RoboBoat 2025: Technical Design Report

M.Adnan KARAGOZ, T.Yarkın USTA, Berkant GUNINDI, Burak AKAN, Mehmet Demir, M.Cenk OZEKINCI, Dogus OZKAN

Özden, National Defence University, Turkish Naval Academy, 34942, Tuzla/İstanbul, Türkiye

1. Summary

Our team, consisting of five cadets and a Phd student from the Turkish National Defense University Naval Academy and an Assoc. Prof. academic advisor, was established in 2024 to participate in the RoboBoat 2025 unmanned maritime vehicle competition. The unmanned maritime vehicle designed by our team features a catamaran hull, known for its stability and safety, and was developed using Rhino3D software. Our team, driven by research and innovation, adhered to the competition's specifications and constraints to design a vehicle capable of completing the required tasks. The design parameters, including mechanical, electronic, and algorithmic elements, were meticulously developed. Performance tests were conducted during the design phase using laboratory resources, yielding successful results. After these evaluations, the production phase commenced, and the design was practically tested, comparing analysis results with those obtained under real marine conditions. Inspired by the late Admiral Özden Örnek, architect of the MILGEM project, our dedicated team has successfully finalized the design of the unmanned maritime vehicle, embracing the principle of serving as a role model for the future.

2. Technical Content

2.1 Competition Strategy

In designing the competition strategy, the primary objective is to ensure the accurate and complete execution of all tasks. The sequence of tasks has been strategically planned to avoid the complexity of mixed algorithms, prioritizing reliability and efficiency. Speed is considered a secondary priority for the team, with optimal speed values determined during surface tests conducted as part of the task development phase. Data collected during these tests were analyzed using specialized analysis software to refine performance metrics. To achieve high maneuverability and stability, the mechanical components of the vessel have been specifically designed and optimized for these objectives. Consequently, both mechanical and algorithmic planning have been structured according to a well-defined hierarchy of priorities, ensuring seamless integration and operational success.

2.1.1 Task approach

The algorithm enables to autonomously return to its initial deployment position by first plotting the coordinates of its starting location. During navigation, objects within the competition area enter the camera's field of view, where they are detected and classified using image processing techniques. The classification of these objects facilitates the identification of specific tasks, which subsequently trigger the execution of corresponding task-specific algorithms. After completing the tasks sequentially, the USV autonomously navigates back to the coordinates it initially plotted at the start.

2.1.1.1 Navigation Channel

An algorithm was developed to follow the route by assigning a midpoint between the gates. In the initial phase, the gates are detected, and the first task algorithm is activated. Thrusters are assigned incremental speed values, and the optimal value is selected based on the vehicle's response and maneuverability under varying sea conditions, ensuring effective navigation and stability.

2.1.1.2 Follow the Path

Upon completing the first task algorithm, the second task algorithm is activated upon detecting the buoys. Using the Zed 2i camera's integrated IMU and depth-sensing capabilities, the distance between the buoys and the vessel is accurately measured and mapped with a mapping algorithm. The USV then navigates using the calculated midpoint between the red and green buoys as its axis of motion, ensuring precise trajectory control and efficient maneuvering, even in dynamic environmental conditions.

2.1.1.3 Docking

In the docking task, the USV approaches the correctly marked pier identified through image processing techniques. Utilizing distance data obtained from the ZED2i camera's depth-sensing capabilities, the USV compares its distance to the pier with the distance to the table indicated on the marked structure. If the difference between these distances is negligible, it is determined that the pier is vacant and suitable for docking. This approach ensures precise identification and efficient decision-making for the docking operation.

2.1.1.4 Speed Challenge

The vessel is programmed to halt upon detecting a red light and proceed when a green light is observed. Upon entering the waiting area, it continuously monitors the traffic lights and initiates the speed test upon detecting a green signal. The primary objective during this phase is task completion rather than achieving maximum speed. After completing a circuit around the blue buoy, the vessel accelerates to return efficiently to its starting position.

2.1.1.5 Object and Water Delivery

The vessel is designed to patrol the designated area to locate targets using an advanced image processing algorithm. Once a target is detected, the vessel approaches it to the predefined distance, activating the mechanism associated with target detection. Following each delivery, the vessel resumes its search for subsequent targets, with the algorithm repeating for efficient task execution. The incorporation of a cross-nozzle design enhances the system's error tolerance, mitigating potential operational issues during the competition. Additionally, the use of a pump to spray seawater eliminates the need for onboard water storage, providing significant advantages in reducing vehicle weight and maximizing internal volume for other functional components.

2.1.1.6 Return to Home

Upon completing all assigned tasks, the USV will autonomously navigate to the pre-determined GPS coordinates corresponding to its initial deployment location.

2.2 Design Strategy

2.2.1 Hull Design

The unmanned maritime vehicle, offering high stability and safe navigation, was designed as a catamaran type using Rhino3D. The hulls, manufactured in two parts for ease of transport and maintenance, each part of the ship 3D printed by ABS flaments and coated with fiberglass. Parts are joined via bolts and sealed for water resistance. Aluminium sigma profiles connect the hulls, with sealed compartments housing electronics and navigation aids securely mounted on the profiles.

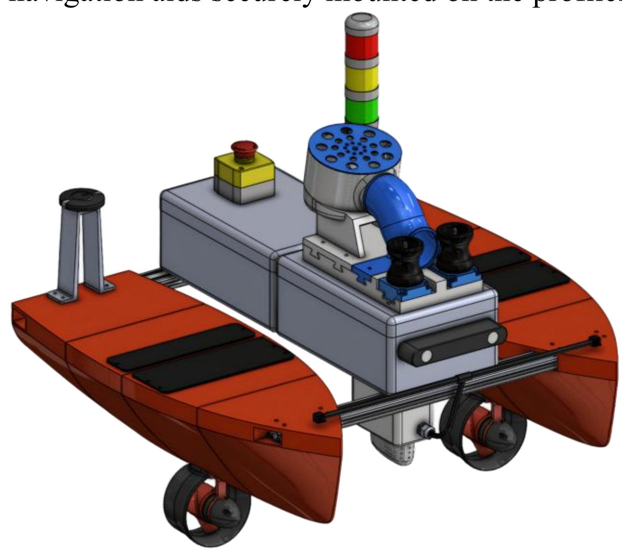

Figure 1. CAD of the "Turtle" boat

2.2.2 Ball Throwing Mechanism

The ball-throwing mechanism was designed using SolidWorks 2023 software and 3D-printed with PET-G filament. The design strategy behind the mechanism was based on the principle, 'The simpler the mechanism, the more efficient it is.' Following this approach, the mechanism was designed to allow a ball to fall between two rotating plastic components, which squeeze the ball, propelling it forward.

The magazine-like structure is intended to hold the balls in place. This structure is rotated by a stepper motor, which turns it 120 degrees when the image processing algorithm sends a command. This action causes the ball to fall through the S-shaped structure. As the ball reaches the end of the structure, it is compressed by the two rotating plastic components. This process transforms elastic potential energy into kinetic energy, propelling the ball toward the designated target[1].

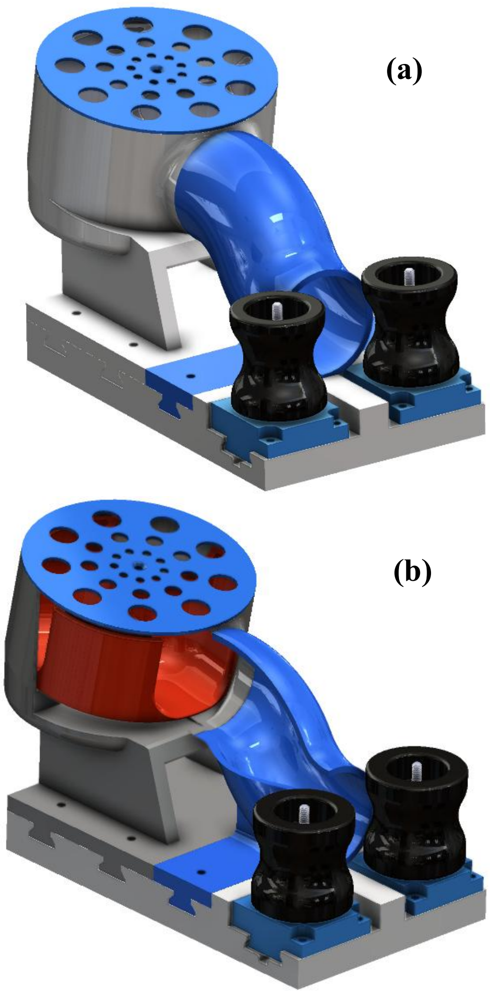

Figure 2. a) Ball-Throwing Mechanism. b) Ball-Throwing Mechanism Cut-Away

2.2.3 Water Spraying Mechanism

The nozzles are mounted on two separate sections of the vessel and are designed to spray water at an angle of 83 degrees, minimizing the impact of potential drift caused by wind and currents. In the system's design, water streams from the nozzles intersect at a distance of 2 meters from the point of discharge. This ensures that when the target is 2 meters away, water from both nozzles converges directly on the target. In cases where the distance increases or decreases, one of the nozzles will remain effective in performing the task. Seawater is drawn directly through a pump, eliminating the need for a water tank on the vessel. This design offers significant advantages in terms of reducing weight and maximizing usable internal space on the vessel.

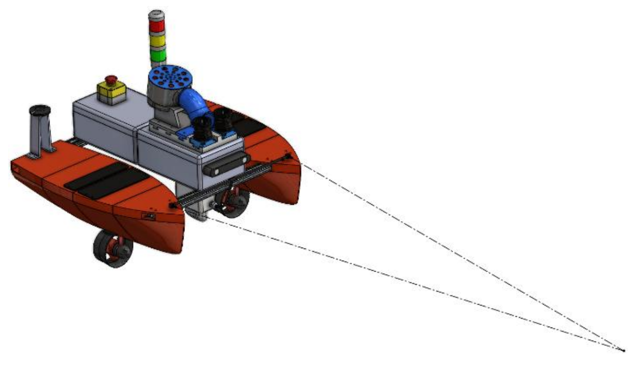

Figure 3. Nozzle Placements

2.2.4 Thrusters

The vehicle's propulsion relies on brushless motors due to their high power-to-weight ratio, efficiency, and low heat generation. Two waterproof Degz Ultras Underwater Thrusters were selected, capable of generating more than 8 kgf thrust @ 6S batteries paired with 80A ESCs. Tests confirmed that the ESCs and batteries pose no overheating risks during operation.

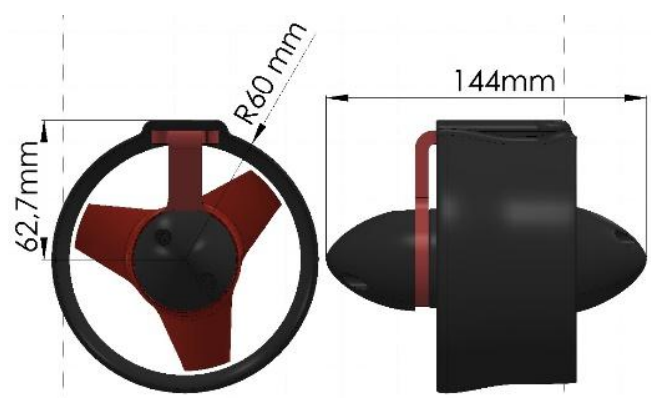

Figure 4. Thrusters

2.2.5 Electrical System Design

The system can be examined under two main electrical categories: power supply and electronic components. In the selection of the battery, the appropriate voltage value was first determined based on the system's requirements and was selected as 6S. This choice was made according to the voltage levels at which the thrusters and mission computer operate most efficiently. Lithium-ion batteries were preferred in terms of capacity and efficiency. LiPo batteries are a type of battery that requires special storage conditions and are transported in a LiPo bag. During the charging process, a balancing charge method is applied to ensure that each cell is safely charged. The battery is carefully positioned on the unmanned underwater vehicle.

In the event of a malfunction in the electronic circuits, an SSR (Solid State Relay) is used for each battery to disconnect the power source remotely. Additionally, an emergency stop button is available on the unmanned underwater vehicle for manual power disconnection. To withstand high current capacities, aluminum and multi-stranded cables are preferred; these cables are silicone-coated on the outside and are heat-resistant. Connectors are used at connection points to prevent electron splashes. The mission components are powered by the power distribution board. The power distribution board prevents voltage fluctuations. Components such as the Nvidia AGX Orin are protected from high current flow by a glass fuse. The system has been tested for current and temperature, and it has been verified that there are no issues.

2.2.6 Communication

Radio Telemetry system aim to transmit the GPS position, speed over ground, temperature, current (A) and other datas required from the vehicle to the ground control station with minimal delay and high accuracy, ensuring timely responses to potential issues. The RFD 900x radio telemetry system, which has a range of up to 40 km when used with 900 MHz and 3dbi antenna[1], operating at 900 MHz and compatible with MAVLink v2.0, was selected for its high data transfer rates. No delay was achieved while conducting perfomance tests.

2.2.7 Safety Design

The vehicle features water-resistant materials and stable navigation capabilities. It includes a lifting mechanism for crane operations, sealed compartments for electronic devices, and a red button for emergency power cuts. Additionally, a remote power cut-off switch ensures immediate power disconnection if necessary. The propulsion system is also protected from foreign objects. There are no sharp points on the vehicle body.

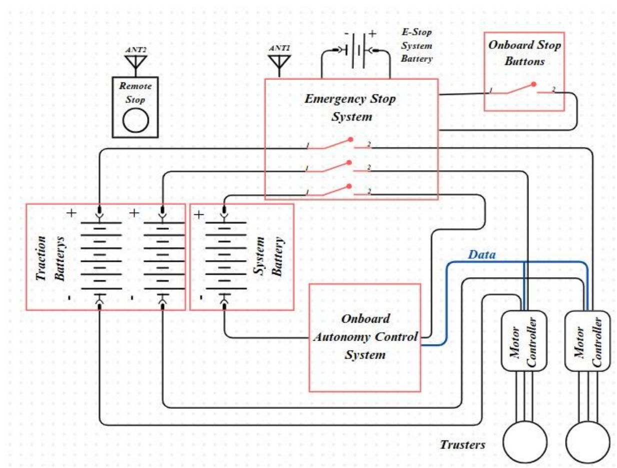

Figure 5. Emergency Stop System

2.3 Testing Strategy

In this study, resistance, thrust, and other performance parameters of the vessel were determined prior to sea trials using Maxsurf Resistance and Ansys Fluent software. As a result of the analyses, the optimal speed range of the vessel was identified. During the tests conducted at maximum revolutions per minute (RPM), no overheating or issues with the electrical system were observed. This indicates that the vessel poses no safety risks when operating at high speeds.

By utilizing the analysis programs, sea conditions were simulated before the sea trials, and the necessary equipment was prepared. The primary purpose of the sea trials was to test the thrust power of the vessel under real sea conditions and evaluate its performance. During these tests, the vessel's responses at different speed levels were observed, and desired results were achieved in terms of maneuverability and stability.

The manufacturer's data regarding the thrusters is presented in Figure13. Based on these data, thrust, efficiency, and current values were obtained at different RPM levels. These values were validated during sea trials and played a significant role in the development of mechanical and software systems.

This study presents a comprehensive approach to optimizing vessel performance by combining theoretical analyses with practical testing phases.

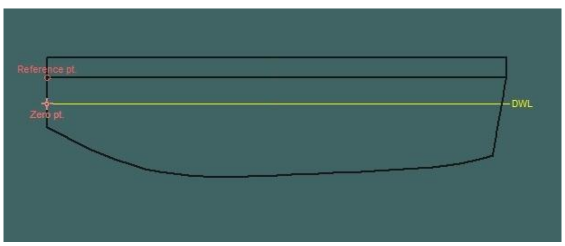

Figure 6. Design waterline of the Boat

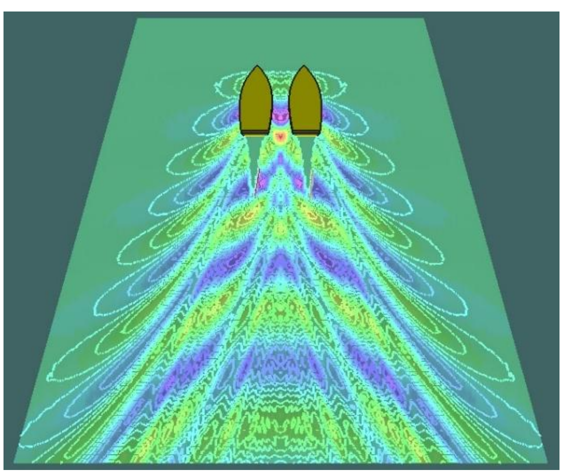

Figure7. Wave Formation Simulation

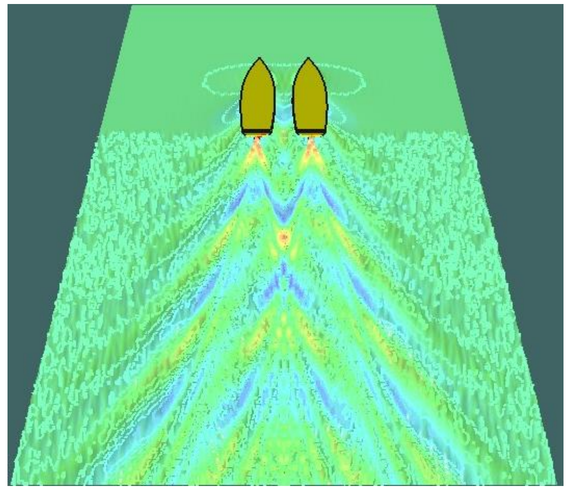

Figure8. Wave Formation Simulation

3.CONCLUSION

The unmanned maritime vehicle was designed in alignment with RoboBoat 2025 requirements. Task prioritization and modular design ensured simplicity, maintainability, and transportability. Stability and maneuverability were prioritized, while cabling minimized magnetic interference. Thrust tests was conducted and results were found similar with the manufacturer's data which is 8kgf thrust @24V (figüre 13).[2] Using the NVIDIA Orin AGX as a companion computer provided us with high processing speeds and performance, enabling the use of larger data packages for algorithms and image processing. The mechanical components required to execute the tasks were uniquely designed and rigorously tested to ensure their precise and reliable performance. With inspiration from Admiral Özden Örnek, the team successfully finalized the design, embodying a dedication to future innovation.

4.ACKNOWLEDGEMENTS

Our team, established in 2024, has greatly benefited from the resources and facilities provided by the Turkish Naval Academy. The procurement of equipment was generously funded by the Ministry of National Defense, the Military Factory and Shipyard Management Joint Stock

Company (ASFAT A.Ş.), SUPRA Defence Company and the National Defense University, while R&D activities were conducted under the auspices of the university's Mechanical Technologies Club. Pool and sea tests were carried out using the facilities of the university, ensuring a comprehensive evaluation of our project. We extend our heartfelt gratitude to the Naval Academy for their invaluable support and to our advisor, Assoc. Prof. Doğuş Özkan, for his unwavering guidance and motivation throughout this journey. Additionally, we would like to express our sincere thanks to YONCA Shipyard for their assistance in the coating process of the vessel, which significantly contributed to the success of our work.

5. REFERENCES

[1] RFDesign, RFD900x Data Sheet, RFDesign. [Online]. Available: https://files.rfdesign.com.au/Files/documents/RFD900x%20DataSheet.pdf. [Accessed: Jan. 28, 2025].

[2] J. D. Cutnell and K. W. Johnson, Physics: A Strategic Approach, 2nd ed. Hoboken, NJ: Wiley, 2013.
Degz Robotics, "Utras High Power ROV AUV and Vessel Underwater Thruster," Degz Robotics, [Online]. Available: https://degzrobotics.com/product/utras_rov_auv_vessel_underwater_thruster/. [Accessed: 28-Jan-2025].

APPENDIX A : Components Lists

Table 1. Components Lists

	Vendor	Model/Type	Specs	Custom/ Purch ased	Cost	Year of Purchase
ASV Hull Form/Platform	Özden	Catamaran	3D printed and glued with epoxy.	Custom	-	-
Propulsion	Degz	Ultras	Approximately 8.5 kgf of thrust at 24V, a voltage range of 12V to 24V, a maximum operational depth of 500 meters, and constructed with durable polycarbonate and polyurethane materials	Purchased	$338	2024
Power System	Zeee	6s Li-Po Battery	10000mAh 22.2V 120C High discharge rate and durability.	Purchased	$306	2025
Motor Control s	Pixhawk	OrangeCube	STM32H743, 480 MHz, ARM Cortex- M7 microcontroller, 1 MB RAM, 2 MB Flash.	Purchased	$760	2024
CPU	Nvidia	Nvidia Jetson AGX Orin	8-core Arm Cortex-A78AE CPU, up to 2048-core NVIDIA Ampere GPU with 64 Tensor Cores, up to 64 GB LPDDR5 RAM, 275 TOPS AI performance, multiple I/O options, and support for advanced AI and robotics applications.	Purchased	$2800	2024

Teleoperation	RFD	RFD900 Radio Modem	High powered 900Mhz, ISM band radio modem designed for long range serial communication.	Purchased	$115	2024
Compass	Stereo Labs	Zed 2i	120 FOV, Built-in IMU barometer, magnetomete r, positional tracking, spatial object detection, neural depth sensing		-	2024
Inertial Measurement Unit (IMU)	Stereo Labs	Zed 2i	120 FOV, Built-in IMU barometer,		-	2024
Camera(s)	Stereo Labs	Zed 2i	120 FOV,Built-in IMU barometer, magnetomete r, positional tracking, spatial object detection, neural depth sensing	Purchased	$533	2024
Hydrophones	N/A	-			-	-
Algorithims	Depth sensing and object detection + IMU navigation system	-		Custom	-	-
Vision	Custom made python and cpp codes	-		Custom	-	-
Localization and Mapping	Custom made python and cpp codes	-		Custom	-	-
Autonomy	Custom made python and cpp codes	-		Custom	-	-
Open Source Software	OpenCV	-		Custom	-	-

Appendix B : Performance Testing Results

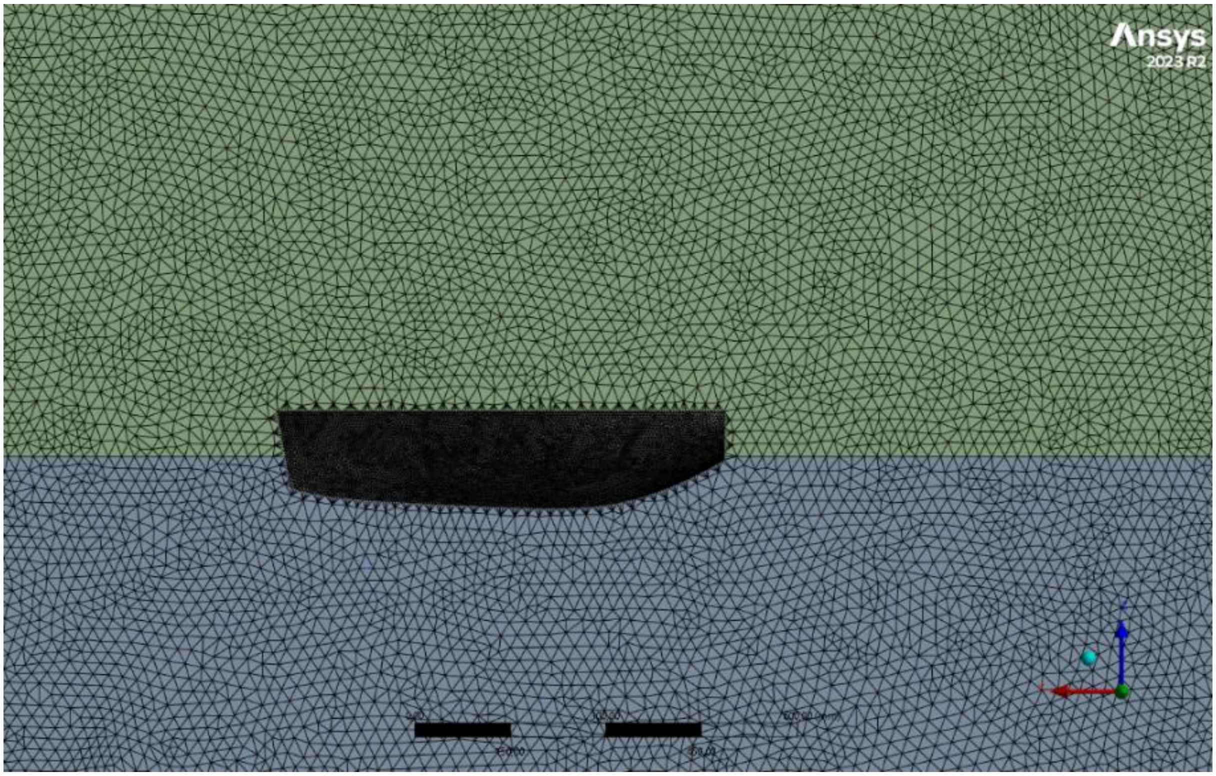

Figure9. Mesh view

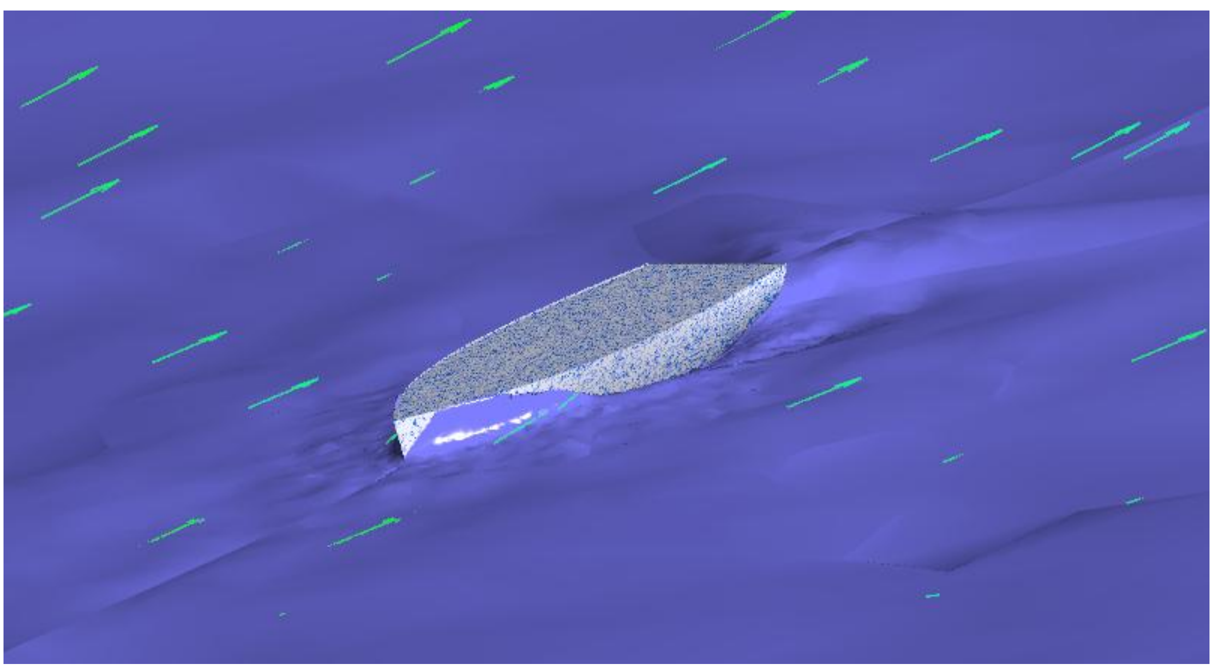

Figure10. Wave Modelling @ 6kts

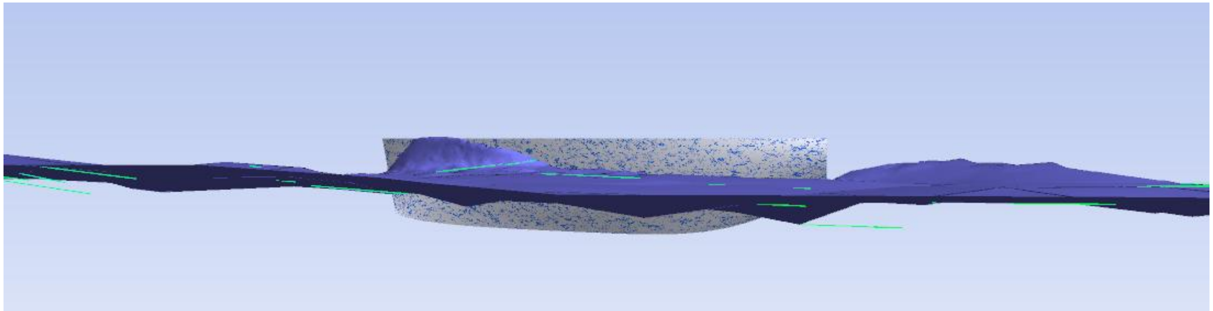

Figure11. Wave Modelling @ 6kts

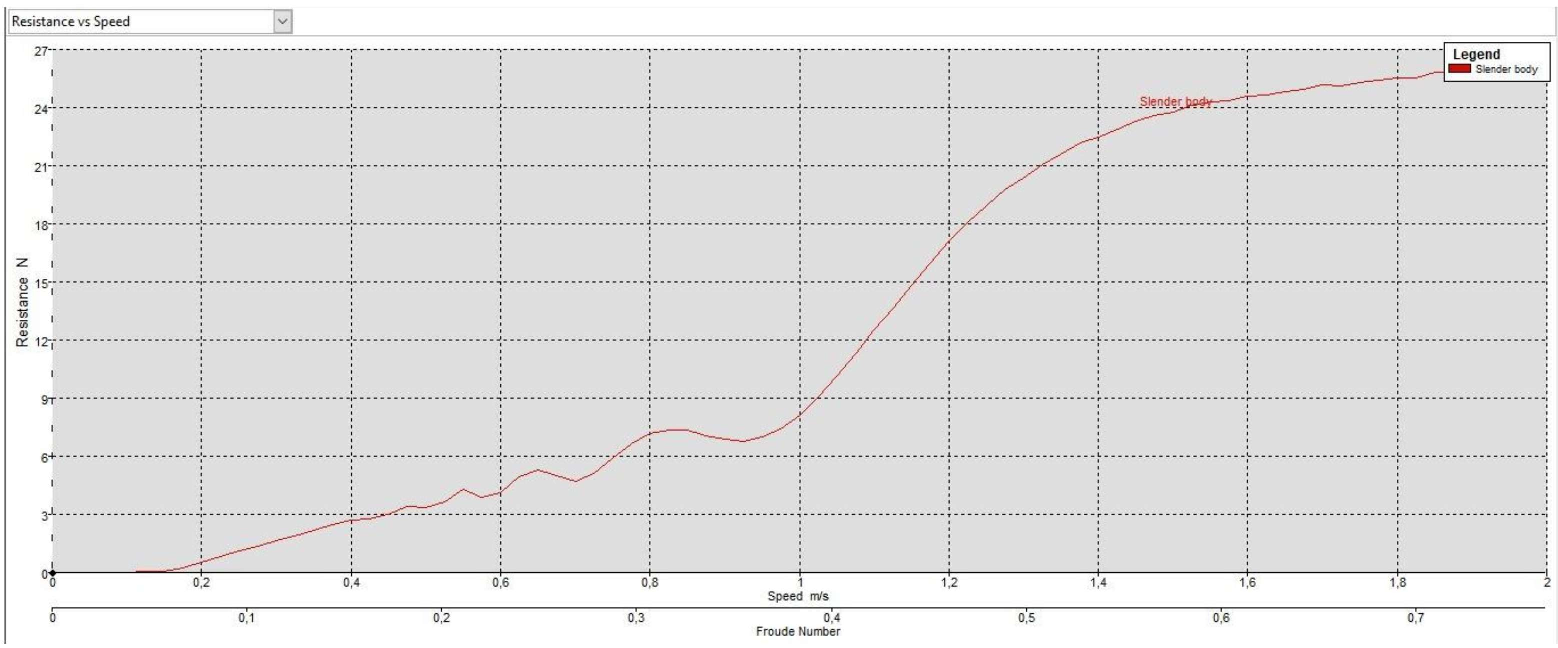

Figure12. Resistance Analysis @ 4kts

Appendix C : Hydrostatic Tests

Table2. Resistance Analysis

	Speed (m/s)	Froude No. LWL	Froude No. Vol.	Slender body Resist. (N)	Slender body Power (W)
1	0,0000	0,000	0,000	--	--
2	0,0500	0,019	0,033	0,01	0,00
3	0,1000	0,038	0,066	0,03	0,00
4	0,1500	0,058	0,100	0,08	0,01
5	0,2000	0,077	0,133	0,52	0,10
6	0,2500	0,096	0,166	1,10	0,27
7	0,3000	0,115	0,199	1,64	0,49
8	0,3500	0,134	0,232	2,19	0,76
9	0,4000	0,153	0,266	2,70	1,08
10	0,4500	0,173	0,299	2,99	1,35
11	0,5000	0,192	0,332	3,35	1,67
12	0,5500	0,211	0,365	4,28	2,35
13	0,6000	0,230	0,399	4,12	2,47
14	0,6500	0,249	0,432	5,27	3,43
15	0,7000	0,269	0,465	4,70	3,29
16	0,7500	0,288	0,498	5,86	4,40
17	0,8000	0,307	0,531	7,16	5,73
18	0,8500	0,326	0,565	7,34	6,24
19	0,9000	0,345	0,598	6,86	6,18
20	0,9500	0,364	0,631	7,01	6,66
21	1,0000	0,384	0,664	8,13	8,13
22	1,0500	0,403	0,697	10,12	10,62
23	1,1000	0,422	0,731	12,53	13,78
24	1,1500	0,441	0,764	14,82	17,05
25	1,2000	0,460	0,797	17,10	20,52

Table3. Item Placement

Item Name	Quantity	Unit Mass kg	Total Mass kg	Unit Volume litre	Total Volume litre	Long. Arm cm	Trans. Arm cm	Vert. Arm cm
Lightship	1	6,0	6,0			30,60	0,00	10,20
box	1	4,0	4,0			31,00	0,00	23,00
mot-port	1	0,9	0,9			35,00	-25,00	-2,00
mot-starboard	1	0,8	0,8			35,00	25,00	-2,00
bat-port	1	0,0	0,0			64,00	-25,00	12,00
bat-starboard	1	0,0	0,0			64,00	25,00	12,00
Total Loadcase			11,7	0,0	0,0	31,38	-0,21	12,80
FS correction								0,00
VCG fluid								12,80

Table4. Hydrostatic Values Table

Draft Amidships cm	10,73
Displacement kg	11,70
Heel deg	-0,1
Draft at FP cm	11,06
Draft at AP cm	10,39
Draft at LCF cm	10,68
Trim (+ve by stern) cm	-0,66
WL Length cm	69,30
Beam max extents on WL cm	70,47
Wetted Area cm^2	3510,95
Waterpl. Area cm^2	2247,44
Prismatic coeff. (Cp)	0,709
Block coeff. (Cb)	0,376
Max Sect. area coeff. (Cm)	0,531
Waterpl. area coeff. (Cwp)	0,792
LCB from zero pt. (+ve fwd) cm	31,43
LCF from zero pt. (+ve fwd) cm	30,05
KB cm	7,37
KG fluid cm	12,80
BMt cm	128,45
BML cm	59,71
GMt corrected cm	123,02
GML cm	54,27
KMt cm	135,81
KML cm	67,07
Immersion (TPc) tonne/cm	0,002
MTc tonne.m	0,000
RM at 1deg = GMt.Disp.sin(1) kg.cm	25,12
Max deck inclination deg	0,5584
Trim angle (+ve by stern) deg	-0,5495

Appendix D : Thruster Analysis

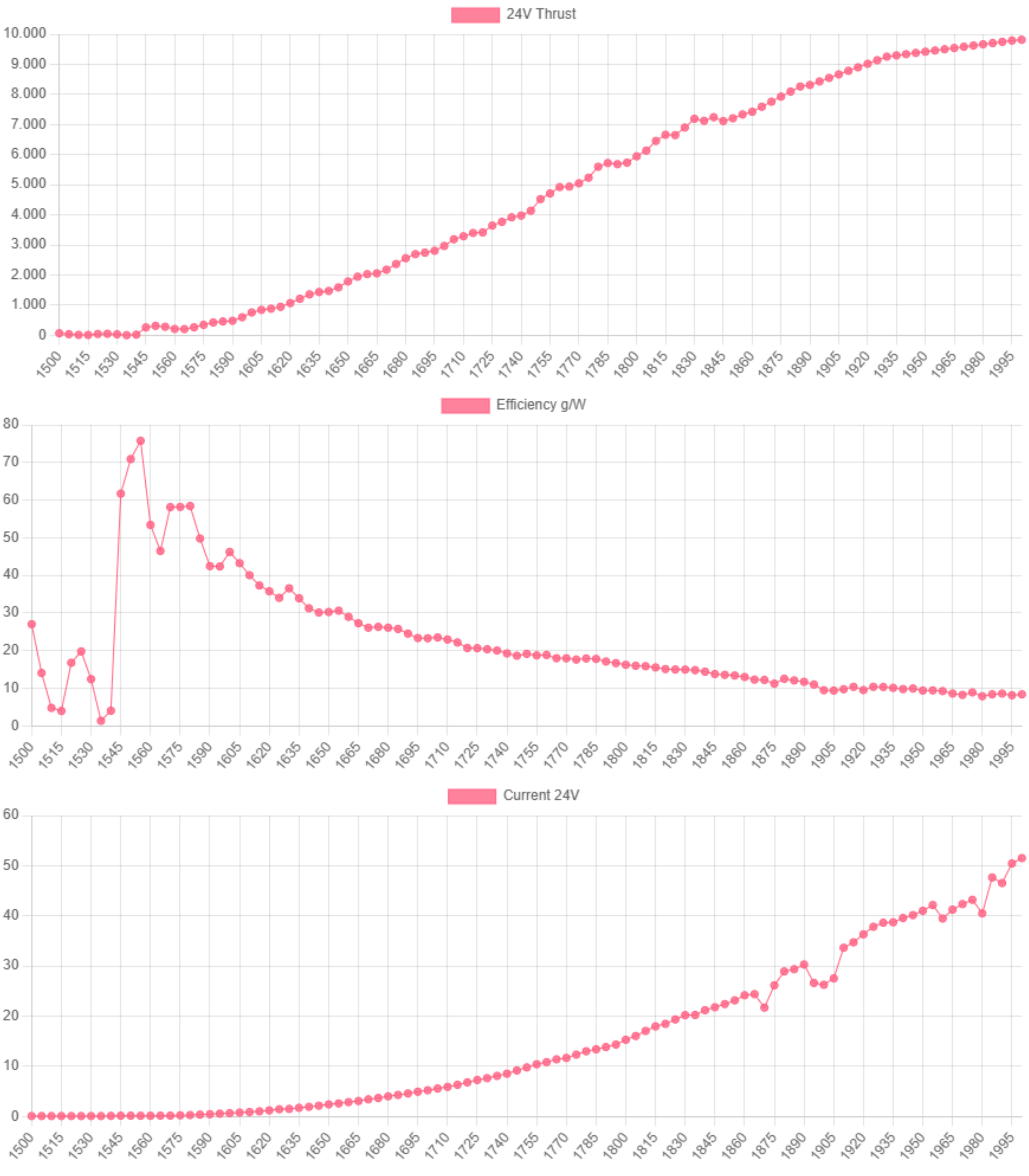

Figure13. Thruster Analysis @ 24V

Figure14. Thrust Test @ 24V