Deep Impact

An ambitious effort to take a manned submarine to the bottom of the Earth's five oceans is pushing subsea technology to its limits. Jon Excell reports

It's something of a cliché. But we still know more about our closest cosmic neighbour than the depths of our own oceans.

While 12 astronauts have walked on the surface of the moon, just two manned missions have made it to the deepest known point on the Earth's seabed: Challenger Deep in the Pacific Ocean's Mariana Trench (10,916m).

And although robotic probes have been sent to almost every corner of our solar system, the murkiest depths of our own planet remain a mystery: a risky frontier of bone-crushing pressures and near-freezing temperatures where navigation is difficult and the prospect of rescue remote.

Which makes a current effort to land a manned-submersible on the deepest parts of the world's five oceans all the more exciting and impressive.

The so-called Five Deeps mission is the brainchild of thrill-seeking US financier Victor Vescovo, who is hoping to add the bottom of the world's five oceans to an explorer's CV that already includes the 'seven summits' and skiing expeditions to the North and South poles.

The project ticked off its first milestone late last year, when – aboard a hi-tech submersible developed by Florida based submarine manufacturer Triton – Vescovo became the first human to reach the Puerto Rico trench in the Southern Ocean (8,376m). Last month, he reached the southern portion of the Atlantic's South Sandwich Trench (7,433.6m) and in the coming months plans to land his vessel on the bottom of the Java Trench, thought to be the deepest point in the Indian Ocean; Molloy Deep in the Arctic Ocean; and, of course, Challenger Deep.

But the $48m (£36m) effort is much more than a rich man's vanity project. Those involved – who include some of the world's leading experts in deep sea exploration – describe it as a scientific mission without precedent, an undertaking that has driven the development of a host of advanced submarine technologies and which will shine new light on our planet's most mysterious frontier: the 6,000-11,000m Hadal Zone, a world of deep, dark trenches home to some of the hardiest and most unusual living organisms on the planet.

Clearly, achieving this requires some pretty extreme engineering, and that begins with the submarine at the heart of the project, the 11.2 tonne, titanium-hulled Triton 36000/2 (or Limiting Factor as Vescovo has named it).

Triton's chief engineer John Ramsay, who is based in the firm's UK engineering office in Devon, told *The Engineer* that the vessel is unlike anything he has designed before.

Whilst most of the firm's subs are able to make use of off-the-shelf components from other sectors such as oil and gas, nothing is really available for depths beyond 6,000m, he said. So the team has had to develop a host of technologies from scratch: from the pressure-compensated batteries that power the sub to its assorted manipulators, thrusters and electrical systems.

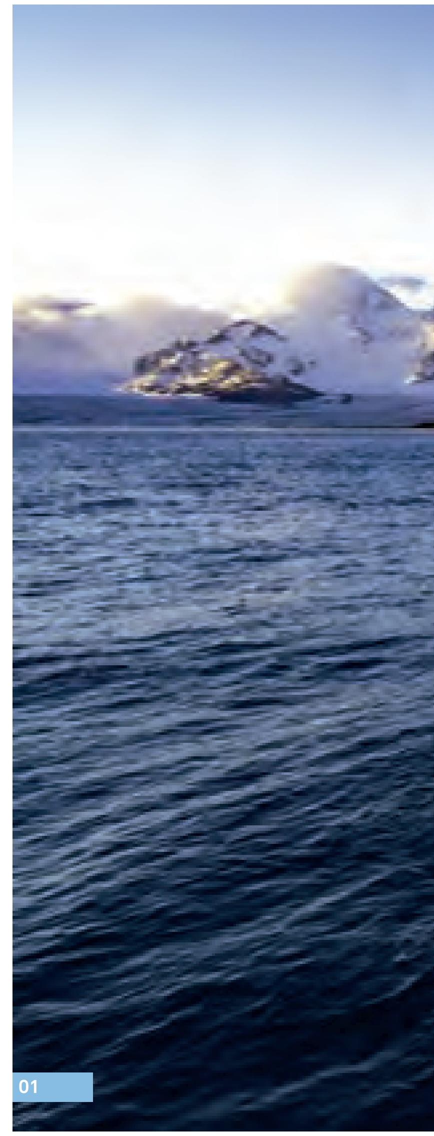
The most striking feature is its giant titanium pressure hull, a precision-engineered 90mm-thick structure, able to withstand 16,000psi and accommodate two passengers within its cosy 1.5m diameter confines.

Formed from giant forgings joined without welds and machined to within 99.933 per cent of true spherical form, the production of the hull was, said Ramsay, a major challenge.

"Normally if you make a pressure hull like this it would all be welded. But we were determined from the start that we wouldn't have any welding... because it introduces so many unknowns into the design. It means that essentially once it's welded you don't really know the strength in the weld, it causes everything to move and shift, you want it to be as close to a perfect circle as you can."

The end result is a hull that is barely affected by the enormous pressures it encounters at full depth. Ramsay estimates that it reduces in diameter by just 4mm, quite an achievement considering it has the equivalent to the weight of the US's largest aircraft carrier pushing down on it.

One of the most problematic areas of the hull was the design of the viewports, which are made from acrylic and therefore not as strong as the titanium. "The pressure on the acrylic is higher than the rated strength of the acrylic – so it's quite an unusual design," said Ramsay. "As the sub dives deeper the acrylic viewpoint gets pushed into a conical opening and moves about 7mm into the viewport seat. It's all designed to distribute the stresses evenly at the maximum diving depth."



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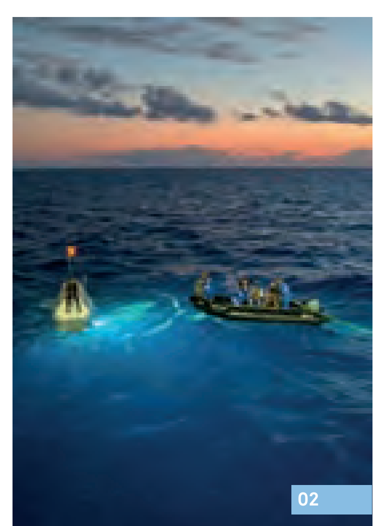
01 The Submarine shortly before its successful visit to the South Sandwich Trench. Image: Caladan Oceanic

02 The Limiting Factor returns from its Dec 2018 trip to the Puerto Rico Trench. Image: Caladan Oceanic



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Despite the enormous pressures, space constraints within the pressure vessel, coupled with the challenges of passing electrical signals through a titanium hull, mean that many of the key components – including the submarine's lithium polymer batteries – are actually stored outside and designed to operate at the ambient pressure. "Electronics where possible need to be pressure-tolerant, so they're immersed in oil that's compensated at water pressure," explained Triton's chief electrical engineer Tom Blades.

The batteries power 10 powerful electric thrusters controlled by joysticks within the vessel. These include four transverse manoeuvring thrusters, two additional thrusters for manoeuvring up close and four vertical thrusters that can be used to arrest the submarine's weight-enabled descent. "If you're descending and for any reason you want to stop for a moment, you can arrest the descent with the thrusters without having to drop all the weights," explained Ramsay.

Electrical wiring for carrying control signals and power is passed through the pressure hull via a series of specially designed penetrators, developed for the project by Aberdeen firm CRE. These use an innovative glass-to-metal seal to ensure that the pressure integrity of the hull isn't compromised.

Beyond the innovative design elements, one of the key factors that differentiates the submarine from other deep diving vessels is that it has been engineered for repeated use.

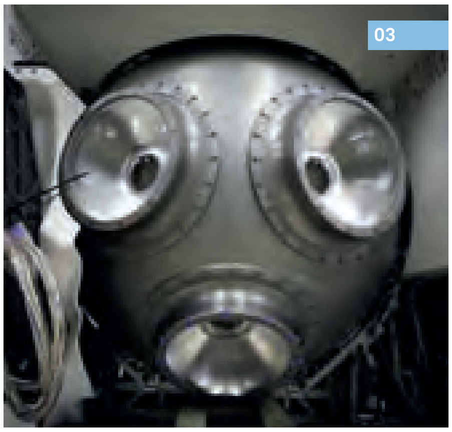
While previous efforts, such as the two successful attempts to reach the bottom of Challenger Deep (the Swiss-designed Trieste in 1960, and James Cameron's Deepsea Challenger in 2012) were one-off dives, the Triton sub has been designed to perform thousands of missions.

To achieve this, the engineering team had to work closely with the marine certification body DNV GL to get the vessel approved. "That level of scrutinisation... sets it aside from what you might call a prototype or a sub that was only going down for one specific dive," commented Ramsay.

Getting the design to this point called for a rigorous programme of testing. And in the absence of any existing facilities the team worked with Barcelona-based submarine manufacturer ICTINEU on the development of the largest high-pressure hyperbaric chamber in Western Europe. This has been used to test every single component at pressures 1.2 times greater than those experienced during actual use.

Another major aspect of the design has been the development of safety and redundancy systems to ensure that, in the event of a problem, the submarine can get back to the surface without assistance. "It's going to be on its own," said Ramsay, "There's no chance of getting rescued when you're down at 11,000 metres."

Alongside back-up batteries, thrusters and breathing equipment, one of the key innovations here is that all of the external features, including the thrusters, batteries and manipulators, are ejectable, meaning the pilot can rapidly increase the buoyancy of the sub and also disentangle it should it become snagged on something. "Every sub pilot's biggest fear is pulling a rope into the thruster," said Ramsay. "The safest and most reliable way is to just have the thrusters drop if you snag onto anything – we use these



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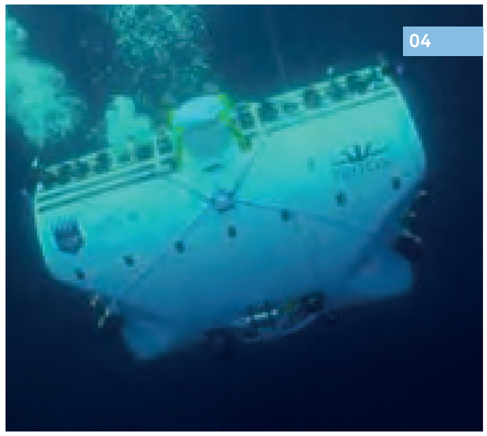

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amazing explosive bolts where you apply a current to a sheath around the bolt and after about 90 second it snaps," he explained.

While the submarine is the star of the show, it is just one element of a wider package which includes a support vessel (the DSSV Pressure Drop) and a series of advanced unmanned subsea landers. These are particularly key to the development of an innovative underwater GPS system that uses modems on the surface vessel, the landers and the sub itself to triangulate the position of the vessel and help it navigate to its target.

Triton's Tom Blades explained that while submarines operating at shallower depths typically use so-called ultra-short baseline (USBL) systems that communicate with a surface vessel using acoustic pulses, this method of navigation is not effective at greater depths.

"To get all the way down to full ocean depth you need to use much lower-frequency sound," he explained, "which gives you the problem that you can't sense direction without a much larger array." The solution has been to use acoustic modems that can transmit and receive analogue voice communications and also data.

These subsea modems have a high-precision time reference synchronised to GPS on the surface. Whenever data is sent from the subsea modems, the time of sending is encoded into that message. "You compare that to the time at which the message was received and you have time of flight which, using bathymetry data, we can calculate the speed of sound through water and get a distance," explained Blades. "We use all these distances to triangulate the sub's position."

Alongside their role in the navigation system, the subsea landers are also a key component of the scientific side of the mission and are equipped with a host of sensors, baited cameras, traps and push cores that can be used in collaboration with the submarine to record, collect and return samples from the seabed.

This area of the project is being headed up by one of the world's leading experts in the deep ocean and the technology required to study it: Newcastle University's Dr Alan Jamieson.

Over the course of his career, Jamieson has carried out some of the pioneering work in Hadal Zone exploration, discovering dozens of new species of fish and crustaceans and writing one of the definitive books on the topic: *The Hadal Zone: Life in the Deepest Oceans*. He even has a species of shrimp named after him: the Princaxelia jamiesoni.

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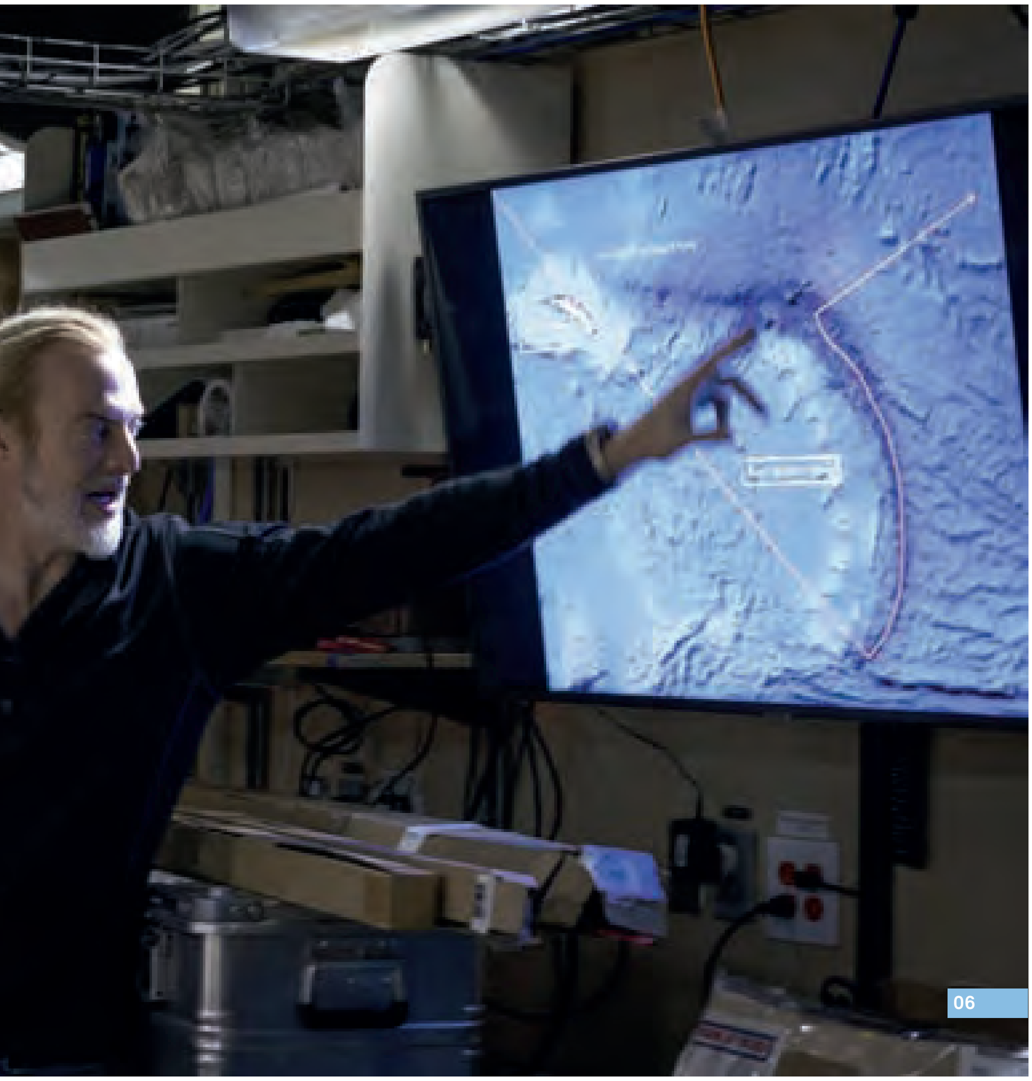
Dr Alan Jamieson



03 The Sub's precision-engineered Titanium pressure hull

04 Limiting factor during one of its test dives

05 The submarine aboard its support vessel, the DSSV Pressure Drop

06 Victor Vescovo studies data on the South Sandwich trench. Image: Caladan Oceanic

07 Early engineering work by one Triton's engineers

However, despite being involved in around 250 dives of 6,000m and deeper in the last 12 months (all of which relied entirely on free-falling landers) he believes the Five Deeps mission could be a game-changer.

"This Five Deeps thing is a really big jump forward because of the sub," he told *The Engineer*. "When we use baited landers we can film and sample all of the mobile animals that come to us, but there's a whole bunch of stuff that isn't attracted to bait so the sub and lander combined give us the best of both worlds.

"I think the true legacy of this is going to be the scientific and exploration side."

Of the sites being visited by Five Deeps, the Mariana Trench is the only one that Jamieson's group has been to before. And he expects that examining other trenches will lead to the discovery of a number of new species and also, as he puts it, "help join up some of the dots".

One of the big things his group is looking at is genetic connectivity. "The deep trenches are very isolated," he explained. "They're like an upside-down island.

"There's a lot of things that live at the bottom of trenches but can't get from one to another. But the tectonic plates have been moving all of the time, so we have what Darwin was talking about with his finches except on a much, much bigger scale and it's happening right now.

"You can see genetic diversions between two trenches that have been slowly moving apart for the last 50 million years." Getting similar samples from all of the five deeps sites will, said Jamieson, help the group start to develop a bigger picture about how life evolved on earth.

The mission will also, he said, dramatically improve the information we have about the seabed. "One of the first things we did when we got involved was to work with colleagues at BGS (British Geological Survey) to go through the five deeps and have a look at the bathymetry, the data, the quality of the data and when it was taken, and where people think the deepest places are. And it was amazing – every single one of them was wrong. There was one time in the Tonga trench we found a vertical wall about 1km high that isn't even on the charts!"

While much of this existing data was acquired using pretty primitive equipment, the echo-sounder aboard the Five Deeps support vessel is, he said, the most advanced instrument of its kind in the world, and will significantly advance our knowledge of what lies beneath. There is even the intriguing possibility that it could identify hitherto undiscovered depths.

Despite Five Deeps' undeniable scientific promise, in the age of the remotely operated vehicle there is – Jamieson concluded – something a bit old-fashioned about the notion of a manned research submarine. "They're a thing of the past because they're so unbelievably expensive. To operate them you need a whole different level of support vessel and an army of technicians to keep them going."

But, as with space exploration, there is something undeniably exciting about having a human in the loop. And Five Deeps' package of technologies, which goes on sale for the princely sum of $45m once Vescovo's mission is complete – could offer someone with deep enough pockets an opportunity to build on this excitement. "Having someone in it grabs people's attention," mused Jamieson. "Kids don't look at ROVs and go 'wow!'" ■