UV2

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UNDERWATER VEHICLES

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2 John Street,
London WC1N 2ES

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Editor: John Howes
John@ut-2.com
+44 7859905550

Editorial Assistant:
Jenny Séqua

Production:
Sue Denham

Advertising:
Zinat Hassan
UT3subsea@gmail.com

Tel: +44 (0) 845 6522 483
Mobile: +44 (0) 781 1200 483

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In these days of headline AUVS and ROVs shattering technology barriers everywhere, in this issue we look at other vehicles that make an equally important contribution

Front Cover: *A Slocum underwater glider investigating fresh water influences in the Taranaki Bight, New Zealand. Image: NIWA*

NEXT ISSUE: AUVs

DEREGT SUPPLY MINING CABLES

DEREGT HAS DEVELOPED THE CABLE SYSTEM FOR A NEW DEEP SEA MINING UNDERWATER VEHICLE

Apollo II Image: Royal IHC

“Scarce metals and minerals lie at the bottom of the ocean,” said Jeroen Romijn, Sales and Marketing Specialist at DeRegt Cables. “Many countries are looking into the possibilities of mining these raw materials at a depth of 4-6km.

"In such extreme conditions, standard equipment is ineffective. Maritime technology company Royal IHC is working on the development of an unmanned vehicle that can remove these valuable materials."

Royal IHC has joined forces with an army of suppliers including DeRegt Cables, to share knowledge within the framework of Blue Nodules, a European Union research project aimed at developing a deep-sea mining system.

In total, fourteen parties from seven European countries are considering how these nodules can be mined with minimal impact on the environment.

The system that has been developed can best be compared to a large vacuum cleaner, the *Apollo II* is equipped with a 5.5km- long pipe. Six powerful pumps transport the nodules 'harvested' by the vacuum cleaner to the mother ship.

This operation requires a lot of energy: about 5MW. By way of comparison, one megawatt can supply about a thousand households with electricity at the same time. DeRegt developed a one-fits-all cable so that one part can be easily replaced.

The most vulnerable elements are placed in the middle of the cable. Each steel wire is individually sheathed to protect it against corrosion. For optimum protection, the outside of the cable is covered with double steel armour. The test vehicle hangs on this cable and powers the ***Apollo II.***

Mining requires so much energy that a battery is not enough," said Wiebe Boomsma, Manager Product Development at Royal IHC.

"The system has been tested in the Mediterranean. Like in the ocean, there's almost no tide there. As a test site, it's easier to reach, less deep and the bottom is very similar to the ocean's."

Together with the Royal Netherlands Institute for Sea Research (NIOZ), IHC looked at the impact of the vehicle on the environment and the technical possibilities.

"In June, Blue Nodules comes to an end," Boomsma said. "The cable developed by DeRegt fits well on the underwater vehicle we developed and is ready to be sold commercially. That why DeRegt has been our strategic partner for subsea cables and umbilicals for over a decade” said Wiebe Boomsma.

NEWS

OCEAN INFINITY ACQUIRES MMT

Ocean Infinity Vessels

Ocean Infinity has acquired marine survey and data analytics provider MMT. The enlarged company will maximise the potential of Ocean Infinity’s fleet of Autonomous Underwater Vehicles (AUVs) and the soon to be launched Armada fleet of uncrewed, low-emission, robotic ships.

The company will be uniquely placed to support its international clients’ data acquisition requirements, working across multiple sectors including, energy, subsea cables, government and defence.

Following the acquisition by Ocean Infinity, MMT will continue to operate under the MMT brand. The enlarged group will have a headcount of over 300 people and will operate from an expanded geographical footprint with offices in the US, Sweden, UK, Singapore and Norway.

Reach and MMT has a pool cooperation where the risk and profit on certain vessels are shared, as well as a 50/50 ownership in ***Surveyor AS*** which owns our two high speed survey Surveyor ROVs.

The successful pool cooperation between Reach and MMT will continue unchanged.

● Ocean Infinity

In partnership with the University of Portsmouth, Airborne Robotics and Bentley Telecom, Ocean Infinity is to develop an autonomous offshore wind farm inspection capability utilising aerial drone swarms deployed from an uncrewed marine robotic vessel.

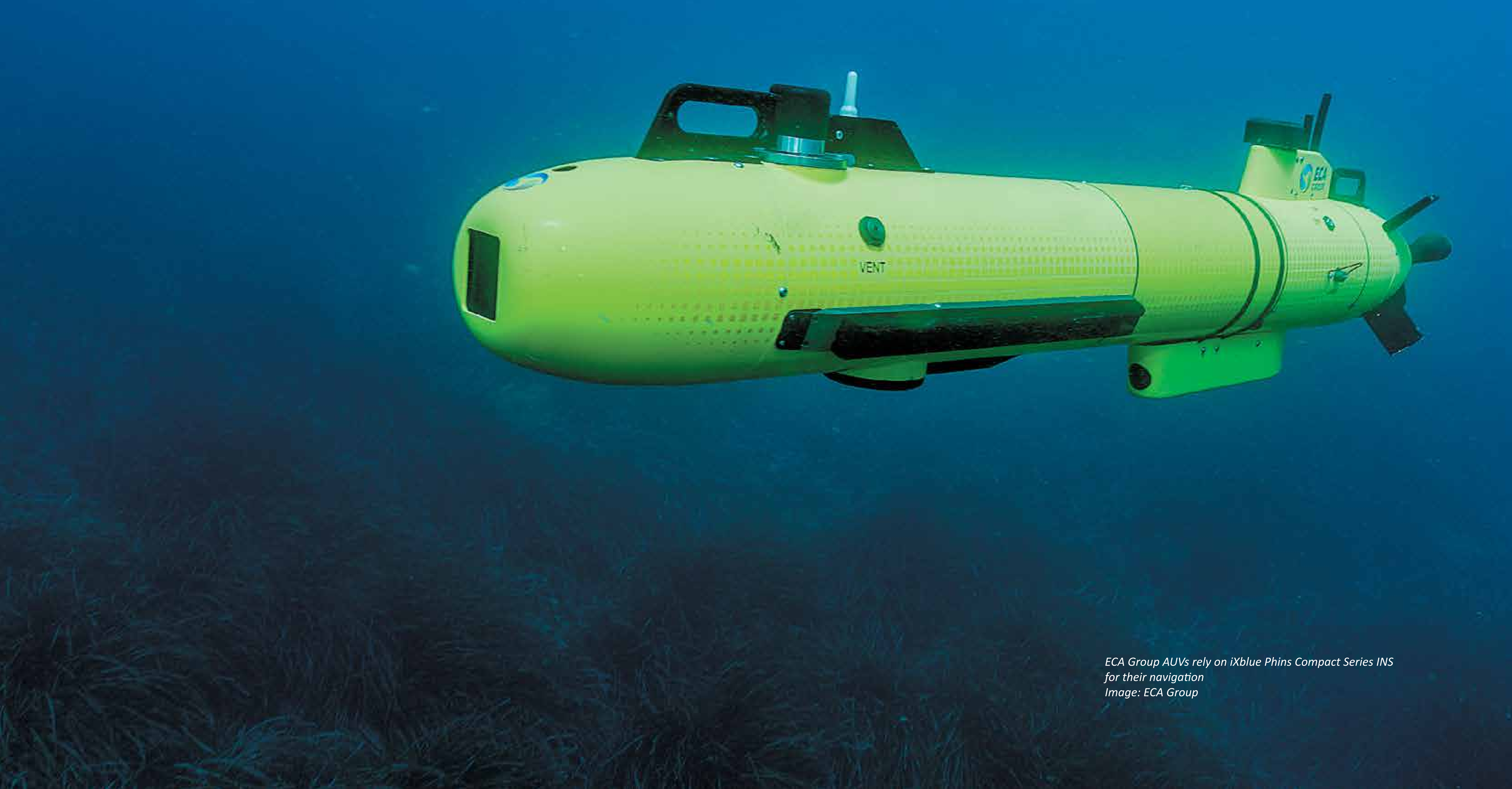
Using 5G and satellite connectivity, the project will see a swarm of drones autonomously inspect wind turbines subsequently removing the need for manual, human inspection.

A 36m Armada uncrewed robotic vessel will act as the host vessel for the aerial drones, facilitating launch and recovery, recharge, data download and transmission to shore via satellite.

The £1.67 million project will culminate in a system demonstration in 2022.

PHINS COMPACT SERIES:

MORE ROBUST AUTONOMY FOR ALL AUVS



ECA Group AUVs rely on iXblue Phins Compact Series INS for their navigation
Image: ECA Group

PHINS COMPACT SERIES

Leveraging state-of-the-art expertise in inertial navigation systems (INS), iXblue has developed the Phins Compact Series, a complete range of subsea INS specifically designed to improve accuracy, bring reliable cost-efficient navigation solutions to all AUVs and that is now recognised as a world leader for autonomous navigation.

THE RISE OF AUTONOMOUS PLATFORMS

Recent years have seen the rise of all types of autonomous vehicles, from Unmanned Aerial Vehicles (UAVs), to untethered Autonomous Underwater Vehicles (AUVs) operating in the challenging subsea environment. Offering a flexible turnkey solution for a wide range of applications, AUVs continue to evolve as a growing, dynamic solution.

Able to operate in difficult-to-access as well as hazardous areas where navigation is challenging, AUVs offer a flexible, cost-efficient and safer alternative that acts as a force multiplier and enhances the performance of traditional solutions for various applications including exploration, Metocean, as well as environmental, geophysical, and hydrographic surveys.

“In many regards, AUVs are some of the most, if not the most advanced autonomous platforms in the world. They are the only ones that are always forced to operate in a GNSS-denied environment,” explains Etienne Normant, Inertial Subsea Product Manager at iXblue.

“This is why the navigation solution is such an essential component. Because the navigation brings such a critical capability, we understand the importance of our position on the market. iXblue is not just a supplier of inertial navigation systems.

We believe that we can actually bring more robust autonomy to the platform including a growing importance in providing the positioning solution with our Gaps USBL acoustic positioning system.”

RELIABLE NAVIGATION FOR ENHANCED AUTONOMY

iXblue, recognized worldwide throughout the industry for its pioneering work on the development of Fiber-Optic Gyroscope (FOG) technology that has revolutionized maritime inertial navigation systems (INS), has put extensive efforts in R&D to develop new innovative autonomy technologies.

A key focus for the company, resilient navigation solutions have thus been developed by iXblue and the company is now considered a major actor of this new autonomous era.

Over the years, iXblue has developed long-lasting partnerships with various key industry players including private companies, research institutes and governments, to fully understand and anticipate the needs of the AUV market in order to remain at the forefront of technological advancements.

By truly understanding all specific aspects of the AUV market and its challenges, iXblue was thus able to develop the Phins Compact Series INS, especially designed to offer a scalable and highly accurate and reliable navigation solution that enhances AUV autonomy.

iXblue complete range of subsea INS power robust autonomy for over 80% of AUVs worldwide

PHINS COMPACT SERIES: THE WORLD LEADING SOLUTION FOR AUVS NAVIGATION

The Phins Compact Series is a genuine strap-down solid-state system free of moving parts that offers quiet and stealth autonomous navigation and does not interfere with sonars and other payloads acoustic noise, while also providing increased autonomy to the subsea platforms thanks to its very low-power consumption.

Launched back in May 2016, the Phins Compact Series has since then been chosen by major AUVs manufacturers and integrators to provide reliable autonomous subsea navigation.

Comprising the Phins C3, C5 and C7, the Series offers a fully scalable solution that allows AUVs industry players to choose the inertial navigation system the most suited to their needs, whatever the platform’s size and mission type.

Available in OEM versions, the Phins C3, C5 and C7 share identical architectures and interfaces and incorporate the same algorithms and software, enabling customers to re-use the control system on any other type of AUV via modern interfaces such as Ethernet, reducing initial integration costs.

Benefiting from an MTBF (Mean Time Between Failures) of over 100,000 hours, without any need for preventive maintenance, the Phins Compact Series guarantees the highest level of reliability and robustness and is now considered as the standard navigation solution on which AUVs can rely to be fully autonomous.

“iXblue’s success on the AUVs market rely on many factors. One is, of course, our unrivaled FOG

Hydroid Remus AUV being deployed for a subsea operation

technology. But another of our strong suits are our advanced algorithms. Everything is about data nowadays, and data is key to highly reliable navigation.

"We can think of an AUV as being a mix of a lot of very good sensors, including DVL, GPS, USBL and LBL to only name a few. The challenging part to make the platform fully autonomous, is to merge all those data to provide a reliable navigation capability," states Etienne Normant.

"Thanks to our advanced algorithms and Unscented Kalman Filter, our inertial navigation systems have now become the prime sensor fusion engine, from a navigation, position and timing standpoint. This is why we are able to bring more robust autonomy to those unmanned platforms. We also develop a full software suite, among which Delph INS, that will help users and integrators alike to validate or improve their mission scenarios regarding navigation.

Our software suite incidentally also helps improve the quality of the data collected by the subsea vehicle by postprocessing it. Overall, we have the best technology available for the navigation of AUVs today and this translates into the sheer number of iXblue systems that are now roaming the oceans in full autonomy."

https://www.youtube.com/watch?v=FtjwUNT7trM

BIRNS COAX

BIRNS has introduced new RF subsea connector contacts. Coax subsea connectors had in the past been challenged in a range of design requirements, in many cases resulting in poor impedance, high losses, and inability to provide open face pressure resistance.

BIRNS, however, launched proprietary RF technology with contacts capable of open face pressure ratings to 1433m, UHF insertion loss of ≤0.7 dB at signal frequencies to 3GHz and maximum UHF voltage standing wave ratio (VSWR) of 1.7:1.

The newest product introductions with these features include the BIRNS 1V series, featuring a unique, compact coax contact that offers 75Ω impedance in the same footprint of a 50Ω contact.

The new 1V line is ideal for HD/SD video with signal frequencies to 3GHz. All coax pin configurations in the 6km-rated BIRNS Millennium series are now offered with this new extremely compact coax contact.

BIRNS also launched its 1B series: new ultra-low-loss RF pressure-rated connectors for use to SHF band Ku (18 GHz). The company recently developed these pressure-rated low-loss RF connectors exclusively for the US Military for use to SHF band Ku.

BIRNS 1V 75Ω (left) BIRNS 1C a 50Ω (right)

BLUEPRINT LABS GRANT

Having settled into its new Glebe, NSW headquarters Blueprint Labs has delivered a Reach Bravo manipulator to University of Technology Sydney's (UTS) Centre for Autonomous Systems (CAS). It has also sponsored the Sydney University Mechatronics Organisation (SUMO),

More recently, the company has been awarded a Defence Global Competitiveness Grant, allowing greater opportunity for testing and verification.

The grant will fund an inspection class ROV deployable test vehicle and allow us to conduct certification activities to meet international EMC safety standards.

RE2 ROBOTICS

RE2 Robotics,has unveiled its new robotic arm brand, RE2 Sapien. Its systems feature intelligent robotic arms with intuitive human-robot control interfaces and outdoor (including underwater) computer vision and autonomy capabilities.

The Maritime Dexterous Manipulation System (MDMS), developed for US Navy applications, will now be called the commercially as RE2 Sapien Sea Class arms.

The arms feature high strength-to-weight ratios, precise control, and dexterity that matches or exceeds the performance of human arms.

Film-Ocean ROV

FILM-OCEAN SCHILLING UHD

ROV specialist Film-Ocean has recently invested a six-figure sum in a Schilling Heavy Duty Work Class ROV (Remote Operated Vehicle) and plans to grow its workforce to support the company's ambitious growth plans.

The Schilling Heavy Duty Work Class ROV is capable of operating at depths of up to 4000m and is supported by an Active Heave Compensation Launch and Recovery Systems (AHC LARS). It is a highly manoeuvrable vehicle capable with a large payload.

The HD Work Class ROV is well known within the industry as a high specification vehicle making it an ideal system for IRM, construction support and decommissioning work scopes especially in deeper waters.

As part of its 5-year growth plan, Film-Ocean has expanded its workforce by over 50 percent in the past two years. Recent appointments have seen several new positions being created, that have included an ROV Technical Support Engineer, Stores Person and Crewing Team Lead.

RS AQUA SEAMOR

RS Aqua has signed an exclusive partnership with Canada-based SEAMOR Marine.

The partnership enables RS Aqua to distribute SEAMOR Marine's range of commercial inspection remotely operated vehicles (ROVs) in the UK and Ireland and is part of the company's long-term growth vision.

Established 15 years ago, SEAMOR Marine is one of a few ROV companies in Canada to export globally and their ROVs can be found in every major body of water around the globe.

They are designed for a wide range of applications including search and rescue, fish farm monitoring, pipeline and infrastructure inspections.

BEDROCK SURVEYING

Accurate mapping of the ocean is currently one of the largest data gaps on the planet. Start-up company Bedrock recently announced seed of $8m to solve the technical challenges of bringing such a venture to fruition.

The company say that they have experience in spacecraft, autonomous aeroplanes, manned submarines, and complex autonomous robotic systems. They have also worked with marine data, environmental data, and large cloud systems.

“Over 80% of Earth’s oceans are unmapped, unobserved, and unexplored,” said a source.” Furthermore, it is currently believed that less than 5% of the ocean is bathymetrically mapped at less than 100m resolution. This is a resolution rendered useless for commercial activity.

"Ocean exploration will be solved through the mass acquisition, and interpretation of data — particularly sonar data, at scale.

“Today, survey is typically carried out by fleets of ships or surface vessels. They are expensive and this has driven the cost upwards. These vessels often tow sonars behind them on long, drag-inducing tethers to collect the many other critical datasets commercial, government, and scientific organisations need. It is not operationally or economically scalable.

"Further, the quantity of data generated by even one medium-sized survey of 50km² is tens of TeraBytes. This data may be shipped around (in physical boxes), changing hands from surveyor, to processor, to geophysicist, to GIS specialist, and *finally*, the end purchaser of the data. This process takes 3–12 months depending on the size of the survey.

"Adding to the inefficiency, data cleaning, processing, and interpretation lives on desktop software and requires an immense amount of human-in-the-loop hand-holding to reach a final processed state.

"Bedrock’s solution is a subsea autonomous fleet to capture high-quality, affordable, and reliable data on the seafloor. As such, it has released the early designs of a new Autonomous Underwater Vehicle (AUV), specifically engineered for marine geophysical surveys.

"In order to cope with the enormous quantity of raw data gathered during the course of a single operation, the company is building a cloud data management tool called Mosaic."

FALCON FOR EMERGENCY RESPONSE

The rapid detection of hazardous substances in Turkey's offshore water has been made possible with a Saab Seaeye Falcon operated by MOST Maritime and Environmental Services.

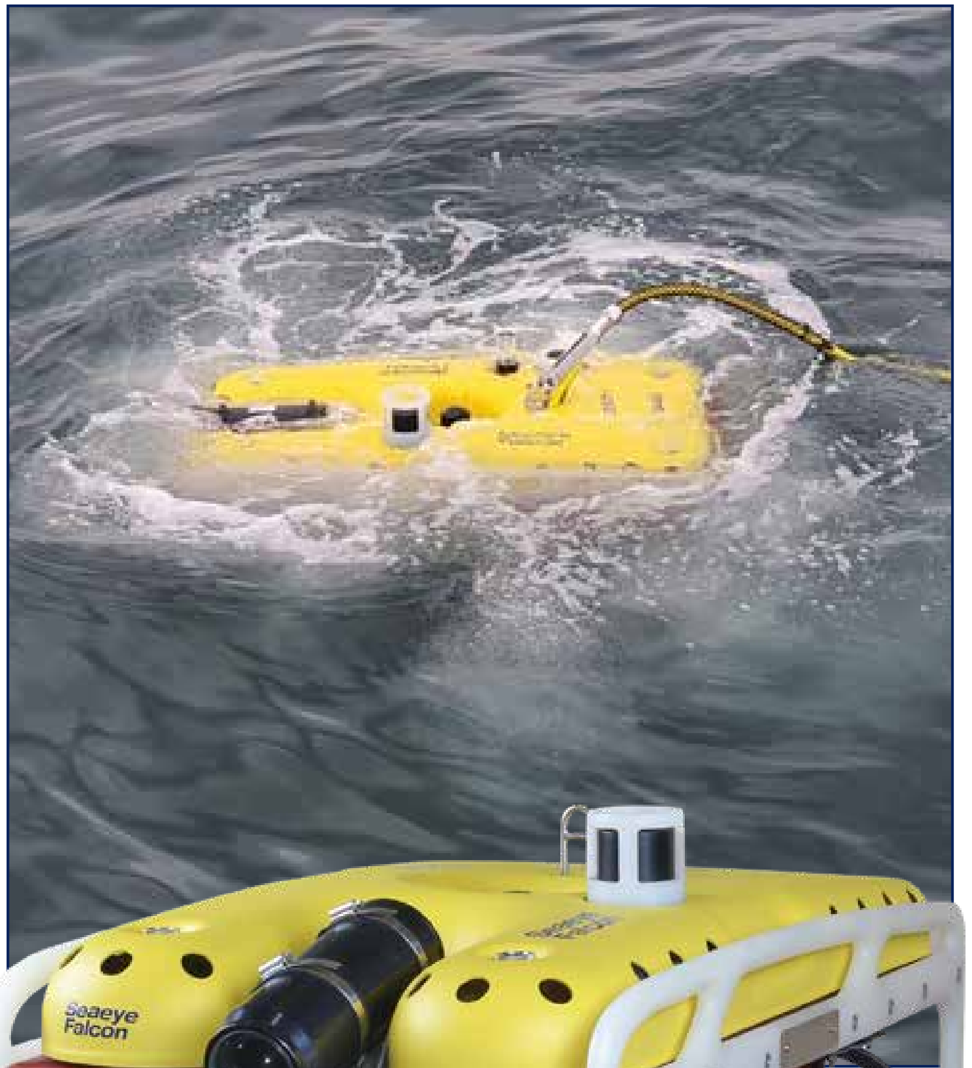
MOST Maritime's emergency response team chose the remotely operated vehicle for its speedy deployment complete with cameras and multi-sensor detectors, ready to locate the incident, observe and secure the danger.

The company provides global emergency response services for petroleum and other harmful substance spills in the sea and inland waterways worldwide.

Easy to deploy, the Falcon's rapid response capability makes it a vital resource for hydrocarbon leak detection where speed is essential to avoid the serious consequences of economic loss and environmental pollution.

Depth rated to 300m and 1000m, the Falcon is the world's top-selling underwater vehicle in its class noted for its ability to handle a wide range of cameras, sensors and tools, and a reliability record covering thousands of hours of undersea operations.

The Seaeye Falcon's success comes from its reputation as a versatile resource, with five powerful thrusters packed into a compact and easy-to-handle metre-sized vehicle enhanced by Saab Seaeye's iCON intelligent control architecture. The resultant design is a highly manoeuvrable, multi-tasking vehicle that is easy to use and able to handle strong currents.



Saab Seaeye Falcon

SCUBACOM

Seashells are the exoskeletons of molluscs such as snails, clams, oysters and many others. They have a critical role in coastal ecosystems such as providing nesting materials, a home or attachment surface for algae, sea grass, sponges, and a host of other microorganisms. Fish also use seashells to hide from predators while hermit crabs use them as temporary shelters.

ScubaCom has the only specimen seashell permit (EP0002) in South Australia which is closely managed by the SA Fisheries Department. Founder Steve Robinson said, "it is my aim to offer seashells to the world with a guarantee that all specimens have been responsibly collected ensuring species sustainability.

We currently have a database of every seashell taken by us (with photos and unique number) and will be able to verify all shells sold by us. You will see this section slowly grow as this business moves forward."

How did this adventure start?

According to ScubaCom's website, Steve was looking for a semi-retirement plan and the opportunity to apply for a specimen seashell permit appeared. It was a tough decision considering his commitment to environmental responsibility and the sustainability of any species collected.

Steve carefully analysed the environmental implications before starting this type of endeavour. "At this stage, I considered very carefully the impact a specimen seashell license would have on the environment."

These considerations included

(1) "this would be the only specimen seashell license in South Australia, so overfishing seemed impossible,"

(2) "the weather would only allow me to fish a small number of days a year,"

(3) "with specimen seashells, only the best shells have value so I would expect to only take about one quality shell out of thirty or more seen,"

(4) "South Australia also has many sanctuary zones protecting many seashell populations and marine parks ensuring minimal impact on species."

Most seashell collection will be done with a JW Fishers' Sealion-2 ROV to allow for individual seashell collection at a depth of 300 meters. The ROV has a modified manipulator arm with docking station so that seashells can be scooped up effortlessly. The umbilical from the surface is attached to the docking station and 25m of cable are coiled on the top shelf which come out when the ROV leaves the station.

This eliminates the umbilical drag from the surface. This method of operation results in zero damage to the marine environment while searching. Using a JW Fishers' ROV also significantly expands the search area to include locations that divers cannot reach.

Any seashells that ScubaCom has for sale on the website will show the fisherman's license number, processors license number, export exemption details, where the shell was caught, identification photo and data base number, and other information.

All of these details are available on a database, which the South Australian Fisheries Department can fully access.

JW Fishers' Sea Lion

HUGIN ENDURANCE

Kongsberg Maritime has launched the next generation of its advanced HUGIN Autonomous Underwater Vehicle (AUV).

Named HUGIN Endurance, the new AUV boosts operational duration to approximately 15 days, enabling extended survey and inspection missions far from shore.

This longevity allows HUGIN Endurance to undertake extensive missions without the support of a mothership. Shore-to-Shore operations offer the opportunity to reduce carbon footprint for commercial activities and yet retain unrivalled data resolution and accuracy.

With this in mind, KONGSBERG has added its Maritime Broadband Radio (MBR) communications system to HUGIN Endurance's payload, allowing it to surface and share large quantities of data swiftly with any suitably equipped installation, such as another vessel, shore station or a wind turbine fitted with an MBR antenna.

For defence applications, HUGIN Endurance makes persistence a reality. Whether it is long range military survey; wide area mine detection, classification and identification; or even patrolling a choke point listening for submarines, this new extended range capability offers new solutions to existing and future challenges.

The HUGIN Endurance can be equipped with a wide array of sensors including the high-resolution KONGSBERG HiSAS synthetic aperture sonar, a wide swath multibeam echo sounder, sub-bottom profiler and magnetometer, together with other sensors to detect parameters such as methane, current and turbidity.

Hugin Endurance

CLASSNK ROV/AUV GUIDELINES

ClassNK has released its "Guidelines for ROV/AUV" which summarise the performance and safety requirements for remotely operated underwater vehicles (ROVs) and autonomous underwater vehicles (AUVs) as part of its activities to meet industry needs related to the establishment of safety standards for innovative technologies and third-party certification.

Up until now, ROVs and AUVs have been mainly used for oceanographic surveys and offshore oil and gas field development, but in recent years their scope in maintaining offshore wind power generation facilities and pipelines has been steadily increasing. Although the utilisation of ROVs and AUVs is increasing worldwide, no international standardisation of such technologies has yet been implemented.

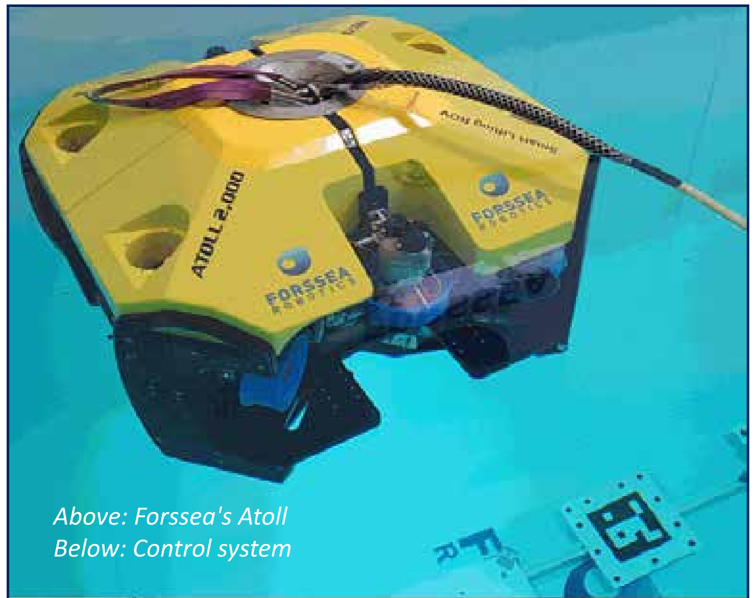
With this in mind, in order to contribute to the safe and effective use of ROVs/AUVs, ClassNK developed the guidelines which establish requirements related to the equipment and basic items that are generally required for the operation of these vehicles, as well as precautions and safety measures, based on the knowledge obtained through demonstration experiments with experts and companies making advanced efforts.

For implementing specific application cases of ROVs, they include the requirement for ROVs service suppliers as well as the procedures in using at ship surveys such as in-water surveys, internal hull surveys of flooded compartments and damage verification.

FORSSEA NEW WAREHOUSE

Forssea recently opened a new warehouse in Sète harbour, France which will serve as a future maintenance base for France Mediterranean offshore wind farms. Six engineers and technicians will work in the new office, where an ROV remote control room is currently being prepared for upcoming surveys.

Forssea has also installed an 8m long by 3m deep test tank to carry out its underwater systems acceptance tests prior deployment in operations. An area will be dedicated to Forssea's underwater vision systems manufacturing and maintenance. Recently, Forssea organised an open day and welcomed several local marine players for complete system presentation.



Above: Forssea's Atoll
Below: Control system

SRV

Forum Energy Technologies has completed manufacturing a highly advanced submarine rescue vehicle (SRV) including cutting-edge technologies, which may be used to extract submariners from distress situations.

Inside the SRV

Forum's latest SRV joins a small group of rescue systems in use around the globe. The LR-class SRV, however, surpasses systems manufactured by other suppliers over the last decade, including the NSRS (NATO Submarine Rescue System) and the 'LR7', which was delivered to China.

The LR-class SRV is built to meet the most up-to-date industry standards and classed by Lloyds Register. It is capable of rescuing up to 17 people at a time and operate at depths of up to 600m.

The new model has increased power and an advanced auxiliary thruster control system that allows for speeds of up to four knots, enabling it to operate in high currents. The vehicle is able to attach to submarines at highly precarious angles, above 40 deg.

The state-of-the-art submersible vehicle also has some of the most advanced sensors and sonars to locate a distressed submarine as quickly as possible. This includes a Doppler velocity log, fibreoptic gyroscope, sonar and depth sensing.

Submarine Rescue Vehicle

All sensors and sonar systems are fully embedded into Forum's software to deliver advanced functionality, including auto depth, auto heading and autopilot. The latter function utilises an electric propulsor pivot mechanism and is unique to the company's LR-class SRV.

The LR-Class SRV is divided into two sections, a command module for pilots and a rescue chamber for the submarine crew. The rescue chamber can be pressurised as necessary to ensure rescued crew are decompressed to prevent decompression sickness.

Once at surface, the vessel latches to a decompression chamber where crew are safely transferred.

GEMINI ROV

TechnipFMC plans to announce additional contract awards for its Gemini ROV the very near future.

The first two Gemini systems have been working for Shell Offshore in the Gulf of Mexico since August of 2020.

Both systems are delivering the expected performance and productivity improvements resulting from the automated tooling exchange, ability to carry and work with many tools subsea, and the integrated fluid intervention capabilities.

UNDERWATER INDUCTIVE CONNECTOR

Norwegian subsea technology company Blue Logic has created a new company, Subsea USB, to provide its underwater inductive connectors to the global subsea industry.

Inductive connector

The product rights, technology and patents of Subsea USB's connectors were previously jointly owned with the Kristiansand-based Wireless Power and Communication (WPC). All assets within the product area have been transferred to Subsea USB, which will focus on sales, marketing and further development of its growing range of underwater inductive connectors.

Subsea USB may also accelerate further development of its technologies by raising external capital. "Market interest for underwater wireless connectors, with either one or two-way transmission of energy and signals, is expected to grow rapidly in the near future as the benefits of doing more subsea operations remotely using robotic systems are harnessed," said Helge Sverre Eide, the new managing director.

Subsea USB's are already supporting subsea operations in the offshore industry. The connectors are being used, for example, at Equinor's standard underwater charging station for underwater drones and enables such vehicles to be permanently installed on the seabed.

Vehicles operating from subsea charging stations can use Subsea USB's wireless connectors to charge and upload/ download inspection and assignment data. "Underwater charging stations are set to increase efficiency in offshore operations, with more availability, as well as increasing personnel safety during underwater operations, because humans do not need to be on or near site," adds Eide.

"Importantly, this innovation will also reduce the carbon footprint of these operations." Blue Logic will continue to be a reseller of Subsea USB's inductive connectors for underwater use and use these in their customer projects.

Blue Logic will also continue with all other ongoing activities, with the exception of pure new development of inductive connectors, for example in relation to underwater charging stations and tooling solutions for drones.

The transfer of the product area inductive connectors to Subsea USB will not affect ongoing customer projects at Blue Logic. Both Blue Logic and WPC believe that the continuation of inductive connectors for underwater use in a separate dedicated company, Subsea USB, will contribute to further growth in this future-oriented product area.

Subsea USB

RROV CUTTING TOOLS

Webtool has launched a series of long-term deployment RROV (Resident ROV) tools. Designed for up to 120 days continuous deployment, the tools are supplied with custom RROV interfaces allowing the easy storage, activation and recharging of the hydraulic cutters.

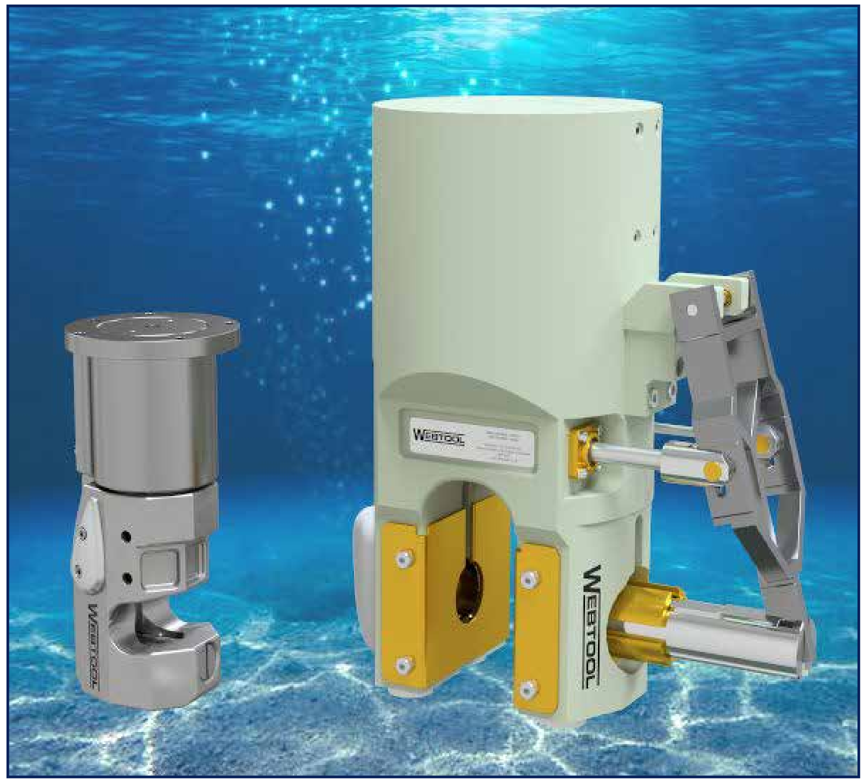
Webtool RROV hydraulic cutters are used for cutting steel wire rope, guide wire, fibre rope, umbilical, electrical cable, hoses and tubing during installation, repair and maintenance (IRM) tasks.

Once activated the hydraulic cutter provides a clean cut in seconds. For the RROV tools, the core cutting mechanism features a custom interface to suit the RROV's storage and operation requirements.

This includes interfaces for the manipulator arm, RROV or subsea storage and hydraulic connections.

Recent investments in CAD / CAM software enable Webtool to offer a seamless development of RROV cutting tool interfaces.

Manufactured from durable and lightweight materials, the tools are corrosion resistant and can be used at any water depth. In addition to standard cutting tools, Webtool is able to supply tools for RROV special applications.



RROV Cutting tool

FEATURE: SEABED CRAWLERS

AMPHIBIOUS VEHICLES

Over the years, the underwater survey industry has developed sophisticated measuring tools to quantify a wide variety of parameters. Sometimes, these tools can work at long ranges but more often, it is necessary to get them in relatively close proximity to the subject being measured. This, therefore, requires some sort of delivery vehicle.

Companies can select from many types, each with benefits and drawbacks that may either make them ideal for a given requirement or completely rule them out.

Survey boats are one of the most common vehicles, able to move very fast and cover large areas quickly. The downside, however, is that they can’t operate well in the very shallow water of the break zone.

In recent years the emergence of remotely operated and autonomous robotics has allowed unmanned surface vessels (USV) to become a popular choice with the survey sector. They are fast, light, supremely manoeuvrable and can work in relatively shallow waters. They are, however, limited by sea state.

Autonomous Underwater Vehicles (AUVs) have become extremely competent in large area surveys and the duration that the vehicles can operate autonomously, increases progressively. These too, however, are not particularly proficient in shallow waters and they still inherently require a support craft.

Quad copters have made an impact on the survey sector. They can cover a large area extremely quickly. Their problem is that they cannot see through turbid water and have a relatively limited mission time before requiring recharging.

Human measurement is very flexible, able to make intelligent decisions at site. The

drawbacks that they are limited to very shallow waters and calm conditions unless backed up by some sort of diving spread.

All these are very commonly used to great effect. One extremely versatile but relatively underused technology, however, is the amphibious bottom crawler. These too have their drawbacks, but are the only device that can travel across land, along the miles out to sea in one contiguous movement virtually regardless the sea conditions above.

Some crawlers are capable of working up to the edge the continental shelf, maybe down to 300m water depths. Alternatively they can cross shallow rivers, continually measuring as they move. Their potential applications are diverse.

"Autonomous amphibious bottom crawlers are very suitable for many commercial applications such as cable or buried pipeline surveys, beach shore end surveys, UXO and debris survey, acoustic monitoring and coastal management," said Graham Lester of Wight Ocean.

Isle of Wight-based Wight Ocean are a marine robotics consultancy that can be used for selecting the correct vehicle and then integrating work packages and technologies together to achieve a required solution. "Unlike floating alternatives, they provide a very stable platform which in turn, improves measurement quality and repeatability," he said.

"They can sit underwater for months if necessary for measurements over tidal cycles or long periods of time. It is even possible to recharge the crawlers underwater. They are a particularly good solution if the user wants a persistent presence such as for security purposes or military observation."

Amphibious bottom crawlers come in a wide range of sizes and able to accommodate range of payloads. They can carry heavy and modular sensor payload suites. They might travel a course with survey tools one

Crawler deployed from a van

AMPHIBIOUS VEHICLES

week and the travel pretty much the exact same course with a completely different survey package the next. The amphibious crawlers can move over a variety of different terrains and can climb 50deg slopes.

The vehicle’s operational route is normally pre-programmed although, using a retractable floating buoy and transmit the data via an RF link in real-time while the crawler remains underwater is an alternative.

The crawlers can be remotely operated by cable from shore or boat, but a more common arrangement is autonomous. There are two main types of battery – Lithium Iron and Lithium Ion, depending on the required duration or whether the vehicle is required to transported by air.

APPLICATIONS

“They may be useful for surveys prior to bringing in offshore or wind farm cable ashore . Pipeline surveys are another example. The amphibious crawler is able to accurately log navigation data and survey measurements in a continuous route from the seabed until it gets in land.

In or out of the water, it can not only take physical samples using coring and cone penetrometer testing, but can use magnetometers to recognise ordnance buried along the route.

“The user is not at the mercy of the tides, with increased weather windows and lower survey costs” said Lester. "High-energy inshore areas can contain entrained air bubbles which may cause difficulties from vessel mounted sonars from boats to give fans readings.”

Autonomous bottom crawlers are also being considered as a useful military tool. Some are small enough to be launched out of a submarine or unmanned underwater vehicle. Such small, stealthy models can be used by specialist users, say, for reconnaissance on opposed beaches. Being difficult to detect, they can go into ports and harbours and monitor ship movement.

At the other end of the range, some amphibious crawlers are so powerful that they can carry 0.5t and pull more than that in a trailer behind them, possibly to bring equipment, dive gear or other payloads etc, to a point ashore.

Crawler entering the water from the beach

Amphibious vehicle

The Sea Beast, the largest amphibious crawler can carry 0.5t

Vehicles are available in various sizes

COASTAL MAPPING

One potentially significant market for which autonomous amphibious crawlers are entirely suited, is environmental shoreline monitoring.

“Half the world’s population lives within 100km of the coast and the sea level is rising,” said Lester. “Many are moving from plans from ‘protect our shorelines’ to ‘protect our cities’.

“In real estate alone, one investigation has ventured $1.0 trillion worth of property is at risk and 300,000 residential and commercial properties will face chronic and disruptive flooding by 2045 accounting for $135 billion in damage and forcing 280 000 US citizens to adapt or relocate (All property management 2019).

“Recently, three Hurricanes Harvey, Irma and Maria caused $200 billion of damage and over 3000 deaths. The US National Flood Insurance programme is already $20bn in debt. Cities are, therefore, taking the problem very seriously.

“One solution may be to install a protective sea barriers. Miami is investing $10million in flood protection while New York City is considering its own city-wide barrier.

Elsewhere, mangrove or eelgrass has been shown to be more resilient to storms. These living shorelines trap carbon provide a fishery habitat. For such schemes to happen, however, it is necessary to map the area in detail in order to establish a baseline and to record annual changes. An amphibious crawler would seem a particularly useful vehicle for this application.

UNMANNED AMPHIBIOUS SURVEY SOLUTION FOR ARMY

Ultrabeam Hydrographic, specialist in high-resolution 3D marine asset survey, recently designed, built and successfully demonstrated an amphibious unmanned survey platform for the British Army.

The proposal was developed in response to a MoD Defence and Security Accelerator (DASA) funded project, '***Map the Gap***', run on behalf of the Defence Science and Technology Laboratory (Dstl). Ultrabeam Hydrographic, in conjunction with subsidiary Foundry Cub, was awarded one of five contracts to develop a remotely-operated reconnaissance aid to help British Army troops safely and stealthily advance across water obstacles in enemy territory.

CROSSING CHALLENGE

Currently, the only way of identifying suitable water crossing points is to send Royal Engineer reconnaissance troops to survey both banks of the river, exposing them to danger which also risks compromising the operation by signalling interest in that location to the enemy. The ultimate aim is to remove personnel from these dangerous tasks with a remote system that allows more crossing locations to be surveyed, increasing the choices available to commanders and giving an opportunity to surprise the enemy.

CUSTOM DESIGN

Ultrabeam Hydrographic specialises in high-precision hydrographic survey capability for marine assets including harbours, bridges, oil and gas platforms and offshore renewable energy installations.

It designs and custom builds its own vessels and platforms to carry technology including multibeam sonar, laser scanner, high resolution cameras and imaging sonar. Its range of vessels built to date are compact and highly manoeuvrable due to a unique vectored thrust propulsion system providing a stable platform for optimal performance of survey equipment, even in difficult or hazardous conditions.

The company's Technical Director, Gabriel Walton, saw an opportunity with the Map the Gap industry call, to leverage its experience of on-water survey to develop an amphibious craft. The result was a high-spec, autonomous, hydrographic survey vehicle that could operate on land and on water and transition smoothly between these environments.

They named the vehicle the 'Argonaut'.

Walton commented: "The Project Argonaut team at Ultrabeam started the initial design work in September 2020, moving to 'build' within weeks. We brought in various partners including the Applanix Corporation, who kindly granted us use of their inertial navigation system and Nortek, who supplied an Acoustic Doppler Current Profiler (ADCP).

"The Argonaut's control system was developed by Dynautics," Walton added, "who successfully adapted their MicroSPECTRE auto-pilot, traditionally used for marine vessels such as USVs, to drive the vehicle remotely both on water and on land."

BUILD DETAIL

By stripping back and customising an existing, proven off-road vehicle design, Ultrabeam created a fully-electric off-road and on-water platform.

Two 5kW brushless motors were fitted to drive the vehicle on land, with Torqeedo brushless outboard motors providing on-water propulsion and Tesla lithium battery components providing the power.

The Argonaut platform was fitted with a survey payload including an engineering-grade laser scanner and a high-resolution multibeam sonar, coupled with the Applanix inertial navigation system. The system also incorporated a fully-portable ground control station, designed to fit inside a small Peli case, from which connections can be broken out to link up to a larger control site where available.

This mobile command centre enables access to onboard computers and the control of measurement equipment as well as giving the ability to control the vehicle and set its various autonomy modes.

SUCCESSFUL FIELD TRIALS

Field trials were completed in December 2020, with the 3m long, 450kg Argonaut successfully navigating difficult terrain as well as efficiently transferring to the water. The amphibious unmanned vehicle was designed to overcome several foreseen challenges, including ground bearing capacity, bank height and gap width issues as well as river flow- it successfully tackled everything in its path.

On land, the 8x8 wheel-drive vehicle reached a speed of 8mph at 3000rpm, with the motors capable of 6000rpm for 16mph speeds where necessary.

The Argonaut was also able to successfully scale a 45deg incline. In the water, the shallow-draft Argonaut reached a speed of 4mph with the bow thruster enabling accurate heading control and the ability to perform strafe movements.

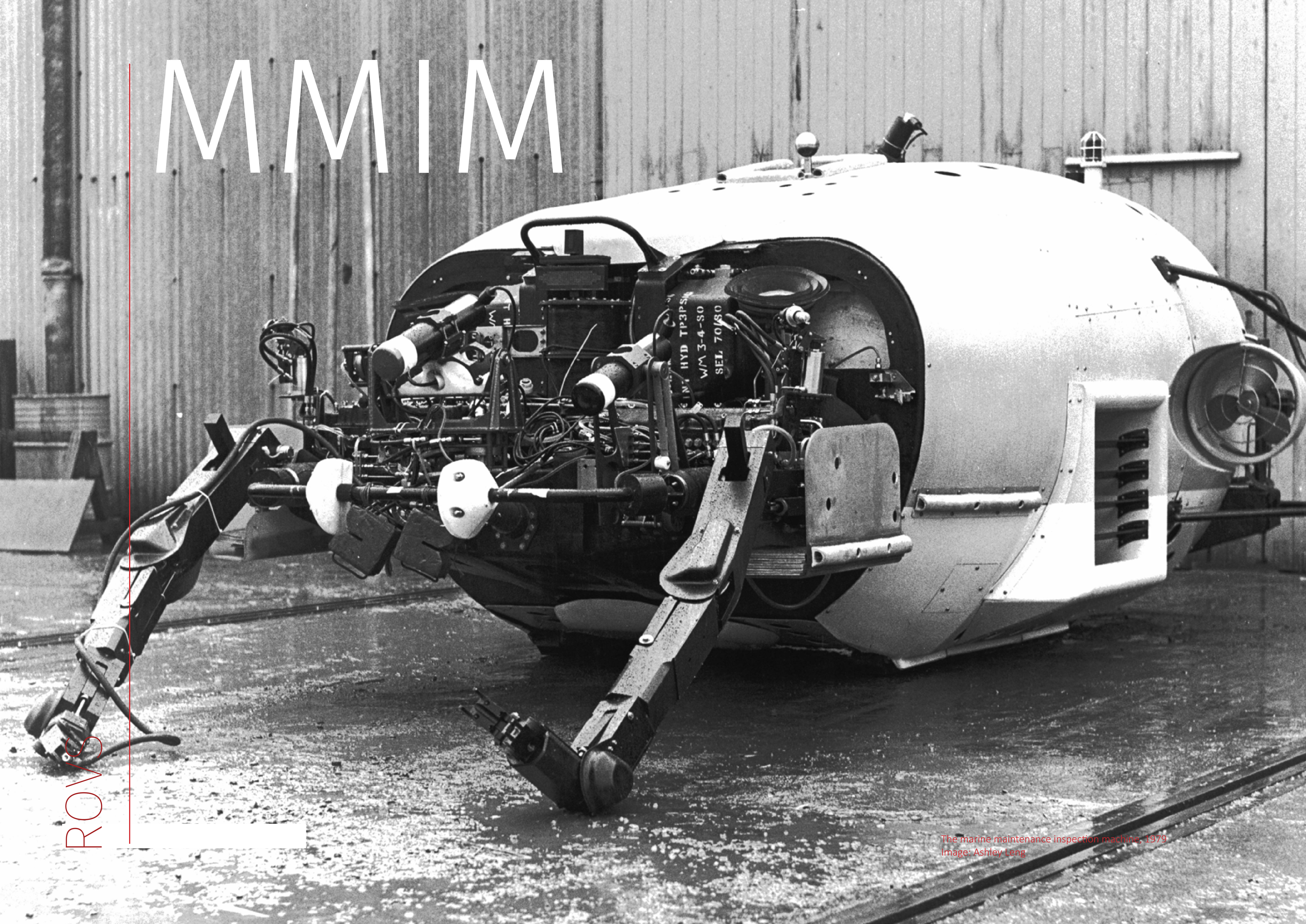
Dynautics' auto-pilot provided auto heading, route following, position holding, auto speed and strafe movement tests.

Based on these field trials it is estimated that the endurance of the Argonaut amphibious vehicle is well over 12 hours, with an estimated range of 20-60 miles, dependent on terrain and speed.

With the second phase of the Map the Gap project now launched, Ultrabeam Hydrographic hopes to be able to further develop its solution for British Army troops. Meanwhile, the unique Argonaut has already been deployed commercially on various inshore survey tasks in hard-to-reach locations.

Argonaut

MMIM



The marine maintenance inspection machine, 1979
Image: Ashley Leng

MMIM

The Marine Maintenance Inspection Machine was designed and built by Slingsby Engineering for Sonarmarine under a project jointly funded by the Department of Energy, BP and Sonarmarine. Sonarmarine was later acquired by Subsea Offshore to become its ROV division. By and large, the vehicle was not a success but contributed greatly to the design of future vehicle designs

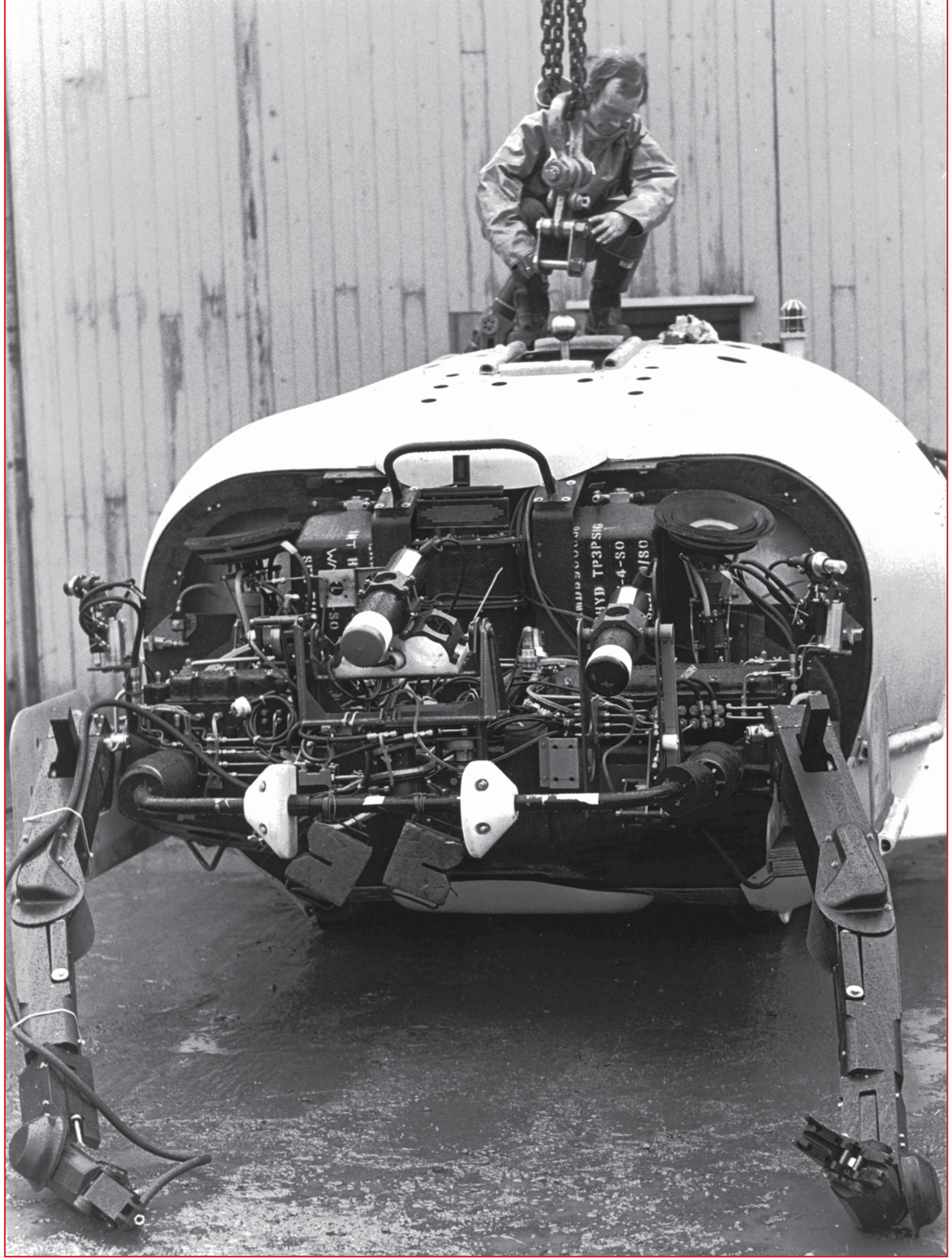
In the late seventies, there were relatively few underwater vehicles available, however, the growing demand from the offshore industry to provide inspection services, particularly for its jacket legs, promised a potentially huge market. What BP particularly required was a specialist vehicle to perform inspection of its new Magnus platform.

The early Central/Northen North Sea platforms had to be engineered to withstand considerable environmental forces, but the scale of these was largely unknown. Being some of the first such jackets anywhere in the world, they were engineered with a safety margin and erring on the side of caution an over-engineering the structures.

It was vital to know how these behaved in order to design the next generation so inspection became important. Of particular interest was corrosion and looking for flooded members. It was against this background that the MMIM was devised.

“It was a giant” remembers Ashley Leng, one-time worker at Slingsby and now MD at Throxenby. A full 5m in length and weighed around 5t in air at the time when a close competitor in the market, the spherical RCV 255, was designed to be small enough to deployed out of a torpedo tube.

“Those were the days of the two-colour sports car and the MMIM style was no different,” he said. “It was orange at the top and yellow at the bottom. This was always questionable because the best colour at being seen from the surface is yellow while the best colour for seeing underwater is white or more practically, cream because the backscatter from a white subject reflects back into the camera and blinds the viewer. At night, it was invisible.”



A characteristic of early underwater vehicles was that they were inherently unreliable and a key aspect of the MMIM design involved addressing some of these issues.

Where possible, it employed tried-and-tested equipment such as cameras, lighting, thrusters etc, while purpose-designed components and subcomponents were manufactured at Slingsby under tight quality control procedures and underwent rigorous testing.

DEPLOYMENT

A unique feature of the MMIM was its deployment system.

The launch system consisted of a dedicated single boom crane purpose-built for the system. The crane arm could slew around and launch the vehicle through the moon pool or over the side.

A drum housing armoured cable was incorporated onto the launch crane. This armoured umbilical was connected to the garage that was mounted on the top of the vehicle.

“It was colloquially and even officially called a garage, but it was nothing like the launch and recovery system that we know today," said Leng. "It was affectively more of a docking frame – a simple aluminium structure that latched on to a ball joint at the top of the vehicle, but played an important part of the operation.

“The MIMM would be lowered down to site by its armoured cable until it reached the planned the underwater worksite

The marine maintenance inspection machine, 1979
Image: Ashley Leng The person on top is Johnny Wall of the test house -famed for his twin carb MiniCooper!

site. Upon reaching a horizontal member, clamps could engage, physically attaching the garage. From that secure position, the MMIM would unlatch from the garage and fly out to conduct the investigation.

"In a normal tether management system, the line comes off a reel located in the garage. Not so with the MMIM because the tether was housed in the body of the MMIM itself, exiting out of the body like a spider.

The tether was much thinner than the main armoured umbilical, maybe 1in. While more delicate, in operation it was not likely to be dragged across sharp objects. An advantage of the thinner line was its considerably lower drag.

VEHICLE

Today's ROVs invariably feature numerous relatively inexpensive thrusters, available off the shelf.

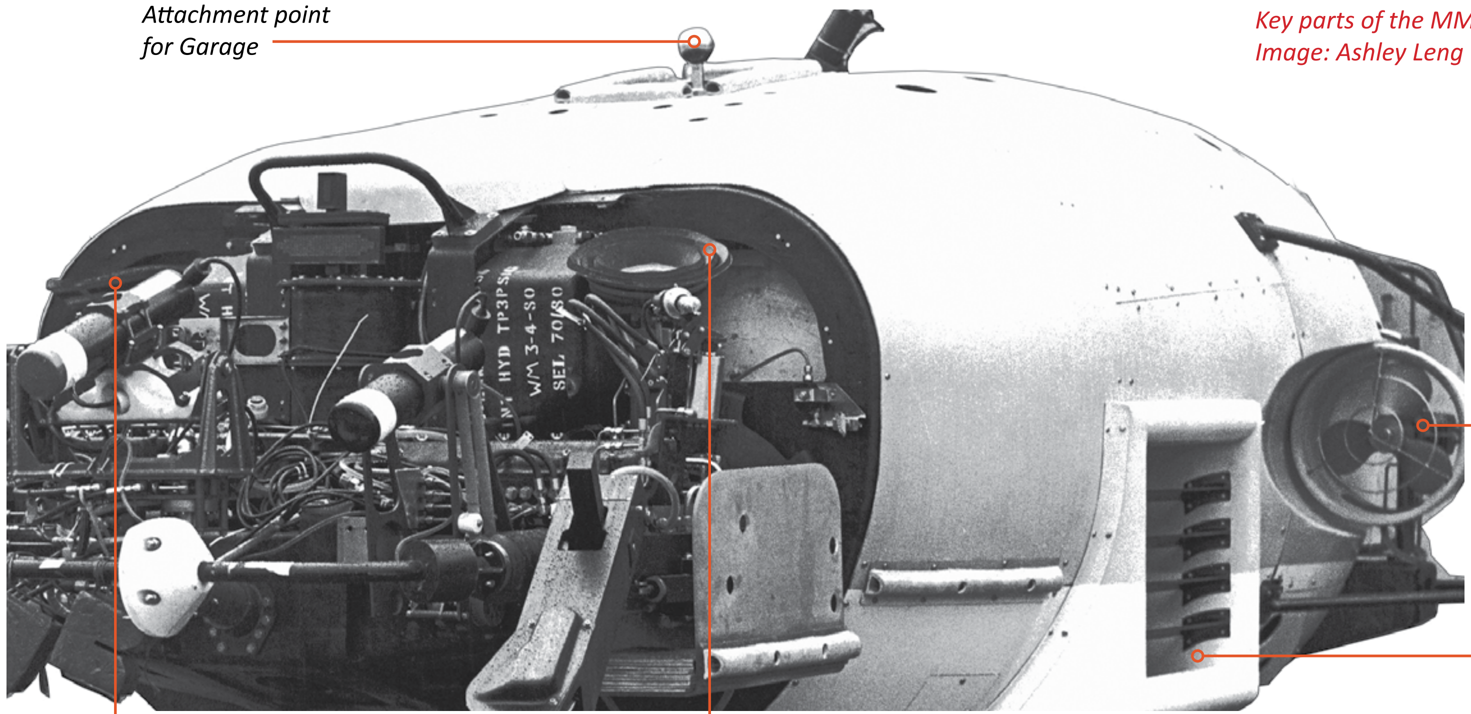
Not so in 1979.

Vehicle power was an important factor in the design. Low powered thrusters often meant that the vehicle could lose control in strong currents, resulting in umbilical entanglement.

The power system on MMIM was based on a pair of Pleuger electric motor driving hydraulic pumps They produced huge amounts of hydraulic power.

The system for MMIM centred around pair of hydraulic motors, maybe 2m long linked to a single 300mm diameter thruster. Water was pushed upwards and outwards

A colour photo of the MMIM Image: Dave Stanley



Key parts of the MMIM Image: Ashley Leng

through exit ports positioned athwardships, either side of the vehicle.

In theory, this gave it stability and allowed it to move sideways and up-/down. Thrusters placed on the side of the vehicle afforded it the ability to move forwards/backwards and turn.

In practice, however, the sudden thrust created a moment and caused the whole vehicle to surge up, swinging one way, then the other and often even barrel rolling. Even modifying the side ducts with curved vanes to redirect the lateral power was only partially successful. The only way to successfully gain control was to cut the output power by half.

Designed for inspection it had an array of cameras and lights as well as UT002 manipulators, the forerunner of the more successful Slingsby manipulators TA009. These didn't have as many functions but were at the beginning of the advanced technology that we have today

One interesting feature of the MMIM was the circular pad at the front of the vehicle. This was is called sticky feet

A sticky foot was essentially a cup consisting of several layers of neoprene that sat on the end of end ram. A water pump was used to pump to evacuate the central tube. When extended, this arm held the vehicle steady when carrying out inspection.

Many years later, this idea was taken up by Slingsby's platform inspection and cleaning vehicle, (PIC). This had broom-like bristles which made a soft seal while inside, a pressure differential between the inside and the outside held the vehicle onto the structure.

As confidence grew, routine inspection gradually moved to risk based inspection. This concentrated on the main threat areas and cycled the targets around the structure over 5-7 years. This method reduced the amount of work vehicles were required to conduct.

"In practice, the vehicle was not particularly successful," said Leng.

"One of its first planned jobs was to work on BP's Magnus but it proved too big . They moved it to Kinsale Alpha in the 80s. I believe Duncan Rae was the last person to fly it before it retired and its parts taken for other project.
"It was very advanced for its time and went to advance the understanding of underwater robotics."

LEGACY
Douglas Scott, who worked closely on the project for many years, talks about the vehicle's legacy. He was the offshore manager and pilot on MMIM and was with Subsea Offshore for the time MMIM was tested on Kinsale A in Ireland.

"Although MMIM was – or ended up being – a bit of a white elephant, to blindly denigrate the vehicle design would be to miss the important technical advances that this system design initiated in other remotely operated vehicles" he said.

"The data control system allowed for diagnostics of the control and hydraulic systems that would eventually lead to the SELMEC data control system- which was later employed for many years – on nearly all SEL-built ROVs.

A 'Sticky Foot"
Image: Douglas Scott

"This enabled the operator to electronically seek out any control problem within the vehicles electronic and hydraulic systems whilst still subsea- and in most cases inform a decision as to continue with the dive – or – recover and fix the problem.

"The SELMEC or SELBUS system also allowed for the use of fibre optic cables within the umbilical's of SEL ROVs – this in turn allowed a smaller diameter umbilical's such as those first used with the SEL TROJAN vehicle – which offered great advantages in the overall size and weight of an ROV system – and fibre cores are of course still used today."

The manipulators were again almost the forerunners of the SEL 7 and 5 function manipulators -their controls / hydraulics were similar to the MMIM system- as was the swash plate control of the hydraulic thrusters, which allowed for a finer control of the thruster and importantly allowed for better diagnostics of the thruster system and was employed on many SEL built ROVs.

"The garage for the MMIM system was initially secured to the horizontal member of a structure, using what became to be known as '*sticky feet*'" said Scott.

"There were two of these suction pads on the garage, but it was found that they did not work well when the horizontal member had any marine growth – so for the MMIM work on Kinsale A – these were removed and a grab-type

system was manufactured – basically the pilot would leave the grabs open, then fly to a member and then close the grabs over the member.

"The MMIM vehicle would then exit the from the garage and using its own umbilical winch – fly into the structure. The original suction pads were of a different design to that shown and leaked- therefore losing suction.

"The "sticky foot" did not go away and is still very much with us today – although it has of course been re designed – but the idea was tried on the MMIM even tough it had been used a number of years previously on the manned diver lockout submarine L1.

"The MMIM vehicle also had a transponder-controlled eject system for the umbilical – basically a cutter that could be operated from the surface via a transmitter – this function was actually tested on the Kinsale A works.

"The MMIM ROV was also fitted with air ballast tanks and these tanks were used on every dive and allowed the vehicle to have a very crude variable buoyancy system – the ballast valves and system were part of the overall vehicle systems and could also be monitored using the diagnostics system.

"The thrusters on MMIM were large and the power output could be "switched" from high to low – which demanded a more complex hydraulic and control system design.

"The fact that MMIM was known to almost be able to "barrel roll" was testament to this – but my own view is that the lateral thrusters position was too far below the centre of buoyancy – but the result was spectacular at times," said Scott.

So overall the MMIM vehicle may have supplied ideas and technical input to the following systems:

- An Electronic Diagnostics system that checked all systems on the ROV
- Basics for the 7 and 5 function manipulators
- Electronic data system that allowed for the use of fibre optics in the SEL umbilicals for the SEL-manufactured ROVs
- Sticky feet that enable ROVs to stabilise themselves to a structure in most currents,
- Air ballast system for ROVs that resulted in a crude variable buoyancy system
- Transponder controlled eject system
- Swash plate control of ROV vehicle thruster's
- Enabled more complex control and hydraulic design of the thrusters. So – overall …………………. not too bad for a white elephant !!!!

FEATURE: UNDERWATER GLIDERS

PROFILING MEASUREMENT

Subsea gliders are essentially three-dimensional extensions of profiling floats.

Profiling floats are designed to travel up and down through the water column, taking subsurface measurements such as direction and speed of water or the temperature and salinity as they pass.

Early designers looked to improve operability by providing some level of manoeuvrability and thus positional control.

The first glider designs dated back from the 1960s, but the epiphany came nearly 30 years later when Henry Stommel and his research partner Doug Webb proposed the idea of a buoyancy engine powered by a heat exchanger, exploiting the thermal gradient between the cold deep ocean water and the warmer surface water.

Since the fist prototype flights were carried out in 1991, numerous companies have developed different vehicles although they have many features in common.

They all have a small size (about 1m50 long and 20cm in diameter) and their weight is around 50kg in air (and +/-200g in water).

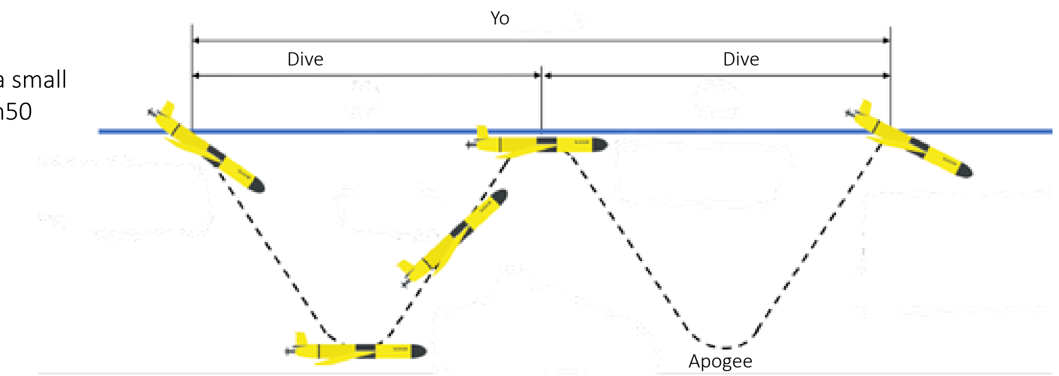
HOW GLIDERS WORK

In around 250 BC, Archimedes famously declared that any object immersed in a fluid will be buoyed up by a force equal to the weight of the fluid that the object displaces. Now recognised as Archimedes' Principle, he went on to explain that if the density of the object is the same as the density of the surrounding fluid, it is described as neutrally buoyant.

If the density of an object is less than that of the surrounding fluid, the object rises while conversely, if it object has a greater density, it sinks.

This is the basic operating principle for the profiling float. By controlling this density variation, it can rise and sink on demand.

The movement is driven by a variable buoyancy device (VBD). This can come in two main forms. At its simplest, is a piston that can evacuate or flood a compartment with sea water. An alternative is to use an oil-filled inflatable bladder that can be extended or retracted from the pressure hull.



It contains sufficient oil to allow the vehicle to float would lie neutrally buoyant as its his density would be equal to the water density

Pushing the oil to and from the bladder changes the into the glider's inner tank changes overall volume.

The body's mass, however, remains the same. As density is calculated as mass per volume, then any decrease in volume results in a corresponding increase in density thus causing the vehicle to sink by gravitational forces. Conversely, when this bladder extends outside the pressure hull, the vehicle's displacement and thus its net buoyancy increases.

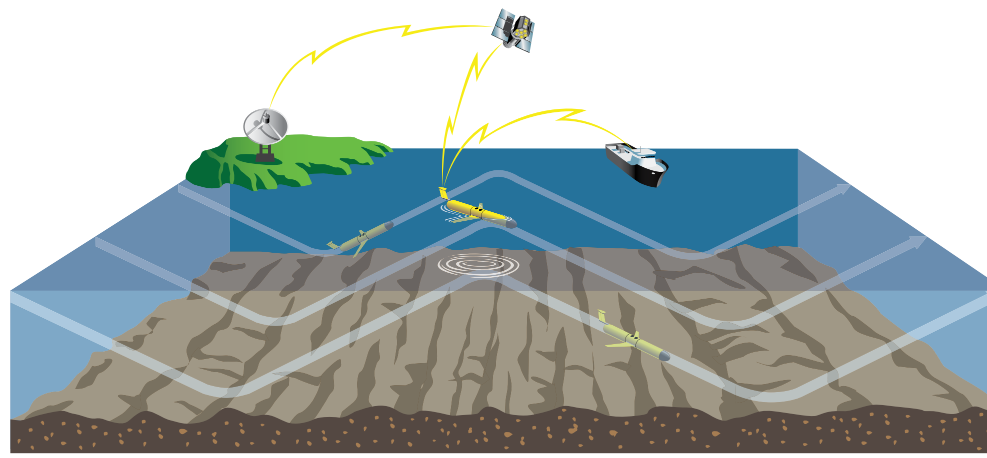
The balance of the glider is so sensitive, that only a slight fluid displacement can be enough to make the descending vehicle rise and vice versa.

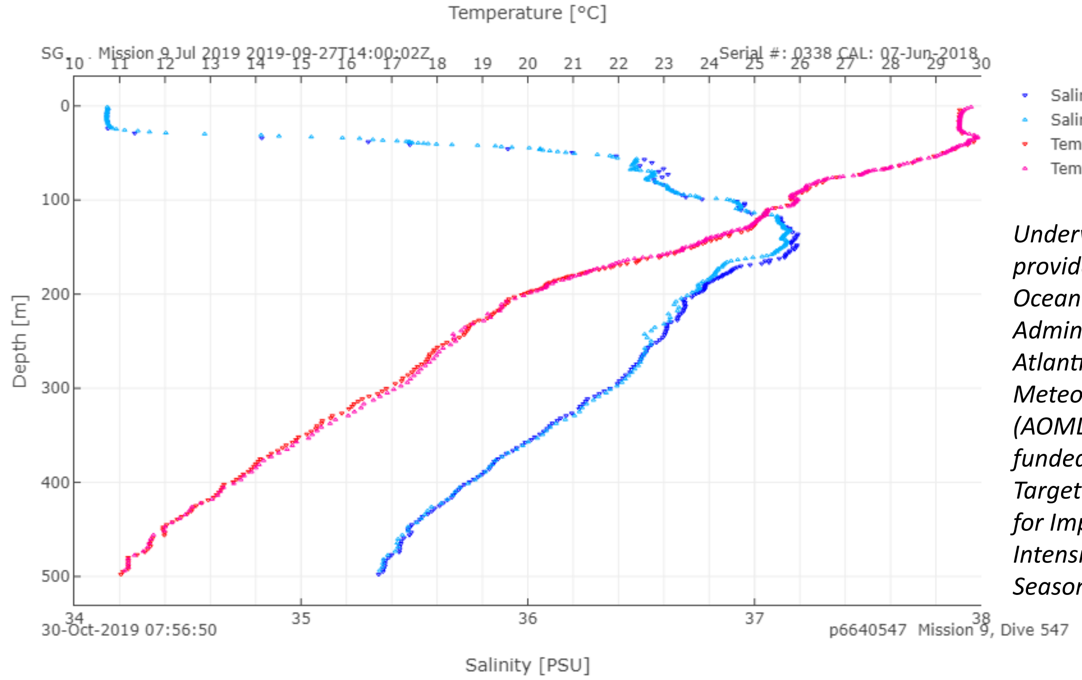
For a glider to work, this vertical sinking movement has to be accompanied by a forward horizontal element to result in a diagonal movement or pitch.

This is enabled by changing the vehicle's centre of gravity and is executed by moving internal ballast - normally the heavy battery packs, forward or backwards. This results in the glider pitching upwards/ downwards.

Steering the Glider is carried out in two main ways. One is to control the Yaw and this is carried out by a t rudder which is magnetically coupled to a servo motor to avoid an opening in the pressure hull. For this to work it is desirable that any unwanted roll is eliminated. This is facilitated by incorporating wings or tail fins

The other way is to allow controlled roll which works in association with the pitch to effectively turn the vehicle sideways





Underwater glider data provided by the National Oceanic and Atmospheric Administration (NOAA) Atlantic Oceanographic and Meteorological Laboratory (AOML) as part of the NOAA-funded "Sustained and Targeted Ocean Observations for Improving Tropical Cyclone Intensity and Hurricane Seasonal Forecasts" project.

IN OPERATION

Obtaining a negative pitch angle initiates the descent, with the vehicle's hydrodynamic shape providing minimal resistance through the water at a speed in the order of 20-40cm/sec.

Upon reaching a specific depth, a pressure sensor triggers the bladder to inflate, increasing buoyancy while shifting the battery position aft. The steep dive angle flattens, passes through its apogee, and starts to point back upwards and slowly climb at a positive pitch angle towards the surface to start the next cycle.

The rising-falling movement that the vehicle makes through the water is often described as a sawtooth profile from the surface to the bottom of the ocean up to 6000m but typically 100-1000m.

At the apex or apogee of the profile, the glider may break surface and transmit data to the onshore pilot via satellite.

The movement between one surface visit and another is referred to as the 'dive, while a simple downwards and return movement is sometimes colloquially known as a YO. As gliders do not have to surface, they can perform multiple "yos" per dive.

After the dive, the vehicle emerges to get a position fix via GPS, send the decimated data back to shore and receive a new mission command from the remote pilot. Before a new dive, a new GPS fix is obtained to better estimate surface currents.

Unlike other AUV platforms with power-consuming thrusters, a glider can last a very long time on a single battery charge because it only uses energy on scarce phases to inflate or deflate its bladder and adjusts its attitude.

The consequent long endurance makes it capable of carrying out surveys at very low costs. They can go places where it is impractical to send manned or free- swimming vehicles that requires support. They can work, for example, in Arctic waters or even through tropical storms.

One of the main part of a glider is its sensor package. The payload size is an important criteria in determining the most suitable sensor suite. Gliders can carry a wide range of instrumentation to conduct high resolution measurements.

The most common data recorded necessary for operating the vehicle are temperature and salinity as ascertaining the velocities over a dive.

Vehicles can also incorporate acoustic equipment such as echosounders and hydrophones. This allows the operators to establish the glider's position while listening to sea mammals track fish or quantifying sea life and measuring ambient noise levels. They can measure optical backscatter at various wavelengths and angles which helps measure turbidity or particle size.

They can also use underwater acoustic modems for data telemetry.

Sensors can be used to measure physical or biochemical parameters such acidity, the presence of hydrocarbons, nitrates, as been integrated for measuring scintillation, microturbulence, nitrates, pH/pCO2, dissolved oxygen, fluorescences and the presence of hydrocarbons.

GLIDER MARKET

The market for this niche vehicle design is dominated by

ROUGHIE
University research platform

SEAS WING
Developed by China's Academy of Sciences Institution of Oceanography

SPRAY
Developed at Scripps Institution of Oceanography.

SEAGLIDER
Originally developed by the University of Washington in 1997, it was licenced to iRobot and then later, by, Kongsberg to provide orders external to the UW.

SLOCUM
Developed by Webb Research, now part of Teledyne

EXOCETUS
Developed by Exocetus Autonomous Systems

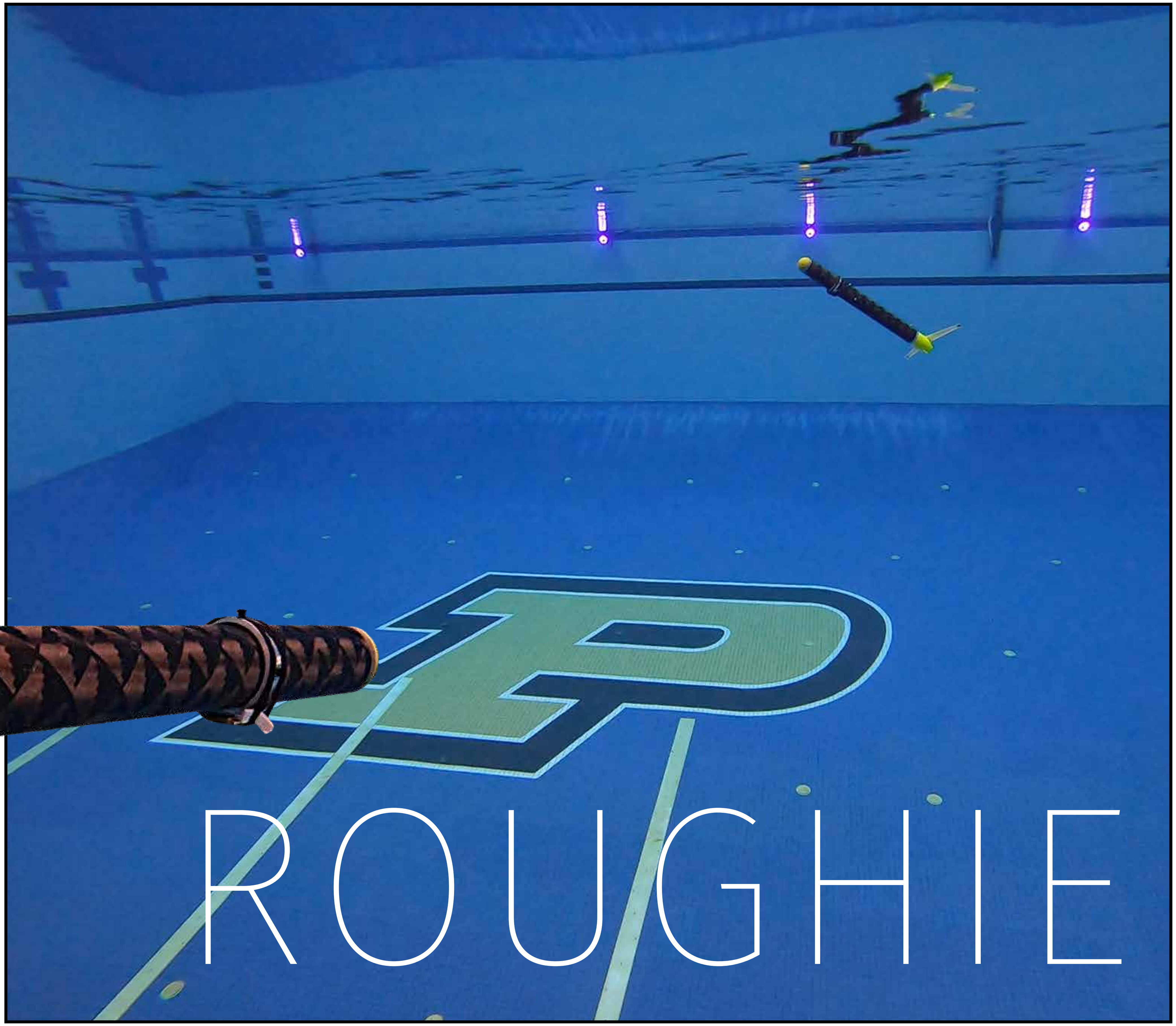
SEA EXPLORER
Developed by Acsa-Alcen

ROUGHIE (Research Oriented Underwater Glider for Hands-on Investigative Engineering) is an agile underwater glider developed by Associate Professor Nina Mahmoudian and her team at Purdue University as an affordable research platform with high capability to not only carry out research, but to evaluate control systems and other navigational tools. She began the project in 2011 while at Michigan Technological University.

With its torpedo-shaped hull, ROUGHIE is 1.2m long and features a static rear wing. The underwater glider weighs 15 kg and can carry a 3kg payload.

It has a minimum operating endurance of three days when operating in shallow water and can achieve a maximum depth of 100m.

The ROUGHIE works by means of a micropump injecting water into a small ballast tank which changes the vehicle's buoyancy and provides an initial glide path angle. To control pitch, a motor drives the vehicle's




ROUGHIE making measurements in lakes

battery forward and backwards. Roll control is achieved by rotating the common mounting rail and all internal components relative to the hull. These actions combine to enable complex flights in the water without the need for external actuators such as propeller or rudder.

“Most underwater gliders can only operate in deep oceans and are not agile for confined spaces,” said Mahmoudian. “ROUGHIE, however, has a turning radius of only about 3m, compared to an approximately 10m or more turn radius of other gliders. It is so manoeuvrable our team has been testing it in the diving well at Purdue’s Morgan J. Burke Aquatic Center.

"By installing a motion capture system of infrared cameras below the water, we can track the vehicle’s movements and characterise its manoeuvring behaviour in three dimensions with millimetric accuracy.

“We preprogramme ROUGHIE with flight patterns ahead of time, and it executes those patterns autonomously,” Mahmoudian said. It can travel in standard sawtooth up-and-down movements to move in a straight line, but it can also assume circular or even S-shaped patterns for use when patrolling at sea.

"The fact that it can perform these tasks within the confined environment of a swimming pool using nothing but internal actuation is incredibly impressive.”

This manoeuvrability means that ROUGHIE is able to follow complex paths and can explore real-world areas other underwater gliders can’t.

“It can operate in shallow seas and coastal areas, which is so important for biology or climate studies,” Mahmoudian said, “and because it’s totally quiet, it won’t disturb wildlife or disrupt water currents like motorised vehicles.”

ROUGHIE can be fitted with a variety of sensors, gathering temperature, pressure and conductivity data vital to oceanographers.

As part of the development, Mahmoudian’s team has sent ROUGHIE into small ponds and lakes with a fluorimeter to measure algae bloom. They have also outfitted the vehicle with compact magnetometers, capable of detecting anomalies like shipwrecks and underwater munitions.

Mahmoudian said. “For the price of a current commercial vehicle, we can put 10 of these in the water, monitoring conditions for months at a time. We believe this vehicle has great value to any local community.”

SEA WING

In late 2020, Indonesian fishermen discovered a Chinese underwater glider, not the first time this type of vehicle type has washed up deep in Indonesian territorial waters. The defence community say that Intelligence gathered by the drone may be valuable to the Chinese Navy reconnoitring potential submarine routes into the Indian Ocean, through Indonesian waters.

The glider is called Haiyi, which can be translated as Sea Wing. It was developed by the Shenyang Institute of Automation. Defence analyst, Janes, describes the Haiyi as 'a torpedo-shaped main body that is constructed from Aluminium alloy or carbon fibre composite material. The nose of the pressure hull contains the underwater glider's buoyancy engine and depth control systems, with the mission payload and control unit located in the middle. At its centre features a pair of swept wings."

Probably a more useful postscript is that Haiyi bears a notable resemblance to the Littoral Battlespace Sensing-Glider (LBS-G) that is manufactured by Teledyne Webb and based on Teledyne Marine's autonomous Slocum glider.

Sea Wing gliders are known to be launched by China's specialist survey ships. In December 2019 the survey ship ***Xiangyanghong 06*** launched around 12 of the drones into the Eastern Indian Ocean.

Back in 2018, a paper by Xiangzhou Song et al, entitled '***China's Vision towards the Tropical Pacific Observing System (TPOS) 2020***' detailed using the Sea-Wing used as part of an intensive field observation experiment.

Sea Wing.family

It envisaged using 12 Sea-Wing gliders equipped with conductivity-temperature-depth (CTD) sensors to investigate the 3D structure and time evolution of an anticyclonic eddy in the northern South China Sea.

The Tropical Pacific is not only interesting from an oceanographic, but also a financial viewpoint. Pacific Rim countries and beyond suffer from extreme meteorological events on periods ranging from days to years that originate from anomalous conditions in the tropical Pacific.

Typhoons frequently impact East Asian countries from June- October with coastal areas being exposed to huge surface waves and coastal storm surges caused by typhoons.

The China Marine Disaster Bulletin, published annually by the State Oceanic Administration (SOA), showed that the direct economic loss by storm surges was almost 0.9 billion US dollars for China in 2017.

The Tropical Pacific Observing System (TPOS) 2020 project was set up to take into consideration this new technological opportunity, increased stakeholder involvement, more robust maintenance and a broader scope of international cooperation.

Sea Wing washed up in Indonesia

SPRAY

The Gulf Stream has a significant impact on global climate patterns and coastal sea levels. Woods Hole Oceanographic Institution (WHOI) has been employing Spray gliders to understand the current's ability to transport heat northward, which plays a role in hurricane development.

"Scientist have been successful in predicting "where" and "when" the hurricanes will occur, but forecasting storm intensity has been more difficult," said researcher Joleen Heiderich in WHOI's Oceanus publication. "This is because forecast models are often missing critical information about the heat stored in the upper thousand metres of the ocean.

"Storms gather energy from warm water at the ocean surface and as high winds blow across this water, they can mix this warm surface layer with cooler water hundreds of feet below. If the warm surface layer is thin, cold water mixing to the surface will rob storms of their strength; however, if warm waters extend down deeper, the surface will stay warm giving the storm more energy to continue growing as it moves."

About every two months, Woods Hole scientists launch a glider from Miami to make its way to its Cape Cod headquarters, where the vehicle is refitted and returned for another mission. Their goal is to keep two gliders in the Gulf Stream at all times—one north and one south of Cape Hatteras, North Carolina.

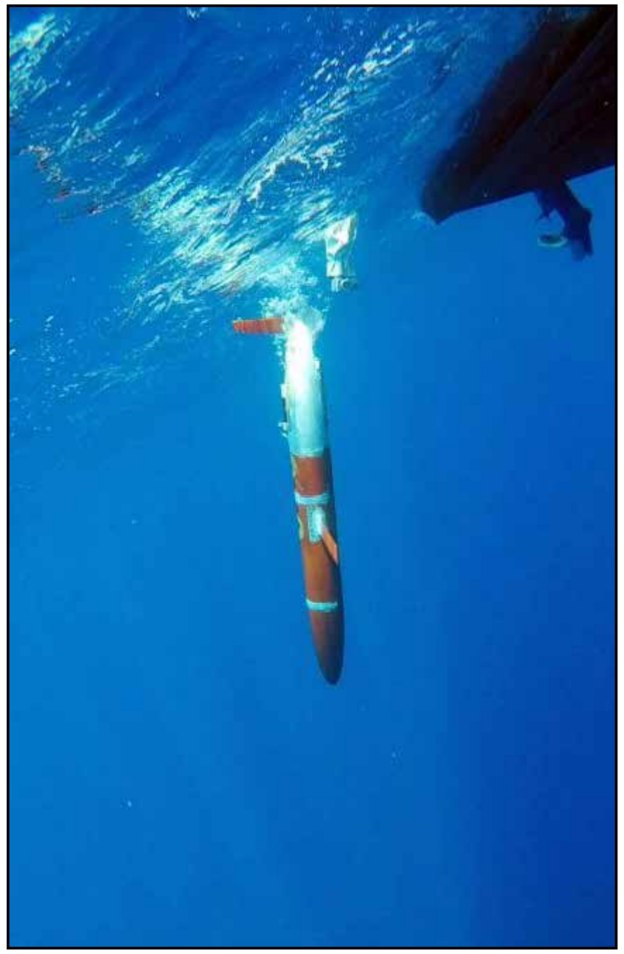
Woods Hole say that the Spray glider is an ideal tool for collecting this data. Satellites provide accurate surface temperature measurement but provide little information about heat stored below the surface. Ships are very expensive and not the best place to be in a storm.

In addition to logging critical temperature data from various depths along the Gulf Stream, the gliders also measure the speed at which the current moves up the coast is indicative of how fast it carries heat northward.

FLOW

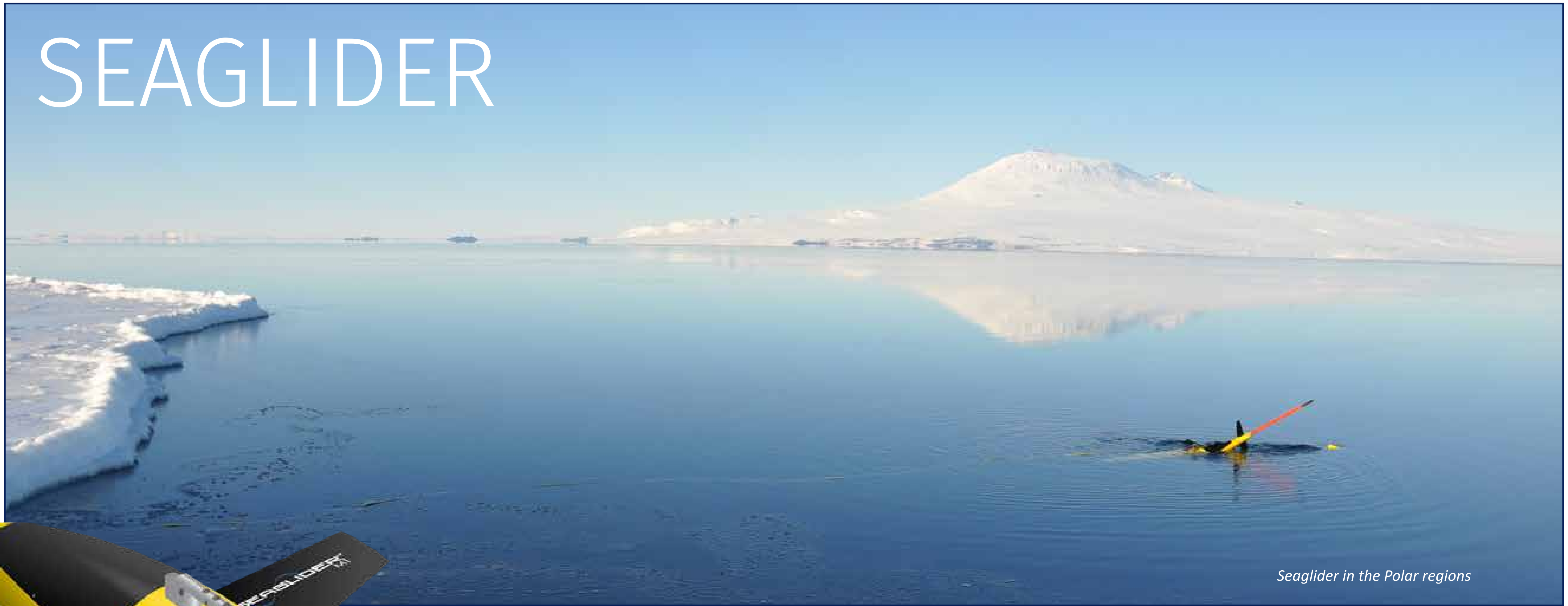
The Gulf stream normally passes along the US eastern seaboard up to Cape Hatteras, where it veers towards toward Europe. According to a paper published by Heiderich, co-researcher Robert Todd and other colleagues, however, hurricanes can actually be strong enough to cause one of the world's strongest ocean currents to slow down. They reported that in 2017, hurricanes Jose and Maria bore down to such an extent that the Gulf Stream slowed by an estimated 25– 40% for about two weeks.

WHOI also launched Spray gliders off North Carolina as part of a two-year long multi-institutional project known as PEACH (Processes driving Exchange At Cape Hatteras). This work measured oceanic and atmospheric conditions at a major confluence of currents, including the Gulf Stream, near Cape Hatteras, an area that juts out into the Atlantic and is often affected by hurricanes



Spray gliders work months at a time—measuring seawater temperature, salinity, and current velocities in the upper kilometre of the ocean. Every few hours, a spray glider will transmit its data via satellite back to scientists in Woods Hole, Mass. (GoPro photo by Patrick Deane)

SEAGLIDER



Seaglider in the Polar regions

Huntington Ingalls Industries (HII) has significantly expanded its position in the unmanned systems industry over the past year.

With the acquisition of Hydroid and its REMUS and Seaglider autonomous underwater vehicle (AUV) technology, HII formed the Unmanned Systems business group under its Technical Solutions division. The company now offers AUVs in all class sizes—from small to extra-large—and is positioning itself to be one of the world leaders in unmanned systems.

Within the HII AUV portfolio, the Seaglider M1 has served 16 countries worldwide for various missions, including climate research, defence, marine research and physical oceanography. This long-endurance AUV uses changes in buoyancy to move through the water column in a sawtooth pattern to collect high-resolution temporal and spatial data.

Internal sensors monitor vehicle heading, depth and attitude during dives. The Seaglider dives through water with up to a 10-sigma density differential without adjustment of the ballast and changes in buoyancy are achieved through the inflation and deflation of an oil-filled bladder. This allows for forward propulsion at speeds up to 0.75kts.

Data from the Seaglider is transferred anywhere in the world via satellite communications in near real-time based on user-defined intervals.

Seaglider

When surfaced, the Seaglider also obtains a GPS fix to aid in navigation and can receive new commands or updated missions via satellite. Without the need for external moving parts, the Seaglider is very robust and reliable. Missions can last up to nine months depending on configuration and sampling rate.

The Seaglider can be outfitted with a variety of sensors, including conductivity/temperature/depth (CTD), oxygen, fluorometer/backscatter, turbulence, current profiler, photosynthetic light, passive acoustic monitoring and echo sounder.

The National Oceanic and Atmospheric Administration (NOAA) Atlantic Oceanographic and Meteorological Laboratory (AOML) has used a fleet of Seaglider AUVs since 2014 for hurricane monitoring.

The data collected by the program is used to improve the operational hurricane models and the prediction of the track, intensity, structure and amount of rainfall throughout the life-cycle of a storm. In 2020, NOAA AOML and partners completed a total of nine four-month missions with Seagliders, collecting more than 13 000 individual temperature and salinity profiles without loss of a single vehicle.

Future development of the Seaglider will include optimizing SWaP: size, weight and power. The company applies continuous research and investigation of new, higher-density power sources to increase endurance, and partners help customise sensors and payloads to minimise weight and size to increase vehicle capabilities.

Modifications to the variable buoyancy system can increase the density range of operations, allowing Seaglider to easily transition from fresh water to salt water without the need to reballast.

A Seaglider deployed for hurricane monitoring in 2018. Image: NOAA AOML

Slocum Glider, Teledyne Webb Research

G2 TO G3

Years of gaining experience with its G2 glider provided useful input to the design of the latest model – the Slocum G3.

"One of the advances that Teledyne made when developing the G3 when compared with the G2 was to enlarge the buoyancy engine," said a source.

When freshwater from a river enters the sea, it can cause a marked difference in density If a glider suddenly encounters fresh water bodies of within the sea water- phenomenon known as 'freshwater lensing' and can cause the glider movement to stall.

There are two solutions to this.

One is to increase the size of the buoyancy engine. The G3 has a 1000cc unit along with a larger pump, which helps the glider to get through density structures and increases the speed of the vehicle.

The second is to add a propeller to increase the trust an push the glider through. Normally, the G3 achieves an average speed of 0.5m/sec or around 1kt. Using the propeller, however, allows the vehicle to achieve double that with speeds up to 2kts. This, in turn, gives more control in areas such as the Gulf Stream, in which has its own currents that may need to be overcome.

An advantage of a propeller is that it can get the glider from A to B. It gives the vehicle greater mission flexibility. The downside of using the propeller, of course, is increased battery consumption.

The Slocum G3 can employ one of different battery types, depending on the application. Alkaline batteries are useful solution for 350–1200kmdistances, while rechargeable Lithium ion batteries can achieve distances up to 3000km.

The designers also developed systems to enble the glider to explore in water depths down to 4000m. Last year, Teledyne Marine announced that its Slocum G2 Glider, *Silbo* completed a four-year journey

illustration courtesy of Teledyne Webb Research

that circumnavigated the Atlantic Ocean in four legs.

The *Silbo* was named in honour of its 2011 maiden voyage from Iceland to the Canary Islands, a Spanish archipelago off the coast of northwestern Africa. Silbo Gomero is a language of the Canary Islands, used to communicate across the deep ravines and narrow valleys that extend across the island.

The project dates back to 2016, when the *Silbo* glider was fitted with an extended energy bay and thruster.

It was then launched in the early spring from Cape Cod, Massachusetts.

For the first leg, from Cape Cod to Ireland, *Silbo* covered a distance of 6557km in 330days. While in Ireland, *Silbo* participated in a Glider Training session hosted by the Marine Institute and P&O Maritime Services, Galway.

On the second leg, *Silbo* flew from Ireland to revisit the Canary Islands, covering 3695km in 178days, and participated in "glider school" at the research facility Oceanic Platform of the Canary Islands (PLOCAN) and

the University of Las Palmas de Gran Canaria (ULPCG).

The third leg took 418days (believed to be another autonomous glider record), where Silbo flew from the Canary Islands to St. Thomas, U.S. Virgin Islands, again crossing the Atlantic Ocean and gliding 6256km.

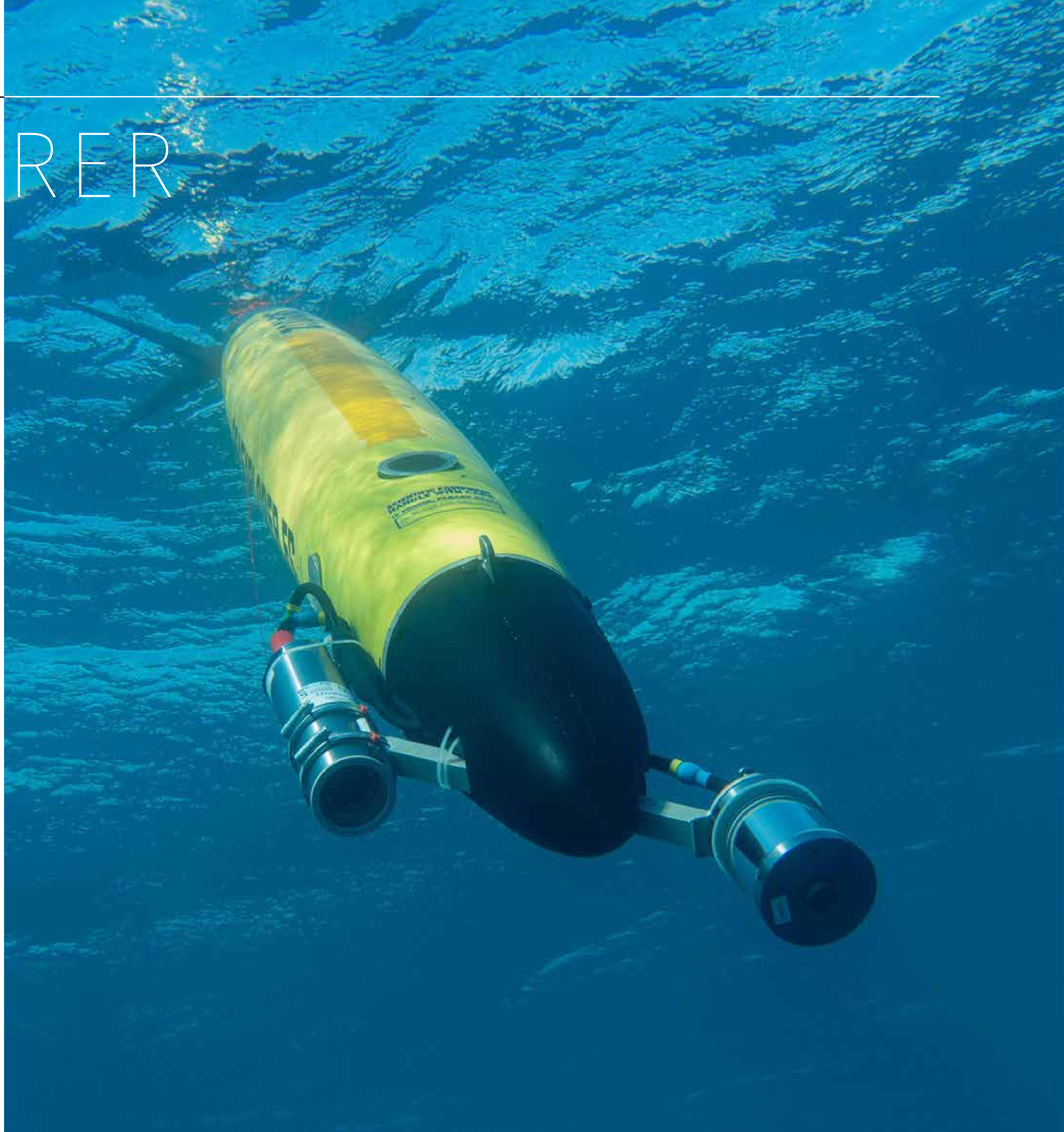
Supported by staff and students from University of the Virgin Islands (UVI), St. Thomas, Teledyne technicians recovered, recharged and re-deployed *Silbo* in less than 24 hours. *Silbo's* fourth and final journey to south of Martha's Vineyard completing the final 6236 km trek in 348 days.

During this transit Silbo spent three months flying a butterfly pattern south of Bermuda contributing data to Bermuda Atlantic Time-series Study (BATS).

Silbo then joined the Gulf Stream becoming the season's first storm glider as Tropical Storm Arthur passed directly over the glider. In all, *Silbo* covered 22,744 km and spent roughly 1273 days at sea.

During Silbo's incredible journey, it collected hurricane data, corrected current models, and provided close to 5000 CTD casts that aided meterological forecasting.

SEAEXPLORER



In 2007, the French company ACSA, now known as ALSEAMAR, first launched the SeaExplorer glider programme. By 2018, the company followed this up with the second generation model called X2. Today, it has delivered more than 50 units to institutions around the world.

The vehicle body is 0.25 wide and measures 2m in length with a further metre for the foldable antenna. The resulting weight is 59kg in air.

It design does not incorporate side wings ***per sae***, but instead, a tail which is said to reduce operational risks such as entanglement, fin breakage, etc. The wingless hydrodynamic profile provides the ability to improve gliding movement critical for minimal energy consumption and for speed.

COMPONENTS

The design is roughly divided into three parts, a central dry component surrounded by front and rear 'wet' sections that permit water to ingress freely into the hull.

The nose houses a wet payload (which can hold a large range of sensors from a pumped CTD to acoustic devices, turbulence sensors, etc.

Immediately behind this is the 5.5Kg dry payload area dedicated to the integration of dry sensors including four puck ports, the payload electronics processing (dedicated open-source CPU) and balancing weights.

Connected to this is the main battery pack section that also provides the moving mass to set the vehicle attitude.

Next to this is the navigation system including the oil bladder that provides the variable buoyancy. It also houses the release system and the connectors for charging, powering up and onshore data transfer.

At the tail section, the fins are 56 cm only, lowering the risk of entanglement.

FEATURES

The glider incorporates a number of features designed to improve costs and reduce time spent in key operations.

Payload

The glider has 9 lit / 8 kg of payload available for integration of greater sensing capabilities.

Rechargeable batteries

Many gliders are fuelled by primary batteries, however, from the start, rechargeable Li-ion batteries were central to the SeaExplorer design.

The standard rechargeable Lithium-Ion batteries located in the middle section, means that the user does not need to send the vehicle back to the manufacturer's premises or open the vehicle for pack replacement.

Only 20 hours are needed to fully recharge the glider before re-launching at sea, strongly reducing the cost of operating the glider as well as reducing the risk of leakage. There is no re-ballasting required.

The lifetime is around 500 charge/discharge cycles (about 10 years). Each cell has built-in protection devices to ensure safety in case of exposure to heat, short circuit, and overcharge and over discharge.

Since 2018, however, primary lithium battery packs have also been made available for available for extended endurance.

Propulsion
The SeaExplorer has a single buoyancy engine that can work in both shallow and deep waters, propulsion is controlled by varying a 1000 ml volume of oil. With its high pump output, the ballasting dynamics provide fast pull-ups and sharp turns (20m turn radius and 2m overshoot). It is easy to steer and high density range with no external actuator.

Different nose cones for the vehicle body

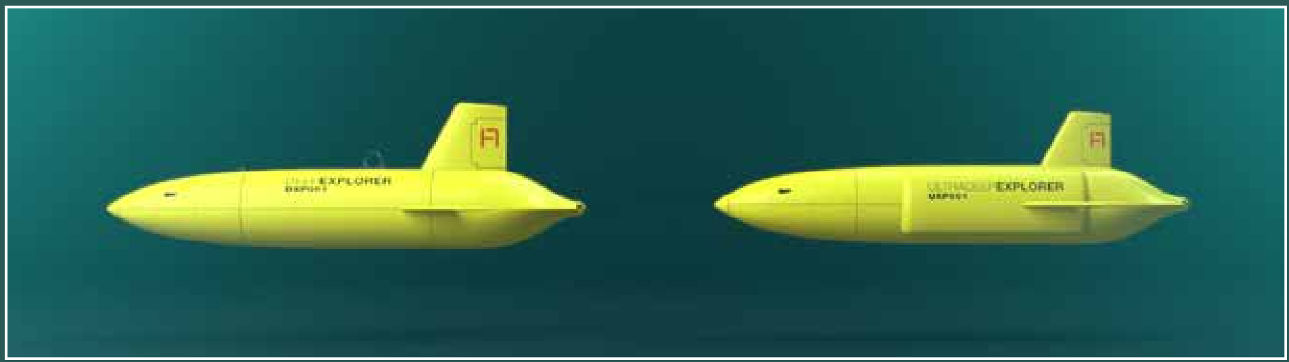
Interchangeable payload sections
The front payload section, with its science sensors can be easily removed from the glider vehicle section and replaced by another payload section with a different sensor configuration.

All SeaExplorer payloads sections are balanced to be the exact same weight, whatever the sensor configuration is. The customer can swap a payload to another in less than 30 minutes (4 screws and 1 internal connector), switching without having to recalibrate and rebalance the glider.

BRIDGES

In 2019, the Ultradeep Explorer Prototype was unveiled. It was developed as part of the f BRIDGES (Bringing together Industry for the Development of Glider Environment) initiative underwritten by an €8 million grant funded by the European Union ALSEAMAR ihas let the project from the outset.

The platform has multiple sensing, surveying and monitoring capabilities to support long-term in-situ exploration and protection of the coastal and deep ocean as well as seabed mining.



Attitude
The pitch and roll angles are controlled by the moving the battery pack. To adjust the pitch angle, and thus glide slope, the controller moves the battery pack precisely fore and aft. With a large range of displacement, it is easy to compensate and finalise the trim by moving internal mass for attitude adjustment and heavy payload compensation. Actuator position is continuously loop controlled.

Bottoming capability
The SeaExplorer is able to smoothly land on the seabed and remain anchored there for duration ranging from few minutes to several days. This navigation mode can be decided by the pilot during the mission.

It is useful for ADCP measurements (to get a fixed reference point) but also for taking acoustic recordings (Habitat health status, Human noise mapping, Defence applications) and for Hypoxia measurements (Oxygen depletion that occurs in the first 1-2m above the seabed).

Methane and Hydrocarbons sensors
Already integrated and available off-the-shelf: the Sea Explorer has proposed a Methane sensor to detect natural gas emanations for example, and a sensor targeting directly hydrocarbons with the MiniFluo-UV sensor.

Navigation
The navigation system is composed of attitude sensors (gyroscope and compass), pressure sensor, a GPS receiver and communication sub systems connected to a low power processor board. It commands sensors and actuators to produce specific movements and behaviours set up in the mission file or ordered through Satellite communications updates.

In addition, this board, associated with embedded software, enables functionalities such as behaviour recording, sub system testing and internal parameter monitoring and navigation law set-up. This provides control of the complete system at all times.

Once defined, the main controller board executes the mission using a pressure sensor for depth computing, a solid state compass and attitude sensor for heading, pitch and roll angle inputs and a GPS receiver used to obtain the geo referenced position when surfacing.

COMMS
At the rear of the glider is a 1m antenna that integrates 3 communications systems.
This foldable antenna allows optimal communication in most weather conditions (tested at sea in very harsh weather conditions).

The communication system is composed of:
- A GPS receiver necessary for position and time updating.
- An Iridium satellite connection for worldwide remote access during the mission.
- A radio link for short range wireless connection useful during launch and recovery phases.

The Iridium modem is used for worldwide communication when the vehicle is at sea. When conducting a mission, on the surface, the vehicle establishes satellite communication to transmit status and navigation orders. Because it is a two way communication, the pilot can also send new orders to adjust flight and navigation.

MOD 2

Since a group of Connecticut-based engineers bought the intellectual property and manufacturing rights the Exocetus glide following a series of non-technical issues.

The new company Exocetus Autonomous Systems immediately set out to commercialise the $15 million glider.

The result was the launch its MOD 2 model which boasted three main points. It had a high speed of 2kts, a large ballast system and a large body that could accommodate a capacious electronics payload.

"While most subsea gliders are typically designed to carry out long-duration sensing programmes in the deep oceans, the Exocetus designers recognised that there was a demand to focus more on the shallow waters of coastal areas. These coastal areas are characterised by higher currents, particularly at the mouth of river estuaries where the fresh waters meet with the saline sea water. This often results in significant density variations that pose a problem to delicately balanced vehicles.

"Instead of simply adapting an existing model of glider, they began to look at the specific conditions that the new glider was likely to encounter, and size the most suitable internal components to satisfy the demands. The rest of the glider could then be built around this body.

A key enabling feature of the Mod 2 is its buoyancy engine. At 5 litres (or 5% of the total volume), this engine is more than 7 times larger typical legacy gliders (the first to be developed and established in the market). It is the size of the engine that enables operations over wide variations of water densities.

INTERNAL DESIGN

The design of the Exocetus features a central pressure vessel that contains the sensor payload, and behind this in the rear, a battery pack that moves forward and aft to adjust the pitch.

While the buoyancy engine of most gliders is based on an internal bladder, that of the Exocetus is different. The device is located in the nose and is based on an is an open-ended piston system driven by a hydraulic micro- pump. The barrel of the piston always remains in continual contact with the water outside at all times.

Thus, decreasing the density (changing the volume but keeping the mass constant) happens when the piston pushes water out of the open ended barrel.

Conversely, to increase the density, a solenoid allows the pressure differential between the seawater and the vacuum chamber to drive the piston back. This ingests water and forces the hydraulic oil back into the accumulator.

The MOD 2 Glider is designed to be configured by users and has a large, watertight electronics bay provides space, power and communications for the sensory payload. These tool can have direct access to the glider's communications and navigation data and it has a dedicated science processor.

The sensors packages can be added internally or remotely with mounting points located either on the bulkhead or remotely at multiple locations in the nose and tail.

The glider has a very wide operating envelope. The limitation of some vessels is not so much the depth, but the shallowness they can work at.

The Mod 2, however, is designed to operate down to depths of 200m.This often means that it passes through areas where freshwater is suddenly encountered, such as passing across the mouth of a river or estuary.

Density variations can be caused by salinity changes from fresh water rivers, runoff and tides, or by changes in ocean temperatures

In such a case can affect the buoyancy of a glider. The engine of the Mod 2 is Five times larger than that of typical gliders and automatically compensates for additions of weight, and powers through variations in water density. The engine also includes an adaptive system so that if the glider encounters changing water conditions, specific salinity or density, the vehicle can both recognise and automatically adjust the ballast using the engine.

It also has an emergency Recovery system based on an independent emergency processor powers a system

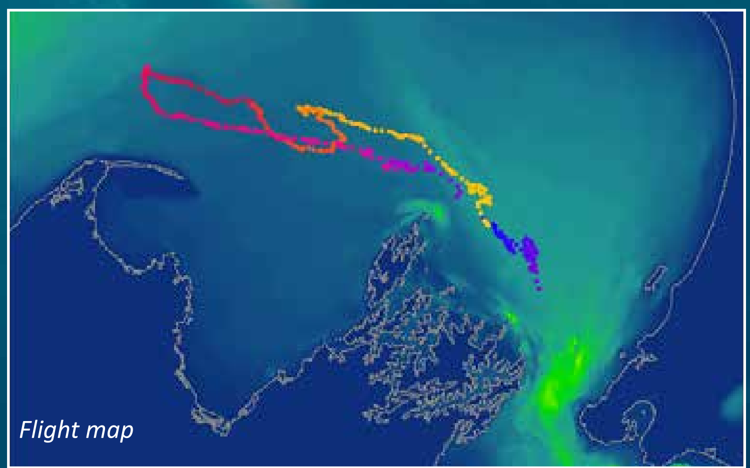
It is powered by an alkaline battery system weighing 70lbs and about 4000W hours of power or 14 MJ although there is a lithium option which gives 18 500W hours or 67MJ. The selection depends on the load and the programme duration.

Exocetus says that at a travel speed of 2kts, a lithium system is good for around 1500 miles.

Dr Joe O'Callaghan, a coastal oceanographer from National Institute of Water and Atmospheric Research (NIWA) has been examining how rivers flow out into Greater Cook Strait, New Zealand and especially focusing on the subsurface processes. To help this work, she has been assisted by two Slocum autonomous gliders, Betty and Manaia, set up for work in shallow and deep water work.

"Operating the vehicles in the largely underexplored fast-flowing Cook Strait was a steep learning curve and every time we deployed the vehicles, we gathered new and valuable information. The glider missions were supported by NIWA and the Sustainable Seas National Science Challenge. These programmes allowed us to

NIWA



Flight map

NIWA's Slocum glider
Inset - the Cook Strait, New Zealand

This is an excerpt from Marine Tech Talk podcast. To listen to the full interview, find Marine Tech Talk on any podcast station or at www.teledynemarine.com/marinetechtalk add to and consolidate the various sources of information," said O'Callaghan

"We understand the basics of how waters flow into bays but we have been surprised by the research findings from Cook Strait, which have shown that it has been possible to track river signals up to a hundred kilometres out to sea. The land area is characterised by short mountainous rivers taking sediments into the coastal bays but our assumption was that river flow would be ultimately restricted by processes occurring in the bays and the flow wouldn't make it out into the continental shelf sea.

"We used a multiplatform approach including regional modelling and satellite observations as well as the glider observations to look at the features. The two gliders ran 4 to 6 week missions, with SeaBird CTD packages, a Wetlabs ECOtriplet, and an Anderra oxygen optode to measure biophysical properties. The gliders enabled us to observe the small-scale subsurface features.

"The area around Cook Strait has quite pronounced tidal currents so we used chartered fishing vessels to get the gliders out into the open waters.

"The Cook Strait currents run up to 6 kt but given the glider's speed is typically 0.5kt, it was tricky to make progress in that environment, but we succeeded in collecting essential data. Underwater glider technology was game-changing for this research.

"Ocean glider observations were more effective at tracking rivers than satellites because they can map the ocean in all weather conditions, at much better resolution, and capture subsurface ocean dynamics."

NIWA
Taihoro Nukurangi

NIWA's Slocum glider on its launch cradle

BALTIC SURVEYS

The Baltic is one of the worlds largest inland seas, with the North covered in ice for long periods. Parts of the brackish water sea are over 450m deep while its ecosystems host important living resources and biodiversity.

Over the years, however, human exploitation, the accumulation of pollutants and agricultural runoff have had a dramatic impact on the health of the ecosystem.

Nutrients entering into the marine environment may enhance the growth of phytoplankton, leading to, amongst other things, reduced light conditions in the water. Decay of excess phytoplankton leads to excessive consumption of oxygen. The process is known as eutrophication. At the start of the decade, at least 97% percent of the Baltic Sea region was assessed as eutrophied.

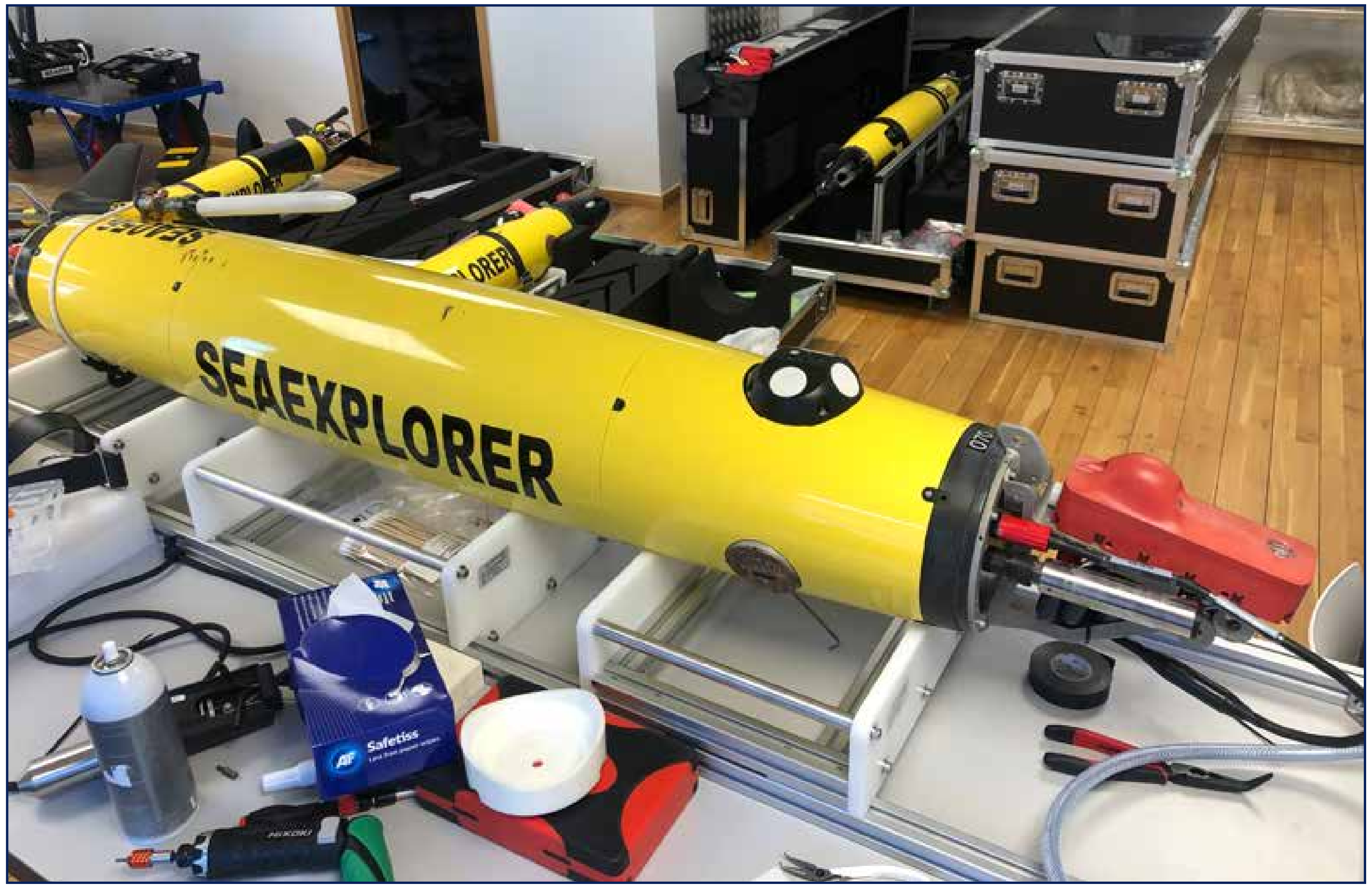
With eutrophication, oxygen levels in the Baltic dropped off dramatically. Anoxia may be offset by salty water from the North Sea passeing through the Kattegat, transporting oxygen as it flows, but there is evidence that this current occurs more infrequently than once it did.

The problem is not helped by the fact that the underwater processes are not well understood, and relies on data collected in the last century from regular but limited resolution national programmes.

"The areas is very complex" said Bastien Queste, Assistant Professor at the Department of Marine Sciences, University of Gothenburg,

"The currents controlling the inflow and outflow of waters between the North Sea and Baltic Sea impact the whole ecosystem, from the biochemistry down to the local biology, with linkages to eel grass meadows,


Launching the glider



Preparing for deployment

deep coral propagation and fish community structures.

Collecting much finer scale resolution data of this region will provide a critical foundation from which national and international research teams can build understanding and knowledge.

VOTO
The Voice of the Ocean was founded to allow scientists to assemble long data series and spend time to really be able to answer the crucial questions.

More specifically, the SAMBA (Smart Autonomous Monitoring of the Baltic Sea) project aims to fundamentally change the landscape of ocean observations in the Baltic Sea and connecting seas, collecting high-definition, ecosystem wide datasets.

“We are building a team of experts, supplied with the leading edge of smart and autonomous instruments to collect the largest and highest resolution, dataset of the Baltic Sea, from chemistry and physics at the molecular level, to weather, fisheries and ocean functions across the Baltic Sea," said Queste.

"At present, most of our current knowledge of the Baltic Sea’s ecosystem is gathered from ship surveys and fixed-point observatories supported by sporadic research projects. This multidisciplinary project will look at the Baltic from large scale to microscopic and include the impact on fisheries, weather and interactions with the climate.

One useful weapon in the SAMBA arsenal are gliders. The project has 4 active gliders, with this number growing to 10 by the end of 2021. In addition, there are two Sailbuoy unmanned vessels and a further two on order.

These will measure .

Temperature and Salinity. These will document the origin and fate of waters observed to highlight how they may exchange chemical properties across the water column, from the seabed to the surface.

Ocean Currents. These will measure movement on a macro scale as well as small spiralling features, such as inflows near the sea bed vital for oxygen replenishing.

The vehicles measure from the full water column down to 50cm size currents.

Dissolved Oxygen. This is a key indicator of Baltic Sea health.

Algal Pigments. These document the growth and type of microscopic algae responsible for cycling nutrients and forming the base of the food web. They will aslo pinpoint harmful algal blooms which impact fish and human health.

Zooplankton. Zooplankton eat microscopic algae but food for juvenile and adult fish. Their behaviour, health and distribution help us better understand where fish may breed and feed.

Fish: The measurements wil l be performed by Sailbuoys with fisheries echosounders, and linked to a project partnered with SAMBA

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ALGAL BLOOMS

The health of the Great Lakes is of great concern to a wide range of agencies, not least the water companies and fishing community.

Recently, the University of Windsor in Canada has been collecting real-time aquatic observation data using its Slocum glider Cormorant to investigate harmful algal blooms and monitor oxygen levels in Lake Erie.

Windsor University was awarded a $16 million grant from the Canadian Foundation of Innovation to provide instruments for science and engineering for work in the Great Lakes basin," said Aaron Fisk, a professor at the University of Windsor and Science Director for the Real-time Aquatic Ecosystem Observation Network (RAEON).

"This doesn't supply money for the research per sae, but goes to provide equipment as well as technicians to operate it. It was part of the grant led to the purchase of Slocum gliders.

"The gliders give us the ability to work closely with the Canadian research community and our binational partner, United States which also operates a glider fleet. Not only does the grant allow access to underwater gliders, but also a range of components and sensors that can allow us to monitor harmful algal blooms and dissolved oxygen issues – recognised as a problem in the Great Lakes, particularly Lake Erie.

"There is a large commercial fishery on Erie with many ships passing through the area. Our goal was collect data for hypoxaemia algal blooms. Interestingly, it is not a big algal bloom year because the water levels have been high but because of COVID, we wanted to capture the data in these strange times.

The nice thing about the glider is that it gives a high resolution and because the vehicle travels up and down the watercourse , it can define where the thermocline and the anoxic zone lie across the transect.

"Gliders are also useful in detecting acoustic receivers in fish tags. If there's anything we've learnt about fish movement over the past five years, is that they move a lot more than we thought and in areas we didn't expect. We had plans to have gliders out in mid April this year as part of an annual cooperative science monitoring initiative. We especially wanted to try the new G3 gliders in the shallow water".

The Slocum glider preparing for deployment in the Great Lakes.
Image: RAEON

The glider pilot is Cailin Burmaster and RAEON Director is Katelynn Johnson

This is an excerpt from Marine Tech Talk podcast. To listen to the full interview, find Marine Tech Talk on any podcast station or at www.teledynemarine.com/marinetechtalk

HYDROCARBON DETECTION

Hydrocarbon seeps are a global phenomenon, sometimes coinciding with the first discovery of oil and gas in an area. Where these appear underwater, the hydrocarbon leak out of the ground through fractures and sediments, passing from the seabed and up through the water column in a slow but steady flow.

"A number of factors can affect seepage detection" said Orens Pasqueron de Fommervault of ALSEAMAR, "including hydrocarbon expulsion rates along with external elements such as bottom currents, tides, and changes in atmospheric pressure. The processes, however, are largely unpredictable and still not well understood. Over the years, this has prompted the development of various seep detection methods, however, the evolution of autonomous platforms and the development of miniaturized low-power consumption hydrocarbon sensors have brought a technological breakthrough that is now available for offshore exploration activities."

Throughout the second half of 2019 and the beginning of 2020, ECOPETROL, the Colombian national oil company, conducted a glider campaign in the Caribbean Sea. They subcontracted ALSEAMAR to acquire in-situ data at sea to support its offshore exploration activities.

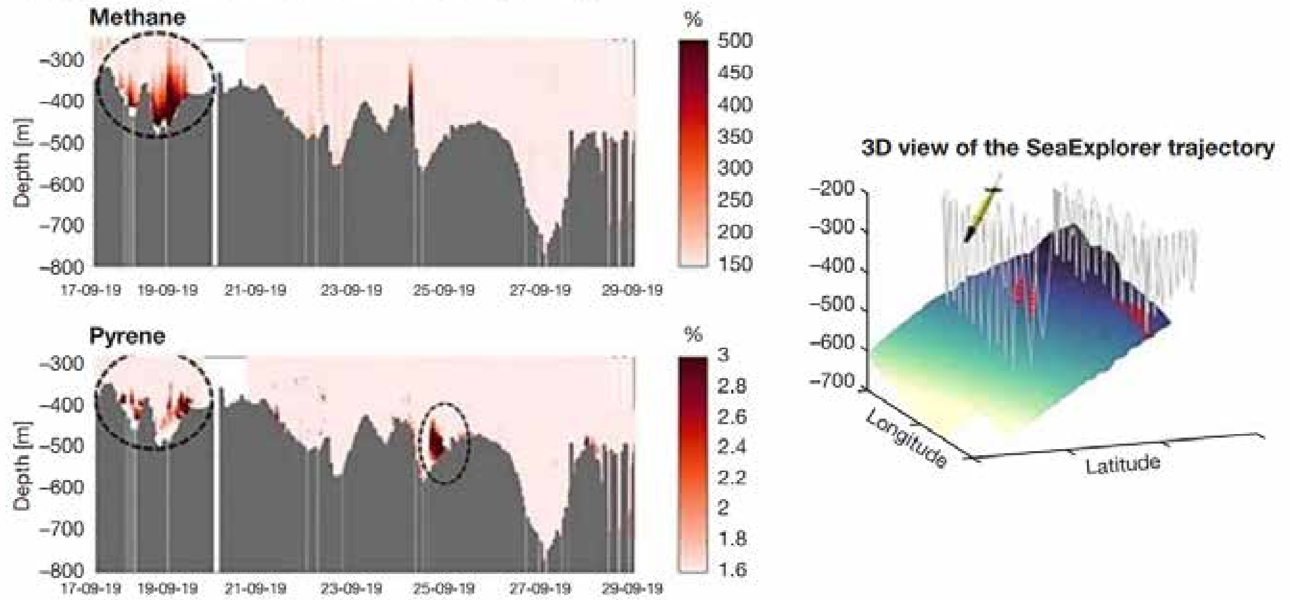
"The survey involved a pair of SeaExplorer gliders, each of which performed six months of continuous monitoring at sea" said Efraín Rodríguez-Rubio of ECOPETROL. "Both gliders housed a classical conductivity, temperature, and depth (CTD) probe as well as a Sea-Bird Scientific dissolved oxygen sensor. One of the gliders was also equipped with an additional acoustic doppler current profiler (ADCP). This metocean configuration allows measuring water currents in real time, to assist our offshore operations and to validate numerical ocean models".

The other glider incorporated an oil and gas sensor suite: this included a Sea-Bird Scientific SeaOWL sensor (for the measurement of turbidity, fluorescence of chlorophyll-a & oil), an ALSEAMAR MiniFluo-UV oil sensor (for the measurement of proxy of pyrene and fluorene-like compounds), and lastly a Franatech METS sensor (for the measurement of dissolved methane concentrations).

ECOPETROL selected the survey site after analysing previous ASTER and sentinel satellite observations, which aimed at detecting oil slicks. This study suggested pervasive patches of potential oil slicks in the area, corresponding to variations in the sea surface roughness as well as other physical properties.

Synthetic aperture radar (SAR) images, however, are known to return many "false positives" for oil slicks, caused by natural phenomena which generate patches of similar appearance. "The autonomous detection of hydrocarbons in an oceanographic context is challenging" said Daniel Rincón-Martínez from ECOPETROL. "To accurately detect and characterise natural seepages, a faithful data processing and analysis procedure is needed".

TIME SERIES OF METHANE AND PYRENE ANOMALIES



LEFT: Time series of methane and pyrene anomalies (% relative to the background) with glider bottom track data presented as a bathymetric profile in grey). **RIGHT:** 3D view of the SeaExplorer trajectory illustrating the saw-tooth pattern of the diving (grey lines) with the location of highest methane anomalies (> 500% relative to the background) represented in red (the navigation over this specific transect was completed in seven days).

This operation begins by converting the data onto physical units using factory calibration coefficients adjusted from usual bias (offset, temporal drift, and thermal lag). Resulting data are then converted into anomalies by computation of deviations from a mean state plus a baseline correction. Finally, an automatic procedure is set up to detect oil and gas seepage using objective thresholds.

"Being the main constituent of natural gas, methane is usually used to detect hydrocarbon seeps", continued Rincón-Martínez. In the seven-day methane time-series example, anomalies were very strong. Two significant and persistent methane concentration increases were observed at the seafloor and spreading up to 250 m above. Those results provided very precise location of the seeps and the evidence of active gas expulsion.

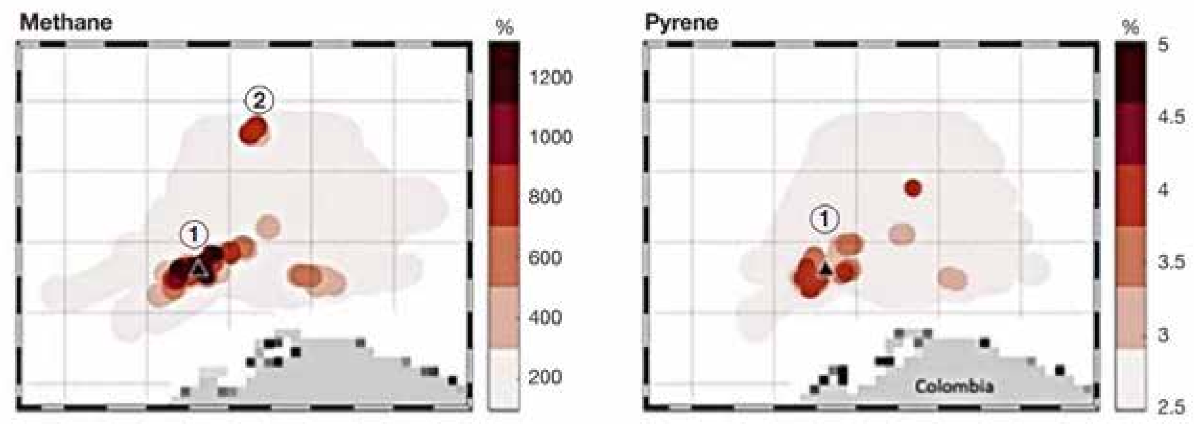
"These events were not isolated and were observed frequently across the six-month survey. In order to increase the likelihood of detections and to better characterise the nature of the system we wanted to analyse the oil concentrations."

The majority of commercially available sensors are based on optical properties. These are impacted by natural fluctuations and water mass characteristics, which makes the measurement sensitive. The detection procedure, however, highlighted anomalies relative to the background noise.

The anomalies detected with optical sensors were smaller compared to methane-sensor ones, but still statistically significant. Looking at the output of the MiniFluo-UV sensor, it is evident that oil anomalies occurred concomitantly with methane increase. Even if detections did not perfectly match in time (one day of difference), they were spatially close.

"Looking at the data output, the site is not only characterised by methane, but also probably by oil leaks,

MAP OF METHANE AND PYRENE ANOMALIES AT 50 M ABOVE THE SEAFLOOR



Map of methane and pyrene anomalies at 50 m (164 ft) above the seafloor (% relative to the background). The black triangle indicates the position of maximum methane detections.

although at this stage it is not possible to determine the relationship between near-surface hydrocarbon seepage and subsurface petroleum systems".

Information on the hydrocarbon charge type (gas versus oil), however, provides ECOPETROL with useful information for data-based decision making regarding the acquisition or divestiture of lease blocks in the area.

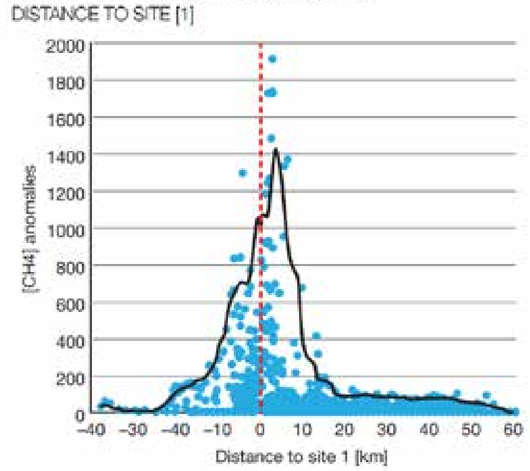
"At a broader scale, the whole glider-dataset collected provides a comprehensive and stationary view of the region" said Efraín Rodríguez-Rubio. "There is a spatial coherence between the various parameters and confirms active seepage during the survey period".

A distribution of anomalies was indeed recognised along a southwest–northeast axis, parallel to the isobath 400 m (1,132 ft). The coordinates were converted into distance to evaluate the plume extent. Far away, it was observed a background level in the range 0-100%, suggesting the area is characterized by a system of aligned seeps rather than a single seep.

Oil and gas anomalies of smaller magnitude also appeared "floating" in the water column although a cross-comparison with current measurements would be necessary to determine the source of the gas detected (local seepage or advection from another site).

While glides can provide direct imaging of seepage and confirm the presence of active petroleum systems in the area, the data also permitted a better understanding of the area (seepage size, occurrence, etc.). However, bathymetric and seismic re-examination of the area is required to better understand the nature of seepages (i.e. faults, sub-bottom gas flows, diapirs, mud volcanoes, gas hydrates).

DEEP ANOMALIES PLOTTED AGAINST THE DISTANCE TO SITE [1]



Deep anomalies plotted against the distance to site [1]. The black curve represents the main envelope of points.

ROBOT-ROBOT LAUNCH

Over the years, gliders have proven particularly useful tools for providing general underwater profiling, but like everything, they have challenges.

One such is the organisational difficulty associated with getting the them to a required location at the desired time, for example, to accurately coincide with a spring bloom, a volcanic eruption or a hurricane arriving.

Travelling under their own power, ocean gliders can often take many weeks to arrive at their destination and along the way, consuming battery power, which can potentially reduce the survey time after arriving on station.

An ideal way to mitigate this is for the glider to be delivered to site by ship and launched fully charged.

Researchers at the University of East Anglia (UEA) however, have successfully carried out another option – using an autonomous surface vehicle to deliver the glider to site.

Speaking at the MATS 2020 event, PhD student Elizabeth Siddle elaborated on the project.

"By being able to deploy the Sea Glider using another autonomous vessel, we reduce our reliance on ship time that is not only very expensive, but also can be very difficult to procure. Another important advantage with this, as with any uncrewed vehicle, is that we don't need to send people out to remote and dangerous locations.

"UEA operates a surface vessel from AutoNaut, which is used primarily to collect surface data. Named the Caravela, we have equipped it with a range of meteorological and oceanographic instrumentation. It is able to measure shortwave radiation, longwave radiation, wind velocity, air temperature and humidity at the surface. In the water, we have a CTD for near-surface temperature and salinity as well as a ADCP for surface current velocity.

"Using this data, we hope to calculate heat and momentum fluxes and better understand the ocean mixed layer heat budget."

AutoNaut uncrewed surface vessels are wave powered, with sprung foils providing forward propulsion. Caravela is unique in that its aft foils have been adapted to fit a Seaglider carrying mechanism. When the remote pilots are ready for the release, the Seaglider can be pushed backwards by the mechanism, shortly to surface behind Caravela.

A lightgate across the Seaglider fin informs the pilots if the Seaglider has successfully left the mechanism.

"Unfortunately the Seaglider cannot be recovered using this mechanism, so we still need to source a ship for recovery," said Siddle

EUREC4A

"At the start of 2020, we took Caravela on its first full deployment as part of the Eurec4a field campaign," noted Siddle. "Eurec4a investigated the interplay between clouds, convection and circulation and their role in climate change through a vast set of measurements of the ocean and the atmosphere.

"As part of this campaign, Caravela was to study the intersection between route of the German vessel ***RV Meteor*** and the route of the HALO aircraft. We prepared the glider and Caravela on Barbados and successfully piloted it towards the study site. We decided to release the Seaglider quite early on in the transit, however as Caravela was travelling slower than anticipated; quite possibly due to large areas of seaweed the surface. The glider, accumulating useful profiling data as it travelled, arrived at the study site only a day behind the Caravela.

"At the study site, we piloted Caravela around an hourglass-shaped sampling pattern, 10km wide. The vehicle stayed around the study site for 11 days and managed to complete this survey pattern eight times. The Seaglider, alongside two more Seagliders deployed from the ***R/V Meteor*** provided us information on temperature, salinity and currents in the ocean mixed layer and aid with air-sea flux investigations"

"It was very useful to capture surface data with the Autonaut and deep water data with the glider and see how the data from the surface compared with the underwater profile. We hope this data will support other scientists within the Eurec4a campaign and look forward to seeing how our autonomous vessel data can be used.

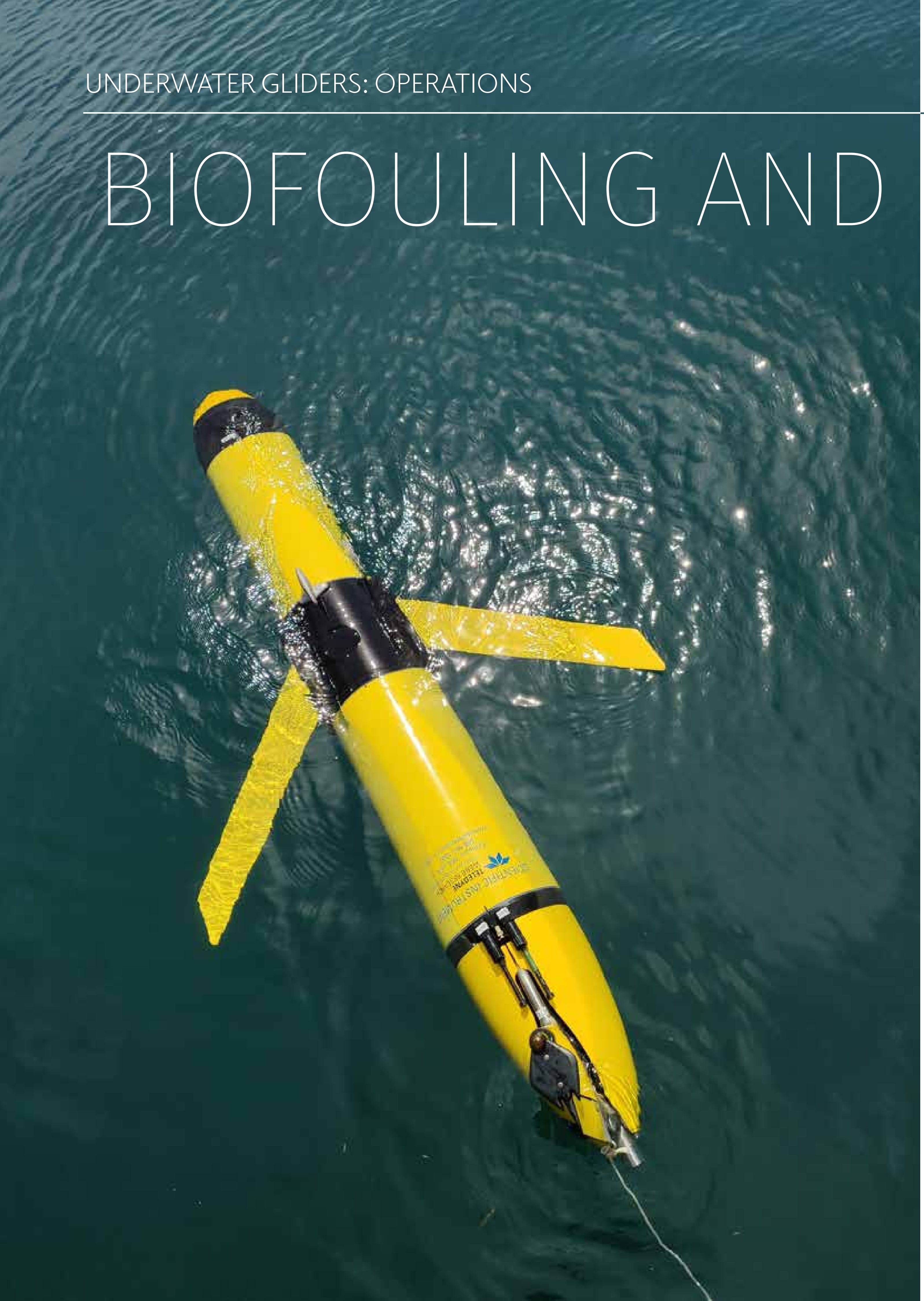
"In the future, we would like to look in more detail at how the motion of Caravela affects the quality of measurements, for example, how aspects such as pitch and roll

affect our downward radiation measurements especially,

how to go about correcting these sort of readings. In terms of future deployments, we hope to take Caravela down to the Antarctic to complete air-sea interaction studies where measurements of this type are sparse" concluded Siddle.

AutoNaut carrying the Seaglider Image:Beth Siddle

BIOFOULING AND WING LOSS



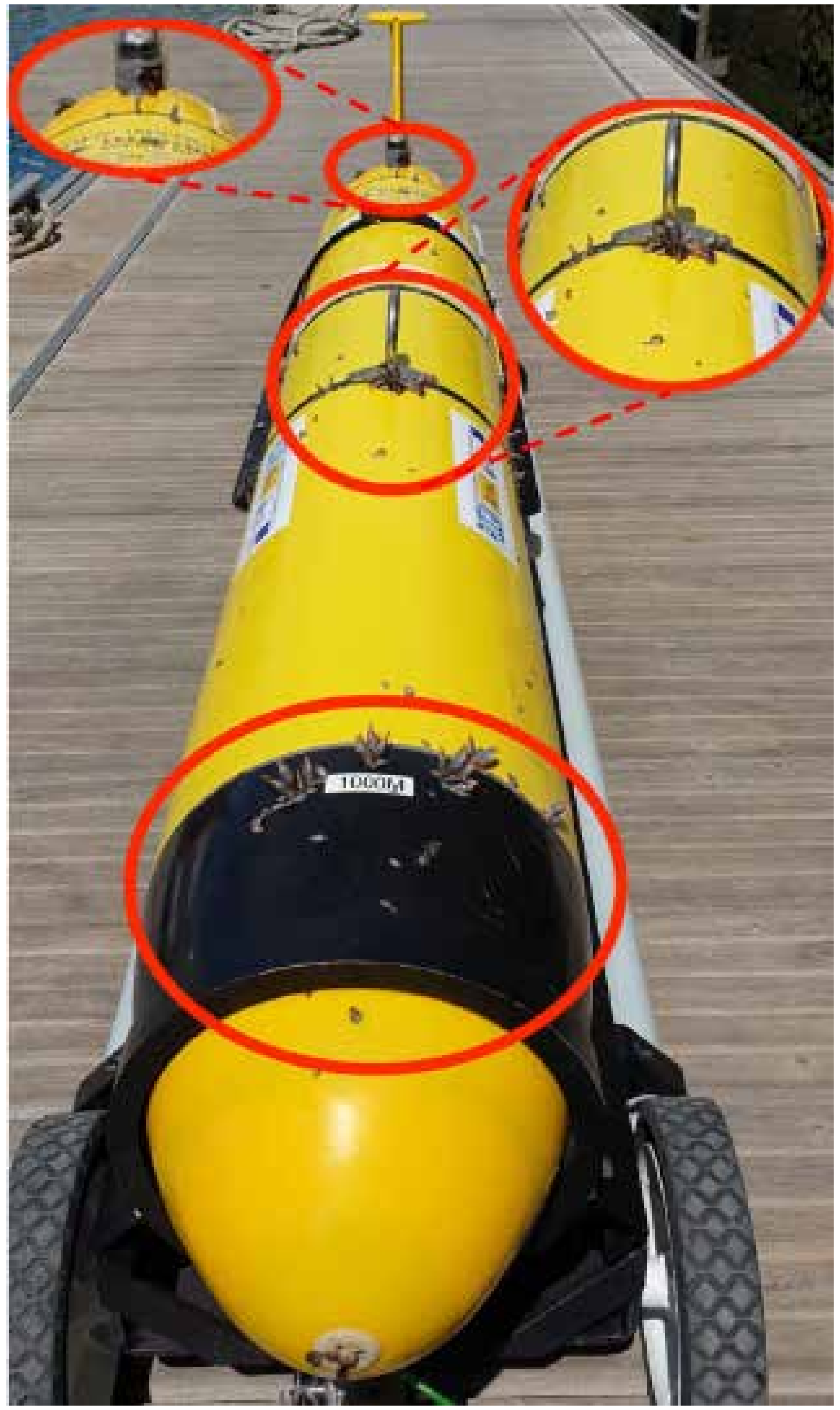
Biofouling is a well-recognised agency for increasing frictional drag on the hulls of ships and increasing the power required for movement. What is less understood, however, is how biofouling affects underwater gliders. In a mechanism that is very sensitive to buoyancy and dive angle, any addition of non-uniform weight can make the gliders unresponsive and sometimes require immediate recovery.

At the recent IEEE-organised AUV2020 symposium in Canada, Enrico Anderlini, Researcher at University College London, discussed the problems.

"In the past, work has been carried out to investigate the impact of biofouling during a glider deployment in the South Atlantic where marine growth was observed to cause a drop in speed with time and an increase of 1deg in the angle of attack, but at present, the community only has limited datasets of biofouled hulls and there are no real strategies to correctly identify the onset of marine growth. Our approach has been to add artificial biofouling onto a glider in field tests off the coast of Gran Canaria, and then compare the glider's dynamics with exactly the same vehicle but used conventionally.

"One of the most common places that the shellfish attach themselves to is the nose and at the edges of the cylindrical sections of the hull. The junction of the cylindrical hull sections offers good grasping points for the roots of the shellfish larvae.

Our team used a used a Slocum G2 operated by PLOCAN. Before it was launched, the researchers attached

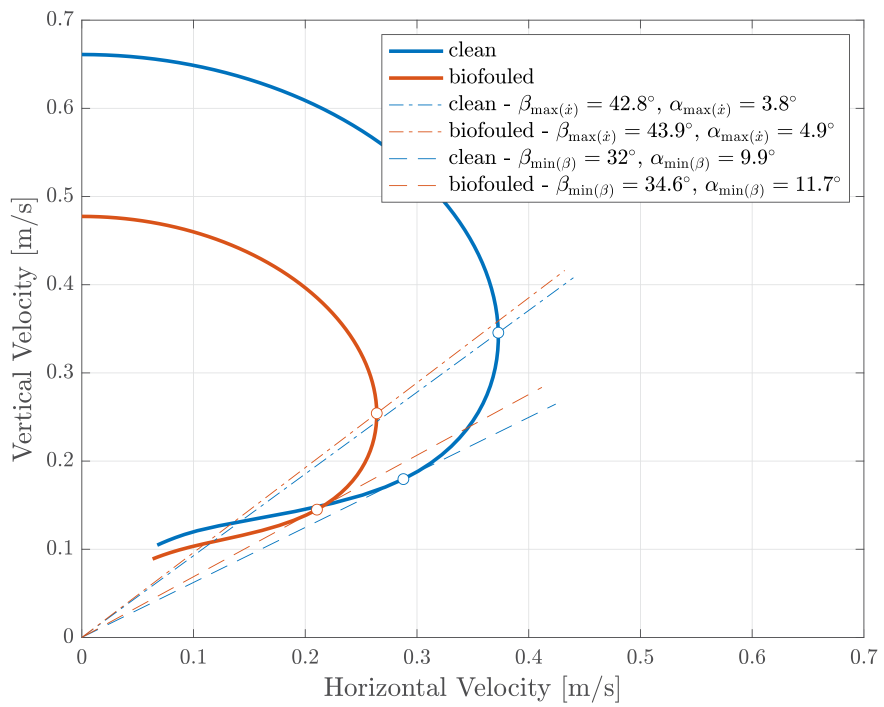


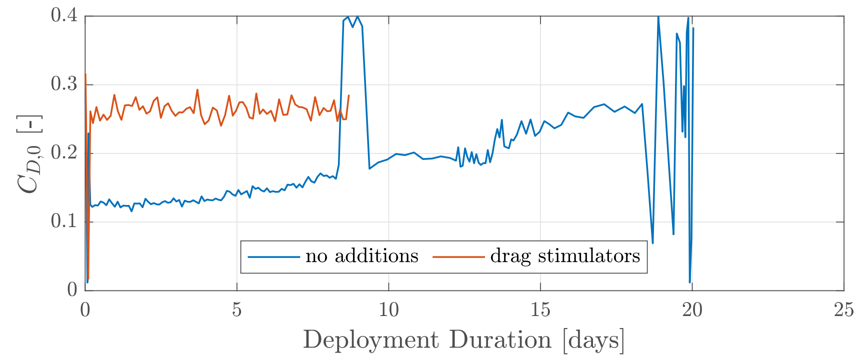
Biofouling on the cylindrical hull

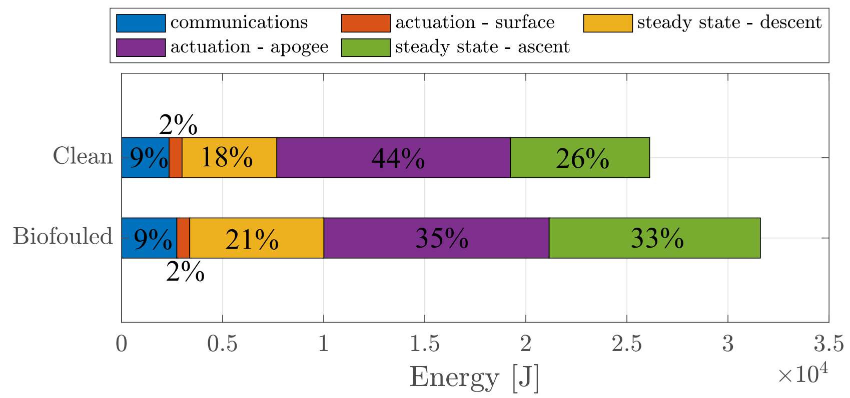
drag stimulators to induce turbulent flow and simulate high levels of marine growth."

In total, three drag stimulator belts were connected to the glider, each consisting of a 780 mm × 9 mm nylon cable tie, a heat-shrink cover to increase friction and ten 3D-printed 40-mm-long mussels, each of which was connected to the cable tie at 50-mm intervals by means of high strength fishing line passing through two drilled small holes.

The front drag stimulator consisted of ten 40mm-wide neoprene folded strips instead of the







3D-printed shells. To avoid serious ballasting challenges, these drag stimulators were designed to be neutrally buoyant.

"Both missions were constrained by time rather than battery energy," said Anderlini. "The magnitude of the volume and pitch angle were set to 260 cm3 and 26◦, respectively, for most dives.

To increase the range of the vertical velocity and pitch angle, a few dives were run with combinations of a volume of-200 cm3 and-260 cm3 in descents and pitch angles with a magnitude of 18◦, 26◦ and 30◦. In ascents, the full capacity of +260 cm3 was used at all times."

In this test, the maximum depth was capped at 200m to avoid possible structural and/ or hydrostatic problems with the stimulators.

After the vehicle was recovered, the drag stimulators were removed and the glider redeployed although increasing the depth to 1000m.

"We found that the biofouling drag stimulators clearly lowered the speed, causing the steady- state flight stage to last longer and thus a shortening of mission duration," said Anderlini. "Simulated marine growth resulted in a significant drop in speed. From the tests, we found the drag stimulators caused an increase of 92% in the drag coefficient of 37% in the induced drag coefficient.

Conversely, because of their design, the impact on the net buoyancy was negligible. "

"The drag stimulators increased the lift coefficient by 46%- mainly due to the extremely large size of the 3D-printed shells of the drag stimulators. In fact, real biofouling may cause a reduction in lift coefficient.

"One thing we discovered was that operational phases play a more important role on the glider's overall energy consumption for the biofouled hull, reducing the deployment duration for the same available energy. This is due to the longer duration of the steady-state phases because of the lower speed in the water.

It is interesting to note that because the pressure inside the hull is lower than atmospheric pressure, this greatly helps reduce the actuation energy costs, as the bladder can be retracted before descents without operating the buoyancy pump, which is the greatest power draw.

"From the data, we were able to develop a simple model-based condition monitoring tool to help pilots recognise the onset of marine growth so that a safe vehicle retrieval can be planned if needed."

WING LOSS

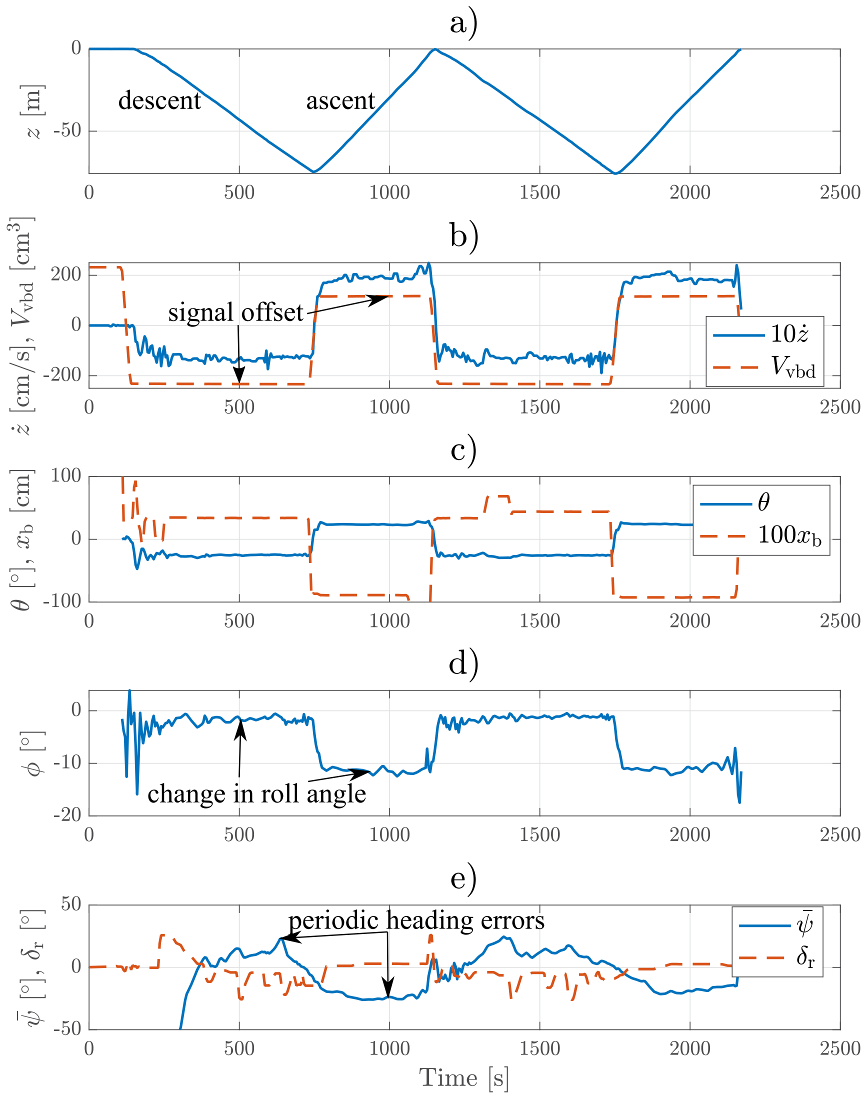
A characteristic feature of underwater gliders is the sheer distances they can travel. Vehicles can be at sea for months and being so relatively isolated, it is sometimes quite difficult to ensure that they are working optimally where a simple visual inspection would reveal potential problems.

Over the past five years, two of the Slocum underwater gliders operated by the UK National Oceanography Centre lost a wing mid-mission without the pilot being aware of the problem until the point of vehicle retrieval.

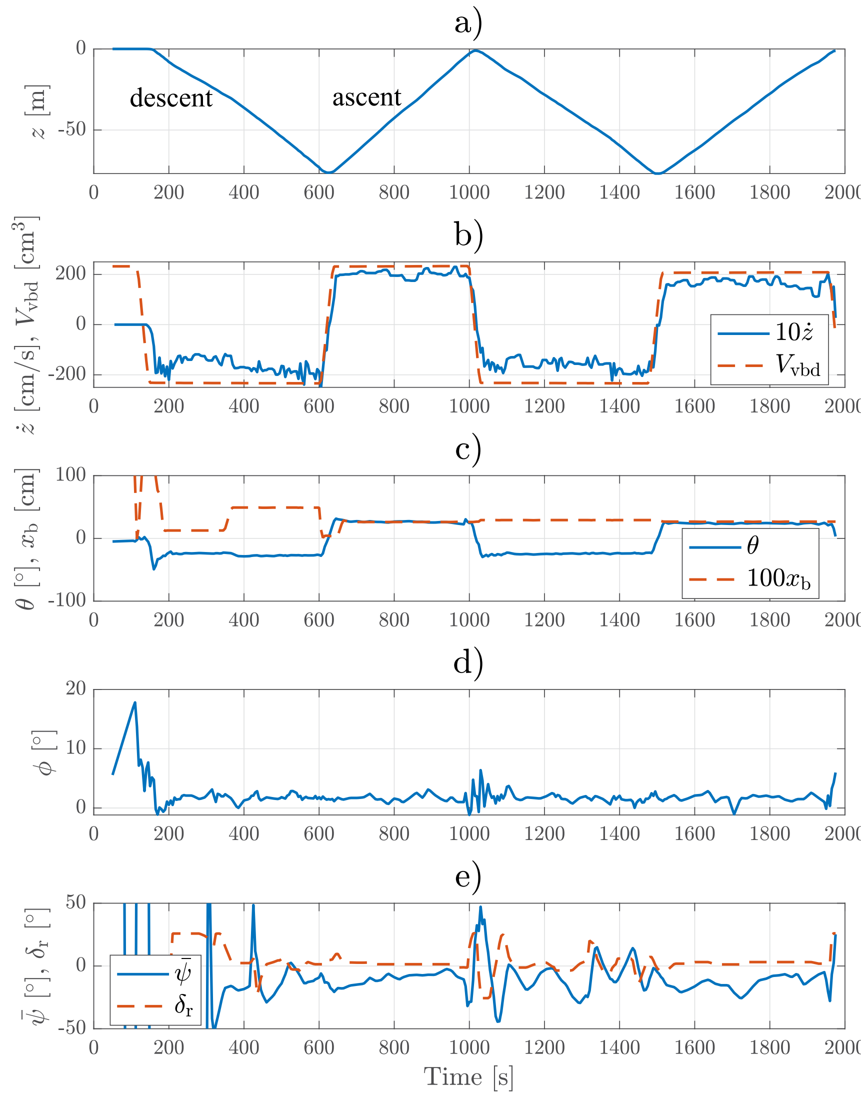
This prompted researchers to collect and analyse the data from the two deployments to detect when this happened and to develop a fault detection system identifying wing loss.

"Wings and their locking mechanisms are not as able as the pressure hull to withstand large impact loads," said Enrico Anderlini, Researcher at University College London." In case of significant collisions, wings can detach from the glider body.

Glider Unit 436 Damaged



Glider Unit 436 Intact



“During a normal operation, the remote pilots routinely monitor progress along the target waypoint and check the battery, both for health and consumption. They carry out a daily check of the glider subsystems, examining the dive profile to ensure it is symmetrical and the glider is reaching the target depth.

"The most common errors identified are relatively mild aborts such as glider stalls, behaviour errors and communication interruption but pilots only look deeper if the glider fails to dive correctly or is not making progress towards a waypoint. Anything else can easily go unnoticed.

“Re-analysing the data showed that the wing loss was a sudden event for both gliders, with an impact with marine traffic being the likely cause. This sudden phenomenon causes a change in the roll angle between descents and ascents, an increase in the net buoyancy, higher variance in the yaw and rudder angles in the glider, a rise in the energetic cost of transport and a drop in the horizontal speed through the water.

The drag coefficient is unaffected."

DETECTION

The main changes to the system dynamics associated with the event are an increase in the positive buoyancy of the glider and the occurrence of a roll angle on the side of the lost wing, with significant difference between dives and climbs.

The researchers looked detecting wing loss in two ways- rule-based and model-based.

"Rule-based diagnostics focus on changes in roll angle," said Anderlini. "It relies on bespoke heuristics, usually in the form of if-then statements, obtained from designers’ observations of the system. It looks at the difference in the value of the roll angle between dives and climbs.

"The model-based system, however, captures the change in buoyancy. In some vehicles, the pitching moment is counteracted by a change in the battery position, while the yawing moment is corrected by the rudder.

Conversely, the shift in the position of the centres of buoyancy, gravity, lift and drag will cause a roll moment that at equilibrium results in a list angle.”

Ideally, the fault detection system should be able to identify problems other than purely the loss of wings.

"After identifying the two sections of the dataset where the vehicle operated with and without a wing, the energetic cost of transport (COT), (quantified as the ratio of the energy expenditure and the product of the vehicle’s mass and distance travelled) was computed to assess the impact of the loss of one wing on the glider's dynamics.

The developed tools have already been used to successfully detect wing loss and inform pilots of the event during a new deployment in 2020, so that a safe retrieval could be planned. Since sensors are known to fail and the roll sensor is non-critical to the operation of the glider, a back-up diagnostics system has been developed based on the dynamic model of the vehicle, capturing the change in buoyancy.

Both systems are able to correctly detect the loss of the wing and notify pilots, who can re-plan missions to safely recover the vehicle.