RoboBoat 2026: Technical Design Report Kaan Technology Club

Görkem Kemal Ermurat, Mustafa Dursun, Berfin Karal, Ufuk Çana, Emre Yenice, Eren Taşdemir, Yasemin Makal, Serhat Asım Yiğit, Gamze Dabbakli, Ömer Ömeroğlu, Enes Diyarbakırlı, Tahsin Emirhan Kavlak, Sefa Şahin, Şiar Tunçdemir, Halil Ölmez, Adana Alparslan Türkeş Science and Technology University, Türkiye, Adana

Abstract - **This report presents the design and manufacturing of the autonomous surface vehicle Ertuğrul, developed by the Kaan Technology Club for the RoboBoat competition. A catamaran hull configuration is adopted to enhance stability, support modular integration, and ensure safe operation in dynamic marine environments. Ertuğrul is designed to autonomously execute mission tasks including waypoint navigation, obstacle avoidance, ball launching, and target engagement. The design prioritizes operational safety, software reliability, and predictable behavior over system complexity. A layered, safety-oriented software architecture enables the vehicle to operate under sensor uncertainty and environmental disturbances, transitioning to predefined safe modes when necessary to ensure robust competition performance.**

1. INTRODUCTION

RoboBoat is an international competition where teams develop autonomous surface vehicles capable of performing navigation and mission tasks in real and dynamic marine environments. Reliable perception, robust decision-making, and safe autonomous behavior are therefore critical to success.

This project marks the first RoboBoat participation of the Kaan Technology Club. Accordingly, the design prioritizes reliability, operational safety, and predictable behavior over complex or experimental solutions. The developed vehicle, Ertuğrul, is designed to maintain stable and controlled operation throughout competition tasks.

Wave-induced motion is identified as a key challenge, as it affects vehicle stability and degrades LiDAR and vision sensor performance. To mitigate this, conservative decision-making strategies are adopted to ensure safe operation under sensor uncertainty. Manual override and emergency stop capabilities are also included to enable immediate human intervention when required.

2. COMPETITION STRATEGY

The competition strategy of the Kaan Technology Club prioritizes safe, controlled, and reliable task execution over aggressive or high-risk maneuvers. The primary objective is to ensure that Ertuğrul can attempt and complete all competition tasks in a stable and predictable manner. Mission tasks such as waypoint navigation, obstacle avoidance, ball launching, and target engagement are executed using predefined operational modes tailored to task requirements and risk levels. This structured approach ensures consistent system behavior and reduces unexpected subsystem interactions. Safety is embedded at the core of the strategy through software-based checks, sensor validation, and state-dependent decision logic. Under degraded environmental conditions or reduced sensor confidence, the system transitions to conservative operating modes to maintain stability and prevent mission failure.

3. DESIGN STRATEGY

3.1. Hull Design and Analysis

Values	
Length	*1150.57 mm*
Beam	*714.4 mm*
Height	*199.86 mm*
Draft	*120 mm*
Weight	*24.7 kg*

Table 1. Main Physical Parameters of the Ertuğrul ASV

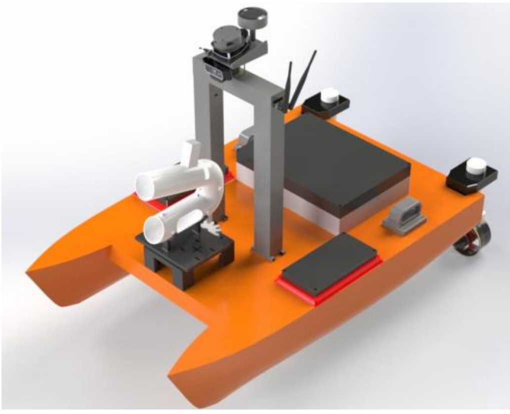

Figure 1. General 3D design of Ertuğrul, showcasing the catamaran hull configuration and sensor tower layout.

The hull design of Ertuğrul is primarily focused on stability, durability, and watertight integrity to ensure reliable autonomous operation under challenging marine conditions. A catamaran configuration is selected to enhance transverse stability and reduce sensitivity to wave-induced roll motions.

To enhance stability, heavy components such as batteries are positioned within the hulls to serve as ballast. This configuration lowers the Center of Gravity and increases the Metacentric Height, thereby optimizing both static and dynamic stability. These features are critical for maintaining seaworthiness in wave-disturbed environments[1][2]. The batteries are secured in waterproof housings to ensure electrical safety. Structurally, the hulls utilize a hybrid birch and balsa wood framework, selected for its superior strength-to-weight ratio. This core is reinforced using a hand-layup method with multi-layer composite lamination for increased rigidity and impact resistance, followed by a marine-grade finish to guarantee watertight integrity.

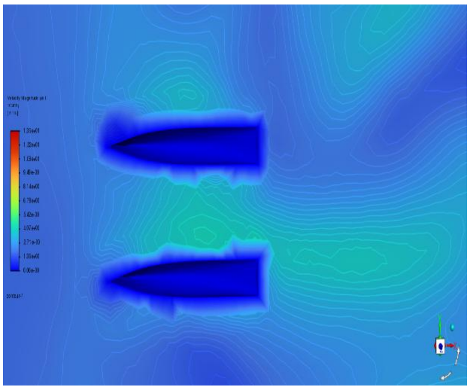

Figure 2. Hydrodynamic flow and the generation of waves

Figure 2 presents the velocity vector field and the free-surface wave generated around the USV from the CFD simulation performed using ANSYS Fluent. At a design speed of 1.30 m/s, the simulation shows a typical bow wave and acceleration in the velocities along the sides of the hull, succeeded by a marked wake area downstream that ensures proper energy dissipation. The wave pattern produced is continuous and stable without undue turbulence, which shows that the geometry of the hull minimizes wave resistance effectively. A correctly distributed balance of flow is important for the stability during autonomous navigation and the exactitude of sensors during missions.

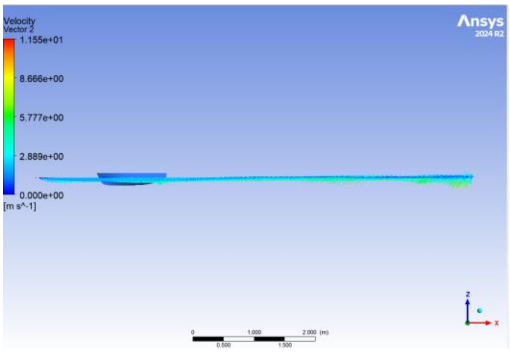

Figure 3. Twin-Hull Interaction

Figure 3 shows the wave structure and associated velocity field formed on the free surface as a result of the ship's movement on the water. Significant changes in velocity vectors are observed due to the acceleration and change in direction of the flow along the free surface as the ship moves.

3.2. *Propulsion*

The propulsion and steering mechanism of the Ertuğrul is designed to provide high agility, safety of operation, and control during the autonomous mission. The vehicle employs two Degz Utras BLDC motors with a thrust of 8 kgf each; the motors are fixed at the end of the dual-body hulls. The steering of the vehicle is performed through the differential thrust method; this eliminates the need for the rudder system [3]. This allows the control of the propulsion system independently; this is important during low-speed control of the robot during the mission.

Figure 4. A representative propulsion module of Ertuğrul showing a single BLDC motor and mount

The platform employs two identical units mounted at the stern of each hull to achieve differential thrust control.

3.3. *Mission Mechanisms*

TThe mechanisms in Ertugrul focus on being mechanically simple, modular, and safe for operation. The high level of integration with 3D printing enables fast iteration and geometric control. The system is broken down into self-contained modular subsystems, making it easy to maintain and integrate.

3.3.1. Ball Launcher Mechanism

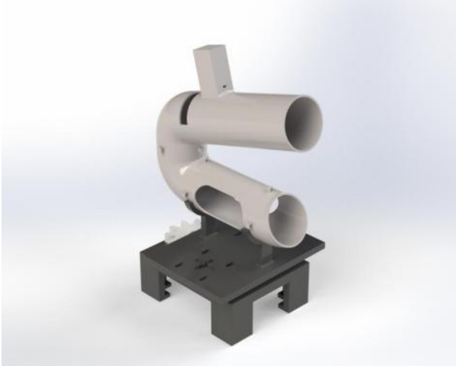

Figure 5. Detailed view of the Ball Launcher Mechanism, including the vertical magazine and the friction-based launching subsystem.

The launching system is made up of a vertical magazine system, a feed system, and a friction-driven launching unit. The rubber balls are delivered by the force of gravity to a predetermined location where the linear pusher, powered by a crank slider mechanism, propels the balls one by one to the launching stage. This design helps overcome the problem of jamming by utilizing the conversion of rotational motion into linear motion. The launching system uses two counter-rotating wheels with a spacing just smaller than the rubber ball radius; the wheels provide the rubber ball with a friction-driven acceleration.

3.3.2. *Aiming and Turret Mechanism*

The aiming system uses a gear-driven system in its mechanism to ensure accurate launching angle adjustment. For safety purposes, the control sequence synchronizes the system to lock the ball feeder until the launching device attains its operational speed and is in the ready state.

3.3.3. *Water Cannon System*

The water cannon uses a custom 3D-printed nozzle, which is positioned at an angle to improve the water trajectory. This water cannon system is directly integrated into the ball launcher assembly, which helps save space while making the Vehicle structure simpler.

3.4. LIDAR Mounting System

For efficient data acquisition, a LiDAR mounting platform was designed and developed using additive manufacturing. The mounting platform is lightweight, stiff, and resistant to vibrations, which otherwise may degrade measurements. Additionally, it is angled by 10° to improve detection of surface-level objects, reducing self-interference between the vessel's physical structure and the sensor. The sensor is also positioned 50cm above the deck to improve the field of view. The mounting stand is 28cm wide, offering sufficient stability.

Figure 6. LiDAR mounting structure designed at a 72-degree inclination to optimize the scanning field and minimize interference.

3.5. *Electrical System*

The electrical system of the vehicle is designed keeping in mind reliability as well as modularity. Instead of using complex designs of printed circuit boards, the adoption of commercial components in modular forms was preferred..

3.5.1. *Energy Management*

The energy source of the system includes two Masterflight 6S (22.2V) 10000 mAh Li-Po batteries with a 65C discharge rate. These batteries maximize operation duration. The system architecture is built upon a Dual-Path Power Architecture, which isolates the power lines into Clean and Dirty lines. Clean line powers the autonomous systems. To prevent interference from motor noise and voltage spikes, this line is tapped before the main safety relay and is isolated with dedicated voltage regulators. Dirty line powers the propulsion system. Energy distributed via the KNPDB-02140 Power Distribution Board is physically cut off by an 80A Safety Relay in emergency situations, complying with safety protocols.

3.5.2. Computing & Sensors

In autonomous missions, the AI processing component is the NVIDIA Jetson Xavier NX module. The module is mounted on the Auvidea JNX30D carrier board for increased robustness when exposed to marine environments and vibrations. The computing performance of 21 TOPS allows for real-time processing of image processing algorithms. Stabilization and control of the vehicle are achieved using a CubePilot Cube Orange with a 32-bit ARM7H processor. High accuracy positioning of one centimeter is achieved using the CubePilot HERE 4 GNSS receiver with Multi-Band RTK and CAN FD protocols. Telemetry with a long range can be achieved using the RFD900X modem, while manual control can be achieved using the Radiolink R9DS receiver with the SBUS protocol.

3.5.3. Safety & E-Stop Architecture

The key safety feature of this system is the Wireless Emergency Stop (E-Stop), which is implemented through an Arduino Nano and MOSFETs. The E-Stop logic circuit is powered by a two-cell (2S) Li-Ion battery configuration, which is separate from the system's power source (see Appendix A). This ensures that the safety system will continue to function even during a failure of the system battery. When an E-Stop situation occurs, pressing an E-Stop Button or giving a remote command through LoRa will activate an 80 A relay to interrupt power to the propulsion system's motors. When an E-Stop is triggered, only the propulsion system will be turned off; the Jetson board and GPS will continue to function to track the location and status of the vehicle.

3.5.4. Propulsion & Actuation

The vehicle achieves mobility through DEGZ Ultras BLDC thrusters. Their magnetic coupling technology eliminates the risk of water leakage. The motors are controlled by waterproof Surpass Hobby KK 150A ESCs, designed to withstand harsh marine environments. The shooting mechanism is precisely controlled using an Arduino Uno and a CNC Shield driver board to drive the stepper motors. For voltage regulation of servo motors and peripherals, an XL4015 Buck Converter is utilized to minimize power loss.

3.5.5. Electrical & Electronics Box

The EE box houses all critical electrical and electronic components within a waterproof enclosure designed for marine environments. The enclosure is implemented in a modular configuration, allowing rapid removal and reinstallation of the electronics unit in case of faults, inspections, or maintenance during testing and competition scenarios.

To mitigate the risk of water ingress caused by repeated removal and installation of the enclosure, a custom sealing frame was designed and manufactured using 3D printers. This frame ensures alignment between the enclosure and the hull interface while maintaining watertight integrity. The solution preserves modular accessibility without compromising environmental protection. Inside the EE box, the Jetson, ESCs, and the PDB systems are integrated into a centralized layout. This configuration improves cable management, system organization, and ease of troubleshooting.

Figure 7. Internal layout of the EE Box, showing the integration of the NVIDIA Jetson, ESCs, and PDB systems.

3.6. SOFTWARE

3.6.1. Vision

The perception system relies on YOLOv8 for real-time object detection. To provide three-dimensional spatial localization with high accuracy, a geometry fusion algorithm is used. This involves the transformation of the centers of the bounding boxes in the 2D images into angular coordinates and matching these with the range values obtained by the LiDAR system for depth estimation of the objects. Temporal and probability filters are used to reduce the effects of false positives and improve object tracking.

3.6.2. Navigation System

Based on the ROS2 Nav2 stack, the navigation component converts high-level autonomy commands into motion primitives. It is a waypoint-based controller, as the path planning is continuously updated by the fusion of perception results. The execution state of the trajectory is tracked using the Nav2 Simple Commander API, which has triggers for failsafe stops and recovery maneuvers in case of planning and obstacle threshold violations.

3.6.3. Main Autonomy System

The overall autonomy system supports an autonomy execution mechanism as the central coordinator for perception, navigation, and mission processes, implemented as a Finite State Machine (FSM). The FSM controls the mission process by managing states such as (Idle, Execute, Recovery, Completed, Search). The mission process is implemented as separate tasks as modular units that communicate with the FSM and produce atomic status indicators (Success, Failure, Running). The transitions among the states in the FSM are controlled by the status indicators, such that success leads to the next sequence in the mission plan, while failure transitions to error handling states (e.g., retry, skip, or safe-stop).

3.6.4. Testing & Simulation

Before testing the algorithm in the real world, it is tested through a Gazebo simulation environment. This environment simulates the dynamics of a vehicle, its buoyancy, as well as its sensor noise through the Robot Operating System (ROS). Therefore, the method ensures a thorough test of a logic or control system before implementation on a physical vehicle.

3.6.5. Tasks

Task 1: Evacuation Route & Return

The unmanned surface vehicle (USV) independently moves through the gate defined by red/green buoy pairs with the goal of targeting the midpoint between the buoys. In situations of incomplete perception, the control system models the geometry of the gate by means of a single perceived buoy (ghost buoy) with a time-constrained forward progression strategy.

Task 2: Debris Clearance

The vehicle moves through the channel with pairs of buoys, choosing the best gate. If the center route is blocked by an obstacle, the target is altered so that the vehicle can pass through. To avoid deadlock, the vehicle uses the time-limited progression technique, which avoids stagnation due to lost perceptions.

Task 3: Emergency Response Sprint

The USV moves through a gate and enters search mode to track a light beacon. After detecting the color of the beacon, it performs a directional circle on the respective buoy (yellow) and enters through the entry gate. Failsafe features are incorporated to ensure safe shutdown in case of dubious sensor information.

Task 4 - Supply Drop

The process relocates the target points identified by YOLO from Pixel Space to Actuator Space. The pixel error ($E_{pixel} = P_x - C_x$) is calculated with respect to the center of the image ($C_x = W/2$) and is further transformed into angular displacement (θ). Using a resolution of 1.8 steps per degree, the motor displacement is calculated by the transfer function $S_{motor} = \theta \times 1.8$. The Arduino controls a relay-switched 12V/3A water pump for releasing the payload.

Task 5: Navigate the Marina

The USV scans docking slots to identify available positions based on the color of Solid Color Cylinders. It moves forward, scanning right and left. Upon identifying the target color and aligning, it autonomously docks. If a slot is occupied or incorrect, the vehicle proceeds to scan the next slot.

Task 6: Harbor Alert

The system detects an active signal. The DOA of the signal is determined by signal processing algorithms. The USV independently navigates and hovers at a location that verifies the alert region.

3.6.6. Communication

The communication between the USV and the Ground Control Station (GCS) is performed through the Wi-Fi connection. There is also the custom-developed video server based on the Flask framework, which is utilized in the compression and transmission of the camera images. This enables real-time situational awareness for the operator. There is also the incorporation of the terminal-based mission control interface. Furthermore, the GCS uses the redundant RF connection, which offers the hardware safety (e-stop) that is independent of the software network.

4. REFERENCES

[1] J. Mégel and J. Kliava, “Metacenter and ship stability,” *American Journal of Physics*, vol. 78, no. 7, pp. 738–747, Jul. 2010, doi: 10.1119/1.3285975.

[2] E. V. Lewis, Ed., *Principles of Naval Architecture: Vol. I - Stability and Strength*. Jersey City, NJ: SNAME, 1988.

[3] Pandey j., Hasegawa k., Study on Turning Manoeuvre of Catamaran Surface Vessel with a Combined Experimental and Simulation Method, 2016.

APPENDIX A: ELECTRONICS DESIGN

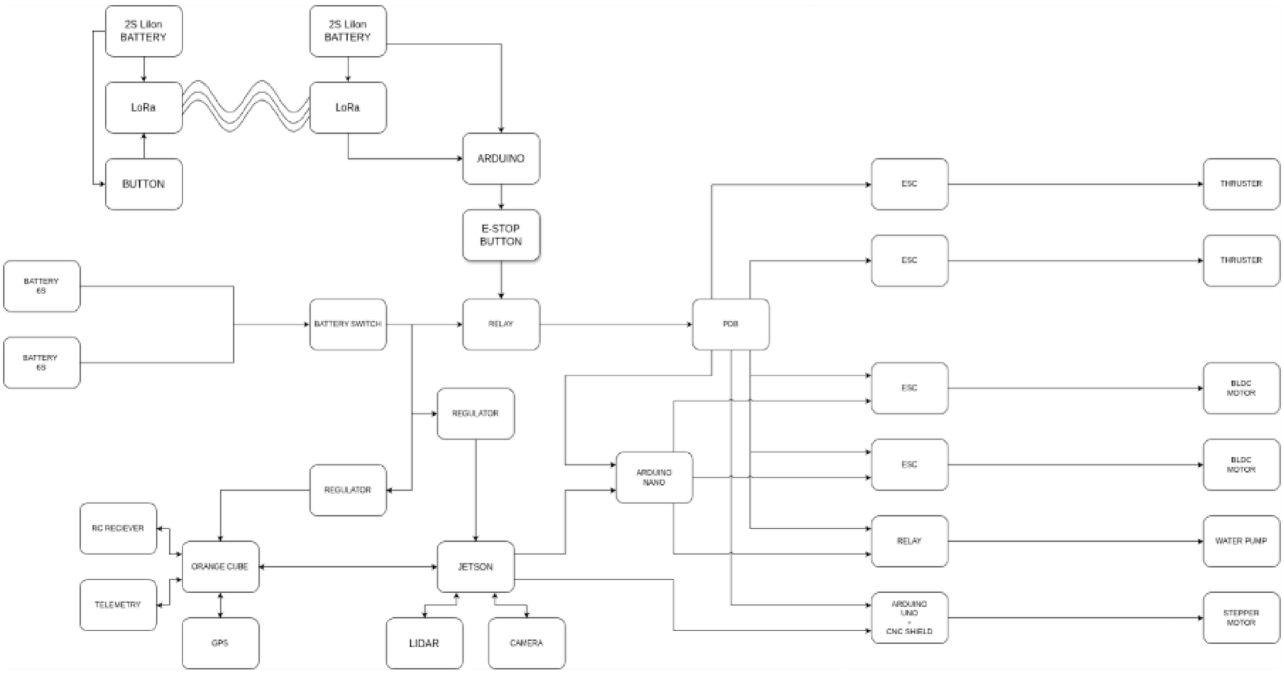

Figure A.1. Schematic diagram of the electrical design of the USV

Category	**Component**	**Vendor**	**Model/Type**	**Specs (Technical Details)**	**Custom/Purchased**	**Cost (USD)**
Power & Safety	Main Battery	Masterflight	6S Li-Po	22.2V 10000mAh, 65C Discharge	Purchased	200$
Power & Safety	Aux Battery	Generic	2S Li-Ion	7.4V, Emergency Circuit Power	Purchased	75$
Power & Safety	PDB	Kaan Tech	KNPDB-02140	High Current Dist., Solder Pads	Purchased	50$
Power & Safety	Power Relay	ELO	80A Relay	12V/24V Coil, Main Cut-off	Purchased	30$
Power & Safety	Master Switch	Autoline	Battery Switch	Manual Isolation, High Current	Purchased	25$
Power & Safety	E-Stop	Generic	Mushroom Head	IP65, Latching, Twist-to-Release	Purchased	25$
Power & Safety	BuckConverter	Generic	XL4015	Step-down, 24V to 12V/5V	Purchased	10$

Power & Safety	Relay Driver	Generic	IRF3205	N-Channel MOSFET, Low-side Switch	Purchased	10$
Computing	AI Computer	NVIDIA / Auvidea	Xavier NX / JNX30D	21 TOPS AI, Industrial Carrier	Purchased	600$
Computing	Autopilot	CubePilot	Cube Orange	Triple Redundant, Ext. Kalman Filter	Purchased	833$
Sensors	GPS / GNSS	CubePilot	HERE 4	Multi-band RTK, CAN FD Protocol	Purchased	500$
Sensors	LIDAR	Slamtec	RPLIDAR A1	360° 2D Laser Scanner, Obstacle Det.	Purchased	220$
Sensors	Camera	Logitech	C920s PRO	1080p, Computer Vision Tasks	Purchased	75$
Control	MCU (Actuators)	Arduino	Uno R3	Turret & Launcher Management	Purchased	20$
Control	MCU (Safety)	Arduino	Nano V3	Isolated Logic for E-Stop	Purchased	15$
Control	Driver Shield	Generic	CNC Shield V3	Stepper Motor Driver Expansion	Purchased	10$
Control	Telemetry	RFDesign	RFD900X	Long Range, AES Encrypted, 900MHz	Purchased	1000$
Control	Receiver	Redytosky	915 MHZ Receiver	915 Mhz	Purchased	35$
Control	Remote Stop	Generic	LoRa Module	915MHz, Independent Trigger	Purchased	20$
Control	Transmitter	Jumper RC	T-14	EdgeTX, Hall Gimbals, ELRS/2.4GHz	Purchased	200$
Propulsion	Main Thruster	DEGZ	Ultras Thruster	Brushless, Magnetic Coupling	Purchased	555$
Propulsion	Main ESC	Surpass Hobby	KK 150A	Waterproof, High Current, Thermal Mgmt	Purchased	120$
Actuation	Turret Motor	Generic	NEMA 17	Stepper Motor, Precision Positioning	Purchased	100$
Actuation	Pump Relay	Generic	5V Relay Module	Opto-isolated, Logic Level Switch	Purchased	10$
Actuation	Water Pump	Seaflo	1100GPH Bilge	12V Submersible, Centrifugal	Purchased	32$
Actuation	Launcher ESC	Hobbywing	Skywalker 60A V2	5V/5A UBEC, 60A Cont. Current	Purchased	40$

Actuation	Launcher Motor	Sunnysky	X2814 1250KV	Brushless Outrunner, High RPM	Purchased	30$

Table A.1. List of the electrical components.

APPENDIX B: MECHANICAL MANUFACTURING PROCESS

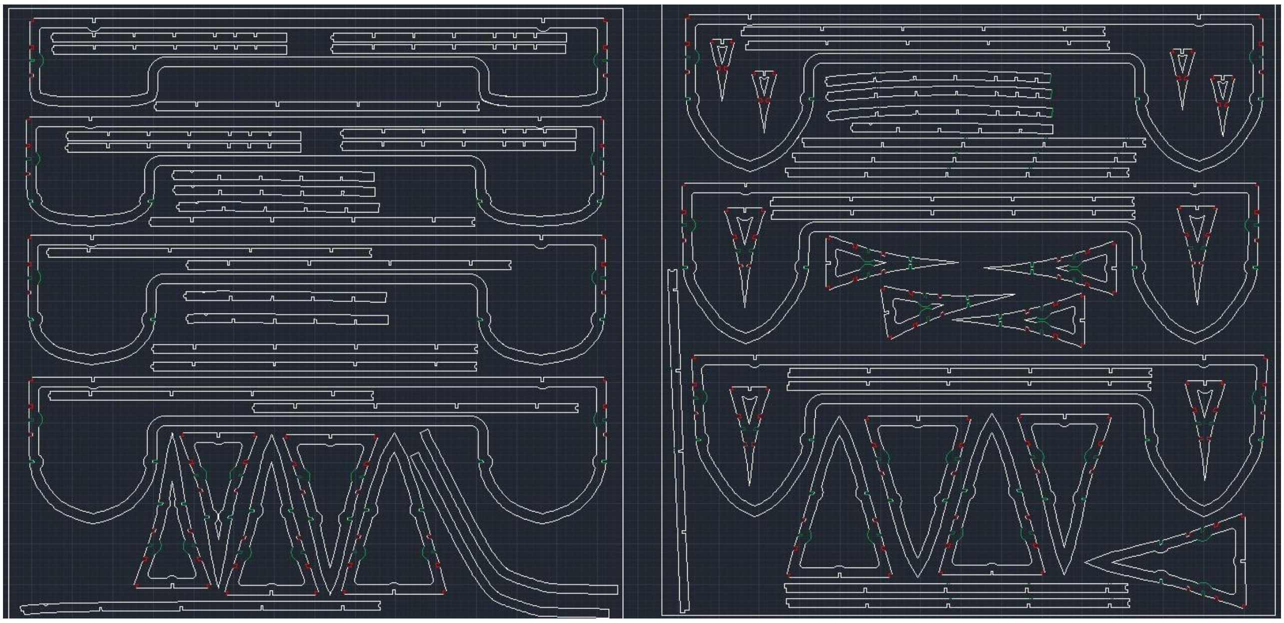

Figure B.1. Ertuğrul Body Structure Laser Cutting Plan and Part Layout

The process of manufacturing the vehicle starts with the development of the model of the vehicle in Auto CAD, Solidworks and Maxsurf. This stage of the process helps in determining the shape of the vehicle. After the completion of the design process, the main body frame of the vehicle is developed using birch wood. This stage of the process requires the birch wood because the wood helps in giving strength to the vehicle. This stage of the process is important because, during this time, the design of the vehicle is directly transferred to the physical product. After the completion of the development of the main body frame, the body of the vehicle is designed. This stage of the process requires balsa wood because of its lightweight properties. Balsa wood is chosen because of its ability to help in the design of the hydrodynamic body of the vehicle. Its properties are best suited for molding the outer structure to enable it to move easily in the water and to take on the desired final shape. After the molding is finished, various surface treatments are carried out to provide strength to the structure and to make it waterproof. In order to provide strength to the structure, five layers of fiberglass were laminated on top of it. After that, one layer of carbon fiber was also laminated on top of it to provide it with more rigidity while keeping it light in weight. In this stage of lamination of the composite materials, an epoxy resin was used to bond the structure together and to provide it with complete waterproofing.

After this, small gaps on the surface of the composite coat were filled using a body filler, which made it smooth and even. Sanding was then done, which made the outside shell smooth, without any bumps or irregularities on its surface.

The final stage involved painting the vehicle to complete its aesthetic look. Additionally, it served as another form of protection from the environment. With this, the final look of the vehicle had been achieved.

APPENDIX C: CFD ANALYSES OF THE SUB-COMPONENTS

The figures present the finite element analysis results of the launch mechanism components and motor mount under static loading conditions.

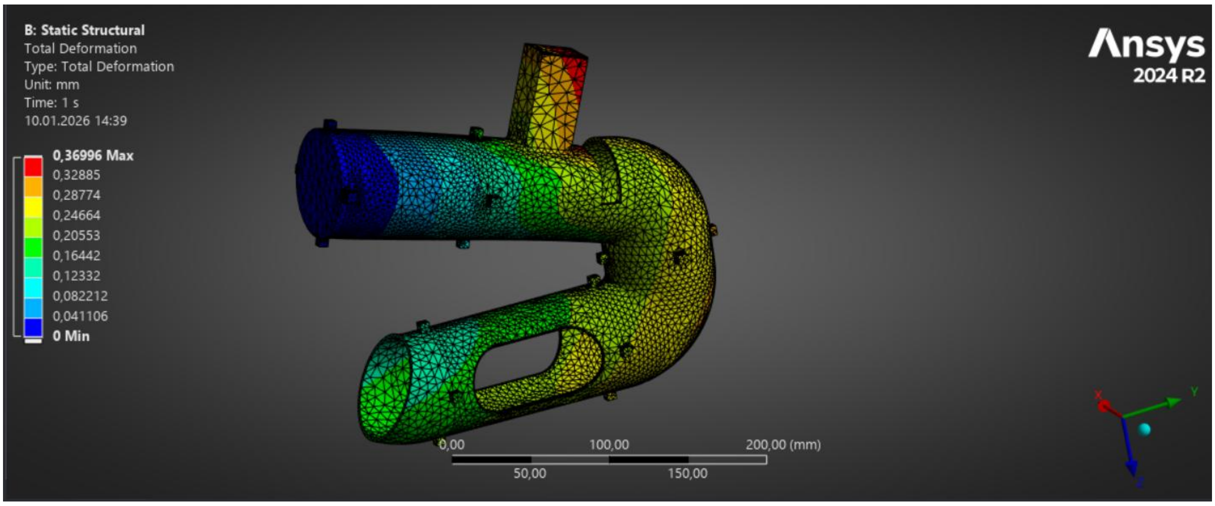

Figure C.1. Total Deformation Analysis of Launch Mechanism Component I

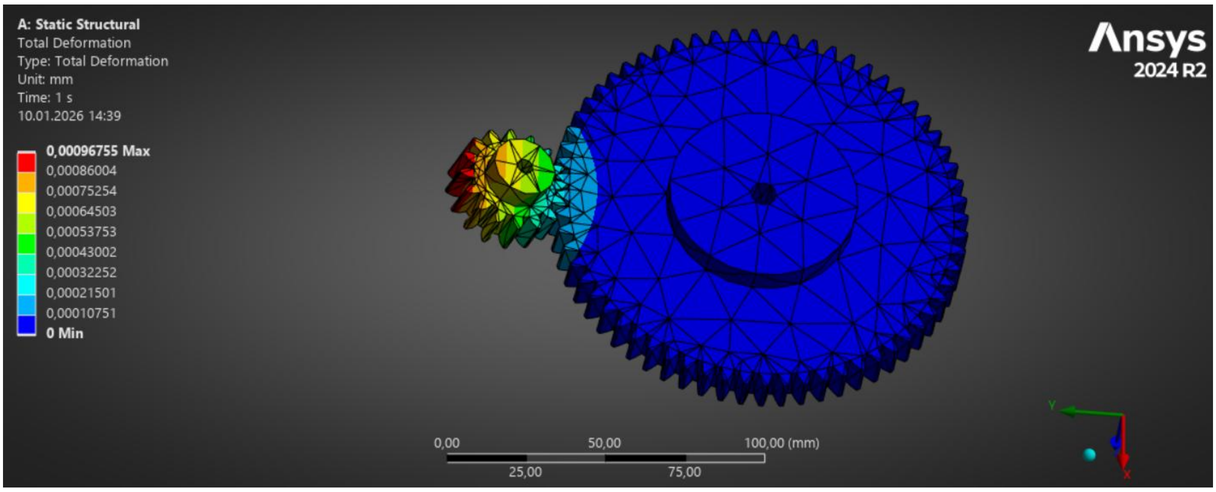

Figure C.2. Total Deformation Analysis of Launch Mechanism Component II

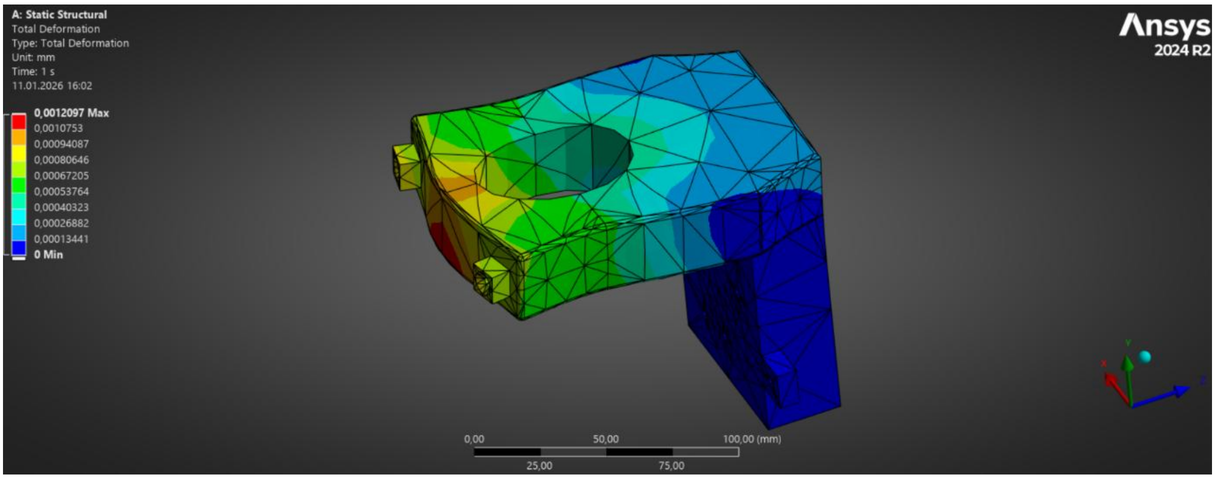

Figure C.3. Static Structural Analysis of Motor Mount (Total Deformation)

APPENDIX D: SOFTWARE DESIGN

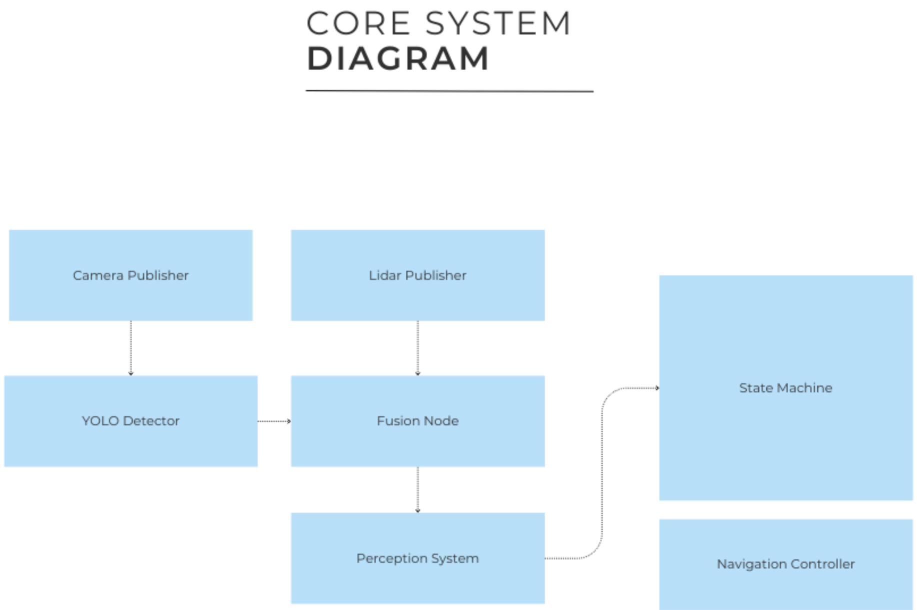

Figure D.1 – Diagram of the autonomous system

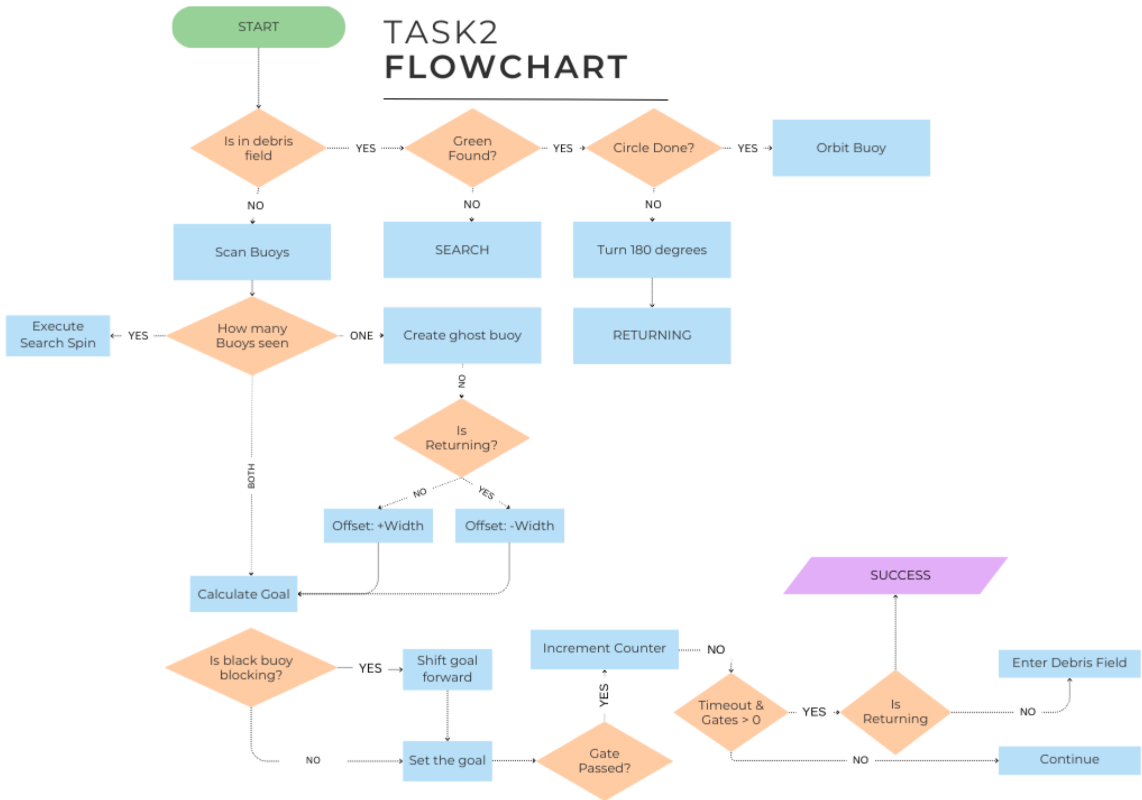

Figure D.2 – Flowchart of the algorithm of the task 2

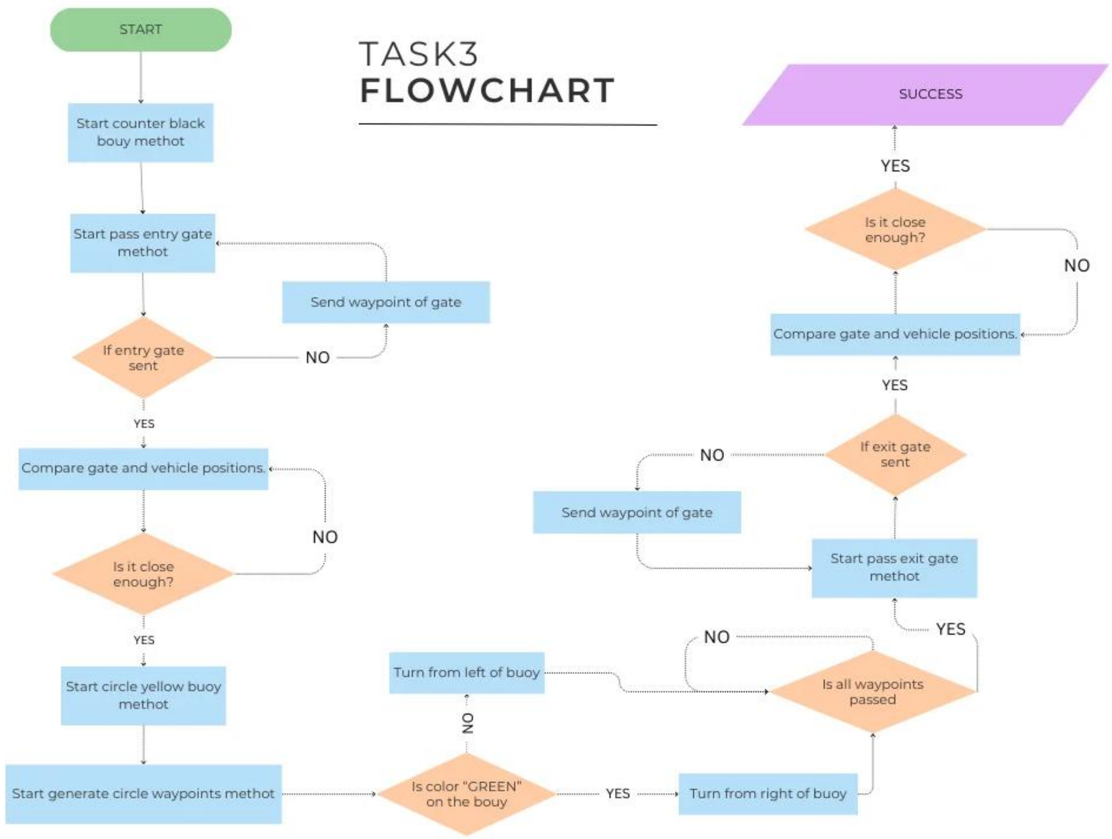

Figure D.3 – Flowchart of the algorithm of the task 3

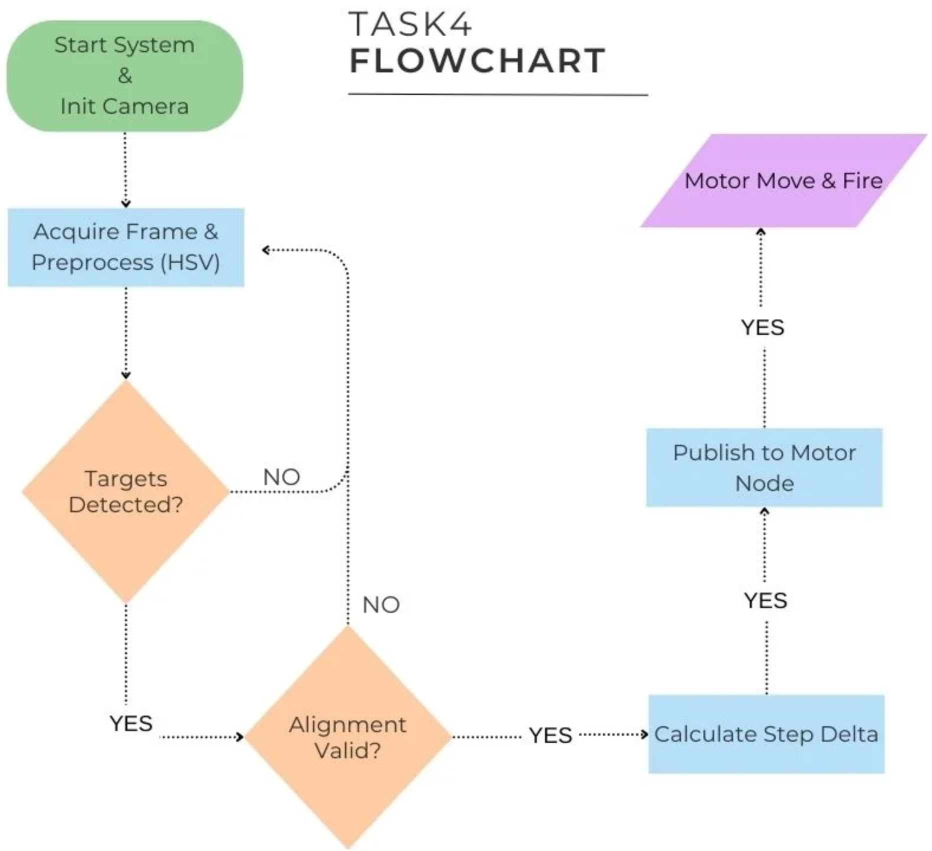

Figure D.4 – Flowchart of the algorithm of the task 4

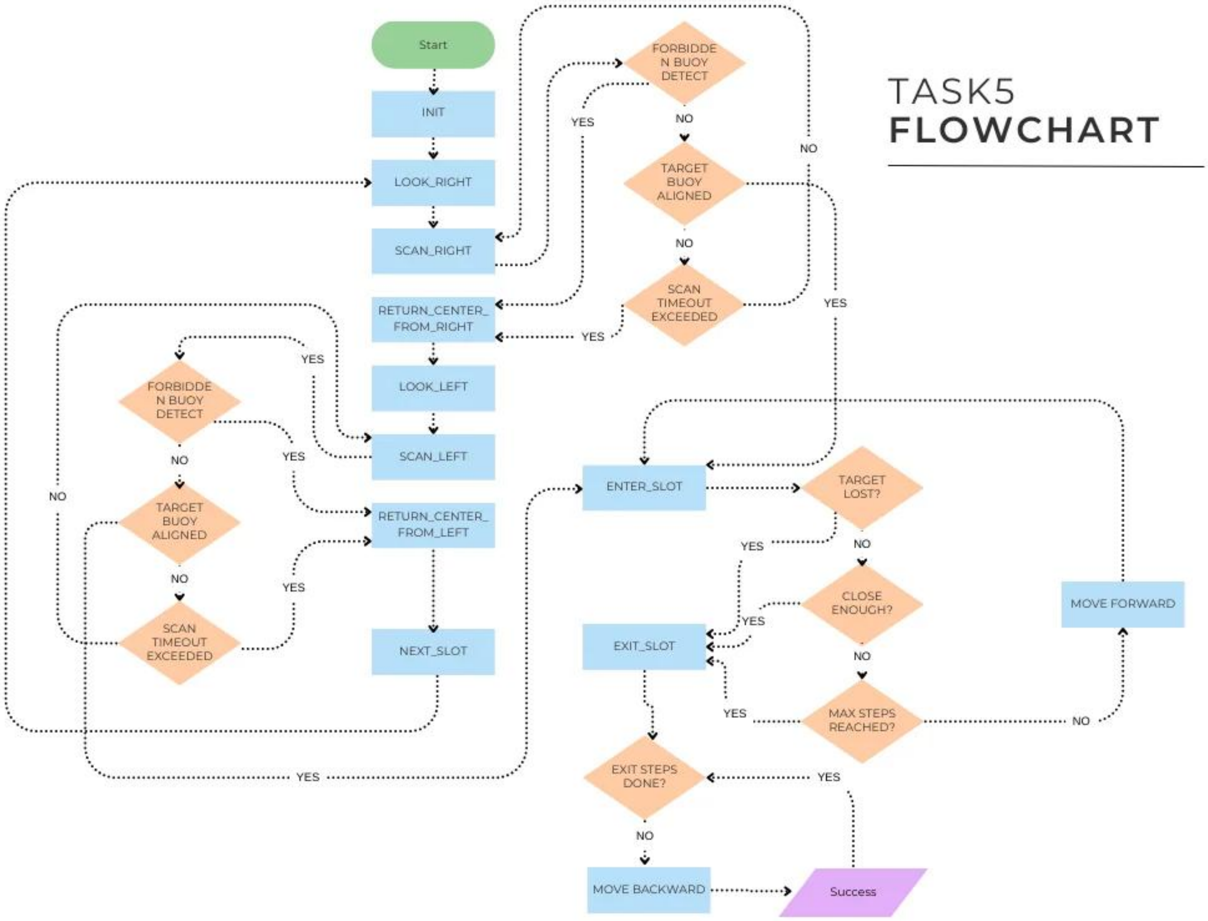

Figure D.5 – Flowchart of the algorithm of the task 5

APPENDIX E: RESULT AND DISCUSSION

Figure E.1 - General view of the catamaran USV prior to hydrostatic testing

1. **Early Stage: Manufacturing and Hydrostatics**

We began production with initial challenges in additive fabrication: the warping and bonding of layers required reprints of critical components. The initial positioning of the hull in the water resulted in the stern being 2cm below the desired position in the waterline; thus, we adjusted the position of the battery to rectify the situation. A critical safety issue became apparent during the static pressure tests, where minute leaks appeared at the connection points for the propulsion systems due to the misuse of torque in these areas. We remedied the situation by strictly observing the torque requirements during the sealing process. A situation arose during manual operation where the craft grounded itself and damaged a propeller; consequently, we drew tighter safety margins during our subsequent tests.

Figure E.2 - Testing of the Ertuğrul propeller propulsion system

2. **Mid-Stage: Electronics & Integration**

In this phase, the main focus was on accommodating the Electronics Box (EE Box) and positioning the sensor array. The most challenging part of the battery and EE Box installation was the narrow tolerances of the hull, which caused problems with conventional maintenance. Obtaining a shared reference frame for the LiDAR and Camera system also generated geometric obstacles. These issues were remedied by developing better cable organization for easier battery/EE Box installation and designing adjustment mounts for exact positioning of the sensors. The final stage involved the software stack that ran on top of NVIDIA Jetson. This became the biggest bottleneck because of compatibility issues, “dependency hell,” between Jetson OS and ROS2 variants and sensor drivers. The time spent aligning everything to get everything right took up most of this stage. This challenge ended with containerization technology (Docker), which made it possible to successfully conduct autonomous waypoint navigation.