FINAL STATUS REPORT

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**Introduction**

 **Context**

Autonomous Underwater Vehicles (AUV) are robotic machines designed to operate in underwater environments. AUVs can be deployed for a range of purposes may be equipped with a variety of scanners, sensors, and navigational devices, depending on their application. They have distinct advantages over Remotely Operated Vehicles in that they require little to no human control or guidance and capable of extreme depths and long deployments [1].

They are commonly used in ocean environments for exploration and research activities. Notably, AUV's have been used in the oil and gas industry to survey sites for potential pipeline placement and for surveying pipelines once they have been installed [2].

AUV's are commonly used for scientific research to study ocean currents, biology, nutrients, and water properties and quality. They have been used to assist in archeological searches for shipwrecks or searches of lost aircraft [1]. However, autonomous underwater vehicles are not typically equipped to recover such objects, but merely locate them.

The military is a leading researcher in AUV's. Their research includes reconnaissance projects and ordnance disposal systems such as the Transphibian [3, 4] which is capable of locating and triggering underwater mines.

As autonomous machines, there are a number of ways that AUV's propel themselves, the most common of which is by propeller, like a boat. However, novel alternatives abound including those which glide with wings or mimic a variety of aquatic wildlife [9]. In order to complete their tasks, they are fitted with navigation systems capable of operating underwater, and a range of intelligence systems to plot a course and to allow for decision-making based on their environment [5].

While submarines and ROV’s have been around for decades, it was not until the 1970’s that universities and research institutions pioneered autonomous versions. Their capabilities were limited and were considered only “proof of concept” until software developments allowed for more complex tasks [6].

In the early 1990’s, AUV research was accelerated by MIT for special research projects in the Antarctic. MIT later partnered with Woods Hole Oceanographic Institute (WHOI) to develop Autonomous Ocean Sampling Network which brought together a variety of autonomous and manned systems for oceanographic research. This even included a deployable mooring to allow AUV's download data, recharge batteries, and relay data to researchers [7].

Currently, AUV's are commercially produced by only a handful of companies, worldwide. Bluefin Robotics (US) [1] arose out of research from MIT and today provides construction services for their designs. Other notable producers include Kongsberg (Norway) [2], and EvoLogics (Germany) [9]. These companies provide several models for a variety of purposes.

Woods Hole Oceanographic Institute (WHOI), a non-profit research institute, is a recognized leader in design and use of underwater vehicles, including AUV's. WHOI is partially responsible for the location of the Titanic shipwreck in 1985 and Air France flight 447 in 2011 [10].

The University of Alaska - Fairbanks has a research program including numerous drifting and autonomously-powered vehicles that it uses in its oceanographic research network [14].

While AUV's have proved extremely useful, the industry remains small as it is unclear if it they can remain economically feasible [6].

 **Background Information**

**Density**

Water is typically considered an incompressible fluid. While its density varies with pressure and temperature, this difference is considered negligible for the purposes of this project. Pure water is most dense at about 4’C at 1000 at i decreases from there. Table 1 depicts density as a function of temperature.

|  |  |  |
| --- | --- | --- |
| T [‘F] | T [‘C] | Pure Water [kg/m^3] |
| 32.0 | 0.0 | 999.87 |
| 39.2 | 4.0 | 1000 |
| 50 | 10.0 | 999.75 |
| 60 | 15.6 | 999.07 |
| 70 | 21.0 | 998.02 |
| 80 | 26.7 | 996.69 |

Table 1: Water density in environments likely experienced [12]

Impurities in the water alter these properties, though not significantly. The density of seawater at 25’C is frequently cited to be near 1028 kg/m^3 [13].

**Water Pressure**

Pressure under water varies linearly with depth and is a function of water density, (eqn. 1). This is independent of direction

p = ρgh (Eqn. 1)

 where:

p = water pressure [N/m^2 or Pa]

ρ = fluid density [kg/m^3]

g = gravitational constant (9.81 m/s^2)

h = depth below the surface [m]

The net force on a submerged surface is applied perpendicular to the surface and is described in equation 2.

 F = pA (Eqn. 2)

 where

 F = force exerted on the surface [N]

p = water pressure [N/m^2 or Pa]

 A = area of the surface [m^2]

**Buoyancy**

Buoyancy is the force applied to a submerged object in a direction opposing the object’s weight. It is proportional to the volume of liquid displaced by the object, according to equation 3. When drawn as a vector, the buoyancy acts through the centroid of the object.

 Fb = ρVdispg (Eqn. 3)

 where

Fb = the buoyant force [N]

Vdisp = total volume submerged [m^3]

ρ = fluid density [kg/m^3]

 The total weight of an object follows:

 Fg = mg (Eqn. 4)

 where

 Fg = the weight of an object due to gravity [N]

 m = mass of the object [kg]

g = gravitational constant (9.81 m/s^2)

The net force exerted on a submerged object is the sum of the forces in equations 3 and 4. If this is positive, a net upward force is applied and the object will move to the surface. A negative net force will cause the object to sink further.

Fnet = Fb + Fg = ρVdispg + mg (Eqn. 5)

If equation 5 equals zero, it is considered “neutrally buoyant” and will tend to remain at the depth to which it is submerged. This is extremely rare and difficult to obtain. Due to the near-incompressibility of water (Table 1), there is little change in density - and therefore F\_b - for small changes of depth.

However, if an object is only partially submerged, equilibrium is simple to achieve. The object will float according to equation 5, where V\_disp is the product of an objects cross-sectional area and the depth to which it is submerged. If the buoyant force is greater than the gravitation force, the object will rise until the weight of the water displaced is equal to the weight of the floating object, or sink lower if the buoyant force is less.

**Project Statement**

A preliminary design for an Autonomous Underwater Vehicle (AUV). The completed design will not be fully autonomous, but controlled through radio signals to propel itself and maneuver in a typical sized swimming pool. The design will be modular meaning there will be room for future upgrades to the sensor and control systems in order to achieve full navigational automation. A working prototype will be constructed and tested by the end of the semester.

**Scope of Project**

* Scope: a hull, propulsion, navigation mechanisms for an autonomous underwater vehicle. The vehicle can operate (submerge, propel, turn, and resurface) in a pool, under radio control from an operator.
* Depth range: At this point the AUV will only be tested in the pool and therefore only needs to be able to go to the depth of the pool.
* A turning radius which allows the AUV do a figure eight in the pool.

**Deliverables**

* propulsion system, including battery
* navigation system, motion control, RC control
* hull, submersion and resurfacing control

**Method**

**Hull**

The hull is primarily constructed from a 6” acrylic pipe. It will be capped at the ends with cone and tail sections of 3D-printed plastic. Bulkheads will also be printed and evenly spaced throughout the hull. The whole assembly will be held together with ¼” threaded rods. This will ensure a cohesive, rigid structure and allow for modifications such as moving bulkheads along the threaded rods or adding or removing bulkhead sections within the hull with limited effort.

The hull will contain several distinct modules within the main body, each separated by a bulkhead. These intermediate areas will contain the water-tight containers (WTC) to contain sensitive equipment.

Access to the WTCs is through the capped ends of the pipe.

The hull itself will not be watertight. With the need to frequently access the interior and due to so many perforations in the hull, it was determined that a perfect water-tight seal would be all but impossible, and the consequences of leakage could mean the loss of the entire AUV. Instead. The hull will be intentionally flooded and water-tightness will be ensured by the WTC’s.

*Current Status: The hull is complete but bulkheads will not be permanently mounted to the exterior piping until their final position is determined.*

*Next Steps: Finalize positions and attach bulkheads. Drill perforating holes in the hull to allow water to easily pass through.*

**WTC**

The water-tight containers make up the body for each individual module. They will be wide-mouth Nalgene bottles, selected for their low cost and availability. For modules holding equipment, they will include a 3D-printed structure mounted on the inside of the lid on which to mount electronics. Wiring and hoses that connect the modules will run through the lids, sealed by a flexible silicone sealant. Wires and hoses will be sized long enough so that WTC’s may be repositioned within the hull.

*Current Status: The water-tight containers have been constructed and tested for leaks.*

*Next Steps: WTC are complete.*

**Ballast**



The ballast system adds or removes weight from the AUV, thereby altering its buoyancy and allowing it to descend or ascend in the water. Two WTC’s will be used as ballast tanks, positioned in the very front and very back of the main body of hull. They will be connected to two medium-pressure submersible water pump in series. The WTC’s will be empty upon entering the water. Pumping water into the tanks will increase the weight of the hull by an expected 2-2.5 lbs. The WTC containers will remain sealed so this will have the effect of pressurizing the air and water inside the tanks.

A one-way check-valve ensures water only enters the tanks during pumping, and a normally-closed valve allows water to exit when it is desired. The valves are excellent seals so an additional bypass ball valve was added to allow for a minimal built-in leakage rate. This allows the pressurized air to slowly force out the water over time, ensuring that in the event of a loss of power, the AUV will eventually regain positive buoyancy and float to the surface - a built-in fail-safe device. Adjusting the ball valve changes the rate at which the submarine will resurface under the these conditions.

*Current Status: The ballast system has been constructed and tested. All valves have been installed.*

**Controls**

Controlling surfaces will consist of two pairs of rudders and planes that will be used in a + configuration at the rear of the sub and one pair of forward planes. The controlling surfaces will be actuated by servos.

Rough calculations were made to estimate required rudder and plane geometry as well as the torque required from the servos to provide the maneuverability objectives. This information was used to chose Hitec HS-5646WP high torque, waterproof servos.

Servos will be connected to control surface by a shaft which will penetrate the hull. These shafts will be connected to the control surface shafts by a control arm and linkage system.

*Current Status:* HS-5646WP has been received

*Next Steps:* Print control surfaces.

**Radio**

Most radio frequencies used in RC vehicles such as cars, planes, and boats use a 2.4 GHz frequency to transmit the necessary control signals. However, underwater this frequency does not transmit well and the working range is very small so a 75 MHz receiver and transmitter will be used which has been known to penetrate depths up to 25ft. Radio systems come in a range of different channels and for our control system we’ll need at least six channels.

*Current Status: WFLY 6 channel 75mHz transmitter and Lepton 6 channel receiver received.*

*Next Steps: Install and test ordered items.*

**Control Surfaces**

The control surface configuration chosen for this vehicle has the rear planes and rudders placed behind the propellers in a + shaped formation. Placing the rear control surfaces behind the propellers allows for better maneuverability during acceleration. For other configurations, you need forward motion for the control surfaces to provide change of direction. Here, the control surfaces provide directional control as long as the propellers are pushing water.

When forward planes and rear planes are used, they may be operated seperately. The rear planes are used to keep the sub level and the forward planes are used to dive and surface. The choice was made to use forward planes so that an off the shelf angle driver, which controls the rear planes for automatic leveling of the vehicle.

The ADF Angle Driver and Failsafe were ordered to provide automatic leveling. The angle driver has an accelerometer which detects pitch and compares it with the pitch signal coming from the radio transmitter. If the pitch signal and accelerometer do not agree, the angle driver sends a corrected signal to the rear plane servo.

*Current Status: ADF Angle Driver received.*

*Next Steps: Install and test ordered items.*

**Propulsion**

Underwater propulsion presents several design challenges. The driveline must be watertight, or at least water-*resistant* enough to not damage electrical components and cause internal corrosion. The propellers should fit the vehicle and shouldn’t “slip” or cavitate too much and need to provide sufficient thrust to counter lots of drag and be able to accelerate a large payload. The motors need to provide enough torque and shouldn’t spin too fast causing propeller slippage. The entire system needs to be as efficient as possible as energy storage space is limited.

Underwater travel and robotics isn’t a mainstream industry so there are many unique solutions to these problems and no big suppliers of AUV parts. Many designs have been experimented with by colleges and hobbyists and displayed on the internet for the public. Extensive web surfing yielded an understanding of what is do-able given the budget and time constraints.

The propulsion system will use dual brushless motors. Brushless motors have gained popularity in model engineering and radio controlled applications due to their high power-to-weight ratios and better efficiency over typical brushed systems. Power is supplied to each motor from an electronic speed controller (ESC) which supplies an AC power signal that can be programmed for specific performance requirements. The ESC can also provide a separate voltage required by the controls.

The maximum current draw from the motors is 32 amps so both the ESCs and batteries need to be capable of supplying at least this much. The chosen ESCs have a max draw of 45 amps so even at high loads the ESCs should stay cool. Lithium-Polymer (LiPo) batteries are made to withstand high discharge and are very lightweight and compact but cost significantly more than a lead-acid battery. Sealed lead-acid (SLA) batteries are heavy, bulky, and cheap. They can be found with discharge rates to suit the needs of the motor and may be advantageous if extra ballast is needed. It has been decided that the motor, prop, and ESC will be connected to a voltage supply to test performance under a load over a range of voltages to determine which battery to buy and how much capacity will be enough.



Each motor will be connected to a 3/16” stainless steel drive shaft that rides within a water-resistant stuffing box. The stuffing box will be made of an aluminum tube with SAE 841 bronze sleeve bearings at each end as shown in figure 1. The bearings are made of a porous material impregnated with oil for very low friction. The hollow aluminum tube will be injected with a waterproof grease to minimize water penetration. Spring-loaded PTFE shaft seals may also be added if necessary to provide a better seal for deeper water and higher pressures.

A 65mm diameter, 3-bladed propeller made by Graupner was chosen for the propellers. They come in both left and right handed drive so the props will spin in opposite directions to minimize excessive roll when engaging. These props were tested by OpenROV and outperformed many similar ones in terms of efficiency and maximum thrust.

*Current Status: Main propulsion components have been selected.*

*Next Steps: \_\_\_\_\_\_\_\_\_\_\_*

**Assembly**

Printing of the tail section did not occur in time for assembly of motor and control surface servos. A metal subframe design was used so that components that would be subject to large loads would be mounted to metal instead of plastic.

**Testing**

The entire ballast system has been fully tested. Tests were run at 12V. The combination of the two pumps drew 1.0 amps. Multiple tests showed that the two pumps can fill the tanks with one pound of water total in about 15 seconds. They can add a second pound of water in 25 more seconds. At that point the two tanks are half full and the pumps can no longer pressurize them any further. This should be a sufficient weight range to allow the AUV, if balanced to be just slightly buoyant, to operate easily with minimal pumping. In total, the tanks can be filed with two pounds of water in 40 seconds. This requires 133mWh per cycle. However, if the submarine is weighted well with fixed ballast, this can be greatly reduced. If only the first pound of water is required to submerge the submarine, the can be reduced to 50mWh per cycle.

The solenoid valve that releases the tanks draws 0.24A at 6V. It can release the entire contents of the ballast tanks in 50-75 seconds. It has total energy consumption of 26mWh per cycle.

**Budget**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Propulsion and connecting hardware** | **Quantity** | **price each** | **total** |  |
| **Graupner 3 Bladed Propeller LH 65mm M4** | **1** | **5.06** | **5.06** |  |
| **Graupner 3 Bladed Propeller RH 65mm M4**  | **1** | **5.06** | **5.06** |  |
| **HobbyKing Donkey ST3007-1100kv Brushless Motor** | **2** | **9.85** | **19.7** |  |
| **Turnigy Multistar 45 Amp Multi-rotor Brushless ESC 2-6S** | **2** | **15.99** | **31.98** |  |
| **XT60 Harness for 2 Packs in Parallel** | **1** | **2.31** | **2.31** |  |
| **SAE 841 Bronze Flanged Sleeve Bearings 3/16" Shaft Dia. x 5/16" O.D. x 1/2" Length** | **8** | **0.87** | **6.96** |  |
| **High-Strength 2024 Aluminum Tubes 1/2" O.D. x 0.310" I.D. x 12" Length** | **1** | **12.13** | **12.13** |  |
| **Type 303 Stainless Steel Miniature Drive Shaft 3/16" Dia. X 12" Length** | **2** | **7.66** | **15.32** |  |
| **SAE 863 Lubricated Bronze Sleeve Bearings 3/16" Shaft Dia. X 5/16" O.D. x 1/4" Length** | **6** | **0.37** | **2.22** |  |
| **Type 18-8 Stainless Steel Adjusting and Postitioning Stud 1/4"-20 Thread, 3" Overall Length, 1"** | **6** | **3.11** | **18.66** |  |
| **Spring-Loaded PTFESeal 1/16" Width, 3/16" Shaft Diameter, 5/16" Seal OD** | **6** | **13.83** | **82.98** |  |
| **Impact-Resistant Polycarbonate Round Tube 6" OD, 5-3/4" ID, 4ft Length, Clear** | **1** | **123.04** | **123.04** |  |
| **Double Seal Buna-N O-Ring AS568A Dash Number 437 6" x 6 1/2" Nominal** | **2** | **3.07** | **6.14** |  |
| **Optically Clear Cast Acrylic Sheet 1/4" Thick, 6" x 6"** | **1** | **5.49** | **5.49** |  |
| **Aluminum One-Piece Clamp-On Shaft Collar 3/16" Shaft Dia.** | **6** | **2.32** | **13.92** |  |
| **MultiPurpose 6061 Aluminum Sheet-Unpolished 0.190" Thick, 6" x 12"** | **1** | **22.92** | **22.92** |  |
| **18-8 Stainless Steel Cup Point Set Screw 3-48 Thread, 3/16" Long, 50ct** | **1** | **5.54** | **5.54** |  |
| **SAE 841 Solid Bronze Thrust Bearing 1/4" Shaft Dia. 5/8" O.D. 1/16" Thick** | **6** | **0.96** | **5.76** |  |
| **0.770" Clamping Hubs 3/16" Bore** | **3** | **7.99** | **23.97** |  |
| **0.770" Set Screw Hubs 3/16" Bore** | **2** | **4.99** | **9.98** |  |
| **Servo to Shaft Coupler 3/16"** | **2** | **12.99** | **25.98** |  |
| **Standard Servo Plate B** | **3** | **6.99** | **20.97** |  |
| **Lightweight Hub Horn (Hitec)** | **1** | **3.99** | **3.99** |  |
| **Channel Bracket A** | **1** | **4.99** | **4.99** |  |
| **6-32x1/4" Heavy Duty Ball Linkage** | **1** | **9.99** | **9.99** |  |
| **12" 6-32 Threaded Rod** | **2** | **2.35** | **4.7** |  |
| **Clamping Shaft Coupler 1/8" to 3/16"** | **2** | **12.99** | **25.98** |  |
| **5/16 6-32 Socket Head Machine Screw (Zinc-Plated)** | **1** | **1.79** | **1.79** |  |
| **9/16 6-32 Socket Head Machine Screw (Zinc-Plated)** | **1** | **2.39** | **2.39** | **519.92** |
|  |  |  |  |  |
| **Controls** |  |  |  |  |
| **Atx Crystals Crystal Set - AM Ch69** | **1** | **15.93** | **15.93** |  |
| **HiTec 35646W HS-5646WP Waterproof Digital Servo/** | **3** | **48.36** | **145.08** |  |
| **WFLY 6 channel Transmitter 75 MHz** | **1** | **119** | **119** |  |
| **Lepton 6 channel reciever** | **1** | **79.99** | **79.99** |  |
| **The ADF Angle Driver and Failsafe** | **1** | **79** | **79** | **439** |
|  |  |  |  |  |
| **Submersion system** |  |  |  |  |
| **1/4" 12V DC Electric Plastic Solenoid Valve** | **2** | **16.99** | **33.98** |  |
| **3/8 in. x 1/4 in. x 10 ft. PVC Tubing** | **2** | **3.73** | **7.46** |  |
| **#10 O-Rings (10-Pack)** | **1** | **2.27** | **2.27** |  |
| **#5 O-Rings (10-Pack)** | **1** | **2.27** | **2.27** |  |
| **1/4 in. x 10 ft. Threaded Electrical Support Rod** | **3** | **4.98** | **14.94** |  |
| **1/4 in.-20 tpi Zinc-Plated Hex Nut (100-Piece per Box)** | **1** | **5.37** | **5.37** |  |
| **1 in. Zinc Plated Non-Removable Pin Narrow Utility Hinges** | **5** | **2.26** | **11.3** |  |
| **1/2 in. x 520 in. Thread Seal Tape** | **1** | **1.47** | **1.47** |  |
| **Dynamax Series 200 Pump 2 Pack** | **1** | **59** | **59** |  |
| **Storage Bottle, 32oz** | **5** | **6.99** | **34.95** |  |
| **Wide Mouth Bottle Cap** | **3** | **4** | **12** |  |
| **Storage Bottle, 16oz** | **2** | **5.99** | **11.98** |  |
| **Nano Gear Pump** | **2** | **15** | **30** |  |
| **Two-way 226 Nylon Ball Valve 1/4"FNPT x 1/4"FNPT** | **2** | **8.11** | **16.22** |  |
| **1/4" x 1/4" x 1/4" Hose ID Black HDPETee** | **8** | **0.49** | **3.92** |  |
| **1/4" NPT x 1/4" Hose ID x 1/4" Hose ID Black HDPETee** | **6** | **0.52** | **3.12** |  |
| **1/4" Hose ID x 1/4" Hose ID Black HDPE Connector** | **8** | **0.24** | **1.92** |  |
| **1/4"FNPT x 1/4"Hose ID Polypropylene Female Adapter** | **8** | **1.39** | **11.12** |  |
| **1/4" NPT x 1/4" Hose ID Black HDPEAdapter** | **6** | **0.28** | **1.68** |  |
| **1/4" NPT x 1/4" Hose ID Black HDPEElbow** | **8** | **0.5** | **4** |  |
| **1/4" Hose ID x 1/4" Hose ID Black HDPEElbow** | **8** | **0.48** | **3.84** |  |
| **1/4" ID x 3/8" OD x 1/16" Wall Bev-A-Line IV Tubing** | **20** | **0.66** | **13.2** |  |
| **1/8" NPT x 1/4" Hose ID Black HDPEELBOW** | **4** | **0.5** | **2** |  |
| **1/8" NPT x 1/4" Hose ID Black HDPEADAPTOR** | **4** | **0.24** | **0.96** |  |
| **1/4” PPStandard Check Valve** | **2** | **0.74** | **1.48** |  |
| **1/4" x 2.00"L Hose Polypropylene Mini Check Valve** | **2** | **2.03** | **4.06** | **294.51** |
| **Grand total** |  |  | **1253.43** |  |

**Gantt Chart**

attached

**Summary**

Construction of a moderately sized AUV with a couple features unique for its size. A high pressure pump ballast system, which has a failsafe inherent to its design. An aft of propeller control surface array, which aids low speed maneuverability.

**Conclusion**

Future plans and recommendations will come after assembly and testing.

**References**

[1] Bluefin Robotics, <http://www.bluefinrobotics.com/applications/search-and-salvage/>

[2] Kongsberg Maritime, <http://www.km.kongsberg.com/>

[3] “Robots clear waterways of deadly mines,” ABC News, available at: <http://abcnews.go.com/Technology/story?id=3428257&page=1>

[4] NOAA - Ocean Explorer: Transphibian, [http://oceanexplorer.noaa.gov/explorations/08auvfest/background/AUV's/media/movies/transphibian\_auv\_video.html](http://oceanexplorer.noaa.gov/explorations/08auvfest/background/auvs/media/movies/transphibian_auv_video.html)

[5] NOAA - Ocean Explorer: AUV Intelligence, <http://oceanexplorer.noaa.gov/explorations/08auvfest/background/auvintelligence/auvintelligence.html>

[6] Blidberg, D. “The development of autonomous underwater vehicles (AUV); a brief history,” http://ausi.org/publications/ICRA\_01paper.pdf

[7] MIT: AUV Lab, <http://auvlab.mit.edu/history.html>

[8] NOAA - Office of Coast Survey, <http://www.nauticalcharts.noaa.gov/csdl/AUV.html>

[9] EvoLogics, http://www.evologics.de/en/products/glider/index.html

[10] Woods Hole Oceanographic Institute, <http://www.whoi.edu/main/topic/underwater-archaeology>

[12] US Geological Survey: Water Density, <http://water.usgs.gov/edu/density.html>

[13] Specific Gravity of Liquids, <http://www.engineeringtoolbox.com/specific-gravity-liquids-d_336.html>

[14] University of Alaska Fairbanks Institute of Marine Science ART Lab, <http://www.ims.uaf.edu/artlab/projects.php>

**Resources**

Autonomous Undersea Vehicle Application Center (AUVAC), <http://auvac.org/>

NOAA: Ocean Explorer, [http://oceanexplorer.noaa.gov/explorations/08auvfest/background/](http://oceanexplorer.noaa.gov/explorations/08auvfest/background/auvs/auvs.html)[AUV's](http://www.google.com/url?q=http%3A%2F%2Foceanexplorer.noaa.gov%2Fexplorations%2F08auvfest%2Fbackground%2Fauvs%2Fauvs.html&sa=D&sntz=1&usg=AFQjCNF9C6SsaDqptsUma0AVL1jo2npafg)[/](http://oceanexplorer.noaa.gov/explorations/08auvfest/background/auvs/auvs.html)[AUV's](http://www.google.com/url?q=http%3A%2F%2Foceanexplorer.noaa.gov%2Fexplorations%2F08auvfest%2Fbackground%2Fauvs%2Fauvs.html&sa=D&sntz=1&usg=AFQjCNF9C6SsaDqptsUma0AVL1jo2npafg)[.html](http://oceanexplorer.noaa.gov/explorations/08auvfest/background/auvs/auvs.html)