RoboBoat 2025: Technical Design Report

Tramola Team

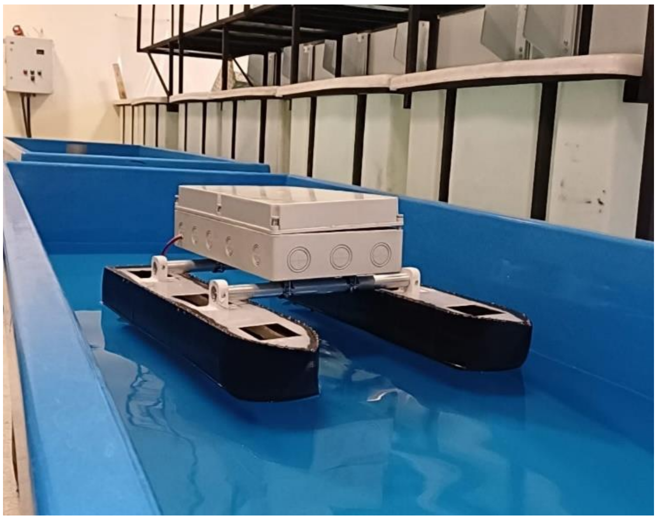


Figure 1:Tramola Vehicle

1. ABSTRACT

The Tramola Unmanned Surface Vehicle Team is embarking on an exciting journey this year by participating in the RoboBoat competition for the first time. Aware of the challenges and learning processes that come with the first year, the team has focused on simplicity to effectively and efficiently complete the tasks. The core philosophy of the project is to design and build a fast, robust, and reliable vehicle from scratch, ensuring that the software testing phase begins as quickly as possible. In line with this philosophy, the design process emphasized modularity and simplicity, avoiding unnecessary complexities to streamline both production and maintenance processes. The software development process was structured to align with the team's goals, adopting a principle of starting testing early. Additionally, the testing phase was organized systematically, utilizing realistic scenarios to optimize the vehicle's capabilities. Recognizing the first year as a period of gaining experience, the team has adopted a flexible and learning-focused approach throughout the process, aiming to lay the foundation for future successes.

2. COMPETITION STRATEGY

As our team was newly participating in the competition, realistic priorities were established at the outset of the software development process

Primary focus was placed on Task 1 (Navigation Channel), Task 2 (Mapping Migration Patterns - Follow the Path), and Task 6 (Return to Home). Successfully completing these tasks was considered critical for demonstrating that the vehicle's basic functions were operating correctly and reliably.

Task 3 (Treacherous Waters - Docking) and Task 4 (Race Against Pollution - Speed Challenge) have been identified as secondary priorities for our team. Low-risk strategies have been adopted for these tasks. On the other hand, Task 5 (Rescue Deliveries - Object and Water Delivery) has not been prioritized initially due to its complex nature. However, it is planned that the focus will shift to this task if time and resources permit.

This strategy ensures that attention is directed towards successfully completing the highest-priority tasks, in alignment with the main objectives of the competition.

2.1 TASK BY TASK STRATEGY

2.1.1 TASK 1- NAVIGATION CHANNEL

The algorithm employs an object detection method to identify the nearest pair of red and green buoys. Once detected, the algorithm calculates the midpoint between the two buoys and directs the boat towards this point. The boat's path is continuously adjusted to maintain alignment with the midpoint, ensuring accurate navigation.

2.1.2 TASK 2- MAPPING MIGRATION PATTERNS: FOLLOW THE PATH

Object detection is used by the algorithm to identify the nearest red, green, and yellow buoys. If no yellow buoy is detected, the boat is directed to the midpoint between the red and green buoys. If a yellow buoy is present, the boat is steered toward the largest gap between the three buoys. At the end of the mission, the number of yellow buoys is reported to the GCS via a Wi-Fi connection.

Although mapping objects by determining their positions using distance measurement with a stereo camera is considered more reliable, this approach is chosen because using real-time positions on the screen is simpler and faster from a software perspective. This method results in reduced complexity and improved processing speed.

2.1.3 TASK 3- TREACHEROUS WATERS: DOCKING

While the ASV circles the dock clockwise, the side camera is used to search for the desired shape. If a ship is detected at the location of the shape, movement continues. If no ship is detected, the shape is cantered in the camera view, and the ASV moves closer until the shape reaches a certain size threshold.

2.1.4 TASK 4- RACE AGAINST POLLUTION: SPEED CHALLENGE

The process is initiated with the detection of a green light signal by the object detection algorithm. The boat is guided through the gate formed by red and green buoys, black buoys are avoided, the blue marker buoy is circled, and the same gate is used for the exit. When black buoys are detected by the stereo camera, their number and coordinates are recorded by the system. Before a buoy is counted as new, its location is compared with previously recorded coordinates to avoid duplicates. After the task is completed, the number of detected buoys is displayed on the screen for the referees to observe.

2.1.5 TASK 5- RESCUE DELIVERIES: OBJECT AND WATER DELIVERY

When the ASV detects the vessel identified by the model, its direction is adjusted to center the cross sign in the field of view. Once the direction is corrected, the vehicle moves straight toward the cross sign until it reaches the desired proximity. When close enough, the delivery command is executed.

2.1.6 TASK 6- RETURN HOME

A vector is defined from between the black gates toward the previously recorded starting position. As the vehicle moves along this vector, obstacles detected by the model are avoided through local deviations using avoidance vectors. Eventually, the vehicle reaches home.

2.2 DESIGN STRATEGY

2.2.1 STRATEGY OF MECHANICAL DESIGN

2.2.1.1 DESIGN CONSIDERATIONS FOR HULL AND ASV

During the hull design process, various types of vessels were thoroughly analysed, and their advantages and disadvantages were compared. Considering the challenges and methods of the production process, the team chose a catamaran hull design. The main reason for selecting the catamaran was its ability to provide high stability on the water, ensuring smooth and steady movement of the vehicle.

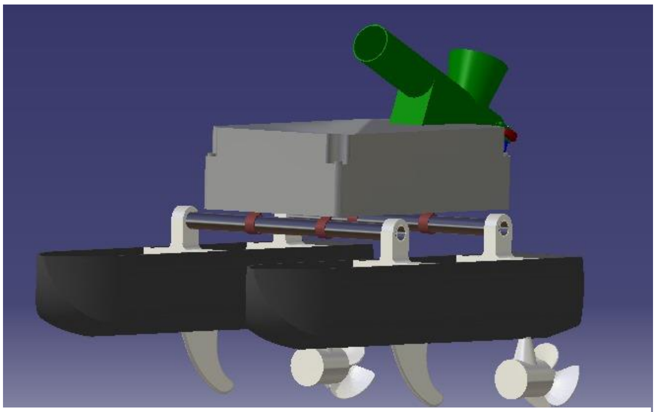


Figure 2: Vehicle design on the CAD software

The length-to-width ratio was determined by analysing data from various manufacturers, and the dimensions were optimized to maintain performance without compromise. Another key factor in choosing the catamaran was the relatively easier and more efficient production process. The hull structures were designed and manufactured using 3D printers with PLA filament. PLA was chosen because it is naturally derived, environmentally friendly, and offers a sustainable option.

Using this method, the 12-piece hull was assembled with epoxy material and sealing equipment, minimizing waste and adopting an ecofriendly approach. The two main hulls were joined with aluminium connectors, and a box containing all the vehicle’s electronic components was placed on top. Additional measures were taken in the catamaran design to improve stability during turns and reduce the risk of capsizing.

Fins were added under the hull to ensure more balanced and secure movement on the water. The cross-sectional areas of these fins were carefully analysed, and the NACA-0006 profile was selected. This profile was chosen based on the boat's dimensions, load capacity, manoeuvrability, and performance criteria. Through extensive analysis and flow tests, it was determined that this profile improves stability and optimizes hydrodynamic performance.

As a result, an ideal structure was achieved in terms of performance and efficiency during the design and production phases.

2.1.1.2 DESIGN OF PROPULSION SYSTEM AND THRUSTER

During the motor selection process, the vehicle's weight, dimensions, and speed requirements for the competition were carefully considered. Brushless motors were chosen for their ability to deliver high power with minimal efficiency loss. In addition to their efficiency, brushless motors are known for their durability and longer lifespan. The technical specifications of the brushless motors were thoroughly examined, and a motor with a higher capacity than the required power was selected. This strategy aimed to limit the motor's output, preventing overheating and minimizing performance losses caused by heat. This approach ensured the motors operated more reliably and had a longer lifespan.

The motors were symmetrically mounted at the rear of the hull, with one positioned on the right and the other on the left. Although the motors are water-resistant, waterproof covers were designed around the motors to minimize potential damage. The vehicle's right and left turns were achieved through power control applied to the motors. In this method, reducing or completely cutting power to one motor allowed the vehicle to change direction. This mechanism enhanced the vehicle's manoeuvrability while offering a simple and effective control solution.

To generate thrust, 12 cm diameter, three-blade propellers were attached to the output shafts of the motors. To prevent energy loss, no transmission components were used; the propellers were directly mounted on the motor shafts. The propellers were specifically designed, considering the water’s inflow and outflow directions, and were manufactured using 3D printers. This production method reduced costs while ensuring the propellers were made to meet the design requirements.

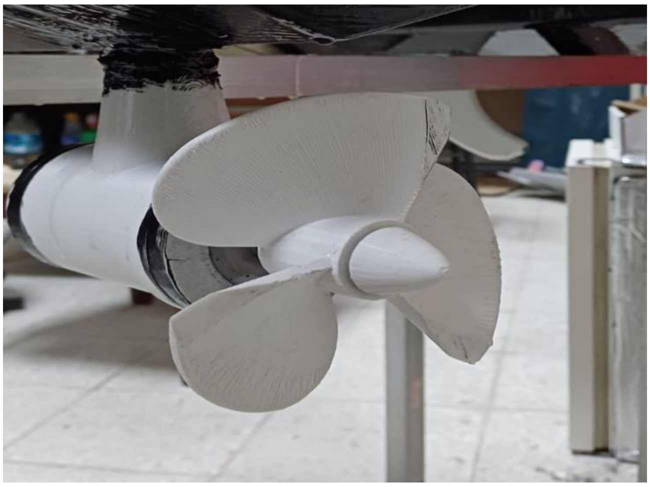


Figure 3: Propeller

To enable both forward and backward motion, bi-directional ESCs (Electronic Speed Controllers) were integrated with the motors. These ESCs allowed the motors to operate in reverse, increasing the vehicle's mobility and flexibility during tasks.

Thanks to the design and integration process, the vehicle's propulsion system achieved an optimal balance of performance, efficiency, and durability.

2.1.1.3 DESIGN OF OBJECT AND WATER DELIVERY MECHANISMS

The ball-launching mechanism was designed with simplicity and functionality as the primary focus. The mechanism consists of a hopper that can hold three balls, a lid to release the balls into the barrel, two launching discs, and a 40 cm long barrel. When the hopper's lid opens, a ball falls into the barrel and is positioned between two discs powered by DC motors. These discs, rotating in opposite directions, propel the ball forward with significant force. The 40 cm barrel ensures that the ball is launched accurately toward the intended target.

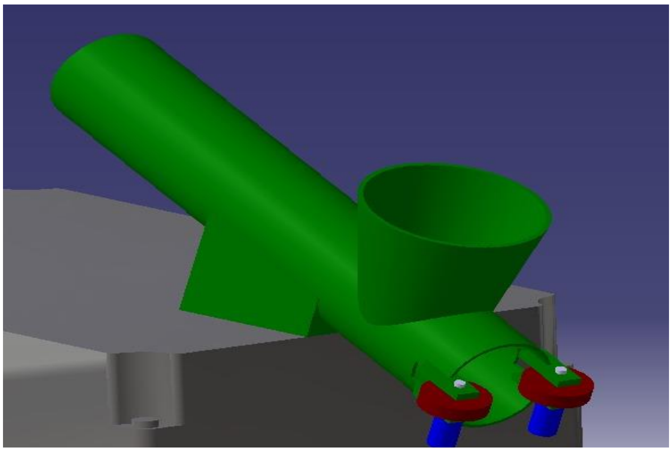


Figure 4: Object and water delivery mechanism

The hopper is carefully designed to allow seamless ball transfer into the mechanism, minimizing the risk of jamming or misalignment. The speed of the rotating discs can be adjusted to suit various distances, providing flexibility for different scenarios. This simple yet effective approach reduces mechanical complexity while enhancing reliability and performance.

The water-launching mechanism, on the other hand, consists of a DC water pump, plastic tubes, and a specially designed nozzle. The pump draws water from the lake and delivers it through the tubes to the nozzle in the vehicle's aiming system. The nozzle operates based on Bernoulli's principle, narrowing the cross-sectional area through which the water flows to increase its velocity. This design allows the water to reach longer distances effectively.

Both mechanisms were designed with practicality and reliability in mind. The ball-launching mechanism provides a straightforward solution for accurate targeting and precise shots, while the water-launching mechanism combines fluid dynamics with robust components to deliver high performance over long distances. This holistic design approach ensures that the vehicle is versatile, efficient, and capable of adapting to various operational scenarios.

2.2.2. DESIGN STRATEGY OF SOFTWARE

2.2.2.1 NOVIGATION AND AUTONOMOUS CONTROL

In the competition, the Pixhawk flight controller was used to implement the vehicle's control and navigation mechanisms. Pixhawk, which operates with the open-source flight control software ArduPilot, was chosen for its cost-effectiveness and high performance. During the vehicle's testing phases, IMU and GPS data were monitored using the Mission Planner ground control software, which was connected to the Pixhawk.

2.2.2.2 COMPUTER VISION

Since the effective use of image processing algorithms was fundamental to all tasks in the competition, this topic held great importance. We used a cost-effective stereo camera to acquire image data. For processing the image data, we chose the open-source Darknet deep learning framework. Our choice was influenced by our hardware limitations, the ease of use of the YOLOv4 library, and its seamless compatibility with the CUDA cores on the Jetson's GPU. To accelerate our custom-trained YOLOv4 models for the tasks, we converted them to the ONNX format, which is compatible with the TensorRT library included in the Jetson Nano. This allowed us to achieve fast real-time inference on our limited hardware.

2.2.3 STRATEGY OF ELECTİCAL SYSTEM DESIGN

Providing a reliable power supply for the vehicle's onboard computer, motors, and control system is critical for ensuring successful performance. To meet this requirement, LiFePO4 battery packs, designed by our team, are used. These batteries have a nominal voltage of 12.8 Volts and a capacity of 18,000 mAh, providing sufficient energy for long-duration operations and high-power demands. Additionally, these batteries offer high efficiency and safety, as LiFePO4 technology provides a longer lifespan and generates less heat compared to other battery types. The power distribution architecture has been meticulously planned to ensure stable operation of all electrical systems in the vehicle, and it is detailed in the accompanying power distribution diagram.

The custom-designed power distribution board has undergone rigorous testing. Initially, its theoretical performance was validated through simulation. These simulations helped predict the board's behaviour under different conditions and enabled early identification of potential issues. Following the simulation phase, the PCB (Printed Circuit Board) layout was carefully designed, and real-world tests were conducted on the physical board.

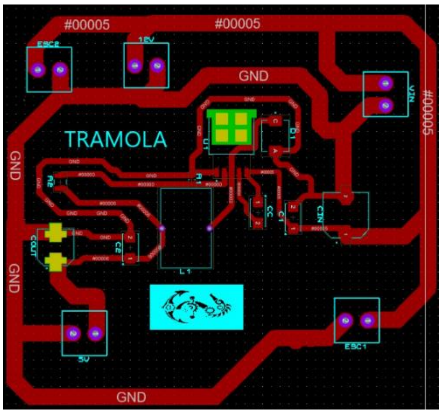


Figure 5: PCB design

During these stages, the reliability and performance of the power distribution board were confirmed, and the physical construction of the board was tested to ensure it met electrical safety requirements.

This custom solution provides a significant advantage for the vehicle's power distribution system. Specifically, it eliminates complex wiring setups and minimizes potential issues such as contact failures. As a result, the reliability of the vehicle's electrical system is enhanced, and maintenance requirements are reduced.

The electrical schematic, which transparently presents the entire power distribution and connection processes, is shown in Figure 4. This schematic illustrates all the necessary connections, components, and electrical paths, ensuring that team members and maintenance personnel can easily understand the system.

2.2.3.1 Control and Emergency System

The control of the vehicle's motors is managed via the Pixhawk system. Electrical control is achieved through a relay mechanism, which can be triggered both remotely via Arduino and manually using a mechanical switch. Additionally, in case of an emergency, a method has been implemented to supply power only to the Arduino when the relay is deactivated. This ensures that a vehicle halted due to an emergency can be safely restarted remotely. The details of the implementation are illustrated in Figure 6.

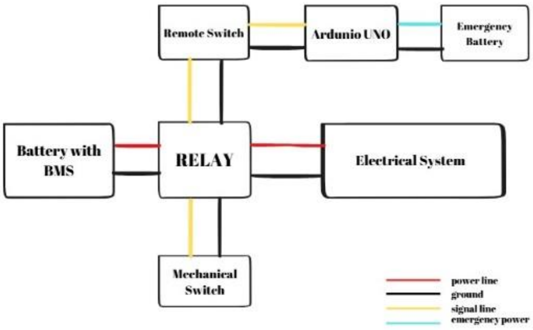


Figure 6: Detais of emergency system

2.3 TESTING STRATEGY

After completing the mechanical, electrical, and software components, various tests were conducted to observe the vehicle's behavior on the course. As this is our team’s first year participating in RoboBoat, these tests are of great importance for evaluating the vehicle’s performance.

In the mechanical tests, the vehicle’s waterproofing and balance were checked, the desired speeds were achieved, and the design was confirmed to be successful. In the software tests, image processing and movement capabilities were evaluated, and the desired mobility was achieved. The electrical tests aimed to verify the stability and proper functioning of all components, which were successfully completed.

2.3.1 SIMULATION TESTS

The VRX simulation was used to test the functionality of the software developed for autonomous surface vehicles. The simulation was designed to replicate real-world conditions, including environmental factors like waves and wind, as well as settings such as the RoboBoat 2025 contest area. This allowed for the observation of whether the code written successfully performed the designated tasks and how it behaved in different scenarios. Simulation tests were used to accelerate the software development process and identify errors.

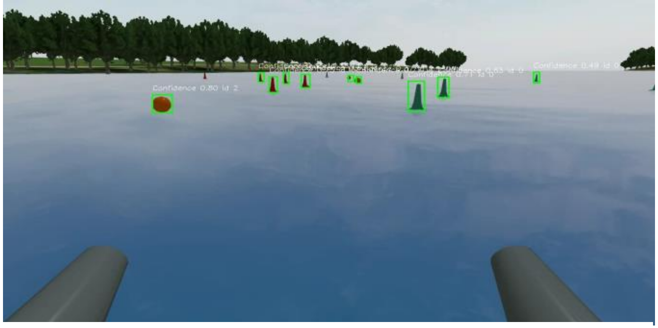


Figure 7: Simulation in the VRX

2.3.2 DRY TESTS

Dry tests were conducted to verify whether all components of the system were functioning properly. Initially, the startup of the boat and the accuracy of signal transmission from the radio to the motors were tested; this stage was aimed at ensuring uninterrupted communication and lossless signal transmission. In the next phase, the main system component, Jetson, was activated, and it was tested whether the data received from the sensors was correctly transmitted to the control units. The motors were thoroughly tested to verify their ability to operate accurately and efficiently at the given speed values, and it was observed that the desired speeds were reached, and stable operation was achieved. During manual control tests conducted using the RC controller, the sensitivity of the controller was adjusted to facilitate easier manual control. Additionally, sample training objects used in the simulation were placed in front of the camera to test the accuracy of the object recognition model, and it was confirmed that the objects were correctly identified by the model. During indoor tests conducted in the working environment, GPS signal issues were encountered; however, these issues were resolved by using simulated GP.

2.3.3 WATER TESTS

After being launched into the water, the vehicle was successfully controlled using the RC controller. All direction changes (forward, backward, right, left) were performed through the controller, and the vehicle responded to each command as expected. Additionally, the camera mounted on the vehicle was used to capture photos and videos, which were processed by the Jetson Nano and sent to a computer on the same network via Wi-Fi. This way, the photo transmission task for the competition was tested.

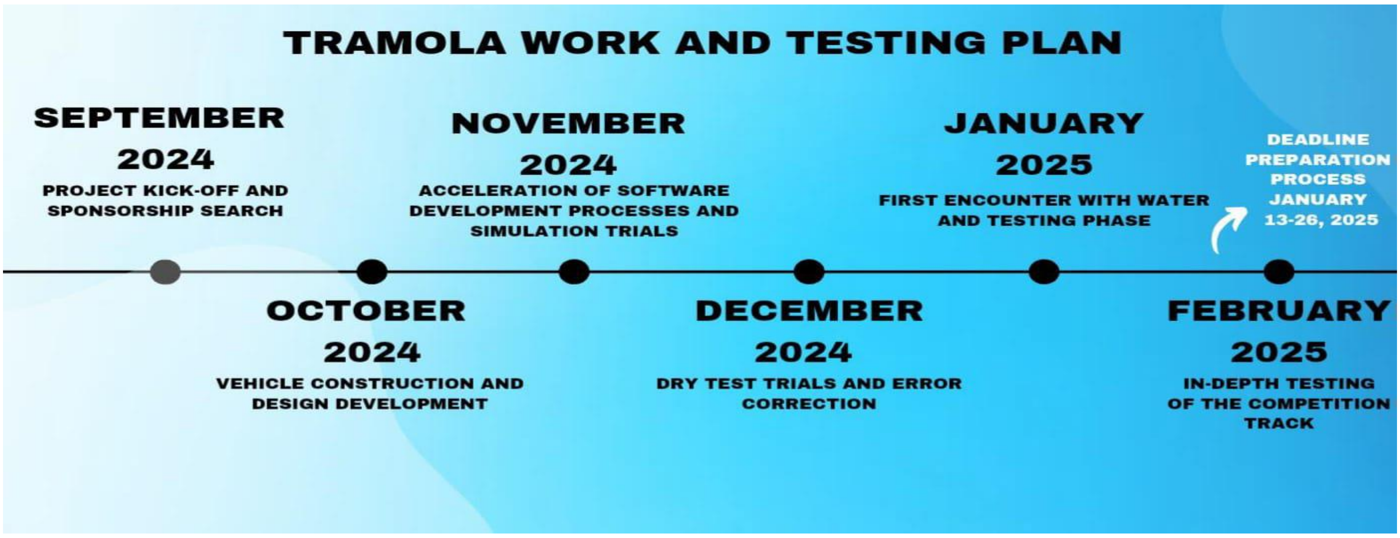
2.3.4 POWER TESTS

The motors of the vehicle were paired with an ESC suitable for their current draw, and comprehensive tests were carried out accordingly. All components used in the vehicle were initially subjected to short circuit tests, followed by tests using power supplies with adjustable voltage and current limits. Subsequently, power tests of the vehicle were conducted out of the water using a BMS-controlled battery. Finally, the vehicle was tested in water in both manual and autonomous modes. No abnormal heating was detected during any of these three testing phases. The tests were conducted at a constant room temperature of 27°C. Temperature sensors were integrated into the vehicle's components, and periodic measurements were taken and recorded separately for each component. The averages of the measurements taken at specific intervals were calculated and documented.

3. ACKNOWLEDGMENTS

We would like to begin by expressing our sincere gratitude to Hacettepe University and its dedicated staff for providing us with the opportunity to bring this project to life. We are deeply thankful for the knowledge and financial support provided by our sponsors, Özdisan, Niğtaş, and Simcustomtr. Their contributions were crucial in transforming this project from an idea into reality. Finally, we extend our appreciation to the Hacettepe Mechanical Society for their ongoing support as we have grown and developed within their community.

Appendix A: Test Plan & Results



TRAMOLA WORK AND TESTING PLAN

SEPTEMBER 2024
PROJECT KICK-OFF AND SPONSORSHIP SEARCH

OCTOBER 2024
VEHICLE CONSTRUCTION AND DESIGN DEVELOPMENT

NOVEMBER 2024
ACCELERATION OF SOFTWARE DEVELOPMENT PROCESSES AND SIMULATION TRIALS

DECEMBER 2024
DRY TEST TRIALS AND ERROR CORRECTION

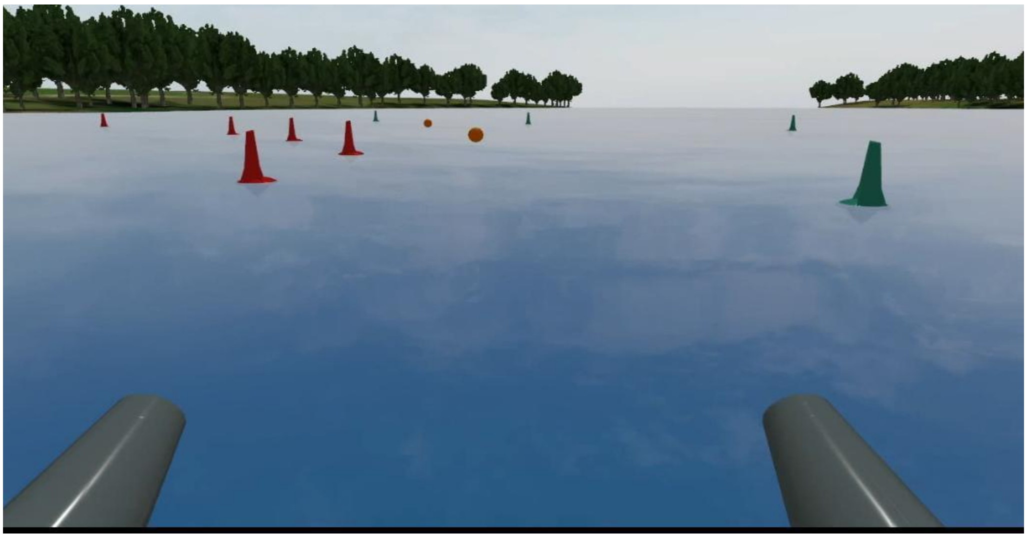
JANUARY 2025
FIRST ENCOUNTER WITH WATER AND TESTING PHASE

DEADLINE PREPARATION PROCESS
JANUARY 13-26, 2025

FEBRUARY 2025
IN-DEPTH TESTING OF THE COMPETITION TRACK

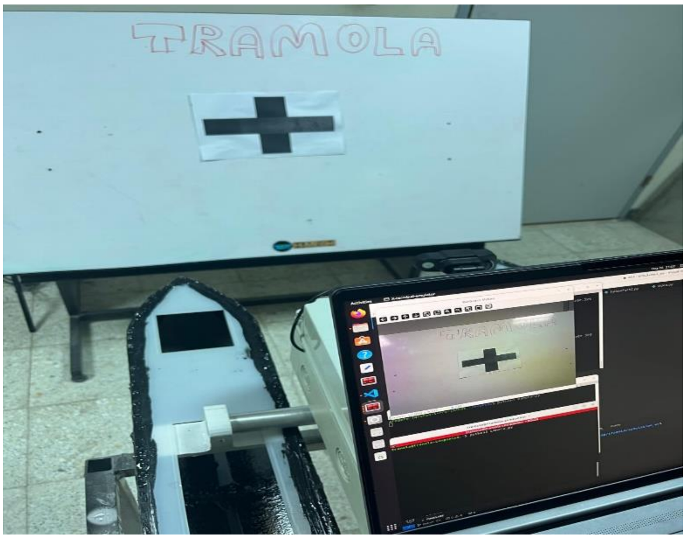
Timeline for the tests

When the decision was made by our team to participate in the competition, limited time was available. Therefore, during the vehicle’s construction phase, the necessary algorithms were developed on a simulation platform by the software team to begin the testing process as soon as possible. During the simulation tests, tracks were created based on the tasks outlined in the RoboBoat 2025 Handbook, and the vehicle's predicted behaviors were assessed. Additionally, considering the weather conditions of the competition area, Nathan Park, performance tests under various current and weather conditions were conducted on the Tramola vehicle through simulations.

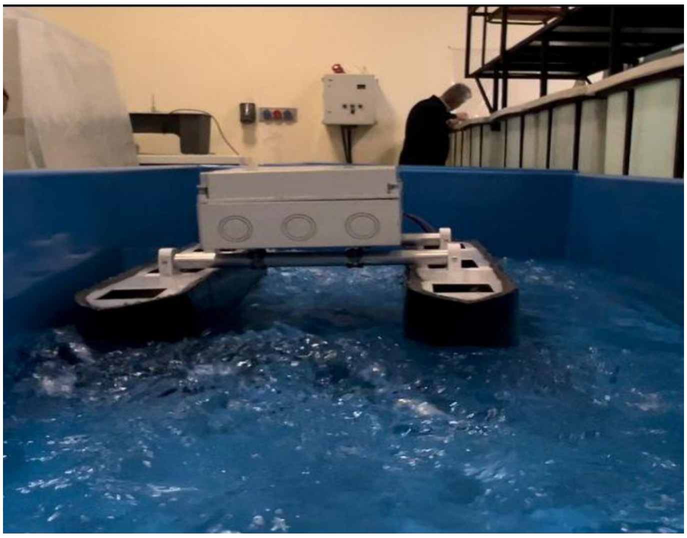


Simulation in the VRX software

Since Hacettepe University, where our work is being conducted, is in Ankara and this city does not have enough water space to test the vehicle, obtaining official permission for testing was challenging. As a result, after the simulation tests to test the physical components of the vehicle we did dry tests. The object recognition model was tested with 3D printed obstacles. The sensitivity of the RC controller and motor thrust thresholds were adjusted. The range of the RC receiver was tested and found to be sufficient.



Camera and Jetson Nano test



Motors and stability test

After conducting the dry tests, water tests were conducted at the Hacettepe University Hydraulic Machine Laboratory. There the basic maneuvering capabilities of our USV were evaluated. During tests conducted with the RC remote controller, it was observed that the propellers were not working synchronously, as the left propeller was rubbing against the motor case. The distance between the propeller and motor case was increased, and subsequent tests showed that the issue was resolved. Additionally, the sinking depth was evaluated based on the boat's weight, and waterproof performance tests were conducted.

First buoyancy test in the hydraulic laboratory

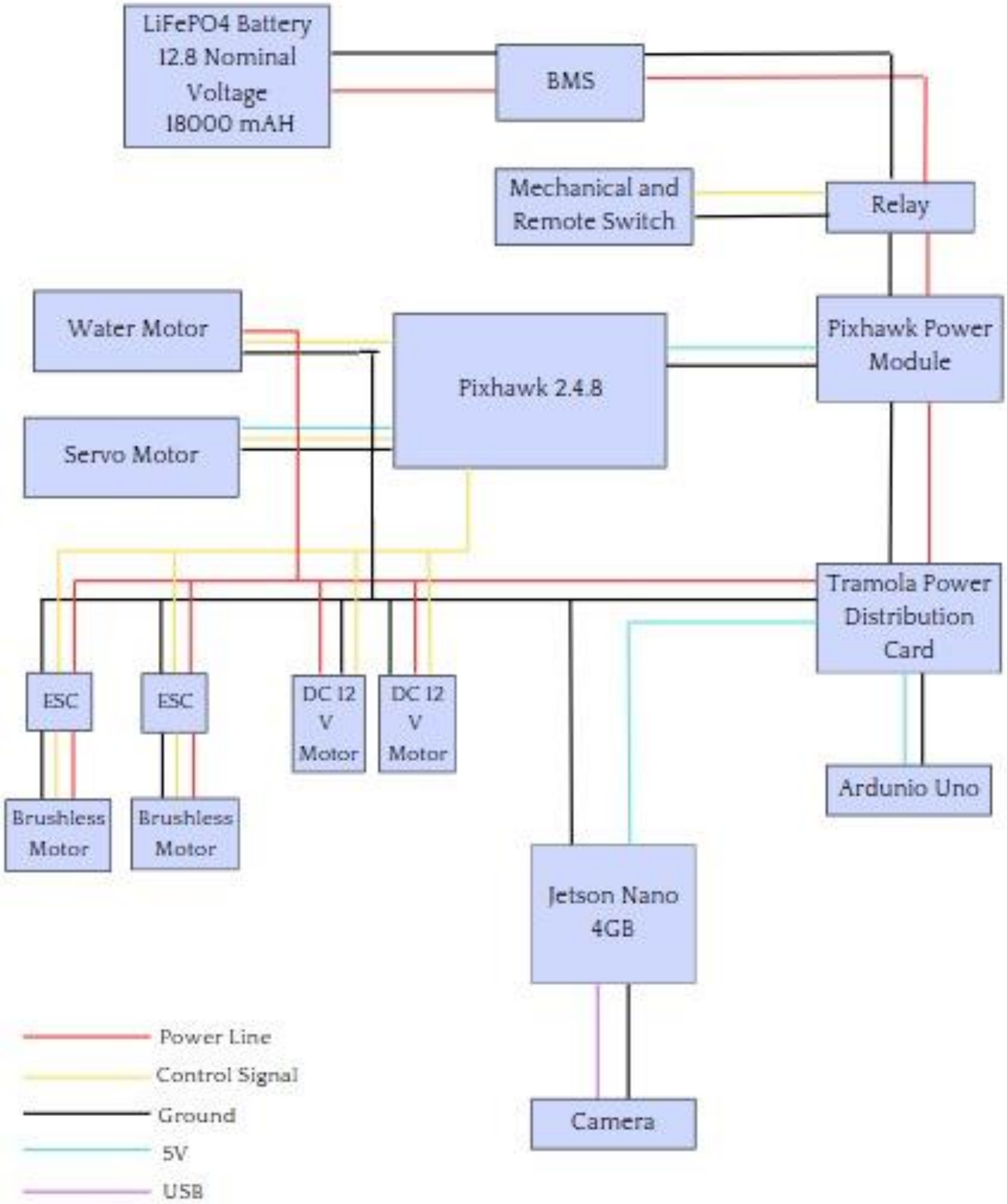
Hacettepe University test pool

The upcoming tests will be conducted in our university's pool. The courses from the handbook will be recreated here, and the algorithms developed in the simulation will be tested to see if they work properly in reality

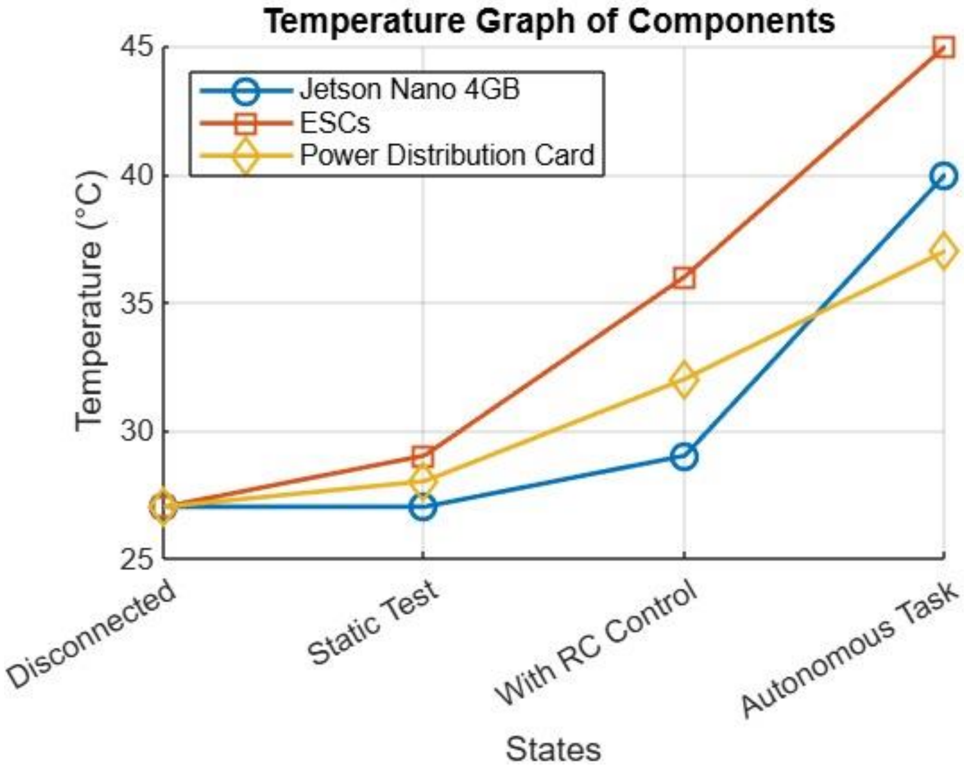
Appendix B

COMPONENT	VENDOR	MODEL /TYPE	SPECS	CUSTOM / PURCHASED	COST	YEAR
ASV Hull Platrofm	Self-developed	Catamaran	90cm-60cm-50cm	Custom	25$	2024
Waterproof Connectors	Motorobit	TPWS24	Product link	Purchased	12$	2024
Propulsion	Sk3	5045 500kv	Product link	Purchased	200$	2024
Motor Controls	Degz Robotics	Degz-blu 30 A	Product link	Purchased	40$	2024
Battery	Orion	Lifepo4 Irf32700	Product link	Purchased	40$	2024
CPU	Nvidia Development	jetson nano	Product link	Purchased	300$	2024
Teleoperation	Radiolink	T8FB 8 CH	Product link	Purchased	70$	2024
Inertial Measurement Unit (IMU)	Pixhawk	2.4.8	Product link	Purchased	200$	2024
Compass	Pixhawk	pixhawk compass module	Product link	Purchased	40$	2024
Camera	Logitech	960-001372	Product link	Purchased	40$	2024
Vision	YOLO	V4			Free	2024
Autonomy	Open robotics	ROS			Free	2024
Open-Source Software	Open Robotics	ROS melodic			Free	2024

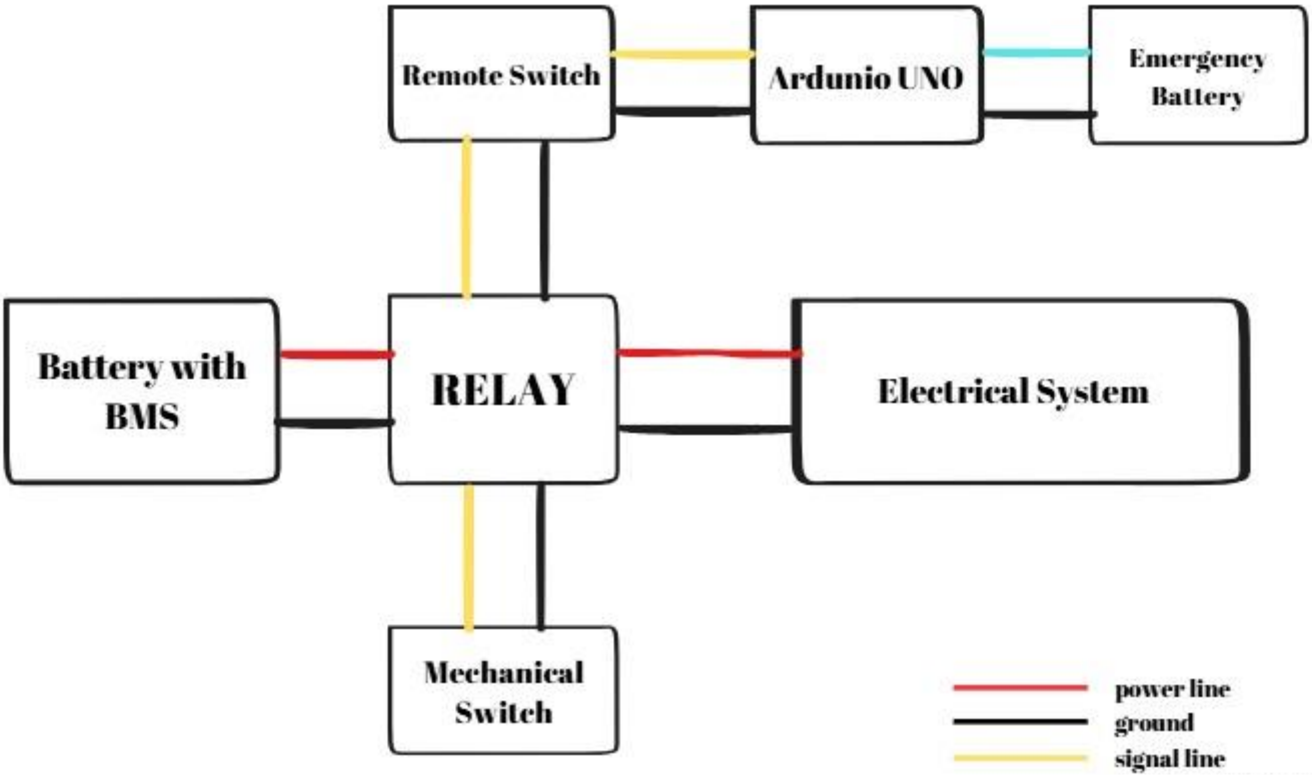
Appendix C: Electrical Diagrams



Electrical diagram for the vehicle

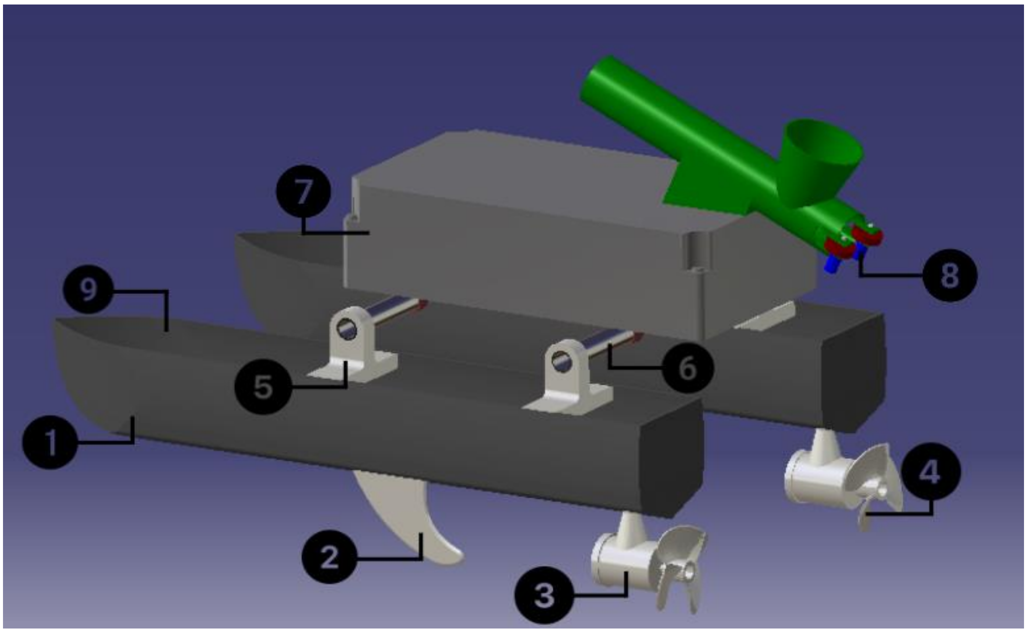


Temperature graph of components during the tasks



Emergency system diagram

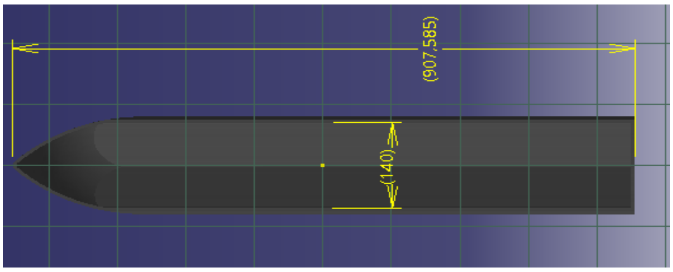
Appendix D: Parts of Vehicle



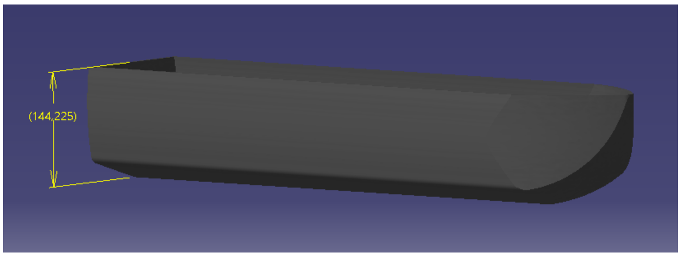
Parts of vehicle

Parts of vehicle

ITEM	QUANTITY	LIST OF VEICHLE COMPONENTS
1	2	Hull
2	2	Stabilizer Fin
3	2	Motor Casing
4	2	Propeller
5	4	Joint Component
6	2	Aluminium Connector Tube
7	1	Waterproof Enclosure for Electrical Components
8	1	Object and Water Delivery Mechanism
9	2	Hull Cover

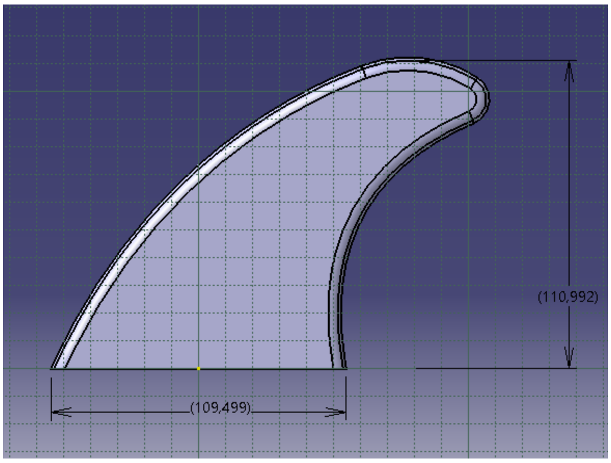


Item 1 with dimensions

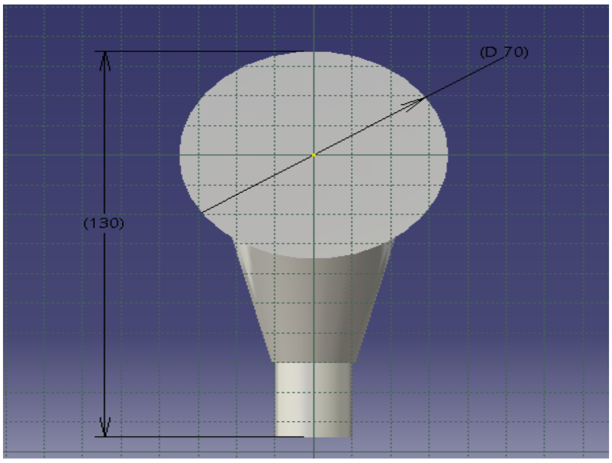


Item 1 with dimensions

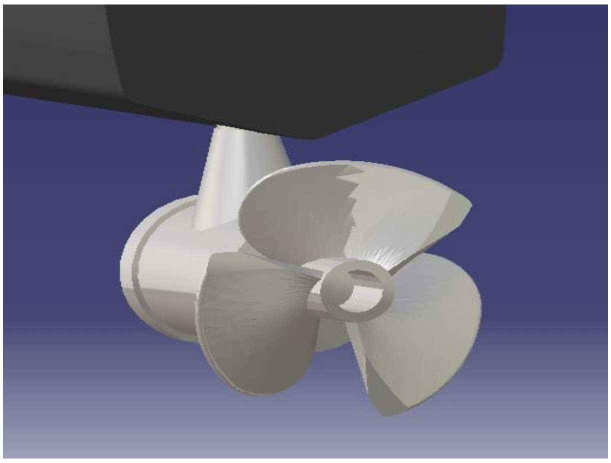
Water Contact Surface of the Vehicle	0,2845 m^2
Total Volume of Vehicle	0,18m^3
Total Weight of the Vehicle (Including Components)	5,20kg



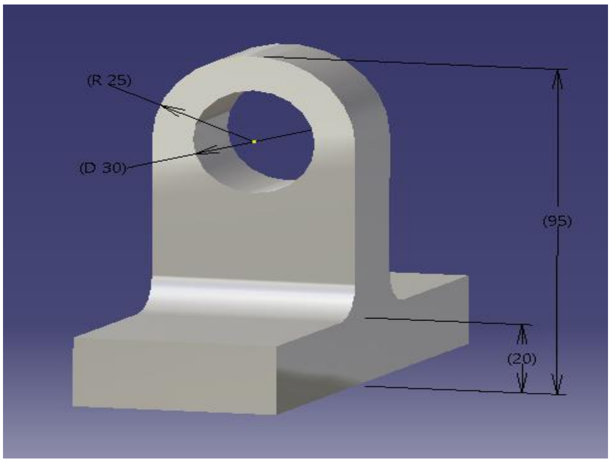
Item 2 with dimensions



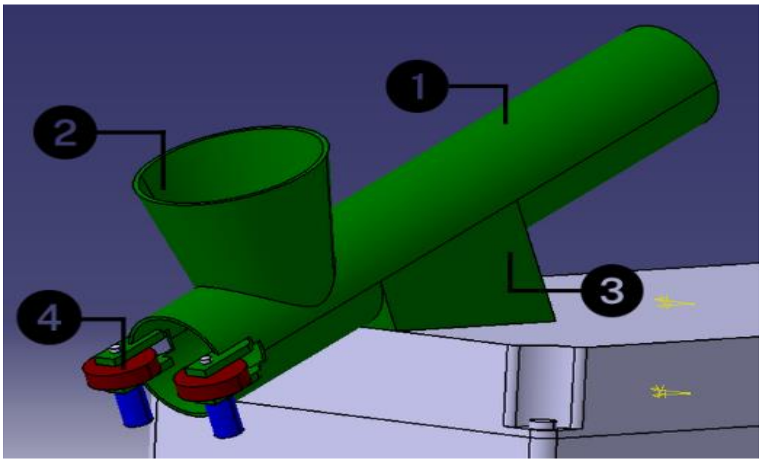
Item 3 with dimensions



Item 4



Item 5 with dimensions



Item 8 with its parts

Parts of item 8

ITEM	QUANTITY	COMPONENTS
1	1	Barrel
2	1	Reservoir
3	1	Support of barrel
4	2	Pusher disc

Appendix E: Variables

Variables:

QPump = 60 L/H = 0.00001667 m3/s (volumetric flow rate)

DNozzle = 1 mm = 0.001 m

rNozzle = DNozzle /2 = 0.0005 m

ANozzle = π * $(rNozzle)2$ = 7.8* 10^-7 m

$\boldsymbol{\rho}$**Water** ≈ 1000 kg/m3

Nozzle Output Velocity ($\boldsymbol{v}$):

υ $pump = QPump/ANozzle$ = 2,13m/s

Momentum (p):

p =ρ$Water * QPump *$ υ$pump$ = 0,03 kg*m/s

Moment (τ):

τ =$rNozzle * p$ = 0.000017 Nm

5.0 Force (N):

F = ρ *$QPump$ * υ =0,03 N

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