RoboSub 2026 Technical Design Report

San Diego State University (SDSU Mechatronics)

Sponsors

SeaByte, BrainCorp, Lorimar Marine, SeaBotix, Solidworks, and Matlab.

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Abstract

For RoboSub 2026, the SDSU Mechatronics team is upgrading Caracara with major mechanical, electrical, and software improvements, transforming it from a navigation-focused platform into a fully capable autonomous underwater vehicle (AUV) able to complete all competition tasks. The team is also introducing Torpico, a second AUV designed to work collaboratively with Caracara through coordinated task execution and inter-vehicle communication. To support reliability and performance, the team has adopted a comprehensive testing and validation strategy across all critical systems.

1. Competition Strategy

1.1 Core Strategy

The main goal of this competition year is to improve on the baseline that we have set in previous years while maintaining ease of use, ease of maintenance, reliability and versatility to accomplish multiple tasks. To achieve this we are using the following strategies:

1.2 Dual-Vehicle Strategy

Last year we used two AUV's, we had our main sub Caracara and our specialized sub Scion. This year Caracara is returning with upgrades and a new specialized sub Torpico. Having two AUV Caracara excels in precise control. Due to the larger size, Caracara struggles with speed, while Torpico excels at it. By having multiple vehicles, each vehicle can specialize. In this case, Torpico is maneuverable, and Caracara has extra features. Having two subs also allows for Inter Vehicle Communication, and provides a backup where one sub flooding does not end our competition.

1.2.3 Capability-to-Task Alignment

One of the main concepts behind this year's strategy is to divide and conquer. Each sub has its own weaknesses and strengths, and completes specific tasks in the pool based on their specialization. The main difference between the two subs is a spectrum ranging from high maneuverability and low modularity (Torpico) over to low maneuverability and high modularity (Caracara). Torpico is focusing on the navigation tasks, namely doing gate tricks, going through slalom, going to octagon and returning home, and making sure to hit dropper to qualify for time bonus. Caracara is focused on the tasks that require additional hardware, namely the tasks for torpedoes and claw.

1.3 System Overhauls

1.3.1 Mechanical Changes

For mechanical, two major changes were made: the frame of caracara being fully replaced by anodized parts to prevent corrosion and rust, and the use of a compact tube design for maximizing maneuverability with the newest sub, Torpico.

1.3.2 Electrical Architecture Redesign

Prioritized durability and safety by implementing fuses across the board on both power boards, improved future proofing with spare connectors on torpico power board, and used an FPGA for maximum flexibility in Torpico electrical system.

1.3.3 Software Architecture Upgrades

In software, a major upgrade was the organization for tasks now using higher level modes with internal states in a hierarchical state machine.

1.4 Risk Assessment

1.4.1 Mechanical Risk

The main risk concerns potential leaks, which has been addressed by using off-the shelf tubing specially made to fit the O-ring seal bought from Blue robotics for our latest sub.

1.4.2 Electrical Risk

The major concern was not having enough rails or signals to support additional hardware, which has been addressed by adding spares in both power boards and the FPGA with lots of ports in Torpico.

1.4.3 Software Risk

The primary risk is failure to switch tasks. This has been addressed by having the tolerances for every task transition be individually customizable, and using a robust hierarchical state machine.

2. Design Strategy

2.1 Caracara Mechanical

2.1.1 Torpedo Launcher

The system consists of electronically powered torpedoes that use supercapacitors for onboard energy storage and are activated through a Hall effect sensor. A launcher pushes the torpedoes away from a magnet, triggering their activation. Each torpedo is assembled from three 3D printed sections sealed with O-rings: a nose cone containing counterweights for stability, a main body housing the electronic system, and a tail section with the DC motor for propulsion.

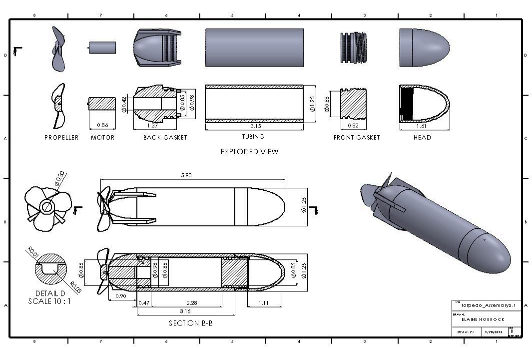


Figure 1: Torpedo Schematic

2.1.2 Robotic Claw

The claw subsystem features a scissor lift design that utilizes Caracara's modular frame by fitting compactly beneath its feet. The design of the claw itself was inspired by a robotic TPU flexure gripper and a talon-like claw. The former provided stable grip, while the latter offered adaptability when grabbing objects due to its compactness. This combination provides flexibility and stability while grasping objects.

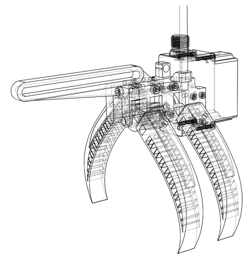


Figure 2: Claw Diagram

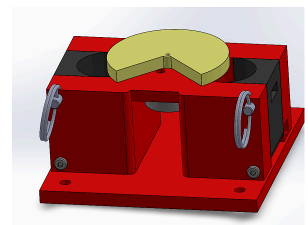


Figure 3: Dropper CAD

2.1.3 Dropper

The dropper subsystem was designed with simplicity, compactness, and reliability as primary objectives. Rather than relying on bulky enclosed servos or large linear actuators, the system utilizes a compact brushless motor paired with a resettable fuse mechanism and a custom "Pac-Man" shaped release door. This design allows one at a time deployment, improving reliability. Being able to wait between drops lets us increase the chance of getting the marker in the correct spot.

2.1.4 Primary Frame Changes

Following extensive use during the 2025 competition season, the AUV experienced significant rust and corrosion across several structural components. To address these issues, all heavily corroded surfaces were remanufactured and black anodized to improve corrosion resistance and extend the operational lifespan of the metal components. In addition, the buoyancy foam mounting bulbs were redesigned to rebalance the vehicle and compensate for newly introduced weight. Major modifications were also made to the sub's feet structure to create more space for the new subsystems.

Figure 4: Caracara CAD Drawing

2.1.5 Internal Rework

During the previous competition season, Caracara exhibited several internal design limitations, including inefficient cable management, limited battery endurance, and suboptimal weight distribution. To address these issues, the vehicle's battery capacity was doubled and the internal component layout was redesigned to improve overall balance and stability by using a double stacked battery system near the vehicle's center of mass, with the display on top.

2.2 Caracara Electrical Stack

2.2.1 Powerboard

The Caracara power board is used to deliver power from up to two batteries to the various electrical components contained within the sub, as well as handling control signals and hardware kills. It features power switching MOSFET arrays to distribute heat and add redundancy. The design also incorporates a comparator to rapidly switch between batteries, prioritizing saving the internal battery. It contains four battery voltage rails, VAO which is always on, VBATSW which is the switched rail, and VESC for powering the ESCs and motors, gated by a hardware kill connected to an external magnet that can be pulled by a diver for safety purposes. Lastly is 3V3, fed by a 3.3V regulator for powering lower-voltage components.

2.2.2 MCU board

Caracara's MCU PCB serves as the connection point between hardware components and software communication. The PCB utilizes an STM32 G474RBT6 microcontroller for its 17 hardware timers and communication protocols. Apart from the microcontroller, the board also possesses an IC that allows for pressure/depth data readings. The firmware design philosophy lies within simplicity and versatility, in which a custom USB protocol is used to transmit serial data from user software to the MCU board, which then individually controls 8 motors, dropper servos, and torpedo all at once through the hardware timers with PWM. Additionally, through the same USB dataline, Caracara's shutoff, depth sensing, and kill handling can be controlled over GPIO or USB.

2.2.3 Interface board

The interface board on Caracara sits in its own box behind the sub, containing the primary I/O for the sub. It contains a waterproof button, a magnet for killing the motors safely, and a wet connector for ethernet communication. Since space is limited, we opted to choose a single button and have it alternate colors to denote what mode the button is in, namely green for the start script, blue for debug mode, and red for turning the power off.

2.3 Caracara Software Stack

2.3.1 General Architecture

The key design considerations behind the Caracara software stack are reliability and connectivity. Reliability has been achieved through using tried and true systems to the club, like shared memory and python multiprocessing, and connectivity is achieved by connecting it all together through shared memory values and building around a single configuration file.

2.3.2 Vision

The vision system is divided into pre-deployment and deployment stages. During pre-deployment, synthetic underwater datasets are generated in Blender by randomizing environmental parameters such as lighting, water conditions, object position, camera angles, and HDRI backgrounds. Annotation meshes are projected into the camera view to automatically generate YOLO-format labels for training. During deployment, the ZED stereo camera provides both RGB images and depth matrices. DBSCAN clustering is applied to the depth data to identify candidate object regions while filtering out large background surfaces such as walls and the pool floor. These candidate regions are cropped from the RGB image and passed into YOLO for inference. The final detections return the object class, confidence score, image position, and estimated depth, allowing the AUV to localize and interact with competition targets.

2.3.3 Control System

Caracara's control system is responsible for maintaining stable and efficient movement throughout the pool during autonomous operation. High-level movement commands are generated by the mission planner and finite state machine, then passed to the control system to regulate the vehicle's position, depth, and heading. The vehicle's PID controllers use sensor feedback from the Doppler Velocity Log (DVL) and depth/pressure sensors to evaluate Caracara's motion through the water. By comparing the desired movement with the measured vehicle response, the control system can adjust thruster outputs to improve stability and accuracy. Well-tuned PID controllers allow Caracara to move efficiently between locations in the pool and transition smoothly through different finite state machine states.

2.3.5 Mission Planner

The mission planner feature of the sub consists of two main pieces: the yaml configuration file, and the web GUI (General User Interface). A hierarchical state machine commands the sub to approach specific coordinates, which are a virtual map of the pool listed in the yaml configuration file. The Orin is also hosting a Django server that creates a web GUI, which allows users to edit the coordinates in this configuration file through an easy to use interface. The server uses PyYAML to parse the configuration file, display them in the web GUI, and then save the newly edited values back into the yaml file.

2.4 Torpico Electrical Stack

2.4.1 Powerboard

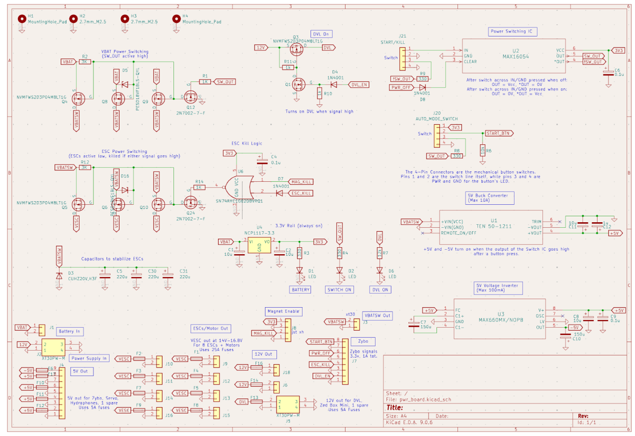


Figure 5.1: Powerboard Schematic (KiCad)

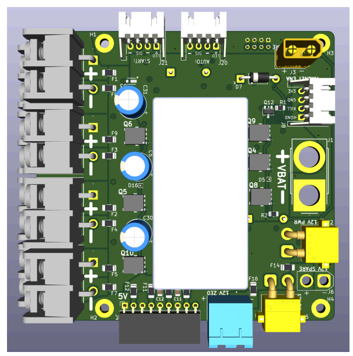


Figure 5.2: Powerboard CAD Model (KiCad)

The power board on Torpico utilizes a 4S 16.8V Lipo battery and 12V power supply, and delivers power to different components on the submarine by splitting it up into four different voltage rails: VBAT, VBATSW, VESC, 12V, 5V, and 3V3. VBAT is the 16.8V rail that directly comes from the battery and is switched immediately through the MOSFET array into the VBATSW rail. VESC comes from VBATSW which directly powers the ESCs for the motors, gated by a hardware and software kill. The 12V rail receives power from an external power supply, used to send power to the ZED Box Mini and a gated 12V to the DVL. The 5V rail uses an onboard buck converter that powers the Zybo FPGA and servo for the dropper. Lastly, 3V3 provides 3.3V from a voltage regulator, used primarily for LEDs and small ICs.

2.4.2 Zynq SoC

The Torpico electrical system is built around the Zynq SoC at its center, which primarily manages control signals for the sub. This particular setup uses the Zybo Z7 s20 development board, which contains a Zynq 7020 FPGA (Field Programmable Gate Array) chip at its center. The Zynq SoC consists of three primary sections, those being the Processing System (PS), the Programmable Layer (PL), and the General Purpose Input/Output (GPIO). The PS is running a lean version of custom-built linux using the Yocto operating system building tool, which includes only the dependencies needed for the sub. The PS enables the use of high level languages like C and Python, as well as networking features. The SoC receives commands over UDP from the master Orin computer, and a script running on the SoC then uses linux commands to write to the raw registers accessible to the PL over the AXI 4 Lite protocol. The values in these registers are converted into control signals in custom VHDL modules and IP Cores in the PL, most notably the PWM modules that read an integer in microseconds and create a matching square wave to control the motors. The PL also routes other control signals from these registers.

2.4.3 Magnet Kill board

To externally disable the ESC control signals and shut down the motors, we used a simple PCB with a Hall Effect Sensor to trigger a signal whenever a magnetic field was detected near the system. The magnet board is powered by 3.3V through a JST XH header from the power board, and transmits data through the same connector to the power board, which is then transmitted to the Zynq SoC.

2.4.4 Battery Sensing Board

This board uses the ADC of a Raspberry Pi Pico to convert voltage signals to a single numerical reading. The JST 5 pin Connector connects to the balance connector on the 16.8 V LiPo, and the Pico is powered via USB. Since the Pico can only handle 3.3 V, a voltage divider circuit was used to scale the voltage down from a maximum of 16.8 V to 3.3 V, which is compensated for on the software side and finally sent to the GUI via USB.

2.5.5 "PALMS" Hydrophone processing board

The PALMS project is an analog front-end detection system for underwater acoustic pingers. The system isolates pinger frequencies at design-specific 20 kHz, 25 kHz, 30 kHz, 35 kHz, and 40 kHz, with automatic adjustment for range and pulse frequency (with best performance ranging from 0.5 s to 2 s). This system filters, amplifies, and holds/decays targeted signals to be digitized and sent for external computation to calculate the time-difference of arrival from multiple different hydrophone transducers.

2.6 Torpico Mechanical Structure

2.6.1 Mechanical Structure

Torpico's external structure was designed to maximize both structural robustness and lightweight performance. The complete frame weighs approximately 10 lbs, with all major components mounted directly to the primary C-channel supports that serve as the vehicle's main structural backbone. This configuration enables operators and divers to safely handle the AUV from virtually any point. The handles, inspired by ergonomic bicycle grips, provide improved comfort and ease of transport for the sub. In addition, Torpico incorporates a fully tool-less disassembly system, allowing rapid access to internal components and enabling efficient battery swaps between competition runs. The vehicle is also equipped with a rear gantry featuring a dropper subsystem similar to the one implemented on Caracara, along with an M16 Modem to support inter-vehicle communication.

Figure 6: Torpico Hull

Torpico's internal structure was designed to be as compact and yet accessible as possible. To meet our design goals of minimizing the vehicle's footprint, our mechanical team worked hand in hand to create PCBs that accomplished both mechanical and electrical goals. A key component in the internal structure is the PCB sandwich plate. The material choice of 6061 Aluminum serves multiple purposes as its structure is able to have a higher strength compared to its PETG counterpart. It also helps dissipate heat off our SSD and other components. The plate has the ability to hold two PCBs on both sides and easy disassembly helps to keep internals compact and accessible.

2.7 Torpico Software

2.7.1 Software Architecture

Torpico draws from the exact same codebase as Caracara, but uses a few alternative scripts for setup. It relies on environmental variables to identify which scripts to use, but is otherwise the same, with variations based on sending commands over UDP to the Zynq SoC instead of USB to the MCU board in Caracara.

3. Testing Strategy

3.1 Compartmentalized Electrical Testing

Individual boards on Torpico and Caracara, including the power distribution boards, hydrophone board, magnet kill/interface boards, and voltage reading boards, were electrically tested through ensuring minimum debugging interfaces like programmable/power LEDs and communication protocols, and through extensive use of standard laboratory equipment to test for connectivity and shorts with a multimeter or data signal integrity with our oscilloscope, and checking for unexpected temperatures using a thermal camera after putting parts under load.

3.2 Integration Testing

Integration testing is handled by the critical components of the full stack being tested together against a series of probable inputs and expected outputs. This includes the scripts in software sending commands over UDP to the FGPA, which then calls a script that writes to the registers shared between the PS and PL, where they control the module outputs which are then observable on the motor behavior, as well as an oscilloscope connected in parallel to ensure the pulse widths are as expected. In Caracara, this is done through the microcontroller instead of the FPGA, but the process remains the same.

3.3 Software Testing and Validation

The object detection model is trained using a synthetic underwater dataset generated in Blender and expanded through image augmentation techniques such as blur, noise, color shifts, and partial occlusions to better simulate real underwater conditions. A pretrained YOLO11 segmentation model is then fine-tuned on RoboSub-specific classes and deployed onto the AUV using the best-performing model weights from training. Model evaluation is performed using both recorded footage and live pool testing. During deployment, the vision system uses the ZED stereo camera and depth-based DBSCAN clustering to improve object detection and reduce background noise. Individual tasks such as Gate, Slalom, and Octagon can be validated independently before being combined into full autonomous runs. During testing, the software stack records telemetry data such as DVL readings, target positions, and active states, allowing the team to analyze performance and refine behaviors throughout development.

4. Acknowledgements

For our acknowledgements, we would like to thank our sponsors SeaByte, BrainCorp, Lorimar Marine, SeaBotix, Solidworks, and Matlab. We would also like to thank SDSU for hosting our club and supporting us financially. Lastly we would like to thank our mentors, Austin Owens, Leverett Bezanson, Zach Noel, and Umut Cabuk for their counsel.

Appendix A: Requirements Traceability Matrix

RN: Robonation Requirement as defined in the Robosub Handbook for 2026
ME: Mechatronics Requirement for all AUV’s
CC: Mechatronics Requirement for Caracara
TP: Mechatronics Requirement for Torpico

Source	Description	Validation	Fulfilled By
RN 5.3.1.2	AUV shall be fully autonomous, additionally each AUV shall operate fully independent of the other	Inspection	1.2.1
RN 5.3.1.3	AUV shall stay fully beneath the surface during autonomy	Test	3.3
RN 5.2.2.4.1	AUV’s shall weigh under 60kg / 132 lbs	Demonstration	Appendix E
RN 5.2.2.4.2	AUV’s shall fit within a 3ft x 3ft x 6ft volume	Inspection	Appendix E
RN 5.3.1.5	AUV’s shall be powered by batteries that do NOT exceed 60VDC	Analysis	2.1.5, 2.4.1
RN 5.3.1.5.1	AUV’s shall not be changed or charged during autonomy	Inspection	2.1.5, 2.4.1
RN 5.3.1.6	AUV’s shall have a clearly marked kill switch that disconnects the batteries from all propulsion components and devices on the AUV’s	Demonstration	2.2.1,
RN 5.3.1.7	AUV’s shall have shrouded thrusters or propellers with a 2 in distance between the top of the spinning disk and the edge of the shroud	Inspection	Appendix B (Blue Robotics T-200)
RN 5.3.1.8	AUV’s shall be buoyant by > 0.5% of their mass when unpowered	Analysis	Appendix G
RN 5.4.1	AUV’s should drop a marker into a 2ft x 2ft box	Demonstration	2.1.3
RN 5.4.1.1	AUV’s drop marker shall not	Inspection	2.1.3

	weigh more than 2 lbs in air		
RN 5.4.1.2	AUV's drop marker shall display the team's name, color, or emblem	Inspection	2.1.3
RN 5.4.1.3	AUV's shall carry a maximum of two markers	Inspection	2.1.3
RN 5.4.2	AUV should deploy torpedoes during autonomous operation	Demonstration	2.1.1
RN 5.4.2.1	AUV's torpedoes shall fit inside a 2in x 2in x 6in rectangular volume	Inspection	2.1.1
RN 5.4.2.2	AUV's torpedoes shall not weigh more than 2lbs in air	Demonstration	2.1.1
RN 5.4.2.3	AUV's torpedoes shall move at a speed no more than 1m/s	Inspection	2.1.1
RN 5.4.2.4	AUV's torpedoes shall display the team's name, color, or emblem	Inspection	2.1.1
RN 5.4.2.6	AUV's shall carry a maximum of two torpedoes	Inspection	2.1.1
RN 5.4.3	AUV's should be able to detect acoustic frequencies between 25kHz - 30kHz	Demonstration	2.5.5
ME 1.1	AUV's shall be rated for submersion at 1m underwater for 3 hours without seal failures	Demonstration	3.2
ME 1.2	AUV's shall be operable for 1hr while fully powered and all motors are at 50% power	Demonstration	Appendix F
ME 1.3.1	AUV's shall have less than 0.5psi loss in pressure over the course of 2 hours when pressured to a minimum of 10psi above atmospheric pressure	Test	Appendix F
ME 1.3.2	AUV's shall have any visible bubbles for 2 hours when vacuumed to a minimum of 10psi under atmospheric pressure	Demonstration	Appendix F
ME 2.1	AUV's shall contain a power rail	Analysis	2.2.1,

	within the range of 7VDC to 20VDC capable of 40W continuous power draw		2.4.1
ME 2.2	AUV's shall contain a power rail with a nominal voltage of 12VDC	Analysis	2.2.1, 2.4.1
ME 2.3	AUV's shall contain a power rail with a nominal voltage of 5VDC	Analysis	2.2.1, 2.4.1
ME 2.4	AUV's shall operate from and maintain full functionality from a nominal 16.8 VDC LiPo 4S battery	Analysis	2.2.1, 2.4.1
ME 2.5	AUV shall be equipped with a functional BAR02 depth sensor powered by the 5VDC power rail	Demonstration	2.2.2, Appendix B
ME 2.5.1	AUV shall read and decipher BAR02 signals	Test	2.3.4
ME 2.6	AUV shall be equipped with a functional A50 DVL powered by the 12VDC power rail	Demonstration	2.2.1
ME 2.7	AUV's shall contain a power flush function	Demonstration	2.2.1
ME 3.1	AUV's shall have vacuum fittings per hull for vacuum pressure testing	Inspection	Appendix F
ME 3.2	AUV's shall be able to be remotely controlled via bulkhead tether	Demonstration	2.2.3
ME 3.3	AUV's shall have control on all 6 axes of movement	Demonstration	2.3.4
ME 3.4	AUV's shall communicate via Acoustic Modems at a minimum frequency of 1Hz	Test	2.3.5
ME 3.5	AUV's shall have logging per mission	Demonstration	2.3.1
ME 3.6	AUV's should be configurable from an external GUI	Demonstration	2.3.6
ME 3.7	AUV's shall have a single point of entry for autonomy	Analysis	2.3.1

CC 1.1	Caracara shall have a mounted mechanism for firing torpedoes	Inspection	2.1.1
CC 1.2	Caracara shall have a mounted mechanism for dropping markers	Inspection	2.1.3
CC 1.2	Caracara should have mounted claw with at least 1 degree of freedom	Inspection	2.1.2
CC 1.3	All caracara boxes shall have pressure testing fittings	Inspection	Appendix F
CC 2.6	AUV shall be equipped with a functional StereoLabs Zed 2i powered by the Onboard Jetson Orin via USB	Demonstration	2.3.3
CC 2.6.1	AUV shall read and decipher StereoLabs Zed 2i color camera data	Test	2.3.3
CC 2.6.2	AUV shall read and decipher StereoLabs Zed 2i stereodepth data	Test	2.3.3
CC 3.1	AUV shall be able to identify underwater objects at a success rate of 70%	Test	2.3.3
TP 1.1	Torpico shall be less than 50% of the internal volume of Caracara	Inspection	2.6.1
TP 1.2	Torpico shall have less than 50% the weight of Caracara	Demonstration	2.6.1
TP 1.3	Torpico shall have an easily accessible internal mounting system	Inspection	2.6.1
TP 1.4	Torpico shall have corrosion resistant materials on its exterior	Analysis	Appendix F
TP 2.1	Torpico should power multiple onboard IMU’s via USB from Zybo Dev board	Inspection	-
TP 3.1	All VHDL modules shall be verified through OSVVM	Test	Appendix D

Appendix B: Hardware List

Component List (Torpico)

COMPONENTS	VENDOR	MODEL	SPECS	CUSTOM/ PURCHASED?	COST (TOTAL)	YEAR OF PURCHASE
Frame	McMaster	4592T151	Anodized	Purchased	$540	2026
	SendCutSend	Custom	N/A	Purchased		2026
Vehicle Hull	Blue Robotics	Watertight Enclosure	130mm x 300mm	Purchased	$210	2026
O-Rings	McMaster	-162 Buna-N 70A	N/A	Purchased	$5.10	2026
	McMaster	-255 Buna-N 70A	N/A	Purchased	$7.81	2026
Waterproof Connectors	SubConn	Underwater Subsea Connector	N/A	Sponsored	N/A	2026
Buoyancy Control	Blue Robotics	R-3312	Subsea Buoyancy Foam	Purchased	$48	2026
Fastening Hardware	McMaster/Amazon	M3/M2.5	Standoffs	Purchased	$45	2026
	McMaster	M3/M.25	Screws	Purchased	$82.24	2026
	McMaster	M6	Nut with Spring	Purchased	$ 3.30	2026
	Blue Robotics	M3	Long Standoffs	Purchased	$36	2026
	McMaster	¼-20”	Bolts and Nuts	Purchased	$250	2026
Sandwich Plate	SendCutSend	Custom	N/A	Purchased	$38.46	2026
Internal Structure	N/A	PLA/PETG	N/A	Custom	$150	2026
Heat Sink	McMaster	8822T957	Adhesive-Mount Heat Sink	Purchased	$11.42	2026

Thrusters	Blue Robotics	T200	N/A	Purchased	2160	2026
Light	Blue Robotics	Lumen Subsea Light (Preconnected)	1,500 Lumens	Purchased	$375	2023
External Addressable RGB LEDs	BTF Lighting	WS2811	16.4 ft	Purchased	$16	2024
Tactile Buttons	TE Connectivity ALCOSWITCH Switches	PB6B2FM3M1CAL03Y500	N/A	Purchased	$40	2026
8x Electronic Speed Controllers	Blue Robotics	Basic Esc	30 Amp	Purchased	$300	2024
Internal Power Board	PCB Way	Custom	N/A	Purchased	$150	2026
Onboard Processor	Zed	Zed Box Mini	N/A	Purchased	$850	2026
Forward Camera	Stereolabs	Zed X Mini	N/A	Purchased	$550	2026
DVL / IMU	Waterlinked	A50	N/A	Purchased	$7000	2026
Depth / Pressure Sensor	Blue Robotics	Bar02	10m	Purchased	$75	2024
Processor Operating System	Ubuntu / Nvidia	24.04 LTS	N/A	N/A	N/A	2024
Inter-Process Communication	Mechatronics	Custom	N/A	Custom	N/A	2024
Programming language(s)	Open-Source	C	C90	Open-Source	N/A	Before 2020
	Open-Source	C++	C++12	Open-Source	N/A	Before 2020
	Open-Source	Bash	Bash 5.1	Open-Source	N/A	Before 2020

	Python Software Foundation	Python	Python 3.11.9 LTS	Open-Source	N/A	2024
Vision Algorithms	Scikit-Learn	DBSCAN	Python	Custom (coded)	N/A	2026
	Ultralytics	YOLOv11	Python	Custom (trained)	N/A	2026
Vision Data Simulation	Blender Foundation	Blender	Version 5.1+	Custom (scripted)	N/A	2026
Autonomy Architecture	Mechatronics	Finite State Machine	Custom	Custom	N/A	2026
Motor control	Mechatronics	Custom	N/A	Custom	N/A	2024
Localization and mapping	Mechatronics	Custom	Custom	Custom	N/A	2024

Component List (Caracara)

COMPONENTS	VENDOR	MODEL	SPECS	CUSTOM/ PURCHASED?	COST (TOTAL)	YEAR OF PURCHASE
Frame	McMaster Carr	47065T10	2x1 aluminum rails	Purchased	$120	2026
	McMaster Carr	47065T101	1x1 aluminum rails	Purchased		2026
Vehicle Hull	SendCutSend	Custom	N/A	Purchased	$3281	2023-2026
O-Rings	McMaster Carr	94115K022	N/A	Purchased	$15.21	2023-2026
	McMaster Carr	9452K109	N/A	Purchased	$14.21	2023-2026
	McMaster Carr	9452K377	N/A	Purchased	$24.33	2023-2026
	McMaster Carr	9262K666	N/A	Purchased	$8.99	2023-2026
Waterproof Connectors	Blue Robotics	WetLink Penetrator	N/A	Purchased	N/A	Before 2020
Buoyancy Control	Oycevila	Marine Flotation Foam	Polyurethane Expanding Foam	Purchased	$40	2025
Fastening Hardware	McMaster Carr	10-32 bolts, 10-32 nuts	Socket Head Screws	Purchased	$200	2023-2026
	McMaster Carr	M3 bolts	Socket Head Screws	Purchased	$50	2023-2026
	McMaster Carr	¼-20 bolts, ¼-20 nuts	Socket Head Screws	Purchased	$80	2023-2026
	McMaster Carr	8-32	Socket Head Screws	Purchased	$20	2023-2026
Thrusters	Blue Robotics	T200	N/A	Purchased	N/A	Before 2020
Torpedoes	Mechatronics	Custom	N/A	Custom	N/A	2025

Light	Blue Robotics	Lumen Subsea Light (Preconnected)	1,500 Lumens	Purchased	$375	2025
External Addressable RGB LEDs	BTF Lighting	WS2811	16.4 ft	Purchased	$16	2024
Piezo-Electric Button	Other	N/A	N/A	Purchased	$50	2024
Servo	HiTec	HRC36954 Servos	N/A	Purchased	$228	2026
Servo Enclosure	Blue Trails Robotics	Underwater Servo Kit SER-2000	N/A	Purchased	$185	2026
Lithium Ion Polymer Battery and Spares	Hoovo	4s	91.76Wh	Purchased	$116	2023
Power Converter	Mechatronics	Custom	N/A	Custom	$250	2024
Power Regulator	Blue Robotics	Tekko32 F4	4 x 30 Amp	Purchased	$200	2024
Battery Monitoring	Mechatronics	Custom	N/A	Custom	$30	2025
Internal Communication	Mechatronics	UART	N/A	Custom	N/A	2024
	Mechatronics	CAT 6 Ethernet	N/A	Custom	N/A	2026
External Communication	Mechatronics	CAT 6 Ethernet	N/A	N/A	N/A	2026
8x Electronic Speed Controllers	Blue Robotics	Basic Esc	30 Amp	Purchased	$300	2024
External LED Control Board	Mechatronics	Custom	N/A	Custom	$15	2025
Internal Micro-Controller	Mechatronics	Custom	N/A	Custom	$30	2024

Board						
Onboard Processor	Nvidia	Jetson Orin	N/A	Purchased	$2370	2023
Internal Display	Crowpi	RC070	N/A	Purchased	$44	2024
Forward Camera	Stereolabs	Zed 2i	N/A	Purchased	$550	2026
AHRS	PNI	Trax2	N/A	Purchased	$1,250	2025
DVL / IMU	Waterlinked	A50	N/A	Purchased	$7000	2023
Scanning Sonar	Blue Robotics	Ping360	N/A	Purchased	$2,750	2025
Depth / Pressure Sensor	Blue Robotics	Bar02	10m	Purchased	$75	2025
Processor Operating System	Ubuntu / Nvidia	24.04 LTS	N/A	N/A	N/A	2024
Inter-Process Communication	Mechatronics	Custom	N/A	Custom	N/A	2024
Programming language(s)	Open-Source	C	C90	Open-Source	N/A	Before 2020
	Open-Source	C++	C++12	Open-Source	N/A	Before 2020
	Open-Source	Bash	Bash 5.1	Open-Source	N/A	Before 2020
	Python Software Foundation	Python	Python 3.11.9 LTS	Open-Source	N/A	2024
Vision Algorithms	Ultralytics	Yolo V5	N/A	Open-Source	N/A	2025
	Mechatronics	Faster R-CNN	N/A	Open-Source	N/A	2025
	Mechatronics	Vision Transformer	N/A	Custom	N/A	2025
Vision	Mechatronics	LSTM	N/A	Custom	N/A	2025

Algorithm Discriminator						
Vision Data Simulation	Unity Technologies	Unity	Unity 6	Custom	N/A	2025
Autonomy Architecture	Mechatronics	Finite State Machine	Custom	Custom	N/A	2025
Motor control	Mechatronics	Custom	N/A	Custom	N/A	2024
Localization and mapping	Mechatronics	Custom	Custom	Custom	N/A	2024

Appendix C: Acronyms

Acronym	Definition
3D	3 Dimensional
AUV	Autonomous Underwater Vehicle
AXI	Advanced eXtensible Interface
DBScan	Density-Based Spatial Clustering of Applications with Noise
DC	Direct Current
DVL	Doppler Velocity Log
ESC	Electronic Speed Controller
GPIO	General-Purpose Input/Output
GTKWave	open-source waveform viewer
GUI	Graphical User Interface
HSM	Hierarchical State Machine
HTML	HyperText Markup Language
I2C	Inter-Integrated Circuit
IC	Integrated Chip
IP (Core)	Intellectual Property
IVC	Inter-Vehicle Communication
JST	Electrical Connector Type
kHz	Kilohertz
lbs	Pounds (weight)
LED	Light Emitting Diode
LiPo	Lithium Polymer
MCU	MicroController Unit
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor

mm	Millimeters
NaCl	Sodium Chloride (salt)
NOR	Not Or
OSVVM	Open Source VHDL Verification Methodology
PCB	Printed Circuit Board
PETG	PolyEthylene Terephthalate Glycol
PID	Proportion Integral Derivative (control)
PL	Programmable Logic
PSI	Pounds per Square Inch
PWM	Pulse Width Modulation
PyYAML	Python library for YAML
SPI	Serial Peripheral Interface
SSD	Solid State Disk
TPU	Thermoplastic PolyUrethane
UART	Universal Asynchronous Receiver-Transmitter
UDP	User Datagram Protocol
USB	Universal Serial Bus
UUT	Unit Under Test
V	Volt/s
VHDL	Very High-Speed Integrated Circuit Hardware Description Language
YAML	Yet Another Markup Language
YOLO	You Only Look Once (computer vision model)

Appendix D: OSVVM Testing

UUT: Zync SoC

During VHDL development for the Zynq SoC, all VHDL has been verified using OSVVM (Open Source VHDL Verification Methodology). This is an open source verification library tailor-made for VHDL, which was used to create robust self-checking testbenches to ensure the modules behaved as intended. This means that the modules used in the VHDL codebase were subject to several test cases as follows: The nominal test case is the best-case-scenario, used for simple testing during module development. The random test case is a large-scale stress test sending tons of randomized inputs and tracking the outputs, automatically checking if the behavior is as expected. There is the stop test case, which tests the stop signal used to send the stop pulse width (such as how a 1500 microsecond pulse will stop the blue robotics T200 motors), and the binary test case, which verifies the binary mode that the main module runs in when receiving a 1 or 0 for the input instead of a typical pulse width. The testbenches keep track of every signal, counting up all passes and fails, and delivering a final verdict. Once the modules passed all test cases, as well as observing their behavior on a waveform using GTKWave, modules were verified and ready to be packaged into IP Cores in the final block design.

Appendix E: AUV Size/Weight

Torpico:

575mm x 570mm x 179mm
weighs ~32lbs

Caracara:

596mm x 536 mm x 410mm
weighs ~78lbs

Appendix F: Hardware Tests

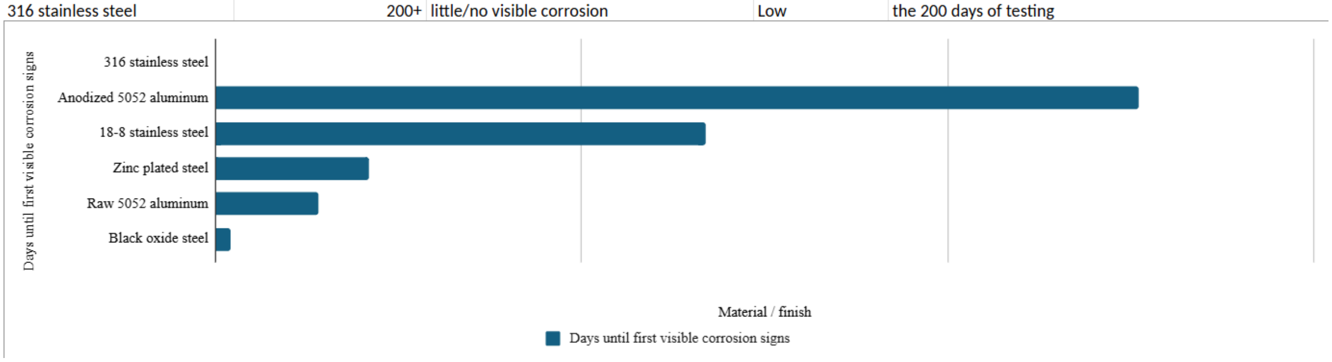
UUT: Vehicle Hull
Pressure Testing:

Once both sealing surfaces were manufactured, a pressure validation test was conducted to verify the integrity of the hull and ensure no water ingress would occur during underwater operation. The AUV was sealed using blank plugs, pressurized to 13 PSI, and monitored over several hours to confirm pressure retention. Additionally, Liquid Snoop leak detection fluid was sprayed onto leak-prone areas to make any minor leak more apparent. The test pressure was selected as 1.5 times the maximum pressure expected at the operating depths of the Wollet Aquatic Center, providing an additional safety margin. To further improve reliability, the team has also incorporated the use of a portable air compressor for pre-deployment pressure checks prior to any water operations.

UUT: Exterior Components
Corrosion Testing:

A major focus of this year's development effort was improving the vehicle's resistance to corrosion in harsh underwater environments. To evaluate the most suitable materials for the sub's external hardware, a comparative corrosion study was conducted using zinc-plated steel, black oxide steel, 18-8 stainless steel, 316 stainless steel, raw 5052 aluminum, and anodized 5052 aluminum. Each material sample was submerged in a saltwater (NaCl) solution and monitored on a daily basis to assess long-term corrosion performance. After 200 days of testing, 316 stainless steel demonstrated significantly superior corrosion resistance compared to the other materials evaluated. As a result, 316 stainless steel was selected as the primary fastener material for all external bolts and exposed hardware on the vehicle.

Material / Finish	Days Until First Visible Corrosion Signs	Likely First Sign	Confidence	Notes
Black oxide steel	2	orange/brown rust at edges or scratches	Medium	Black oxide alone has limited protection; oil/sealant greatly changes result.
Raw 5052 aluminum	14	dull gray/white oxide or small spots	Medium	5052 has good general corrosion resistance; results were mostly small and localized.
Zinc plated steel	21	white zinc corrosion product before red rust	Medium	Zinc protects steel sacrificially; coating thickness and scratches on the part strongly affect timing of corrosion.
18-8 stainless steel	67	small surface spots	Low-Medium	18-8 showed little to no corrosion for a long time, only minor amounts in crevices. This specimin also had an interuption during the testing so data ay be inaccurate.
Anodized 5052 aluminum	126	minor discoloration/staining; coating still protective	Medium	Anodizing improved aluminum's corrosion resistance; minor discoloration offured on the scratches
316 stainless steel	200+	little/no visible corrosion	Low	316 is highly resistant in; visible corrosion never appeared in the 200 days of testing



Appendix G: Buoyancy and Dunk Testing

UUT: Vehicle Hull
To ensure stable underwater performance during operation, extensive buoyancy and dunk testing was conducted on each AUV throughout its development cycle. Achieving proper buoyancy and balance was critical for maintaining vehicle stability, reducing unnecessary thruster load, and improving maneuverability during autonomous task execution.

The vehicle utilizes closed-cell buoyancy foam as its primary flotation method due to its lightweight properties, resistance to water absorption, and ease of integration within the frame. Multiple foam configurations were tested, and a design covering to the highest point on the wing, yet spread across with majority in the corners was determined as the optimal balance between positive buoyancy and overall stability. The foam was then carefully adjusted to align the center of buoyancy with the vehicle's center of mass, minimizing unwanted pitch and roll during operation.

Dunk testing was then performed incrementally as new subsystems and structural components were added to the vehicle. During each test, the AUV was submerged in a controlled environment to evaluate buoyancy characteristics, trim angle, leak prevention, and structural integrity. Additional adjustments were made to achieve near-neutral buoyancy while maintaining a slight positive buoyancy margin for safety and recovery purposes. After the final amount needed was determined, a plastic housing was made to encase the foam which helps keep it all aligned and in place.