Desert WAVE: Enter the Dragon

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***Abstract*— This paper presents Arizona State University Desert WAVE's (Women in Autonomous Vehicle Engineering) strategy for its second competition, including hardware and software design, testing results, and the progress made to date constructing its second AUV, Dragon. Dragon includes the team's first attempt at advanced manipulation using a pneumatics system. Dragon will compete in conjunction with the team's original AUV, Phoenix. Both AUVs will use a combination of acoustic and visual sensors to achieve midcourse and terminal guidance. The team is also creating a vision-based object detector and is in the process of evaluating different neural network options. The team's current inability to conduct in-water testing will be supplemented by simulators that test vision, control systems, and other software.**

***Keywords*— AUV, Women in Engineering, RoboSub Competition**

I. Competition Strategy

In 2019, as a first-year team, Desert WAVE earned third place by focusing on the systems integration of its AUV, Phoenix (Figure 1). It used COTS (commercial off-the-shelf) components to enable early in-water testing, and allow more time for software development. The team realized that it could not attain a suitable software-hardware collaboration for the more difficult mission-specific tasks in its first year, so testing focused on refining navigation methods. Desert WAVE pursued a strategy of completing limited missions to earn a time bonus. Phoenix's lack of vision software resulted in a reliance on a fiber optic gyro (FOG), a doppler velocity log (DVL), surveying techniques, and waypoint input to position and navigate to task locations. Prior to competition rounds, tasks were hardcoded to execute in a predetermined order. This method proved to be very effective; Phoenix accurately maintained her heading and velocity, largely due to the FOG used in her navigation system. The AUV attained a maximum speed of 2.5*kts*, which ensured additional attempts during the team's allotted time. To offset the lack of vision software, Phoenix recorded video footage during each competition round to use in preparation for the following competition season.

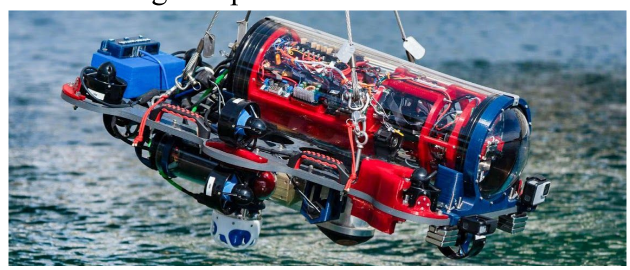

Fig.1 Phoenix entering the water at the 2019 RoboSub Competition

Entering the 2020 competition season, the team analyzed the results of the previous competition and recognized deficiencies to improve upon. Phoenix's main weakness was the inability to complete several challenges that required manipulation and advanced vision algorithms. Additionally, in previous competitions, first place was consistently earned by teams with two cooperating AUVs. This motivated the team to design a second, more capable AUV, Dragon, to compete alongside Phoenix (Figure 2). Adding a second AUV would present the opportunity to score more points in less time. Two AUVs would also create a redundancy of capabilities in the event that one of the AUVs failed to complete a task.

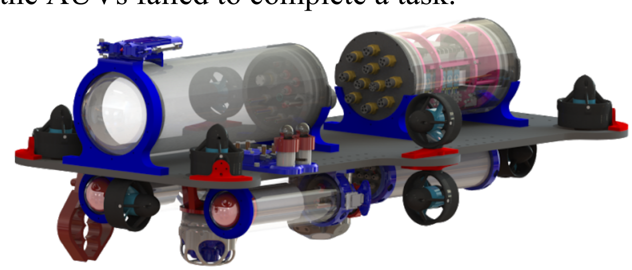

Fig. 2 CAD render of Dragon's current design

During Dragon's development, Desert WAVE continued to employ strategies that proved to be successful during the 2019 competition. It used mechanical and electrical hardware that is identical to or compatible with Phoenix. Both AUVs use an identical streaming, packet-based, serial communication protocol, allowing any code enabling that protocol to remain unaltered. Dragon possesses COTS components and reuses many mechanical designs originally created for Phoenix. Since the thruster configuration on Phoenix resulted in high speeds, the configuration was kept the same for Dragon. These decisions saved time during hardware and software development and reduced the number of spare parts required to support the two vehicles.

Phoenix has limited manipulation abilities and was not designed to allow for modifications or upgrades. This motivated the team to design Dragon with a pneumatic system, giving the new AUV the advanced manipulation capabilities necessary to accomplish tasks requiring either projectiles, marker droppers, or grabber mechanisms. In order to achieve neutral buoyancy, due the large volume of Phoenix's 8*in* diameter hull, 9*kg* of steel and lead were affixed to the frame. This resulted in a 76 point weight penalty at the 2019 competition. Dragon's five-hull modular design displaces less water than Phoenix's three-hull design. Splitting the AUV's component systems into smaller hulls (Figure 3) also allowed different sub-teams to work on multiple systems in parallel with each other.

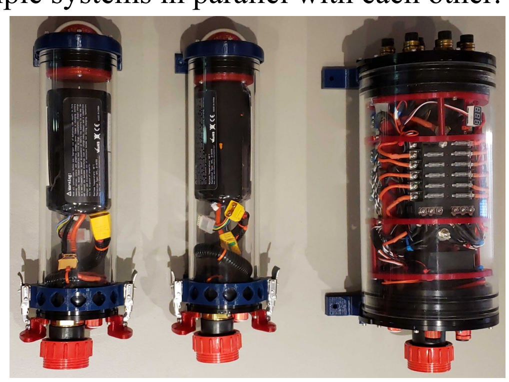

Fig. 3 Dragon's battery hulls and thruster hull (right)

As in the 2019 RoboSub Competition, the team will visually survey the field to calculate waypoints with the help of Google Earth. These waypoints will be used to navigate the AUVs to an area near the task. As an AUV approaches the target destination (midcourse guidance), it will use computer vision to identify the target, visual servoing to make final adjustments (terminal guidance), then execute the appropriate actions to complete the task. Upon completion, the AUV will move to the next designated waypoint location to repeat the process. The implementation of a vision system enables the AUVs to rely less on a priori knowledge of an environment and facilitate advanced manipulation capabilities.

During the competition, Phoenix will attempt the challenges that it is capable of, while Dragon attempts the challenges that Phoenix cannot. Each AUV will choose a different route (Bootlegger or G-man) and pass through the gate. Phoenix will attempt the Make the Grade (buoy) challenge and will surface in the octagon. Dragon will attempt to move the bottles to the appropriate table in the Cash or Smash (octagon) challenge, open the bin and drop her marker droppers in the Collecting challenge, and fire her projectiles in the smaller hole of the Survive the Shootout (torpedo) challenge. Dragon will automatically attempt Phoenix's missions after she completes her own, in case Phoenix was unsuccessful. However, if Phoenix has already been successful in both surfacing in the octagon and touching the correct side of the buoy, the team will call the end of the run after Dragon completes the torpedo challenge.

II. Vehicle Design

This section will focus on the design and current progress of the team's latest AUV, Dragon. An in-depth discussion of the design of Phoenix can be found in see the team's 2019 RoboSub technical design report, since she was primarily designed during the 2019 season [1].

Like Phoenix, Dragon's design uses COTS and 3D printed components. Dragon was designed to be just as fast and accurate, but more capable than Phoenix. The addition of a pneumatics hull provides the hardware needed to complete all of the challenges in the competition.

Dragon’s four custom boards, each designed by a student, include the Main board (located in the computer hull) seen in Figure 4, Motor Control board (thruster hull), Pneumatics board (pneumatics hull), and the Sensor Fusion board (computer hull). While Phoenix had one board processing tasks, the change to four allows Dragon’s Main board to limit the number of tasks it is processing at any given time.

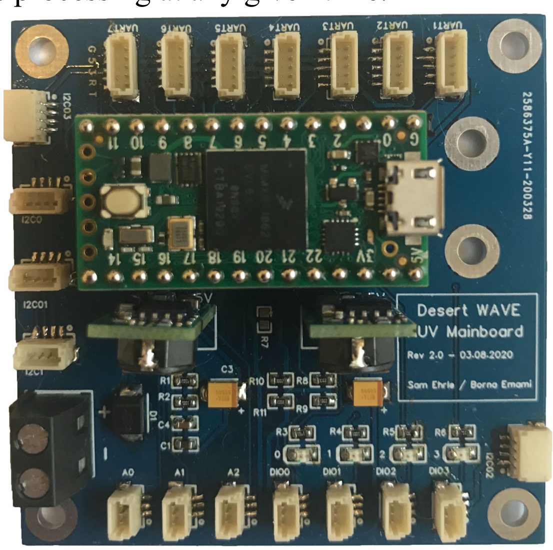

Fig. 4 Dragon’s Main board

While Phoenix utilized a single-axis FOG, Dragon was upgraded to use a three-axis FOG. Unlike a single-axis FOG, the three-axis one does not have to be mounted on a gimbal. Eliminating this moving component saves space and decreases the risk of the gimbal getting caught or stuck. The three-axis FOG removed the need for Dragon to have a separate IMU (inertial measurement unit) which, along with the DVL, sends data to the Sensor Fusion board. The board uses this data to generate yaw, pitch, and roll angles used to control the AUV with a sensor fusion algorithm. The team is currently evaluating different options for which sensor fusion algorithm to use. This information will help provide position and velocity estimations. By collecting data from multiple sensors, the Sensor Fusion board generates a more consistent, accurate, and dependable source of information needed for navigation.

The Pneumatics board controls Dragon’s eight solenoids. These solenoids actuate $1in$ stroke pistons to control the projectile launcher, marker dropper, and grabber mechanism. Having experienced the difficulty of trying to load projectiles into Phoenix while on the dock at the 2019 RoboSub Competition, both the projectile launcher and marker dropper were designed to be easily accessible and can be loaded quickly using one hand. When the projectile launcher, shown in Figure 5, is loaded, a spring is compressed behind the projectile. A piston then opens the hatch that restrains the projectile, the stored energy is released, and the spring propels the projectile forward.

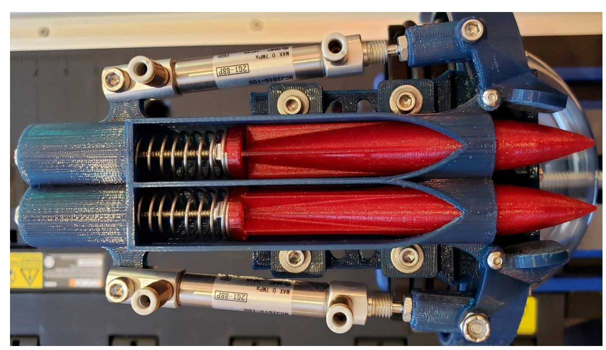

Fig. 5 Projectile launcher mounted on top of Dragon’s computer hull

The marker dropper used on Phoenix in the 2019 competition was actuated by a sprinkler valve that proved unreliable. The magnets intended to release the markers often failed, causing the markers to become jammed. While Phoenix used a magnetic-pull system, Dragon releases markers with pneumatic pistons (Figure 6). During initial testing, this design proved to be simple, reliable, and efficient.

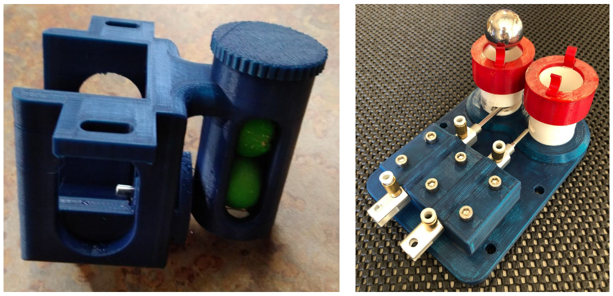

Fig. 6 2019 (left) vs. 2020 (right) marker droppers

The diagram in Figure 7 shows the software architecture of Phoenix, and how information is communicated between two boards.

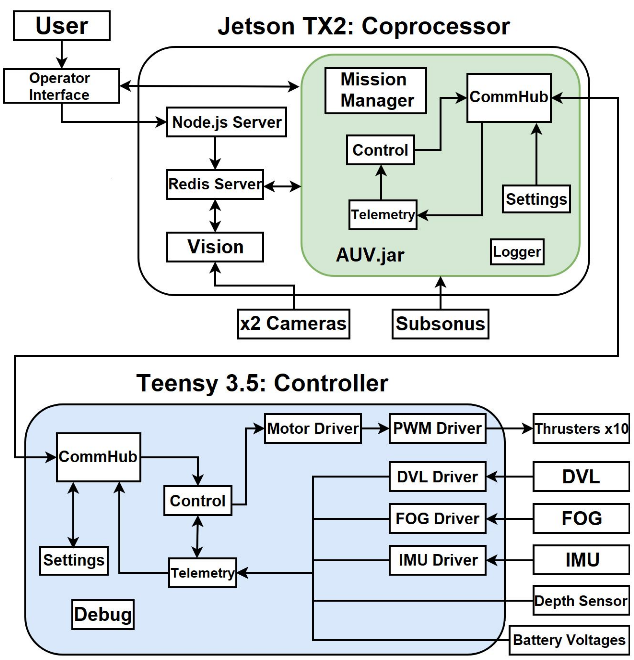

Fig. 7 Software architecture of Phoenix

Dragon uses a similar architecture, except that the role the Teensy controller plays in Phoenix is divided up into four different boards to accommodate the multiple hulls of Dragon. Additionally, the team utilizes a software-in-the-loop (SIL) simulator to allow the AUV code to be tested within a modeling environment. This enables the remote testing of software without requiring the AUV hardware by simulating the serial Teensy-Jetson connection over a user datagram protocol (UDP) interface.

Reliably completing the manipulation challenges requires robust vision algorithms. The team had previously planned to use the Darknet YOLO (You Only Look Once) framework for object detection. However, after a series of weekly workshops exploring deep learning methods, the team decided to switch. It is now exploring specific network options, including MobileNet. The team is currently training a neural network to identify detailed images such as the G-man and Bootlegger, while simpler identifications such as the Cash or Smash table will use an HSV (hue, saturation, value) technique.

III. Experimental Results

Much of the testing planned for Dragon was postponed or modified to accommodate for safety in the face of the COVID-19 outbreak. The projectile launcher, marker dropper, and their accompanying electronics were tested and adjusted extensively before being integrated into Dragon. Tests were conducted both in bathtubs and out of water in order to abide by social distancing guidelines. Five deploy scripts were written for each board across the two AUVs, that collect the common directory as well as board-specific directories, to allow the team to edit and upload only specific portions of the code as needed. This helps to minimize errors, avoid conflicts, improve debugging, and streamline code changes to specific systems that might need to be made during competition runs.

All large 3D printed components were first manufactured as low-density draft prints to test fit and functionality before being printed at full infill in their final form. Each new hull was separately tested for water tightness with a vacuum testing system and then submerged underwater (Figure 8). Currently, the thruster hull, battery hull, and the pneumatics hull have been tested for water-tightness, producing no water leaks.

Fig. 8 Testing the thruster hull for water-tightness

All four of the printed circuit boards built for Dragon, and the code for sending and receiving packets between them, were tested by a team member from her home. Packet communication between the Main board and the other boards was tested using LED sticks with different light patterns as indicators for different processes.

To support the integration of computer vision capabilities, the team developed a vision simulator that features a module which graphically represents a real life “vision feed” of what the robot sees without directly interfacing with the cameras. The programming team will use this simulator to test the vision algorithms to recognize images in the water when it sees them through the cameras, a substitute due to the current difficulty of in-water testing. To accommodate social distancing and allow individual work, shapes to be identified were physically printed and cut out, photographed in different lighting, shadows, and types of water, and modified digitally to feed the network as much data as possible.

Last year, the team had difficulty testing its Subsonus hydrophone array in the local pools due to noise picked up from echoes. During the 2019 RoboSub Competition, Desert WAVE used its Subsonus to collect acoustic data at the TRANSDEC facility. The data obtained from the TRANSDEC pool will be used as a baseline to adjust for that noise when testing.

Dragon is still a work in progress. The design, construction, and assembly of the computer hull needs to be completed. Once this is achieved, the team can finish designing Dragon’s frame and begin her final overall assembly. A significant amount of work also remains in software development, particularly in computer vision. Once the construction of Dragon is complete, the team will prioritize in-water testing. The team recognizes that simulations can never fully replace in-water testing, and aims to have Dragon undergo at least 200 hours of in-water testing before she competes at the 2021 RoboSub Competition. With improved vision and manipulation capabilities, Desert WAVE looks forward to competing in the summer of 2021 with two AUVs.

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Appendix A: Component Specifications: Phoenix

Component	Vendor	Model/Type	Specs	Cost(if new)
Buoyancy control	Blue Robotics	• Stainless steel ballast x10 • Subsea Buoyancy Foam: R-3312	• .43 *lbf* • 8"x4"x.5"	
Frame	Port Plastics	PVC sheet	.5" thick	
Waterproof Housing	Blue Robotics	• 8" enclosure x1 • 3" enclosure x2	• 24" long • 11.75" long	
Waterproof Connectors				
Thrusters	Blue Robotics	• T100 Thruster x6 • T200 Thruster x4	• Max thrust: 5.2 *lbf* • Max thrust: 11.2 *lbf*	
Motor Control	Blue Robotics	Basic ESC x10	30*A* brushless ESC	
High Level Control	Mouser	Teensy 3.2 Dev board	ARM processor	
Actuators	Lowes	Sprinkler valve	24*V*	
Propellers	Blue Robotics	• T100 Propellers x6 • T200 Propellers x4	• 3" diameter • 3" diameter	
Battery	Blue Robotics	LiPo batteries x2	4 cell, 18*Ah*, 16.8*V*	
Converter				
Regulator				
5*V* Power Supply	Vicor	Development board	20*A*, 5*V*	
CPU	NVIDIA	Jetson	256-Core NVIDIA Pascal GPU, Dual-Core NVIDIA Denver 64-Bit CPU	
Internal Comm Network	Simrex Corporation	WiFi Radio	5*GHz*	
External Comm Interface	MCI Networks	Fiber Optic Transceiver	5V ST / Ethernet set	
Programming Language 1	C++			
Programming Language 2	Java			
Internal Measurement Unit (IMU)	Sparkfun	Razor IMU	3-axis	
Doppler Velocity Log	Teledyne	Explorer 600	4-Head	
Camera(s)	Leopard Imaging	LI-IMX274-MIPI-M12 x2	1/2.5" 8.51M CMOS HD digital imager	
Hydrophones	Advanced Navigation	Subsonus	Range of 1000*m*	Donated
Manipulator				
Algorithms: vision	Darknet and YOLO			
Algorithms: acoustics	Subsonus (proprietary)			
Algorithms:localization and mapping	Dead reckoning midcourse guidance and vision-based target acquisition and terminal guidance			
Algorithms: Autonomy	Mission sequencer			
Open source software	OpenCV			
Team size	22			
HW/SW expertise ratio	14/9			
Testing time: simulation	20 *hours*			
Testing Time: in-water	37 *hours*			

APPENDIX A: COMPONENT SPECIFICATIONS: DRAGON

Component	Vendor	Model/Type	Specs	Cost(if new)
Buoyancy control	Blue Robotics	• Stainless steel ballast x10 • Subsea Buoyancy Foam: R-3312	• .43 *lbf* • 8"x4"x.5"	• $9 x10 • $9 x5
Frame	Port Plastics	PVC sheet	.5" thick	$125
Waterproof Housing	• Port Plastics • Blue Robotics • Blue Robotics	• 6" enclosure • 6" enclosure • 3" enclosure x3	• 20" long • 11" long • 11.75" long	• $125 • $98 • $86 x3
Waterproof Connectors	MacArtney	• Optical Series • Circular Series		• $5,000 • $3,000
Thrusters	Blue Robotics	• T100 Thruster x10 • T200 Thruster x6	• Max thrust: 5.2 *lbf* • Max thrust: 11.2 *lbf*	• $119 x10 • $169 x6
Motor Control	Blue Robotics	Basic ESC x16	30*A* brushless ESC	• $25 x16
High Level Control	• Sparkfun • JLC PCB	• Teensy 4.0 Dev board x4 • Main board • Sensor board • Thruster board • Pneumatics board	ARM processor	• $24.80 x4 • ~$65 each
Actuators	SMC Pneumatics	• Cylinder - Single Acting Spring Return Cylinder • 3/2 Solenoid Valve	• NCJ2D10-200S • 5VDC-SY113-SMO-PM3-F	• $16.36 x8 • $30.38 x8
Propellers	Blue Robotics	• T100 Propellers x10 • T200 Propellers x6	• 3" diameter • 3" diameter	Came with thrusters
Battery	Blue Robotics	LiPo batteries x2	4 cell, 18*Ah*, 16.8*V*	$289 x2
Converter	HJ Garden	Adjustable Step-Up Boost Converter Module	DC-DC 3V-32V to 5V-35V 4A	$11.59
Regulator	DROK	DC Car Power Supply	8A/100W 12A Max DC 5-40V to 1.2-36V	$11.89
CPU	NVIDIA	Jetson Xavier	6-core NVIDIA Carmel ARM® v8.2 64-bit CPU 6 MB L2 + 4 MB L3	$399
Internal Comm Network	Simrex Corporation	WiFi Radio	5*GHz*	Donated
External Comm Interface	Simrex Corporation	WiFi Fiber Optic Transceiver	ST/Ethernet set	Donated
Programming Language 1	C++			
Programming Language 2	Java			
Fiber Optic Gyro w/ IMU	KVH Industries	DSP-1760	3-axis	Donated
Doppler Velocity Log	Nortek	DVL 1000	300*m* max operational depth	$14,960
Camera(s)	Leopard Imaging	LI-IMX274-MIPI-M12 x2	1/2.5" 8.51M CMOS HD	$356.55 x2
Hydrophones	Advanced Navigation	Subsonus	Range of 1000*m*	Donated
Manipulator	Pneumatic grabber			
Algorithms: vision	Neural network & HSV			
Algorithms: acoustics	Subsonus (proprietary)			
Algorithms:localization and mapping	Dead reckoning midcourse guidance and vision-based target acquisition and terminal guidance			
Algorithms: Autonomy	Mission sequencer			
Open source software	OpenCV			
Team size	22			
HW/SW expertise ratio	14/9			
Testing time: simulation	*0 hours*			
Testing Time: in-water	2 *hours*			

APPENDIX B: OUTREACH

Desert WAVE aims to inspire future generations of women engineers and provide them with educational opportunities to learn and thrive. With its success last year, Desert WAVE has advocated for women in engineering through appearances in local live and prerecorded newscasts, news articles, ASU publications, videos, etc. The team's story even went national when it was picked up by Good Morning America.

Since the spring of 2019, Desert WAVE has been involved in dozens of outreach events. Virtual and in-person events ensure that Desert WAVE can connect with all members of the community, from elementary-aged children to members of industry (Figure 9). Some of the outreach initiatives that Desert WAVE is involved with include SeaPerch volunteering, VIP Meet and Greets for elementary school students, FIRST Lego League judging, Holiday Hack, and ASU's Summer Engineering Experience camp. Together, these outreach events encourage young people to engage with STEM.

Fig. 9 "RIPPLE" learning about Phoenix

At an in-person VIP Meet and Greet for local elementary school children, young girls who were inspired by the team had the opportunity to see Phoenix up close, meet the team members, receive a team photo, and were recognized as "RIPPLEs" (Really Impressive Person Preparing to Learn Engineering). The team hopes that as the RIPPLEs grow, they will eventually become a part of Desert WAVE.

This summer the team developed the Mission Phoenix video game to help teach about AUVs and different levels of autonomy. At Makers Making Change's Holiday Hack (Figure 10), Desert WAVE and Degrees of Freedom (an all-girls high school robotics team) modified electronic toys for the purpose of making them more accessible to children with disabilities.

Fig. 10 Desert WAVE member working with a Degrees of Freedom student during the Holiday Hack

Desert WAVE and Degrees of Freedom share a big sister-little sister relationship. One Degrees of Freedom student said, "I thoroughly enjoyed working with Desert WAVE during the hackathon. The ladies are all very bright, and apart from being great mentors and engineers, they gave me an insightful perspective on life as an ASU student. From ensuring that I understood each step of the adapting process and the function of the different tools we used, to joking around with us at lunch, our big sister team made me feel included, involved, and valued."