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MSU Robocats Student-Club Organization: Technological Overview of the "Balboa" AUV

Abstract— Representing Montana State University in the 2026 RoboSub competition is the RoboCats autonomous underwater vehicle "Balboa." Building on lessons learned from the previous competition season, the 2026 design emphasizes reliability, safety, maintainability, and subsystem integration rather than a full mechanical reinvention. The vehicle retains the compact frame, modular electrical layout, and multi-effector philosophy developed for the previous platform while refining the components that proved to be weak points in testing and competition use. Major mechanical improvements include a redesigned torpedo housing with improved retention and charging contact, a sealed ballast housing for reclaimed lead shot, a protective vertical thruster guard, an aluminum grabber axle, and a transition from ASA to PETG for most printed structural components. The electrical subsystem continues to use a compact modular architecture with onboard power protection, centralized distribution, and bulkhead pass-throughs for external devices. The software system has been reworked around a dedicated operator control application and an onboard Jetson-based hardware service to support vehicle control, telemetry, sensor integration, and future autonomous behaviors. Together, these updates are intended to improve Balboa's performance in navigation, ball-drop tasks, torpedo launch, and grabber-based tasks while providing a safer and more robust platform for continued iteration.

Index Terms—Autonomous Underwater Vehicle, Balboa, Reliability, Safety, Modularity

I. Competition Strategy

The RoboCats strategy for the 2026 RoboSub season is based on prioritizing reliable point-scoring tasks in a deliberate sequence. Rather than attempting to maximize task breadth at the expense of consistency, the team selected a progression that aligns with the current maturity of the platform and the lessons learned from prior competition experience.

The team's task priorities for the 2026 season are navigation tasks first, followed by ball dropper tasks, torpedo tasks, and finally grabber tasks. Navigation remains the highest priority because stable gate approach, heading control, depth control, and visual alignment directly determine whether downstream effectors can be used effectively.

Once the vehicle can navigate repeatably, the ball dropper provides a relatively simple and high-value scoring opportunity with low mechanical complexity. Torpedo tasks were prioritized next because the team already had a functioning concept, but several design weaknesses from the previous season needed to be corrected before the subsystem could be used reliably. The grabber is prioritized last because it requires the greatest precision in alignment, manipulation, and control coordination.

This strategy reflects the broader 2026 objective of converting observed failure modes into targeted design improvements. Rather than adding complexity for its own sake, the team focused on strengthening the subsystems that limited prior performance, resulting in a vehicle that is safer to handle, easier to maintain, and better prepared for repeatable competition use.

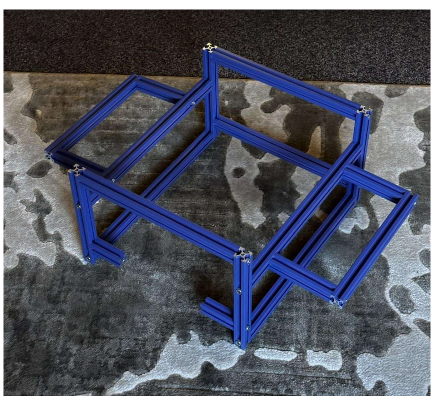
II. Design Strategies

A. Mechanical

1) Frame and Enclosure

Balboa continues to use its compact enclosure and modular frame strategy to reduce buoyancy, simplify transport, and improve serviceability. The electrical enclosure is mounted within a T-slot 2020 extruded aluminum frame, which provides a rigid structure while allowing components to be repositioned or replaced as the vehicle evolves. Retaining the established frame also lets the team focus engineering effort on the subsystems that produced the clearest reliability or safety issues during the previous season.

Inside the enclosure, removable printed trays keep electronics organized and elevate sensitive hardware away from the bottom of the enclosure in the event of minor water intrusion. This arrangement supports maintenance and provides a repeatable location for electrical hardware. Metal bulkhead connectors continue to be used for pass-throughs because they provide a more robust and leak-resistant interface than the simpler alternatives used previously.



Frame of the Submarine

The team also revised its material selection strategy for printed components. The previous vehicle used ASA extensively because it was initially expected to perform well for the application. In practice, ASA did not meet the team's manufacturing and durability needs as well as expected. For the 2026 vehicle, PETG is used for most printed components because it is easier to print consistently, less expensive, and sufficiently temperature resistant for the intended operating environment.

2) Ballast System

One of the most important mechanical changes for 2026 is the ballast system. In the prior configuration, diver weights were zip-tied to the exterior of the submarine. Although this was functional, it left bulky weights exposed on the vehicle and did not integrate cleanly with the frame. The new design uses a dedicated streamlined housing filled with reclaimed lead shot. The lead shot is sealed inside the housing so it cannot be exposed to pool water. The new assembly gives the vehicle a cleaner external profile and a more intentional method of locating and retaining ballast.

3) Ball Dropper

The ball dropper remains a comparatively simple effector that supports one of the team's higher-priority scoring objectives. The mechanism uses a solenoid-actuated release to deploy the scoring payload. Its straightforward actuation and compact packaging make it appropriate for a task attempted after basic navigation is established, without requiring the alignment precision demanded by torpedo or grabber operations.

4) Torpedo System

The torpedo system is one of the primary areas revised from the previous season. The torpedoes remain self-propelled by small DC motors and electrically charged through contact pads while seated on the underside of the vehicle. The previous housing did not retain the torpedoes securely enough and did not maintain dependable contact for charging. For 2026, the housing was redesigned around these two requirements: stable retention before launch and more consistent electrical contact during charging. This revision preserves the underlying torpedo concept while directly addressing the failure mode that reduced its reliability.

5) Grabber

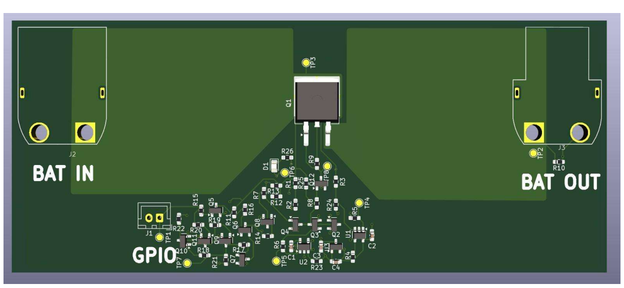
The grabber remains mounted to the underside of the vehicle and uses flexible TPU fingers that rotate downward to conform to target geometry. The most important 2026 revision is the central axle. The previous ASA-printed axle could be damaged by the motor torque, so it was replaced with a 3D printed aluminum axle to provide a stronger load-bearing drive component. Safety was also treated as a design requirement this season. Following a serious injury involving a vertical thruster, the team added a thin protective guard intended to prevent accidental finger contact while keeping the flow path as open as practical.

B. *Electrical*

The 2026 electrical system maintains the same general architecture developed previously because no meaningful electrical redesign was required this season. The team's electrical priorities remain modularity, compactness, and reliable power management within the confined enclosure. Maintaining the existing layout also reduces integration risk while the team concentrates on the mechanical reliability improvements and the new software architecture.

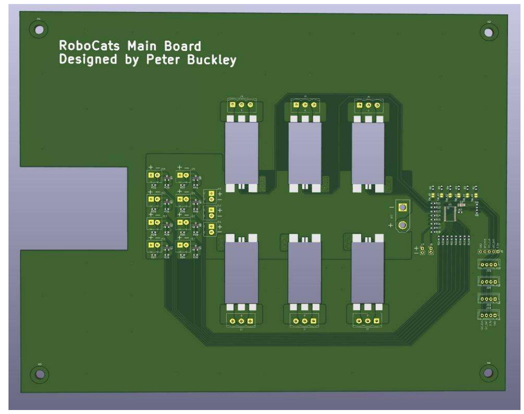
1) Voltage Protection

Power from the battery is routed through a dedicated voltage protection stage before entering the main distribution system. The protection design is intended to shut down the vehicle under abnormal voltage conditions and when a leak signal is received from the control system. Since this architecture was not a primary source of the previous season's design problems, it was retained as part of the stable electrical foundation for the 2026 vehicle.



2) Power Distribution

The power distribution board shown routes power and control to the vehicle's thrusters, sensors, and external effectors. Its PWM control interface provides a common electrical path for thruster and actuator commands from the onboard computer. Keeping this centralized interface is important for the 2026 task sequence because navigation, the ball dropper, torpedoes, and the grabber all depend on predictable actuator command delivery.

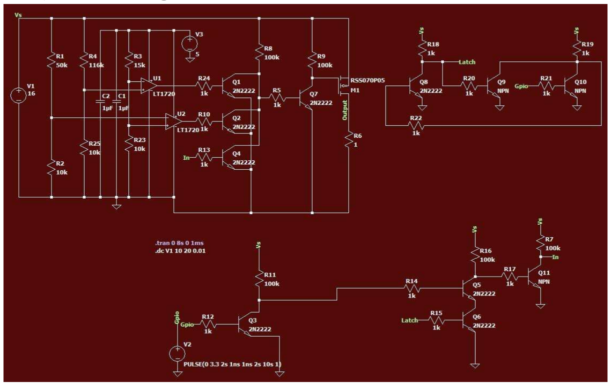


3) Connectors

The previous vehicle's connectors were straightforward, but in turn, they proved to be less dependable. Due to their simple yet unreliable nature, multiple small and non-critical leaks occurred. This was enough of a concern that Robocats invested in new, higher-quality connectors which used a more robust assembly to prevent future leakages. These connectors use a traditional bulkhead on one side and a silicone-filled metal connector as the input. All three of the new effectors were fitted into these connectors while minimizing the number of pins used. This was achieved by combining shared ground wires.

Balboa retains this bulkhead-style external pass-through strategy for motors, sensors, and effectors. The connectors provide a robust sealing approach and allow the revised mechanical assemblies to be incorporated without changing the enclosure philosophy.

4) Voltage Protection Board Simulations



Voltage protection board simulations remain relevant to the retained electrical architecture. The simulated operating thresholds and leak-triggered shutdown behavior provide design evidence for the protection stage used in the current vehicle. Since no meaningful electrical redesign was made for 2026, the existing validation of the protection concept supports the decision to focus current-season redesign effort elsewhere.

The protection stage and distribution board together establish the electrical base needed by the current mechanical and software subsystems. This continuity is intentional: components that were not identified as primary failure points were preserved, allowing the team to devote time to the torpedo housing, ballast integration, grabber durability, thruster safety, and software-control changes.

C. Software

The 2026 software system was substantially reworked to better support vehicle operation, subsystem integration, and later autonomous task execution. The current design separates the operator interface from onboard hardware control. A dedicated desktop control application runs on the operator laptop, while an NVIDIA Jetson AGX Orin onboard the vehicle hosts the service layer responsible for communicating with sensors and actuators.

1) System Architecture and Sensing

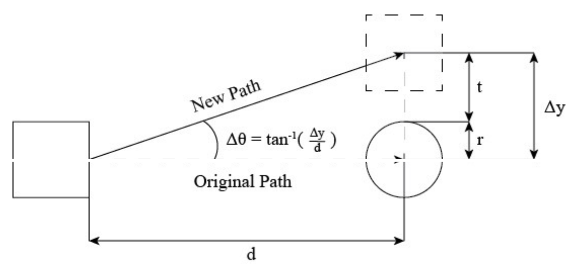
The onboard service layer interfaces with the BNO055 inertial measurement unit, the Bar02 pressure-based depth sensor, the camera suite, the PCA9685 PWM controller, the thrusters, and the external effectors. Centralizing these hardware interfaces on the Jetson produces a clear control path from sensor feedback to actuator command and makes individual devices accessible through a consistent test workflow.

2) Operator Interface and Perception

The desktop application provides command input, telemetry display, live camera viewing, and subsystem testing in a unified interface. It supports manual tethered operation, heading hold, depth hold, motor testing, solenoid testing, and sensor checks. The camera and perception interfaces also provide the foundation needed for target-recognition workflows used in navigation and later effector alignment.

3) Navigation and Mission Control

Navigation is the first software priority because every scoring task depends on reliable vehicle placement. Heading and depth feedback support stable movement through navigation tasks and provide the control foundation needed before the ball dropper, torpedo system, or grabber can be used. The vehicle software is organized so that mission logic can request motion and effector actions through the same onboard hardware interfaces used during direct testing.



The software structure follows the competition task priority order. Navigation and alignment capabilities are developed first, followed by the ball dropper as the least complex effector action. Torpedo and grabber behaviors require progressively tighter positioning and are therefore layered onto the same telemetry, camera, and actuator interfaces instead of being developed as disconnected control systems.

The completed software architecture defines the intended control system for this season: an operator application communicating with the onboard Jetson service, with sensor feedback and actuator commands exposed through a common interface. This provides a practical platform for system checkout, tethered operation, and mission development.

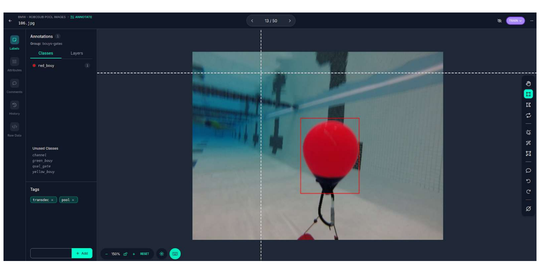
Separating operator tools from onboard hardware control also improves maintainability. During troubleshooting, the team can examine sensor data, test motors or solenoids, and monitor camera streams without requiring a complete autonomous mission run. This is important for a vehicle with several external mechanisms that must each be verified before integrated operation.

4) *Data Collection and Annotation*

Competition-specific image data can be collected in the pool environment and annotated to support target-detection workflows. This approach allows the perception system to be refined using underwater examples representative of the actual challenge environment and supports navigation and future task-specific alignment behavior.

5) *Model Training and Deployment*

Machine-learning and perception workflows support target recognition and future autonomy features within the updated architecture. Trained models can be deployed through the onboard software service so that perception outputs, navigation commands, and effector actions remain integrated within the same control environment.



Tagging an Image for Use in a YOLOv8 Training Dataset

II. Testing Strategies

A. *Torpedo and Effector Testing*

Testing of the vehicle's effectors focused on the failure modes observed in earlier development. The torpedo subsystem was evaluated for propulsion, buoyancy behavior, launch behavior, and electrical charging contact. The ball dropper was tested for repeatable actuation and release, and the grabber was tested with the revised aluminum axle in place of the failed printed axle concept. The new torpedo housing remains the outstanding focused validation item because it is the specific revision intended to improve retention and charging contact.

B. *Leak and Integration Testing*

Because the enclosure includes multiple penetrations for connectors, cameras, and mounted hardware, leak testing remains central to integration readiness. The enclosure and its penetrations were tested to check the pressure boundary before extended vehicle operation. Testing was also completed for the sealed **ballast housing** approach, the grabber axle revision, and the **vertical thruster guard**. These checks address the physical changes that distinguish the 2026 vehicle from the previous design.

C. *Driving, Navigation, and Safety Testing*

Driving and mobility testing emphasized correct motor behavior, repeatable maneuvering, heading stability, and depth control because navigation tasks are the team's top competition priority. The software control interface supports those checks through tethered driving, telemetry, live camera viewing, heading hold, depth hold, and hardware test controls. The thruster guard was also included in the completed validation effort to address operator safety around the vertical thrusters. These completed tests support integration readiness; they do not by themselves claim successful autonomous completion of competition tasks.

III. Acknowledgments

The Montana State University RoboCats would like to thank the organizations and partners that support the team's work and make continued development possible. The team is grateful to Montana State University for providing the institutional home that allows the club to operate and grow. The team also thanks ORION Innovation Partners, SOLIDWORKS, the United States Department of Defense, NAVSEA, Blue Robotics, Blue Trail Engineering, Buckley Power Company, AttaBox, and the Naval Nuclear Laboratory for their support of RoboCats and the Balboa vehicle. Their contributions help provide the tools, materials, components, and opportunities required to design, build, test, and compete.

References

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[2] Intel, "Intel RealSense Depth Camera D456," 2026. [Online]. Available: https://www.intelrealsense.com/.

[3] Blue Robotics, "Bar02 High-Resolution 300 m Depth/Pressure Sensor," 2026. [Online]. Available: https://bluerobotics.com/.

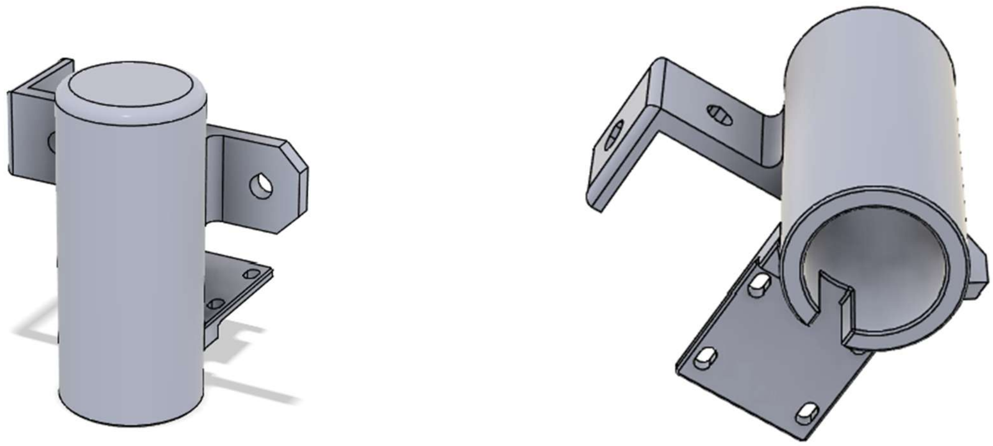
[4] Bosch Sensortec, "BNO055 Intelligent 9-axis absolute orientation sensor," 2026.

Appendix/Supplementary Material

Item Name	Quantity	Individual Cost	Total Cost
Acrylic Dome (1in)	2	$8.47	$16.94
Elegoo ASA Filament	3	$17.99	$53.97
Overture 95a TPU	1	$28.99	$28.99
Heated Insert Kit	1	$15.98	$15.98
1/8 in acrylic 12x12	1	$8.25	$8.25
Support bracket (4 pack)	7	$5.20	$36.40
M5x40mm Socket Head Bolt (25 pack)	1	$8.54	$8.54
M5x18mm Socket Head Bolt	16	$1.98	$8.09
M5x12mm Pan Head	56	$1.65	$9.99
Extrusion 700mm	7	$39.99	$279.93
3.0V 3.3F Capacitor	12	$1.80	$21.60
Torpedo Motors	3	$8.49	$25.47
Conductive Rods	4	$1.12	$4.48
Female connector for rods	12	$1.46	$17.52
Epoxy Mix With Syringe	1	$24.99	$24.99
DC 12V 3RPM Geared Motor 90 degrees	1	$14.99	$14.99
M5 Male Ring Eye Bolts	1	$6.99	$6.99

20mm T-slot pivot	2	$14.99	$29.98
#Small Door latch solenoid 12V	2	$7.50	$15.00
#Large solenoid	2	$14.95	$29.90
Handle	2	$11.47	$22.94
M5 nut and bolt kit	1	$12.99	$12.99
M5 Tee Nuts	1	$11.85	$11.85
Letter Stamping Set	1	$9.99	$9.99
Attabox IP68 Enclosure	1	Free (Sponsored)	
JLC PCB	1	$128.37	$128.37
Motor Driver	6	$38.00	$228.00
T200 Thruster	6	$200.00	$1200.00
PCB Components	1	$56.47	$56.47
Batteries	2	$119.99	$239.98
Total			$2568.59

Ball Dropper



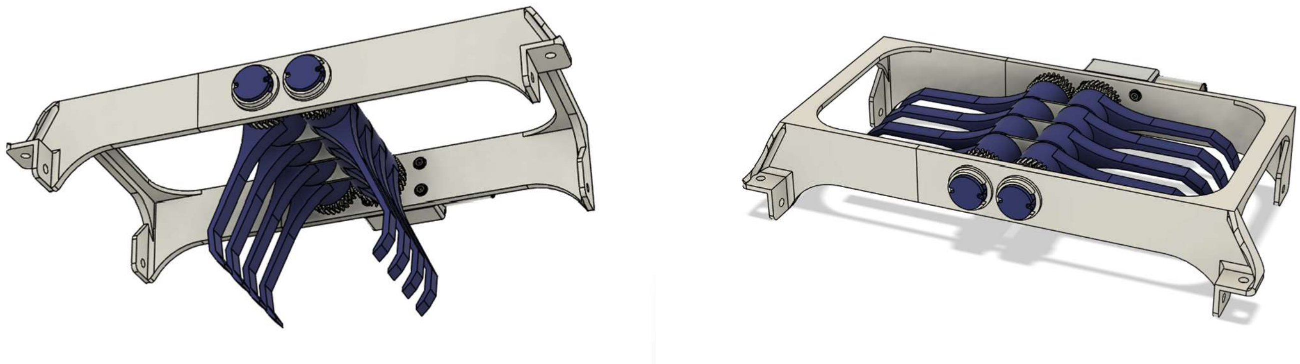
SolidWorks model of the ball dropper.

The images above show two views of the ball dropper design. The part mounts to the T-slot aluminum frame around the submarine, and a compact solenoid-based latch retains the scoring payload until it is commanded to release. This mechanism is retained for 2026 because its operation is straightforward and well-matched to the team's task-priority sequence.

The scoring payload and release geometry were selected to produce a predictable deployment path while keeping the subsystem lightweight and easy to service. For current-season printed replacements, the team uses PETG instead of the broader ASA strategy used in the previous build.

Two ball droppers are mounted near the submarine's front underside to integrate payload deployment with the vehicle's navigation and alignment workflow.

Grabber

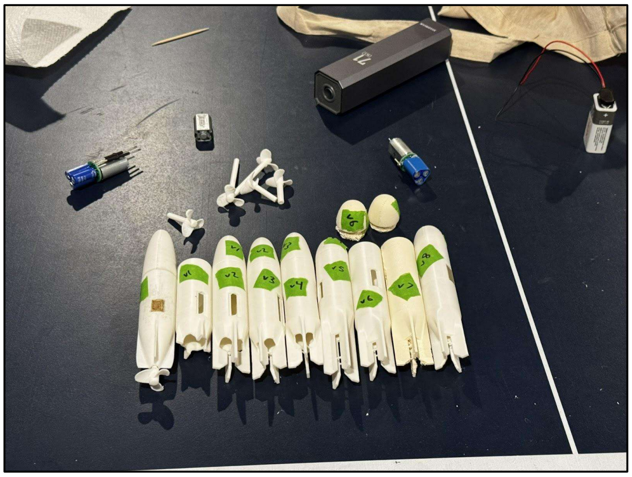


SolidWorks model of the grabber with the underside-mounted frame.

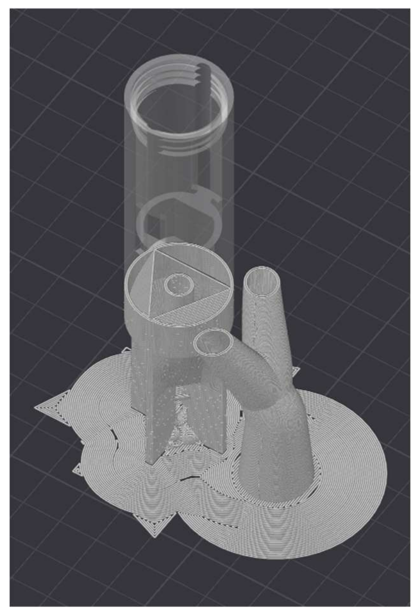
The grabber is made up of eight interlocking fingers, four on each side, connected to a central axle that rotates the fingers together. The fingers store underneath the submarine during normal operation and rotate downward when activated to capture objects from below.

Adaptability was built into the design by making the fingers out of flexible TPU filament so they can conform to objects with different geometries. For the 2026 revision, the central axle was changed from ASA-printed material to aluminum because the previous printed axle could fail under motor torque.

Torpedo



The torpedo went through repeated iterations because it remains one of the most mechanically demanding effectors on the vehicle. It is self-propelled by a small DC motor and charged through brass contact pads while seated in the launcher. The retained torpedo concept provides a compact method of performing a higher-priority effector task after navigation and ball-drop capability have been established.



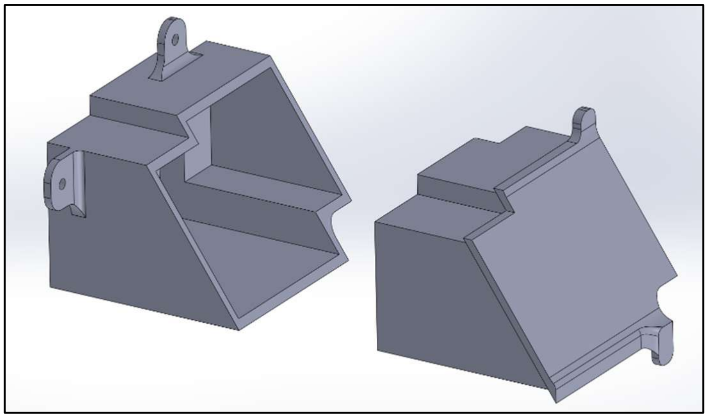
3D structure of torpedo shell

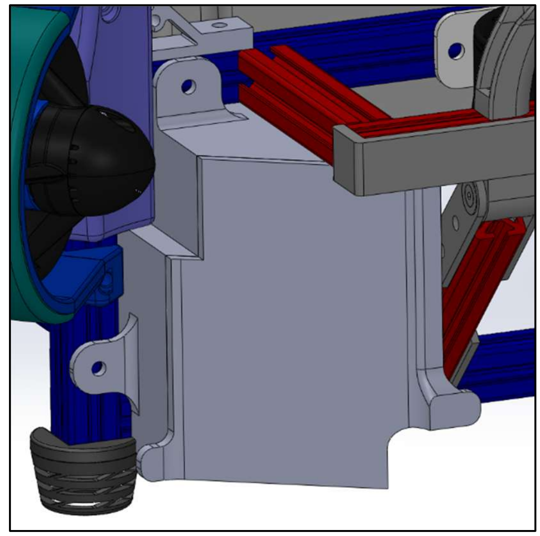
For the 2026 vehicle, the primary revision is the torpedo housing. The previous housing did not retain the torpedoes securely enough and did not provide sufficiently reliable electrical contact for charging before launch. The updated housing is intended to improve both retention and contact consistency so that the torpedo can be armed and released more repeatably.

The torpedo is designed to be neutrally buoyant and remain level underwater so that motor thrust can be used efficiently after release. Balancing buoyancy, electrical packaging, and launch alignment required repeated iteration, making the torpedo system an example of the team's 2026 design approach: preserve a useful subsystem concept while correcting observed failure modes.

Ballast Housing

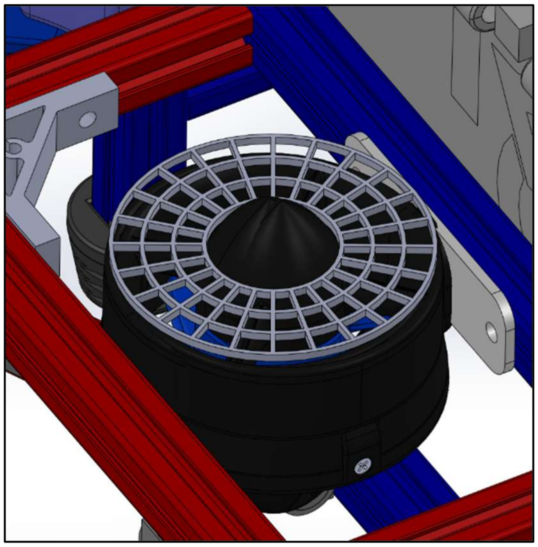
In the previous vehicle configuration, diver weights were zip-tied to the exterior of the submarine to obtain the required ballast. The 2026 design replaces that arrangement with a purpose-built housing containing reclaimed lead shot. The shot is sealed inside the housing so that it cannot be exposed to pool water. This change provides a cleaner external arrangement and a dedicated method for retaining ballast on the vehicle.

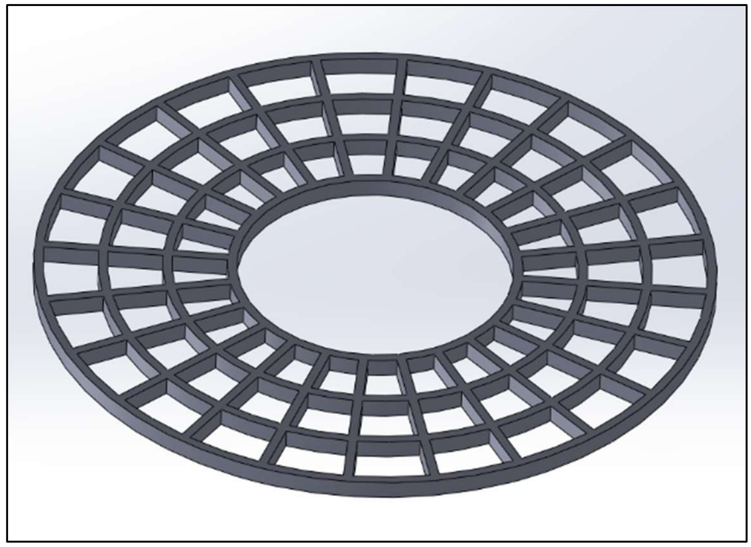




Vertical Thruster Guard

A vertical thruster guard was added in response to the serious injury experienced during the previous season when a finger entered a vertical thruster. The guard provides a physical barrier between handlers and the rotating propeller during setup, retrieval, and maintenance. Its thin geometry is intended to maintain an open flow path while improving operator protection.





Software Architecture and Operator Interface

The 2026 software architecture consists of a desktop operator application and an onboard Jetson AGX Orin service. The operator application provides vehicle commands, telemetry, live camera viewing, and hardware test controls. The onboard service interfaces with the IMU, depth sensor, cameras, PWM hardware, thrusters, and effectors. This separation supports the planned progression from navigation to ball dropper, torpedo, and grabber actions.