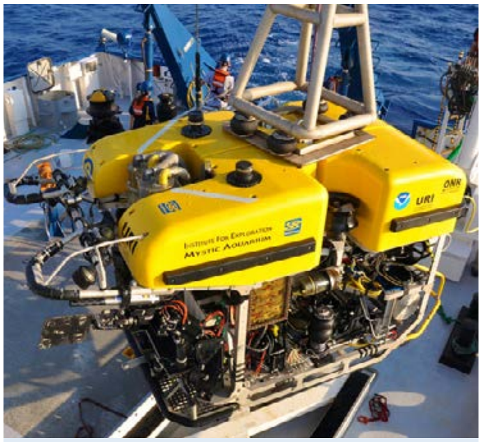
Introduction to Remotely Operated Vehicles and Autonomous Underwater Vehicles

Since the 1930's manned submersibles have been used to observe animals in the water column, though most submersible developments have focused on the seafloor. The opportunity to have a first hand look into the deep ocean holds a powerful attraction for many ocean explorers; but the risk to human life and high cost have placed serious limitations on this type of ocean exploration. Today, thanks to rapid advances in electronics and other technologies, unmanned vehicles have almost entirely replaced manned submersibles as the primary means to directly access the deep sea. Two types of unmanned vehicles are regularly used in ocean exploration missions.

Remotely operated vehicles (ROVs) — These are unoccupied robots usually linked to an operator aboard a surface ship by a group of cables. Most ROVs are equipped with one or more video cameras and lights, and may also carry other equipment such as a manipulator or cutting arm, water samplers, equipment for collecting biological and/or geological samples, and measuring instruments to expand the vehicle's capabilities for gathering data about the deep-ocean environment. ROV developments have improved the understanding of water column animals by facilitating observations of animal behavior, enabling collections of live specimens in pristine condition, conducting manipulative experimentation, and assessing community composition.

Specific ROV systems vary among ships of exploration. Aboard R/V *Falkor*, ROV operations use the *Seaeye Falcon* with a 300 m depth rating, high definition camera and 5-function hydraulic manipulator arm. *Falcon's* compact size (weight = 60 kg out of the water; external dimensions = 1 m x 0.5 m x 0.6 m) makes it ideal for shallow-water surveys, and has been used extensively for remote coral reef survey work. The *Falkor* also operates *SuBastian*, an ROV rated to 4500 meters and fitted with a suite of sensors and scientific equipment to support scientific data and sample collection, as well as interactive research, experimentation, and technology development.

Sometimes form wins—*Deep Discoverer (D2)* is an elegant and powerful 9,000 pounds, designed to bring optimal imagery topside, where it is then shipped to shore in real time. Image courtesy of NOAA *Okeanos Explorer* Program, Gulf of Mexico 2014 Expedition.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1402/logs/apr15/media/drfront.html



Hercules is one of the very few Remotely Operated Vehicles (ROV) specifically designed to be used as a scientific tool. Built for the Institute For Exploration (IFE), *Hercules* is equipped with special features that allow it to perform intricate tasks while descending to depths of 4,000 meters (2.5 miles).
http://oceanexplorer.noaa.gov/technology/subs/hercules/hercules.html

Argus (right) acts as a stabilizing platform for *Hercules*, following the ROV into the water. Image courtesy of The Ocean Exploration Trust.
http://oceanexplorer.noaa.gov/technology/subs/hercules/argus.html

The ROV Went Dark - What Happened?

On Tuesday, July 18, 2017, at 1:13 PM, while diving on an unnamed seamount near Johnston Atoll approximately 800 miles west of Hawaii, remotely operated vehicle (ROV) *Deep Discoverer* encountered a problem. The type of problem which causes the ROV Navigator to report to the Bridge that, "The vehicle has lost power and communications—bail out, bearing 225, speed 0.5 knots." The type of problem which forces a "dead vehicle recovery," ends a dive early, and cancels dives for the next two days. Go to the link below to find out what happened and how the problem was solved.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1706/logs/july28/welcome.html

The E/V *Nautilus* has a two-part ROV system:

- ROV *Hercules*, equipped with six thrusters that allow pilots to maneuver it in any direction, plus two manipulator arms for collecting samples and recovering artifacts, and a high-definition video camera connected via a fiber-optic cable to the control van on *Nautilus*. *Hercules* is capable of operating down to 4,000 meters, and also carries profiling sonars, a Sea-Bird FastCAT 49 CTD, a suction sampling system, and a variety of containers for biological and geologic samples.

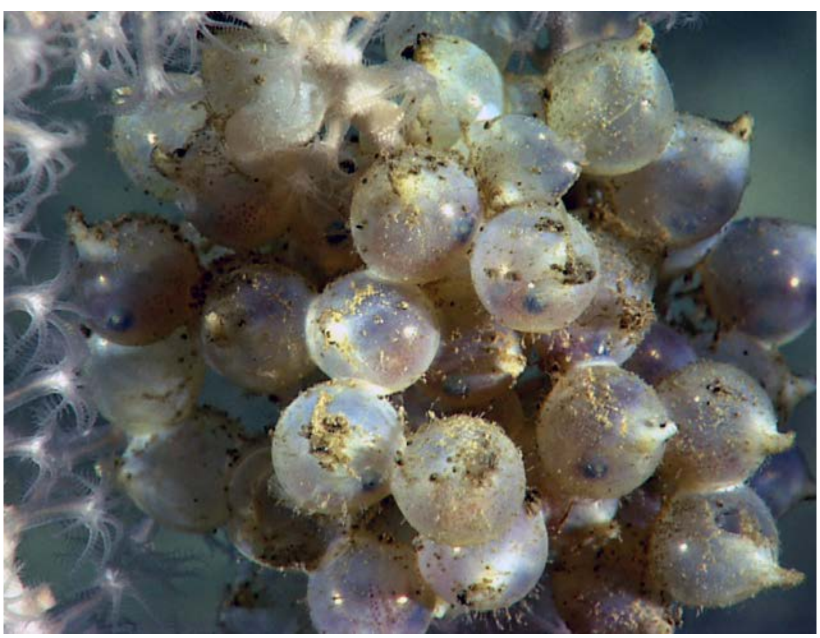
- ROV *Argus* is a stainless steel towsled-style vehicle that dampens the roll of the ship so *Hercules* can remain steady through sensitive operations. *Argus* also provides additional light and serves as an "eye in the sky" during operations. When operating alone, it can dive deeper than *Hercules* - down to 6,000 meters. In addition to high definition video cameras, *Argus* also carries profiling sonar, a sub-bottom profiler, and sidescan sonar.

The NOAA Ship *Okeanos Explorer* also uses a two-part ROV system consisting of ROV *Deep Discoverer* (also known simply as "*D2*") operated in tandem with its sister vehicle, *Seirios*. Technically classified as a 'camera sled', *Seirios* is directly tethered to the *Okeanos Explorer* by a six mile-long armored cable containing power conductors and optical fibers for exchanging data and control signals, and provides ROV pilots with a birds-eye view of *D2* as the pair moves over a survey area. Both vehicles are equipped with high-definition cameras and powerful lighting equipment. *D2's* primary camera is capable of zooming in on a three-inch long organism from 10 feet away, while *Seirios* currently has a high-definition camera, a wide fisheye 'bubble' camera, and several standard-definition cameras that improve pilots' "situational awareness" (knowledge of surrounding

Given all of the ROV's high-tech bells and whistles, it takes a highly skilled team to keep *D2* operating smoothly. Image courtesy of the NOAA Office of Ocean Exploration and Research. Image courtesy NOAA OER.
http://oceanexplorer.noaa.gov/technology/subs/deep-discoverer/media/d2-team.html

environmental conditions). *D2* weighs in at 9,200 lb (4,173 kg), has an overall length of 3.2 m, and stands 2.6 m tall. It has a total sensor payload of over 400 lb (181 kg), a Predator II robotic arm, a hydraulically actuated sensor platform, full color sector scan sonar (a type of sonar that provides a panoramic display of objects around and below a vessel by sending sound pulses in an arc or full circle around a vessel and detecting echoes returned when some of the sound energy bounces off objects in the path of the pulses), and a fully integrated inertial navigation system (which uses gyroscopes and accelerometers to calculate a vessel's position, rather than external references such as satellites used in global positioning systems).

The forward-facing high-definition camera (pictured above) is the most commonly seen view from ROV *Seirios*. Image courtesy of NOAA OER, Deep-Sea Symphony: Exploring the Musicians Seamounts.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1708/logs/sept26/media/camera.html



D2's high-definition cameras are providing scientists and public audiences around the world with close-up glimpses of things we might otherwise never see. Here, *D2* captures an image of tiny bobtail squid eggs, getting so close that you can actually see the eyes of the squid. Image courtesy of the NOAA OER, *Okeanos Explorer* Gulf of Mexico 2014 Expedition.
http://oceanexplorer.noaa.gov/technology/subs/deep-discoverer/media/squid-eggs.html

Remotely operated vehicle *Deep Discoverer's* manipulator arm, labeled. Image courtesy of Art Howard, GFOE; edited by Jeffery Laning, GFOE.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1702/logs/feb28/media/d2arm.html

The AUV *Sentry* being lowered into the water. Image courtesy of Exploring Carolina Canyons expedition. *http://oceanexplorer.noaa.gov/explorations/16carolina/logs/aug28/media/sentry-lowered.html*

The autonomous benthic explorer (ABE) a free-swimming robot, was used on multiple expeditions to find new hydrothermal vents in the deep ocean all over the world, from New Zealand to South Africa and Brazil to Ecuador. Photo courtesy of Christopher German. *http://oceanexplorer.noaa.gov/explorations/10chile/background/exploration/media/exploration1.html*

NOTE: ABE was lost at sea during the Chile Triple Margin Expedition in 2010. Read the following mission logs for the story and some interesting insight and hope!

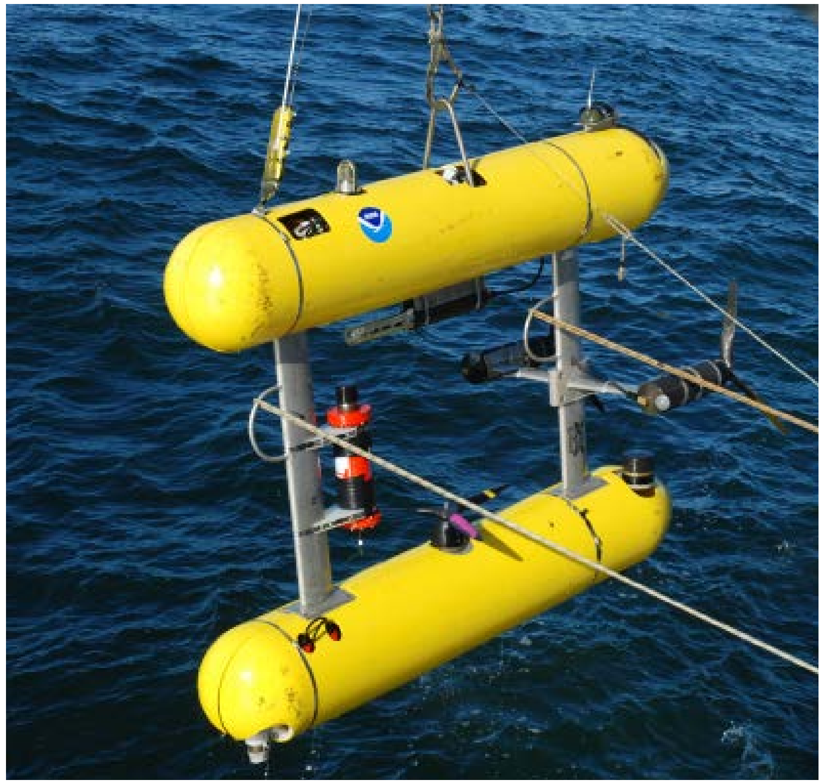
Requiem Explorator
http://oceanexplorer.noaa.gov/explorations/10chile/logs/mar7a/mar7a.html

Post-Triple Junction Blues
http://oceanexplorer.noaa.gov/explorations/10chile/logs/mar7/mar7.html

Epitaph for ABE:

Under the wide and restless sea,
Lies my grave, now let me be;
Glad did I work and now I rest,
Now by deadlines no longer stressed.
And I lay me down with a will.

This be the verse you grave for me;
"Here lies ABE where it longed to be;
Home is the sailor, home to the sea,
Here it rests, now let it be."
— Al Bradley (after Robert Louis Stevenson)



The AUV *Lucille* coming on board the research vessel. With negative buoyancy in the lower hull, and positive buoyancy in the upper hull, *Lucille* is able to remain stable in the unpredictable pitch and roll of the ocean while it follows the terrain of the bottom. Image courtesy of San Andreas Fault 2010 Expedition, NOAA-OER. *http://oceanexplorer.noaa.gov/explorations/10sanandreas/background/auv/media/recovery1.html*

Autonomous underwater vehicles (AUVs) -- are another type of unmanned underwater vehicle that can operate without a pilot or cable to a ship or submersible. This independence allows AUVs to cover large areas of the ocean floor, as well as to monitor a specific underwater area over a long period of time. Typical AUVs can follow the contours of underwater mountain ranges, fly around sheer pinnacles, dive into narrow trenches, take photographs, and collect data and samples. Until recently, once an AUV was launched it was completely isolated from its human operators until it returned from its mission. Because there was no effective means for communicating with a submerged AUV, everything depended upon instructions programmed into the AUV's onboard computer. Today, it is possible for AUV operators to send instructions and receive data with acoustic communication systems that use sound waves with frequencies ranging roughly between 50 Hz and 50 kHz. These systems allow greater interaction between AUVs and their operators, but basic functions are still controlled by the computer and software onboard the AUV. Like ROVs, these underwater vehicles can be equipped with video photography equipment, sonars, water chemistry sensors, and a variety of other instruments. For additional information about AUVs, please see "What Are AUVs, and Why Do We Use Them?" by Denise Crimmins and Justin Manley *(http://oceanexplorer.noaa.gov/explorations/08auvfest/background/auvs/auvs.html)*.