UNDERWATER ROBOTICS

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UNDERWATER R·O·B·O·T·I·C·S

THE MAGAZINE OF THE UNDER ROBOTICS GROUP OF THE SOCIETY FOR UNDERWATER TECHNOLOGY

Saipem has been completing tests on its Flatfish AUV

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BAYONET ON THE CHARGE

Marine robotics technology specialist Greensea Systems has announced the launch of Bayonet Ocean Vehicles, a newly company created to develop, manufacture and distribute the line of amphibious robots it recently acquired from C-2 Innovations Inc.

The deal includes the acquisition of the IP and inventory of C-2 Innovations' crawling robot product line. The robots have been rebranded and are being launched to market as the Bayonet 150, Bayonet 250 and the Bayonet 350 vehicles.

BAYONET

Bayonet Ocean Vehicles say that the seafloor crawling robot systems they have developed fill a void in autonomous ocean systems as they can work in the surf zone and carry larger sensor payloads on the seafloor.

Bayonet Ocean Vehicles has the resources to scale and advance the product line. Strategically, the crawler product line complements Greensea's autonomy portfolio for defence applications. The company enjoys the benefit of the Greensea company portfolio and with that backing, the larger-scale commercialisation of the seafloor crawling robot product line.

The Bayonet product line will feature Greensea's fully open architecture software platform, OPENSEA, which includes precision navigation, payload integration, autonomy, and over-the-horizon command and control.

Bayonet has already secured several defence contracts as the platforms are being adopted into sensor placement and Explosive Ordnance Disposal missions. The company will launch a commercial variant of the platform in summer 2022 focused on hydrographic survey, wind farm survey and maintenance, as well as coastal dredging support.

Deployable from land or water independent of weather, the range of Bayonet crawlers have been designed to transit along the ocean floor as well as on land, making them the only robotic platform in the world capable of working between 40fsw and the dunes on the beach as well as in the deep ocean.

Their application includes amphibious operations and littoral warfare such as mine detection and clearance, seafloor, beach zone and river surveys, environmental, monitoring and wharf inspections.

The three vehicle sizes (Bayonet

Bayonet Ocean Vehicles

150, 250 and 350), provides the ability to scale the vehicle size, configuration and power to meet the demands of the payload, operation duration and environment.

All three Bayonet vehicle sizes are also available in a HD configuration which increases the torque and power of the vehicle to meet more demanding conditions and or heavier payloads.

BAYONET 150
Two person portable vehicle for non heavy weather, small boat deployment and smaller payloads. It measures 33ins by 20ins by 10ins and has a standard Open Deck Space of 24 by 6 ins and a capacity of 350lbs. It weighs 125 lbs has a duration of 22 miles on land or 10 miles in water.

BAYONET 250
This larger 48 by 52 by 14 ins vehicle allows for use in heavier weather and larger payloads. It has a deck capacity of 850 lbs and a 800 lbs drawbar pull. It weighs 250 lbs

BAYONET 350
The largest vehicle capable of handling the harshest conditions and largest payloads. It measures 5 by 6 by 1 ft and weighs 125 lbs. It can move at a speed of 1.8km/hr and has a deck capacity of 1102 lbs (500kg)

GLIDER SERVICE CENTRE

Teledyne Marine and the National Oceanography Centre (NOC) has launched the new NOC Glider Service Centre; a joint partnership created for the servicing, support and repair of Teledyne Slocum Gliders from across Europe.

This new partnership will benefit its European glider customers, avoiding the time and expense of shipping systems back to the US for service and upgrades.

The NOC Glider Service Centre will work with Slocum glider owners across Europe, initially servicing payload bays including sensor calibrations and pressure testing.

Services will gradually increase to offer subassembly servicing (shallow and deep water pumps) and will eventually move into complete vehicle servicing, upgrades and repairs. Training, piloting, spares and sales are also in the pipeline.

REMUS SERVICE CENTRE

HII 's Australian sales partner, BlueZone Group, in now an authorised REMUS autonomous underwater vehicle (AUV) service centre

HII recently announced the selection of its Australian sales partner, BlueZone Group as an authorised REMUS autonomous underwater vehicle (AUV) service centre. The Newcastle-based company will provide local support to REMUS AUVs for the Royal Australian Navy and other regional customers.

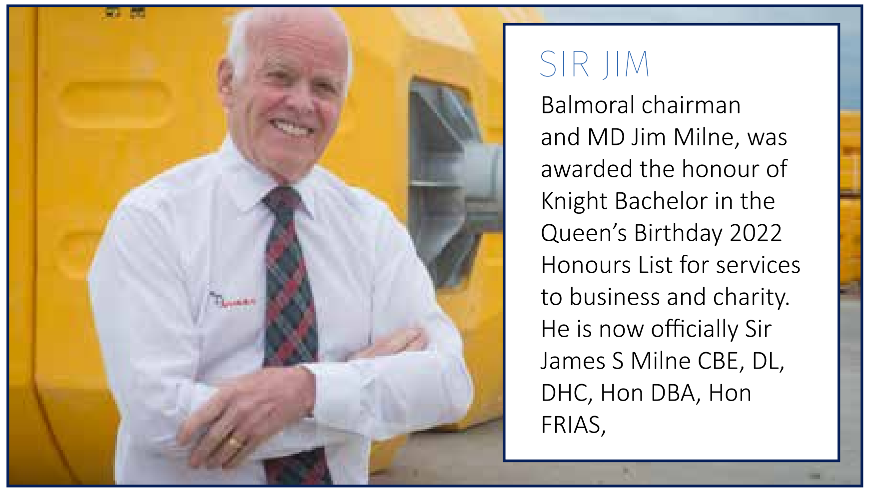
As a REMUS service centre, BlueZone can perform level three depot support, maintenance, and repair of REMUS AUVs at its facility. Services will include regularly scheduled maintenance, repair of modules and components, upgrades, battery conditioning and replacement, and sensor integration. BlueZone will also be equipped to fully test systems and train end users on their operations.

REMUS first entered the Australia market in 2007 when the Royal Australian Navy acquired REMUS 600. HII has since deployed hundreds of AUVs across the globe.

Teledyne Reson F30 and T51 Demonstration in Sydney Harbour Announcements by Rachel Picasso Comparison of sonar performance on multiple targets

● In April 2022 BlueZone Group hosted Teledyne Marine representatives for a demonstration conducted in Sydney Harbour showing obstacle avoidance, target detection, and bathymetric capabilities of the RESON F30 and T51 Multibeam Systems.

Multiple targets, including mine-like objects, were deployed by customers which were all successfully detected by both the F30 and T51. Targets including shipwrecks were also successfully surveyed with data processed using Teledyne PDS, a multipurpose software platform that supports a wide range of tasks within Hydrography, Dredge Guidance, Construction Support and Port Entrance Monitoring.



SIR JIM

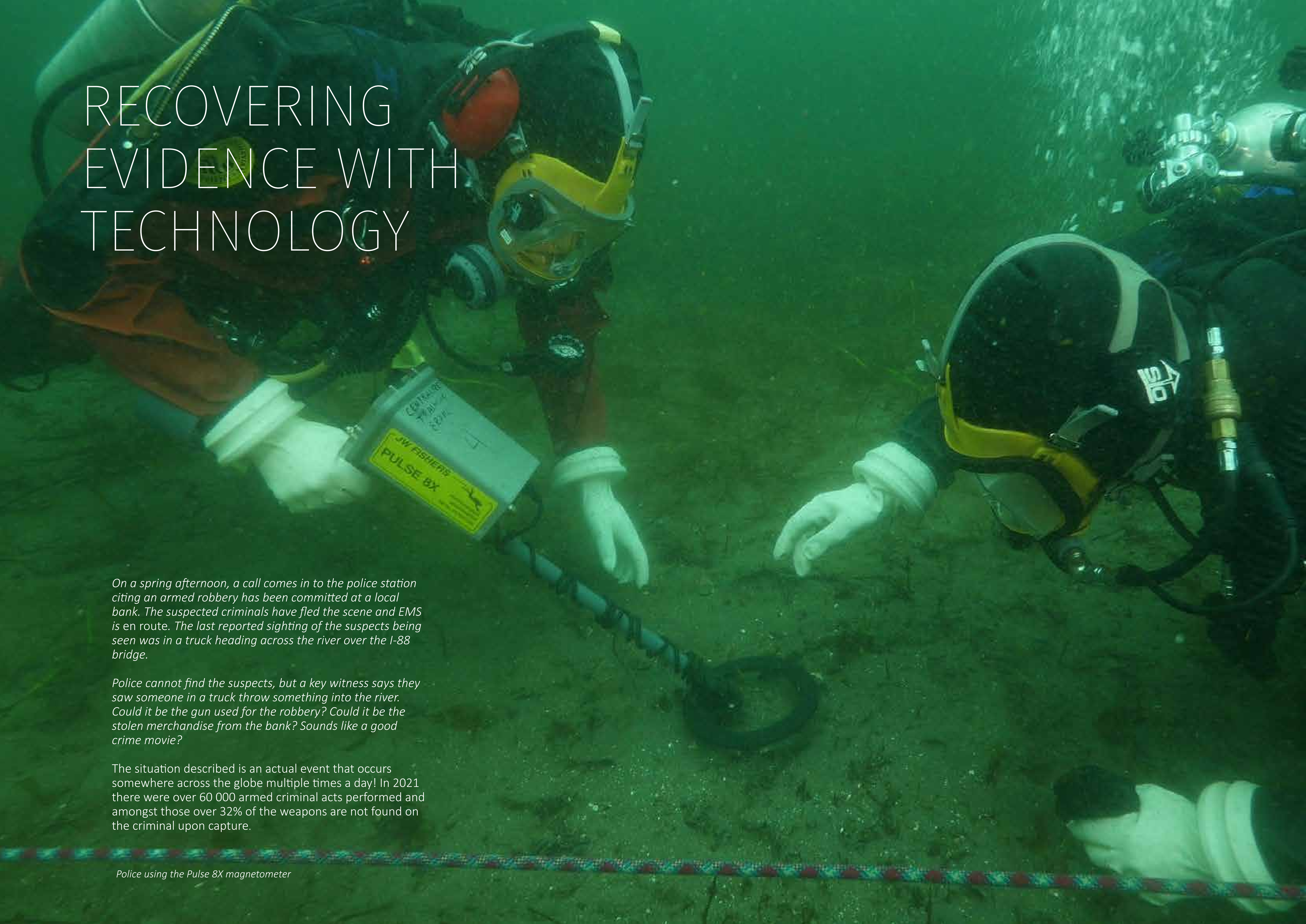
Balmoral chairman and MD Jim Milne, was awarded the honour of Knight Bachelor in the Queen's Birthday 2022 Honours List for services to business and charity. He is now officially Sir James S Milne CBE, DL, DHC, Hon DBA, Hon FRIAS,

RECOVERING EVIDENCE WITH TECHNOLOGY

On a spring afternoon, a call comes in to the police station citing an armed robbery has been committed at a local bank. The suspected criminals have fled the scene and EMS is en route. *The last reported sighting of the suspects being seen was in a truck heading across the river over the I-88 bridge.*

Police cannot find the suspects, but a key witness says they saw someone in a truck throw something into the river. Could it be the gun used for the robbery? Could it be the stolen merchandise from the bank? Sounds like a good crime movie?

The situation described is an actual event that occurs somewhere across the globe multiple times a day! In 2021 there were over 60 000 armed criminal acts performed and amongst those over 32% of the weapons are not found on the criminal upon capture.



Police using the Pulse 8X magnetometer

A metal detector serves as an invaluable tool in the search for and recovery of missing, metallic evidence. This evidence can range from shotguns and handguns to ammunition and knives.

As technology advances it's not only firearms that are now being used in crimes. In today's modern age, cell phones are a massive crime-related item actively being sought by investigators on scene. Phones contain multiple sources of information that could lead investigators down the right path of case solving, becoming essential to recover.

The Pulse 8X is the perfect tool to help locate that missing evidence. JW Fishers has been a leading producer of metal detectors for police, sheriff departments, government agencies and dive rescue teams.

Fishers says that the Pulse 8X is the 'go to metal detector for those that want a commercial detector that can handle the rigours of police and underwater searching on a constant basis with a detection area unsurpassed in the industry.

The Pulse 8X was rated the #1 underwater metal detector rated by The Department of US Homeland Security.

In 2014 the Orange County, California, Sheriff's Department (OCSD) established a metal detector search team. The agency made important considerations regarding equipment selection and the development of training for metal detector use – one detector being the Pulse 8X.

According to the SRRU: "A key feature to consider for ground-search metal detectors is the availability of different sized search coils. One size coil does not fit all.

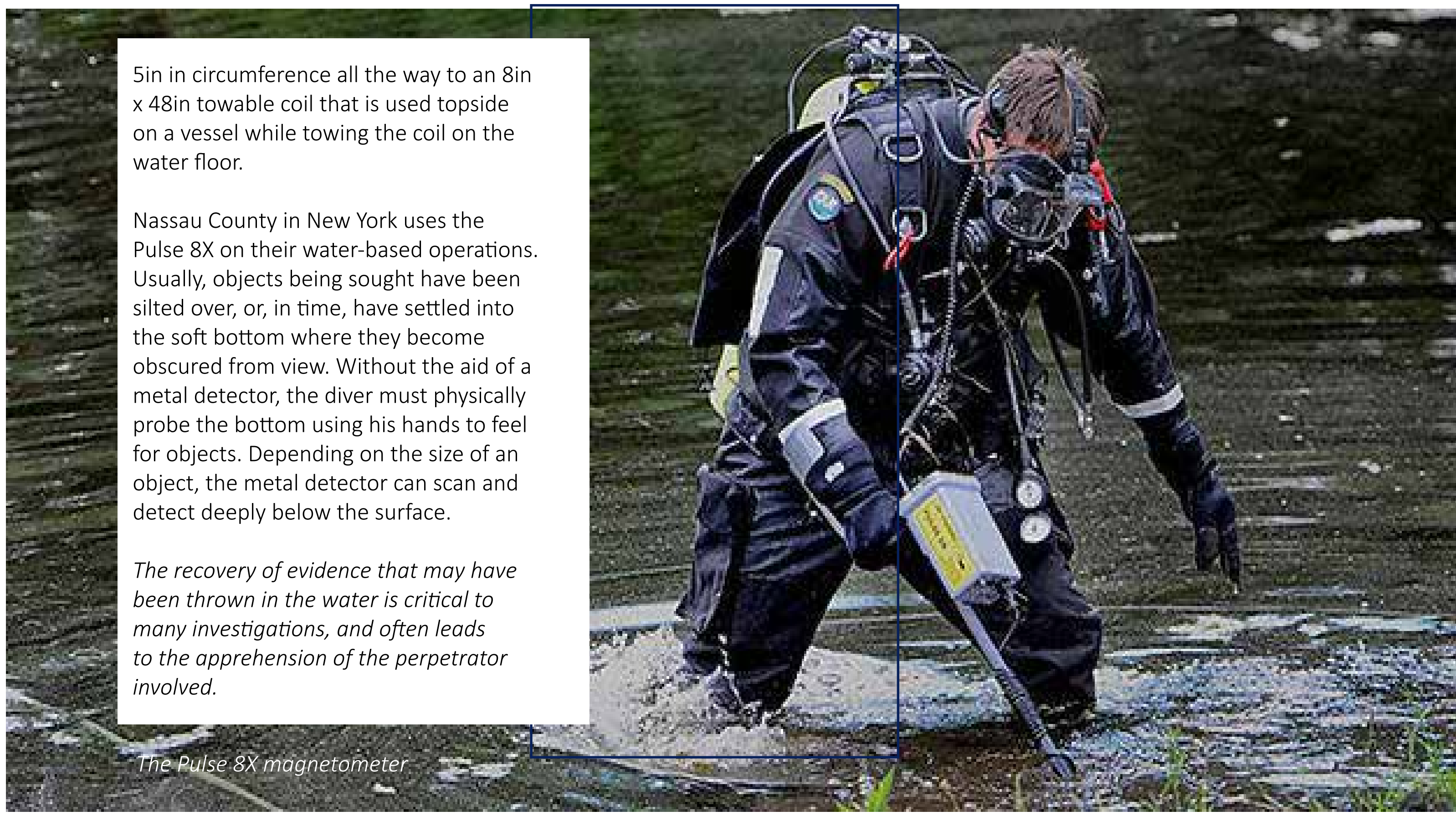
"For most searches, the default choice is the largest coil available for the unit. Such a coil provides the greatest coverage per sweep and the best depth penetration. In some cases, though, the terrain may not allow a large coil to get close to the ground. For these situations, users need a smaller coil."

The pulse 8X offers 7 different coil sizes, with the smallest one being 5in in circumference all the way to an 8in x 48in towable coil that is used topside on a vessel while towing the coil on the water floor.

Nassau County in New York uses the Pulse 8X on their water-based operations. Usually, objects being sought have been silted over, or, in time, have settled into the soft bottom where they become obscured from view. Without the aid of a metal detector, the diver must physically probe the bottom using his hands to feel for objects. Depending on the size of an object, the metal detector can scan and detect deeply below the surface.

The recovery of evidence that may have been thrown in the water is critical to many investigations, and often leads to the apprehension of the perpetrator involved.

Police using the Pulse 8X


The Pulse 8X magnetometer

MultiROV Tank Test

Earlier this year, Aleron hit an important milestone with the MultiROV work class ROV making a splash in the ROVOP test tank.

The MultiROV is one-of-a-kind, offering the operator a flexible solution to subsea remote operations. It is simple to operate with an advanced control system and can be configured to meet changing and demanding operational requirements.

It is flexible, adaptable, and easy-to service, offering customers an ideal solution for maximising efficiencies within their subsea operations.

Aleron is pleased with the outcome of the trials, and are now a step closer to proving how they can improve the operational weather window of ROV systems, particularly in high currents that are often experienced in Wind Farm Construction areas.

OCEANUS

Plymouth Marine Laboratory has revealed plans for the world's first long-range autonomous research vessel. Plymouth-based M SUBS Ltd were commissioned to design the 24m *Oceanus*

Supported by seed funding from the Natural Environment Research Council (NERC), the sleek, futuristic-looking and fully unmanned *Oceanus* has been designed as a self-righting, light-weight, mono-hulled autonomous vessel capable of carrying an array of monitoring sensors to collect data for research into critical areas such as climate change, biodiversity, fisheries and biogeochemistry.

Designed primarily to make the transatlantic sampling voyage from the UK to the Falklands, the *Oceanus* will carry an advanced scientific payload and use the latest AI technology to help navigate the best course to its target location, with real-time input from weather forecasts and other marine data feeds.

Currently most oceanographic sampling is performed either through fully-manned research trips or via moored data buoys and smaller autonomous devices, such as PML's recently launched Autonaut and EcoSubs as part of Smart Sound Plymouth.

Although still important for validation purposes and more complex tasks, research trips are costly, logistically challenging and have an environmental footprint while smaller autonomous devices are restricted in their range.

Oceanus research vessel

The *Oceanus* represents a ground-breaking vision of how long-range marine research can be carried out in a more environmentally-benign way. While a fuel-efficient diesel engine will still feature, it will be complemented by on-board micro-energy generation devices and solar panels on the deck. With the weight of people and living facilities also removed this will greatly reduce fuel consumption compared with traditional manned research vessels.

The Command Centre for *Oceanus* will be hosted at PML and will display oceanographic conditions in near-real time across the ship's transect, providing scientists and other users with open access to the latest and most robust oceanographic data.

In situ sampling will still be needed at times to validate the autonomously collected data and to perform more complex monitoring and experiments that require proximity to the sample sources. However, autonomy on this scale will allow for radically more responsive and more frequent data collections at a wider range than currently possible, helping to plug any gaps in datasets and greatly improve marine modelling.

The idea for the vessel was borne in the wake of the Mayflower Autonomous Ship, also developed and built in Plymouth by M Subs and partners including IBM. The vessel's name *Oceanus* was the name of the first child to be born on the original Mayflower in 1620.

ATOM EV

Soil Machine Dynamics (SMD) and intelligent offshore services provider Rovco have signed a Letter of Intent (LOI) for next generation EV Work Class ROV (WROV) technology.

SMD will provide Rovco with a new Atom EV high performance electric WROV, this will be the first of a fleet of vehicles designed to interface with Rovco's latest computer vision and AI capabilities, offering a smarter way of working to drive efficiency and lower project costs. This solution enables Rovco to offer a step change in autonomous services to its client's, powered by its technology spin-off, Vaarst.

The Atom EV WROV operates with superior precision in 3kt water currents, drastically increasing the ROV operating window and enabling Rovco to offer services that others with older technologies cannot.

The new vehicle's cutting-edge DC power system offers high efficiency and a reduced CO_2 footprint, together with adaptive onboard flight control which interfaces seamlessly with Vaarst technology and supports future advances in this pioneering solution.

The Atom EV WROV will be paired with an all-electric launch and recovery system (eLARS) from MacArtney, pushing its eco-credentials even further.

FLATFISH

Throughout 2021, Saipem successfully assembled the deepwater version of the FlatFish AUV. This was followed by qualification tests both in the laboratory and in sheltered water, concluding with a feature demonstration for a major operator in a Norwegian fjord.

The FlatFish autonomous inspection vehicle originally started life in 2013 as an initiative by Shell Brasil, to introduce advanced computer systems into its subsea robotics programme. At that time, the AUV was simply a proof of concept with basic instrumentation and features.

Shell then invited the Brazilian research institution SENAI CIMATEC to incorporate artificial intelligence and advanced navigation features/ methods into the tetherless new concept vehicle. Early on, SENAI CIMATEC and DFKI (German Centre for Artificial Intelligence) also joined forces in this programme, creating a new vehicle with basic functionalities such as free tetherless navigation; docking and undocking from the docking station and efficiently and safely, operating in an autonomous mode.

At around the same time as these trials were being conducted, Saipem, through its centre of excellence for subsea technologies and robotics Sonsub, was starting to plan its own visionary Subsea Robotics programme. Its ultimate aim was to change the paradigm of underwater inspection.

The Milan-based company recognised there was a material philosophical alignment between the FlatFish design ethos and the embryonic ideas they were developing. As a result, when Shell Brasil proposed a competition to take FlatFish to the next stage of development, Saipem was particularly eager to participate.

In 2018, Saipem successfully won this contest and with it, the exclusive license to further develop the FlatFish technology in order to qualify it for offshore commercial application.

This inaugural work between Shell Brasil and SENAI CIMATEC represented phase zero. The project is now in the second part of phase three, where the qualification test is currently being conducted.

In between times, the company has designed a completely new chassis and frame, and more importantly, incorporated a different architecture to allow the fusion of sensors.

Progressively enhancing its versatility, the development has moved from a shallow water design, with hardware powered by highly complex algorithms, into one capable of reliably carrying out applications in 3000m water depth. It took over two years to complete the manufacturing and another 10 months to conduct the various endurance tests for use in subsea resident mode.

DESIGN

The FlatFish is approximately 4m in length, with an elongated body particularly able to move faster in a forward direction.

Its flat sides and rounded corners allow it to efficiently carry out both horizontal and vertical inspections while the hull offers self-resistance, preventing it from being diverted by the flow of underwater currents. On the front face, lies the main inductor connector port. This enables the power banks to be recharged and exchange data with the remote-control station without using a wet-mateable connection system that could be susceptible to malfunction.

At present, it takes about 10-12hrs to totally recharge the FlatFish. Given an average sea state and conditions, the qualified battery pack provides enough power to allow the FlatFish to travel around 100km underwater.

Part of the design work, however, has been trying to improve the overall capability and look for ways of reducing the time required for a complete recharging. By replacing the existing 2kW inductive connector with a more powerful design, the FlatFish Mk II version will go from zero energy to fully recharged in less than six hours-roughly half the time of the present arrangement.

Landing the vehicle accurately and reliably on a subsea charging station is also particularly important. There are a number of flat table designs being developed that allow power and data transfer, and Saipem has successfully carried out trials on them for subsea resident applications: additional tests have been conducted on a proprietary design consisting of a cage-shaped garage that can also be used for a surface hosted deployment being lowered into the water with the supporting cables doubling as power conduits and data exchange lines.

Enclosing the FlatFish in a garage during launch and recovery also provides assistance when passing through the high energy and potentially destructive areas of the splash zone.

This structure would be lowered over the side of an offshore vessel in exactly the same way as a traditional garage-type tether management system. The difference, of course, is that there is no tether involved and the FlatFish is free to enter and leave from its midwater base on demand. Once the docking latches on the front of the FlatFish stab into equivalent receptacles inside the garage, the AUV becomes secure and charging/transfer can commence.

HYDRONE FAMILY

The FlatFish is very much part of the larger Hydrone family. Commercialised in 2019, the Hydrone-R is a resident subsea vehicle that can be remotely controlled either from shore operated in tetherless mode through subsea wireless communication technology. As a result, the Hydrone-R can navigate from point- to-point as far as 10km in AUV mode, albeit the latest design solutions of Sonsub can stretch the autonomy up to 20km.

While the FlatFish has been designed ostensibly as an autonomous vehicle that is meant to serve a long-distance inspection campaign such as pipeline survey or mooring chain/riser inspection; the Hydrone-R, is more focused on inspection over a limited area where both inspection and intervention tasks are required. The subsea robots share components and software and are both designed to dock and undock into/ onto a recharging station subsea, remaining subsea resident, increasing the time spent underwater.

FLATFISH

INSPECTION AND NAVIGATION

Unlike many elongated AUVs, the FlatFish is hover-capable, which allows enhanced inspection.

Located either side of the FlatFish nose, are LED lights coupled with a pair of accuracy Cathx cameras. These allow 3D imaging and point cloud reconstruction (PCR) and caters for a large variation in ambient lighting, needed to perform riser inspections from the complete darkness on the seabed all the way to 30m water depth.

There is also a laser measurement which also assists in the 3D model reconstruction.

The FlatFish architecture means that information gathered from the cameras, laser, mechanical scanning sonar, multibeam echosounder and whatever sensory tools are incorporated within the vehicle, are merged into a unique data acquisition system in real time. This allows the development of a more comprehensive image model but also feeds into the vehicle's autonomous obstacle avoidance system.

NAVIGATION

One of the most distinctive features of the FlatFish is its movement and navigation system. In total, the vehicle has seven thrusters. The two at the back – protected by guards – provide propulsion and allow the vehicle to achieve a cruise speed of 4kts while tracking objects. In addition, there are two lateral thrusters for controlling the vehicle sway motion and another a set of vertical thrusters, a pair in front and another at the rear.

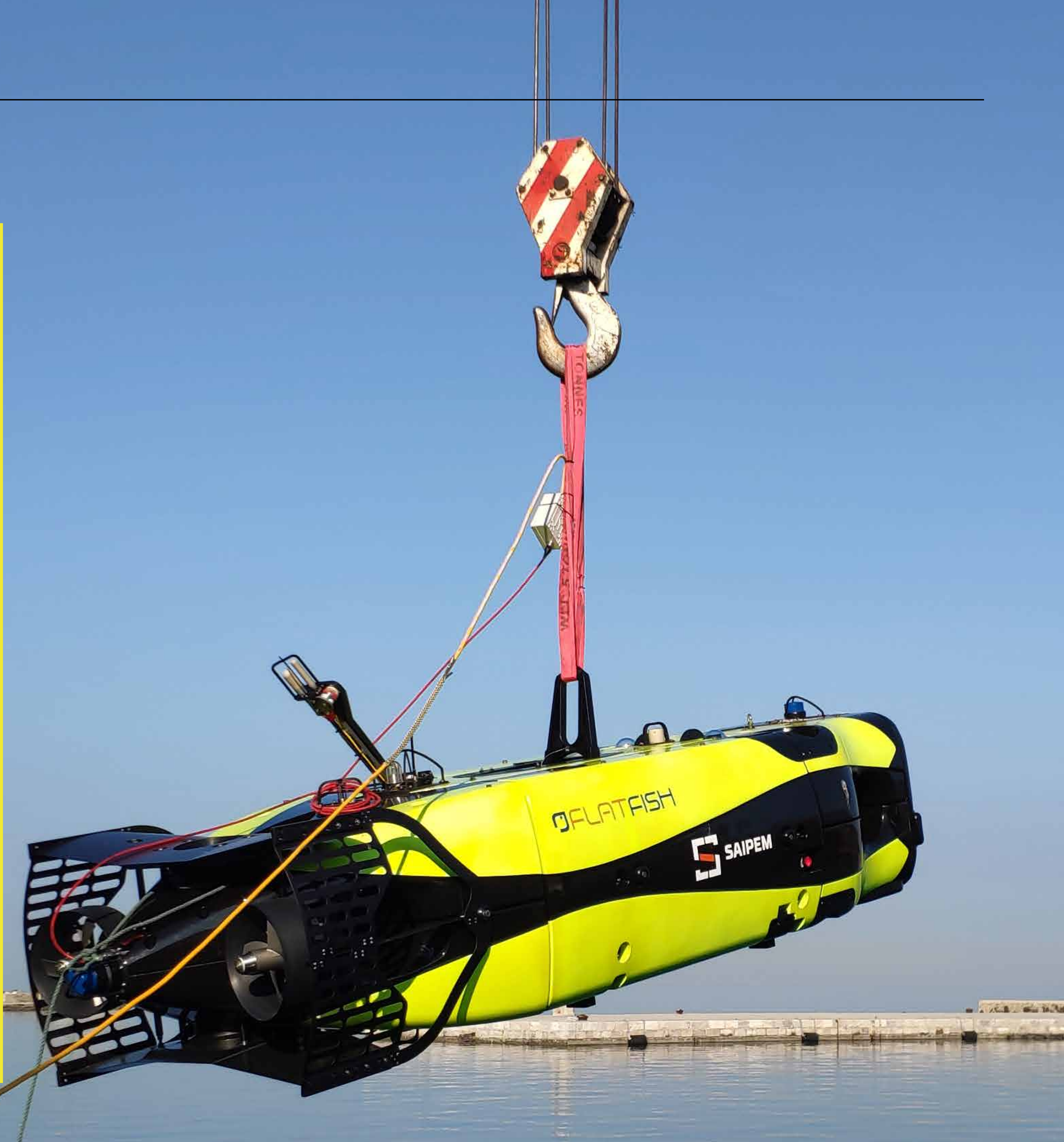
One novel feature incorporated for vertical inspections is that the vehicle incorporates a variable ballast system that allows the FlatFish to pitch easily with the thrusters only used for providing the trim.

By constant communication between the sensors, ballast control and thrusters and sensors, the FlatFish is capable of station keeping in dynamic positioning mode. In operational terms, this enables the FlatFish to be used, say, for operations such as the local assessment of valve leakage, looking at underwater displays, taking cathodic protection measurements and carrying out any work that calls for a fixed stationary position.

This makes it particularly suitable for inspection work on risers or mooring systems. By combining the vision and instrumentation systems, the vehicle is able to navigate along the water column vertically.

For riser inspection, for example, it can move to within a few metres of the surface and dive slowly also in a 360deg riser inspection- something that would be very challenging for a conventional inspection ROV, that would run the real risk of tether entanglement.

This sort of campaign would probably last much more than a single day. Rather than recovering the FlatFish to the surface, Saipem would simply lower the garage down to the required depth midwater, allowing the FlatFish to recharge underwater, upload acquired data and continue the inspections.



T500

Blue Robotics has launched its next-generation T500 Thruster. This has three times more thrust than the T200 Thruster. With a 24V / 43.5A power rating, high efficiency, and ruggedised design, it is an ideal choice for high-power ROVs, surface vessels, AUVs, and more! It comes with a pre-installed WetLink Penetrator for rapid integration into your system.

The company designed the thruster for high-power ROVs, surface vessels, and AUVs, as well as even human-carrying applications like kayaks. It's carefully designed to be rugged, powerful, and flexible in many applications.

The T500 is designed to achieve its maximum performance of 16.1 kgf (35.5 lb) of thrust at an operating voltage of 24V and power consumption of just over 1 kW. That said, it also operates well at 16V, the voltage of our BlueROV2 and lithium-ion battery. At 16V, it consumes a similar amount of power to the T200 Thruster, but is more efficient and generates 70% more thrust.

Like the T200, the T500 Thruster leverages the patented flooded thruster design, which is water-cooled, water-lubricated, and inherently pressure tolerant. It has an encapsulated stator and motor windings, a corrosion resistant magnet rotor, and high-performance plastic bearings. The body and propeller are made from impact resistant glass-filled polycarbonate plastic.

The T500 Thruster is a three-phase sensorless brushless motor and requires an electronic speed controller (ESC) for operation. We recommend the Basic ESC 500, which is designed for the high-power requirements of the T500 running at 24V, however, if you're operating at 18V or less, you may also use the original Basic ESC without any reduction in performance.

The magnet rotor is significantly improved over that in the T200 Thruster. The rotor has rugged construction with high-performance N52 neodymium magnets, protected by a metal abrasion shield lining the inside of the rotor. This prevents the magnets from being damaged due to debris or sand in the thruster.

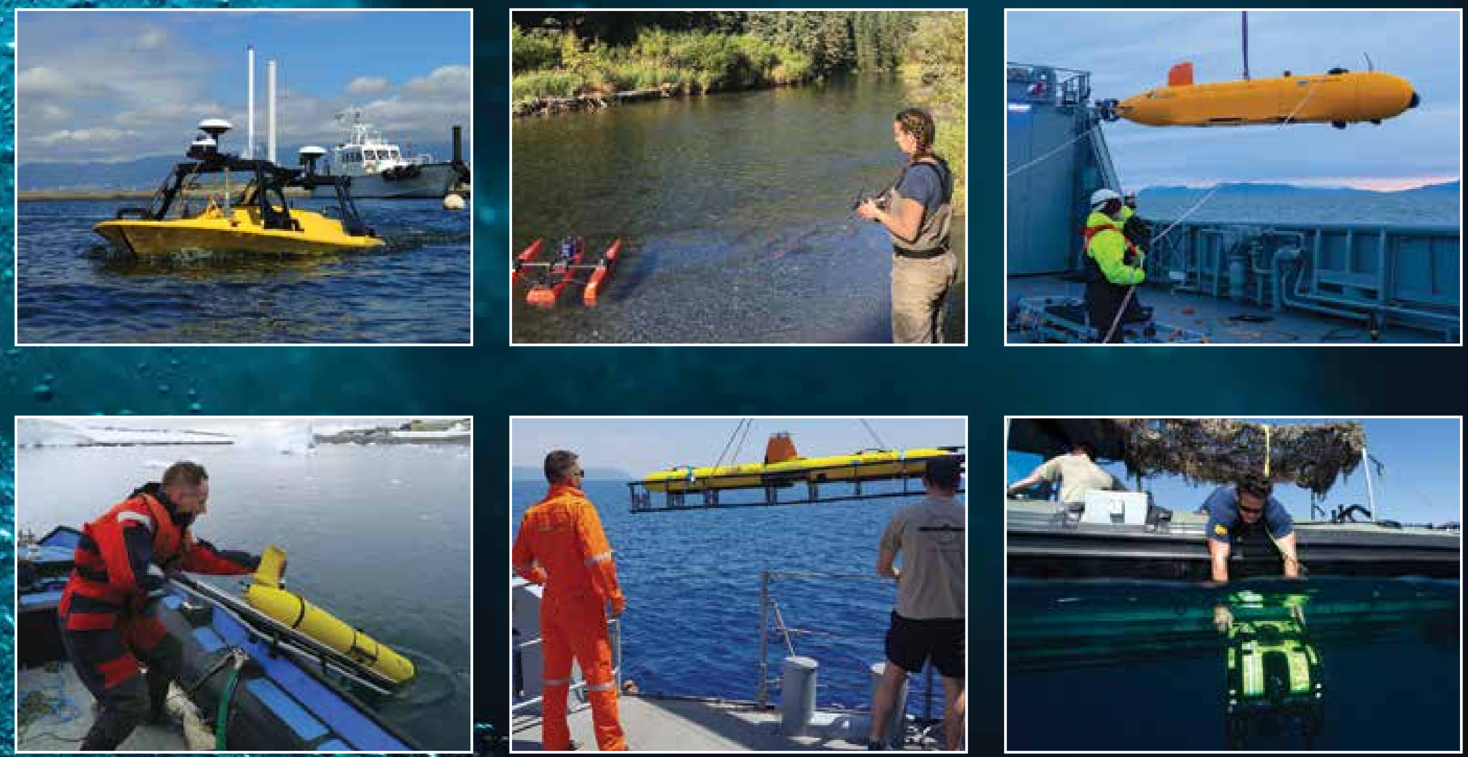
A new overlapping design between elements of the propeller, base, and tail cone minimize the chance of particulate, sand, or seaweed entering and jamming the thruster.

The T500 magnet rotor has a metal abrasion shield to protect the magnets.

It comes with a 1.5 m (59 in) cable with a pre-installed WetLink Penetrator to make it easy to connect to a watertight enclosure or other housing.

SPECIFICATIONS

Length	160 mm	6.30 in
Diameter	141 mm	5.55 in
Core Diameter	62 mm	2.43 in
Propeller Dia	114.5 mm	4.5 in
Weight in Air (with 1.5m cable)	1157 g	2.55 lb
Full Throttle @ 24V		
FWD	16.1 kg f	35.5 lb f
REV Thrust	10.5 kg f	23.2 lb f
Full Throttle @ 16 V		
FWD	9.3 kg f / 20.4 lb f	
REV Thrust	6.2 / 13.8 lb f	
Water Temperature	2-27°C	36-81°F



REMUS 300

THE LATEST AUV FROM HII

HII's new two man-portable REMUS 300 AUV has been selected as the US Navy's next-generation small UUV (SUUV) of choice. The initial phase of production and testing will be conducted throughout this year.

"The REMUS 300 is the most advanced small UUV on the market," said Duane Fotheringham, President, HII Unmanned Systems. "It will provide capabilities that are essential to the Navy mission."

"It came about because our REMUS range extends from shallow water all the way down to 6000m but recently, we started to recognise a real requirement for more specialist vehicles that operated a little deeper than our smallest REMUS 100. The new REMUS 300 is rated to 305m (1000 ft)."

A key feature of the design is a high degree of modularity, which means that the overall specifications largely depend on the number /type of battery systems and payload space required for each specific mission.

At the rear, the 3-blade propeller is directly driven by a DC brush-less motor which gives it a speed of 0-5kts (0-2.6 m/s). The precise manoeuvring is enabled by a cruciform fin control (yaw and pitch).

The communications system is based on a WHOI micromodem 2.0 high frequency (20-30 kHz) with 2.4 GHz WiFi and an optional Iridium system. The antenna also incorporates LED status lights and visible and infrared (IR) and a recovery locating strobe.

For navigation, a iXblue Phins C3 Inertial Navigation System (INS) is supported by a Garmin commercial system (or optionally, a GB-Gram Military GPS) as well as Long Baseline (LBL) and DVL-aided dead reckoning.

AUTOMATION

"In recent years, the whole AUV market has seen significant advances in automation," said Fotheringham. "This is particularly true with the REMUS 300, where a large amount of onboard processing power facilitates edge computing.

This increases the efficiency of the vehicle, particularly while carrying out operations in changing and sometimes hostile environments

One area we have been particularly concentrating on, is health monitoring.

"When carrying out missions, we particularly want to understand more about when it is *not* behaving properly. Maybe for some reason, midway into the survey, something starts to malfunction.

"It may be that the AUV has to fly for hours to the required site before it starts surveying. If the sidescan sonar fails, for example, how can we collect the maximum amount of useful data to complete the mission instead of automatically returning to base? What other tools can be substituted.

The Remus 300 and battery option

LIONFISH

The SUUV program, also called Lionfish, is the next generation Mk18 Mod 1 Swordfish program. The selection follows a two-year rapid prototyping effort involving multiple user evaluations and spiral developments to refine the REMUS 300 design.

The acquisition was facilitated by the Department of Defense's Defense Innovation Unit and their commercial solutions opening process via the other transaction authority.

"If the steering system can suddenly only turn in one direction, what can the AUV do without requiring human intervention.

"We have built in machine learning to make these vital decisions. It may be that the vehicle *does* need to return to base. Maybe not. These decisions are made within the vehicle itself and this requires onboard intelligence.

Automatic target recognition is another huge area in which we have invested a lot of time and the practical rewards are substantial.

IMPROVEMENTS

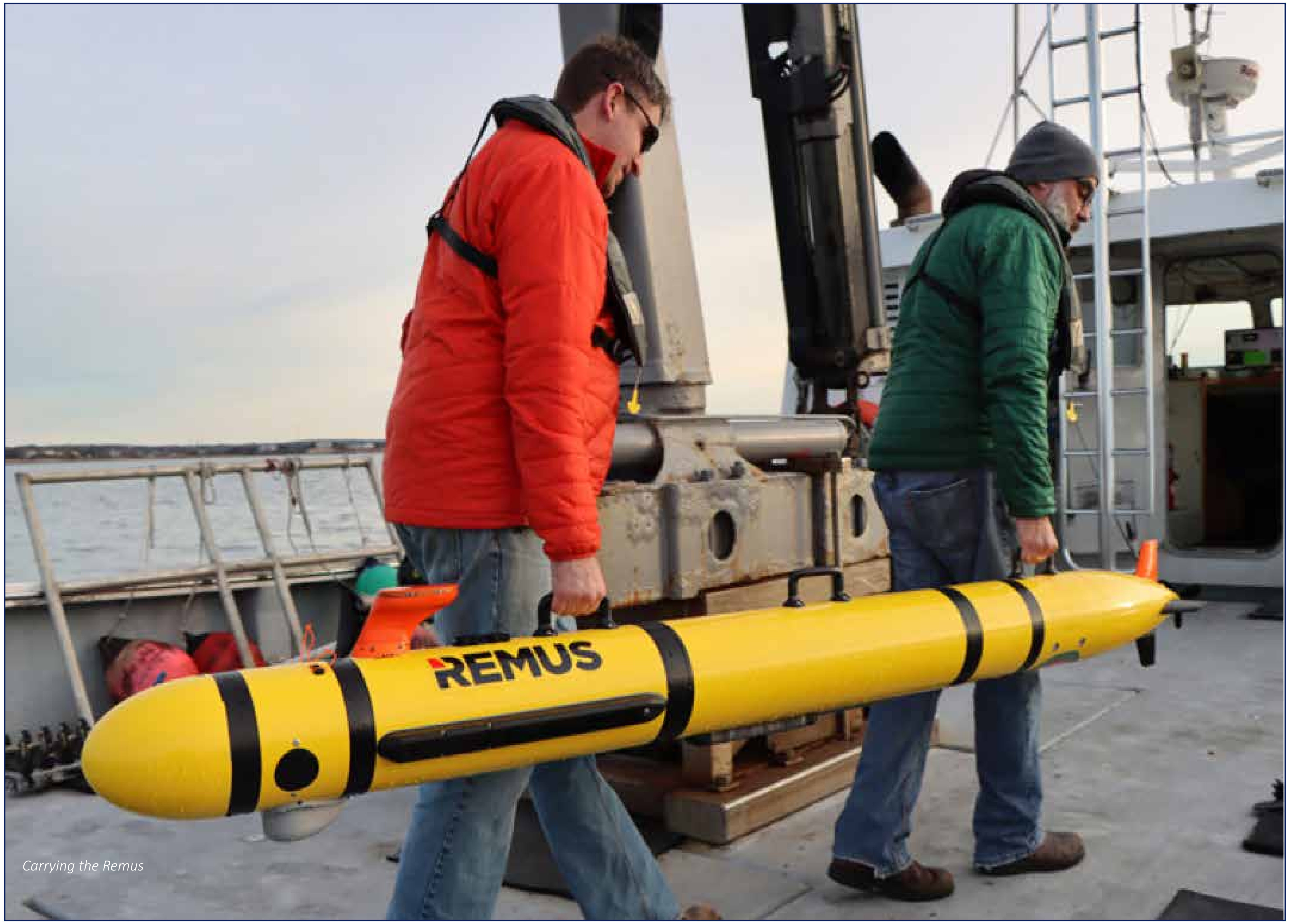
A limiting fact with any autonomous system is available power.

"Our first generation vehicle had completely enclosed battery systems which could be recharged by plugging into a power source," said Fotheringham.

" Recharging took time but this was quite compatible with the sort of operations that these vehicles need to carry out. The battery size was governed by a typical application.

"As the use of AUVs have increased over the years and their immense capabilities have become much better understood, we have come to a point where there is no longer a 'typical' application.

"The REMUS 300 has been designed to carry out a considerably wide range of operations, each requiring diverse tools and different battery sizes with energy densities that



Carrying the Remus

SPECIFICATIONS

Vehicle Specifications:	Three Rechargeable Battery Options		
Li-ion Options	1.5 kWh Battery	3.0 kWh Battery (Standard)	4.5 kWh Battery
Diameter	19cm (7.5 in.)	19cm (7.5 in.)	20.7cm (8.13 in.)
Length	2.03m (80 in.)	2.39m (94 in.)	2.64m (104 in.)
Weight	48.5kg (107 lb.)	58.5kg (129 lb.)	70.3kg (155 lb.)
Est Endurance	10 hours	20 hours	30 hours
Max Range	55km (29nm)	110km (59nm)	165km (89nm)
Recharge Time	6 hours	12 hours	18 hours

can be matched much closer to the mission requirements

"There are three standard battery configurations, namely, 1.5, 3 and 4.5kW/hrs,continued Fotheringham. "The base configuration is 10hrs but this can be extended to 20hrs by a medium battery and up to about 30hrs for the largest pack

"So if the vehicle has a limit of up to 30hrs, how do we even increase that ? One way is to reduce the time getting them into the correct area. This may mean a collaboration between the AUV and surface vessel to transport them to site.

This is commonly carried out by crewed vessels but it is very likely that this role will taken over by uncrewed vessels, and we have taken into account when considering the design.

"Surface transport systems opens the possibility of multiple AUVs in a scenario in which one AUV can be autonomously launched and recovered to the surface vessel, but while it is recharging on deck, we can deploy its twin. This means that we can operate two on a rotational schedule but ultimately, run their own missions autonomously.

"We are also opening the design up to the possibility of retrofitting hybrid energy systems to give longer durations. This may mean incorporating a snorkel or mast which may allow a power DC generator. "

MODULARITY

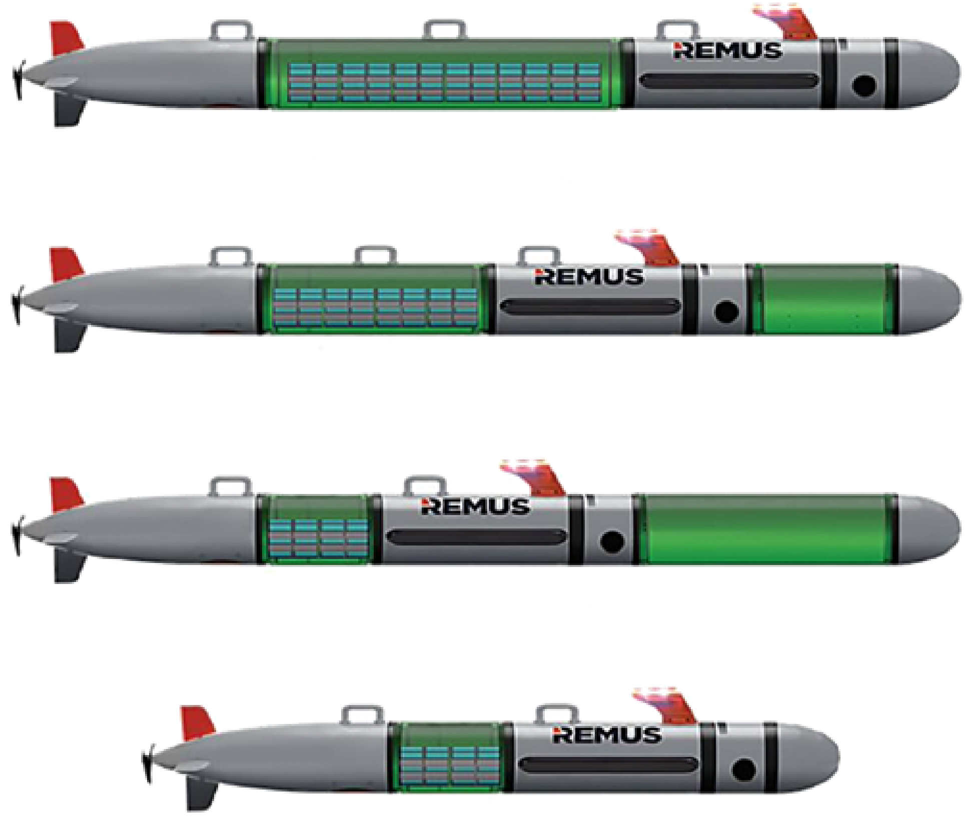
Modularity is also extended into the payload. The REMUS 300 has a Teledyne 300 kHz phased array Doppler Velocity Log with 200m bottom lock as well as a Marine Sonics MK II Arc Scout 900/1800 kHz dual frequency Side Scan Sonar with resolution up to 5cm and a 160m swath. In addition, there is a NBOSI conductivity and temperature (CT) sensor; TE Connectivity depth sensor

There is also capacity in the modular design for optional payload devices, such as a Voyis 4K HD stills camera module with high intensity LED lightbar, a Klein MA-X gap filling sonar and a range of environmental sensors such as a Seabird Scientific Eco Puck Triplet.

"We have also worked hard on the modularity of our software," said Fotheringham. We have an open architecture system as a commercial standard, which exchanges data throughout the vehicle. It is based on a single bus architecture and the new systems and payloads can all communicate with each other.

"As time goes on we are going to extend the capabilities by making the systems available for third party sensors and applications.

"Our customers want these vehicles to be flexible and to be able to add onto them. "Our largest customer is the US Navy but we have delivered to 30 countries around the world 600 vehicles across the range from military commercial.



Different configurations

Carrying out tests in the water

EDGE

Up until recently, perceived wisdom suggested that the most hydrodynamic shape for an underwater vehicle was essentially, a tube with a domed head. Over the years, nearly all torpedoes and most non-hovering AUVs have been designed around this low-drag form.

According to Kongsberg, however, a cylindrical tube may not always be the best hydrographic shape for an underwater platform required to carry a wide range of acoustic sensors.

The company has recently launched a the wet flooded carbon monocoque design with a unique low drag body shape which, it contends, produces a much more efficient movement. It is especially important to ensure a smooth flow of water over the sensors.

After extensive hydrodynamic modelling to refine the hull's low-drag shape, the body form resembles more of an idealised finger shape with a sculptured nose. Kongsberg have named the vehicle, the Hugin Edge.

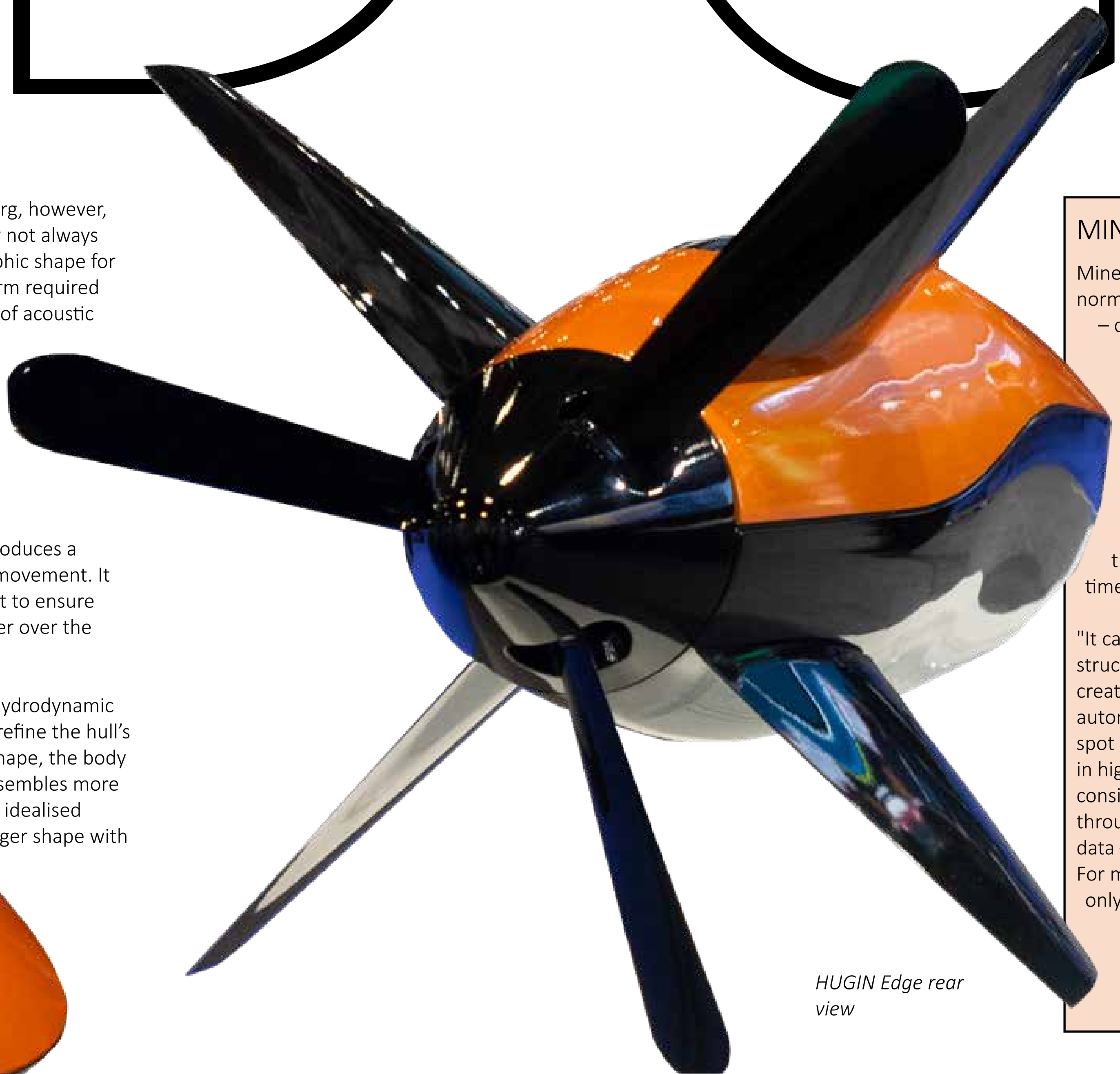
"We are best known in the AUV sector for deep water solutions," said David Mackay, Senior Sales Manager – Marine Robotics.

"We have made a 1000m depth rated HUGIN before (many years ago). However, in the current AUV range, prior to HUGIN Edge, the smallest HUGIN vehicle was depth rated to 3000m, over 5m in length and weighed in at just over 1 tonne, so the mid-sized Hugin Edge opens up a whole new market. The vehicle is 4m long and weighs about 300kg.

"Keeping the vehicle light has meant maximising the power efficiency to give it as long an endurance as possible, and that is why we sent spent so much time working on the hydrodynamic element of the design.

"It is intuitive that the more symmetrical something is, the more evenly fluid would flow around it in a three-dimensional space and therefore, would be more efficient." said Mackay. "In fact, it is not that simple.

HUGIN Edge characteristic nose



HUGIN Edge rear view

MINE COUNTERMEASURES

Mine countermeasures are normally split into four phases – detection classification identification and neutralisation. Traditionally the first three would be carried out as separate missions. These three different operations can now be carried out within a single mission by processing the data on the vehicle in real time while the vehicle's travelling.

"It can analyse the data to reveal structures on the seabed and create a list of targets. It then automatically returns to each spot to photograph the target in high resolution. This saves a considerable amount of time look through and processing the sonar data – it is it's all done onboard. For mine countermeasures, it is only necessary to clear a relatively narrow corridor. The HUGIN Edge can survey a 500m wide swath in a single run.

The defence part of Kongsberg designs naval missiles, and during the modelling process, engineers discovered that radially asymmetric designs produced improved flow characteristics. The Hugin Edge borrows many lessons learned from that model.

Not only is the drag less, but the designers discovered a secondary and perhaps related property, that the vehicle produces less noise and allows an improved performance from sonar sensors.

"The result is a vehicle with an endurance of about 24hrs with sensors running at 85% of the time," said Mackay.

The battery's fast-charge capability means that after a 22hr mission, we could charge it for two hours then get it back working.

SONAR

On the traditional HUGIN vehicle there is a forward looking sonar looking roughly 100m ahead of the vehicle.

"On the HUGIN Edge however, we have gone a stage further, fitting a multi-sector forward-looking sonar that looks up to 200m ahead. This effectively provides 3D sensing capabilities for improved trajectory planning and directional collision avoidance.

"As well as mapping straight ahead, we also look left and right to determine difficult sea bed terrain, and whether it's best to turn right or left.

"We have a high-frequency multibeam echosounder that is directed vertically downwards underneath the vehicle with a beam resolution of 0.7deg, and a swath coverage up to 140 deg, which gives very high quality inspection results.'

There is also a synthetic aperture sonar which looks sideways at a distance of greater than 250m each side and able to image details as small as 5cm across most of that width."

The HUGIN Edge also has a swappable payload bay for either an optical camera system or a sub-bottom profiler. Using the sub-bottom profiler in conjunction with the multibeam echosounder and synthetic aperture sonar allows detailed bathymetric and sub-bottom surveys to be performed.

The swappable camera payload the system can be used for carrying out detailed optical inspection, which is essential for some military applications including mine countermeasures

The comprehensive sensor package means the system is suited to wide range of other military missions including geophysical surveys, rapid environmental assessment, seabed search, as well as carrying out inspection of critical seabed infrastructure

"We are using high-definition machine vision cameras that produce a series of detailed stills images which may be stitched together to provide a wide-area mosaic. LED lighting mounted integral

with the vehicle body is triggered in synchronisation with the camera electronic shutter" said Mackay. The Hugin also has a high-sensitivity magnetometer.

NAV/COMMS

The HUGIN Edge has a range of communication systems installed in a retractable antenna, including high-speed wireless for data download, and long-range RF which can communicate over tens of kilometres in some cases. It has an Iridium emergency satellite beacon so that when on the surface, HUGIN Edge can use the worldwide Iridium network to let the surface operator know exactly where it is.

It is also fitted with a Kongsberg cNode transponder for acoustic communication with a surface vessel while underwater. This can provide accurate navigation position updates from the surface vessel to enhance the accuracy of the inertial navigation system on board the AUV.

It also allows the surface operator to supervise the status of the AUV mission, to check all vehicle systems are operating correctly, sensor data quality and battery status. This acoustic supervision can be carried out down to full operating depth.

The HUGIN Edge uses the same high-performance inertial navigation system as other larger members of the HUGIN family, a system called Sunstone, which has been developed by Kongsberg. The navigation system takes aiding information from a survey grade motion sensor and gyro-compass, Doppler velocity log, multi-sector FLS, conductivity, temperature and sound velocity sensors. This allows the AUV to offer excellent autonomous navigation performance.

MISSION PLANNING

Another innovation introduced on HUGIN Edge is Goal-Based Mission Planning.

Normally, all HUGINs are programmed for autonomous missions based on line-by-line instructions. These may tell the AUV to 'go to this depth, travel at this speed, go to this location, switch on this sensor, etc. The AUV control system then follows the instruction sequence.

Goal based mission planning greatly simplifies the mission planning

HUGIN Edge

process. The user first selects which autonomous assets are being used. It can operate multiple AUVs or USVs at the same time.

The user then selects the type of mission that needs to be conducted, eg, a seabed survey or seabed search mission. The user decides on the geographic area for the mission and can set any exclusion zones or areas where the AUV is not allowed to surface. Special survey requirements can also be included, like survey overlap.

With the press of a button, the system then generates the full mission plan which is downloaded to the AUV before mission deployment.

In-mission adaptive behaviours allow HUGIN Edge to make decisions autonomously based on real-time sensor data, continuously replanning during mission execution to make sure that the overall mission goals are achieved.

USV

From its inception, the HUGIN Edge has been designed to operate autonomously from Uncrewed Surface Vehicles (USVs) using Kongsberg’s automated Launch and Recovery (LAR).

This capability removes the human from the field of operations, enabling remote supervision and minimising operational risk, maximise safety and delivering the lowest carbon footprint.

"Our own boat, the Sounder, is a little bit too small to deploy something like the Hugin EDGE so we are planning an 11 or 12 boat. This will be able to contain two of these Hugin Edges," said Mackay.

The plan is that the USV autonomously takes the AUV to where it needs to be. One will be deployed in the water while the other lies on the vessel deck, charging using inductive charging system which means there are no plugs or cables, or manual intervention systems.

Once the Hugin Edge is recovered, the replacement is launched, thus always having one vehicle in the water.

There is also a provision for emergency recovery.

POWER COLLABORATION

SubCtech and ocean-energy focussed company Ocean Power Technologies have agreed to collaborate on mutually beneficial solutions in North America and the European Union.

OPT provides sustainable power generation and data capabilities with low- and low- to no-carbon solutions allow for smarter and faster actionable insights for ocean operations.

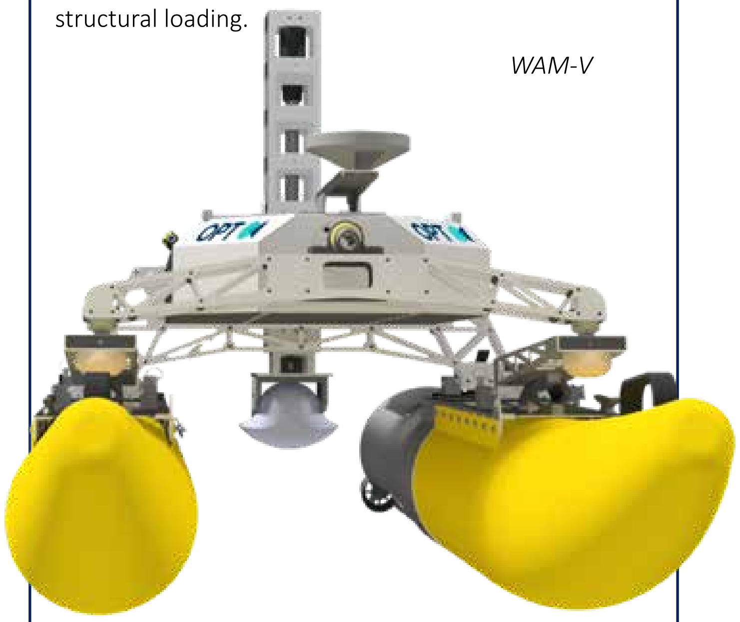
SubCtech provides high-performance, Li-Ion rechargeable battery designs for offshore subsea electronics. Designed for deployments up to 25 years, the electronic and Li-Ion cells are extreme robust and fail-safe.

Applications include subsea electric systems, including Subsea uninterruptible power supplies for monitoring and sensor systems

“OPT’s and SubCtech’s product and solutions have obvious synergies," said Philipp Stratmann, OPT President and CEO," and we are jointly exploring opportunities for combined deployments, as well as potential deepwater and WAM-V optimization projects.”

WAM-V or Wave Adaptive Modular Vessel is an innovative class of autonomous surface vehicles (ASVs) that uses an articulating suspension system to minimize structural loading.

WAM-V



NO LIMITS

TRITON CO-FOUNDER PATRICK LAHEY TALKS ABOUT THE ENGINEERING OF THE DEEP SUBMERGENCE VEHICLE LIMITING FACTOR TO JOHN HOWES

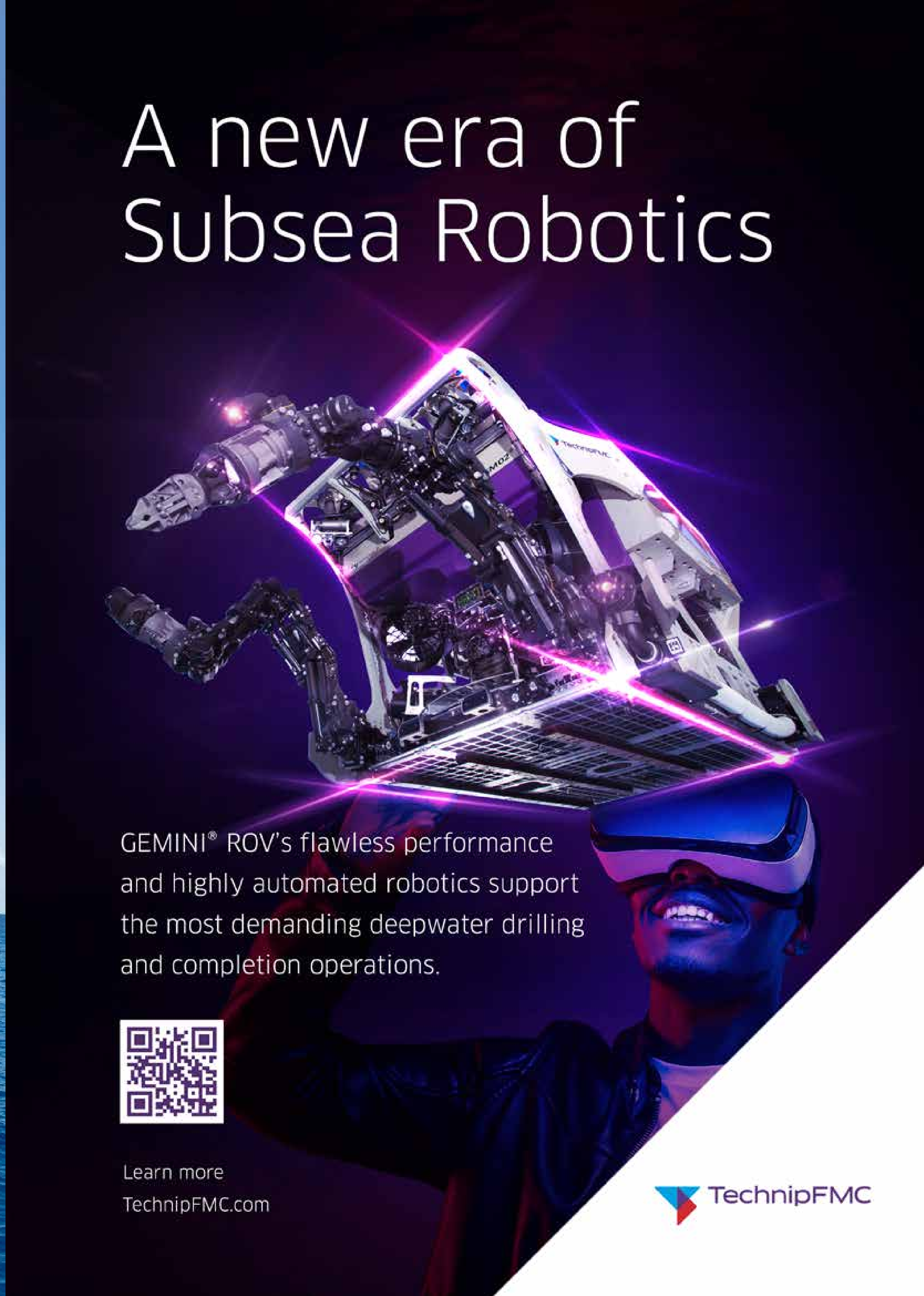
Every year, the SUT/MTS presents the Captain Don Walsh Award for Ocean Exploration. At this year's Oceanology International 2022 event in London, the award was presented to deep sea pioneers Victor Vescovo and Patrick Lahey – by Captain Don Walsh, himself. During the past five years, the submersible Triton Submarines designed, engineered, and built (the Limiting Factor), has successfully dived to the deepest points on the planet.

Victor Vescovo has been called the last great explorer. In the past decade or so, when he wasn't at either pole, he could probably be found at the highest peak of each continent. He didn't so much sleep as recharge ready for the next test. After meeting all the terrestrial challenges, he began to turn his attention to underwater exploration.

He noted that since the 1960s, when the then Lieutenant Don Walsh and Jacques Piccard visited the world's deepest point in the Mariana Trench in the 1960s in the bathyscape Trieste, nothing of great significance had happened in the very deep ocean.

Apart from the Deep Sea Challenger (DSC) project, which enabled film-maker James Cameron to visit the Challenger Deep in 2012, nobody had conducted a crewed expedition


EYOS
TRITON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to the deepest points in the ocean. Vescovo decided he wanted to be the first person to dive to the deepest point in each of the worlds oceans, which became known as the Five Deeps Expedition or the FDE.

Patrick Lahey, Co-founder of Triton submarines was to be the person charged with making Victor Vescovo's dreams a reality with the eventual development of the deep submersible vehicle, the Triton 36000/2, otherwise known as the Limiting Factor or the LF.
"It is not an exaggeration to say the LF has fundamentally changed our relationship with the ocean by providing safe, reliable and daily access to the deepest and most remote areas of our planet for the first time in history," said Lahey. "The difference between the LF and the two vehicles which preceded it (DSC and Trieste), was Triton's commitment to developing a fully accredited (i.e., DNV/GL certified) human occupied submersible capable of making repeated dives to any depth.

When the engineers first started work designing for these extreme depths, they soon discovered that there was literally nothing readily available they could buy 'off-the-shelf 'to incorporate into the submersible. It all had to be created. This challenged their supply chain.

"When Victor first met with me and John Ramsay in 2015 and told us about his personal ambition to dive to the deepest point in each of the five oceans, we confessed that for years, we had been considering how Triton would approach building a hadal depth capable submersible," continued Lahey.

"Unfortunately, the development of a full ocean depth (FOD) submersible required more time, energy, and resources than a small company like Triton had at our disposal. We needed someone with the money and interest to fund such an audacious undertaking and if it wasn't for Victor's personal ambition of diving to the deepest point in each of the five oceans and his willingness to provide Triton with the resources necessary to create the revolutionary craft required to prosecute such an expedition, the Triton 36000/2 or LF might never have happened."

CONCEPT:
"There is a good reason why many of the deepest and most remote areas of the ocean remain unexplored," said Lahey, it's both extremely expensive and also, technically very challenging."

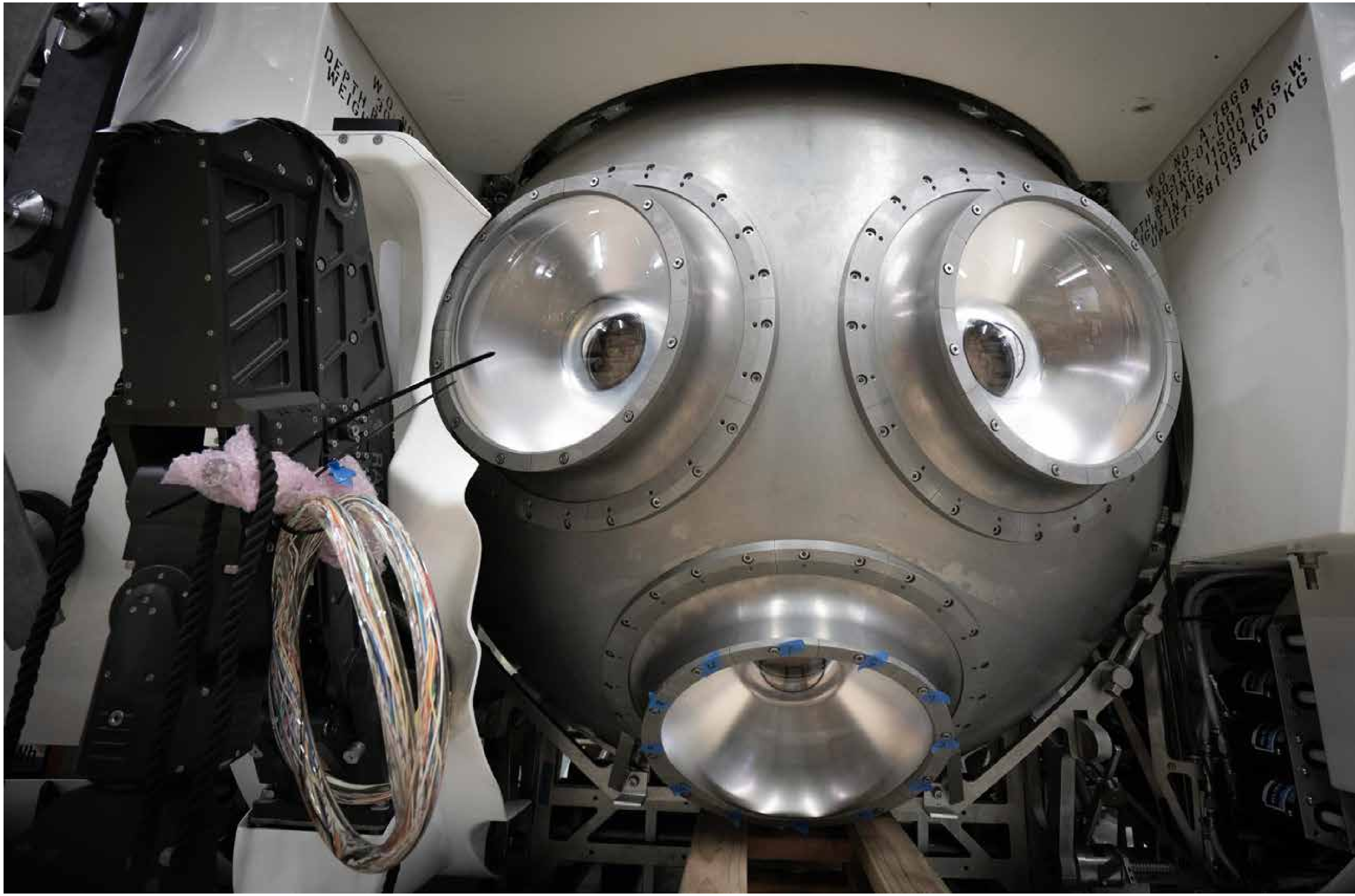
"In 2012, when James Cameron carried out the first solo dive to the Challenger Deep in DSC, he used the smallest pressure hull possible for a single occupant. DSC was designed to make multiple dives but sadly, the craft only made a single, human occupied dive, to the bottom of Challenger Deep before being taken out of service.

“Victor originally wanted Triton to consider developing a vehicle with a small diameter, single-person, and windowless metal hull that could be lowered on a tether down into each of the hadal trenches.”

"Since Victor’s goal was to conduct multiple dives in the deepest trenches in all five of the world’s oceans, Triton strongly argued for the development of a fully accredited (DNV/GL certified) craft equipped with two seats, multiple viewports and a manipulator for maximum value and reward. We needed to approach the development of a full ocean depth capable submersible from a very different perspective – and in doing so, create something that would really 'move the ball down the field'.”

“The pressure hull of James Cameron’s DSC was just 43-inches in inside diameter and 2.5-inches thick (Cameron is over 6 feet tall). Since the submersible Triton planned to develop for Victor was intended for multiple missions over an extended period and the pilot would be on board for up to 16 hours at a time, we could justify using a much larger sphere. In fact, Triton insisted the hull be large enough to comfortably accommodate two occupants otherwise, the craft would have little or no on-going utility beyond the completion of the FDE.

Triton considered two seats an essential deliverable because it would allow a scientist, film maker or another explorer to share the experience with the pilot while also allowing the craft to be operated solo, if necessary.”



The most efficient structure to withstand the crushing pressures found in the deep ocean is a sphere. Like its predecessors, the development of the sphere for the LF would be the focus of the design effort.

“Initially, Triton proposed using a completely transparent pressure boundary made of high-pressure glass, which would provide a much more immersive experience, unparalleled situational awareness, and reduce displacement” said Lahey. “Victor considered but decided against it, stating “he didn’t want to fund a science experiment”.

“Nevertheless, Triton did incorporate three, spherical sector acrylic windows into the LF, which do provide the occupants with excellent forward and downward visibility.”

“We wanted the sphere to be as strong and light as possible, which meant fabricating the hull out of Titanium. Since we didn’t want the sphere to have areas of high stress, we had to create two, perfectly machined hemispheres (within 99.933% of true spherical form), which would be bolted and clamped together rather than welded to avoid the discontinuities or areas of high stress typically created by welding.”

The diving depth of the LF is 11,000 meters or 36,000 feet, which is considered ‘full ocean depth’ or FOD," said Lahey. "However, to comply with the DNV/GL rules, the pressure hull and all of the critical systems associated with the LF had to be tested to 1.2 times the maximum pressure found at FOD.

The completed pressure hull and syntactic foam modules for the LF had to be tested in the only chamber in the world with physical size and capacity to test to FOD plus 20 percent, which is the Krylov State Research Center (KSRC) in St Petersburg, Russia. At KSRC, the complete pressure boundary and syntactic foam modules were tested to 140 megapascals (MPa) or 20,000 pounds per square inch (PSI). Then everything was shipped from Russia to Florida for final assembly.

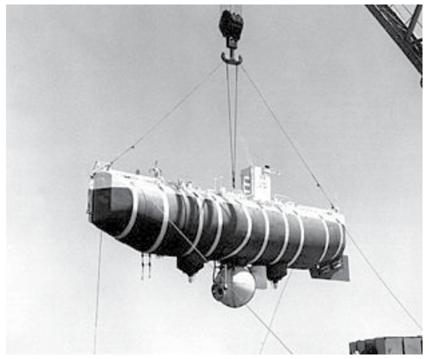
BUOYANCY

The weight of the pressure hull had to be offset by buoyancy. The original Trieste achieved its buoyancy by carrying 85 cubic meters of liquid fuel housed in a thin ‘steel balloon’ above the sphere. Being a liquid, it was virtually incompressible, but this meant it took up a large volume.

In the intervening period, buoyancy systems have advanced significantly. The LF uses a syntactic foam flotation system consisting of six and a half cubic metres of this advanced material, which is made up of glass microspheres in an epoxy matrix. Surrounding the titanium sphere, the syntactic foam buoyancy modules are machined to create a hydrodynamic shape, which enables the LF to travel quickly and efficiently through the water column in the vertical direction (i.e., when diving or returning to the surface).

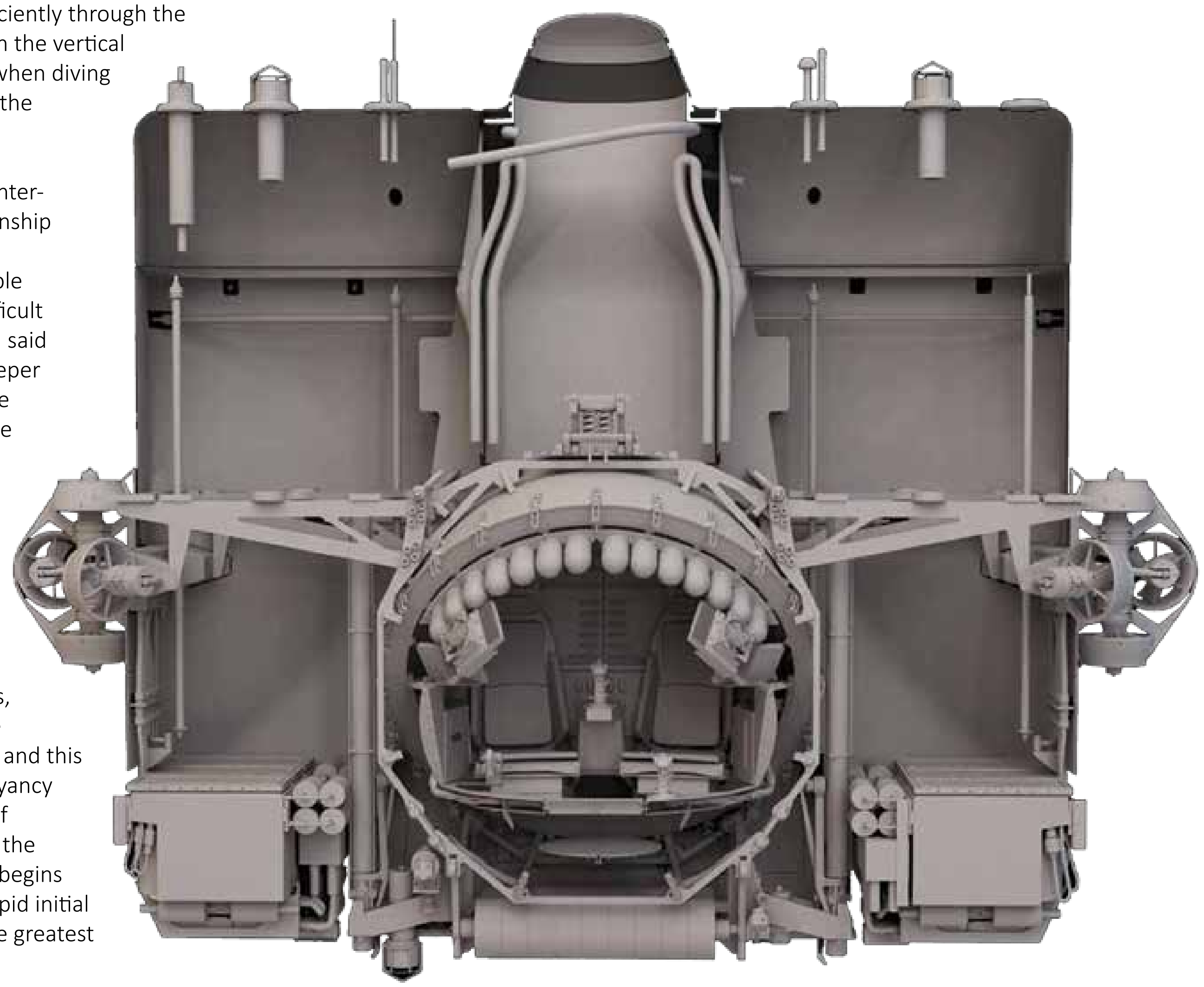
“There is a counter-intuitive relationship with buoyancy that many people initially find difficult to understand,” said Lahey. “The deeper the LF dives, the more weight the submersible is required to carry in order to reach the target depth.”

“As the water depth increases, so too does the specific gravity, and this affects the buoyancy requirements of the vehicle. On the surface, the LF begins a dive with a rapid initial descent and the greatest amount of negative buoyancy.”



The Trieste. At the base is the pressure sphere. Above is the floatation package

"If the LF is ballasted correctly, as the craft approaches the target depth, the pilot will only need to release of a small amount of weight (made up of individual 5 kilogram ‘slugs’ of 75 mm diameter steel-round-bar) from the variable ballast tubes, to achieve neutral buoyancy (typically about 40 kilograms). The exploration phase of a dive is conducted with the LF in a neutrally buoyant condition to ensure the most efficient and effective use of energy.



Inside, the Pilot controls are quickly identifiable and easy to operate. Leather padded seats with multiple seating ensure comfortable 8-12 hour dives in an interior that is both temperature and humidity controlled.

SAFETY FIRST

If a problem occurs at extreme depth, outside help options are either very limited or non-existent. Therefore, everything used in the LF had to be rigorously tested, and a lot of time and effort was invested in identifying and developing redundancies for all the critical systems on the craft, which is a classification requirement too and underscores the importance of accreditation.

"The performance of components on the surface is quite different to how they will behave at eleven hundred atmospheres, and this required the painstaking process of identifying components, incorporating them into circuitry and then testing them through the entire working range of the submersible. This process often required multiple attempts and repeated failures before arriving at a reliable and predictable solution," said Lahey.

"We would routinely take individual components, and pressure test them. We would then take the components that survived, assemble into circuit boards and pressure test those."

"While the primary design requirement of the LF is safety, there is also a practical requirement for redundancy, which directly effects the utility of the submersible," said Lahey.

"It takes approximately 4.5 hrs to reach FOD and about 3.5 hrs to return to the surface. We don't want a pilot to terminate a dive prematurely because of a minor fault. We needed redundancy in systems so a pilot could work around a primary system failure and continue a dive without jeopardizing safety of the craft or the mission.

For example, the electrical system of the LF has a lot more energy than is required to complete even the longest of dives. In addition, the electrical system of the LF is triple redundant and the pilot can use any one or all three of the batteries on each side of the LF (six batteries total) to power downstream devices with no loss in functionality and only a reduction in capacity equal the number of batteries taken offline.

"Power in the LF is derived from a large bank of lithium-ion batteries" said Lahey. Interestingly, we discovered the LF batteries were a weak point in the design and over time their performance degraded from exposure to high pressure and cyclic use. The reliability issues with the LF batteries, encouraged us to develop our own DNV certified ultra-high pressure tolerant batteries, which are DNV certified, and named the Triton Hadal Battery System."

"Since Victor intended to conduct many of the dives in the

LANDERS

To provide support to the submersible and carry out additional science tasks, the project included three nearly identical landers called Flere, Skaff and Closp. They are approximately 1×1.5x 1.8 meter (length x width x height) in size, weigh approximately 900 kilograms, and rated to an operational depth of 11,000 meters.

Negatively buoyant steel ballast weights are used to make the landers dive. At a given time, an acoustic command (or back- up timer) triggers a release mechanism, dropping the weights. The positively buoyant syntactic foam then floats the lander to the surface where an Iridium beacon, Xenon strobe and a flag, aid in the location and recovery by the Pressure Drop support vessel.

On the landers, an L3 modem allows the submersible to accurately navigate the sea floor while enabling scientists on the surface to communicate with the lander.

SCIENCE

A 'bio box' stores geological and biological samples collected by the submersible while Flere and Skaff also have a rack of six push cores that can be recovered. Closp has an autonomous motor driven corer.

There is also a conductivity, temperature, and depth sensor (CTD) to record the hydrographic conditions in the over lying water column and when on the sea floor, in the near bottom water.

A time-lapsed camera system can record the presence and behaviour of large mobile fauna, while two sets of baited traps can recover samples of the more mobile fauna. All three landers also have a Niskin bottle water sampler, which collects 10 litres of bottom water for deep microbial work.

LF as a solo pilot, we had to develop a system, which would return the submersible to the surface in the unlikely event the pilot (i.e., Victor) became incapacitated. The 'watchdog system' is based on a timer circuit, which is automatically reset through the initiation of a regular communication checks or by pushing a switch located on the pilot's console fitted with both an audible and visual alarm indicator.

If activated and not reset by the pilot, the watchdog system will automatically jettison the surfacing, freeboard, and variable ballast tube weights in the LF and return the craft to the surface. In addition, we included eject mechanisms on the LF for any assembly prone to entanglement or that could be used to create positive buoyancy, including expensive systems like the batteries, thruster nodes, and the manipulator arm.

"After building and testing the LF, we conducted multiple test dives to validate correct system operation," said Lahey. "In one of the most memorable test dives, things were not going well. We had multiple system failures and the alarms panel looked like a Christmas tree but none of these faults prevented us from safely continuing the dive until, the manipulator arm unexpected fell off when the frangible bolt holding it in place sheared.

"Paradoxically, the loss of the manipulator arm provided a solution, in the form of the spare conductors we needed, to restore functionality to all the other faulted systems.

Several days later, with the LF rewired using the conductors formerly assigned to the arm, Victor completed the first of the Five Deeps objectives (the deepest point in the Atlantic – the Puerto Rican Trench at 8376m). When the LF was safely back aboard PD, everyone, even those who had given up and didn't believe the LF would ever work properly a few days earlier, suddenly realised the FDE was possible."

"To succeed on an expedition, you have to expect failures, setbacks, and disappointments because they are a part of achieving something difficult. You must believe in your team, and they need the tenacity and grit to push through and overcome challenges even when others have given up. I have never been more proud of a group of people in my life than I was of the team on the FDE, particularly at this moment. It was a privilege and an honour to be a part of such a remarkable endeavour and I am grateful beyond words to all those who contributed to our unprecedented success."

NAVIGATION

Navigating underwater is notoriously difficult. "We worked closely with subsea electronics company L3 Oceania to develop a seamless and simple system that would allow us to know exactly where we were in the LF and communicate subsea landers.

The modems for the L3 system live outside the pressure hull. Normally, the only two options are to enclose the electronics in a one-atmosphere housing or bathe the electronics in oil or some other non-conductive fluid and expose the housing to ambient seawater pressure. We had to ensure the housings for the modems would not implode so they were subjected to an exhaustive design review and multiple pressure tests to the maximum diving depth plus 20 percent.

"We learned many important lessons during the development of the LF and prosecution of the FDE. We have continued to learn more as additional expeditions have been undertaken and successfully completed and we have had the opportunity to test and improve systems further. At Triton, we always look critically at the submersibles we have created and identify ways to improve reliability and performance," said Lahey. There were some systems on the LF that worked better than we expected while others had room for improvement.

At present, the LF is in San Diego undergoing a re-fit. Nothing has been decided on its eventual fate, but it is a unique working vehicle and needs to be periodically disassembled to maintain DNV recertification.

TECHNICAL SPECIFICATION

Capacity	2 passengers
Duration	16 hrs +
Dry Weight	25700 lbs / 11.7 tonnes
Depth	11,000 meters / 36,000 ft
Payload	220kg +
Speed	1-2kn Vertical, 2-3kn Lateral
Surface Ballast	2150 liters total
Variable Ballast	Upto 500kg dive weight + 100kg variable
Length	4600 mm / 15 feet
Width	1900mm / 9.2 feet
Height	3700mm / 12.2 feet
Pressure Hull ID	1500mm / 59 inches
Hatch dia.	450mm / 17.7 inches
24V Supply	Dual Supply + Emergency
Main Battery	65 kWh
External Lights	10 x 20000 lumen LED
Life Support	Oxygen + CO2 scrubber
Emergency Life Support	96 hrs
Viewports	3 x ultra-wide angle
Cameras	4 x Wide-angle situational awareness cameras 4 x high-definition mission-recording cameras

BUOYANCY

At the recent Oceanology show, Trelleborg exhibited the buoyancy materials that were used on the Limiting Factor deep submergence vehicle and described how these differed from conventional systems.

"Across the underwater sector, a wide variety of equipment items are required to float", said Robert Kelly, General Manager Trelleborg Applied Technologies. "These range in scale and application from heavy marine riser strings to pocket micro ROVs. The buoyancy is provided by syntactic foam packages.

"Syntactic buoyancy systems essentially consist of glass spheres or 'balloons' bonded together using an epoxy binder to create a low-density, high-strength composite with a low coefficient of thermal expansion. These spheres range in size.

"Heavy items such marine risers use large spheres or macroballoons to provide buoyancy. Conversely, in the floatation blocks of ROVs, etc, the physical size of the floatation package becomes an issue. This calls for micro balloons that can be packed together to give a greater buoyancy per volume.

Ultra-deep hadal water applications up to 11 000m, however, require specialist syntactic foam able to also withstand significant ambient pressures while having the lightest possible foam, in the smallest package.

“The compressive property of syntactic foams largely depends on the original properties of microballoons," said Kelly, “while tensile properties depend more on the resin matrix material holding the microballoons together. There are two principal ways of adjusting the buoyancy properties of syntactic materials.”

The first method is to change the volume fraction of the microballoons in the syntactic foam structure. Larger microballoons may provide buoyancy, but the gaps between them are filled with resin. Smaller uniform sized microballoons, however, have a higher capacity for floatation.

The other is to use microballoons with different wall thicknesses. In general, the compressive strength of the material is proportional to its density.

SPHERES

Microballons can be constructed using various materials but the most commonly used is glass.

“The hollow thin-walled Eccospheres, (microspheres) are composed of a chemically inert sodium-depleted glass sodium borosilicate glass," said Kelly. "They have good density/strength ratios, clean surface chemistry, narrow particle size distribution, low thermal conductivity and a low dielectric constant. They can be manufactured in two main ways."

The most common uses small glass droplets with an expanding agent. The agent enlarges the glass until it becomes spherical and hardens.

The other method is to combine a fluid mist and a blowing agent. The glass expands, assuming the shape of a deflated ball. This then enters a furnace where the high heat makes this bubble into a perfect sphere.

In post processing, the microspheres are then polished and etched before being put into a flotation tank so that any damaged or broken glass bubbles, or those with irregular particle geometry, can be easily separated and removed. The resultant material has a high strength/weight ratio while being capable of extremely high loadings.

The microspheres generally measure around 50µm diameter, although some are smaller and others, larger. The size distribution is important as it may affect the packing ratio. In general, the larger particles tend to be weaker while the smaller particles are stronger, typically because the smaller spheres have relatively thicker glass walls. The wall thickness of the most dense sphere is around 2–5µm.

Syntactic blocks on the Limiting Factor

MATRIX

There are two main types of syntactic foam – unreinforced and reinforced. Because it has fewer constituents, unreinforced foam is a cheaper option and but beyond 1000m, the pressure becomes too great and it is necessary to select higher performance products with a greater microsphere density.

Reinforced foam uses fibres to make the structure even stronger. The drawback of this, however, is that the fibres also make the foam much denser and consequently, heavier.

The average foam density used for work at 2000m is 24lbs/ft^3. In deeper waters, however, the stronger and heavier microspheres results in a denser block nearer 39lbs/ft^3.

APPLICATION

The way that the syntactic foam is added to the structure depends on the performance characteristics required from the end product.

One method, which is known as ‘pour on pour’, requires the operator to make a suitable mould into which the syntactic foam is poured. Moulds can be made in any shape.

This method typically achieves a 30lbs/m^3 density and suitable for a vehicle operating at up to 300m of sea water. For deepwater applications, however, an alternative way is to fabricate the foam in blocks.

“This is a more efficient way to control the packing of the microspheres and therefore, the foams density,” said Kelly. “These blocks are typically cut into 1m^3 blocks and tested. It is then possible to harvest the most suitable part of the block for the most demanding operations.

“Instead of an average 34lbs/ft^3, it is possible to focus on specific areas of the block that may exhibit densities nearer 26lb/ft^3. These blocks can be machined into any required shape."

WATER

Due to the high hydrostatic pressure conditions to which the Hadal vehicle is subjected to, water will attempt to penetrate the structure. Although the goal is 0% water uptake, in reality at these high pressures, water will always find a way into the foam.

Eccospheres being weighted before testing

Nevertheless, the modules must be constructed using a material that resists or minimises water penetration of water throughout the lifetime, and thorough testing becomes important.

“By monitoring water uptake while applying heat and pressure cycles in a test chamber, it is possible to predict the properties as the material ages," said Kelly.

"Density testing is routinely carried out on blocks. Deepwater foams used on submersibles require a 100% inspection rate and with no cracks or blemishes. They will be hydrostatically tested for 24hrs. In this time, a typical block might take in the water equivalent to weight of less than a 10th of a percent. If this is as much as 3%, however, it fails,” concluded Kelly.

DEEP VISION

DeepSea Power and Light (DeepSea) initially became involved with Five Deeps when the project was at an early stage. It received a general enquiry for SeaBatteries, LED SeaLites and some Super Wide-I SeaCams, but all the company really knew was that these were to be placed on an advanced vessel and three lander systems.

Unlike recent projects to the Marinas Trench, this new vehicle would be occupied with scientific goals rather than adventuring and purpose-designed to carry out multiple missions.

DeepSea responded by providing the camera systems for the lander, two SeaBattery power modules per lander, a Super Wide-I SeaCam and LED SeaLites, each enclosed in titanium housings and rated to work at full ocean depth.

"That is what DeepSea is known for – it is right there in our name," said Aaron Steiner, General Manager, Oceanographic Products. "We carried those products in our portfolio because we'd already worked with other customers that wanted to conduct full ocean depth operations.

"Imaging is so important in the storytelling process," said Steiner. "Looking back to when the first 4K Optim camera took pictures in the Marianas Trench and discovered plastic bags, within a week, every major news organisation in the world was carrying these photos. This story would not have been as prominent without the accompanying imagery."

In order to document the Five Deeps expeditions for the wider media, therefore, project partner Atlantic Productions wanted something better than the Super Wide-I SeaCam, and that's when a conversation got started.

"For us, it was the right request at the right time. We had recently been experimenting with some new camera technologies with the aim of building a very compact system that would combine high quality HD imagery with very long recording time. One of the issues was that they had no ability to bring those high-definition video signals into the sub or record from the landers, so the camera had to store the images within the body."

DeepSea wanted to incorporate the electronics for this camera in the form factor and using the optics of an HD Multi SeaCam. The next challenge was to ensure the 6km rated system would be able to work at 11km. The company essentially had all the components in place, and it was just a matter of assembling them and proving the result.

"This was actually a very quick development cycle from concept to prototype," said Steiner. "Principally, we had to carry out computer simulation to understand what was needed to change in the housing geometry to support a dome yet withstand the immense hydrostatic pressures. We then needed to physically test the camera module itself to understand its operational limits.

4K SEACAM

In 2019, before Five Deeps, Caladan Oceanic (the private exploration company founded by Victor Vescovo) wanted to augment the IP Multi SeaCam with an additional 4k Apex SeaCam when conducting its Titanic expedition.

The operators were so impressed with the capabilities of the camera, that they wanted to make it a permanent asset to the vehicle. This meant it had to be re-rated to 11km.

"Again, we had been working on an 11km rated zoom camera housing for a different customer," said Steiner. "We were essentially able to adapt the electronics into a new housing and provide Caladan with the first ever 4K full ocean depth rated camera. In fact, we are currently working on the camera settings to get them improved low light performance.

"Again, we didn't really have a way to get the high definition or 4K signal back into the submersible and had to carry out all of the video recording within the body. Since then, however, the designers have added a path to get Ethernet signals through into the vehicle. The pilots are now able to monitor and operate the camera using this system."

TESTING

Any time a human is put in such extreme and dangerous environments, it is important to have trust in the technology and materials. This is not only true of the main vehicle, but all the peripherals as well. Even an implosion from a small unit at those immense pressures could have important consequences.

"Only a diligent testing programme would be enough to verify that high degree of confidence we have in the design," said Steiner. "In order to qualify our equipment, we used an automated pressure chamber which allowed us to conduct high cyclic testing programmes.

"Of particular importance in the analysis of possible failure modes, was the dome port housing. More than anything else, cycle testing would reveal potential issues and validate the robustness in this critical area.

"The chamber we invested in is able to change from atmospheric pressure all the way up to 20,000psi (maximum 30,000psi) and repeat this at a rate close to 1000 cycles a day.

"In our testing process, we did that for 10,000 cycles, sometimes interrupting the process and removing components to inspect for movement or deformation in the housing.

"The first product that we tested to 10,000 cycles was the Apex SeaCam. Putting this in context, 10,000 cycles is an outrageously large amount of actual dives. I don't think Alvin has carried out anywhere near that many - maybe 6000 dives over its entire 60 year or so lifetime.

The Skaff Lander surrounded by Grenadiers (Rattails) at 6000m Image : Victor Vescovo

Image from first crewed descent to the very bottom of the San Cristobal Trench south of the Solomon Islands. It was taken from an IP Multi SeaCam, of an IP Multi SeaCam, and has Limiting Factor in the background. Bottoming out at a preliminary 8483m, the bottom had a unique topography. Image: Victor Vescovo

"We don't believe anybody has ever done that sort of rigorous of pressure testing before, however, this regime has now become standard for us. Whenever we make a design update, we'll qualify old products using this same test process.

"A lot of this testing work was driven by Triton," continued Steiner, "because they're understandably passionate about ensuring safety of the occupants.

"One of the ways they go about doing that is to use the expertise of a classification agency to sign off on both the individual design elements and the overall performance of the vehicles that they produce."

For the Limiting Factor, Triton worked closely with DNV GL to certify this submersible for full ocean depth operation. This, in turn, meant that everything on the sub also had to pass the critical DNV GL design reviews and testing protocols.

"For us, that meant that we had to have material tracing and know exactly what material every piece of the pressure housing came from," said Steiner. "There was also some additional on site testing but at that point, we had all the confidence that there were not going to be any issues.

"One of the more interesting pieces of feedback that actually changed the way that DeepSea designed its systems was the result of a failure of its SeaLite installed on the lander.

"The landers were to be deployed in the extremely cold Arctic conditions of the Southern Ocean, however the lights kept dying as they were being prepared for launching.

"This was a surprise as we had carried out a considerable amount of testing on these lights in the freezer in our factory and they should have performed perfectly in the cold environments. We asked for more details and it turned out actually that it wasn't the cold, but the wind.

"In addition to the cold temperatures, the area was subject to high winds – something for which we had never thought of testing. We installed a fan inside of the freezer and managed to repeat the failure issue.

"We had actually designed into the lights a provision for adding additional temperature sensing, so were able to resolve the issue with very minor modifications. We essentially sent them a kit which they could add to the top of the light. After carrying out a quick firmware update, they were able to get things working again out in the field.

"Since then we have permanently installed a fan system into our freezer so that we can replicate those Arctic winds during all testing."

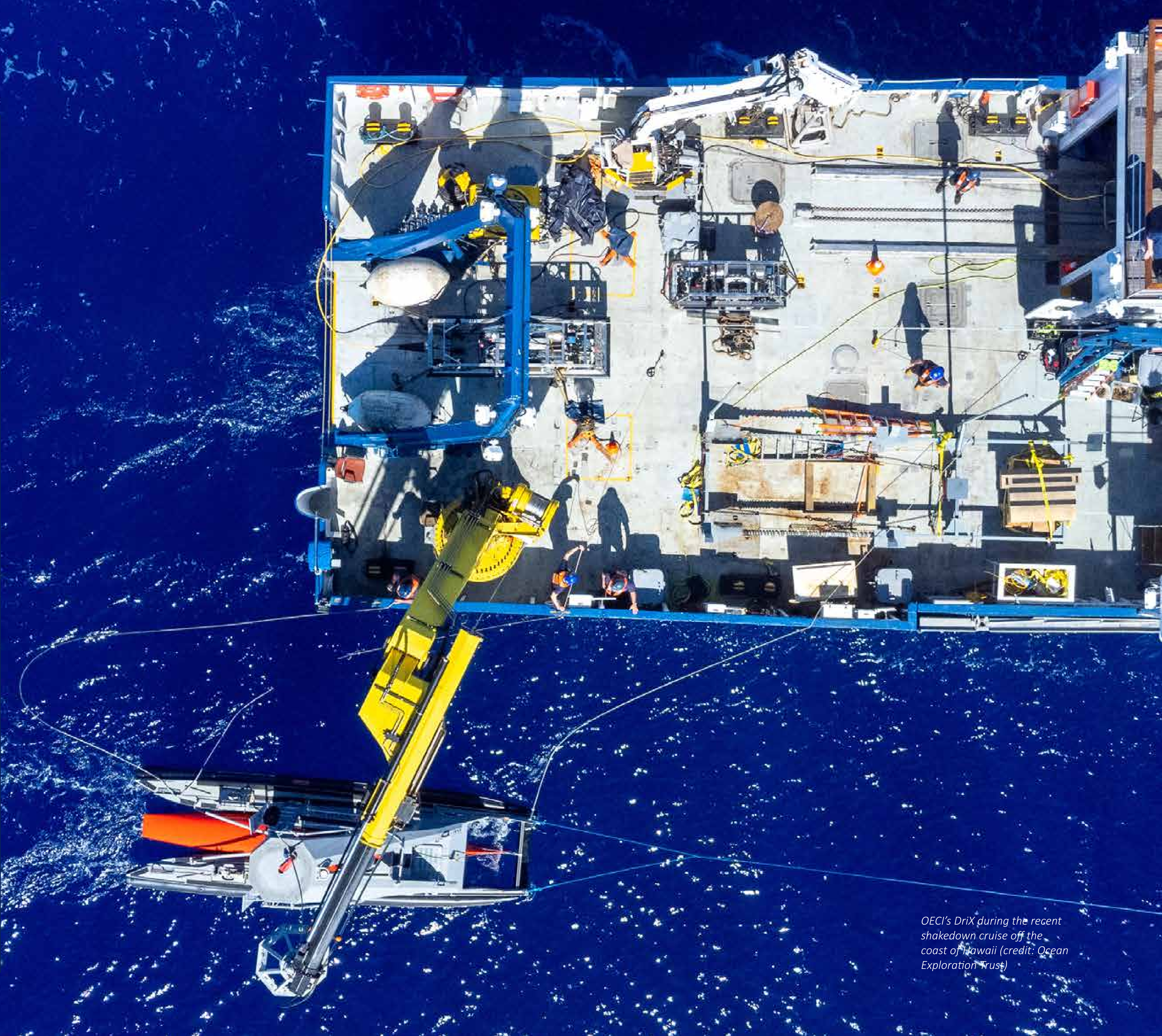
DriX & UDS

The University of New Hampshire's Center for Coastal and Ocean Mapping (UNH CCOM), as a member of the Ocean Exploration Cooperative Institute (OECI), funded by NOAA Ocean Exploration, has taken delivery of an iXblue DriX Uncrewed Surface Vehicle (USV) and its Universal Deployment System. The autonomous solution will help expand the footprint and efficiency of the OECI's ocean exploration operations.

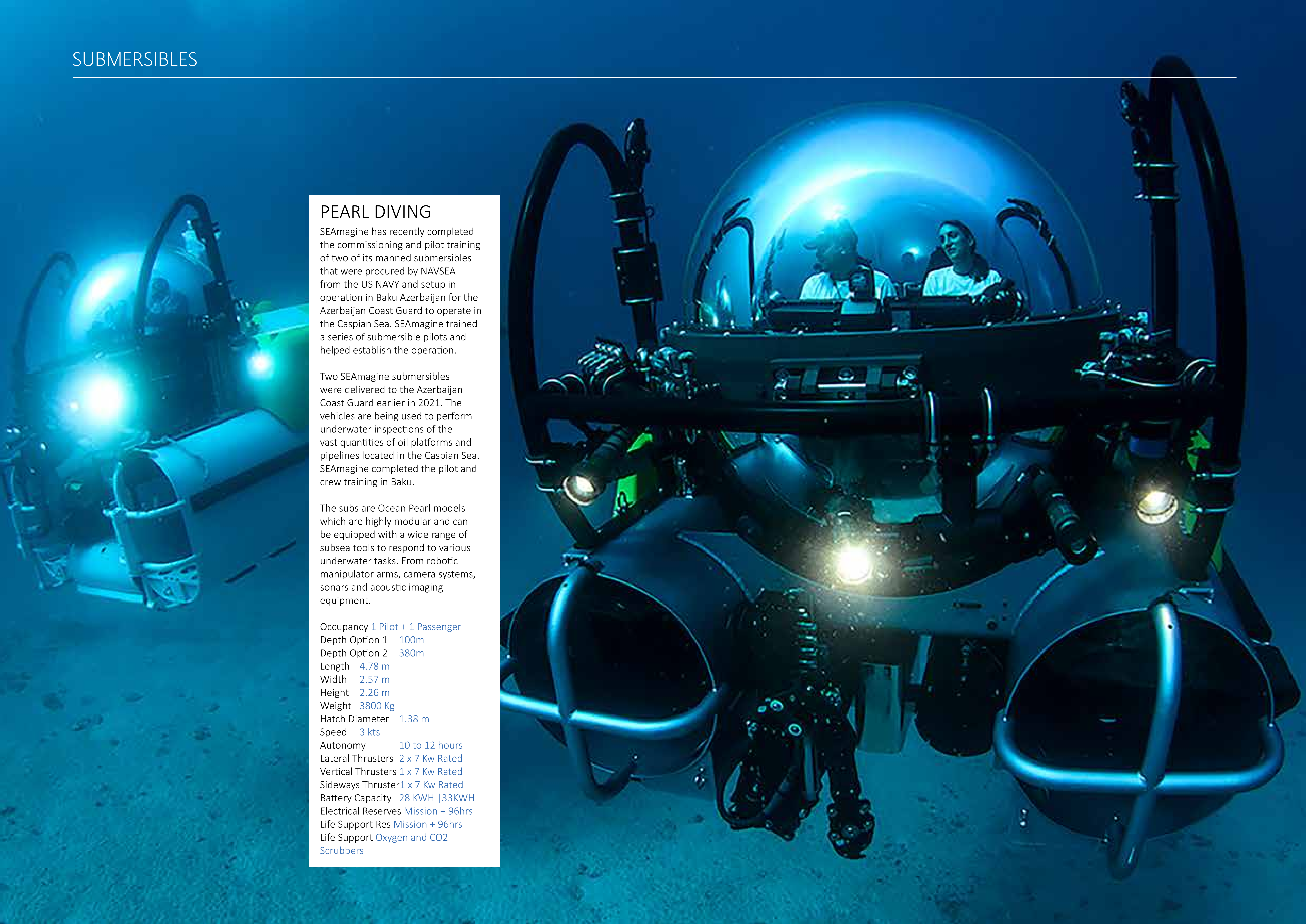
Delivered in July to UNH CCOM, DriX and its novel Universal Deployment System have successfully completed sea acceptance trials and extensive personnel training during the summer of 2021 as well as integration and a first shakedown cruise onboard Ocean Exploration Trust's E/V Nautilus in March 2022.

"We are delighted to embark on this exciting endeavour, working collaboratively with our partners to develop and enhance autonomous technologies that will expand the limits of our capabilities and bring new efficiencies to our efforts to explore and characterize the vast unknown areas of our oceans," said UNH CCOM Director Larry Mayer.

Selected by OECI for its mission endurance, ability to operate at high-speed, and excellent offshore seakeeping ability, DriX will support NOAA Ocean Exploration's mission by providing mapping and characterization capabilities and supporting other autonomous vehicles that are independent of the activities of the mother ship, greatly expanding the efficiency and effectiveness of ocean exploration operations. The research being conducted with DriX will serve to inform NOAA on the potential use of autonomous systems in support of the broad NOAA mission.



OECI's DriX during the recent shakedown cruise off the coast of Hawaii (credit: Ocean Exploration Trust)



PEARL DIVING

SEAmagine has recently completed the commissioning and pilot training of two of its manned submersibles that were procured by NAVSEA from the US NAVY and setup in operation in Baku Azerbaijan for the Azerbaijan Coast Guard to operate in the Caspian Sea. SEAmagine trained a series of submersible pilots and helped establish the operation.

Two SEAmagine submersibles were delivered to the Azerbaijan Coast Guard earlier in 2021. The vehicles are being used to perform underwater inspections of the vast quantities of oil platforms and pipelines located in the Caspian Sea. SEAmagine completed the pilot and crew training in Baku.

The subs are Ocean Pearl models which are highly modular and can be equipped with a wide range of subsea tools to respond to various underwater tasks. From robotic manipulator arms, camera systems, sonars and acoustic imaging equipment.

Occupancy 1 Pilot + 1 Passenger
Depth Option 1 100m
Depth Option 2 380m
Length 4.78 m
Width 2.57 m
Height 2.26 m
Weight 3800 Kg
Hatch Diameter 1.38 m
Speed 3 kts
Autonomy 10 to 12 hours
Lateral Thrusters 2 x 7 Kw Rated
Vertical Thrusters 1 x 7 Kw Rated
Sideways Thruster1 x 7 Kw Rated
Battery Capacity 28 KWH |33KWH
Electrical Reserves Mission + 96hrs
Life Support Res Mission + 96hrs
Life Support Oxygen and CO2 Scrubbers

HYPER SUB

HYPER SUB

Florida-based Hyper-Sub Platform Technologies Inc. has developed and successfully tested its Fast Boat Dry Cabin Submarine (FBS). It is a long-range speedboat that is also able to submerge for extended operations. Its 0.8m draft allowing it to operate right up to the shoreline or navigate rivers and estuaries.

The FBS is suitable for a range of applications aimed at the sport and tourist market, the commercial science and salvage community and the military where it can reside over the horizon, covertly moving into an area and loitering submerged for extended periods of time. Divers remain dry and warm until mission execution.
There is also interest in this unique capability from the offshore energy market for a ‘self- delivering’ ROV with work class manipulators, pipeline survey eqpt etc., particularly for shallow water scenarios.

"The design is scalable and highly modular," said subsea technology consultant Alasdair Murrie. "This means that it is possible to select a huge variety of configurations and payload packages. It can also be easily upgraded for a specific mission needs or future campaigns as projects develop or for fast change-out in theatre. "

Its rigid sea frame provides a low centre of gravity while securing the engines, ballast tanks, battery modules and the dry chamber. The vessel's low-profile design helps stabilise it in turbulent sea conditions, minimising detection and allows it to operate fully submerged and undetected in only 4m. of water.

SPECIFICATIONS

Length:	45’ 2” (14m.)
Beam: (With side tank modules installed):	16’ 6” (5m)
Height:	9’ 6” (3m.)
Draft:	3’ 10” (1.2m.)
Dry Weight:	30,000 lbs.
Pilot Cabin crew:	2
Lock In/Out Chamber swimmers:	up to six
Variable Cargo Capacity:	3,000 lbs.

"In speedboat mode, the aluminium V-hull can be launched from any dock, boat ramp and beach/river estuary. It can then travel hundreds of miles on the surface to arrive at a dive site. It has a standard fuel capacity of 1,987lit of diesel

It is driven by a pair of 480-hp Yanmar 6LY3-ETP diesel with V-drives, each connected to a 4-bladed propeller to give a 26 kts cruising speed at 3000 RPM. It has a maximum speed of 31 kts (min. payload and sea conditions) and planing speed can be achieved in 8 secs.

SUBMARINE

By engaging a control switches, the Hyper-sub can dive to 500ft (150m), traveling submerged for long distances or durations in excess of 12hrs.

When submerged, the electric thrusters are driven by 22.8 kWh or larger capacity batteries. Its twin 60 hp 12in Innerspace thrusters provide a maximum submerged speed of 5.5 kts /10 Kph. It can hover with the aid of two 10 hp vertical Innerspace thrusters. In all, it has a maximum potential submerged range of 260km at 1.4Kts. It can also recharge the battery packs and dive air multiple times via engine driven generator on the surface, or whilst submerged via engine snorkels.

The submarine has a minimum life-support duration of of 12 hrs or 48 hours in emergency situations extending to 72 hours in certain mission profiles. Electrical circuits are rated at 96 VDC and 12 VDC although other voltages are available for additional sensor and tooling payload. It has a 4000 ft3 air storage at 4500 psi

Eight separate air compartments retain over 30,000 lbs. (13,600 kg) of total reserve to carry out a submerged lift for rapid ascents in the event of the most severe emergencies, with four of these chambers providing routine controlled ascent/lifting capabilities up to 15,000 lbs (6,805 kg). There is sufficient reserve air to blow ballast tanks twice at 500ft (152 m) depth using standard air loads.

There is an emergency submerged recovery system in which the boat can surface with all primary air, electrical and hydraulic systems shut down in a controlled fashion. The complete system is designed built and certified in accordance with International Classification Societies (IACS)

LAYOUT

Running down the centre, modular units can be swapped out for different mission cabin options.

The pressure inside the dry cabin doesn’t change, regardless of depth, remaining at ambient surface pressure throughout the mission. It can be customized to suit a variety of specifications and requirements including alternate seating layout, crew or passenger capacity, equipment etc. A floodable diver lock-in / lock-out chamber can also be integrated.

Additionally, it can significantly increase diver bottom times by supplying additional SCUBA air that an also serve to aid decompression routines.

The rear and side deck includes space for ad-hoc equipment, storage boxes, combat swimmer mission apparatus, tool storage, or other payloads.

There are numerous navigation options. These include a Simrad Halo 20+ navigation sonar / radome (or equivalent) as well as an Echosounder with chart plotter. The system can also be offered with full industry leading, automated navigation and supervised autonomy system for surface and subsea, Integrated inertial navigation, vehicle control, automated tasks, payload integration, and target-relative positioning. This will allow for future, unmanned variants.

It carries a hybrid acoustic navigation solution with Doppler Velocity Log, AHRS motion reference unit, north seeking gyro and depth sensor allowing for mid-water station keeping at altitudes from 30cm (12in) to 200m (656ft) plus pre-programmed waypoint following routines – Non-ITAR controlled, it has a full global coverage Iridium Satellite link.

It is fitted with colour zoom and low light monochrome subsea cameras and full lighting array as standard and
underwater, the pilot is assisted by an imaging sonar which can be used for real time diver tracking, obstacle avoidance and measurement of objects in zero-visibility conditions.

Underwater communications can be achieved by a Submerged EPIRB and VHF antennae deployment location and communications capability.

Hyper Sub

NEMO

Submersible manufacturer U-BoatWorx has recently gone from designing and building single units to order, to producing the world's first series-produced submarine. The company is currently building the first 15 NEMO vehicles and aims to have 40 by the end of this year.

The NEMO is a 100m-rated two-person submarine. Its low weight (2500KG) makes it possible to be put on a trailer and be towed behind a car.

It comes in two models.

At only 2000 kg (4400 Lbs) the NEMO 1 is one of the lightest manned submersible ever conceived. With its low-profile lines, the submarine stands only 1.44m above the deck. It is 2.2m wide and 2.5m in length.

The Nemo 1 is rated to 100m water depths and can move at 3kt underwater and can spend for up to 8 hours at a time submerged. It has space for one pilot

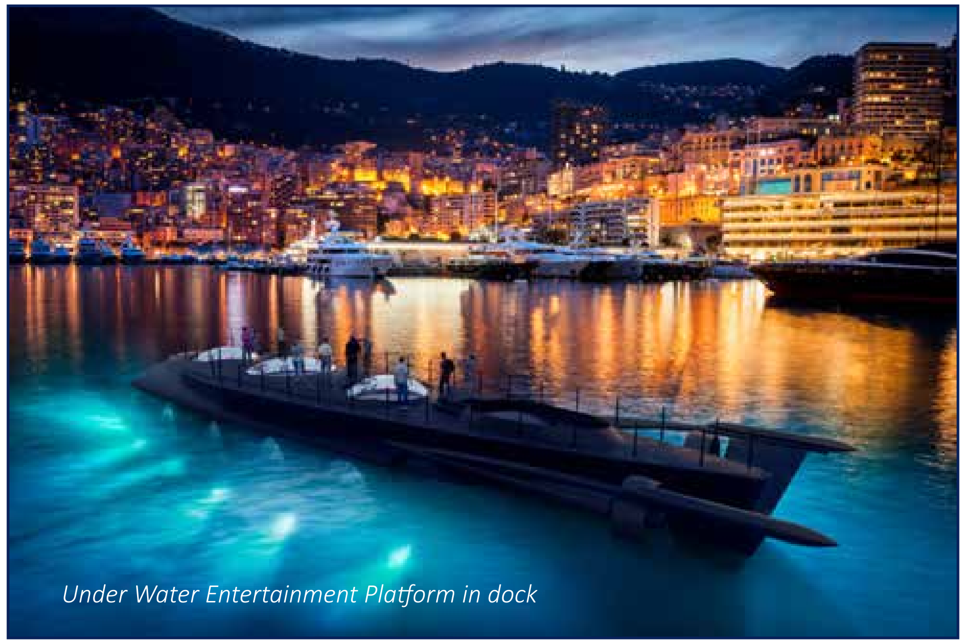
The NEMO 2, is the two-seat variant of the NEMO series. It weighs a little a more at only 2500kg (5510 Lbs) and has the same depth rating.

The sub is slightly bigger with a length of 2.8m, and stands 2.3m wide. It is 1.55m tall. It has the same speed and duration as the Nemo 1.

UWEP

U-Boat Worx has announced a completely new class of submarine – one that has been designed to host the most prestigious and memorable events on the planet.

The "Under Water Entertainment Platform", or UWEP for short, is a completely autonomous submersible with capacity for up to 120 guests, excluding crew. Guests will experience diving to depths up to 200 meters in comfort and style, and are free to walk around just as they would aboard a cruise ship.

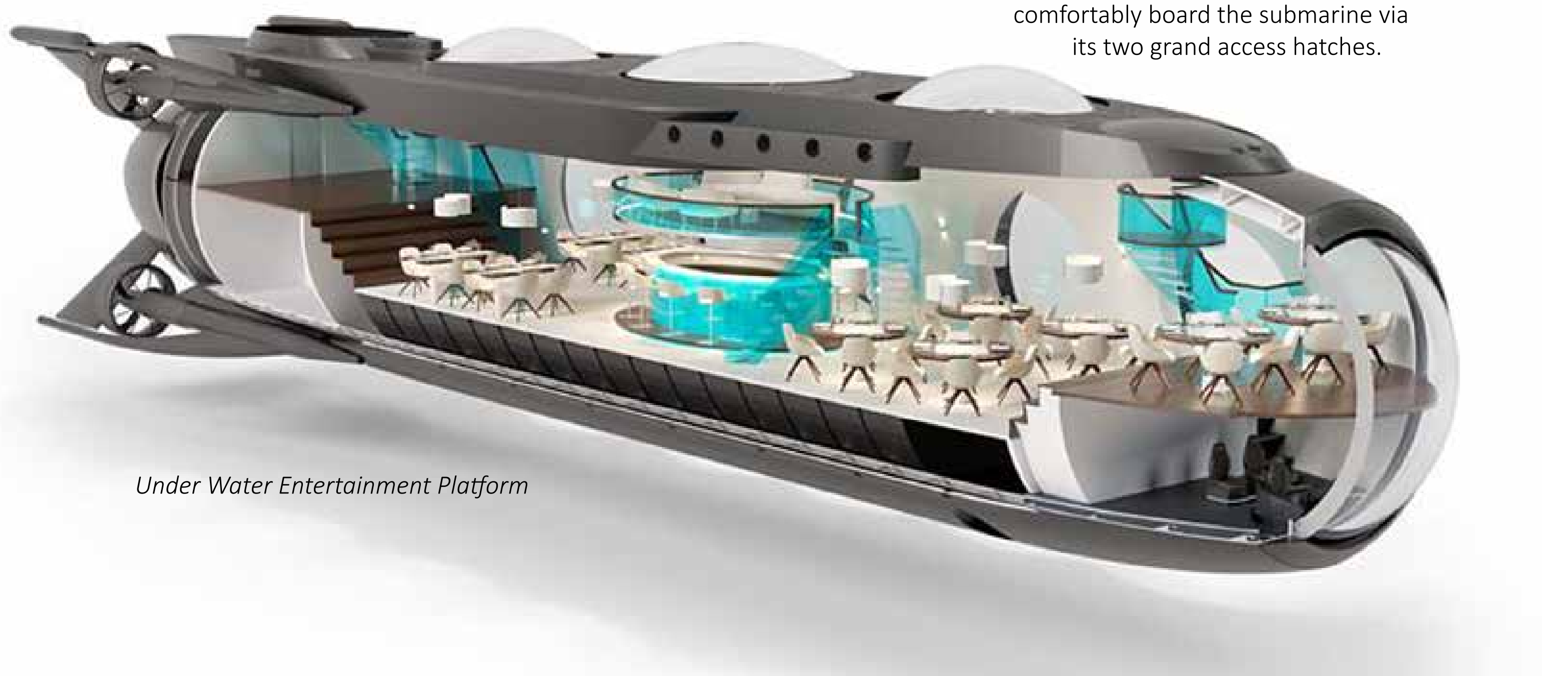


Under Water Entertainment Platform in dock

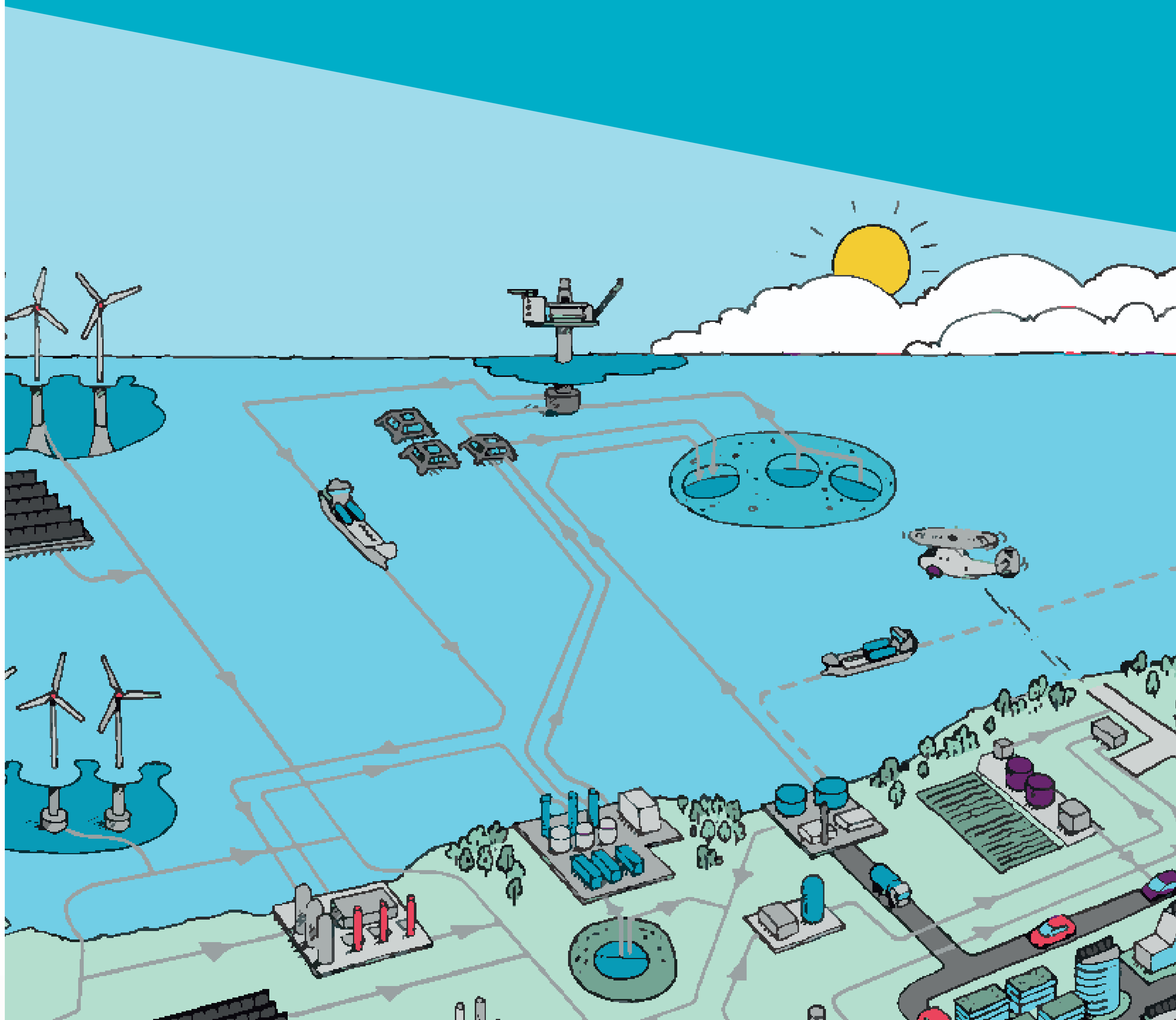
UWEP
Over 150m^2 (1,600 ft2) of floor space can be configured by the operator, varying from an underwater restaurant with 64 seats, a subsea gym, or a deep-sea casino. As a multi-purpose venue, the UWEP is suitably prepared to host product presentations, parties, weddings, conferences, or any other stage-based performance, in the most unique setting imaginable.

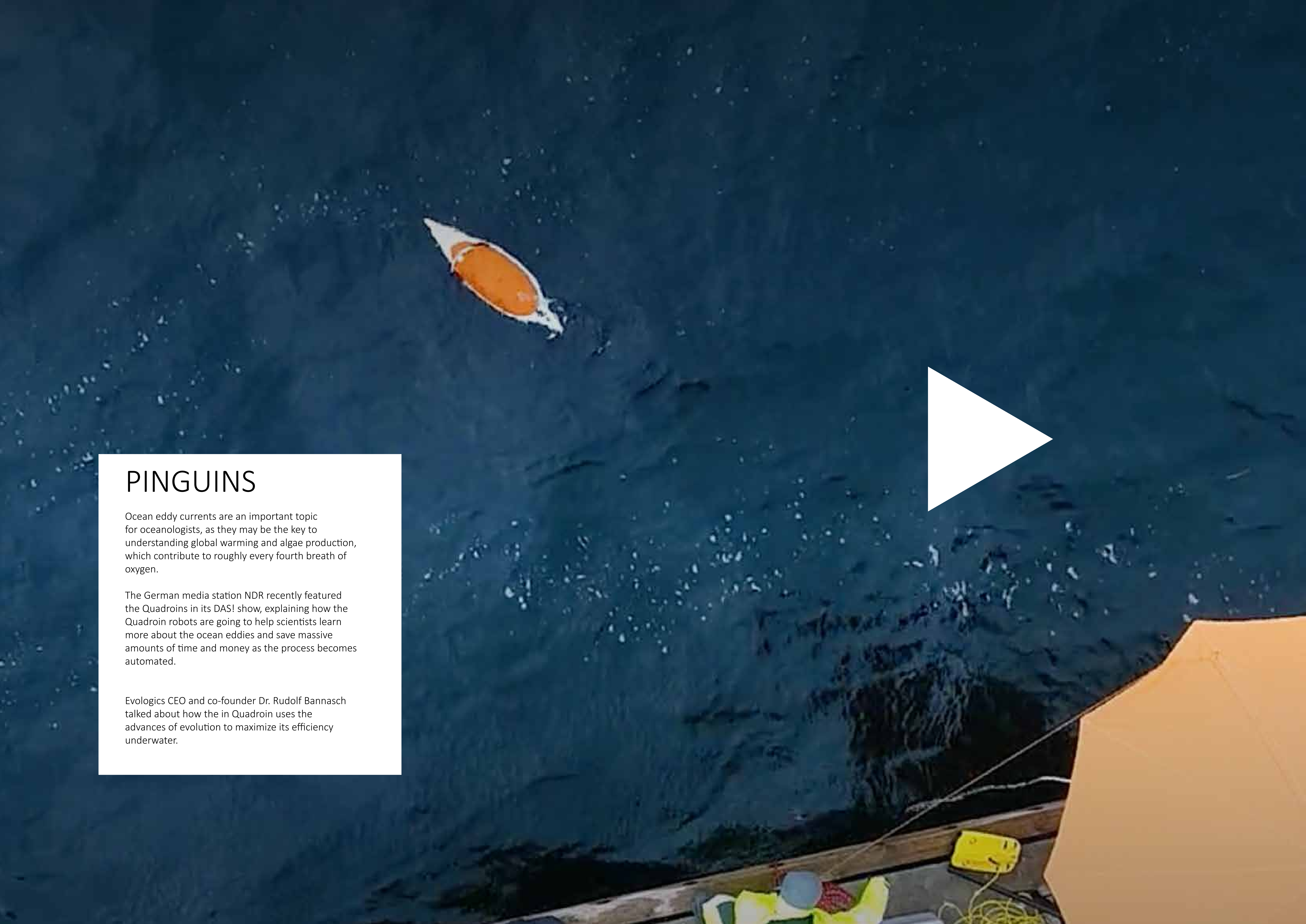
Fourteen windows connect the guests directly to the fascinating underwater world. A series of exterior lights illuminate the surroundings and add an extra dimension, whether to night-time diving or deep-sea dining experiences.

The UWEP runs solely on batteries and can operate non-stop for 24 hours. For the convenience of the guests, the air-conditioned UWEP is fully pressurized, so there'll be no need for decompression. Luxury washrooms and a galley are standard. Between cruises, the UWEP can be recharged and reprovisioned in a port or floating dock, where guests can also comfortably board the submarine via its two grand access hatches.



Under Water Entertainment Platform





PINGUINS

Ocean eddy currents are an important topic for oceanologists, as they may be the key to understanding global warming and algae production, which contribute to roughly every fourth breath of oxygen.

The German media station NDR recently featured the Quadroins in its DAS! show, explaining how the Quadroin robots are going to help scientists learn more about the ocean eddies and save massive amounts of time and money as the process becomes automated.

Evologics CEO and co-founder Dr. Rudolf Bannasch talked about how the in Quadroin uses the advances of evolution to maximize its efficiency underwater.