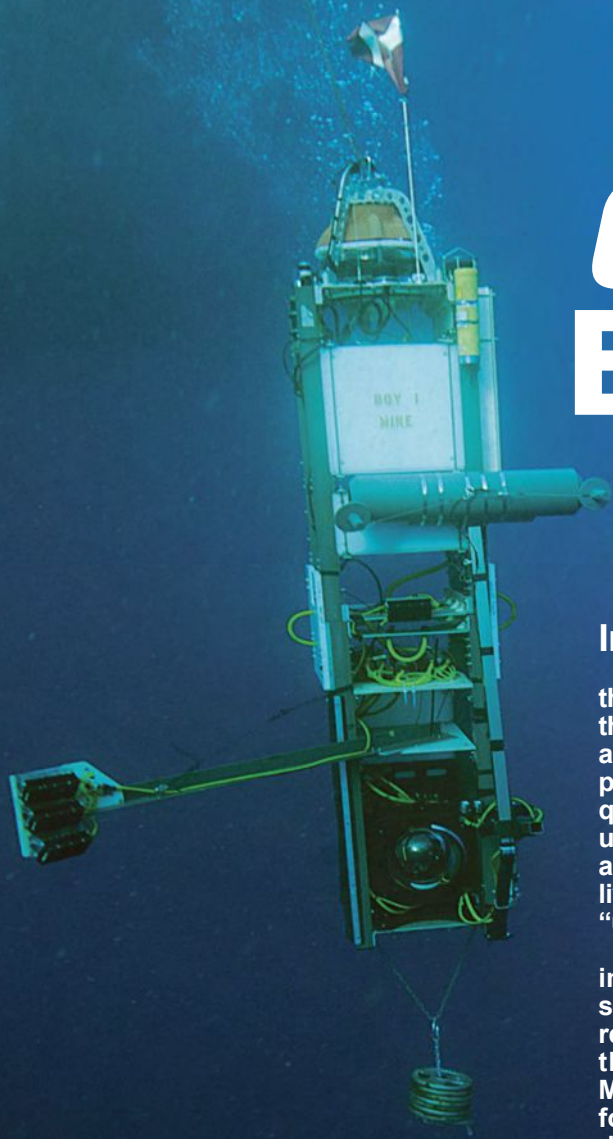


By: Kevin Hardy, Global Ocean Design LLC;
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TECHNOLOGY OF THE *DEEPSEA* *CHALLENGE* EXPEDITION

(Part 1 of 2: The Landers)



Introduction

Virtually all oceanography has been done in the upper 6 km of the ocean, and very little in the 5 km below that in the deep region known as the “hadal zone.” Created by the titanic planetary forces of plate tectonics, earthquakes, volcanoes, tsunamis, and countless unknown species are born there. A lack of access, not interest, has kept the hadal zone living in our common language as something “unfathomable.”

On March 26, 2012, a day like only one other in the entire history of man’s reach into the sea, Explorer and Filmmaker James Cameron resolutely piloted a one-man submersible to the bottom of the Challenger Deep in the Mariana Trench. Once there, he roamed freely for hours in the dark hallways of Neptune’s dungeon as no one had ever done before. To make that happen, the design limits of both manned submersible and unmanned landers were pushed to include the newest ideas and developments, with legacy technology forming a broad foundation.

In his quest to reignite scientific interest and inspire world awareness of the forgotten lands of the ocean trenches, Cameron’s *DEEPSEA CHALLENGE* (DSC) Expedition developed a radically new submersible and twin unmanned “landers” as his primary vehicles of exploration. This two-part series will highlight the technologies, both new and applied, used in the making of the manned and robotic machines that could operate in the extreme pressures of Earth’s ocean trenches.

The DEEPSEA CHALLENGE lander, DOV MIKE, is photographed heading for the bottom of the New Britain Trench near Papua New Guinea. Photo by Charlie Arneson, used with permission, Earthship Productions.

Science

A number of significant biological and geological discoveries were made through the expert observations and targeted sampling performed by the **DSC** vehicles. Giant amphipods, larger and deeper than seen before, and the discovery of bacterial mats clinging to the downslope faces of jagged rocks at the very intersection of subducting plates, are but two examples. Many of the biological discoveries are recounted in the AGU Ocean Sciences 2014 paper “**Submersible Exploration of the World’s Deepest Megafaunal Communities through the DEEPSEA CHALLENGE**,” authored by Natalya Gallo, Center for Marine Biodiversity and Conservation, Scripps Institution of Oceanography/UCSD, and co-authored by key members of the expedition including James Cameron. Other peer-reviewed scientific publications are in process.

Shared Technology

The expedition demonstrated the practicality of interchangeable technologies shared across multiple undersea vehicle types: the submersible, the twin landers, and an ROV. Pressure compensated batteries, LED lights, stereo HD cameras, and acoustic navigation and communications systems found similar application on the different platforms.

Cameron’s **DEEPSEA CHALLENGE** Expedition brought together multiple undersea vehicles to gain the advantages of each, while balancing corresponding disadvantages. The submersible provided the suite of human senses, tactile ability, depth, and payload capacity, but was limited by pilot endurance. The ROV provided imaging, tactile ability, and some payload capacity, but was tethered to a ship and had a limited operating depth. The landers have no mobility or the ability to recognize their immediate environment in detail and selectively sample it, but have persistence and freedom from the ship.

Landers

The “landers” are unmanned free vehicles that transit in free fall from the sea surface to the seafloor, landing upright on the alien surface of that Other Earth. They remain in place, sampling, measuring, and imaging, until acoustically commanded to release their anchor weight and begin their reciprocal free fall upward, back to sunlight and atmosphere.

Advancements in superthick-wall borosilicate spherical housings from Nautilus Marine Service® provide a cost-effective option for ocean trench work, simultaneously providing both an instrument housing and buoyancy. The Vitrovex® spheres can be polished to make a camera viewport, drilled and spot-faced for connectors, are impervious to corrosion, are invisible to light and electromagnetic waves, and made of an abundant and inexpensive material. Their downsides include being prone to conchoidal fractures if struck a glancing blow, surface spalling, and the potential of immense implosive force by catastrophic failure. Some manufacturers of the past produced glass with inclusions of air and char, non-concentricity of inside and outside diameters resulting in variable wall thickness, surface striations, and improperly lapped sealing surfaces — intolerable imperfections in the ultra-deep sea.

The landers utilized a large volume of the same syntactic foam made for the submersible by Acheron® to reduce the potential of an implosion. This was roughly divided into 2/3 for fixed buoyancy and 1/3 for variable buoyancy.

Other component technologies required similar improvement, and piece-by-piece, engineers and their companies, inspired by the challenge, created the key components able to survive ambient pressures of 1,100 atmospheres.

Interchangeable payload modules were being built in parallel, requiring flexibility in the payload bay of the lander.

Basic Description

The lander vehicle body was approximately 14-ft tall, with a narrow width and depth, approximately 2.5 ft x 3 ft, with buoyancy high and weight low, yielding excellent self-righting performance (Figure 1). This also provided a small frontal projected area during descent and ascent, resulting in vertical transit stability, with minimal horizontal offset. The box structure made in-field adaptations simple. Use of low specific gravity materials such as extruded fiberglass shapes, HDPE sheet, and 6061 aluminum plate minimized in-water weight, decreasing buoyancy



Figure 1. The **DEEPSEA CHALLENGE** Alpha Lander, **DOV MIKE**, is lifted by crane during deployment. Photo by Charlie Arneson, used with permission, Earthship Productions.

requirements. Consideration was given to metacentric stability on descent, at the seafloor, on ascent, and at the surface.

Frame

The lander frame was built in two sections to allow disassembly for transport. HDPE doubler plates at the mid-section joint reinforced the FRP frame during deployment and recovery operations. The vehicle was laid horizontally on deck during transport, pre-launch preparation and post-recovery servicing. Because of the vehicle's overall size and weight, use of a crane or A-frame was mandatory.

A 6061-T6 welded and heat-treated aluminum lifting bale was placed at the top. The SolidWorks® design was evaluated using FEA and validated by physical testing. Dual toggle releases were located at the bottom of the frame, providing redundancy.

Two 17-in. x 23-mm thick Vitrovex glass spheres were used, one for the Command/Control sphere at the top of the frame, the other for the Camera sphere, located at the bottom of the frame. Barbell weights were added below the camera sphere to cancel its buoyancy and keep the weight low.

Ballasting and release mechanism

A clump weight was made of 85 lbs of cast iron barbell weights. A chain was run through the middle holes, then fastened back on itself, making a closed loop through the weights. The loose end of the chain is shackled to a large welded ring. Through this ring a second length of chain is passed. Each end of the second chain is held by a separate toggle release mechanism located on either side of the base of the lander. Both toggle releases are held closed by an Edgetech® Inconel burnwire element. One Edgetech burnwire is connected to the command/control sphere, where it may be directed by acoustic command to corrode and release its chain end. The second Edgetech burnwire is connected to an independent, stand-alone countdown timer. Should the acoustic command release system fail for some reason, the back-up countdown timer will initiate the burn of the second burnwire after a pre-set time interval of up to 99 hours. On short duration drops, a Galvanic Time Release (GTR) was also added as a tertiary backup.

Glass housing design and manufacture

The Vitrovex glass housings included drilled and spot-faced penetrator holes. Some refinement continued on the geometry of the edge chamfer to minimize spalling. Some exterior surface spalling was evident after the deepest dives as well. This may be due to residual stress created by localized cooling during the manufacturing process. The spheres were tested to 1,000 atm at Vitrovex plant in Germany. Later testing was done to 1,225 atm at Deep Sea Power & Light®.

Provision was made for two bulkhead connectors and a single purge port. The purge port is used to cycle air over a desiccant to dry it prior to deployment, preventing condensation on electronics or camera lenses at the cold temperatures found at depth.

Command/control sphere

The command/control sphere housed an Edgetech BART Board acoustic transceiver circuitry, recovery beacons, and batteries. The Edgetech BART Board was selected for acoustic command and control because it has two release commands, with an optional daughter board providing four more. These proved invaluable at-sea. The BART system was successfully tested in August 2011 in the Mariana Trench Sirena Deep at 10,800 m using a topside Edgetech Model 8011M Acoustic Transceiver deck unit.

The camera sphere housed a still/video camera, a programmable camera/light controller, and the recorders for the external stereo camera pair, described in detail below.

A 12.75-in. D x 1/8-in. aluminum plate is bolted to a PVC ring mount secured by 3M® 5200 marine adhesive to the interior of each hemisphere. The upper plate holds the recovery beacons and battery. The lower plate holds the Edgetech BART board and battery. Below the lower plate, the bulkhead connectors bring copper connections through from the outside.

The landers incorporated MetOcean/Novatech strobe lights (ST-400) and RDF (RF-700) beacons, minus pressure cases, inside the upper sphere. An RF-700AR, an RDF with remote antenna, was transferred to the submersible. An ST-400 strobe with a custom acrylic head made by Acheron, and a standard RF-700 RDF were mounted to the frame outside the sphere.

Duracell® alkaline cells supplied battery power for the command/control sphere and back-up timers. The camera internal to the sphere used rechargeable LiPO camera battery packs. The PBOF LED cinematographic lights and stereo cameras were powered by Acheron PBOF LiPO battery packs made for the **DEEPSEA CHALLENGER** submersible.

Camera sphere

The camera, the controller, and all other recorders and components were mounted in one hemisphere. The matching hemi-



Figure 2. A Canon 5D camera is seen through the optically polished Nautilus Marine Vitrovex glass housing. Photo by Charlie Arneson, used with permission, Earthship Productions.

sphere was polished to optical clarity and was closed once the detailed pre-cruise checkout was complete.

Imaging system

The **DEEPSEA CHALLENGER** Expedition required imaging systems far superior to any ever utilized at these depths. HD stereo cameras made by the Cameron Pace Group®, spaced ocular distance apart, recorded stunning images of life and land in the ocean trenches.

The spacious interior volume of the Vitrovex glass spheres and ability to take high quality images directly through their polished glass walls was a powerful combination. After exhaustive comparison tests, a Canon 5D Mark II DSLR was selected by Larry Herbst, a seasoned underwater imaging expert, for its high-resolution sensor and low-light capabilities (Figure 2).

In the black depths of the sea, the camera would need to shoot with the lens nearly wide open — resulting in extremely limited depth-of-field. Accurate focusing was critical. A 1-ft deep 50-ft long focusing trough was built to gather focusing data through a horizontal water column, with the camera lens positioned close to the inner apex of a polished glass hemisphere.

For lighting, the lander was outfitted with four PBOF LED “light bricks” made for the **DEEPSEA CHALLENGER** submersible.

Connectors and cabling

MacArtney SubConn® PBOF connectors were used with the LED lights, pressure compensated LiPO batteries, and the L3 comm controller. Standard SubConn connectors were used with adapter ports to bridge between standard thread lengths and the longer threads needed for glass spheres. A special high-pressure fitting was also made by the Lander Team to adapt a fiberoptic feedthrough, designed by Acheron, to the lander camera sphere. Connectors made by SeaCon were used in the back-up timer and junction bottle.

L3 communication system

The L3 Nautronix® unit is a long-range acoustic modem that transmits and receives both voice and data communications and can calculate the range between the ship and submerged platform. The unit was adapted with some effort to both the submersible and landers.

Given the attenuation of the transmitted source level through the 13 to 15 km operational slant range, the L3 Nautronix was designed with a very sensitive receiver. In the field, this sensitivity made background noise the largest problem, mainly that generated by ship’s propulsion and machinery picked up by the topside transceiver module.

Samplers and sensors

Samplers on the lander included Niskin Bottle water samplers, fish net traps, and sediment corers. The fish traps worked well for amphipods. An additional Niskin bottle was mounted on the drop arm to lay on the seafloor and capture animals. The sediment samplers could benefit from further refinement.

The lander also carried an RBR® Ltd. DR-1050, a self-contained, submersible depth recorder. The data provided insight to the landers’ fall rate, bottom time, release time, rise rate, and helped correlate the high definition stereo

images of the life forms and geologic features with the extreme depths where they were found.

Testing

A saltwater basin at Scripps’ main campus was used to check air and water weights of unassembled components. Underwater connectors and fully assembled glass spheres were individually tested to 18,000 psi. Load tests were performed on critical load-bearing components. The first assembled lander was tested in San Diego Bay, then offshore San Diego at a 1-mi depth.

Operation

The lander lay horizontally on deck to make access to all segments convenient and the platform more stable on deck in transit. With multiple dives, the deck crew became quite adept at handling the large lander.

The lander dove largely straight down and back as expected. The fall and rise rates were high enough that little time was spent in any current, minimizing lateral offset. The Edgetech comm system provided good slant ranges. It was important to recover the biological samples as soon as possible.



*Figure 3. In a real-life-as-sci-fi image taken from an ROV, the **DEEPSEA CHALLENGER** submersible piloted by Explorer and Filmmaker James Cameron, rendezvous with the lander, DOV MIKE, at 885 m in the New Britain Trench near Papua New Guinea. Photo used with permission, Earthship Productions.*

Conclusion

The **DEEPSEA CHALLENGER** landers demonstrated their capability as robust and reliable payload haulers, test platforms, autonomous robotic camera, sampler, and sensor platforms. Utilization of common components across several vehicle platforms dramatically shortened the development time.

The remaining unmanned lander, along with spares and related surface support gear, was gifted to the Scripps Institution of Oceanography/UCSD. Combined with funding from HSRH Prince Albert II of Monaco, the hardware became the catalyst for the Scripps “Lander Lab,” a common resource for campus researchers and graduate students to access the deepest ocean depths.

Outreach

A hands-on project “Voyager Activity: Build Your Own Deep-Sea Lander,” was created for elementary school students by James Cameron and Kevin Hardy with Scripps Institution. You can download the design at <https://scripps.ucsd.edu/news/voyager-activity-build-your-own-deep-sea-lander>.

TECHNOLOGY OF THE *DEEPSEA CHALLENGE* EXPEDITION

(Part 2 of 3: *DEEPSEA CHALLENGER*)

By: Kevin Hardy, Global Ocean Design LLC;
Bruce Sutphen, Sutphen Marine LLC; and
James Cameron, Earthship Productions LLC

Introduction

Driven by a deep curiosity to explore hidden places, James Cameron's *DEEPSEA CHALLENGE* (DSC) Expedition could have claimed the motto "Vade, et vide," meaning "Go and see." But to go and see the rolling fields of the lands submerged 7 miles underwater was an unimaginably complex effort led by a single, passionate visionary. The challenges were huge and the danger real.

It had been over 50 years since the last humans visited the extreme hyperbaric world of the Mariana Trench.

Only a lack of access, not interest, has kept us away. That changed forever on March 26, 2012. Explorer and Filmmaker James Cameron roamed freely for hours in the Challenger Deep, in a one-man submersible he co-designed with Australian engineer Ron Allum. Cameron vowed to leave the door open behind him as he left the trench floor. Twin unmanned landers, discussed last issue (ONT, June 2014), complemented the human exploration. This second of a three-part series will begin the discussion of the technologies, both new and legacy, used in the making of the manned submersible. Part 3 in next month's issue will complete the outline of the submersible technologies.

Figure 1. *DEEPSEA CHALLENGER* is prepared for launch by two divers during the *DEEPSEA CHALLENGE* Expedition. Photo by Charlie Arneson, used with permission, Earthship LLC.

Science

A number of significant biological and geological findings were made through the expert observations and targeted sampling performed by the DSC vehicles. A number of peer-reviewed scientific publications by respected oceanographic and planetary science institutions, co-authored with James Cameron and other DSC team members, have been published or are in process.

Design and Project Objectives

The **DEEPSEA CHALLENGER** manned submersible was developed for scientific research in the hadal depths. The development, construction and operation were privately funded on an aggressive timeline, requiring the major cost centers be identified upfront. Development speed and cost effectiveness were improved by capitalizing on interchangeable technologies shared across multiple undersea vehicle types (Figure 1).

The size of the submersible was quickly understood to drive both the cost of building the vehicle and its operations. The submersible size determined the size of the surface support ship needed, its availability and associated costs, including crew, fuel, food, deck gear, logistic support, and operational weather limitations. The Pilot Sphere would also require pressure testing, and that had limited choices above a certain size. With all factors weighed, Cameron made the final call that a single occupancy vehicle was the optimum solution.

The resulting as-launched vehicle air weight was ~12.0 metric tonnes (~13.2 imperial tons), within an overall envelope measuring 8 x 6 x 27 ft.

Vehicle Operational Considerations

The vehicle design gave consideration to the full environmental characteristics of the deep dive, including the high delta ambient pressure, wide temperature range of operation, seawater/galvanic corrosion, ambient light, convection-driven ocean currents, change in density, operational launch and retrieval sea state limits, bottom conditions, communications, data transfer, navigation, acoustic field, vehicle hydrodynamics/ride quality, and any potential biological fouling.

In order to create a manned vehicle to dive the Challenger Deep, only 11° above the equator, the vehicle had to accommodate the thermal shock of moving from a hot deck under a blazing tropic sun to a cooler sea surface, then an extended cold soak at 33°F at 6.83 mi below the ocean surface.

Radio frequencies are filtered in the first inches of depth, making it easier to talk to a robot on Mars than a manned submersible in the sea. There are also significant currents in the water column that can dislocate a submersible from its glide path and scramble acoustic signals used to track the submersible's position and communicate with its pilot.

In the round-trip journey into the deepest ocean trench, the ambient pressure changes from 1 bar/14.7 psi at the surface to 1,100bar/16,300 psi at floor of the trench. The submersible crosses the almost 7-mi distance downward in about 120 minutes. It hurtles on the way back up, covering the same distance in only 70 minutes.

Vehicle Performance and Design

It was felt that there was more to be learned from exploring the nooks and crannies of the ocean floor than in the mid-water, so the vehicle was designed to transit quickly through the 7-mi water depth. This was accomplished by the radical notion of limiting the cross-sectional frontal projected area and elongating the height. The sub had the appearance of a canoe on end (Figure 2). On deck, lying horizontal in its support cradle, it looked like a more traditional submarine. But underwater, it is a creature of the sea, diving vertically like a blue whale plumb

the depths or pirouetting on the seafloor like a graceful Siphonophorae.

Buoyancy

The syntactic served the dual purpose of buoyancy and structural support (Figure 3). The personnel sphere, batteries (Figure 4), thrusters — everything — was hung directly off of the structural foam. No syntactic foam currently made for use at hadal depths met the structural and elastic requirements of the manned submersible design. A considerable effort was put into developing and producing a new composite material, later named ISOFloat, made of hollow glass micro-spheres and structural fiber secured in a toughened epoxy matrix. The foam has a specific gravity of 0.7 and experienced half the volume change as the seawater, increasing the vehicle's buoyancy with depth. The rest of the vehicle was fabricated from polyester fiber-reinforced, toughened epoxy laminates with the ISOFloat structural cores where merited.

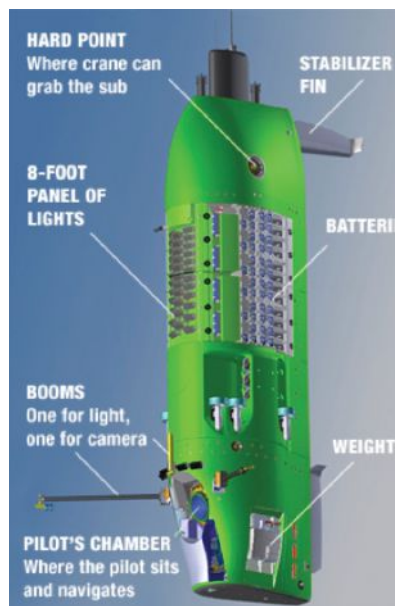


Figure 2. General outboard view of the DEEPSEA CHALLENGER, used with permission, Earthship LLC.



Figure 3. The DSC main spar before painting made of ISOFloat syntactic. Photo by Tim Bulman, used with permission, Earthship LLC.



Figure 4. The PBOF LiPO slots made of ISOFloat syntactic. Photo by Ben Grant, used with permission, Earthship LLC.



Figure 5. DSC stabilizer fin and triplet sub-assembly. Photo by Bruce Sutphen, used with permission, Earthship LLC.

Stability

The initial vehicle geometry had dynamic instability issues as it approached its terminal descent and ascent speeds; however, an integrated Computer Fluid Dynamics (CFD) study and scaled modeling program resolved the issues through tweaks in the volumetric distribution, boundary layer manipulation and passively activated stabilizer fins (Figure 5), which not only constrained the role instability but also induced a small yaw moment constraining the line of flight to a helical path (Figure 6).

The stabilizer fins (aka: Sut-Fins) were fabricated from ISOFloat structural syntactic foam with a 7000-series aluminum spar and UHMWPE (ultra-high molecular weight polyethylene) tiptlets. By using these materials, the fins had a defined near-neutral buoyant moment allowing them to actuate via fluid flow as the vehicle ascended or descended.

Fairings

Submersible fairings were fabricated from a near-neutrally buoyant fiber-reinforced laminate utilizing a toughened epoxy matrix. A vacuum-infusion process lowered the probability of implosive voids.

The polycarbonate mast housed the vehicle's surface communication equipment (e.g., VHF, Iridium Phone and LED strobe lights).

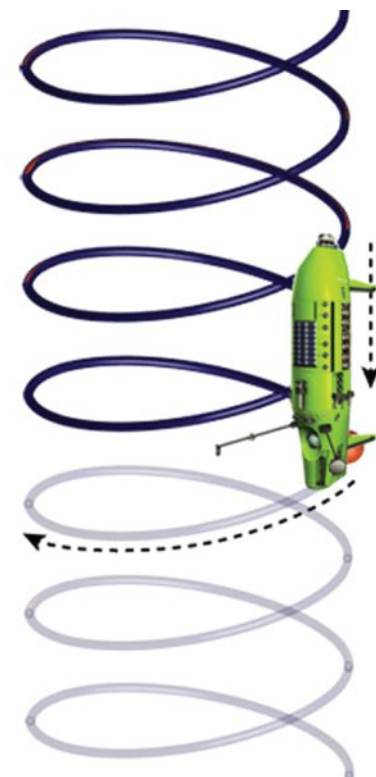


Figure 6. Passively activated stabilizer fins induce a small yaw moment constraining the line of flight to a helical path. Image by Nico Danan, Planet OS/MarinExplore, used with permission, Earthship LLC.

Power

The stored Lithium Ion battery power of the DSC could be configured to be as high as 96 KWh, though the storage used on the 12 manned dives was between 76 and 84 KWh. These came from a maximum of 96 PBOF LiPo battery packs, divided into three busses. The sub could operate off of a single buss in emergency mode. All power and control signals were passed through the pressure hull via four discrete penetrators in the penetrator plate at the upper pole of the pressure hull.

Controls

The main controls of the vehicle were shared between a joystick control and two graphic user interfaces (GUIs) incorporating two standard touch screen tablet displays.

Benthic Translation and Maneuverability

There were 12 PBOF thrusters on the vehicle: 6 vertical and 6 horizontal. These were used for maneuvering on the seafloor and up slopes, 3 kts horizontal and 3.5 kts vertical (Figure 7).



Figure 7. The DSC on deck with vertical thrusters and LiPO battery pods visible. Photo by Tim Bulman, used with permission, Earthship LLC.

Next month

In Part 3, we will examine the **DEEPSEA CHALLENGER's** ballast and trim systems, pressure hull and acrylic viewport design, life support systems, lower pod design, subsurface communications, pilot training, and emergency procedures and conclude with a look into the **DEEPSEA CHALLENGER's** effect on future ultra-deep exploration.

Watch for the movie **DEEPSEA CHALLENGE** 3D in theaters August 8, 2014.

TECHNOLOGY OF THE *DEEPSEA CHALLENGER* EXPEDITION

(Part 3 of 3: *DEEPSEA CHALLENGER*)

By: Kevin Hardy, Global Ocean Design LLC;
Bruce Sutphen, Sutphen Marine LLC; and
James Cameron, Earthship Productions LLC

INTRODUCTION

This required a gut check of epic proportions. “When you gaze long into an abyss, the abyss also gazes into you,” understood German philosopher Friedrich Nietzsche in 1886. With that, Explorer and Filmmaker James Cameron radioed the command to release the surface flotation and began his journey downward solo inside *DEEPSEA CHALLENGER (DSC)* to take on the towering odds against surviving the most extreme hyperbaric environment on Planet Earth: the western Pacific Ocean’s Mariana Trench (Figure 2).

It is a place where animals are accustomed to seeing bioluminescence not sunlight, an evolutionary result of 3.8 billion years of total darkness in that strange Other Earth far below the photic zone. Here is where ambient pressure could have the units, “tsi,” as in “tons per square inch.”

This is the final chapter in a three-part series that describes the new and legacy technology that defined the operational success of the *DEEPSEA CHALLENGE* Expedition.

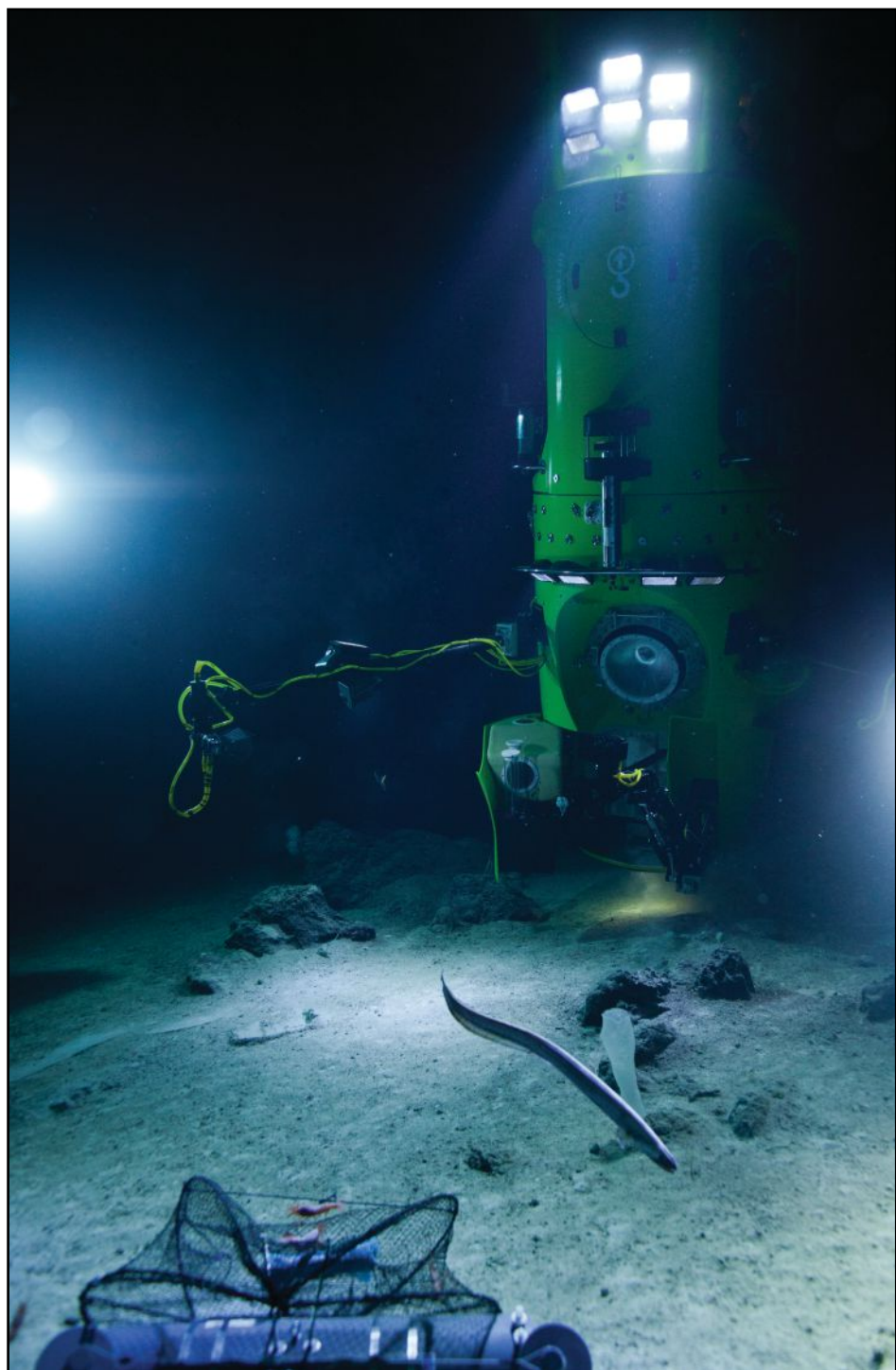


Figure 1. Co-designer Ron Allum pilots the *DEEPSEA CHALLENGER* across the rocky bottom at 850m near Falalop Island, Ulithi Atoll, Caroline Islands, FSM. Visible is the 2m camera boom, pan-tilt and stereo mini-cam, the manipulator, and conical viewport of the pilot sphere. The science bay door below the pilot sphere is seen open. Photo by Earthship LLC.

Ballast and Trim

Unlike the Trieste, the **DEEPSEA CHALLENGER** does not require descent weights to get to the trench floor. The buoyancy of the **DSC** increased with depth because its net volume changed less with hydrostatic compression than seawater. Therefore, the vehicle is ballasted on the ship to be neutrally buoyant at the target depth of the given dive.

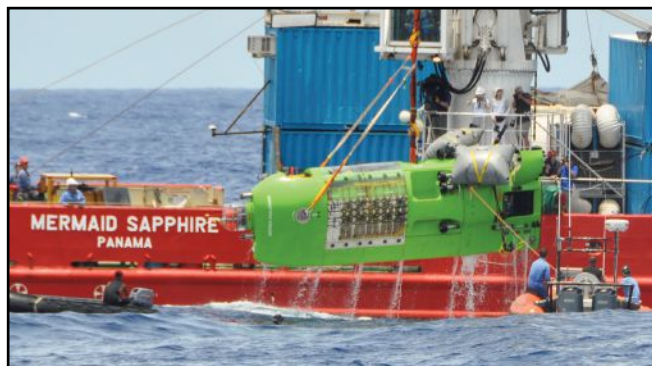


Figure 2. The submersible **DEEPSEA CHALLENGER**, with Explorer James Cameron inside, is lifted aboard the M/V *Mermaid Sapphire* following its deep dive into the East Pond of the Challenger Deep in the Mariana Trench. Photo by Chris Symons. Used with permission, Earthship LLC.

An adjustable-trim system using steel-shot held by an electromagnet is incorporated to allow the vehicle to maintain neutral buoyancy when taking on samples or exploring up a slope or a rising feature.

The ascent weight system provides the vehicle with a safe return to the surface (Figure 3). There are five levels of redundancy on three separate circuits.



Figure 3. The ascent weights with multiple release means. Photo by Chris Symons. Used with Permission, Earthship LLC.

The primary method of dropping the weights is a pilot-operated switch that cut the power to the electromagnetic coils holding the lever arms supporting the weights. The circuit can also be opened by an acoustic command from the surface in the event the pilot is incapacitated. If there is a power failure or the

vehicle runs out of battery power, the electromagnetic coils will likewise de-energize and drop the weights. The second circuit uses a Frangibolt, similar to those used on DSV *Alvin* to drop its manipulator in case of emergency. The third circuit uses a “GTR,” or galvanic time release, a bimetallic fuse that corrodes at known rate (e.g., 18, 24, 36 hrs). Three are used in parallel to provide the proper strength at the preferred time interval. The rate of galvanic corrosion is based on the ratio and mass of the anodic and cathodic materials, plus salinity and temperature of the ambient seawater. A significant effort went into calibrating these fuses to avoid a premature release that would unintentionally abort the dive.

Pressure Hull

The 43-in. diameter x 2.5-in. thick pressure hull is fabricated from high tensile steel EN26, invented in the 1940s for use in large Howitzer-type gun barrels. It is an alloy similar to that used on DSV *Trieste*’s pressure hull in its 1960 deep dive (Figure 4).



Figure 4. DSC pressure hull with interior view of carbon fiber plastic inner shell. Photo by Ron Allum. Used with Permission, Earthship LLC.



Figure 5. Multi-part, carbon-reinforced plastic inner shell of the pilot sphere. Photo by Liam Mahoney, LSM Advanced Composites. Used with Permission, Earthship LLC.

All the equipment populating the pilot sphere is mounted to a high-temperature cure phenolic resin “whiffle ball” made by LSM Advanced Composites (Figure 5). This approach mitigated the need for any hard point fastenings to the pressure hull, while still allowing a dense packing of the interior space. Additionally, this shell-within-a-shell provides thermal isolation for the pilot and collection of condensation away from electronic circuits.

Acrylic Viewport

The hatch, situated at the lower pole, incorporates a custom-designed conic acrylic viewport with a refractive index similar to seawater (Figure 6). The interior curvature of the viewport corrects for the 30% magnification that occurs with the change in refractive index from water-to-air through a flat plate viewport. The viewport was used for either pilot viewing or high-definition video.

Lights and Cameras

A 7-ft tall bank of 21 high-efficiency PBOF LED floodlights, affectionately called “light bricks,” are mounted to the face of the sub above the pilot sphere. Each light brick produces 3,000 lumens of white light. Another five light bricks were placed at strategic points on the sub. Above the 21 light bricks are two “Ty” lights. These unique PBOF LED lamps each produce 42,000 lumens in a spot pattern. Together, these provide immense light in the clear water of the deep ocean, easily illuminating up to 100 ft ahead of the sub. The lights can be turned on and off in banks by the pilot to vary the intensity for up-close imaging or wide-angle distance shots.

A 3-D HD CPG video pair is attached with a pan-and-tilt to an external 6-ft boom with 200-degree slough providing additional spatial awareness to the pilot. On the opposite side of the

vehicle, a similar, but shorter boom is outfitted with a third “Ty” light, the 42,000 lumen PBOF LED spotlight.



Figure 6. The DSC's conic acrylic viewport. Photo by Bruce Sutphen. Used with Permission, Earthship LLC.

Inside the sphere, the pilot can attach a Red Epic, an IMAX-quality 5K digital camera, to the interior of the viewport. The pilot then views images on an interior video display. A small video camera pair inside the sub captures 3-D images of the pilot.

Life Support

The life support system inside the **DEEPSEA CHALLENGER** is a dual closed-circuit rebreather system designed and developed by Ambient Pressure Diving (APD) working with John Garvin, life support specialist for Acheron. The system consists of a primary rebreather that feeds the cabin and a secondary “Bail Out reBreather (BOB) that is “closed loop” and used only in an emergency. The primary system provides over 100 hrs of life support under normal operating conditions. The back-up system utilizes the most current closed circuit rebreather technology to provide the pilot with a fully redundant system in case of an emergency. A small hand-held atmospheric analyzer, the Geotech G100, monitors the cabin's carbon dioxide level as a back-up to the APD system.

Lower Pod

The lower pod is a substantial fiber-reinforced toughened epoxy structure that fits over and around the pilot sphere on the



Figure 7. The lower pod during construction. Photo by Bruce Sutphen. Used with Permission, Earthship LLC.

main vehicle (Figure 7). In addition to housing the hydraulics, compensators, robotics, science payloads, an adjustable trim, and ascent weight systems, it also protects the pilot sphere by absorbing an impact with the seafloor by flowering the components away from the sphere and redirecting the remaining load into the structural syntactic beam. While robust, the lower pod maintains the graceful lines of the sub's hydrodynamic body.

Other design elements

There is a design mandate that every implodable volume on the manned vehicle be filled with Fluorinert, a 3M product used in transformers. The crystal-clear, high-dielectric fluid has a specific gravity of 1.9 that has to be considered in calculating buoyancy and trim. The housings in question include the external MetOcean strobes and RDF beacons and the Iridium phones, packaged in a 10-in. diameter Nautilus-Marine Vitrovex glass spherical housing.

Subsurface Communications

The **DSC** uses an L3 Nautronix long-range acoustic modem to transmit and receive both voice and data communications. It can also calculate total distance (range) between modems. The L3 was initially envisioned to provide two-way data and communication between the triad of vehicles—the **DEEPSEA CHALLENGER** submersible, the M/V Mermaid Sapphire, and the twin unmanned Landers—and substantially achieved that goal.

The L3 Nautronix system uses matched acoustic modems that operate between 8 and 12 KHz and can transmit voice further than 15 km. This had been tested at horizontal distances, but never to depths of 11 km. Thermoclines, haloclines, varying densities, and surface noise all affect the performance of the system. As the project progressed to deeper depths, the methods of operating the system changed empirically to improve the odds of success.

The transmitted source level is attenuated significantly through 13 to 15 km of slant range; therefore, the L3 Nautronix was designed with a very sensitive receiver. In the field, this sensitivity makes background noise the largest problem, mainly that generated by ship's propulsion and machinery and picked up by the topside transceiver hydrophone. Eventually, the entire topside transceiver system was placed in a RHIB (Rigid Hull Inflatable Boat) boat with its dunking transducer suspended on a long cable, increasing the distance from the mother ship's noise to clearly resolve the attenuated signal from **DEEPSEA CHALLENGER**.

The control system of **DEEPSEA CHALLENGER** automatically uses the data modem feature to transmit measured depth, O₂, and CO₂ levels inside the hull, battery voltages, and other critical information. For this mode, a PC running a small application was connected to the L3 acoustic modem.

The submersible pilot and shipboard communication team can also communicate using text messages.

Pilot Training

Using the same male tool for fabricating the pressure hull, two additional pilot spheres were made using 5/8-in. carbon steel. The first was used for the pilot sphere ergonomic and general arrangement/equipment layout. It was then integrated into a refrigerated simulation chamber for conducting pilot and emergency training with all of the systems and components that are in the actual **DSC** vehicle's pilot sphere. The second sphere was not used.

Emergency Procedures

Provision is made to jettison the entire ascent weight system, and the adjustable ballast system on the science door in the event of entanglement. In case of fire and noxious gases, the pilot has a separate closed-circuit emergency breathing system with a full face mask as described above. Provision is made for pilot egress at the surface with the submarine still in the water.

Future

The **DEEPSEA CHALLENGER** submersible was gifted to Woods Hole Oceanographic Institution where it will be conserved and studied to identify innovations that can be harvested and applied to future vehicles of all classes. For further information contact Anthony Tarantino at atarantino@whoi.edu.

More information on the submersible and landers may be found online at <http://deepseachallenge.com> and <http://www.whoi.edu/main/deepseachallenge>.

Watch for the movie **DEEPSEA CHALLENGE** 3D in theaters on August 8, 2014.