Abstract

This year, Desert WAVE is building a new Autonomous Underwater Vehicle (AUV) to work alongside the previous AUV, Dragon. The new AUV was designed to be compact, lightweight, and hydrodynamically efficient to minimize drag and increase agility. Weighing in 57% less than previous designs, it is optimized for speed to allow for a full course run time of three minutes or less between both AUVs. The team's primary goal for RoboSub 2026 is to complete the full mission in under three minutes while maximizing task accuracy and earning the mission time bonus through coordinated dual AUV operation.

Competition Strategy

The mission strategy focuses on speed, reliability, and coordinated task execution through a dual-AUV "parallel play" approach. A coin flip determines starting positions, both AUVs pass through the gate and complete style points while maintaining consistent roles throughout the run. Dragon completes tasks requiring more accurate positioning, including the torpedoes and octagon tasks. The new AUV is optimized for faster navigation tasks, including the slalom and bins tasks. Using its hydrophone array, the new AUV detects the pinger location and directs Dragon's task ordering. This coordinated task completion allows the AUVs to maximize efficiency, completing the mission in under three minutes which earns the time bonus. Once all tasks are completed, both AUVs return home to finish the mission.

A key component to maintaining speed is the use of waypoint navigation [1]. The AUVs follow a sequence of predefined coordinates using onboard sensors to continuously track their position and orientation. This has consistently outperformed other navigation methods in our experience. A hydrodynamic front cross-section of the new AUV was prioritized in order to minimize resistance in the water and increase overall agility, allowing the AUV to move efficiently while requiring less energy to cut through the water.

The team redesigned all object manipulation mechanisms to improve task accuracy and reliability, switching from pneumatics to servo-driven control. This includes marker droppers for the bins task, a launcher for the torpedoes task, and a claw for the octagon. Though pneumatics provide faster actuation at higher forces, they increase complexity and room for error, which nearly cost the team the final run in 2025. Servos will improve system simplicity and longevity, allowing for more reliable task execution.

At the 2025 RoboSub Competition, the team's AUVs used inter-vehicle communication (IVC) [2] to complete the random pinger task, with one AUV locating the pinger and relaying directional data to the other to determine task order. The team will implement the same strategy this year using a custom 4-hydrophone array on the new AUV. It will send a message to Dragon whether to complete the octagon or torpedoes task first, depending on the pinger's location. Unlike last year's single hydrophone, which only approximated pinger direction using signal strength, the new four-hydrophone array enables accurate directional localization of the pinger.

Design Strategy

The focus with the new AUV is speed and accuracy to maximize points for the time bonus and to re-run the mission if needed; in addition to increase accessibility. The previous AUV, Dragon, currently weighs 42.5kg/93.7lbs, which incurs a penalty for exceeding the weight limit. To address these issues, the new AUV was designed in a way so the majority of its components could be manufactured in-house allowing for more design control and customization.

Frame - The new AUV was designed to stay within the weight category while retaining a hydrodynamic shape. This influenced the new AUV frame design which consists of an upper plate, lower plate, and spacers. The upper plate houses four hulls, and the bottom plate houses one hull. To reduce drag the upper hulls are positioned colinearly and coplanar to create the smallest frontal cross-section possible. The frame was designed with aluminum and high-density polyethylene (HDPE) for their rigidity, weight, and density properties. The new AUV's four square hulls house similar components as Dragon's. Dragon's current hull design lacks accessibility. While her multi-compartmental hull design helps in the event of a flood, the use of off-the-shelf hulls mandates tightly packed components; making repairs difficult. To solve this issue for the new AUV, the team machined their own hulls in-house, allowing for a more custom ergonomic design, and an easier repair process. This benefit of customization also permits a design that optimizes the air space within the hulls. A vacuum test was performed to make sure the hulls weren't prone to leaking once manufactured.

Once all the hulls were designed, they were attached to a central top plate. Dragon's HDPE was prone to warping due to heat and the weight of the hulls. Therefore the new AUV top plate has an HDPE and syntactic foam sandwich: one layer of ⅛ inch HDPE, one layer of foam, and another layer of HDPE all on top of a ⅛ inch aluminum plate. This adds buoyancy to counteract the weight of the frame and hulls while maintaining rigidity. Once manufactured and assembled, the frame was found to be heavier than expected with and without the hulls, leading to the use of HDPE for the top and bottom plates. The bottom plate also works to block reflections from the robot for the hydrophones. A stress test was done with a wooden frame prototype to look for any weak points in the design.

Torpedos - Dragon's torpedo launcher is pneumatically operated. Last season, before the finals match, the CO2 canister wasn't retaining air due to an issue with the regulator. To prevent future pneumatic issues, the team switched to underwater servos due to their simplicity for the new AUV system. The design of the torpedo launcher maintains linear motion, similar to Dragon's design, by using spring-loaded shafts to launch, now actuating with servos rather than pneumatics.

Marker Droppers - The new AUV marker dropper mechanism was also designed to incorporate servo motors. The initial design had height and mounting issues. The cylinders holding the markers were not tall enough, so when the tilt mechanism in the center moved down on one side to drop a marker, the marker on the other side was at risk of falling out. A simple solution for this was to increase the height of the cylinders. Additionally, the front of the marker dropper was too heavy for the mount, so it was leaning. A simple positioning fix solved this issue. Appendix B contains CAD images of the redesigned marker droppers.

Claw - The claw was redesigned to use servo motors. The design consisted of a 4-bar linkage with a compliant gripper.

Hydrophone Hull - One new major component on the new AUV is a custom hydrophone array. Four hydrophones with a Teensy-based processing network determine the direction of incoming pinger signals, allowing the AUV to continuously update where the pinger is located as it moves throughout the course. Instead of relying on just one hydrophone, the array collects directional data that becomes more reliable as the robot reaches different orientations during other tasks. This allows the AUV to infer whether the pinger is at the torpedoes or octagon task, and adjust task prioritization accordingly during the run. This improves directional clarity compared to a single hydrophone system, increasing reliability in completing the random pinger task.

Custom-Designed PCB Boards - The PCB boards on Dragon required design changes for the new AUV. The new boards include the Power Distribution Board (PDB) and Thruster Control Board (TCB), along with supporting boards. The new PCB systems use JST-GH connectors [3] for communication signals, with 4-pin connectors for I2C, 3-pin connectors for analog/digital I/O, and 5-pin connectors for UART communication.

The TCB was upgraded to a Teensy 4.1 from a Teensy 4.0 [4] to provide additional I/O for thruster control. This board controls the AUV's thrusters through ESC signals. During design review, several issues were corrected. This includes updating the 5-pin UART [5] connector order to match the AUV main board, reverting incorrect 5-pin connector I2C ports back to 4-pin connectors, correcting the order of thruster outputs, and adjusting connector placement to allow sufficient clearance for connectors.

Previously, power management components (fuse panels, current sensors, etc.) were scattered across several boards, but are now consolidated into a specific for easier power management. Added features include a 5V connector and power supply to power the new electric servos on the power board, as well as a voltage sensor and current sensor, which were previously placed on the TCB. The PDB accepts battery input through an XT90 connector [6] and distributes power through multiple fused outputs, including high-current outputs for thrusters and lower-current outputs for other systems. The board also measures battery current and provides this information to the thruster control board.

Programming and Annotations - The quality of the vision system is the highest priority. This sets a very high standard when it comes to annotating and training the vision system, leading the team to annotate their own images. While the provided public dataset has a large quantity of data for vision systems to use, there are no strict guidelines when it comes to what annotations are accepted into it. The dataset lacks consistent vision classifications, as different teams may annotate certain images differently or have different standards when classifying. Therefore Desert WAVE opts to only use vision data sets annotated by the team to ensure data accuracy and consistency.

To ensure collected data is optimized for the AUV, all annotators abide by the same set of strict rules and guidelines; and all annotations are reviewed for accuracy by a separate team member. For example, a tight boundary must be drawn around the image. If an image is annotated with too wide of a boundary over the object, or if the annotation causes critical parts to be cut off, it is not accepted into the dataset. These standards have allowed the team to build consistent datasets for our vision training.

Testing Strategy

The testing described below is in regards to the new AUV.

Hydrophone Hull - The hydrophone array consists of four Aquarian S1n hydrophones [7], a Teensy 4.1 [8], and two Teensy Audio Boards [9]. Each audio board can only support up to two line inputs. Therefore, they are stacked on top of each other, below the hydrophone hull's Teensy 4.1, in order to support the four hydrophone array design.
Individual and Multichannel Testing - To individually test the hydrophones, the Teensy 4.1 was flashed with code designed to only relay specific data channel(s) that the line inputs were listening to. Once this code was running on the Teensy, it was then connected to a laptop through USB, and used an audio recording software called Audacity [10] to see what audio was coming in on each line input channel in real time. If the setup is properly connected, the result of tapping the hydrophones can be visually seen in real time through the software. If there is an improper connection, no audio will be visible. In addition to testing channels individually, this setup allowed for testing of multiple channels at once. Appendix A contains more documentation on hydrophone testing.
Hydrophone Array Testing - Testing the code for the hydrophone array is a more complicated process. Due to filtering and other optimizations used in the code, a test setting where the hydrophones and pinger are underwater is required. Additionally, the hydrophones must stay in the same orientation without moving to get the most accurate results. This is done by filling a bucket of water and submerging both the hydrophone array and pinger in it, where data can be gathered on whether the code for the hydrophone array is working as expected. Depending on the situation at

hand, the data can be seen in real time through USB using a laptop, or by saving the data to an SD card, which can be analyzed and evaluated afterward.

Torpedoes - The servo was first tuned to a neutral position with equal string tension, allowing small rotations in either direction to launch each torpedo. Each side of the launcher was tested separately before combined testing to ensure that tension on one side of the string would not affect the other. During the spring tension testing, it was discovered that the servo lacked sufficient launch force, so the rocker arms were extended to improve reliability of launches and increase mechanical advantage. Functional testing also found that the string was prone to snagging on nearby components and causing false launches, therefore guiding holes were also added to prevent this.

Marker Droppers - The goal for the marker droppers was to get a reliable method of dropping the steel balls and preventing them from getting stuck. With the new design, one servo is used instead of two pneumatic actuators to operate the marker droppers. The assembly is one 3D printed structure holding both markers and the servo, and can be implemented where needed on the AUV's frame. Additionally there is a pivot that allows the steel balls to drop sequentially and efficiently. This prevents the balls from getting stuck and prevents time delays from occurring.

Frame Stress Test with Wood - Before making the final frame design using HDPE and aluminum, the team conducted a stress test with wood, which was chosen due to its rigidity. A deflection test using a wooden material was performed, where a successful test indicates that the aluminum frame would be able to withstand the same level of forces. This test was done by holding all four corners of the frame and twisting both sides in opposite directions with a 1-2in position differential. Additionally, aluminum machined hulls were temporarily attached to the wooden frame and lifted 1ft off the ground to see how the frame would react to the weight of all the hulls. The goal of the test was to identify any weak points within the design, and with a material such as wood, potential problems could be found before the final design is made. The test achieved the goal, and there was no breakage with the design. Additionally, the wooden frame was tested for ergonomics to ensure that the hulls are still easily accessible. The design was slightly modified to have enough room for students to access the hulls without hassle.

Vacuum Testing the Hulls - The team created a welded aluminium hull to test if the design can be waterproof if welded. To do this, a vacuum pump was connected to a hole within the welded box. The first test weld had a minor leak due to shielding gas contamination, introducing impurities into the weld. After troubleshooting, the second test weld achieved a complete seal with significantly improved weld consistency and appearance.

Test Cuts with Metal for Hulls - Before the hulls were fully manufactured, the team took steps to prevent potential errors when the hulls were underwater. Sample cuts were made to verify the manufacturing process and determine the level of precision required. A plate was made with holes for all the bulkhead connectors to ensure the drill bits and taps were cutting the correct sizes. The hulls met the requirements to be watertight, and this sped up the production process.

PCB Testing - Testing was done on individual boards to verify different functionalities. For the PDB, continuity between battery supply and thruster connections was tested, the 5V regulator output was measured and verified, and servo functionality was tested through the inter-board connector and observed successfully. The fuse status LED test failed when the 14V connection was powered up, and a thruster fuse was removed, though this did not impact mission goals. For the TCB, a Teensy 4.1 running test code demonstrated successful thruster and servo functionality, GPIO LED operation was verified by running test code, and mounting hole alignment was manually tested and verified with the PDB.

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Appendices

Appendix A: Hydrophone Testing

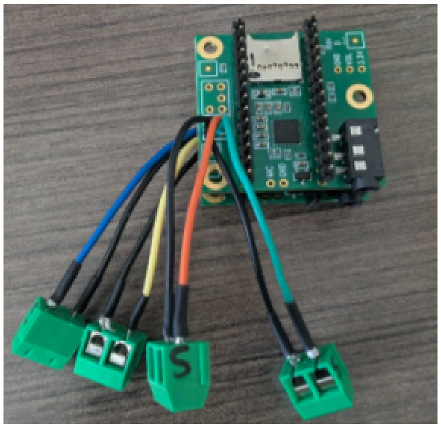

Figure 1: Stacked audio board setup

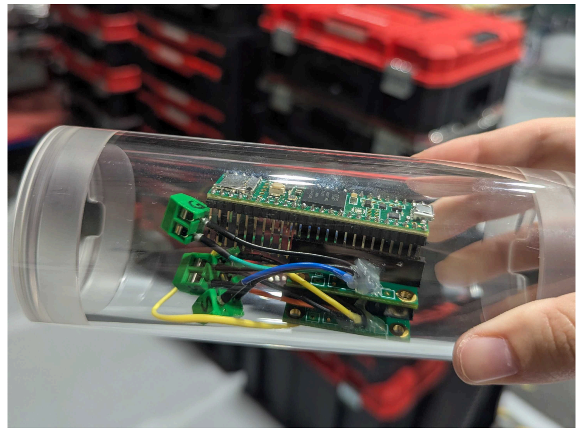

Figure 2: Stacked audio board setup includin Teensy 4.1

```
#include <Audio.h>
#include <Wire.h>
#include <SPI.h>

AudioInputI2S i2s_in;    // audio input (represents line in)
AudioOutputUSB usb_out;  // usb audio output (sends audio from teensy to laptop)

//AudioConnection patchCord1(i2s_in, 0, usb_out, 0);  // left channel connected to left usb output
AudioConnection patchCord2(i2s_in, 1, usb_out, 1);  // right channel connected to right usb output
AudioControlSGTL5000     sgtl5000_1;

// setup and loop
void setup() {
  AudioMemory(1024); // allocates 1024 audio memory blocks
  auto sgt = sgtl5000_1;
  sgt.enable();
  sgt.inputSelect(AUDIO_INPUT_LINEIN);
  sgt.lineInLevel(15); // 0.24 Volts p-p
}

void loop () {
  // empty because the audio library uses interrupts to run in the background
}
```

Figure 3: Teensy code to test an individual line input channel

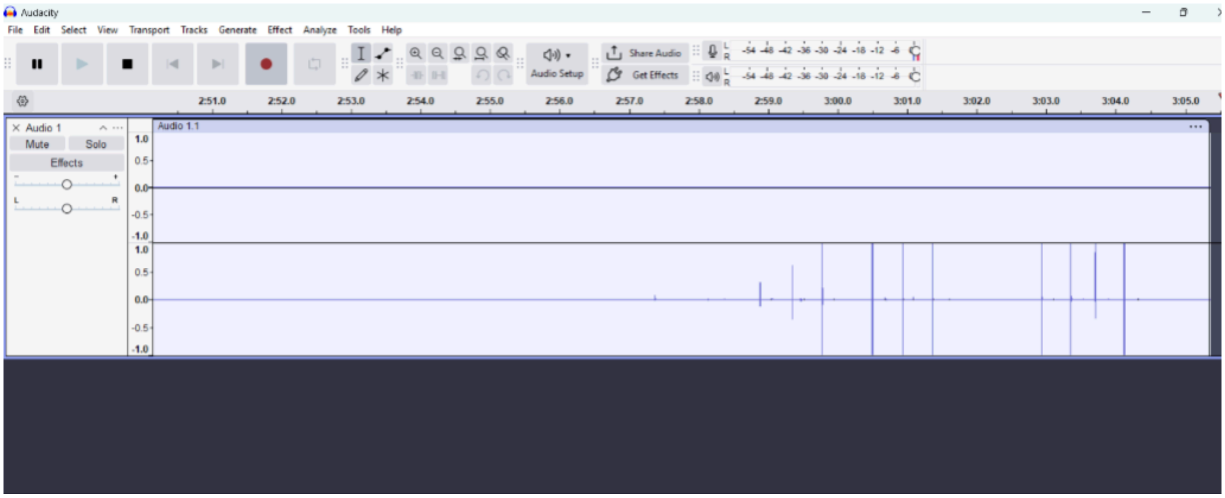

Figure 4: Singular hydrophone through Audacity

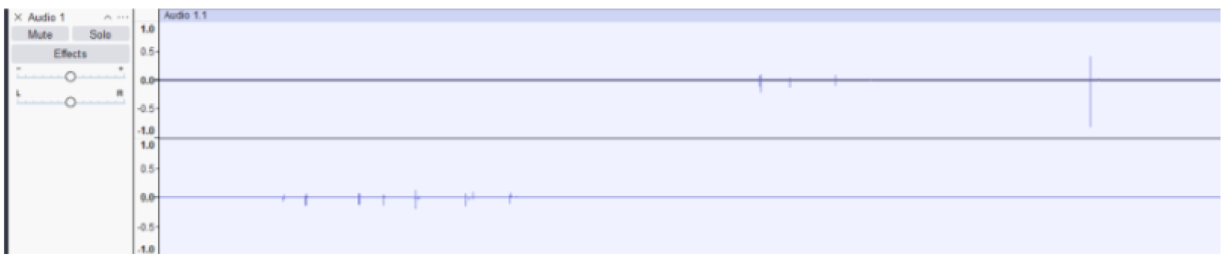

Figure 5: Hydrophone array through Audacity

Appendix B: AUV CAD Images

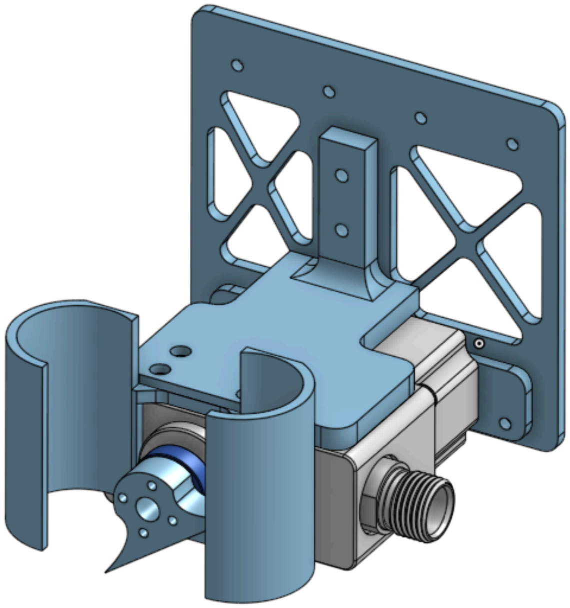

Figure 6: Marker dropper CAD

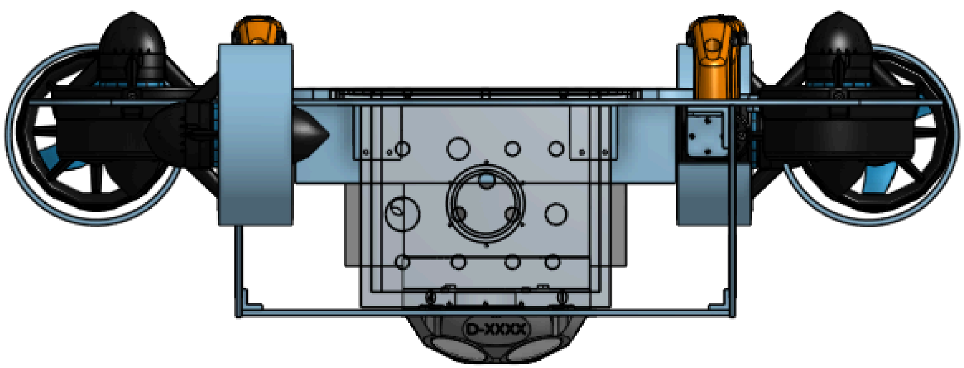

Figure 7: New AUV front cross section