fusion and assign material properties. 2) Apply a 60 N load with appropriate constraints. 3) Run the structural simulation. 4) Verify that stress and deformation remain within safe limits.	Component and Vision Testing	Design Manufacture Team	
	Ensure command from the program can move the actuator accordingly.	1) Integrate the electronic system and control program into the vessel. 2) Power on and arm the Mandakini Raiden 3) Run the program to issue actuator commands. 4) Place an object to trigger the detection logic. 5) Observe whether the actuator moves as commanded.	Off-water Testing	All team member	
Nov, Week 4	Hull can stay afloat.	1) Placing the boat on the lake. 2) Observe the boat and ensure the boat can float safely.	Component and Vision Testing	Design Manufacture Team	

Date	Requirement	Test Description	Type of Testing	Division In-Charge	Documentation
	RTK-GPS integration can work well.	1) Connect GPS with Pixhawk 2) Calibration of the compass and GPS accelerometer 3) Once calibrated, check the GPS satellite 4) Inject GPS with RTK Base 5) Retrieve the RTK Base position data and connect it 6) Observe RTK condiion till appear in Mission Planner	Component and Vision Testing	Mechanic Electronics Team	
Dec, Week 1	Task 1: Evacuation Route and Task 2: Debris Clearence programs work error-free.	1) Open Mission Planner on computer. 2) Connect the Jetson to the computer using MAVROS. 3) Running the Task 1: Evacuation Route and Task 2: Debris Clearance programs at Jetson. 4) Observe visual obstacle detection. 5) Ensure the boat in the simulation runs according to the conditions.	Simulation and Logic Testing	Programming Team	
Dec, Week 2	Mandakini Raiden can complete Task 1: Evacuation Route and Task 2: Debris Clearence.	1) Turn on the Mandakini Raiden. 2) Switch Mandakini Raiden mode to ARM. 3) Run a task program. 4) Observing the movement of the Mandakini Raiden in the water. 5) Observing the detection of poles, buoys and color indicators in field conditions.	On-water Testing	Programming Team	 
	The Task 3: Emergency Response Sprint program can work error-free and correctly.	1) Open Mission Planner on computer. 2) Connect the Jetson to the computer using MAVROS.Menjalankan program Task 3: Debris Clearence di Jetson. 3) Showing obstacles to the camera. 4) Observing the results of visual obstacle and indicator detection. 5) Ensure that boat in the simulation can generate a local waypoint with	Simulation and Logic Testing	Programming Team	

Date	Requirement	Test Description	Type of Testing	Division In-Charge	Documentation
		direction according to the color indicator.			
Dec, Week 3	Mandakini Raiden can complete Task 3: Emergency Response Sprint.	1) Turn on the Mandakini Raiden. 2) Switch Mandakini Raiden mode to ARM mode. 3) Setup gate with a spacing of 1 – 3 meters and a yellow buoy with light beacons in the distress zone. 4) Run the Task 3: Emergency Response Sprint program. 5) Verify gate detection and rapid transit (maximum safe velocity). 6) Verifying the detection of light beacon color indicators. 7) Verifies generate local awaypoints with directions according to color indicators.	On-water Testing	Programming Team	
	Program Task 5: Navigate the Marina.	1) Open Mission Planner on computer. 2) Connect the Jetson to the computer using MAVROS. 3) Run the Task 5: Navigate the Marina program at Jetson. 4) Shows the color indicator and number sign to the camera. 5) Observe the results of visual color indicator and number sign detection. 6) Ensuring the boat in the simulation can stop and move according to the conditions.	Simulation and Logic Testing	Programming Team	
Dec, Week 4	Mandakini Raiden can complete Task 5: Navigate the Marina.	1) Setup arena navigate the Marina. 2) Turn on the Mandakini Raiden. 3) Switch Mandakini Raiden mode to ARM mode. 4) Running the program task 5. 5) Observing the Mandakini Raiden can move according to the conditions. 6) Verify the Mandakini Raiden can park in the smallest number slot and the green indicator.	On-water Testing	Programming Team	

Date	Requirement	Test Description	Type of Testing	Division In-Charge	Documentation
	Program Task 4: Supply Drop Object Delivery.	1) Open Mission Planner on computer. 2) Connect the Jetson to the computer using MAVROS. 3) Run the Task 4: Supply Drop Object Delivery program at Jetson. 4) Show the orange boat and black boat and their symbol to the camera. 5) Observing the results of the detection of orange boats and black boats. 6) Observes system outputs in the form of log/print messages that represent commands to spray water and shoot balls. 7) Ensure the logs displayed match the conditions and sequence of the actions they were designed to take.	Simulation and Logic Testing	Programming Team	
Jan, Week 1	Mandakini Raiden can complete Task 4: Supply Drop.	1) Set up arenas and obstacle task supply drops. 2) Turn on the Mandakini Raiden. 3) ARM Mandakini Raiden. 4) Observing Mandakini Raiden can shoot water and balls as per their objects.	On-water Testing	Programming Team	
Jan, Week 1	Program Task 6: Harbor Alert.	1) Open Mission Planner on computer. 2) Connect the Jetson to the computer using MAVROS. 3) Connecting the microphone to the Jetson. 4) Running the Task 6: Harbor Alert program at Jetson. 5) Observe the state of the boat when receiving a signal from the speakers.	Simulation and Logic Testing	Programming Team	<Not tested yet>
Jan, Week 2	Mandakini Raiden can complete Task 6: Harbor Alert.	1) Set up the drop supply task property. 2) Turn on the Mandakini Raiden. 3) ARM Mandakini Raiden. 4) Observing the movement of the Mandakini Raiden when hearing the sound of the signal from the speakers.	On-water Testing	Programming Team	<Not tested yet>
Jan, Week 2	Mandakini Raiden can complete Task 6: Harbor Alert.	1) Set up the drop supply task property. 2) Turn on the Mandakini Raiden. 3) ARM Mandakini Raiden. 4) Observing the movement of the Mandakini Raiden	On-water Testing	Programming Team	<Not tested yet>

Date	Requirement	Test Description	Type of Testing	Division In-Charge	Documentation
		when hearing the sound of the signal from the speakers.			
Jan, Week 3	Mandakini Raiden can complete all the tasks.	1) Setup the entire arena. 2) Turn on the Mandakini Raiden. 3) Switch Mandakini Raiden mode to ARM mode. 4) Run the entire task program. 5) Observing Mandakini Raiden can move according to the conditions for the entire task.	On-water Testing	Programming Team	<Not tested yet>
Jan, Week 4	Mandakini Raiden can complete all the tasks.	1) Setup the entire arena. 2) Turn on the Mandakini Raiden. 3) Switch Mandakini Raiden mode to ARM mode. 4) Run the entire task program. 5) Observing Mandakini Raiden can move according to the conditions for the entire task.	On-water Testing	Programming Team	<Not tested yet>

APPENDIX D: RISK MANAGEMENT

Table D-1. Risk Management

No	Risk	Cause	Impact	Impact Level	Probablity	Mitigation Plan	Responsibility
1	Propulsion Entanglement	Floating debris, algae, or trash in the water	Motor stall; ESC burnout; Loss of mobility	Medium	Medium	a. Install custom 3D-printed propeller guards. b. Perform scheduled preventive maintenance on propulsion motors.	Mechanics Electronics Team
2	Thermal Throttling (Overheating)	Direct sunlight; High CPU/GPU load	Reduced processing speed; Laggy object detection	Medium	Medium	a. Install active cooling (fans) on OBC (On-Board Computer). b. Add ventilation grilles onF the superstructure.	Mechanic Electronics Team
3	Telemetry/Wifi Drop	Signal interference; Bandwidth saturation	Loss of ground station monitoring	Medium	High	a. Preparing backup system b. Ensure connectors are in good condition	Mechanics Electronics Teams
4	Hull Breach / Water Ingress	Collision with obstacles or dock; Propulsion system leakage (Shaft/Seal failure)	Damage to internal electronics; Sinking risk	High	Low	a. Ensure hull is sealed with marine sealant. b. Perform scheduled maintenance to ensure hull watertightness.	Design Manufacture Team
5	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
6	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
7	RC Signal Loss	Interference (2.4GHz); Out of range; Low battery	Loss of manual control override	High	Low	a. Perform routine checks on battery capacity and voltage. b. Maintain reserve batteries for the RC transmitter.	Driver
8	Voltage Sag / Brownout	High current draw from thrusters; Low battery C-rating	System reboot mid-mission	High	Medium	a. Utilize batteries with higher energy density to accommodate	Mechanics Electronics Team

No	Risk	Cause	Impact	Impact Level	Probablity	Mitigation Plan	Responsibility
						peak load duration. b. Deploy a voltage sensor for live battery monitoring.	
9	Environmental Constraints	Heavy rain; Strong wind/waves	Vision obstruction; Instability	High	Medium	a. Coated all external connectors with waterproof cable. b. Implement robust PID tuning for wave disturbance.	Head of Technical
10	Acoustic Signal Noise	Motor vibration; Echo/Multipath; Wind Noise	Failure to identify pinger source	High	Medium	a. Use vibration-damping mounts for hydrophones. b. Apply digital Band-Pass Filter to isolate pinger frequency.	Mechanics Electronics and Programming Team
11	Computer Vision False Positives	Sun glare; Reflections; Shadows	ASV tracks wrong object or hits obstacle	High	High	a. Use CPL (Circular Polarizing) Filters on cameras. b. Train dataset with extensive data augmentation (brightness/noise).	Programming Team
12	Navigation Drift (IMU/GPS)	Magnetic interference; Multipath error	ASV goes off-course; misses waypoints	High	High	a. Place compass away from high-current wires. b. Use EKF (Extended Kalman Filter) for sensor fusion.	Programming and Mechanics Electronics Team

APPENDIX E: ELECTRICAL DIAGRAM AND EMERGENCY SYSTEM

A. Full Electrical Diagram of Mandakini Raiden

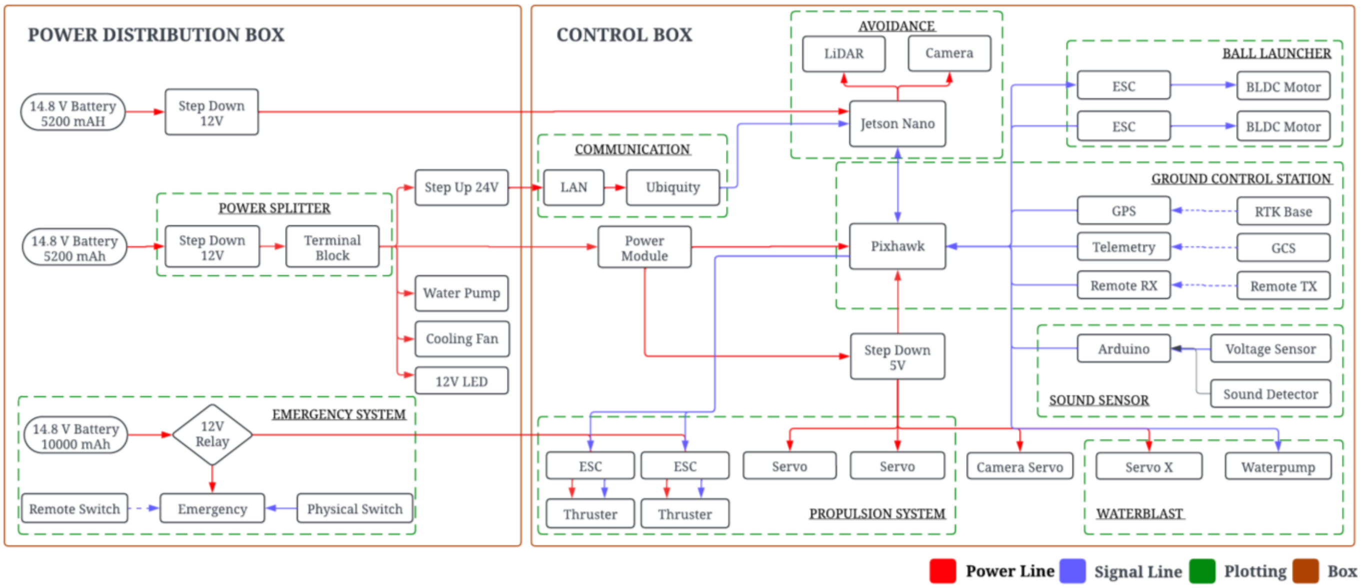


Fig. E-3. Full electrical diagram of Mandakini Raiden

B. Emergency System Breakdown

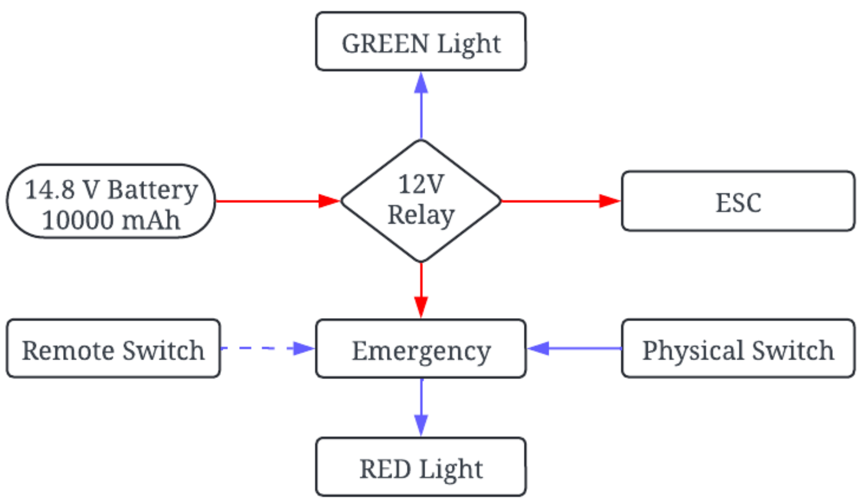


Fig. E-2. Emergency system of Mandakini Raiden

APPENDIX F: ANSYS AQWA SIMULATION

A. *Ansys Aqwa Simulation Mandakini Raiden (2026)*

Environment

Wave Amplitude: 0.02 m

Wave Frequency: 2.3 Hz

Wave Direction: 180°

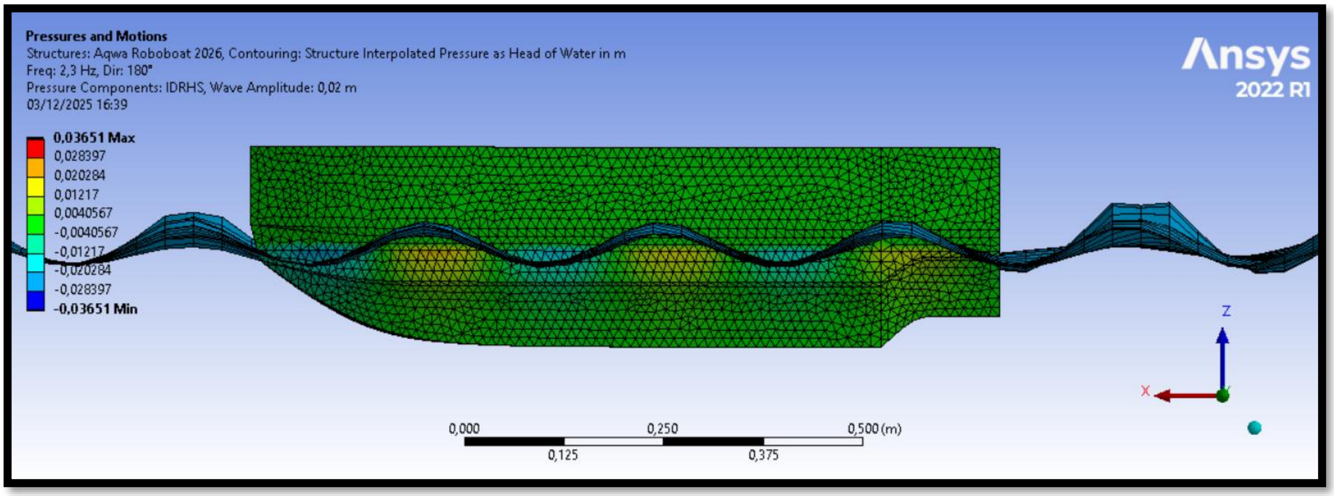


Fig. F-1. Ansys Aqwa simulation Mandakini Raiden

B. *Ansys Aqwa Simulation Mandakini Zenith (2025)*

Environment

Wave Amplitude: 0.02 m

Wave Frequency: 2.3 Hz

Wave Direction: 180°

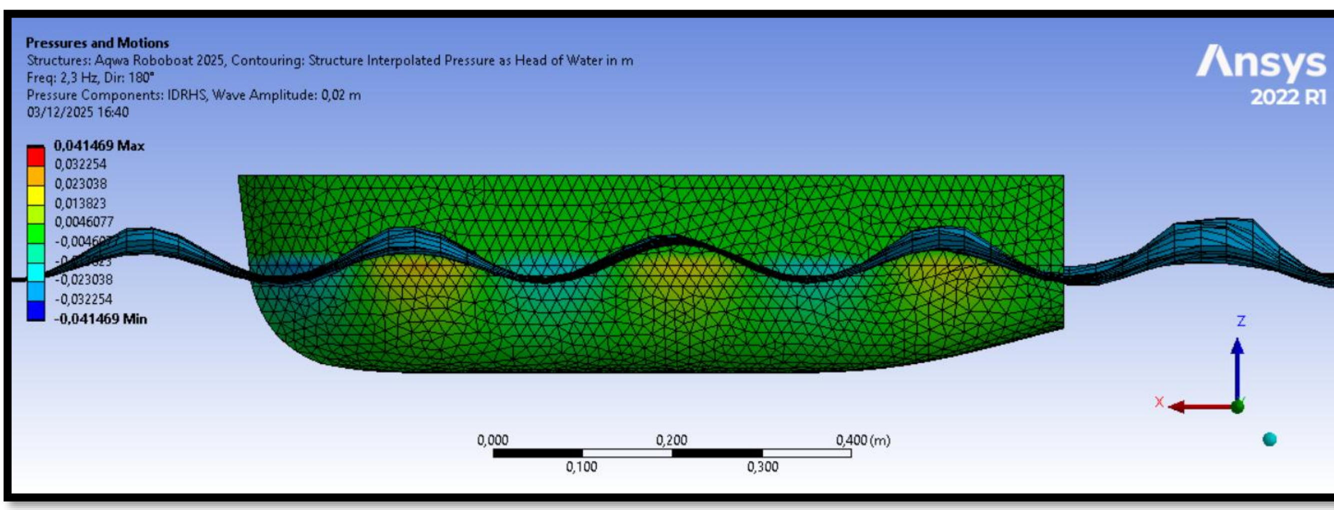


Fig. F-2. Ansys Aqwa simulation Mandakini Zenith

C. Wave Frequency – RAO Position

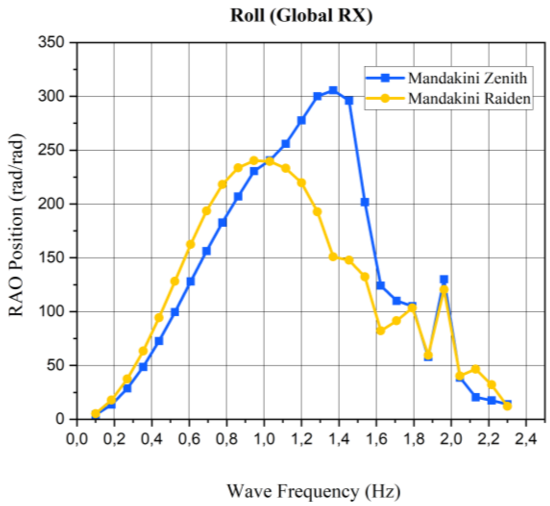


Fig. F-3. Roll result

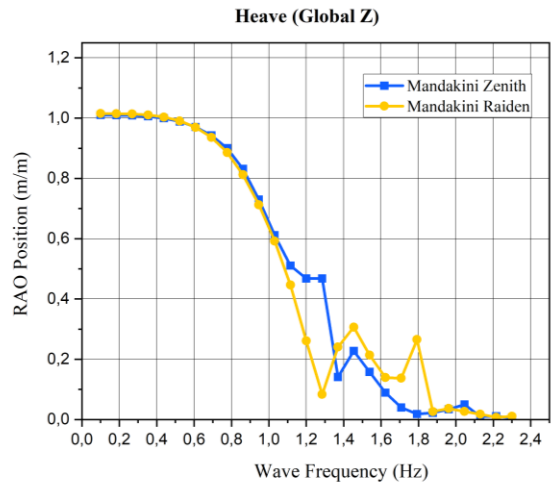


Fig. F-4. Heave result

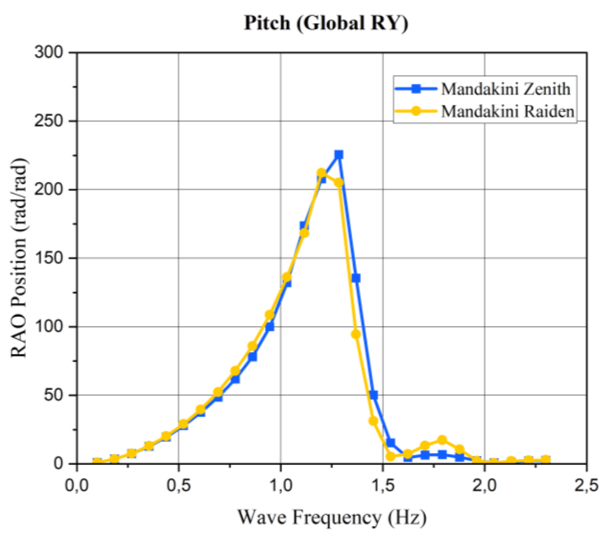


Fig. F-5. Pitch result

APPENDIX G: STABILITY SIMULATION

Table G-1. Stability Simulation Result

Heel to Starboard (deg)	GZ Value (m)	
	Mandakini Raiden	Mandakini Zenith
0	0.000	0.000
10	0.244	0.130
20	0.334	0.229
30	0.305	0.235
40	0.268	0.207
50	0.223	0.172
60	0.171	0.132
70	0.114	0.088
80	0.055	0.041
90	-0.004	-0.005
100	-0.063	-0.052
110	-0.120	-0.098
120	-0.173	-0.141
130	-0.223	-0.180
140	-0.267	-0.214
150	-0.305	-0.240
160	-0.333	-0.222
170	-0.257	-0.128
180	0.000	0.000

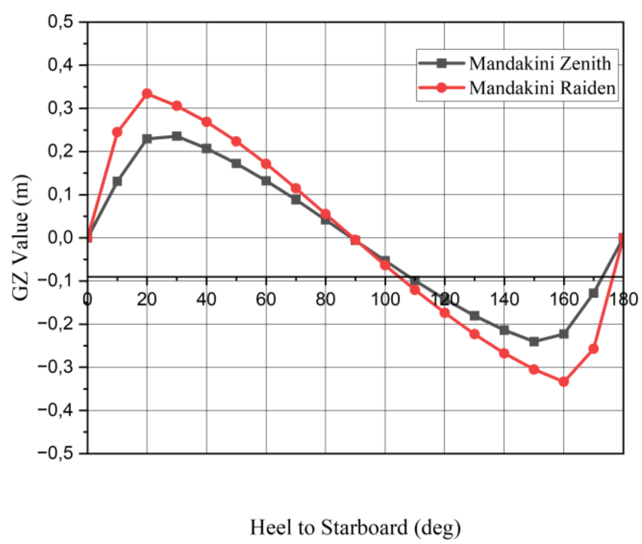


Fig. G-1. Stability simulation results

APPENDIX H: HULL RESISTANCE

A. Ansys Fluent Simulation Mandakini Raiden (2026)

Environment

Fluid Velocity : 2 m/s
Number of Iterations : 500
Water Density : 998 kg/m³
Air Density : 1225 kg/m³

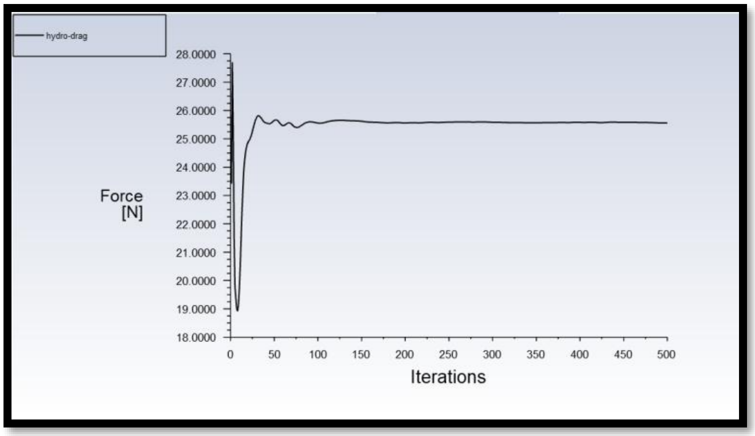


Fig. H-1. Ansys Fluent simulation Mandakini Raiden

B. Ansys Fluent Simulation Mandakini Zenith (2025)

Environment

Fluid Velocity : 2 m/s
Number of Iterations : 500
Water Density : 998 kg/m³
Air Density : 1225 kg/m³

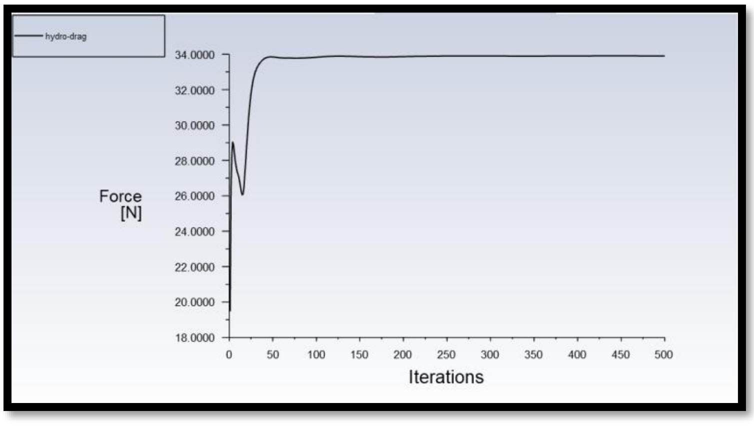


Fig. H-2. Ansys Fluent simulation Mandakini Zenith

Table H-1. Resistance Simulation Result

Type	Resistance (Newton)
Mandakini Raiden	25.55
Mandakini Zenith	33.91

APPENDIX I: FRAME SIMULATION

A. Fusion 360 Simulation Static Stress

Material Type: Aluminium 2014-T4

Material Properties:

Yield Strength = 290 MPa

Density = 2.800E-06 kg/mm^3

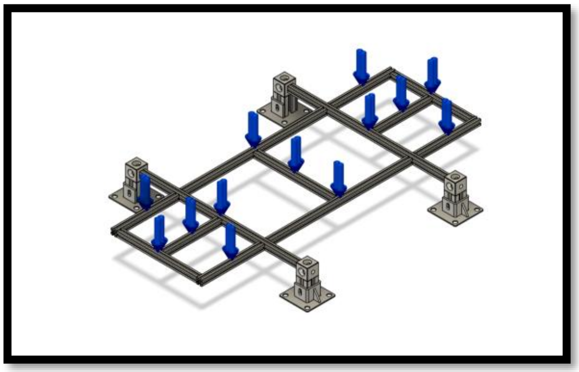


Fig. I-1. Axial force

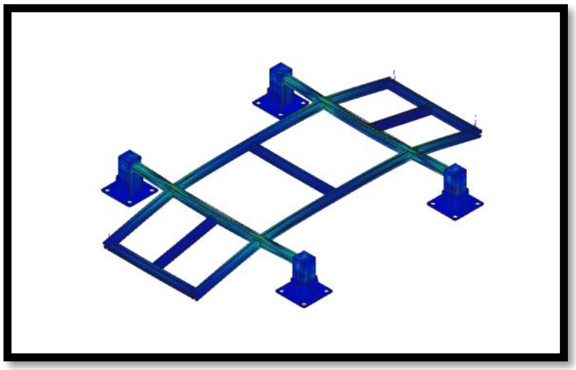


Fig. I-2. Von Mises stress

Table H-1. Frame Simulation Results

Parameter	**Value**	
	Minimum	**Maximum**
Axial Force	0	60 N
Reaction Force	0	13.149 N
Von Mises Stress	0	7.636 MPa
1st Principal Stress	−1.791 MPa	8.951 MPa
3rd Principal Stress	−8.798 MPa	1.651 MPa

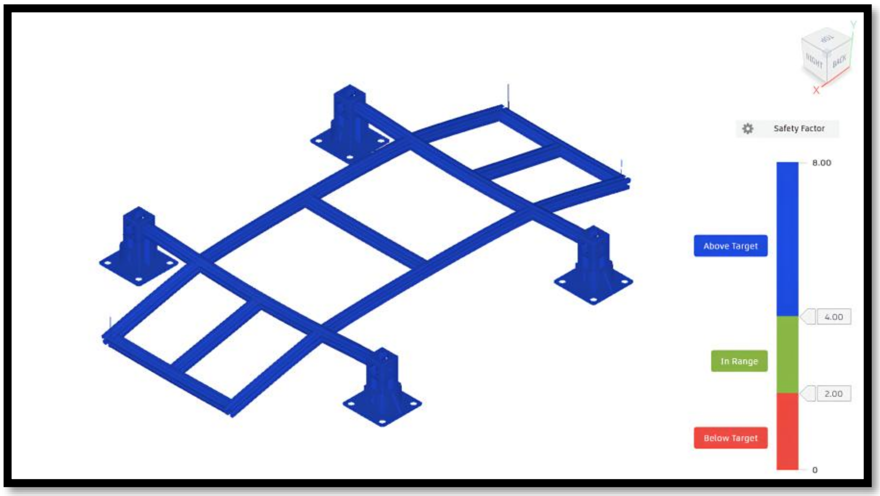


Fig. I-3. Safety factor

APPENDIX J: THRUST CALCULATION

T200 @ 16 V

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

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

Maximum forward using T200 @16 V recorded in Mandakini Zenith (2025):
$10.2/2 = 5.1$ kg f per thruster

$$K = 1 + k\left(\frac{D}{h} - 1\right)$$
$$K = 1 + 0.07\left(\frac{76}{70} - 1\right) \approx 1.008$$

$$T = T \times K$$
$$T = 5.10 \times 1.008 \approx 5.13$$

$$\eta = \frac{T}{Tmax} = \frac{5.13}{5.25} \approx 97{,}7\%$$

Maximum forward using T200 @16 V recorded in Mandakini Raiden (2026):
$10.2/2 = 5.1$ kg f per thruster

$$K = 1 + k\left(\frac{D}{h} - 1\right)$$
$$K = 1 + 0.07\left(\frac{76}{70} - 1\right) \approx 1.027$$

$$T = T \times K$$
$$T = 5.10 \times 1.027 \approx 5.23$$

$$\eta = \frac{\mathrm{T}}{Tmax} = \frac{5.23}{5.25} \approx 99{,}6\%$$

T	=	Thrust	D	=	Thruster Diameter
T_{max}	=	Max Thrust	h	=	Distance to Hull
η	=	Efficiency			
K	=	Installation Factor			

Positioning the thrusters directly to hull can reduce external flow losses, improving the thrust efficiency and allowing the T200 thrusters to operate closer to rated maximum thrust.

APPENDIX K: OBJECT DETECTION AND COMPUTER VISION TESTING

To evaluate the performance of YOLOv4 and YOLOv4-Tiny, model training was conducted using a dataset of 500 labeled images with 7 classes of objects, which were divided into 70% training data, 20% validation, and 10% test. All models were trained up to 6000 iterations (max_batches) using the Darknet framework with consistent hyperparameter configuration, while variation was only done on input resolution through width and height parameters. The training process was conducted on identical computing environments to ensure a fair comparison, and the accuracy of the detection was evaluated using the mAP@0.5 metric on the test dataset.

For real-time inference testing, the entire model was converted to the TensorRT format and deployed on the NVIDIA Jetson Nano using FP16 precision. Performance measurements are carried out by running direct inferences on the camera stream at 1280×720 resolution, with the main metric in the form of frames per second (FPS). A summary of the results of the accuracy and speed of inference tests is presented in Table K-1.

Table K-1 Results of YOLOv4 and YOLOv4-Tiny Performance Evaluation on Jetson Nano

Model	Resolution	mAP@0.5	FPS (Jetson Nano + TensorRT)
YOLOv4	416 × 416	79.02%	12 – 13 FPS
	640 × 352	84.88%	9 – 11 FPS
	608 × 608	84.41%	5 – 6 FPS
	960 × 544	-	-
	1280 × 720	-	-
YOLOv4-Tiny	416 × 416	72.78%	40 – 42 FPS
	640 × 352	**81.69%**	**29 – 32 FPS**
	608 × 608	79.55%	19 – 20 FPS
	960 × 544	83.17%	12 – 14 FPS
	1280 × 720	-	-

Due to GPU hardware limitations, several high-resolution configurations were not included in the training process. Specifically, YOLOv4 at an input resolution of 960 × 544 and 1280 × 720, as well as YOLOv4-Tiny at 1280 × 720, were not trained and evaluated because the increased computational and memory requirements exceeded the capabilities of the available training devices, resulting in potential instability during training.

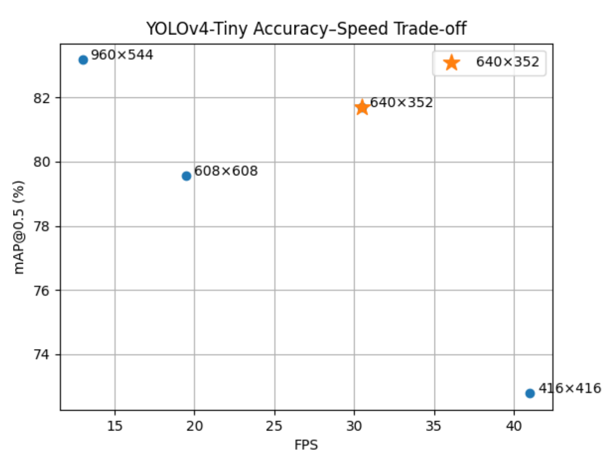


Fig. K-1. YOLOv4-Tiny accuracy–speed trade-off

APPENDIX L: COMMUNICATION CONFIGURATION

Learning from the signal interference constraints last year, the Bengawan UV team conducted an in-depth evaluation of the frequency selection strategy (see Table L-1) We conducted a field experiment by comparing the frequency configurations of 40 MHz (Auto) and 20 MHz (Channel 11) every distance of 20 meters to a radius of 100 meters. The test data proved that the use of Channel 11 with a narrower bandwidth (20 MHz) was much more effective in reducing noise and maintaining the stability of the Mandakini Raiden control in a frequency-intensive competition environment, as can be seen in Fig. L-1 and L-2

Table L-1 Communication Configuration Comparison

Distance	**Configuration Ch.Auto/40 MHz**		**Configuration B Ch.11/20MHz**	
	Latency	**Loss Package**	**Latency**	**Loss Package**
20	65	0.8	32	0.1
40	73	1.0	35	0.2
60	85	1.4	42	0.4
80	97	2.0	51	0.7
100	120	3.4	64	1.2

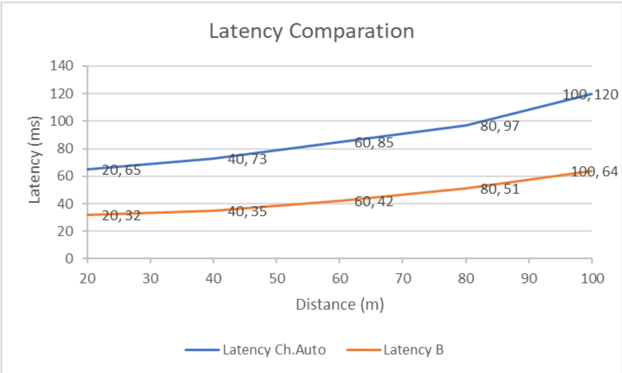


Fig. L-1. Comparison latency config Ch. Auto and Ch. 11

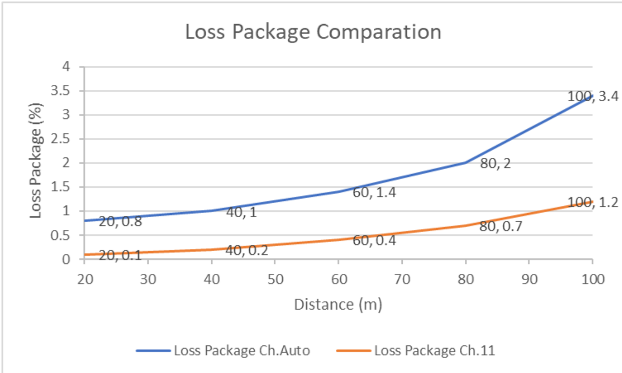


Fig L-2. Comparison Loss Package Config Ch. Auto and Ch. 11

APPENDIX M : GLOBAL POSITIONING SYSTEM TESTING

The performance test of the GPS navigation system is carried out by utilizing predetermined waypoints and data retrieval is carried out repeatedly at each point. The parameters observed included vertical accuracy, horizontal accuracy, and overshoot in various GPS conditions, namely 3D Fix, RTK Float, and RTK Fixed. Each waypoint is tested three times to evaluate the stability and consistency of the position measurement results. A summary of the accuracy test results is further presented in Table M-1 and Fig. M.

Table M-1. GPS Accuracy Test

Mode	Waypoint	Average Vertical Accuracy (m)	Average Horizontal Accuracy (m)	Average Overshoot (m)
3D Fix	1	2.26	1.19	2.56
	2	2.25	1.13	2.52
	3	2.12	1.10	2.39
	4	2.20	1.15	2.48
RTK Float	1	0.18	0.11	0.21
	2	0.14	0.09	0.17
	3	0.16	0.12	0.20
	4	0.17	0.14	0.22
RTK Fixed	1	0.03	0.02	0.04
	2	0.02	0.01	0.03
	3	0.03	0.01	0.03
	4	0.02	0.01	0.02

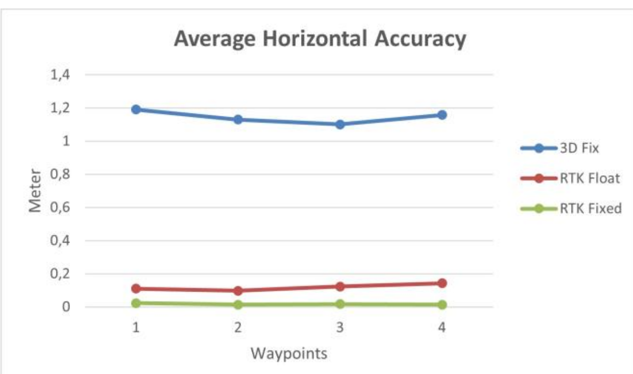


Fig. M-1. Average horizontal accuracy

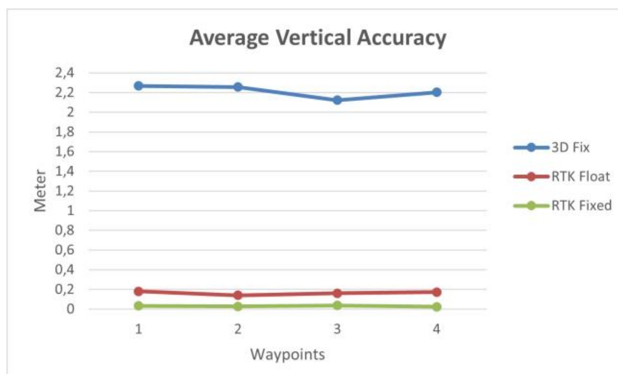


Fig. M-2. Average vertical accuracy

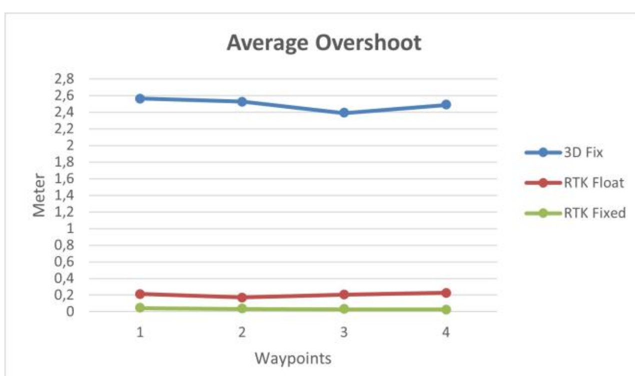


Fig. M-3. Average overshoot

APPENDIX N : SOUND DETECTION TESTING

The sound frequency detection system was tested using predefined reference frequencies with repeated measurements for each frequency. An omnidirectional microphone combined with a MAX4466 amplifier was used to capture and condition the acoustic signal for analog-to-digital conversion. The evaluated parameters included detected frequency, error percentage, sound source distance, and sound level. Tests were conducted at 600 Hz, 800 Hz, and 1000 Hz with ten trials for each frequency to assess detection accuracy and stability. The results of sound detection terting are summarized in Table N and Fig. N.

Table N-1. Sound Detection Testing Summary

Reference Frequency (Hz)	Trial	Detected Frequency (Hz)	Error (%)	Mic Source Distance (m)	Sound Level (dB)
600	1	584	2.67	0.10	73.24
	2	611	1.83	0.20	71.08
	3	604	0.67	0.30	70.56
	4	611	1.83	0.40	68.91
	5	604	0.67	0.50	65.37
	6	580	3.33	0.60	64.62
	7	597	0.50	0.70	62.15
	8	586	2.33	0.80	61.84
	9	581	3.17	0.90	60.09
	10	570	5.00	1.00	59.73
800	1	804	0.50	0.10	75.42
	2	807	0.88	0.20	72.18
	3	794	0.75	0.30	71.66
	4	811	1.38	0.40	69.05
	5	802	0.25	0.50	68.79
	6	794	0.75	0.60	66.21
	7	798	0.25	0.70	65.94
	8	815	1.88	0.80	63.47
	9	791	1.12	0.90	61.12
	10	780	2.50	1.00	60.68
1000	1	1001	0.10	0.10	71.35
	2	1007	0.70	0.20	70.92
	3	992	0.80	0.30	69.18
	4	1017	1.70	0.40	67.64
	5	1012	1.20	0.50	65.08
	6	982	1.80	0.60	64.51
	7	1005	0.50	0.70	63.89
	8	991	0.90	0.80	62.27
	9	1003	0.30	0.90	60.74
	10	983	2.70	1.00	59.06

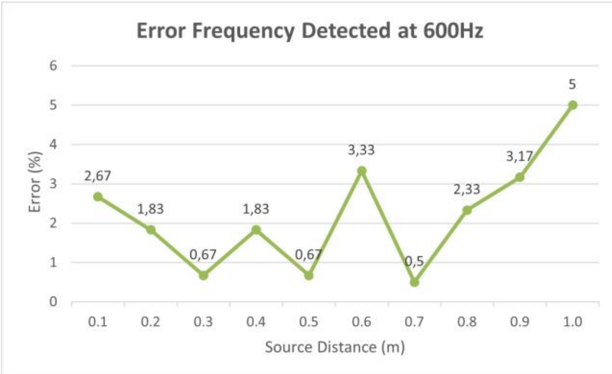


Fig N-1. Error frequency detected at 600 Hz

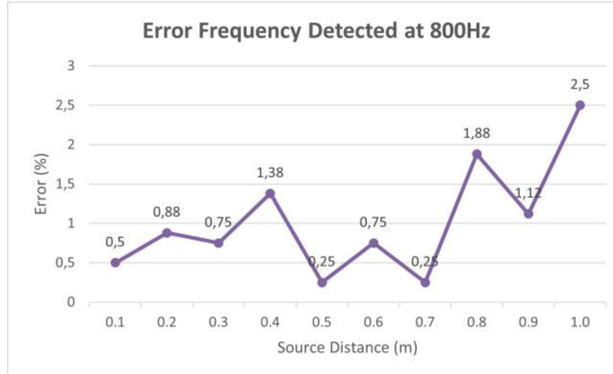


Fig N-2. Error frequency detected at 800 Hz

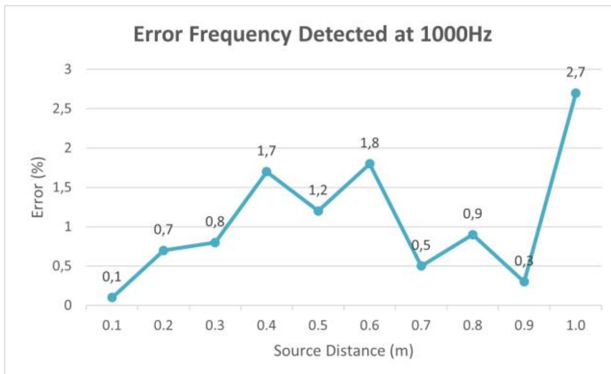


Fig N-3. Error frequency detected at 1000 Hz

APPENDIX O : COST-PERFORMANCE RATIO CALCULATION

A. *Index Definition and Formulation*

1. General Normalized Performance Index

   For performance parameters where a higher value indicates better performance (e.g., FPS, righting arm GZ, maneuver response), the normalized performance index is defined as:

$$I_p = \frac{P_{year}}{P_{baseline}}$$

   Where:
   P_{year} is the performance value of the evaluated design,
   $P_{baseline}$ is the corresponding value of the baseline design.

   Aplicable to:
   - Perception–control responsiveness (FPS).
   - Stability (GZ).
   - Seakeeping related performance.
   - Perception performance.

2. Inverse Normalized Performance Index

   For performance parameters where a lower value indicates better performance (e.g., latency, positioning error), an inverse normalization is applied:

$$I_p = \frac{P_{baseline}}{P_{year}}$$

   Aplicable to:
   - Navigation error (GPS/RTK).
   - Communication latency.
   - Control system delay.

3. Normalized Cost Index

   System cost is normalized using the same ratio-based approach to ensure consistency with performance indices:

$$I_c = \frac{C_{year}}{C_{baseline}}$$

   Where:
   C_{year} is the is the total system cost,
   $C_{baseline}$ is the is the total system cost of the 2025 design.

4. Overall Performance Index

   The total performance index is calculated as the arithmetic mean of all normalized performance indices:

$$I_{performance} = \frac{1}{N}\sum_{i=1}^{N} I_{p,i}$$

   Where:
   N is the number of evaluated performance parameters.

5. Cost–Performance Ratio

   The final efficiency metric is defined as:

$$Cost\ to\ Performance\ Ratio = \frac{I_{Performance}}{I_C}$$

   This ratio directly evaluates whether performance improvements outweigh cost increases.

B. Total System Cost Comparison

Table O-2. Total System Cost Comparison

Item	Mandakini Zenith (2025)	Mandakini Raiden (2026)	Change	Cost Index
Total System Cost (USD)	2,276.9	2,796,9	+520.0 (+22,83%)	**1.228**

The total system cost of the 2026 design increased by 520.0 USD compared to the 2025 baseline, corresponding to a cost index of 1.228. This moderate cost increase enables a significantly higher system performance, which is evaluated using normalized performance indices in the following sections.

C. Overall Performance Calculation

Table O-2. Overall Performance Calculation

Item	Mandakini Zenith (2025)	Mandakini Raiden (2026)	Change	Performance Index
System Responsiveness (FPS)	6.000	30.000	+24.000	5.000
Stability (GZ at 20° heel, m)	0.229	0.334	+0.105	1.460
Navigation Accuracy (Positioning Error, m)	1.500	0.020	-1.480	75.000
Communication Latency (normalized)	1.000	0.550	-0.450	1.820
Overall Performance Index				**16.950**

Table Notes:

- The 2025 system (Mandakini Zenith) is used as the baseline ($I = 1.00$).

- Performance indices are derived directly from quantitative data reported in the respective TDR documents.
- For parameters where lower values indicate better performance, inverse normalization is applied.

D. Cost-Performance Ratio

Table O-2. Overall Performance Calculation

Item	Mandakini Raiden (2026)
Cost Index	1.228
Overall Performance Index	20.820
Cost-Performance Ratio	**16.950**

The cost–performance ratio indicates that the 2026 design achieves a substantially higher performance gain relative to its cost increase. While the total system cost increased by approximately 22.8%, the overall performance index improved by more than an order of magnitude.

APPENDIX P : GLOSSARY

A

Actuator	:	A device that converts control signals into physical motion, such as motors and servos used for propulsion and mechanisms.
Algorithm Module	:	A software component responsible for navigation logic, waypoint generation, and decision-making processes
ANSYS Aqwa	:	A hydrodynamic simulation software used to analyze vessel stability, motion response, and wave interaction.
ANSYS Fluent	:	A computational fluid dynamics (CFD) software used to simulate hull resistance and fluid flow.
Arduino	:	A microcontroller platform used for processing sensor data and interfacing with electrical components.
ARM Mode	:	An operational state where the autopilot enables actuators and allows the vehicle to move.
Autonomous Surface Vehicle (ASV)	:	Unmanned surface vessels that can operate autonomously using computer-based navigation and control systems.

B

Bandwidth	:	Frequency bandwidths available for data transmission in wireless communications.
Beam (BOA)	:	The overall width of the vessel, influencing stability and buoyancy.
Block Coefficient (CB)	:	A dimensionless coefficient representing the fullness of a hull shape.
Braitenberg Algorithm	:	A reactive navigation algorithm that maps sensor inputs directly to motor outputs for obstacle avoidance and path following.

C

CAD (Computer-Aided Design)	:	Software used to create detailed 3D models of mechanical components and systems.
Catamaran	:	Boat design with two parallel hulls connected by deck or frame.
Communication Latency	:	The time delay between sending and receiving data in a communication system.

Composite Structure	:	A material system composed of two or more distinct materials, such as fiberglass and resin, to enhance strength and reduce weight.
CUDA	:	A parallel computing platform by NVIDIA used to accelerate GPU-based processing.

D

Darknet Framework	:	An open-source neural network framework used for implementing YOLO-based object detection.
DC Converter	:	An electronic device that converts one DC voltage level to another.
Demihull	:	One of the two hulls on the catamaran design
Displacement Hull	:	A type of hull that prioritizes buoyancy by pushing water to the side when moving.
Draft	:	The depth of the part of the boat that is submerged in water while floating.

E

EKF (Extended Kalman Filter)	:	Estimation algorithm that combines data from various sensors to improve the accuracy of position and orientation measurements.
ESC (Electronic Speed Controller)	:	A device that regulates the speed of electric motors based on control signals.

F

Finite State Machine (FSM)	:	A control model that divides system behavior into discrete states with defined transitions.
Flared Hull	:	Hull design with upwards widened sides for increased protection against wave blows.
Flat Bottom Hull	:	Hull type with a flat bottom that provides high initial stability.
FPS (Frames Per Second)	:	A measure of how many image frames are processed per second by the vision system.

G

GCS (Ground Control Station) : A land control station used to monitor and control boat remotely.

GPS (Global Positioning System) : A satellite navigation system that provides geographic location information.

H

Hull : The hull or hull that provides buoyancy and the main structure.

Hydrodynamic Losses : Energy losses caused by fluid resistance acting on a moving body.

I

IMU (Inertial Measurement Unit) : Sensors that measure acceleration, angular speed, and orientation use accelerometers and gyroscopes.

Interrupt-Based Algorithm : A control method that allows immediate response to external signals while other processes are running.

J

Jetson Nano : An NVIDIA embedded computing platform used for AI and vision processing.

L

LiDAR (Light Detection and Ranging) : A sensor that measures distance using laser pulses for obstacle detection.

LOA (Length Overall) : The overall length of the vessel from the front end to the rear.

LWL (Length Waterline) : The length of the boat's waterline when floating.

M

MAVLink : Lightweight communication protocol for data exchange between autopilot and ground control station

Mission Planner : A ground control software used for simulation, monitoring, and configuration.

Midpoint Navigation	:	A navigation method that steers the vessel toward the midpoint between detected markers.

P

Pixhawk	:	An autopilot controller handling low-level control and sensor integration.
PWM (Pulse Width Modulation)	:	Digital signal modulation technique to control motor speed or servo position.

R

RAO (Response Amplitude Operator)	:	A transfer function that describes the response of the boat's motion to waves at various frequencies.
ROS (Robot Operating System)	:	A middleware framework for the development of robotic software that provides communication services between nodes.
Round Hull	:	The hull design has a curved shape that provides smooth stability but the initial stability is lower.
RTK (Real-Time Kinematic)	:	A high-precision GPS technique that uses a base station for real-time correction, results in centimeter-level accuracy.

S

Sensor Fusion	:	The process of combining data from multiple sensors to improve accuracy and reliability.
SITL (Software In The Loop)	:	Software simulation that allows algorithm testing without physical hardware.

T

TensorRT	:	An NVIDIA optimization library for accelerating deep learning inference.
Thruster	:	A propulsion device that generates thrust to move or steer the vessel.

V

Vacuum Infusion Process (VIP)	:	A composite manufacturing technique that uses vacuum pressure to infuse resin into fiber layers.

Vision System	:	A perception subsystem that processes camera data for object detection and navigation
Von Mises Stress	:	An equivalent stress measure used to predict material yielding under load.

Y

YOLO (You Only Look Once)	:	Neural network architecture for real-time object detection.
YOLOv4-Tiny	:	A lightweight version of YOLO optimized for embedded systems with limited computing power.