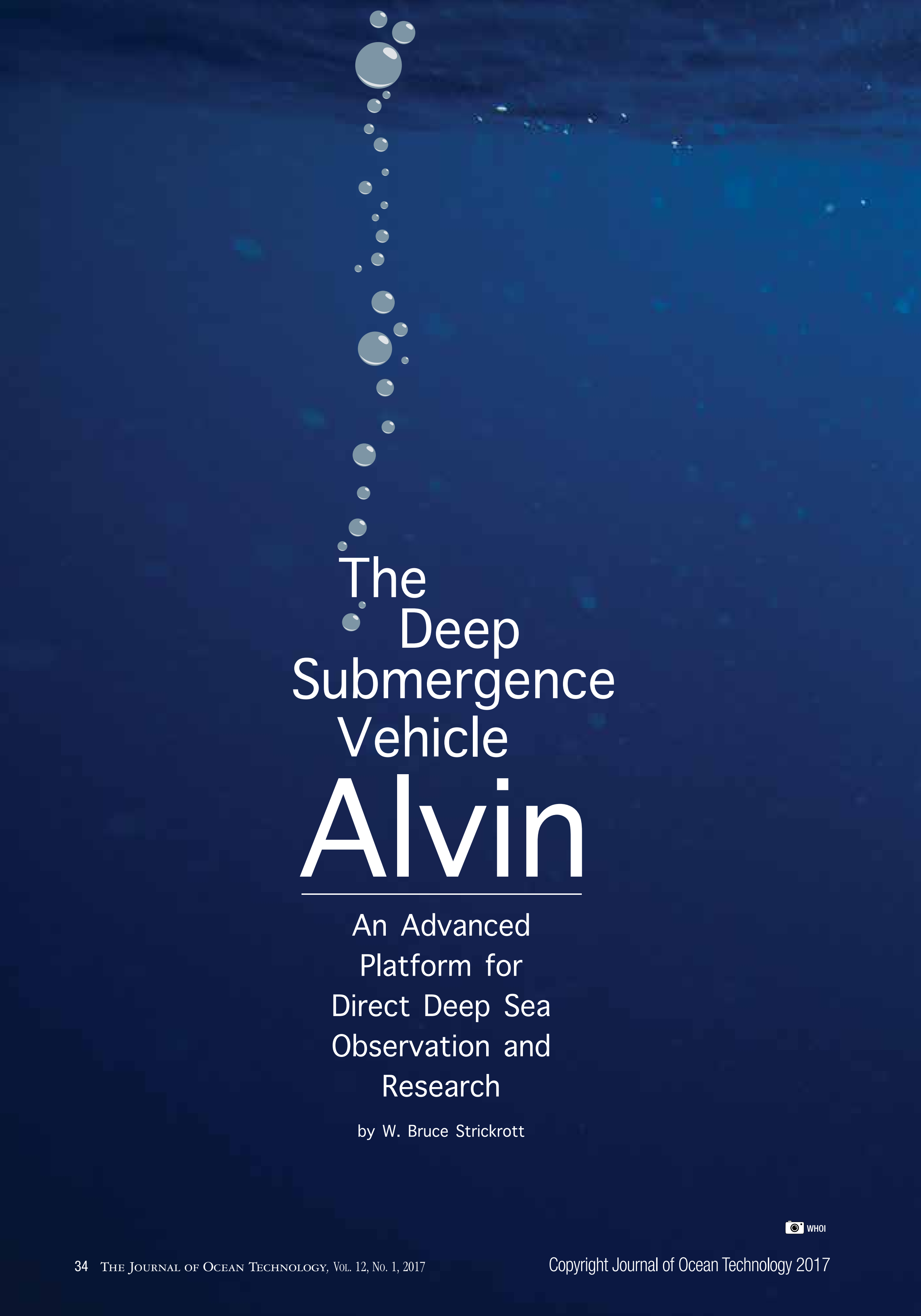

WHOI

The Deep Submergence Vehicle Alvin

An Advanced Platform for Direct Deep Sea Observation and Research

by W. Bruce Strickrott

Human occupied vehicle (HOV) Alvin enables in-situ data collection and observation.

The question "what is the most extreme creature you encounter during a deep dive in Alvin?" is often asked during our public outreach events with schools and museums. There are many answers and all are worthy of the title as most extreme – the giant *Rifita Pachyptila* tube-worms that live and feed at hydrothermal vent environments; *Alvinella Pompejana* worms that live directly in the high temperature vent fluids; the unique vent shrimp, *Rimicarus Exoculata*, that use specialized cells on their carapace to sense hydrothermal vents in the infrared spectrum. All thrive in extreme environments. However, the most appropriate answer to the question is that human beings are the most extreme species in the deep ocean.

Humans are not physically capable of surviving in the high pressure, often toxic, environment of the deep ocean. However, we are capable of safely visiting harsh environments on Earth and in our solar system. To do so, humans have had to utilize our amazing intellect to overcome the challenges to a physical presence in extreme environments. Through the application of our understanding of the natural world and our knowledge of physical laws, humans have developed advanced technologies to enable successful human visitations to the harshest locations on Earth.

For over 51 years, the Woods Hole Oceanographic Institution (WHOI) has exhibited this unique human trait through the operation of one of the world's premier extreme vehicles, the manned, deep submergence vehicle Alvin.

Beginning of a Legacy

In the early 1960s, Allyn Vine, a WHOI oceanographer, identified the need for a new class of deep diving submersible. At that time there was no effective means for scientists to perform direct research, exploration and experimentation in the deep sea. To tackle this challenge, a team of WHOI engineers collaborated with the US Navy to develop the deep submergence vehicle Alvin and in June of 1964 Alvin officially entered service. Since its commissioning, Alvin has made thousands of dives and has played a critical role in the continuing advances in oceanographic science (Figure 1). Alvin's entry into service as a scientific research tool represented a significant change to the methods used to study the deep ocean.

Thousands of scientific observers have used Alvin to make the amazing journey to the seafloor. Their experiences have led to many significant discoveries and helped uncovered the secrets of Earth's deep water environments. Today, a newly rebuilt Alvin remains in service and continues operations as a valuable asset for deep sea research and understanding.

Alvin is Never Finished – An Evolving Design

Periodically, Alvin's systems are replaced and upgraded with more advanced components and the newest technologies. Through the years, the vehicle's capabilities have continually evolved to meet the changing demands of the scientific users and to enable new methods for oceanographic research.

In 2013, the Alvin team completed the most extensive upgrade to the vehicle's systems since its original inception. Completion and certification of the new vehicle represented the culmination of years of design studies, project planning and new system development. The major overhaul and upgrade period was a significant technological endeavour intended to greatly improve Alvin's capabilities and to ensure that the vehicle is an advanced, 21st century deep sea research tool.

Bigger is Better – Alvin's New Sphere

A principal part of the upgrade was the installation of a new titanium personnel sphere. The new sphere is the third in Alvin's history, replacing a smaller sphere installed in 1973. WHOI engineers, in collaboration with the Southwest Research Institute and the

Alvin Dive Statistics

Alvin Dive Statistics	as of 12/31/2016
Total Dives	4,872
Total Depth	10,088,572 metres
Average Depth per Dive	2,071 metres
Total Time Submerged	34,026 hours
Average Time Submerged per Dive	6.98 hours
Total Persons Carried	14,607
Dive Purpose Breakout	
Biology	1,867
Geology/Geophysics	1,540
Chemistry/Geochemistry	687
Engineering/Equipment Tests	306
Search/Survey/Recovery	244
Orientation/Training	147
Certification	81

WHOI

Figure 1: Alvin dive statistics.

scientific user community, optimized the new sphere configuration and in-hull environment. Sphere size, maximum depth rating, total viewport compliment, size and placement were important variables considered during the design phase.

Ultimately, the new personnel sphere was 20% larger, capable of diving to 6,500 metres and includes a suite of five strategically placed viewports. Three large (18 cm) forward facing viewports and two smaller (13 cm) side viewports provide excellent overlapping fields of view extending from the front of the submersible to the extreme port and starboard sides.

The replacement sphere represents a significant improvement over the older system, which was smaller, had only three small viewports, no overlapping observation areas and was limited to a depth of 4,500 metres.

Staying Afloat – Complex Syntactic Foam Buoyancy

Primary buoyancy for deep water vehicles is provided by externally mounted syntactic foam material. As a part of the upgrade, Alvin received new lighter foam rated for 6,500 metres. Every block was extensively tested for manufacturing quality and pressure tolerance to ensure the material was adequately safe for manned use. Advanced machining technologies allowed implementation of complex shapes that give the new vehicle a modern, more streamlined appearance.

Ergonomically Speaking – Alvin's New Interior

The larger sphere and new systems required a redesign of the in-hull environment. WHOI engineers solicited input from scientific users, students from the Rhode Island School of Design, experienced spacecraft engineers and senior Alvin pilots to develop the new interior. The final design balances personnel comfort, equipment placement and access with a configuration that naturally promotes use of the five viewports (Figure 2). New seating arrangements, ergonomically placed piloting controls, HD touch screen interfaces and video monitors transform Alvin's interior. Observers entering the vehicle for the first time routinely use the word "wow" to describe their impression of the new design.

Light Speed – Fibre Optic Penetrators

Principal to Alvin's mission is the ability to collect large quantities of dive data. External sensors and components continually send information to the in-hull network for display and processing. To enable high speed data transmission, WHOI engineers worked with Lancer Systems to develop a high-pressure fibre optic penetrator for Alvin. Through-hull penetrators are populated with a total of 24 optical fibres that provide a superb means to transmit large quantities of data and high definition video information. High-speed transmission of vehicle commands and system status are effectively distributed through the vehicle's new data network.

Network of the Deep – Alvin's New Data System

Prior to 2012, Alvin's data system was limited in the ability to process large quantities of data. While there was a serial data network for a small number of in-hull science data computers, the system did not utilize a dedicated in-hull network as a primary component of the data system. Equipment interfaces used analogue circuitry with no additional digital command and control capability. Science data needs utilized serial data methods (RS232) to transfer information to dedicated in-hull notebook computers (typically user supplied). The system was limited in bandwidth and had no significant means for real-time vehicle system and science data integration and processing. All data travelled over hard-wired circuits with the associated limit to data transfer rates.

The new submersible includes a modern, vehicle-wide data network that links primary vehicle systems and sensors with a suite of in-hull computers and externally distributed microprocessors and controllers. Intelligent science interfaces and dedicated microprocessor controlled power supplies are linked throughout the data system via a redundant fibre optic data loop. Video and imaging systems are integrated into the wider data system for access and control. Science supplied sampling devices and sensors utilize the network to collect and process large quantities of environmental data. Advanced, user supplied sampling tools, notebook computers, tablets and any other network capable equipment can easily integrate into the new data system.

Alvin's data system is designed specifically to enable users to integrate novel high-tech sampling devices and sensors for enhanced data collection.

Taking Command – The New Command and Control System

Historically, Alvin has relied on analogue circuitry to provide pilot and observer interface with submersible systems and manoeuvring controls. Although effective, the method supplied little informational feedback to the pilot for system status and fault evaluation. The new Alvin includes a fully redesigned command and control (C&C) system that greatly enhances the pilot's ability to manage the submersible's systems.

Utilizing a hybrid digital/analogue command architecture, the C&C balances an integrated microprocessor interface with robust hard-wired circuits. System commands are initiated via a modern touch screen graphical user interface (GUI). Dedicated GUI pages provide automated and manual control of ballasting, sensors, external lighting, cameras, and numerous other submersible components and systems. Primary battery and bus-power information and individual component status is reported real-time for display. Any identified faults are visually flagged to notify the pilot of potential problems or reduced performance. All data is recorded and available post-dive for performance evaluation.

The new C&C system is highly adaptable and configurable to meet the needs of an individual dive series and provides a significant improvement to Alvin's operational capabilities.

Xs, Ys and Zs – Precision Manoeuvring in Three Axes

Prior to the upgrade, Alvin used six thrusters to provide motion in three axes (3-fore/aft, 2-vertical, 1-rotational). The single horizontal rudder thruster, mounted near the stern of the vehicle, provided limited capability for Alvin to rotate in-place and direct lateral motion was not possible. The new vehicle includes an additional forward-mounted, horizontal thruster that enables full rotational and lateral motion capabilities.

Proportional manoeuvring commands are initiated via two joysticks. A primary joystick controls fore/aft, rotational and lateral motion with a secondary joystick controlling vertical motion. Digital manoeuvring modes include auto-heading, auto-altitude, auto-depth, auto-X/Y and stick-lock. Additional manoeuvring command inputs are possible through fore/aft/vertical potentiometers and lateral/rotational control switches. Incremental positional control in three axes is available via a dedicated GUI page on the C&C touch screen.

Alvin retains a redundant analogue control system for use in the event of a full digital system failure. The backup system uses the same piloting devices (joysticks, potentiometers, switches) for three-axis manoeuvring.

Alvin's new position control system represents a significant improvement to the vehicle's ability to support scientific operations. Alvin is now capable of performing very accurate sonar mapping and photo-mosaic missions, precision transects over long distances and stable position holding near bottom sampling sites (Figure 3).

Are We There Yet? – New Navigation System

In the early days, Alvin used very primitive systems for navigation during a dive. Simple acoustic methods provided ranges between the ship and sub. Visual cues and natural landmarks, dead-reckoning and hand-drawn maps were often used to create an understanding of a particular dive location. Correlating sample information with accurate positional information was difficult.

Eventually, acoustic methods were developed to provide more accurate means to track the submersible. Acoustic beacons and ranging methods (long baseline navigation) improved the ability to track vehicle position during dives.

Presently, Alvin uses a modern navigation system that provides very accurate positional information. The shipboard system uses a resident ultra-short baseline acoustic navigation set to determine the vehicle's position relative to the ship. Accurate shipboard GPS information is used to determine Alvin's position on Earth.

On board the submersible, Doppler velocity sensors, a fibre optic gyro, magnetic compass and attitude sensor provide vehicle specific information to the Alvin data and navigation computers. WHOI engineers developed an advanced navigation "engine" to calculate and display vehicle position on the in-hull navigation touch screen display. Dive specific

WHOI

Figure 2: Alvin's new interior balances personnel comfort, equipment placement and access with a configuration that naturally promotes the use of the five viewports with new seating arrangements, ergonomically placed piloting controls, HD touch screen interfaces and video monitors.

target locations, navigational waypoints and high definition bathymetric map underlays (obtained from WHOI's Sentry AUV) are available for use during the dive. All navigation data is recorded and available post-dive for future mission planning and science data correlation.

Dedicated shipboard navigation stations provide parallel navigation processing and display to topside watch-standers and scientific observers.

Lights, Cameras, Action – High Definition Imaging and Lighting

Initially, the sub carried only a small number of stand-alone external film and video cameras. Observers utilized in-hull handheld 35 mm cameras as a principal source of dive images. Image quality, post-dive availability and long term stability were limited.

Since then, Alvin's complement and type of camera equipment has evolved in tandem with advancements in photographic technologies. Imaging data (still and video) is now a significantly important component of Alvin's data product. The new vehicle incorporates a professional grade in-hull video system with a number of integrated high quality external video and digital still cameras. It is fully configurable and adaptable, and able to readily incorporate the newest camera technologies (4 K).

The system uses six high definition video cameras, two mounted on digitally controlled pan and tilt units, two with integrated pan and tilt mechanisms, one super wide-angle fixed focus and one HD still/video camera. Digital video and still images are recorded on high density digital disk media. Multiple pilot and observer HD video monitors and camera controllers provide the ability to view and manage the external cameras and collected images.

A specialized frame-grabber system collects incremental snapshots of user selected video sources to create a time-based sequential image file. Dive specific navigational and meta-data are embedded in the frame-grabber file and are extremely useful for post-dive review and mission planning. Frame-grabber files are offloaded post-dive and are now available online for public access on the WHOI web site.

Degrees of Freedom – Enhanced Manipulation and New Workspace

Alvin is a workhorse for science and routinely carries a large array of scientific sampling tooling, collection devices and deployable sensors. The science work space is located at the front end of the submersible and includes the sample platform (basket) and two hydraulic, seven-function manipulators (Figure 4). Before 2012, the science payload was limited to approximately 90 kg and two manipulators were mounted at fixed locations with limited total effective range of motion.

The new sub includes a redesigned work space with a modular fully configurable science basket. Useful payload is doubled to 180 kg and manipulators are mounted on extended, rotational swing-arms that provide an additional degree of freedom. Manipulators can now rotate 135° from the front of the vehicle to the port and starboard sides of the submarine.

Dedicated power channels (electric/ hydraulic) and high speed data system interfaces (wired and fibre optic) are resident on the basket for use by science supplied sampling equipment and cameras.

In Case of Emergency – Thruster Releases

Alvin is designed to ensure that the pilot has appropriate responses to the many potential emergency situations. Redundant systems and emergency procedures ensure the vehicle safely returns to the surface. The original design included a sphere-release mechanism to enable an emergency return to the surface, but during the upgrade WHOI engineers determined that installation of the new personnel sphere required removal of the sphere release capability. To ensure the new vehicle retained an appropriate emergency response, WHOI

Figure 3: Alvin's new position control system represents a significant improvement to the vehicle's ability to support scientific operations. Alvin is now capable of performing very accurate sonar mapping and photo-mosaic missions, precision transects over long distances and stable position holding near bottom sampling sites.

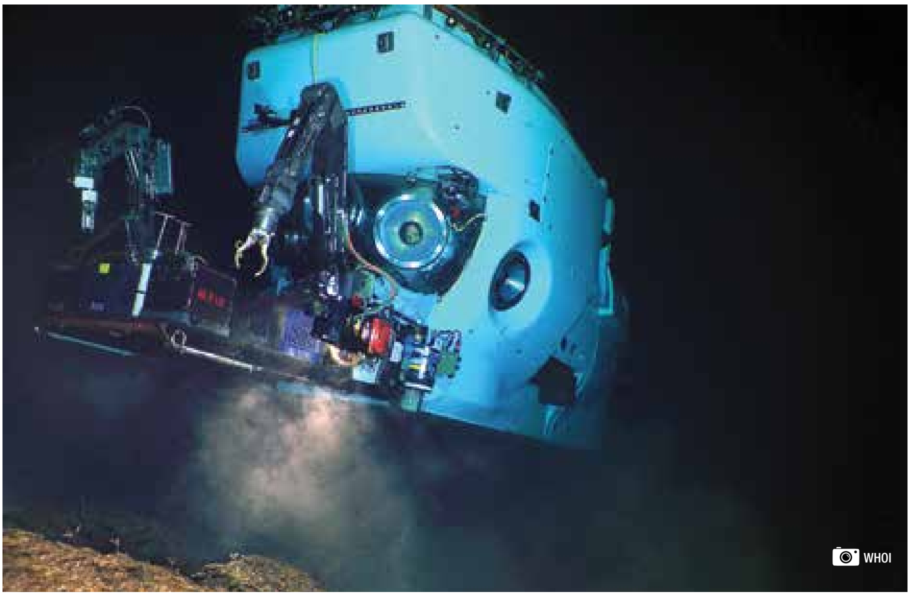

Figure 4: Alvin is a workhorse for science and routinely carries a large array of scientific sampling tooling, collection devices and deployable sensors. The science work space is located at the front end of the submersible and includes the sample platform (basket) and two hydraulic, 7-function manipulators. Manipulators are mounted on extended, rotational swing-arms that provide an additional degree of freedom, and can now rotate 135° from the front of the vehicle to the port and starboard sides of the submarine.

engineers designed specialized component release mechanisms. Manipulators, science basket, main batteries and thrusters use an electrical/mechanical release system that enables jettisoning of an assembly in the event of an emergency. A releasable "rescue-buoy" with an ultra-high strength synthetic line enables additional emergency support from the surface ship. Multiple circuit redundancies ensure emergency systems function in the event of a loss of vehicle power.

The Sound of Data – Wireless Data Transmission

Alvin engineers are currently implementing an acoustic data transmission system to enable wireless data transfer to the surface ship. The system provides the capability to share dive data and digital still images with the surface observers. A dedicated science observation station on the support ship displays vehicle navigational information, still images and mission data and an acoustic SMS messaging channel allows text communication between the topside and subsurface scientists. With proper cruise planning, dive data transferred to the surface ship can be made available for transfer to shore-side participants via satellite telepresence.

The Future is Now – Taking the Sub to 6,500 Metres

At present the WHOI team is finalizing design work to complete certification for operations to 6,500 metres. Final system integration and certification is scheduled for completion in 2020. Operations to 6,500 metres will provide scientists with the opportunity to conduct research from shallow ocean depths into the hadal zone and will greatly increase Alvin's access to Earth's oceans.

A Continuing Legacy

Early deep ocean research utilized relatively primitive methods to collect data and specimens with sampling performed by scientists on the surface ship. Trawl nets, Nansen water samplers, dragged dredges and other crude mechanisms provided very limited capabilities to directly understand seafloor environments. In time, 20th century technological advances improved the ability to better survey the oceans. Sonars, magnetometers and other techniques allowed seafloor mapping and helped to identify areas for focused research. But none of these advances enabled human visitation of deep water environments. Alvin's arrival in the 1960s forever changed the nature of deep sea investigation.

Today, deep ocean research requires the use of innovative tools for effective experimentation. Advances in unmanned systems (ROVs, AUVs, gliders) provide a new suite of capabilities for research, but nothing will supplant the value of an actual physical presence at a sampling site. Although advanced imaging technologies have greatly improved the value of remote viewing, these new technologies cannot equal the capability of human eyesight when employed for direct observation of the seafloor.

Presently, the use of new technologies and enhanced sensor and sampling capabilities ensures that Alvin remains an important tool for scientific research. Alvin's inherent ability to collect large quantities of scientific data significantly adds to the overall value of a trip to the seafloor. Observers return from a dive with a wealth of human experience, enhanced by the high quality vehicle images and data. This combination is unmatched by any unmanned system.

For over 51 years the manned deep submergence vehicle Alvin has ensured scientists have access to the deep sea. The new enhanced Alvin will continue enabling important discoveries well into the future, proving that through the combination of the application of our intellect with advances in technology, humans will remain as the most extreme creatures on the seafloor.

Bruce Strickrott is the Group Manager and senior pilot of the manned deep submergence vehicle Alvin, operated as a part of the US National Deep Submergence Facility at the Woods Hole Oceanographic Institution. He has worked as a member of the Alvin Group since 1996 and has over 330 dives as Pilot in Command. He obtained an ocean engineering degree from Florida Atlantic University. While at college he worked as a scuba dive master aboard the University's research boat the R/V *Oceaneer IV*, working to support engineering diving projects. Mr. Strickrott spent six years in the US Navy working on surface combatant ships as a weapons electronics technician including deployments during Operation Desert Shield/Desert Storm. When not working with Alvin, he lives on Cape Cod with his family and enjoys promoting exciting careers in science, math and engineering to college and high school students.