Desert WAVE: Dragon's Debut

B. Ashcroft, J. Ayala, I. Bushroe, P. Garibay Jaquez, S. Lepore, L. Matancillas, M. Molnar, A. Schoonover,
K. Vasudev, H. Vergunst, J. Villanueva Castro

Mentors: B. Emami, D. Frank, B. Kahn, D. Kahn, F. Lajvardi, F. Nueperger

***Abstract* — Desert WAVE (Women in Autonomous Vehicle Engineering) is a team from Arizona set to compete in the 2023 RoboSub Competition. The team's autonomous underwater vehicle, named Dragon, includes 10 thrusters, passive sonar, doppler velocity log, fiber optic gyroscope, and two cameras. Dragon is capable of precise autonomous navigation, manipulating objects, locating the position of an acoustic signal, and classification via vision processing. The team primarily tested subsystems of Dragon separately as they continued to be developed. This included testing the communication between hulls, testing the pneumatically operated marker dropper, grabber mechanism, and projectile launcher, and training Dragon to identify objects in the water using machine learning and HSV models. This paper describes the methods used to accomplish the full integration of subsystems and the physical manufacturing of Dragon.**

I. COMPETITION GOALS

At the start of the 2023 competition season, Desert WAVE focused on completing Dragon, the team's second AUV (autonomous underwater vehicle). While the team's first AUV, Phoenix, is functional, Dragon is more capable, as it was designed and built with a pneumatics hull to allow it to complete challenges that require advanced manipulation. The goals the team focused on were to further develop the vision systems for Dragon and improve the mechanisms designed for the challenges requiring advanced manipulation. The similarity of Phoenix and Dragon's designs and the modularity of their components allowed innovation to come from smaller, test-based, iterative design changes. The team focused on executing and optimizing systems that were conceived in previous years, rather than developing new ones.

At the RoboSub challenge course, Dragon will move quickly and attempt all of the tasks. As in 2019, Desert WAVE will use surveying techniques to generate waypoints, as shown in Figure 1. The AUV will use the waypoints to navigate to the vicinity of each task with a fiber-optic gyroscope and doppler velocity log (DVL). Waypoint navigation will allow Dragon to move quickly. Once near the task, the goal is for Dragon to use a combination of HSV filtering and machine learning to detect the task objects. If the team is not yet able to reliably use vision to navigate by the 2023 competition, Dragon will be able to navigate solely using waypoints, although possibly with less accuracy. In this case, the team will continue working to implement vision for the 2024 competition season. Desert WAVE will complete the tasks in the order outlined in Table I.

Fig. 1. Example of course surveying to locate mission tasks.
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II. DESIGN STRATEGY

This is the first year that Dragon is fully functional. Dragon's design, as shown in Figure 2, was designed for modularity. Each of the two batteries has its own hull, supplying the thrusters and computer systems separately so that fluctuations in voltage from the thrusters do not affect the delicate systems in the computer hull. The computer hull makes decisions and handles sensor processing while the thruster hull controls power to the thrusters. The pneumatics hull houses a custom pneumatics board and eight solenoids for each respective system. These solenoids actuate one inch stroke pistons that operate Dragon's projectile launcher, grabber mechanism, and marker dropper. Separating these systems into different hulls reduced the design complexity of each hull. It also allowed multiple team members to design the various hulls in parallel. In the event of a leak, separating the systems into five hulls will also contain damage to only one system. A tradeoff of the modular hull design was that it created communication challenges between the multiple hulls that were tackled with telemetry.

Table I
Tasks Desert WAVE Will Attempt

Order	Name	Task	Notes
1	Oh for crying out loud	Coin Flip	Depart gate at random orientation
2	Style Points	Change in Orientation	Spin 360° twice in yaw direction
3	Destination	Gate	Choose a side to start the course
4	Path	Identify 1st path marker	Follow the path towards the bins
5	Location	Bins	Lift cover, drop markers in correct bin
6	Path	Identify 2nd path marker	Follow path towards the buoy
7	Start Dialing	Buoy	Bump into appropriate side of the buoy
8	Goa'uld Attack	Torpedo	Fire through small opening
9	Engaging Chevrons	Octagon	Move chevrons to correct location

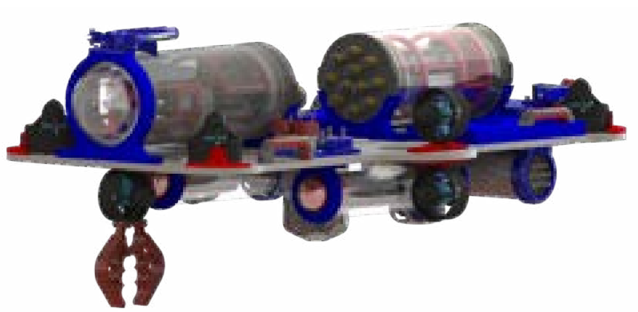

Fig. 2. CAD model of Desert WAVE's AUV, Dragon.

Once the pneumatics system is capable of autonomously actuating the pistons, the team will test Dragon's ability to launch projectiles through an underwater target consistently. This will involve perfecting the AUV's ability to position itself in front of a target and then shoot accurately using its vision systems. The launcher was positioned directly above the front facing camera to make it easier to line up with a target.

Dragon's computer hull is powered by one of two 16.8 *V* batteries, and was designed for usability, visibility and to maintain proper operational temperatures. The computer hull has three sets of ten LEDs, which provide visual feedback to the surface and divers to determine the status of the AUV. The final design houses the Jetson Xavier NX, a 3-axis fiber-optic gyro, two cameras, two fans, the power bus, a variety of switches, and two of Dragon's four custom boards (the AUV's main board and sensor fusion board). While the team's first AUV, Phoenix, only has one electrical board, Dragon features multiple custom boards to reduce stress on any one board. This improves debugging, since problems can be isolated to a specific board, and each board acts as a breakpoint. Programmers can also detach the computer hull from Dragon and perform additional testing without requiring the rest of the AUV. For transport, the computer hull can be removed from the AUV and fixed to the temporary frame shown in Figure 3, which the team refers to as the "boogie board".

Fig. 3. Independent transportation of Dragon's computer hull, nicknamed the "boogie board."

There are two ways to disable Dragon: a mission switch and a kill switch. The mission switch, depicted in Figure 4, controls power to the thrusters and is triggered by a magnetic contact switch. The kill switch, a repurposed SubConn connector, controls the power to the AUV's main board. If the mission switch fails, the kill switch can be removed to disable the AUV.

Dragon's thruster configuration allows it to translate and rotate freely with redundancy. This thruster configuration was carried over from Desert WAVE's first AUV, Phoenix, because of the advantages it provided in the team's first competition. It prioritizes speed to allow more runs to be attempted during the mission and maximize the time bonus. Throughout the competition, the AUV will primarily move forward, so four thrusters produce thrust in the surge direction. Dragon can achieve velocities up to 1.2 *m/s* in this direction. Four vertical thrusters allow the AUV to control its depth. Finally, two bow thrusters make minor alignment adjustments in the sway direction. All of the thrusters used on the AUV are placed along the perimeter of its frame, maximizing the moment that the thrusters exert to enable quick and efficient turning.

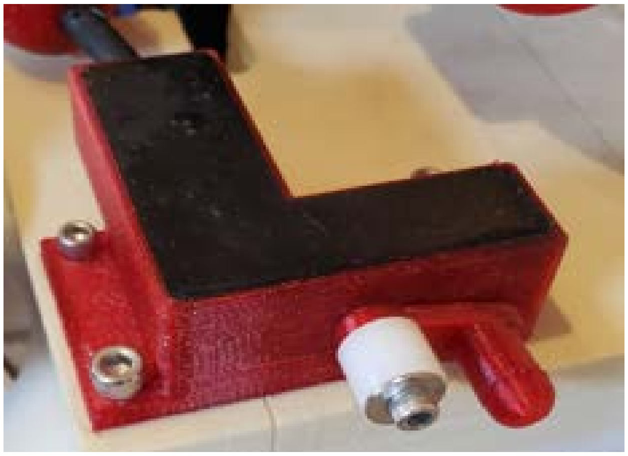

Fig. 4. Mission switch used on Dragon.

Dragon can lose the function of at least one thruster, and in some cases up to four, and still be fully maneuverable with adjustments to the software. In the future, the team intends to incorporate fault tolerance by programming Dragon to automatically sense the failure of a thruster and adjust the power to the other thrusters accordingly.

Dragon's programming and electrical systems use telemetry to communicate among the three main hulls. The telemetry data receives a real time status (heartbeat) of the eight active solenoids for the pneumatics board, running status of all ten thrusters from the thruster board, and data from the DVL and additional sensors. Communicating back and forth from the main board, the team's system allows the AUV to have current diagnostics displaying on a user interface (UI). From this screen, the team can change the AUV's thruster configuration by adjusting which pins are in a ready state and which pins for thrusters get moved to an idle state. Using the UI, Dragon's pneumatic actuators, cameras, sensors, and the overall operation of Dragon can also be manipulated. This allows the AUV to be versatile in its approach to carry on with the team's competition strategy.

III. TESTING STRATEGY

The team continues to test the reliability of the structural, electronic, and programming components. The team performed unit tests on the software used for the pneumatics, thruster, and vision systems using a Teensy 4.0 Development board before testing code on any circuit boards. The marker dropper, grabber mechanism, and projectile launcher were tested for performance during a previous competition season, before being attached to the frame. More information can be found in our previous technical design report [1].

Integration tests, including testing communication between thrusters and boards, and communication to the sensors using LED strips, have been the main tests conducted before the competition. Next, the team will start stringing missions together in sequence to simulate full competition runs.

A. Structure

Once the computer hull's internal structure was complete and its length was determined, the layout of the components on the frame were finalized in SolidWorks CAD software. To verify that the mounting holes were located properly in the CAD model, the team mounted components to a laser-cut wooden prototype frame. Dragon was weighed and put in water with this wooden frame to evaluate its buoyancy. This test is pictured in Figure 5. Since wood is lighter than PVC (the material originally intended for the frame), this was not a perfect test of overall buoyancy, but revealed the relative weight balance between port and starboard, and bow and stern.

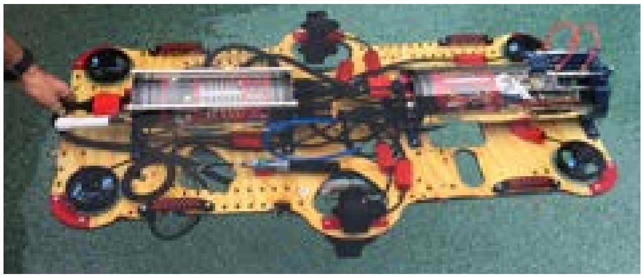

Fig. 5. Buoyancy test of Dragon with wooden frame.

Dragon's frame was originally intended to be manufactured out of PVC, like Phoenix, but using PVC caused the AUV to sink. HDPE is lighter than PVC and closer to the density of water, which is 0.97 *grams/cm*^{3}, whereas PVC has a density of 1.42 *grams/cm*^{3}. As a more neutrally buoyant and lighter material, it helped reduce the weight of Dragon's frame, shown in Figure 6. Reducing the weight of the AUV allows the team to earn more points at the competition and means that less foam was needed to adjust its buoyancy.

Fig. 6. HDPE frame being cut on a CNC router.

Initial buoyancy tests revealed that Dragon tended to pitch upwards in the front, so the team used polyurethane foam to balance the stern of the AUV. The foam has a low density, but resists hydrostatic pressures at depths up to 300 *m* below the surface. Once this foam was added, further testing showed that the AUV also listed slightly to its starboard side due to the weight of the marker dropper payload. An additional 1082 *cm*^{3} of foam was added at the stern to balance the AUV, shown in Figure 7. With these final adjustments the AUV was balanced and its buoyancy was slightly positive.

Fig. 7. Buoyancy test of Dragon with foam and its final frame constructed out of HDPE.

B. Manipulation

To assess the functionality and performance of the grabber mechanism, the team conducted two tests. The first test involved using solenoids to activate the pneumatic piston responsible for opening and closing the grabber mechanism. Once the pneumatic piston was activated, the grabber mechanism was used to lift two wooden blocks, each weighing approximately 102 *grams*, as shown in Figure 8.

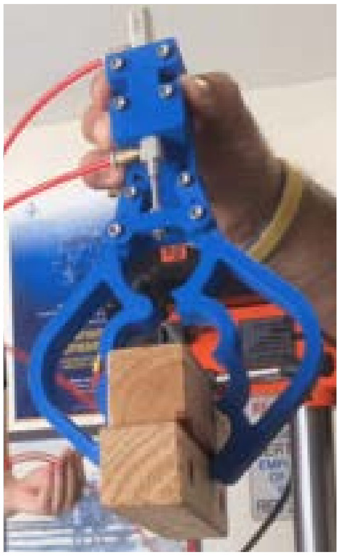

Fig. 8. Testing the grabber mechanism with a solenoid.

Figure 9 shows a second test, where a scale was used to determine its grip strength. The grip was measured to be approximately 683 *grams*. Both tests verified the grabber mechanism is capable of grasping and lifting objects.

Future tests will evaluate the grabber mechanism's pick-up and drop accuracy and structural strength. Based on the results of these tests, the team will make modifications to it that may include adding a rubber coating for improved grip and redesigning its mount for safe storage during transport in and out of water.

Fig. 9. Testing grip strength of the grabber mechanism.

The projectile launcher, shown in Figure 10, is operated by two pneumatic pistons, one for each projectile. Each piston opens a hatch to release a PLA projectile from a bay that is powered by a compressed spring. Before the launcher was attached to the AUV, it was tested in a bathtub. The projectiles launched straight forward, but rose to the surface almost immediately due to their buoyancy. More projectiles were printed at greater infill percentages until a nearly neutral but slightly positive buoyancy was achieved. The launcher was attached to the AUV and manually tested in a pool. It was found to launch in a straight line for 1 *m*, even with disturbances in the water, and only started to rise to the surface after a few seconds. However, the projectiles were produced with fused deposition modeling, which adds melted plastic to a part in layers and is inherently porous. As such, this design will soak up water and become less buoyant the longer it is submerged. The team will attempt to achieve a consistent density in future years by printing the projectiles with SLA (stereolithography), which is a watertight form of additive manufacturing. The projectiles will be printed slightly above and below neutral density to account for any minor differences in the density of water between the water at the TRANSDEC facility and the pool used for testing.

C. Thrusters

As explained in the Design Strategy Section, Dragon was designed with ten thrusters to provide redundancy. The AUV can have any one thruster fail or certain combinations of up to four thrusters and still be able to achieve full mobility. It would be preferable for Dragon to have all ten thrusters running, but the AUV only needs six degrees of freedom to be operational. To achieve this, the programming sub-team is setting up a redundancy panel in the UI that allows the AUV to reconfigure and recalibrate different thruster configurations to allow for that change of orientation in the shortest amount of time. The benefit to this is that if a thruster fails during a run at the competition and there isn't time to replace it, the thruster code could be quickly reconfigured to allow the AUV to navigate without the failed thruster.

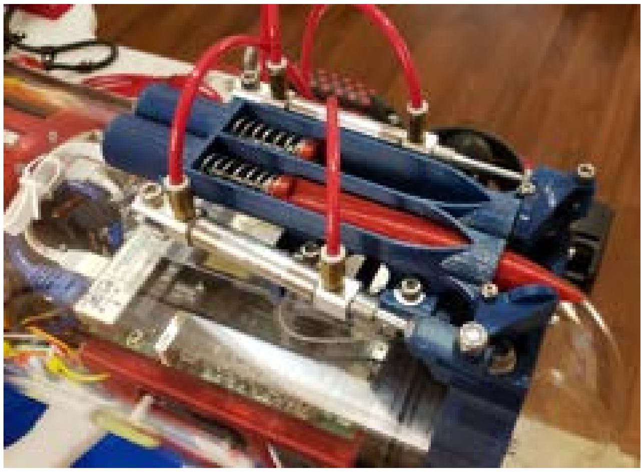

Fig. 10. Projectile launcher mounted on the computer hull.

Upon completion of the redundancy panel, unit tests will be performed on the computer hull to verify that the signal is being transmitted from the thruster code. After successful unit testing verified by LEDs in the computer hull, communication between the computer hull and the thruster board will be verified. Performing bench tests, Dragon will be tested with all ten thrusters to indicate that the modification to the UI panel did not affect the overall operation. Dragon will then be tested for losing one or more thrusters in multiple configurations.

Additional future testing will begin by testing ten fully operational thrusters and then placing one or more thrusters in idle to time Dragon's runs. A potential issue with the redundancy panel for Dragon is the change over time from running all ten thrusters to changing the configuration of the AUV on the UI. The team knew that changing the configuration of the thrusters could add additional minutes to Dragon's run and could delay the possibility of reaching every obstacle.

D. Sensor Verification

In-water testing was conducted after all the code had been debugged and tested on land. A 300 *ft* tether allowed for real-time communication with Dragon during in-water testing. For example, Dragon's sensor readings were able to be displayed on a laptop on the surface in real-time. Using this information, the team tested Dragon's positional accuracy using a DVL and Leica laser distance meter. With the DVL mounted on Dragon, Dragon was commanded to drive forward in 1 *m* increments. A foam block attached to Dragon was elevated so that it always remained above the surface, as shown in Figure 11. Using the distance meter, the team was able to verify the distance Dragon actually traveled. DVL measurements were compared to the distance meter measurements, and compared in Table II.

Fig. 11. Dragon's DVL being tested with the Leica laser distance meter.

TABLE II
POSITIONAL ACCURACY TESTING WITH DVL

Distance (*m*) Measured by DVL	**Test 1 Distance (*m*) Measured by Distance Meter**	**Test 2 Distance (*m*) Measured by Distance Meter**
4.00	4.164	4.950
5.00	5.339	5.952
6.00	6.315	6.952
7.00	7.364	7.957

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REFERENCES

[1] K. Afshari, I. Bushroe, J. Dirks, F. Duarte, L. Dukes, S. Ehrle, M. Espinoza, W. Foster, S. Ganti, P. Garibay Jaquez, K. Green, D. Guzman, J. Heun, B. Johnson, B. Koehl, M. Molnar, S. Nieto, P. Ramirez, L. Roty, A. Schoonover, M. Strube, C. Torres, R. Wagen "Desert WAVE: Enter the Dragon" RoboNation, 2020. [Online].

Appendix A: Component Specifications

Component	Vendor	Model/Type	Specs	Custom / Purchased	Cost	Year of Purchase
ASV Hull Form	• Port Plastics • Blue Robotics • Blue Robotics	• 6” enclosure • 6” enclosure • 3” enclosure x3	• 20” long • 11” long • 11.75” long	Purchased	• $125.00 x1 • $98.00 • $86.00 x3	2021
ASV Hull Platform	Port Plastics	HDPE sheet	.5” thick	Custom	$125.00	2021
Waterproof Connectors	MacArtney	• Optical Series • Circular Series	Industry standards	Purchased	• $5,000.00 • $3,000.00	2021
Propulsion	Blue Robotics	• T100 Thruster x10 • T200 Thruster x6	• Max thrust: 5.2 *lbf* • Max thrust: 11.2 *lbf*	Purchased	• $119.00 x10 • $169.00 x6	2021
Power Systems	Blue Robotics	LiPo batteries x2	4 cell, 18 *Ah*, 16.8 *V*	Purchased	$289.00 x2	2021
Motor Controls	Blue Robotics	Basic ESC x16	30 *A* brushless ESC	Purchased	$25 x16	2021
CPU	NVIDIA	Jetson Xavier	6-core NVIDIA Carmel ARM®v8.2 64-bit CPU 6 MB L2 + 4 MB L3	Purchased	$399.00	2021
Teleoperation	Microsoft	Xbox controller	Series X/S	Purchased	$26.00	2019
Compass	N/A	-	-	-	-	-
Inertial Measurement Unit (IMU)	KVH Industries	DSP-1760	3-axis	Purchased	$17,000.00	2021
Doppler Velocity Log (DVL)	Nortek	DVL 1000	300 *m* max operational depth	Purchased	$14,960	2021
Camera(s)	Leopard Imaging	LI-IMX274-MIPI-M12 x2	1/2.5" 8.51M CMOS HD digital imager	Purchased	$365.55 x2	2021
Hydrophones	Advanced Navigation	Subsonus	1000 *m* range	Purchased	$12,000.00	2021
Algorithms: Vision	-	MobileNet, Gaussian, Canny, approxPolyPD, Dilate	-	-	-	2019
Algorithms: Localization and Mapping	-	Waypoint navigation	-	Custom	-	2019
Algorithms: Autonomy	-	Linear state machine	-	Custom	-	2019
Open Source Software	OpenCV	HSV and machine learning	-	-	-	2021