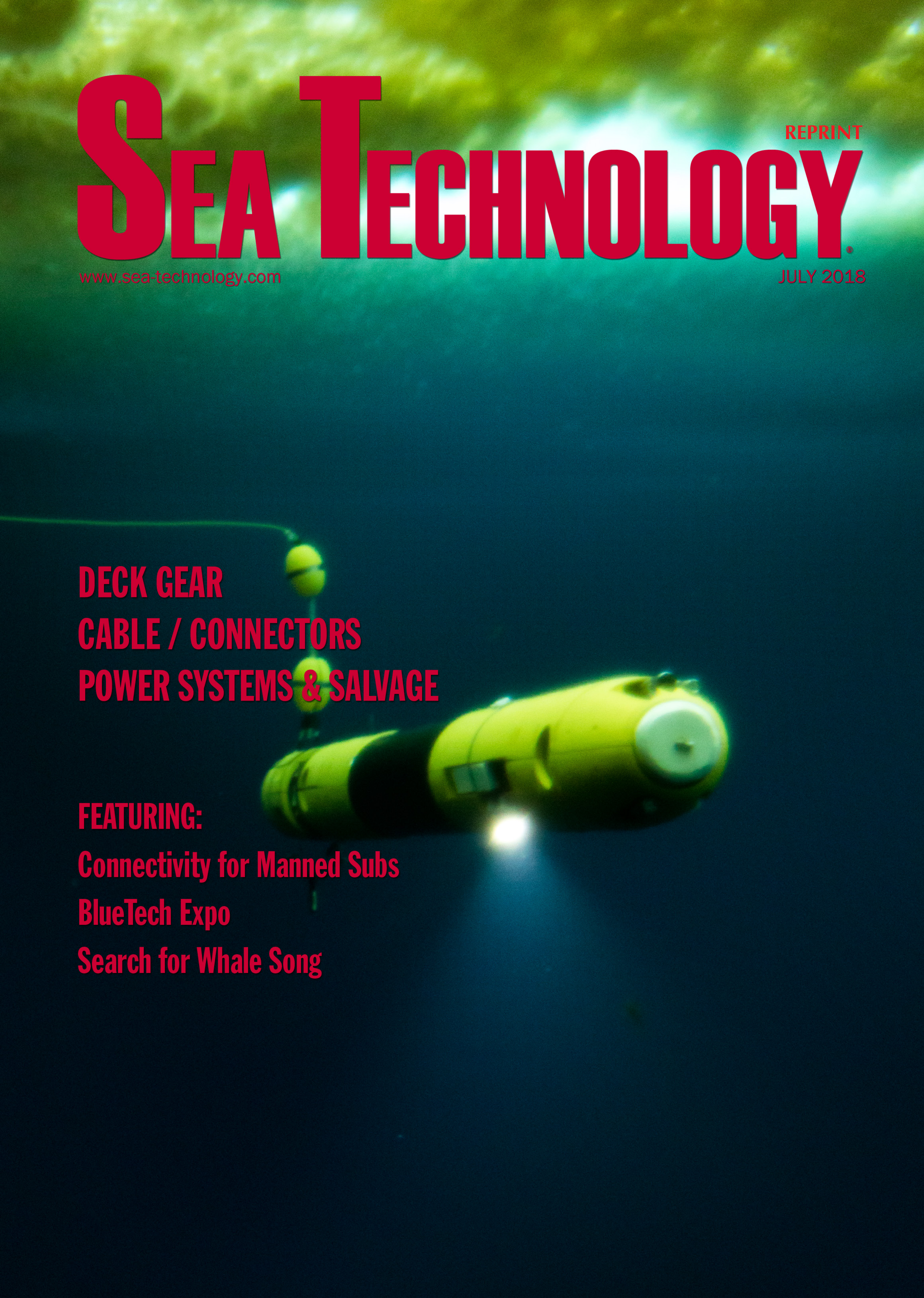

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Custom Penetrators, Cable Assemblies

Bespoke Components for DeepFlight Super Falcon 3S Personal Sub

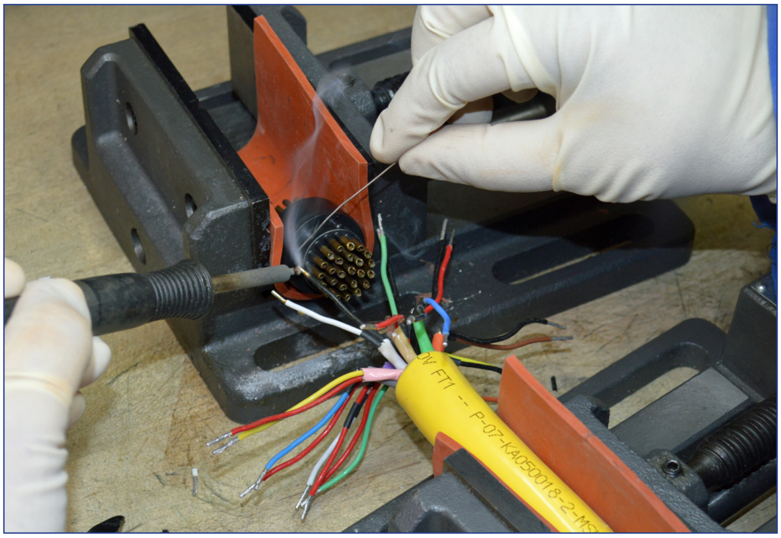
By Amy Brown

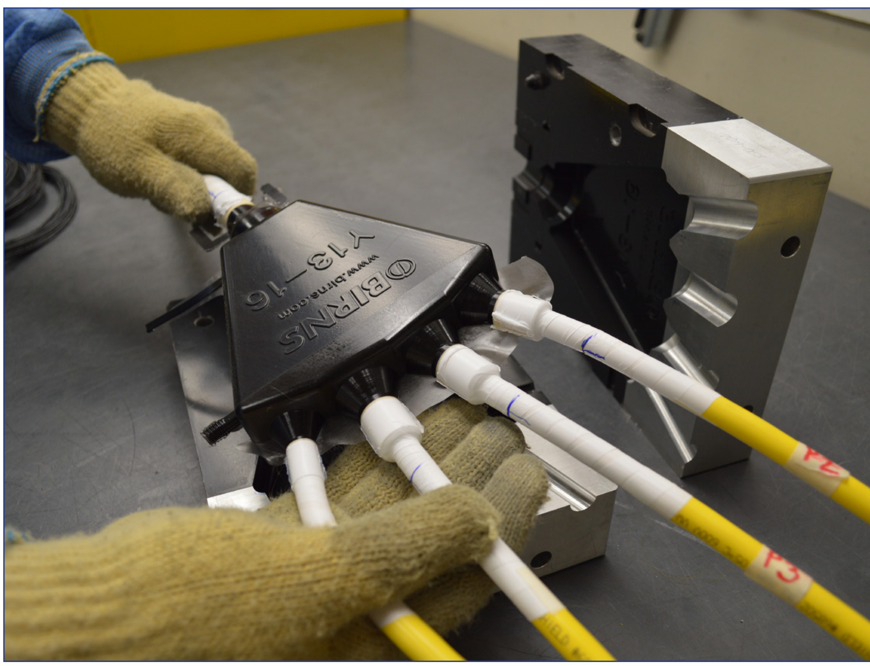
Providing connectivity for today's advanced manned submersibles is both an art and a science. Engineers can now develop bespoke solutions that deliver high-performance characteristics, fit into highly specific dimensions, and conform to the form, fit and function of these vehicles using out-of-the-box approaches.

A recent example of such customization came when DeepFlight, from Point Richmond, California, was designing a new manned submersible, the DeepFlight Super Falcon 3S, a state-of-the-art craft that was introduced to the industry in late 2017 and officially launched at Four Seasons Resort Maldives at Landaa Giraavaru in May 2018.

The Super Falcon 3S is DeepFlight's first vehicle that can carry up to three occupants (one pilot, two passengers) and was specifically designed for ocean tourism at resorts and other locations. The submersible is 8 by 3.3 by 1.4 m (26.2 by 10.8 by 4.6 ft.) and weighs 3,400 kg (7,500 lb.). Its endurance/autonomy is up to 8 hr., and the vehicle is rated to 100 m (330 ft.). The sub required the design of new custom, high-density, ABS-certified penetrators and cable assemblies from BIRNS Inc. of Oxnard, California, for a wide range of functions on the vehicle.

For years, DeepFlight has been developing and marketing innovative new electric





(Top) Cable conductors are soldered to inboard and outboard sides of a P25 insert by a J-STD-001 Class 3 and WHMA-A-620-A Class 3 certified technician. (Bottom) A complex junction is removed from its mold after the polyurethane solidifies.

(Top to bottom) EH-7 cable is inspected before moving on to final IR testing. Final continuity testing is carried out on each assembly, to ensure that all circuits are operational. Two EH-3 penetrator assemblies transmit primary power from the port battery to the pressure hull for inboard electronics.

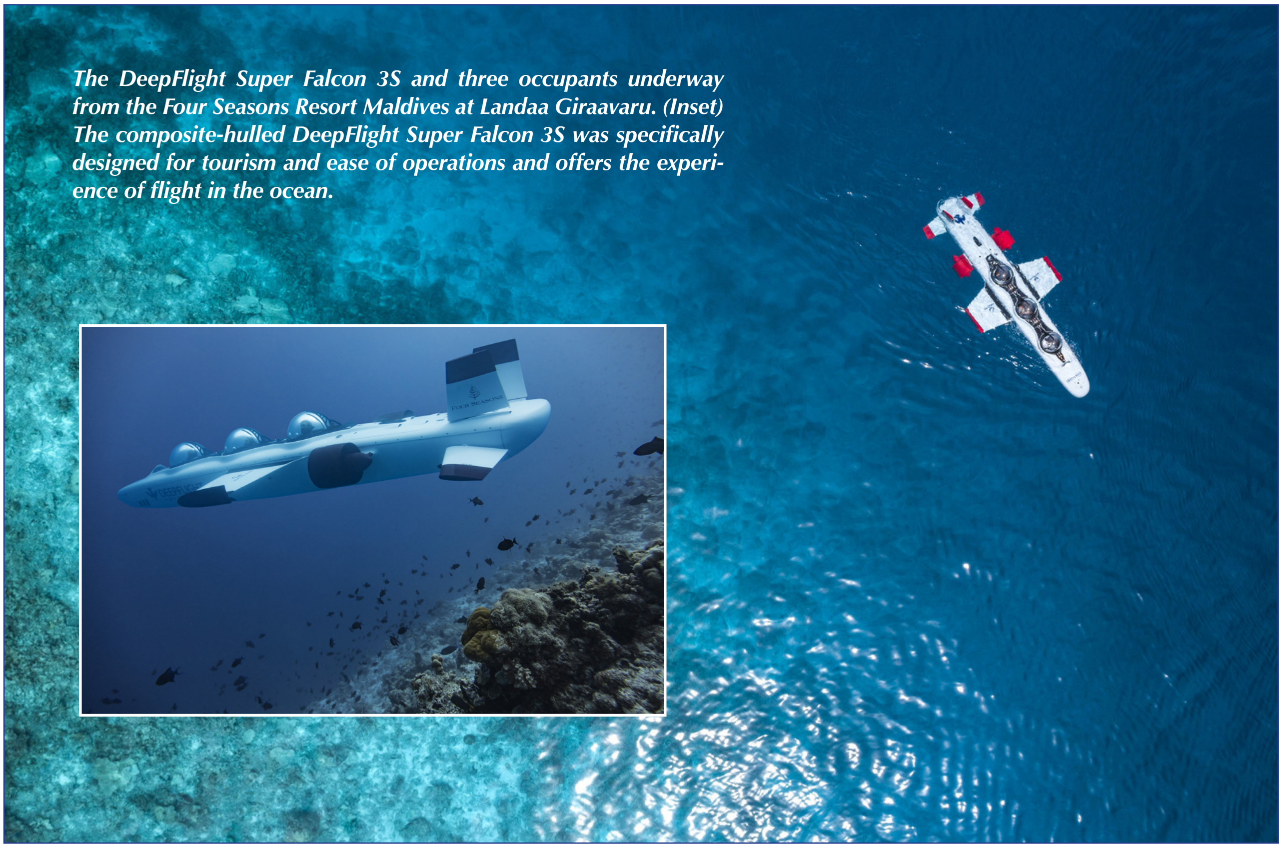
submarines that are lightweight, intuitive to operate and provide a unique, three-dimensional underwater flight experience, with a simple cockpit enabling operators to safely dive with minimal training. Most personal submarines are based on designs for research-focused tasks, making them heavy and complex to operate, but the DeepFlight Super Falcon 3S was specifically designed for tourism and ease of operations. The sub is also the first composite-hulled submarine to be certified by Lloyd's Register. The use of composites allows the company to build high-strength, low-weight craft that are the most lightweight submarines on the market. DeepFlight is committed to being environmentally friendly, so its submarines do not have skids (and, therefore, cannot land on reefs or the seafloor), have low acoustic emissions and are low voltage, meaning they are safe to operate around swimmers and marine life.

The custom penetrator assemblies are robust systems that safely and reliably transmit electrical power or signal through a pressure boundary without compromising its integrity. One of the many advantages of penetrators is that they decrease the complexity of electrical systems and reduce dependence on operator skill, requiring minimal maintenance, and are suitable for long-term deployment in harsh marine environments. To that end, the BIRNS custom penetrators featured polyurethane overmolding on the outboard side, with robust inserts and O-rings, and rigorous ABS-compliant testing protocols.

Assembly Functions

The DeepFlight Super Falcon 3S required a total of 16 penetrator assemblies for functions on board ranging from navigation and communications to battery power. The penetrators had 1.5-in. hex flats and anodized 1-in. aluminum shells, versus the standard stainless, as they were to be mounted to an aluminum bulkhead and DeepFlight needed the materials in contact to be the same to avoid galvanic corrosion. DeepFlight's hull and pressure bottle penetrations for the project were already designed but did not match any standard penetrator sizes, so BIRNS adapted a BIRNS Millennium 3P connector shell with 1-20 UNEF threads to fit the system and developed custom 25 pin inserts for the assemblies. These custom penetrators had cables using 20 to 16 AWG conductors and conductor counts from two to 24 with maximum voltage per wire of 44 V, maximum current of 4 A continuous per conductor and maximum power required of 250 W, and came in a range of cable design configurations.

For navigation and other relevant functionality on the sub, BIRNS supplied two EH-2 assemblies, each with a single P25 penetrator, with a 27-in. Y cable leading to four wetmate five-pin connectors. This cable harness connected the depth transducer, altimeter, Tritech MicronNav tracker and Micron data modem to the pressure



The DeepFlight Super Falcon 3S and three occupants underway from the Four Seasons Resort Maldives at Landaa Giraavaru. (Inset) The composite-hulled DeepFlight Super Falcon 3S was specifically designed for tourism and ease of operations and offers the experience of flight in the ocean.

hull. Two EH-7 single penetrator Y cable assemblies that led to four wetmate connectors on a 16-in.-length cable formed a cable harness to connect the elevator and rudder control signals from the pressure hull to the control surface actuators. A set of two EH-8 single penetrators with Y cables formed a cable harness, which connected the thruster control signals from the pressure hull to the vehicle's main thrusters.

DeepFlight Super Falcon 3S's communication system allows the pilot to verbally communicate with the surface support craft through a cable harness that connects the UQC underwater telephone signals from the pressure hull to the UQC transducer, which then broadcast and receive underwater communications. This is supported via two EH-1 assemblies, which each feature a single penetrator attached to a DeepFlight-furnished transducer and a 10-in. external cable.

The system's lithium-iron phosphate battery connectivity is sustained with two EH-3 double-ended penetrators with 7-in. cables that connect the primary power for electronics inside the pressure hull from the port battery to the pressure hull. Two EH-17 double-penetrator, double-ended assemblies with 8-in. cables connect the input power from the charging port to the port battery. Two additional EH-18 double-penetrator, double-ended assemblies each have 8-in. cable lengths and connect the input power from the starboard charging port to the starboard battery. General backup power is connected with two EH-4 double-ended penetrator assemblies with 7-in. cables, forming a cable harness that connects the backup power for electronics inside the pressure hull from the starboard battery to the pressure hull.

Penetrator Development

The P25 inserts were carefully constructed, with 25 gold-plated copper-alloy contacts for strong electrical performance and were insulated with glass-reinforced epoxy (GRE) for advanced dielectric characteristics. They were cured in a custom 40-ton hydraulic transfer press that allows computer-controlled precision for injecting GRE and tested per BIRNS ABS-approved Test Procedure ETP-6510-101 (Electrical Penetrators-Submersible and Non Submersible Pressure Vessels for Human Occupancy). The initial testing sequence requires the inboard sides of the inserts to be subjected to helium pressure (1,000 psi) testing. After the successful helium testing phase, with no evidence of leaks, cracking, extrusion or other signs of failure, the cable conductors were soldered to both inboard and outboard sides of the insert by J-STD-001 Class 3 and WHMA-A-620-A Class 3 certified technicians.

The insert assemblies then underwent continuity and insulation resistance (IR) testing procedures. The IR testing requires that all 25 conductors be individually tested at a test voltage of 500 +/-50 V DC (707 V AC) for interference between one another and the penetrator shell—a minimum reading of 200 MΩ is required to pass. Once that test was successful, the shell was attached to the penetrator.

The assemblies were then overmolded in BIRNS's NAVSEA S9320-AM-PRO-020 certified molding facility (certified for fabrication of U.S. Navy submarine outboard cables). The overmolding process began with wire terminations being encapsulated with epoxy adhesive, and polyurethane subsequently injected into mold cavi-

"The sub is in frequent use at its first resort in the Maldives, introducing travelers to unique new views and ways to experience flight in the ocean."

ties to harden and cool. This sealed the penetrator/cable interface, provided strain relief, precluded discontinuous bending and added elastomeric mechanical strength to the junction. Many of the penetrator assemblies for the project also had complex junction molds, splitting into two segments (Y molds) or up to four segments. These challenging overmolds require particular care during the process; the technician must ensure that there is sufficient slack for the wires in the mold cavity, to avoid sealing them in with too much tension, while keeping these high-density wires centered in the mold and not allowing any wires to touch the mold cavity. If that were to happen, it could create a direct leak path into the assembly and could allow water ingress, which might cause it to short.

Each penetrator assembly was then tested for continuity and IR once again, prior to formal ABS witness acceptance testing. Next, the complete assembly was subjected to a dielectric withstanding voltage (Hi-Pot) Test—where each conductor is tested at 1,480 V DC for 60 sec., before automatically moving to the subsequent channel, with a reading below 29 μA required to pass. Then, a six-cycle saltwater hydrostatic pressure test was performed, in which the outboard side of the penetrator is held to pressure of 1,000 psi. During the sixth cycle, while under pressure, the entire penetrator was given another extensive IR test at 500 V DC for the 25 conductors, testing between each conductor and all other conductors, and between each conductor and the test chamber. The penetrators were then cleaned with a mixture of soap and water. The entire ETP-6510-101 testing procedure was overseen by an on-site ABS inspector, who verified the integrity and accuracy of all tests performed. All relevant documents, calibration certificates, drawings, procedures and data capture points pertaining to testing were reviewed and manually approved by the ABS inspector underwriting the results of the testing. This on-site inspection was conducted once for the insert helium leak testing and once during hydrostatic pressure testing and electrical testing after termination and polyurethane overmolding.

When the completed assemblies were shipped to DeepFlight's team in California, they were inspected and tested by applying vacuum pressure to all completed assemblies to verify seal integrity before installation on the sub. The testing of the complete system continued during sea trials before heading to the team's submarine base in the Maldives. The penetrator assemblies continue to perform well since the successful launch of the DeepFlight Super Falcon 3S line, and the sub is in frequent use at its first resort in the Maldives, introducing travelers to unique new views and ways to experience flight in the ocean.

Acknowledgments

The author would like to thank the team at DeepFlight for providing valuable data and images for the development of this article. **ST**

Amy Brown is the chief marketing officer for BIRNS Inc. and is responsible for developing and managing a comprehensive set of strategic marketing and communications programs.