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Editor-in-Chief
Dr Scott Steedman CBE FREng

Managing Editor
Gemma Hummerston

Publications Officer
Portia Sale

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A computer-generated image of the RRS *Sir David Attenborough* shows it breaking through ice. Image courtesy of Rolls-Royce

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EDITORIAL

BACK TO THE FUTURE WITH HYDROGEN


Dr Scott Steedman

Hydrogen is making a comeback. Once the major element in the 'town gas' used for cooking, heating and lighting in homes across the UK for 150 years, hydrogen was displaced as a source of power by a vast conversion programme to 'natural gas' during the 1960s and 1970s to take advantage of gas fields in the North Sea. However, with 57% of natural gas now being imported and the UK's production falling, the time may be right to switch back to hydrogen.

Pilot tests of hydrogen-fuelled trains are already under way in Germany. Hydrogen cars and buses are on the roads today in the UK, but the popularity of electric vehicles and the shortage of hydrogen refuelling stations has limited their take-up. Now, a series of feasibility projects is investigating the wider potential for the use of hydrogen in buildings and transport as a major source of renewable energy.

In November last year the Department for Business, Energy and Industrial Strategy (BEIS) appointed an Arup-led consortium that includes Kiwa Gastec to manage a £25 million Hydrogen for Heat programme, which is researching the use of hydrogen in domestic appliances and potential technological solutions that would address safety risks and minimise disruption.

Political interest in hydrogen is also rising. On 3 July, a new All Party Parliamentary Group on Hydrogen held its first AGM, chaired by Anna Turley MP and backed by industry as well as leading trade unions, which see the potential for creating employment.

There are plenty of hurdles to overcome, but the main challenge is the infrastructure itself. Converting your cooker to burn hydrogen is just the start. Every appliance in an area needs to be modified or changed before any switch to a new fuel. The gas network needs to be able to distribute enough supply of hydrogen to meet peak demand. Hydrogen can be made from water using electrolysis, but the more common approach is to use methane (via a process called steam methane reform). If methane is the feedstock for hydrogen, the CO_2 released needs to be securely stored to achieve a carbon neutral source of energy.

The pioneering H21 Leeds City Gate project, led by Northern Gas Networks, is investigating how a switch to hydrogen can be achieved in practice. Working with the city of Leeds, H21 has confirmed that the existing gas distribution network not only has the capacity but could be converted, stage by stage, with minimal disruption to the public. After all, the UK has already been through the reverse process when it switched off town gas.

In an alternative approach, Keele University is halfway through HyDeploy, a project that will blend hydrogen with natural gas on its 600-acre campus. The aim of HyDeploy is to determine what proportion of the conventional gas supply to homes could be substituted by hydrogen without requiring modification of existing appliances. If HyDeploy succeeds, producers might be able to mix up to 20% hydrogen into the normal gas supply. With the first phase of the HyDeploy project now complete, the Health and Safety Executive (HSE) will assess the results of safety checks in homes and buildings prior to a live trial starting in 2019.

Hydrogen could also make sources of renewable electricity in remote and rural areas more efficient by providing a means of energy storage. Since 2013, Orkney has been a net exporter of electricity but without storage, the turbines have to be shut down when the power is not needed. Surf 'N' Turf is an innovative community project on the Orkney island of Eday, where there is a test site for manufacturers of tidal turbines. Together with a 900 kilowatt wind turbine on the island, these offshore turbines create more power than the islanders can use. Instead of losing the excess energy, Surf 'N' Turf uses electrolysis to produce hydrogen and oxygen. The oxygen produced by the electrolyser is released to the atmosphere and the compressed hydrogen shipped to Kirkwall, where a fuel cell generates heat for nearby buildings and auxillary power for ferries docked in the port.

With these and other projects underway, the signs are promising that in the near future hydrogen may yet again play an important role in the UK's energy mix. With vision and commitment, this quiet and imaginative revolution looks increasingly like an emerging industry with national impact and international opportunity.

Dr Scott Steedman CBE FREng
Editor-in-Chief

IN BRIEF

BLOODLESS TEST FOR MALARIA WINS AFRICA PRIZE

Brian Gitta with Africa Prize judge Rebecca Enonchong, Founder and CEO of AppsTech, who described his invention as "simply a gamechanger"

In June, Brian Gitta, the inventor of a non-invasive malaria test, was announced as the winner of the Africa Prize for Engineering Innovation at an event in Nairobi, Kenya.

His innovation, Matibabu, tests for malaria quickly, accurately and without drawing blood. It is a low-cost, reusable device that clips onto a patient's finger and requires no expertise to operate. A red beam of light is shone through the user's finger, and detects changes in the shape, colour and concentration of red blood cells, all of which are affected by malaria. Within one minute, the results are available on a mobile phone that is linked to the device.

In Nairobi, the four finalists, from Ghana, Nigeria, Uganda and Zimbabwe, pitched their innovations to a panel of judges and a live audience. The finalists were selected from a pool of 16 shortlisted candidates, who all received tailored business mentorship.

Brian won the first prize of £25,000, while three runners-up won £10,000 each. The runners-up were chemical engineer Collins Saguru, who developed AltMet, a process that recovers the precious metals found in the autocatalytic converters of all petrol and diesel vehicles. Electronics engineer Ifediora Ugochukwu developed iMeter, which helps prevent tampering with electricity meters and gives consumers more transparency and control over their energy use. Mechanical engineer Michael Asante-Afrifa created Science Set, a textbook-sized science lab that contains specially developed materials needed for science activities and experiments.

Run by the Royal Academy of Engineering, the Africa Prize provides a package of support to engineering innovators in sub-Saharan Africa, which includes funding, comprehensive business training, bespoke mentoring, and access to the Academy's network of high-profile engineering experts and their network.

ENGINEERING EXCELLENCE RECOGNISED

In June, the Royal Academy of Engineering hosted its annual Awards Dinner to celebrate and recognise engineers who have made a remarkable contribution to the industry.

Owlstone Medical was announced as the winner of the MacRobert Award 2018, the UK's longest running and most prestigious prize for innovation in UK engineering. The company received a gold medal and the team members shared a cash prize of £50,000. Owlstone Medical has developed a non-invasive procedure that aims to quickly and painlessly identify a range of diseases through a simple breathalyser test. Its Breath Biopsy platform has the potential to save hundreds of thousands of lives and $1.5 billion in healthcare costs globally ('MacRobert Award 2018', *Ingenia* 75).

Mishal Husain, news anchor and broadcaster, hosted the ceremony at which several other awards were presented. The Major Project Award was presented to the team behind the Ordsall Chord, a new railway line connecting Manchester's Piccadilly and Victoria stations for the first time, in recognition of the collaboration, skill and engineering flair necessary to deliver such a complex, multidisciplinary feat of railway engineering.

HRH The Duke of Kent presented Lucien Bronicki, from Ormat Industries Ltd, with the Prince Philip Medal for his contribution to cost-effective power recovery by successfully developing power plants using organic fluids.

An integral part of the Great North Rail Project, the Ordsall Chord incorporates the first asymmetric network arch bridge in the world. The Chord uses only 540 metres of entirely new track to connect Manchester's existing railway lines via a brand-new viaduct spanning the River Irwell

Five young engineers received the RAEng Engineers Trust Young Engineers of the Year awards, established with the generous support of The Worshipful Company of Engineers: Khouloud El Hakim, Project Manager at Bechtel Ltd, who also won the Sir George Macfarlane Medal for demonstrating outstanding excellence in the early stage of her career for her work on Crossrail; Simon Bowcock, Lead Materials and Corrosion Engineer at BP; Dr Christopher Donaghy-Spargo, Assistant Professor of Electrical Engineering at Durham University; Dr Robert Hoye, Junior Research Fellow at the University of Cambridge; and Chetan Kotur, Executive Assistant to the CEO at Polestar.

The winners of the Silver Medals were also announced (see page 34).

WORLD'S FIRST LIQUID AIR ENERGY STORAGE PLANT

The plant was developed in partnership with recycling and renewable energy company, Viridor, and partly made possible by over £8 million in funding from the UK government © Highview Power

The world's first grid-scale liquid air energy storage (LAES) plant has opened in Pilsworth, Bury. A pioneering way to store power, the plant acts as a giant rechargeable battery to absorb excess energy, which it releases when needed.

LAES uses excess power to cool air to -196°C, which transforms it into a liquid that is stored at low pressure. The liquid air is then pumped to high pressure and heated to create a gas that turns a turbine to create electricity without combustion when power is required. Although batteries can have higher efficiencies, LAES technology enables energy to be stored for long periods, is cheaper than batteries at large scale and can provide power for longer than lithium-ion batteries. The technology does not use hazardous materials, can be recycled easily and has a lifespan of over 30 years.

The Pilsworth plant, operated by Highview Power, has a capacity of five megawatts and can store 15 megawatt hours (MWh) of electricity, which is enough to power about 5,000 homes for around three hours. A commercial-scale plant would have a capacity of 50 megawatts, but the LAES plant has the potential to be scaled up to hundreds of megawatts.

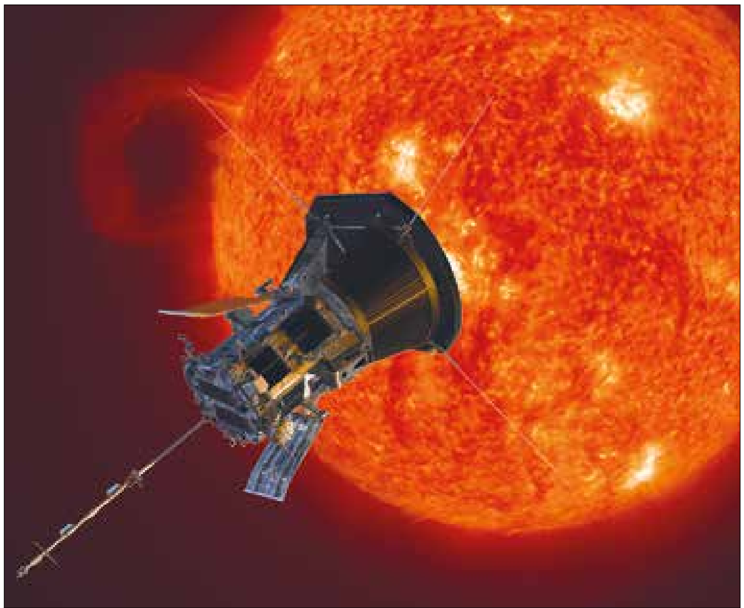
MISSION TO 'TOUCH THE SUN' LAUNCHED

On 12 August, NASA launched its first ever mission to 'touch the Sun' with the lift-off of the Parker Solar Probe, which aims to provide unprecedented close-up observations of the star.

The spacecraft is named after Eugene Parker, an astrophysicist who first described solar wind in 1958. It will travel directly into the Sun's atmosphere, using Venus's gravity to bring its orbit closer to the Sun over seven years. Set to become the fastest-moving manmade object in history, the probe will eventually be seven times closer to the Sun than any spacecraft has ever been, at 3.8 million miles away (Earth is 93 million miles away from the Sun). The spacecraft and instruments are protected from the Sun's heat by a 4.5-inch-thick carbon-composite shield, which can withstand temperatures of nearly 2,500 degrees Fahrenheit.

When the spacecraft reaches the outermost part of the Sun's atmosphere, known as the corona, it will take in situ measurements and images. This will help scientists understand the corona, and expand knowledge of the origin and development of solar wind. It will also enable scientists to forecast changes in Earth's space environment that affect life and technology on Earth.

To track the mission's progress, visit **www.nasa.gov/content/goddard/parker-solar-probe**



An artist's concept of the Parker Solar Probe spacecraft approaching the Sun
© NASA/Johns Hopkins APL/Steve Gribben

JOIN IN WITH THE YEAR OF ENGINEERING

20 TO 23 SEPTEMBER
NEW SCIENTIST LIVE

New Scientist Live returns to Excel in London for its third year. The science festival will have zones based around the cosmos, Earth, humans, technology and engineering, and will feature interactive demonstrations, speakers and experiences.

Engineering highlights include a virtual reality rollercoaster and a pop-up planetarium. Professor Mark Miodownik MBE FREng, materials scientist, will be giving a talk on *Liquids: the delightful and dangerous substances*, and neuroengineer Professor John Donoghue will discuss *Building bionic people*.

In the engineering section, the Royal Academy of Engineering stand will showcase the *This is Engineering* campaign ('Digital campaign aims to tackle skills shortage', *Ingenia* 74), with protagonists from some of the films demonstrating how their passions have turned into engineering careers.

Ingenia readers can get a 10% discount on tickets by using the code RAENG10 at **live.newscientist.com**

New Scientist Live

SEPTEMBER
THIS IS ENGINEERING SEASON TWO

This is Engineering season two launches with films showcasing seven new engineers working in exciting areas. To see the new films, visit **www.thisisengineering.org.uk**

18 TO 28 OCTOBER
MANCHESTER SCIENCE FESTIVAL

This year, Manchester Science Festival celebrates engineering with a number of hands-on activities, ranging from magnet experiments and megastructure building to bioengineering and drones. Visitors can see Stephenson's Rocket, learn about electricity and energy expert James Joule, and tour the University of Manchester's High Voltage Test Lab. The festival takes place across venues in Manchester, with its headline exhibition, *Electricity: the spark of life*, held at the Museum of Science and Industry.
www.manchestersciencefestival.com

Manchester Science Festival

11 OCTOBER
THE GREAT SPACE CHALLENGE

Children under 12 from across the UK are invited to build a module, such as a lab or a sleeping pod for an 'International Space Centre', which will be brought together to create a huge space station at the Great Space Challenge festival in Harwell, Oxfordshire, during a day full of space-themed activities.
www.greatspacechallenge.com

27 OCTOBER TO 4 NOVEMBER
FUTURE ENGINEERS

Taking place at the National Railway Museum in York, Future Engineers is a week-long event that invites visitors to experiment, problem-solve and create through hands-on activities and live performances from scientists and engineers.
www.railwaymuseum.org.uk/whats-on/future-engineers

2018
ENGINEER YOUR FUTURE

This interactive exhibition at the Science Museum is for teens thinking about their futures. Several challenges, games and films help people understand what engineers do and whether it might be the right career choice for them.
www.sciencemuseum.org.uk/see-and-do/engineer-your-future

2018
INVISIBLE SUPERHEROES EXHIBITION

Invisible Superheroes is a year-long exhibition held by the Institution of Civil Engineers in London to commemorate the organisation's 200th anniversary and celebrate the role that civil engineers play in transforming lives and safeguarding our future. The exhibition focuses on the unsung heroes behind some of the world's most amazing engineering projects, using state-of-the-art technology to bring the best examples of civil engineering to life.
www.ice.org.uk/events/exhibitions/ice-invisible-superheroes-exhibition

5 TO 9 NOVEMBER 2018
TOMORROW'S ENGINEERS WEEK

This week aims to show young people how exciting a career in engineering can be. Tomorrow's Engineers highlights the stories of several engineers and how their work is making a difference. It also provides a number of activities for schools, colleges and organisations.
www.tomorrowsengineers.org.uk

© Rosa Fay

To discover more events taking place across the country as part of the Year of Engineering, please visit **www.yearofengineering.gov.uk/inspired**

HOW I GOT HERE

Q&A

SINEAD O'SULLIVAN
AEROSPACE ENGINEER

Sinead says her biggest inspiration was being at the NASA Johnson Space Center (Mission Control) when the Curiosity Rover landed on Mars: "Its entry, descent and landing sequence was choreographed into what was called the 'seven minutes of terror' – the time that it took Curiosity to get from the top of Mars' atmosphere to the surface. This feat of engineering is more daring than most sci-fi plots!"

Sinead O'Sullivan is an academic researcher at Harvard Business School and the US Center for Climate and Security, working on aerospace engineering, technology, business and policy. She is also commercialising her own technology that monitors real-time interference in democratic elections.

WHY DID YOU FIRST BECOME INTERESTED IN ENGINEERING?

I've always loved physics and maths, and loved playing team sports. When I was 15, I was given the opportunity to travel to NASA's Johnson Space Center as part of a space camp. There, I met astronauts who were engineers, spoke different languages, played cool sports and were musicians in bands. It was the first time I really learned what engineers do, and how multidisciplinary it is as a job. I learned that I could do all the things I enjoyed most, at the same time, through engineering.

HOW DID YOU GET TO WHERE YOU ARE NOW?

Within engineering, I have always been focused on aerospace, specifically the space sector. I did my Bachelor of Aerospace Engineering at Queen's University Belfast, where I focused on unmanned aerial vehicle (UAV) design and build. After a couple of years working in a computer science role, I attended the International Space University in France where I gained experience in satellite constellation design as well as human spaceflight and astronaut missions.

For a few years I then worked as a researcher at the Aerospace Systems Design Laboratory (ASDL), an academic research laboratory in the US, where I managed two separate human spaceflight mission design projects for NASA (one to Mars and one to an asteroid). I also worked on underwater and autonomous robotics for the US Navy, drones and some UAV policy research.

After ASDL, I moved to Harvard Business School to pursue my MBA. I was sponsored by the Royal Academy of Engineering as a Sainsbury Management Fellow, which allowed me to get rigorous management training that I could apply to the engineering sector. I really enjoy the mix of engineering, management and academia and have stayed with one foot in research and one foot in engineering since.

WHAT HAS BEEN YOUR BIGGEST ACHIEVEMENT TO DATE?

There are several projects that I've worked on that have brought about large personal satisfaction, but I think the most rewarding aspect of what I've done is mentor and watch younger talent make an impact in the space sector. I run several initiatives to engage with younger or aspiring engineers. I was very fortunate to have had a lot of guidance myself, so I understand the impact

QUICK-FIRE FACTS

Age: **29**

Qualifications: **Bachelor of Aerospace Engineering, Certificate of Space Studies, Master of Aerospace Engineering, Master of Business Administration**

Most-used technology: **The Audible app on my phone, where I can download and listen to millions of audiobooks.**

Three words that describe you: **Tenacious, empathetic and curious**

that it can have when making decisions about education or career planning. There's a lot of exceptional talent in the UK and it's amazing to see some of the students I've mentored being recognised on an international level.

WHAT IS YOUR FAVOURITE THING ABOUT BEING AN ENGINEER?

Engineering is a team-orientated industry, and by far my favourite aspect of engineering is the people. The engineers that I've been lucky enough to work with have all been incredibly passionate about the space industry and are relentless in their drive to further understand and discover our solar system. The space industry is also one of the most inclusive communities I've come across yet – diversity is celebrated and actively contributes to the high levels of innovative technologies being created. One of the coolest teams I worked on included a robotics programmer who was blind, and we created very novel ways of working together to create an amazing outcome.

WHAT DOES A TYPICAL DAY AT WORK INVOLVE FOR YOU?

There is no typical day, which is why I love my job! On the research side, I read a lot, sometimes up to 40 papers or journal articles a week. I then find other academics to use as a sounding board to try to digest and make sense of the subject matter. Since my work is highly interdisciplinary I often look to other fields for inspiration to tie together my ideas, so I spend time reading philosophy, in art galleries or attending more artistic lectures to widen my thinking.

In terms of commercialising my research, I spend a lot of time with my co-founder who is developing the underlying technology, working with investors and lawyers to create a viable business entity, and with customers to develop a product that has a positive, long-term impact.

WHAT FIRST GAVE YOU THE IDEA FOR YOUR TECHNOLOGY?

I have an interest in macro-economics, particularly the evolving form of democracy in an increasingly digital world. I spend a lot of time discussing ideas around digital democracy with colleagues at the Harvard Kennedy School of Government, where I am a member of the British and Irish Caucus.

I met my technology co-founder when I was giving a lecture at Georgetown University in Washington DC on space economics, and we decided to create a set of tools that could effectively monitor real-time interference in democratic elections. Fast forward a few months, and we are actively monitoring the US mid-term elections as well as having recently monitored the UK local elections in May.

HOW WOULD YOU ENCOURAGE OTHER YOUNG ENGINEERS TO DEVELOP THEIR OWN TECHNOLOGIES?

There are a million and one ways to develop new technologies. However, I would suggest starting with a real-life problem that you have experience with – if it is meaningful to you, you will be able to create a more meaningful solution that others will want to adopt. Developing something new that has not been done before is very difficult, and it's natural to get frustrated along the way. But if you take enjoyment from learning and can iteratively improve on your idea you will get much better at the process of technology creation, which is an enormous skill.

WHAT WOULD BE YOUR ADVICE TO YOUNG PEOPLE LOOKING TO PURSUE A CAREER IN ENGINEERING?

A degree in engineering provides you with an analytical framework that can be used to solve problems in any field, whether it's science, engineering, business, finance or even languages. Within the engineering sector there are so many different types of industries, all of which have many opportunities that can provide dynamic and exciting career prospects. My own career was not a straight line from my engineering undergrad to where I am now, so my advice would be to experiment within engineering and technology and learn new skills as you go along.

WHAT'S NEXT FOR YOU?

Within academia, I am hoping to continue my involvement in the space and business areas; the industry is really taking off (or should I say blasting off!) and it's a fascinating time to be involved. With my new technology venture I am opening a UK and European capability, so I am looking forward to becoming more involved with the UK technology sector. Outside of work I am about to start building an amateur rocket that will be launched up to 30,000 feet in Europe in November, so I am definitely looking forward to being more hands-on for the next few months.

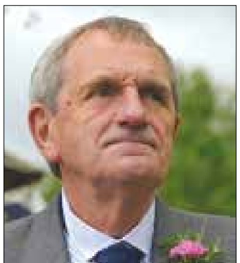
OPINION

SUPPORTING THE DIGITALLY LEFT BEHIND

As vital services and aspects of people's lives increasingly move online, a large community of people are being digitally left behind, unable to access digital services that many of us take for granted. IT systems experts Dan Bailey, Dr Maurice Perks and Chris Winter argue that it is up to IT systems engineers, among others, to ensure that everyone can take advantage of, and enjoy, the digital revolution.


Dan Bailey


Dr Maurice Perks


Chris Winter

Consider not being able to pay your electricity bill, find the best deal for home or car insurance, manage health issues, submit a claim for social benefits or even buy things. All these everyday tasks, and many more, depend increasingly not just on having access to communication technology but on having the physical or mental ability and confidence to use services provided by digital technology.

As digital services become increasingly essential to society, and as cost-cutting closes traditional ways of fulfilling these tasks, many millions of people become members of the digitally left-behind community (the DLBC).

Being part of the DLBC is about more than accessibility to fast broadband or understanding how to use a mouse. The DLBC exists because the entry level to the digital world is set too high for many. The obstacles to effective interaction in a digital society are not simple and include:

- age
- physical issues
- technical complexity
- financial limitations
- trust.

These obstacles grow by the day, as many of the agencies and businesses that the public has to deal with move their services from paper and personal contact to digital interfaces. Too often these new interfaces have been designed for people who can understand and afford the latest technology. Consequently, the bar is set too high for individuals who cannot, or do not want to, participate.

Engineering complexity is at the heart of the problem. Computer technology and the design of the applications that we use to access many services have created interfaces that many people simply cannot master or do not trust. The result of this growing 'digital divide' has been to create a three-tier population.

There is an *elite* community of people who are confident in, and early adopters of, digital services and can deal easily with complicated interfaces. Then there is what we can describe as the *coping* community of warily self-sufficient people who may be

We cannot address the DLBC's needs without a full understanding of its makeup and aspirations. Without this understanding, digital designers will struggle to specify new user interfaces that tear down the barriers to access, thus creating a growing divide between the DLBC and the rest of society

uneasy with the technology but who can use some applications. The bottom tier consists of the large *DLBC*, whose plight indirectly affects everyone.

The digital limitations of the 'digitally challenged' inhibit them from seeking and getting better jobs, simply applying for a driving or TV licence, accessing public services, booking a holiday and more. This handicap also applies to a significant number of younger people, whose digital capability amounts to little more than texting, gaming and emailing.

You might think that we have known about this challenge for ages, and that actions are in hand to fix the problem. In reality, accessibility and better broadband, the main focus of those actions, are not enough. We cannot address the DLBC's needs without a full understanding of its makeup and aspirations. Without this understanding, digital designers will struggle to specify new user interfaces that tear down the barriers to access, thus creating a growing divide between the DLBC and the rest of society.

As engineers, we could start to tackle these barriers through using interdisciplinary systems thinking – an approach that looks at how a system's parts interrelate, work over time and within the context of larger systems – coupled with broader user analysis, to come up with and validate sustainable solutions. This approach should include bringing together the designers and engineers charged with building the digital services for online banking, government services, retail, and the many support groups already trying to help the DLBC.

Only in this way can we begin to answer some of the many questions that need the be addressed. What does a dementia-friendly bank account look like? When will we be able to fill in a tax form with voice only? When will it cost pennies rather than tens of pounds to connect to the internet? When will the internet truly be easy for 'dummies' to use? When will most people safely trust the internet? How can we tackle, in a user-friendly way, the issues of trust and privacy, such as the removal of the physical assurance of cheques, identity theft, password proliferation and personal data security, not to mention unsolicited emails?

To mitigate this threat, we need to take some vital steps. To begin with, we need to understand the extent of the problem. One way to achieve this would be for the Office for National Statistics to work with academic researchers to establish the size of the DLBC population, whether this is increasing or decreasing, and the community's societal and economic impact. A next step would be for the Department for Digital, Culture, Media and Sport to take the lead in government and address the challenges in a systematic and properly resourced way.

There will also have to be R&D to create new approaches to bringing digital services to the DLBC. For this to happen, UK Research and Innovation should make an appropriate investment in understanding and addressing the needs of the DLBC.

The IT industry must also play a significant role in this process, by examining its own methods and thinking so that systems really meet the needs of everyone and not just the 'digital elite'. Suppliers of systems and applications can also play a more effective and responsive role by collaborating on ways that make it easier for the DBLC to participate in the digital revolution.

It is perhaps also worth pointing out that the measures described would not just benefit the digitally disadvantaged. To pick just one example, everyone who has to complete an online tax form every year would welcome more user-friendly technology.

Establishing and reducing the size of the DLBC is very important for the community itself and for the economics of the IT marketplace and many of the businesses that use IT as a major channel for their products and services.

BIOGRAPHIES

Dan Bailey is Chief Technology Officer for IBM UK & Ireland Services. He has over 24 years of experiences in the IT industry, having worked across the globe in numerous industries.

Dr Maurice Perks is a retired IBM Fellow, with more than 40 years' experience in IT systems across several sectors. He spends one day a week helping the DLBC at an IT walk-in centre.

Chris Winter is an independent IT consultant, IBM Fellow emeritus and Royal Academy of Engineering Visiting Professor at the University of Plymouth. His IT career began in 1969.

The new RRS *Sir David Attenborough* can break through ice and is designed to enable scientific investigations in some of the most remote and inhospitable regions in the world © Rolls-Royce

A GREAT BRITISH POLAR EXPLORER

The rapid melting of polar ice caps could have catastrophic consequences for oceans across the globe. To understand the role that the polar oceans play in our changing world, Britain is debuting the RRS *Sir David Attenborough* – one of the most advanced polar research vessels in the world, which will operate in some of the most remote and inhospitable regions on Earth. Science writer Sarah Griffiths discovered the ship's impressive features.

Attempts to understand and respond to the challenges of climate change depend on improving our understanding of the processes involved. The climate research community in the UK now has a new tool, the Royal Research Ship (RRS) *Sir David Attenborough*, which will replace two ageing polar research ships and enable world-leading research in Antarctica and the Arctic for the next 25 years. Like many 'scientific instruments', this 129-metre-long vessel pushed maritime engineering to its limits, in a design that optimises the vessel's ability to support science in extreme environments. It includes instruments and laboratories that will enable scientists to study the ocean, seafloor and atmosphere. When it becomes operational in 2019, the ship will be capable of spending 60 days at sea without resupply over a range of 35,000 kilometres. It will also be able to deploy, operate and control a range of remote-piloted, state-of-the-art robotic technologies.

Commissioned by the UK's National Environmental Research Council (NERC), built by Cammell Laird to a Rolls-Royce design and operated by the British Antarctic Survey (BAS), it is the result of a £200 million investment from the UK government. The polar ship will operate throughout the year, supporting an Arctic research cruise in the northern summer and carrying out research programmes and transporting people and supplies to BAS research stations in Antarctica during the austral summer.

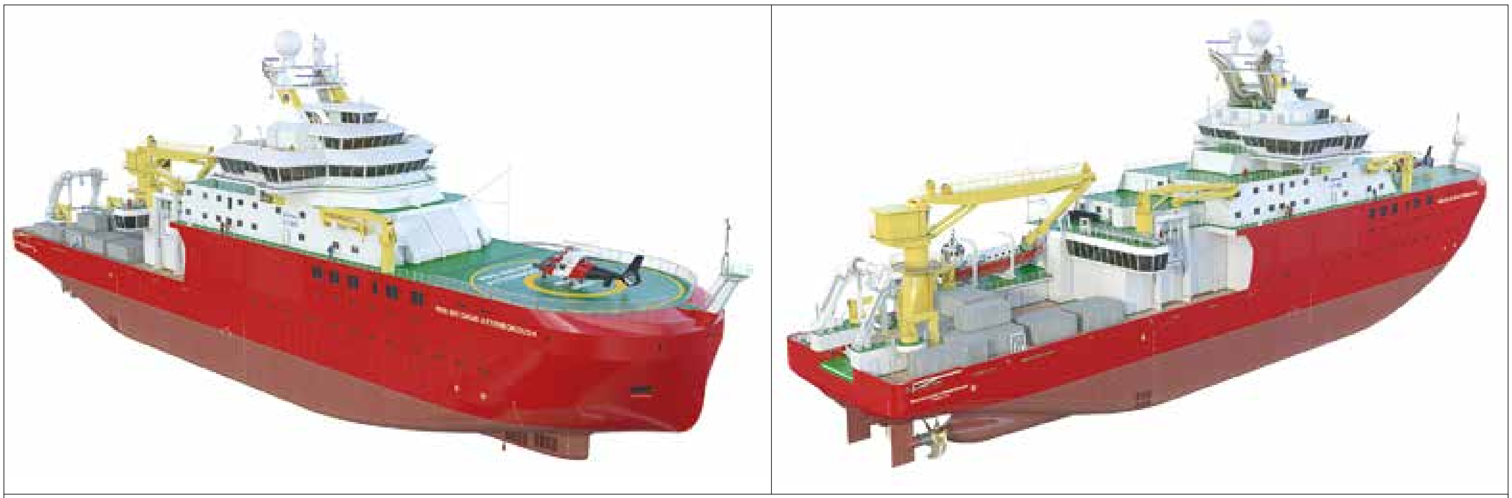
SPECIALLY-SHAPED HULL

The combination of untraditional requirements and multifunctionality of polar research vessels makes the RRS *Sir David Attenborough*'s hull special, but also created the most engineering challenges. Engineers working on the ship, together with scientists from BAS and UK universities, had to design a ship that makes minimal underwater radiated noise (URN) while producing extreme force when breaking ice and cutting through towering ocean waves to achieve its missions, all while carrying supplies. While icebreaking is of vital importance to the ship, it is only part of its operating profile; the vessel must behave predictably and be fuel efficient in all operating modes during a year of operation.

When it comes to icebreaking, the RRS *Sir David Attenborough* can cut through ice up to 1.5 metres thick with additional snow cover, at a minimum speed of three knots. It will do this by using a clever arrangement of powerful engines and its specially-shaped hull. The shape of the vessel's silent hull is developed from other icebreakers designed by Rolls-Royce, and is informed by the company's experience gained from designing more than 1,000 fishing, seismic research and offshore vessels. Engineers used advanced computer modelling techniques and multiple model tests to come up with the hull shape, which is a refinement of the typically flat bow. However, it is not too flat, as the flatter the bow, the higher the risk of 'slamming', the term used to describe the juddering crash

VITAL STATISTICS

- Length: 129 metres; beam: 24 metres; weight: 15,000 gross tonnes
- Scientific cargo volume of approximately 900 cubic metres
- Endurance: up to 60 days (Polar regions)
- Range: 19,000 nautical miles at 13 knots (24 kilometres an hour) cruising speed – more than enough for a return trip from England to Rothera Research Station on the Antarctic Peninsula, or to circle the entire Antarctic continent twice!
- Ice breaking capability: up to 1 metre thick at 3 knots (5.6 kilometres an hour)
- Bow and stern thrusters for excellent dynamic positioning in challenging conditions
- Launch and recovery of aerial and ocean robotic systems
- Crew: approximately 30
- Accommodation for up to 60 scientists and support staff



Engineers have designed the ship's hull so that it breaks the ice by pushing it down and shoving as much as possible below and to the side of the unbroken ice sheet. By doing this, less ice will follow the water flow at the bottom of the vessel and end up in the propellers, which creates noise, power peaks and loss in thrust, as well as in the broken channel behind the vessel. This area should be as open as possible to allow towing of equipment for scientific work and reversing if necessary. The underwater design of the aftship, which houses the two large propellers, is also designed for maximum strength and to allow ice to flow behind the ship without risk of it jamming between the specially designed twin 'skegs' (the tapering after the keel) © Rolls-Royce

when a hull that has risen upwards as it moves through a wave falls back into the water – it is noisy, slows the ship down and can even damage the structure.

Both the water flow around the hull and the airflow over the structure were computer modelled in detail to understand how the shape would interact with its environment. This was important from the ship's running prospective and also for the scientific measurements. The generation of bubbles from the hull's movement through the water and how they flow around the hull's surface could have a significant negative effect on acoustic sonars. Extremely low underwater radiated noise is essential to avoid interference with survey equipment and to minimise disturbance to marine mammals or fish distribution. This meant that it was important for engineers to find the best location for underwater acoustic equipment, while antennas and meteorological sensors needed to be in a place where they will have an undisturbed flow and would not be polluted by exhaust or ventilation outlets. To do this, Rolls-Royce engineers carried out a comprehensive computational fluid dynamics (CFD) study that looked at underwater analysis for different sea states and at various speeds through the water. As a result, connections were carefully welded and smoothed to avoid vortexes so that bubbles will not interfere with scientific transducers and sensors fitted on the hull. The team developed bow and bottom shapes that will lead bubbles away from the sensors, known as 'sweep-down'.

QUIETER ENGINES

One of the key challenges of designing the ship was to make it powerful enough to break ice, but also enable 'silent running' for environmental monitoring and to not have a detrimental impact on its surroundings. Since the Industrial Revolution, our oceans have become around 100 times louder, which is of concern to conservationists who believe vessel noise can have a devastating impact on already struggling species such as whales. The ship must also be quiet so not to have a damaging effect on scientists' research.

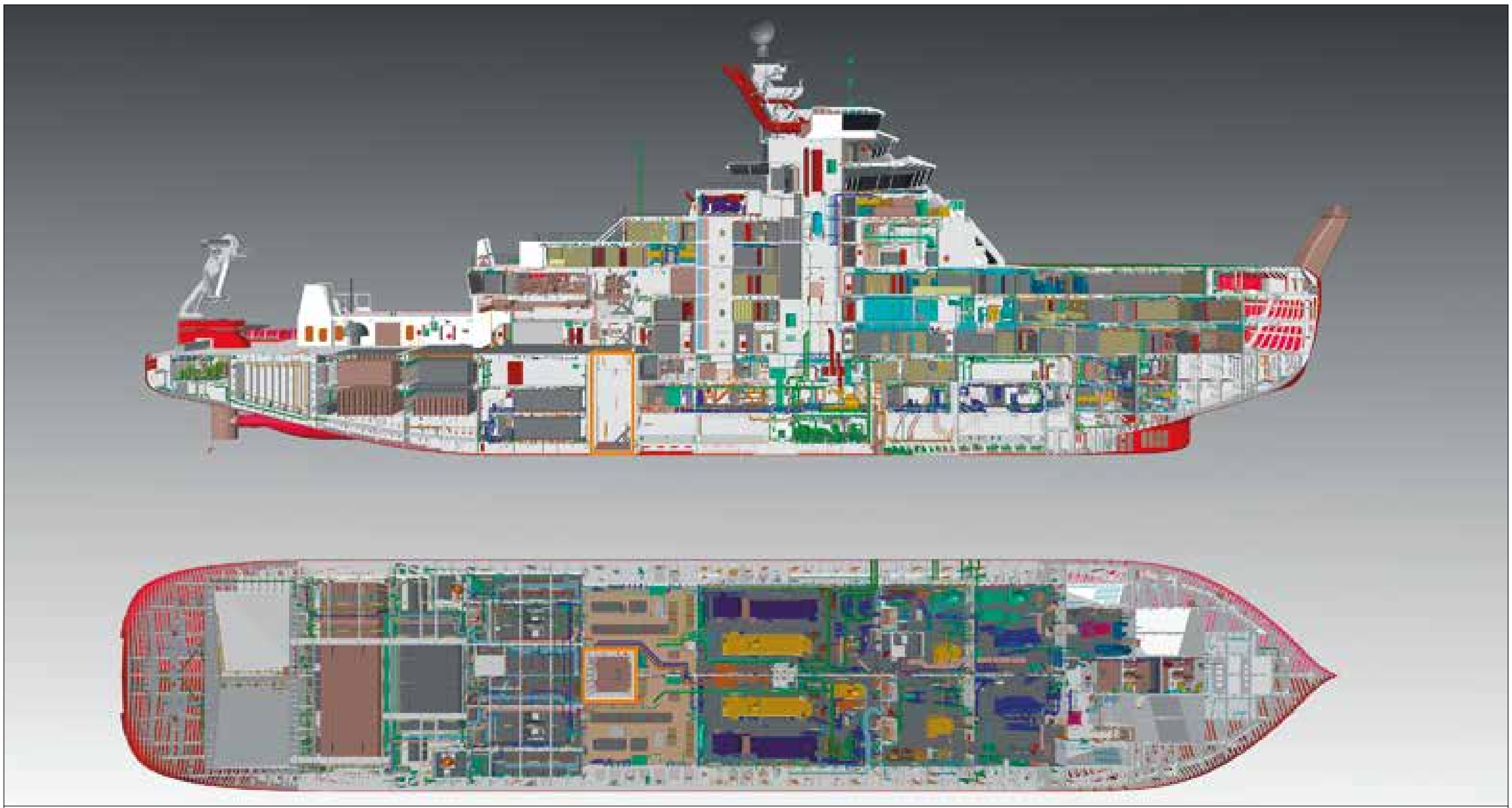
The RRS *Sir David Attenborough* has four Rolls-Royce Bergen B33:45 engines onboard, which provide the mechanical propulsion to push the ship through the ice. Two of them are nine cylinder and two six cylinder, which together produce 18 megawatts of energy to drive two propeller shafts.

Propellers and the main engine are normally the biggest source of noise, so engineers designed both the foundations and the ship structure to reduce the noise and vibration levels in a wide frequency range, enabling the vessel to meet the strictest noise and vibration levels possible. Engineers used finite element method (FEM) analysis when developing the critical steel structure, which ensures the lowest impact on the sensitive sealife and the best comfort for the crew and scientists onboard. The nine cylinder engines are designed with a rigid cast iron block with significantly reduced vibration levels. They are 'double resilient mounted' to dampen out and reduce the transfer of noise to the vessel's hull and then into the surrounding sea.

All engine connections and other noise-generating machinery onboard, such as pumps and compressors, are via flexibles to further prevent the transmission of noise into the hull. The RRS *Sir David Attenborough* also has two Rolls-Royce five-bladed controllable pitch propellers, which form part of a Rolls-Royce Promas unit. This unit integrates the propeller with a hubcap, rubber bulb and a special rudder profile to provide very high steering forces and minimise drag and noise.

The ship uses variable valve timing, an intelligent system that responds to load, to ensure the engines always receive the ideal amount of air for maximum responsiveness and efficiency. Running at a fixed speed of 720rpm, they use low sulphur fuel and have good fuel efficiency. They are also fitted with selective catalytic reduction systems, which are integrated into the electronic engine management system and monitor and control all key engine functions and exhaust after treatment.

The engines provide electric power generation onboard to reduce the vessel's fuel consumption, emissions, noise and vibration, as well as increasing redundancy and consequently safety. Two energy storage units are connected to the main switchboard, which



The RRS *Sir David Attenborough* is the first British polar research ship to have a moon pool – its location on the ship is indicated by the orange coloured squares on the image above. A watertight, hydraulically-operated single leaf door secures the moon pool, and opens to leave a four metre by four metre clear space through to the bottom of the ship. The trolley arrangement that is used to guide equipment into the ocean can be seen just above the coloured box on the top image © Rolls-Royce

will each provide a peak output of 2750 kilowatts, as well as fulfilling a blackout prevention function in the event that the running generator trips off the switchboard. This will enable more efficient use of the generators by providing the safety backup that would otherwise require running a second generator.

The vessel has two completely separate engine rooms with duplicated systems in each, which should provide resilience in the event of an issue in one engine room. It also increases efficiency as it will be possible to power down some systems in one engine room while running normally on the other.

A POLAR RESEARCH FIRST

The RRS *Sir David Attenborough* is the first British polar research ship to feature a moon pool – a vertical shaft measuring 11 metres high that runs through the vessel so it is open at deck level and the sea at the hull. Moon pools are becoming a more common feature on research vessels as they enable the ships to operate in more sea states, including ice flows, where previously submarines and other instruments could not be deployed over the side of ships.

The moon pool's purpose is to allow scientific equipment to be deployed and recovered at the most stable part of the hull, which is easier and safer than deploying submarines over the side in rough seas. There is a cursor, or trolley arrangement, that guides the equipment as it passes through the pool, which has a hydraulically operating, rotating latching mechanism that will accurately position loads as they pass through the moon pool trunk. To do this, there are two full height rails at the forward end of the moon pool for most equipment. However, for equipment that requires greater support, because of its size or positioning, there are a further two rails at the aft end of the trunk itself that give greater stability to deployed equipment.

MARINE ROBOTICS

During its polar missions, the RRS *Sir David Attenborough* will deploy a new generation of autonomous and remotely operated vehicles. Its ocean gliders and submersible vehicles will enable scientists to access real-time data efficiently, which optimises use of time and research resources. Data from these deployments will shed new light on what happens when ocean water melts Antarctic ice shelves, and how this may influence future sea-level rise.

The ship's autonomous underwater vehicles (AUVs) have been developed and built by the Marine Autonomous Robotic Systems Group, which is part of the National Marine Facilities based at the National Oceanography Centre (NOC) in Southampton. The AUVs include the long-range autosub named Boaty McBoatface as a result of a public vote. Despite being a third the weight of older models Autosub3 and Autosub6000, Boaty can travel for more than 10 times the distance and stay in the water for longer. The key to this performance is efficient propulsion at a slow speed and by keeping tight control of the power used by the AUV sensors and control systems. This is possible thanks to improved microprocessors, which have ample processing power but use very little energy.

The autonomous unmanned yellow submarine can travel under ice and reach depths of 6,000 metres with a 6,000-kilometre range, allowing it to collect data from locations that may be dangerous or impossible for humans to reach. Using sensors, it can measure ocean and seabed properties, such as: conductivity; temperature and depth; ocean turbulence with a micro-

Boaty McBoatface is one of several autonomous unmanned vehicles onboard the RRS *Sir David Attenborough*. Robotic submarines and marine gliders will collect data on ocean conditions and marine biology and deliver it to scientists working in the ship's onboard laboratories © National Oceanography Centre

structure probe; the amount of phytoplankton in the water by measuring the fluorescence of their chlorophyll; and turbidity (cloudiness or haziness). Acoustic instruments measure the water current up to 80 metres above and below Boaty's position, as well as the depth of the seabed and the draft of the ice along the vehicle's track.

Before launch from a research ship, scientists program the AUV's computers with instructions of where to go, what to measure and what depths to go to. With no link to the mothership, all communications with the AUV use acoustics while it is underwater (with a typical range of a few kilometres). However, Boaty periodically surfaces and transmits data back to the scientists via a satellite data link.

Boaty's first under-ice mission was beneath the Filchner Ice Shelf in West Antarctica, which is the second largest of its type in the world. The sub spent a total of 51 hours under the Antarctic ice, travelling 108 kilometres over the duration of the deployment and plunging to depths of 944 metres. It spent 20 hours exploring beneath a section of the ice shelf that was 550 metres thick. It was a challenging deployment for the autosub, with sea temperatures very close to the freezing point of seawater beneath ice shelves, where there are significant tidal currents and the high southerly latitudes posed difficulties for the AUV's underwater navigation. By travelling underneath floating ice shelves, the AUV has the potential to aid investigations about rapid and sudden ice mass loss.

Accurate navigation is a challenge for an AUV. At the sea surface, they can be positioned using GPS, but satellite signals cannot penetrate the top few millimetres of the ocean. They rely on an approach known as dead reckoning: the AUVs bounce sound off the seabed and can measure their speed relative to it by measuring the Doppler shift of the echoes. The AUV must also accurately sense its heading, using a fibre optic gyro-based sensor to give accuracy of better than 0.1 degrees. Overall, accuracies of about one metre error for each kilometre travelled are achievable. Navigation accuracy is critical to many survey missions, so the NOC is researching and developing techniques to improve upon this performance. Boaty has one drawback: while it can track geographic features and stay a certain distance from the sea floor, it cannot avoid unexpected obstacles.

The ship does not have ocean gliders of its own, but will deploy those owned by institutions or borrowed from the National Marine Equipment Pool at the NOC. Despite this, gliders are a key scientific instrument for the ship, as they can be used to measure oceanographic parameters such as chlorophyll levels, temperature and salinity,

ENVIRONMENTAL CREDENTIALS

The RRS *Sir David Attenborough* has to conform to stringent environmental regulations that are part of the International Maritime Organisation's (IMO) Polar Code, including the MARPOL convention, which is designed to prevent the pollution of the marine environment by ships, whether by accident or during routine operations.

Engines: Four main engines are configured to operate efficiently across the wide range of conditions that the vessel is likely to encounter. A smaller harbour generator is also installed to allow the vessel to operate when in port without the main engines idling.

Batteries: It has electrical systems with five megawatts of peak effective battery capacity. Batteries reduce the vessel's fuel consumption, emissions, noise and vibration, as well as increasing redundancy and, consequently, safety.

Oil: An oily bilge water separator, consisting of a high-speed centrifuge, will reduce the oil content of the bilge water discharged.

Sewage: Two sewage treatment plants treat black water (sewage) and grey water (other domestic wastewater) to meet the discharge standards required by MARPOL and the US Coast Guard. In areas such as the Antarctic, where zero discharge of sewage is permitted, holding tanks capable of storing waste for 45 days are provided.

Ballast water treatment: The onboard ballast water system has an approved treatment plant following the IMO's International Convention for the Control and Management of Ships' Ballast Water and Sediments. It controls the transfer of harmful aquatic organisms and pathogens through the ship's ballast water system into the ocean.

Protection from marine growth: The ship's hull is coated with a non-toxic paint system that provides a hard, impermeable coating that, along with manual removal of fouling at an early stage, offers longlasting protection without the use of chemicals. Furthermore, the internal seawater systems are protected by an electro-chlorination unit that uses sodium chloride and an electrolyser to generate sodium hypochlorite. This chemical prevents growth of marine organisms in the ship's cooling systems.

Noise: For underwater radiated noise, the vessel has been designed to achieve a DNV-GL Silent (R) notation during surveys at speeds up to and including 11 knots, and a DNV-GL Silent (S) notation while towing seismic equipment at 6 to 8 knots in calm seas, preventing noise pollution that could otherwise negatively impact polar wildlife as well as science experiments.

Green passport: This facilitates the application of the IMO Guidelines on Ship Recycling. This document is produced by the shipyard at the construction stage and contains an inventory of all materials used in the construction of the ship.

which are then transmitted back to the ship.

While AUVs are propeller driven, gliders use an expandable oil-filled bladder to change their buoyancy, enabling them to move vertically in the water. As liquid is pumped in or out of the bladder, the volume of the glider changes while its mass remains the same. The movement of internal weights back and forth enables a glider to angle itself to dive or climb in the water and it has an inbuilt compass, which it uses to steer a course. The gliders move slowly, at less than 1 mph, but can maintain this speed for months on end. The slow and gentle way a glider flies enables it to measure from 1,000 metres to within a couple of metres of the surface, without disturbing the structure of what it is measuring.

While the glider technology has been around for about 20 years, modern gliders carry a payload of modern scientific sensors. A glider's great strength is its ability to build up a picture of the structure of the ocean in both space and time, called 4D sampling, which gives scientists fine detail over a wide area. They are good at mapping the position of oceanic fronts, plotting the change in the thermocline where the surface water meets the deep oceanic water and many other slowly changing features that are important in the calculations behind oceanic global warming models.

READY FOR THE SEA

In early July 2018, the ship was launched for the first time into the River Mersey from Cammell Laird's shipyard in Birkenhead, by its namesake Sir David Attenborough. Highlighting the importance of the research ship and the role it is expected to play in positioning the UK at the forefront of climate science, Sir David said: "This ship is going to be key to the future salvage of our planet or at least its preservation." Using its technical abilities and sophisticated instruments, let's hope it helps preserve the Earth's polar regions for generations to come.

BIOGRAPHIES

Einar Vegsund is Vice-President Design and Hydro at Rolls-Royce – Marine. He has been with Rolls-Royce for 24 years and has held leading roles in the Rolls-Royce Ship Design & Systems team since 2002.

Lars Alv Haugen is a contract manager for Rolls-Royce – Marine, with responsibility for coordination of the installation and commissioning of all Rolls-Royce equipment. He has been with Rolls-Royce since 2004, following senior engineering roles at ABB and Teekay Shipping.

On 30 October 2018, Tim Stockings, Operations Director at the British Antarctic Survey, will be giving a talk at the Royal Academy of Engineering titled Extreme Engineering: Antarctica. *For more information and to book tickets, please visit* **www.raeng.org.uk/events**

Each of the new Queen Elizabeth Class aircraft carriers can accommodate up to 50 F-35B fighter jets. For the past 12 months, pilots have been simulating landing on the ships' decks before flight trials take place © Aircraft Carrier Alliance

FLYING WITHOUT WINGS

Later this year, HMS Queen Elizabeth, the first of the UK's new Queen Elizabeth Class aircraft carriers, will head out to the US to operate with the F-35B aircraft for the first time. In a small corner of Lancashire, a group of pilots has been 'flying' the aircraft in a flight simulator in preparation. Neil Cumins spoke to Dr Steve Hodge, BAE Systems' Senior Simulation Engineer, about how the £2 million simulator provides a realistic and immersive experience.

There is always great interest in the launch of new aircraft carriers, and the new Queen Elizabeth Class (QEC) vessels represent an unprecedented feat of engineering ('Building Britain's biggest warships', *Ingenia* 67). As the largest Royal Navy warships ever constructed, each £3 billion aircraft carrier can accommodate up to 50 F-35B fighter jets, which are capable of performing vertical landings. Although the F-35B is manufactured by Lockheed Martin Aeronautics, BAE Systems assembles around 15% of every plane, from fuel systems to the rear fuselage.

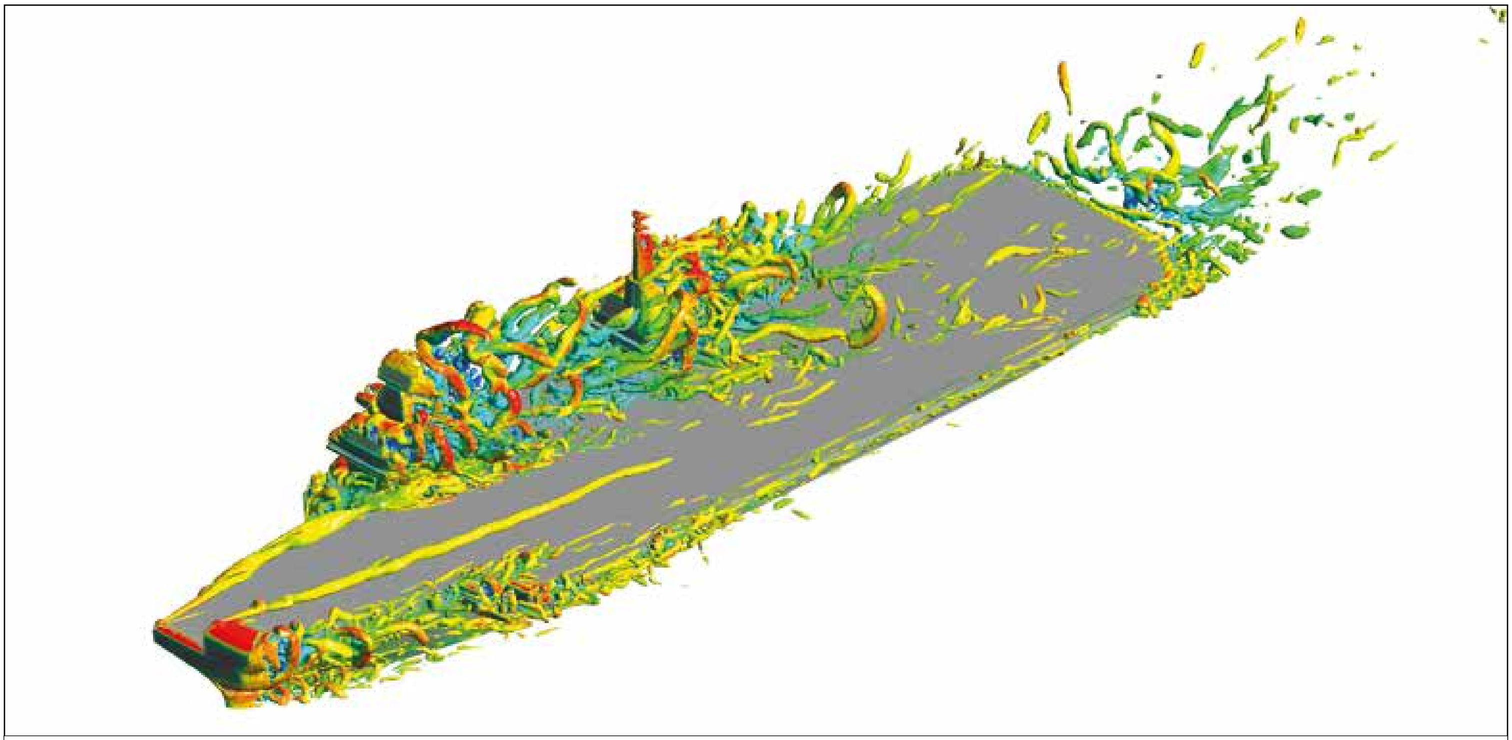
BAE Systems is also one of three companies that was involved in the design and construction of each aircraft carrier, which gave it an insight into the challenges of operating aircraft from the vessels. For example, landing on a ship presents particular challenges in terms of airflow and deck motion, but the timescales for introducing the aircraft carriers into service meant that real-world testing opportunities would be limited. It was therefore necessary to create a simulator capable of accurately reflecting the complexities of a vertical landing on deck, in a variety of different weather conditions.

To achieve this objective, BAE Systems turned to a group of in-house engineers and programmers. This team needed to create a simulator that could accurately replicate the experience of landing an F-35B in fluctuating wind conditions. It did this by precisely modelling the vortices and turbulence generated as wind hits the 280-metre-long aircraft carrier and is forced upwards over the flight deck. With each F-35B worth $122 million, potential issues had to be resolved in laboratory conditions.

AN EVOLVING SYSTEM

Dr Steve Hodge is the Senior Simulation Engineer at BAE Systems, with responsibility for developing the air-wake model used in the F-35/QEC simulator. His involvement with the simulator began in the early Noughties, when the UK government decided to proceed

As well as allowing pilots to practise flying, the simulator includes a full representation of the ship's flying control tower (FLYCO), where the landing signal officer onboard the carrier plays an important role in controlling aviation operations © BAE Systems



A visualisation of vortices being shed from the superstructure as wind flows around the aircraft carrier, modelled using computational fluid dynamics. This is an example of the air-wake models being integrated into the F-35/QEC integration simulator © University of Liverpool

with the proposed Aircraft Carrier Alliance (the partnership between BAE Systems, Thales UK, Babcock and the Ministry of Defence that is delivering the aircraft carriers) to develop HMS *Queen Elizabeth* and HMS *Prince of Wales*. Since then, Dr Hodge's team has consistently advanced the boundaries of computer modelling and simulation models, including a world first in air-wake modelling.

Dr Hodge explains that there are two parts to the F-35/QEC aircraft carrier integration simulator that his team has developed: "There's the actual piloted simulator with a cockpit the pilot gets into, but there's also the FLYCO [flying control tower] simulator. That's on the aft island of the aircraft carrier, where the flying control team sits, including the landing signal officer. We realised as time went on the importance of integrating the landing signal officers and the FLYCO team into our simulations." The simulator is now in its second iteration. Having started off with a hydraulic motion platform, it now has a fully representative cockpit with an electric motion system, high-resolution screens and a replica of the FLYCO environment next door, from where the landing signal officer can communicate with the pilot in real time.

According to Dr Hodge, the retrospective introduction of FLYCO is only one aspect of a gradually evolving brief: "We've worked throughout the whole QEC development cycle, so the focus of the simulator has changed. When I first got involved, it was more about helping to develop the visual landing aids and the flight deck markings on the carrier. Then we started putting more fidelity into the aircraft model, so we integrated a high-fidelity model of the F-35, which we developed with our partners at Lockheed. We integrated that with our models of the carrier and started to use it not only for the visual landing aids, but also for developing landing techniques such as the shipborne rolling vertical landing. We've evolved not just to cover the design of the ship but also the design of the aircraft." This has included supporting preparations for first of class flight trials, which are due to commence later in the year. This simulator will allow flight test engineers to test in different conditions, so that they can make the most of the time they have during the real first of class flight trials onboard the ship.

RECREATING AIR FORCE

A hugely significant – and world-leading – advance was made in terms of integrating air-wake modelling into the F-35B flight simulator. "If you imagine the air flowing over the sea," Dr Hodge explains, "it starts to create vortices and turbulence whenever it hits the ship. The angle the wind hits the ship at creates different patterns

The fully immersive simulator has a cockpit moved by an electric motion platform. Highly specialised engineering data was fed into the simulator to replicate the disturbances that an aircraft would experience, meaning that when a pilot lands an F-35 in the simulator, they feel the motions that they would feel in real life © BAE Systems

of airflow over the deck and around the ship. The pilot has to fly through the turbulent air wake behind the carrier in order to land on it, so it's been really important to model that ship air wake in order to make the simulator as realistic as possible." Sponsored PhD students at the University of Liverpool have been looking at advanced computational techniques to model the air wake, before integrating their findings into the simulation using high-performance computers: "The machine we use for that needs a lot of processors and memory to hold all the air-wake data, before mapping it onto a grid to apply it to the aircraft as it flies through the air wake. We've got a machine with one terabyte of data and 64 processors to model the air wake in real time."

This sort of processing has taken the team into unchartered territory, according to Dr Hodge. "Elements have been done in the US, but there hasn't been a place where it's been done on this scale – and there hasn't been a situation where everything's been brought together. You might have someone who's done air-wake modelling, and there are plenty of aircraft flight simulators out there, but there's no other simulator in the world where you can fly the F-35 to the aircraft carrier, stand inside the FLYCO simulator and see it land while interacting with the pilot. This is the only place where the air wake and ship motion are modelled and the simulator accurately reflects the aircraft handling qualities and the airflow around the ship. There's nowhere else all these models have been put together and integrated into one place in such high fidelity."

WIND BREAKERS

The computational analysis required to accomplish this in an engineering simulator is also innovative. "We can basically scale up the wind models to represent different wind strengths," Dr Hodge says, "but when it comes to different wind directions, you don't have any choice but to compute the air wake. As the wind goes up in magnitude, the flow pattern doesn't really change a great deal apart from the vectors getting scaled up slightly because of the wind speed. However, as you change the direction that the wind hits the island of the ship, then the patterns of flow over the deck change dramatically, so we needed to do the computations for each wind

Feedback on the simulator has been extremely positive, according to Dr Hodge: "It's fully immersive and the pilots are very complimentary. They say the motion and high wind conditions give them the sense of stress that other simulators don't"

direction. We've got a database of wind directions going all round the ship. Each one takes about two or three weeks to process on a high-performance computing cluster, and then we extract the data in real time. The computation is quite an important process; it's not just calculating one solution, but multiple time steps. We end up with 30 or 40 seconds of flow data we can replay in the simulator."

To confirm the air-wake model was delivering accurate results, Dr Hodge and his team validated it in a water tunnel at the University of Liverpool using a 3D-printed 1:200 scale model of the aircraft carrier. The team used water instead of air to create a 'wet' wind tunnel, which allowed it to submerge the model of the carrier in a tank and then blow water over it. The team then used anemometers to measure the air speed over the ship at different points. This was still an aerodynamic test rather than a hydrodynamic one, substituting air for water, and comparing the results with anemometer surveys of the newly-constructed HMS *Queen Elizabeth*.

FULLY IMMERSIVE

The F-35 simulator includes a dome with 16 high-resolution projectors in the piloted simulator. It includes a faithful reproduction of an F-35 cockpit, mounted on a cutting-edge and highly responsive electric motion platform that is capable of moving in six axes. It also offers more sensory input and a greater sense of immersion than other simulators. From the simulator's cockpit seat within the dome, pilots can feel the external forces of the air wake, while the projectors create a fully immersive wraparound view of the aircraft carrier and the sea surface.

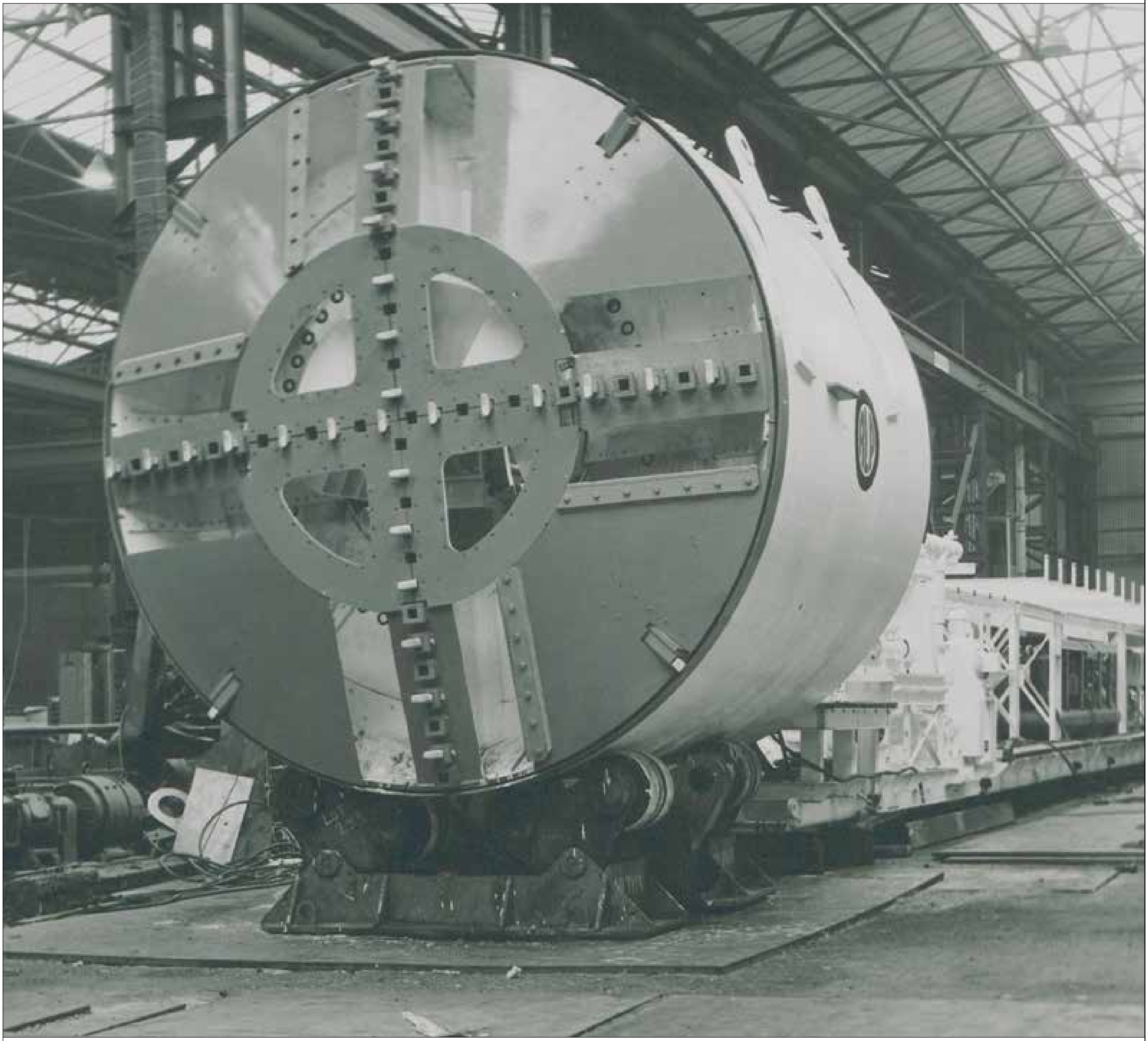
So far, the simulator has been extensively used by the F-35 Integrated Test Force, which includes pilots from the RAF and Royal Navy, the US Navy and US Marines. These pilots are experienced in ship landings, but future F-35B pilots have also been practising the challenges of landing at sea. Feedback on the simulator has been extremely positive, according to Dr Hodge: "It's fully immersive and the pilots are very complimentary. They say the motion and high wind conditions give them the sense of stress that other simulators don't. Beyond that, the flight test team is taking notes on test landings, to help determine what to look for when real flight testing begins later this year." That should enable them to optimise available time aboard the ship, focusing their attention on other elements of the F-35's performance.

Such has been the complexity of Dr Hodge's work that he has used it as the basis of a company-funded PhD. In 2010, his work on ship/air integration using simulation saw him graduate with a doctorate, reflecting the challenges of accurately modelling both the aircraft and its carrier. He concludes by acknowledging the remarkable advances in computing power that have made the current F-35/QEC simulator possible: "If someone had shown me this simulator when I first started modelling the aircraft carrier 18 years ago I would have been astounded. It's amazing what we can do now compared to what we could achieve in those days, and it's just getting better all the time with computing power, digital projectors and other advances. It makes you wonder what we'll be able to accomplish in 20 years' time."

Regardless of how technology evolves in the coming years, the research conducted for the aircraft carriers and F-35B will contribute to future knowledge of air-wake modelling, across other platforms and simulators.

BIOGRAPHY

Dr Steve Hodge is Senior Simulation Engineer at BAE Systems. He has worked in the company's simulation department for 20 years, having previously worked on the Hawk and Harrier fighter aircraft.



John Bartlett CBE FREng's prototype bentonite tunnelling machine in November 1971: the front shows the cutterhead. Bartlett has received the 2018 Sir Frank Whittle Medal for his tunnelling achievements © Institution of Civil Engineers

TUNNELLING OVER TIME

The winner of the 2018 Sir Frank Whittle Medal for 'outstanding and sustained achievement in any engineering discipline' is veteran tunnelling engineer John Bartlett CBE FREng. His greatest – and least well recognised – achievement was his invention of the bentonite tunnelling machine, the precursor of all the world's tunnel boring machines for non-cohesive soils. Hugh Ferguson explains the innovation and its significance, and traces further developments up to the two largest ever such machines, for tunnels now nearing completion in Seattle and Hong Kong.

Boring tunnels through soft rock (such as the chalk on the English side of the Channel Tunnel) or through cohesive soil (such as the London Clay that most of the capital's tube system goes through) is a comparatively straightforward affair. But non-cohesive soils – sands, silts, gravels and mixed ground, where the tunnel face requires continuous support and where ground water almost always threatens to flood the works – present an altogether greater challenge. Traditional solutions include working under compressed air, which is extremely hazardous, and more recently, ground freezing or chemical treatment, which can be very expensive. This explains why deep tunnels were not feasible beneath many of the world's cities, and why London's tube network excluded the southeast of the city where suitable clays were not available, until the Jubilee line extension was constructed in the mid-1990s.

John Bartlett CBE FREng's idea for a radical solution came after a visit to Milan in 1963 to advise a contractor on tunnelling through the city's gravel deposits, laboriously using traditional methods. While there, he was able to observe how Milan's first metro line had been built, using 'cut and cover' rather than bored tunnels. Italian engineers had developed diaphragm walls, an ingenious method of constructing vertical retaining walls in non-cohesive ground by exploiting the properties of bentonite clay to support trenches during excavation. Bentonite is a commonly available clay material that, when activated by chemical treatment to form a slurry, becomes thixotropic (a gel when at rest but a liquid when agitated or in motion). On his flight back to London, Bartlett visualised how slurry trenches and mechanical digger technologies could be combined to create a new type of tunnelling machine, with fluid support of the working face.

The spoil/slurry treatment plant at the head of the shaft for the New Cross experimental tunnel in 1972, showing twin 12-inch diameter hydrocyclone units and a vibrating screen behind © Institution of Civil Engineers

The outcome was Bartlett's bentonite tunnelling machine, which he patented in 1964. The essence of the invention is the use of a thixotropic slurry such as bentonite that is under pressure in a sealed bulkhead at the front of the tunnelling machine, so that the tunnellers behind can work in air at normal pressure. The pressurised bentonite slurry balances the water pressure in the ground, thereby preventing it from flowing into the tunnel and causing major instability. In larger-grained soils, such as coarse sands and gravels, the bentonite also penetrates the ground for a short distance ahead of the excavated face, providing additional stability. The pressurised bulkhead in the tunnelling machine contains a mixture of the bentonite slurry and the excavated soil, which has been cut by the rotary wheel at the front of the closed-face machine. A unique part of the invention is the use of the slurry itself to transport the excavated soil from the pressurised bulkhead via a pipework system to separation tanks on the ground surface. The excavated soil is then separated from the slurry, which is then recirculated through pipework back to the pressurised bulkhead.

GLOBAL USE

It took many years to find the funding to take the invention forward, but in 1971 a prototype machine was built to drive an experimental section of tunnel in New Cross, southeast London, for London Transport who were planning to extend the tube network. The experiment was deemed to be a great success, with tunnelling rates of four metres per 10-hour shift achieved. The invention, and the prototype, included all of the essential ingredients of all the many slurry tunnelling machines (STMs) that were to follow all over the world, although many improvements were made on the way. Unfortunately, further development happened outside the UK, since – apart from a single sewer contract in Warrington – no suitable projects emerged in Britain for a decade or more.

One of the visitors to the New Cross experiment was

JOHN BARTLETT CBE FRENG

John Bartlett CBE FREng © Institution of Civil Engineers

John Bartlett CBE FREng spent most of his career with consulting engineers Mott Hay & Anderson (MH&A), from 1957 until his retirement as chairman and senior partner in 1988. In his early years, he worked on the first Dartford Tunnel, the first tunnelled sections of the Toronto Subway and improvements to the Blackwall Tunnel. He was the project engineer responsible for London's Victoria Line.

From 1966, he was the partner and director responsible for the firm's transport and tunnelling work, including further projects in London and Toronto, advisory appointments in Madrid, Brussels and elsewhere, and design and construction of the second Dartford Tunnel and the Melbourne Underground Rail Loop. He headed the project management of the Tyne and Wear Metro, coordinating its design and construction.

He also had design responsibility for the Channel Tunnel, first as principal designer for the scheme that was started in the early 1970s but abandoned by the UK government in 1975; and again with the revised scheme when MH&A was appointed by the Anglo-French consortium Trans Manche Link as the principal design consultant for all civil and geotechnical engineering on the UK section.

He took out his patent for the bentonite tunnelling machine (BTM) in 1964, and designed and supervised construction of the first, experimental, BTM tunnelling contract in southeast London in 1971–72. In 1973, he was awarded the Royal Society's SG Brown Medal for the invention of the BTM.

He was a founder member of the British Tunnelling Society and its chair between 1977 and 1979. In 1978, he was elected as a Fellow of the Royal Academy of Engineering, and was President of the Institution of Civil Engineers in 1982.

In 1988, he retired as chair of MH&A, having overseen the firm's transformation from a small London consultancy to worldwide success with major projects in five continents, and having led the merger talks that to the formation of Mott MacDonald in 1989, now one of Britain's leading firms of consulting engineers.

Bertha's breakthrough at the end of the two- mile drive for the Alaskan Way tunnel © Washington State Department of Transportation

Eric Jacob of Frankfurt-based firm Wayss & Freytag AG who developed the Hydroshield, very similar to Bartlett's machine but with some important improvements – particularly the introduction of an 'air accumulator' to maintain a constant fluid pressure at the tunnel face. This was first used on a sewer tunnel in Hamburg in 1974, and later on projects such as the Antwerp and Lyon metros. However, most of the subsequent development work occurred in Japan, fed by a major demand for tunnels in non-cohesive ground. Initially these Japanese developments produced improved STMs, all derived from the principles of Bartlett's bentonite machine. By the end of the 1970s, more than 1,000 STMs had been used worldwide.

Meanwhile, an important Japanese innovation led to the earth pressure balance machine (EPBM). This uses the same principles of ground support as the Bartlett invention but with the face supported by conditioned excavated spoil rather than a slurry, and with the excavated spoil removed from the face using a screw conveyor. The EPBMs were being used extensively in Japan from the late 1970s. Almost all subsequent tunnelling machines for non-cohesive ground can be classified as either EPBMs or STMs: the former tend to be used in silty, clayey soils, with STMs preferred in more granular soils.

In the 1980s and 1990s, major projects that used STMs included the British-financed Cairo Wastewater Project, Tokyo Bay road tunnel and the Elbe road tunnel in Germany, while five EPBMs were used for the difficult ground on the French side of the Channel Tunnel, two for Toronto Metro, four for the Storebaelt rail tunnel in Denmark, and one for the St Clair River rail tunnel on the US/Canada border. The Channel Tunnel Rail Link used three EPBMs and one STM.

In the new century, STMs have been used (for example) for the Groene Hart rail tunnel in Holland, the British-designed SMART tunnel in Kuala Lumpur, the Chong Ming road tunnel in Shanghai, the Hallandsås rail tunnel in Sweden, and the Bosporus Eurasia road tunnel in Istanbul. EPBMs have been used in the development of a water tunnel in Buenos Aires, San Diego Outfall tunnel, A86 a L'Ouest de Paris, Westerschelde road crossing in the Netherlands, Tokyo Metro, Moscow Silbenwald road tunnel, M30 Madrid road tunnel, Sparvo road tunnel in Italy and Copenhagen Metro. In the UK, numerous EPBMs were used on Crossrail ('Crossrail: tunnelling on an epic scale', *Ingenia* 56), while STMs were chosen for the Lee Tunnel ('London's deepest tunnel and shafts', *Ingenia* 63), the first section of London's Thames Tideway 'super sewer' project.

SCALING THE MACHINES

Many of these machines have been in the 11 metre to 15.5 metre diameter range, the largest being 15.55 metres, but two tunnels have recently been driven with diameters of more than 17 metres. 'Bertha', the machine for the Alaskan Way highway tunnel in Seattle is the world's largest EPBM (17.48 metres) while the Chek Lap Kok road tunnel in Hong Kong is the world's largest STM (17.63 metres).

Such huge diameters bring issues of scale. Taking the example of Bertha, at the simplest level, the machine's height is more than a five-storey building so just getting from the bottom to the top is a major climb for the tunnellers. At any time, the machine may be straddling several different geological layers, and the weight of the cutterhead and drive unit is nearly 2,000 tonnes. A ring of the permanent tunnel lining comprises 10 segments, each of which weighs up to 16 tonnes and has to be placed behind the machine using vacuum lifting. The maximum thrust to drive the machine forward is 39,000 tonnes, and the total power is 13.44 megawatts.

The Alaskan Way tunnel is two miles long through difficult, seismic ground, and will replace an elevated two-level highway along the Seattle waterfront. It will carry four lanes of highway, stacked with two at the top and two below. The tunnel broke through in April 2017, the internal roadways are complete, and final testing is underway before opening.

A computer-generated image depicts a cross-section of the Alaskan Way tunnel, showing four lanes of highway with with two at the top and two at the bottom © Washington State Department of Transportation

TUEN MUN–CHEK LAP KOK LINK

Meanwhile on the other side of the Pacific Ocean, one of the world's most ambitious construction projects is slowly taking shape – the Hong Kong-Zhuhai-Macau Bridge, with three cable-stayed bridges, three artificial islands and an underground section carrying a new 50-kilometre-long road eastwards from Macau, through the Chinese prefecture of Zhuhai to Hong Kong where it will terminate by Hong Kong's Chek Lap Kok airport on the western island of Lantau.

From there, a new four-kilometre-long undersea tunnel is being driven to connect to the mainland at Tuen Mun in western Hong Kong. Hong Kong has a long tradition of crossing its sea channels with immersed tube tunnels, comprising prefabricated concrete sections floated out and sunk in a dredged channel to form the tunnel. However, in this case, this would have involved major dredging across a busy shipping channel – and across the 'dolphin corridor' used by endangered pink dolphins. Instead, it was decided to bore twin tunnels 50 to 60 metres beneath the seabed, mainly through alluvial clays with frequent sand lenses, with some weak rock (decomposed granite) and mixed ground. Each tunnel contains two lanes of traffic.

Left: The world's largest ever tunnel boring machine, the 17.6-metre-diameter slurry tunnelling machine prior to its use to drive a part of the Chep Lak Kok to Tuen Mun subsea tunnel in Hong Kong; right: The smaller 14-metre-diameter tunnel boring machine driving one of the twin tunnels for the Hong Kong tunnel

But for the steep, 680-metre-long exit at the Tuen Mun end, the northbound carriageway widens to three lanes, which is where engineers needed the large STM.

After successfully completing its 680-metre-long drive, the 17.6 metre STM was converted to a 14-metre diameter machine for the remainder of the drive, by changing the cutterhead and shield but retaining the remainder. A second 14-metre diameter machine was brought in for the other carriageway.

A persisting challenge with STMs is abrasion on the cutter discs at the front of the cutterhead, which require periodical replacement when worn-out. 'Mobydic' – a system of sensors incorporated into the cutter discs to enable wear to be monitored as well as providing real-time geological monitoring – was successfully used on both tunnels, while two other innovations – 'Snake', which is a remote control mechanical arm for cleaning the cutterhead, and 'Telemach, an automated disc-cutter replacement mechanism – were also introduced. Even so, specially trained workers often needed to enter the chamber to replace discs. Where possible, this was done in 'saturation mode', which allowed longer daily working times of up to six hours and greatly reduced the frequency of compression and decompression, thereby reducing the risk of 'decompression sickness' among the workers.

Both tunnel drives were completed by May 2017, and the tunnel is expected to open in 2020.

STARTING A REVOLUTION

"There can be no doubt that a major revolution in the worldwide tunnelling industry was triggered by John Bartlett's invention of the closed face bentonite tunnelling machine," says Lord Robert Mair CBE FREng FRS, President of the Institution of Civil Engineers. "The invention allowed tunnels to be constructed in hitherto difficult and hazardous soil conditions with complete safety and without risk to the operatives. This has enabled a very rapid increase in tunnel construction around the world, particularly in urban areas, for water supply, sanitation and transport – with remarkable benefit to humanity. It has consequently resulted in hugely improved infrastructure in many of the world's cities, especially in developing countries, which is of considerable importance in view of the rapidly increasing urbanisation across the world."

TAILOR-MADE INVENTIONS

Engineers can make a real difference to society and people's lives. For disabled people, engineers can design and create equipment that helps them live more independently. UK charity Remap matches up volunteer engineers with disabled people who need bespoke solutions. Dominic Joyeux asked three engineers what attracted them to the charity and how their innovations had made a difference.

Eilian has had an amputation, which makes using his three-wheeled rollator unsafe. Martin Rees, a retired engineer, created a plastic cup-type holder for his residual limb with a 3D printer and lined it with felt. This was placed into a metal sleeve and then attached to a raised handle bar making it safe and comfortable for Eilian to use © Remap

Engineers have always been called upon to help disabled people. Over the years, they have been instrumental in providing a range of targeted, specialised equipment such as prosthetics, robotic systems, MRI scanners, and manual and motorised wheelchairs, beds and hoists.

For the last 50 years, UK charity Remap has harnessed the expertise of voluntary engineers to pick up where manufactured equipment often falls short. It has helped individuals customise their equipment or created bespoke solutions to enable them to take part in day-to-day activities.

The charity has now partnered with BBC programme *The Big Life Fix*, which shows inventors finding ways to help disabled people to lead more independent and fulfilling lives. Remap helps the BBC in the planning stages to make sure projects are feasible and then, when the cameras are gone, the charity takes on the aftercare, ensuring that any adaptations or breakages are rectified for the individual or their families.

ENHANCED VISION

Rupert Powell became a volunteer with Remap after watching an episode of *The Big Life Fix* with his wife. The programme showed a young man who wanted to take photographs but whose acute skin condition meant that he couldn't hold a camera. After seeing an engineer who worked for Lego find a solution, Rupert's wife said "you could do that" and so he took note of Remap's details on the closing credits and contacted his local York branch to see if he could help out.

Rupert with Ian. The modified virtual reality headset that the engineer developed for Ian was recognised at the 2018 Remap awards © Remap

Rupert's day job is with the international electronics company Extron, which makes audio and video control systems. He is a product manager for remote controls and also trains people in writing software. His hands-on engineering was limited to his amateur astronomy interests, so he was looking forward to building and adapting specialised equipment for disabled people.

At his first meeting, he was allocated to work with Ian, who has a severe visual impairment and can only see a few inches but who wanted to see his football team Liverpool play at Anfield. Ian is a season ticket holder and for years had listened to radio commentary while soaking up the atmosphere from the crowd.

When they met up, Rupert learned that it was the optic nerve that was the problem: Ian's eyes can see but the

Ian wearing his helmet with a modified webcam (left) that is controlled by a wireless PlayStation controller (right)

Rupert's solution involved modifying a virtual reality (VR) headset to incorporate an LCD video display, an image-processing computer, and positioning a camera with a powerful motorised zoom lens on top of a ski helmet

ENABLING ENGINEERS

Remap began in 1964 when an Imperial Chemical Industries (ICI) employee installed a ramp and ceiling hoist for his sister who had polio, in the days before these were available at home. Volunteer engineers from the Teesside chemical plant, both retirees and employees, then helped other people in the area with adaptations and bespoke remedies to challenges they faced.

It used to be that occupational therapists (OTs) provided the majority of clients but, now that Remap is fairly well known, it is roughly a 50–50 split between self-referrals and OT-recommended patients. Although the average cost per innovation is £70, there is no charge to the disabled person and no payment, apart from material expenses, for the Remap enablers.

Remap has 73 local groups nationwide with 1,000 volunteers carrying out 3,500 bespoke projects a year. The volunteers mostly consist of retired and working engineers, woodworkers, electricians, medical practitioners and 'makers' – people who design and make things. They work from home, a garage, a shed, at a firm's workshop, in a maker-space, in university laboratories or wherever there is access to milling, lathing, 3D-printing or machinery that will enable a gadget to be made or adapted.

Local groups meet monthly or bi-monthly and discuss new enquiries, allocate projects, report on adaptations they are working on, and discuss possible solutions to problems they encounter. The scope of requests is wide-ranging. Remap will not help if there is already a product that exists to do the job, but otherwise there is pretty much no limit.

The charity gets no government backing and fundraises through the local groups giving talks and by appealing directly to trusts. Remap is still looking to increase the number of tasks it carries out each year and to add to the number of volunteers on its books.

For more information about the charity or volunteer, see **www.remap.org.uk**

information does not get cleanly through. Ian can only see things that have a bright contrast, so his computer screen at home presents words in a huge font size that need to be viewed on a black or white background.

Rupert's solution involved modifying a virtual reality (VR) headset to incorporate an LCD video display, an image-processing computer, and positioning a camera with a powerful motorised zoom lens on top of a ski helmet. A wireless PlayStation game controller would allow Ian to adjust images by freeze-framing and turning them negative to enhance the contrast.

The main criteria for creating Ian's personalised video system were to make it compact, balanced, light and able to work in real-time. The camera had to be self-operating as it would be too difficult to continually hold. Rupert originally mounted it on the front of the VR headset with a strap holding the whole unit on and a separate box holding the workings in a shoulder bag but there were too many wires floating around and the headset was top heavy. So, the current Mark 2 version [pictured left] was reconfigured, placing the camera on top of a ski helmet and encasing wiring and components.

The camera is a modified webcam that now has a CCTV lens on it because Ian needs telephoto zoom to get closer to the action – webcams are usually built for close up wide-angle work. The camera has 1080 pixel resolution and is streamed on USB 2.0 down the same cable as the HDMI (high-definition multimedia interface) back to the central processing box.

The brain of the box is a Raspberry Pi 3 ('Chips that changed the classroom', *Ingenia* 72,) which relays very close to real-time video to the screen – there are only a couple of hundred milliseconds of delay. There is also a battery backup system for the Raspberry Pi so that it can be switched on and off with an ordinary toggle switch. The whole system is powered by a graphene battery (lithium polymer chemistry effectively), which is the latest technology used for remote-operated vehicles. It is very light with 5.2 amp-hours (AH) capacity and is charged with a built-in smart charger.

Dave Henson MBE, bioengineer and Paralympian, presents a Remap award to Ralph Anderson for his step and platform design in June 2018 © Remap

The wireless handset that links to this system has numerous buttons. One allows the picture to go negative, another increases the contrast. Another button activates a freeze-frame function that allows Ian to study a particular moment in play or to read text. A further button enables edge-detection to help him study text. The handset also allows the user to zoom in on subjects with either optical zoom or pixel zoom, or both.

The software to connect it all together was written in Python3 and uses Open CV video processing library. A Genie programming editor was used to write the code that comes as standard in Linux with the addition of a Pygame library for the game control handset. There's an RS232/USB connection to the Arduino lens control, and all this functions with just 150 lines of code.

It took six months to create and test the vision enhancement headset with Ian's comments considered at each iteration. Now, Ian can not only watch football at Anfield – he is a wheelchair user and has a good position near the halfway line – he also uses the headset for day-to-day tasks such as shopping. Before, he would have to ask people where a certain aisle was and then had to pick up a multitude of tins to read the labels closely before he found the right one; now he can scan aisles and items from his chair. The Royal National Institute for the Blind has expressed an interest in the headset and RS Components, the main distributor for Raspberry Pi and a lot of the components within the innovation, have asked Rupert to produce five more to see if other people can benefit from it. Rupert is not interested in patenting the device, in fact he has placed videos on YouTube detailing how it was made. He says that his kick comes from working out a problem with an end user and then making it happen: "Isn't it amazing that spending just an hour or two in your garage on a Saturday morning can change someone's life!"

HELPING MARGAUX

Ralph Anderson, a mechanical engineer working part time, heard about Remap through reading a short article in *Professional Engineer*. His paid work is mostly office-based so he wanted a chance to put his practical expertise and the tools in his well-stocked garden shed to good use. He had an interview with the Derby group five years ago and was invited to join its monthly meetings. In 2016, one of the referrals was from an occupational therapist at Derby Children's Hospital for a patient called Margaux.

Margaux has skeletal dysplasia (dwarfism) and needed adaptable steps in her bathroom to reach the washbasin. Her parents live in a rented house, which meant that no fastening could be made to the bathroom wall or floor and the existing sink and cupboards could not be altered. Her mother told Ralph that she wanted Margaux to be able to operate a step platform herself and she wanted it to be foldable to that her husband could shave from the same sink.

The step platform locked in up position (left) and Margaux with steps locked down (right) © Pictoria

Ralph made a concept sketch for the family to check before proceeding and then made the steps out of 18-millimetre plywood and 25-millimetre diameter softwood dowels. He made small captive bolt mechanisms so that the dowel has to be pushed across to either lock it up or down by Margaux herself. Solid furniture wax was used to help it operate smoothly, which doesn't leave a mess and lubricates well for a long time.

The interlocks on the steps meant that the steps couldn't drop inadvertently or trap Margaux's fingers and the slots cut into the frame meant that the step could only travel on one path. For adults, it folds up out of the way but is always in place under the basin, available for Margaux. Ralph applied an oil-based undercoat and gloss to finish, using an eggshell paint for the tops of the treads and mixing some fine sand into it to give a non-slip surface that could be easily cleaned. The result is that Margaux has gained some independence and the steps have won Ralph a special mention from Remap at its 2018 awards.

WALKING MORE COMFORTABLY

Caryn Moberly has been a volunteer with the Berkshire Remap group for two years now. She trained as a furniture maker and has helped develop a solution for a woman with multiple sclerosis who walks with two sticks. The woman needs to pause and sit when out walking, so the seat Caryn designed had to attach to one of the client's sticks. It had to be solid and stable when open, very lightweight and quite high so that she could get up from it easily. The stick would have to convert to a stool and back into a stick with one hand as the other would be holding her second stick.

Caryn based her solution on a fisherman's stool and took from it the hinge element. She adapted an aluminium walking stick and then added two carbon fibre rods slightly shorter than the stick. She worked with engineers from the Henley Inventors Club to strengthen the pivot points and the stool is kept in the closed position with a locking ring attached by a cord to a lever.

The combined folding perching stool and walking stick weighs 600 grams and has proved very popular. The design has had several improvements: the legs are fully closed when used as a walking stick; the stick can easily be turned into a stool with one hand; and the stool can be locked into position when needed. People who have had a stroke and a hip replacement have benefited from it too. Caryn is now looking to patent the perfected design and get funding to produce more stick stools.

Caryn Moberly with her stick stool in the closed position (left) and the stick stool in open position (right)

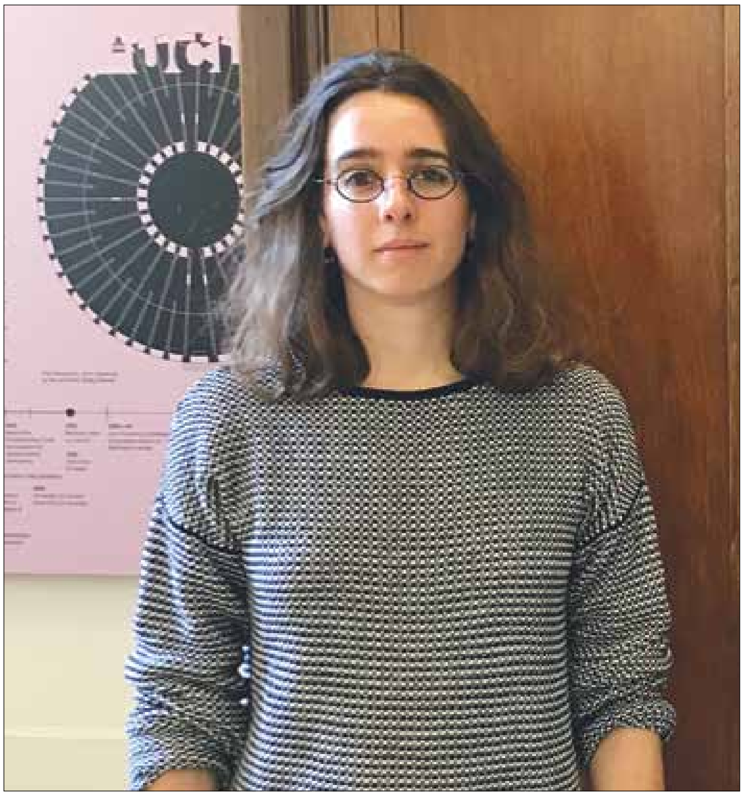
CHANGING LIVES

The thousands of adaptations and innovations made each year by Remap engineers are now being uploaded onto a huge, free, online database, which includes drawings, photos and descriptions, so that volunteers and other interested people around the world can devise their own bespoke solutions.

The last words come from the parents of James Dunn, the 22-year old who was terminally ill and featured on the episode of *The Big Life Fix* that inspired Rupert Powell to become a volunteer. James, who had a chronic terminal condition that meant that his skin peeled off and left him in great pain, needed more help with his camera and so Rupert worked with him for 18 months helping with his photography. James wanted to take pictures to leave a legacy and found focusing on them distracted him from his pain. James died in May 2018 and his father approached Rupert at the funeral to say: "You may think that the things that you do are small and that anyone could do them, but they were a big part of making his life better."

SILVER MEDALLISTS

The Royal Academy of Engineering Silver Medal was established in 1994 to recognise an outstanding personal contribution to British engineering that has resulted in successful market exploitation.



DR JADE ALGLAVE, UCL AND ARM LTD

Dr Jade Alglave, a computer scientist at UCL and ARM Ltd, has developed an innovative mathematical method of specifying computer memory models, an associated language, and software tools for writing and experimenting with the models. Her work has influenced chip designs at major companies including IBM, ARM, AMD and NVIDIA.

She focuses on concurrent programming, which is the process that enables separate components of a computer program to run at the same time, an important function in high-performance computing. It has led to the development of new techniques to model the behaviour of multiprocessors, which helps to overcome the difficulty of finding bugs in concurrent programs.

Dr Alglave's work provides engineers with tools to innovate rapidly during the development of a concurrent system, but can also diagnose problems and bugs in existing systems. It has guided the development of formal models for computer hardware and software, and she has made memory models for various companies. One of these companies is the Heterogeneous System Architecture Foundation, which is an industry standards body comprising several major companies. Dr Alglave's model is part of its documentation and is being used to define the industry standard.

PROFESSOR CHRIS SUTCLIFFE, UNIVERSITY OF LIVERPOOL AND RENISHAW

Professor Chris Sutcliffe (far right) has developed 3D-printed metal implants to treat patients who have experienced trauma or debilitating joint diseases of the hip, knee or spine. His innovation helps to treat thousands of patients each year.

The bone-integrating implants use 3D printing to mimic bone tissue, which enables rapid integration between the implant and the bone and provides far better long-term performance and stability than traditional designs.

He has been instrumental in creating the implants, establishing the computer-aided design (CAD) software used to develop the structures, developing equipment needed to produce materials that are strong and porous enough to be used in production, and devising a way to measure the biological performance of the implants. Professor Sutcliffe also developed the hardware used to process the titanium powder that is used to print the implants.

He has successfully commercialised the research through a partnership with Stryker Orthopaedics, which includes the launch of five families of implants for Stryker's joint replacement and spine franchises. He is also the founder and director of Fusion Implants, which uses the same bone integrating technology to produce veterinary implants for the treatment of musculoskeletal disease and injury in animals.

DR IAIN SCOTT, LEONARDO

Dr Iain Scott has made a significant contribution to the development of radar technology, one of the most crucial technologies of the modern world.

Following a PhD at the University of Edinburgh, which focused on radar signal processing, he joined engineering company Leonardo. There, he was heavily involved in its Vixen-E family of Active Electronically Scanned Array (AESA) airborne radars. These radars use multiple transmitters to send out and measure the reflection of radio waves to determine the distance and speed of targets. Individual control of these transmitters enables simultaneous functions ranging from surveillance and fire control to advanced data link communications.

These developments have made huge progress in the performance, reliability and capabilities of radar, but still faced problems around its narrow field of view. This was overcome with the development of the Raven ES-05, which uses a repositionable antenna to provide a complete forward hemispherical scanning ability, providing aircraft with far greater situational awareness and tactical advantage. The radar has

helped to establish Leonardo as the biggest and most successful airborne radar manufacturer in the world outside the UK, with business worth hundreds of millions of pounds.

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BUILDING A SUSTAINABLE CAREER

Dr Shaun Fitzgerald FREng © Paul Wilson Photgraphy

Dr Shaun Fitzgerald FREng has moved between academia, strategic consulting and running his own business, and is now the new Director of the Royal Institution, one of the UK's longest established scientific institutions. A career that started in research in geothermal energy morphed into working on natural ventilation in buildings, leading to a business that has changed the nature of building design.

For many engineers, it was playing around with machines that got them hooked on the subject: cars and motorcycles are often cited as common catalysts. For Dr Shaun Fitzgerald FREng this was a minor interest, so much so that he was a bit surprised when he turned up for one interview and was asked to assemble a bag of bits. "I still remember the interview," he says. Dr Fitzgerald was still at school and looking for someone to sponsor his degree. "The interviewer was clearly trying to assess how practical I was and whether I could do it. I found it completely uninspiring." The bottom line, he adds, was that "it didn't interest me". For Dr Fitzgerald, who recently took over as Director of the Royal Institution (Ri), engineering meant something very different from manual dexterity, or completing tasks more suited to a mechanic. He had higher aspirations, wanting to make the world a better place through science.

Studying science at school nudged Dr Fitzgerald towards engineering. "I absolutely loved physics and chemistry. I still remember the lessons on inorganic chemistry and just finding the melding of physics with the chemistry lessons. I could see how one fed from the other and vice-versa, but the one thing that really got me going was how it can impact our world. I just got so excited about the use of science to change the world for good."

He found that opportunity at GEC Research, as an engineering apprentice and sponsored student. Along with sponsorship for his engineering degree course at the University of Cambridge, the company offered students a holiday job. The company was, as he puts it, "thinking about the future, about the development of current ideas to make the world a better place". GEC also focused on electrical engineering and the energy business, subjects that took Dr Fitzgerald's fancy and were rooted in science.

After three months at GEC, Dr Fitzgerald began working on a project to develop the first contactless credit card. "That was about the future of commerce and how you didn't have to have a magnetic stripe on your card, and it can have a chip on it." He found it "massively exciting. I ended up doing the coding in assembler code. It was very cutting edge at the time. This was going to change the way that people interacted and how people bought things. This was engineering at its best in my view. The fire had been ignited into my love for science and the application thereof, and the world of engineering."

HIGH ENERGY

Dr Fitzgerald had caught the energy bug on his engineering course at the University of Cambridge. At the end of his second year, he should have spent the summer working at GEC for eight weeks. Instead, he had arranged to spend the long holiday touring energy installations in the US. "I was just so amazed by what was going on in the US, I wanted to go and see it for myself. I visited solar power and wind farms, tidal power facilities, and geothermal hot dry rocks, from the eastern extremities of northern Canada down to the southwest coast."

It was geothermal energy that really caught Dr Fitzgerald's attention. "This was the most beautiful area because it was about physics, in terms of the fluid mechanics of flowing pipes and steam and research that I had been doing at Cambridge. It also had threads of what you can learn about geothermal reservoirs from the chemistry," he adds. Geochemistry was not something that had intruded on his degree course. "I still harked back to my A-level days. It was just the most beautiful example of an integrated science and engineering problem that I wanted to get involved in."

As much as Dr Fitzgerald wanted to find a way of combining these different topics, there was not anyone in Cambridge's engineering department with deep expertise in the area. Instead of leaving the undergraduate to his own resources, the head of the department pointed him in the direction of the Earth sciences department, led by Lord Oxburgh KBE HonFREng FRS. Spotting someone with drive and initiative, Lord Oxburgh did not do the obvious and pass Dr Fitzgerald on to another academic. Instead he suggested that he contact Tony Batchelor, who had set up GeoScience Limited and had expertise running hot-rock projects in Cornwall. Lord Oxburgh urged the student to work at GeoScience for a year and expose himself to the geothermal industry, before returning to do a PhD at Cambridge.

Dr Fitzgerald spent a year with the company. "That year was actually just the most amazing experience," he recalls. It was great to be working for a small company that was just a year old. The work involved doing "really cool stuff in the world of geothermal" along with work for the oil industry "that paid the bills". GeoScience also gave the graduate opportunities that would have been unlikely with larger businesses. He was sent to the US to attend a week-long conference on geothermal energy at Stanford University. He was also under orders to learn something about the power side of the industry as the plant needed to

One recent project for Breathing Buildings was to provide the ventilation for the Dyson Centre for Engineering Design (pictured) at the University of Cambridge. Dr Fitzgerald may have been the company's CEO at the time, but he recalls one incident where he was called in to sort out complaints about the heating in one office. "I said, well this is Dame Ann Dowling's office, you have got to get it right. I went into the office and actually found out that it was not the ventilation system, but the underfloor heating manifold for the radiator." This was 'roll up your sleeves' time for Dr Fitzgerald, who ended up ripping up floor tiles to reveal the truth to the builders © University of Cambridge Department of Engineering

turn the reservoir's energy resources into useful electricity. The week turned into six weeks, as Dr Fitzgerald immersed himself in the engineering of geothermal energy. He even managed to sell some consulting work on the back of solving a problem he had identified in a geothermal reservoir. Pipes kept getting blocked by scale and it was impractical to shut everything down for a monthly clean up. "I built them a model in Excel, which was the first piece of work that I'd ever sold. They still use it apparently."

Much as he had enjoyed his year in industry, Dr Fitzgerald still wanted that PhD, so it was back to Cambridge and the Institute of Theoretical Geophysics to work on the optimisation of geothermal power projects. It was about understanding how liquid is heated and vaporised when injected into depleted geothermal reservoirs, developing mathematical models of heat and mass transfer processes. There were also some novel laboratory experiments to test the models and their predictions.

With the research done, it was back to the US for a year and some more industrial experience. He picked over a geothermal project in Nevada to work out how best to operate it as a money-making venture. He then spent three years in academia, first at Cambridge and then at Stanford University as Geothermal Program Manager and Acting Assistant Professor. The US was clearly more interesting to someone who had accumulated plenty of expertise in geothermal energy. The UK was, after all, hardly a hotbed of enthusiasm for this particular form of renewable energy. Stanford, in contrast, ran an active research programme in geothermal reservoir engineering that continues to this day. Although he enjoyed the engineering, he became dissatisfied with the academic's role and decided to make a career change and to move into the world of commerce.

CONSULTING ENGINEER

Dr Fitzgerald had other reasons for returning to the UK, as his wife had qualified as a doctor. In the US, she would have had to retrain. Add that to his commercial aspirations, and their family plans, and everything pointed towards a return to

Breathing Buildings has persuaded the industry that there is a lot to be said for its concept of 'hybrid ventilation', using pure natural ventilation when external weather conditions are favourable

the UK, even if it meant moving into a different area of engineering. He thought about studying for an MBA, but decided to look for a paid job that would deliver the knowledge that comes with an MBA. So in 1997, he started work as a senior consultant at Bain & Company. He worked as a strategy consultant within "a whole raft of different industries".

The company didn't hire Fitzgerald as an engineer, but thanks to his experience he did more engineering than other people – certainly enough to maintain his enthusiasm for the subject. After four years with Bain, he decided to go back into engineering, but the question arose as to what area of engineering would appeal to a specialist in geothermal energy. "Part of the reason why I was successful at Stanford was that I had become one of the world experts in geothermal and phase transition within geothermal reservoirs." Oddly, perhaps, this turned out to be a good backing for work on ventilation in buildings. It is not fundamentally different from geothermal reservoirs, he explains, because "it is a fluid mechanics heat-transfer problem. I have always felt very comfortable getting into the world of research on natural ventilation buildings, because it is fluid mechanics." There was also the added connection to another engineering interest, energy.

Once again, Cambridge connections proved invaluable and he returned to the university to join a new research programme on natural ventilation in buildings, combining energy and fluid mechanics. It was not long before Dr Fitzgerald succumbed to his need to get the word out to the commercial world. "I wasn't just interested in publishing papers and having them gathering dust on a library shelf. I was interested in publishing papers and sharing the insights about the research to the practising world, the architectural and engineering community designing buildings, to help them understand how they could design their buildings more efficiently." A key aspect of their approach to the design of comfortable and energy efficient buildings was to use natural ventilation rather than refrigeration units and mechanical ventilation.

One way to pass on that research was to "do a bit of consulting on the side", as Dr Fitzgerald puts it. Cambridge University Technical Services provides a safe environment for academics to do consulting work, handling things such as insurance and contract management. "It is a very sensible, great place to start."

It soon became clear that although the architects and design engineers liked the concept, when they put them into their specifications, the builders were less than enthusiastic. "They rightly said, and this is a correct challenge from the contractors, 'Lovely ideas, lovely designs, who can I buy the system from that will do this?' They just wanted to 'buy a box' to bolt on to their buildings. Without that, they responded, 'I'm going to tear up your design and just replace it with the old designs, which use mechanical ventilation.' They wanted a 'plug and play' option."

COMMERCIALISING IDEAS

There was an obvious answer, set up a business to build the boxes. Dr Fitzgerald set up Breathing Buildings, as a commercial enterprise "to make products" based on the research carried out in the BP Institute at the university. The company was not just an experiment in commercialising technology to the market. For one of its investors, BP, it was a testbed for how to commercialise academic research that it had backed via a spin-out route. The oil giant may have put a lot of money into university research, but it had never brought results to market using the route before, when acting in a dual role as venture capitalist and a contributor of university intellectual property to which it had certain rights. BP was an early investor when Breathing Buildings started operations in 2006.

Dr Fitzgerald's aim was to force the building industry to pay serious attention to natural ventilation. "When we set up, we were the only people in town." He wanted to change that. If companies designing and installing conventional ventilation systems could no longer sell the old stuff, they would have to change their ways and become competitors in the natural ventilation business. As Dr Fitzgerald sees it, "real success is when you have changed industry".

That seems to have worked. Breathing Buildings has persuaded the industry that there is a lot to be said for its concept of 'hybrid ventilation', using pure natural ventilation when external weather conditions are favourable, combined with mechanical ventilation at other times. The technology takes heat from people, lights, IT and even solar energy in a building and exploits it to avoid the need for radiators. This approach not only cuts energy use, but does it at no extra cost for the installation. "Our kit doesn't cost any more and the payback is zero years, so the return on investment is infinity." This explains why the company has created systems for schools, universities, supermarkets, shopping malls and one building that claims to be the UK's first zero-energy retail building.

As Director of the Royal Institution, Dr Fitzgerald is keen to build on the organisation's public engagement work and attract more people to science and engineering, especially young people © Katherine Leedale

When it was clear that the building industry had caught on, Dr Fitzgerald decided that further progress would come quicker if Breathing Buildings became part of a larger group. With its own factory in Ely and a team of around 50 people, the company wanted to keep growing. "I believed that the next phase of growth for Breathing Buildings should involve a much stronger relationship with a mechanical ventilation company." In December 2016, Breathing Buildings became a part of Volution.

A NEW ROLE

Dr Fitzgerald was ready for another career move. He plans to spend some time at the University of Cambridge where he is Royal Academy of Engineering Visiting Professor in Sustainable Buildings. He lectures building physics and, as part of other degree courses, on innovation, sustainability and construction. Then there is supervision of undergraduate research projects. The most important aspect of that from an undergraduate point of view, he says, is not the research output but the experience. It is important, he adds, to keep engineers in the profession when they graduate. "It has frustrated me greatly, being a supervisor at Cambridge and seeing undergraduates who go off and work in the city and then five years later are as bored as anything." At Cambridge, he said, "I wanted to inspire the next generation and give people a greater understanding of the joy and the fun, and the impact that science and engineering can have on people's lives."

Dr Fitzgerald hopes to bring this message to his new role as head of the Ri, one of the UK's oldest and best known scientific organisations. In the past, the RI may have been the home of some of the country's most famous engineers, including Michael Faraday, but Dr Fitzgerald is the first engineer to hold the to post in many years. At the Ri, he is well placed to unite not just different scientific disciplines but also science and its applications. With its historic lecture theatre, and such high-profile events as the Christmas Lectures, the Ri attracts a constant flow of younger visitors. It has already announced a new five-year strategy with plans to double in size, a greater digital presence and a new science YouTube channel dedicated to children.

Dr Fitzgerald is also keen to reach people beyond the usual suspects. "Our aspiration is to not only to create the scientists of tomorrow, but to encourage active citizens who have the skills and confidence to critically examine science as part of an informed discussion about its benefits to

Dr Fitzgerald jokes that his friends describe his musical career as a "hobby that got out of control". As a member of Prime Brass, a semi-professional dectet of musicians with a string of sold-out CDs, you can hear Dr Fitzgerald playing trumpet and flugelhorn in cathedrals and other venues around the country
© Prime Brass

society." A part of the Ri's new strategy is "to inspire everyone to think more deeply about science and its place in our lives".

This is in line with his view that science can get lost when it comes to policymaking. "There are too many examples where what was the right policy from the scientists' point of view has not been accepted by the public. Was it because it was the wrong policy? I don't believe that is the case at all from a scientific point of view," he says. "This is not just about technical knowledge, it is about wisdom, which is a word that I hear used infrequently." The way to counter this is to get the message out to a wider audience by working with the likes of the Royal Academy of Engineering and the Royal Society. "This is massively important. They reach different audiences, and have got different strengths."

One ambition that should appeal to most engineers is Dr Fitzgerald's aim to tackle what he calls engineering's 'branding problem'. "I care about it massively. We are tarnished with this brush when people think that an engineer is a guy who comes and fixes your boiler or your washing machine. That's not what an engineer does." One way to dispel this could be to make a closer connection between science and engineering. "The fact that I am an engineer might help. I am just a different version of an applied scientist. If I can help with my Ri hat on, by actually saying look the world of science is the science and its applications. It is not that I want to blur the boundaries, I honestly don't believe there are boundaries."

BIOGRAPHY

Michael Kenward OBE has been a freelance writer since 1990 and is a member of the *Ingenia* Editorial Board. He is Editor-at-Large of *Science|Business*.

CAREER TIMELINE AND DISTINCTIONS

Born, **1966**. Master of Arts in Engineering, University of Cambridge, **1989**. PhD in fluid mechanics and thermodynamics of flow in geothermal reservoirs at the University of Cambridge, **1990–1993**. Geothermal Program Manager, Acting Assistant Professor at Stanford University, **1995–1997**. Senior Consultant, Bain & Company, **1997–2001**. BP Institute Research Associate at the University of Cambridge, **2002–2006**. Chief Executive Officer, Breathing Buildings, **2006–present**. Awarded Royal Academy of Engineering Silver Medal, **2011**. Fellow of the Royal Academy of Engineering, **2014**. Royal Academy of Engineering Visiting Professor in Sustainable Buildings, University of Cambridge **2015–present**. Appointed Director of the Royal Institution, **2018**.

HEATING HOMES WITH ROBOTS

Suspended flooring helps construction workers build level floors above uneven and damp surfaces. However, this has created its own problem: the space between the floor and ground allows cold air to enter properties and can result in 10% to 25% of total heat loss. To solve this problem, construction technology company Q-Bot has created a series of robots that can install underfloor insulation without messy construction work.

The need for a more convenient way to install underfloor insulation arose in a conversation between architect Tom Lipinski and Peter Childs, a professor in engineering design. Along with Q-Bot CEO Mathew Holloway, they addressed the challenge of insulating older housing with the development of a fleet of mini robots that use the Q-Bot team's expertise in architecture, heat transfer, robotics, data management, and business and technology management throughout the whole installation process. In 2014, the first trial of the robots demonstrated an 80% reduction in heat loss through the floor and a saving on fuel bills for residents of up to £300 a year.

Insulating homes with suspended wooden floors often involves removing furniture, carpets and floorboards, then cutting and fitting insulation between floor joists before refitting the floorboards and carpets, which can be an expensive, time-consuming and messy process. A Q-Bot robot can fit insulation in one to two days, creating little or no waste.

Q-Bot allows insulation to be installed in houses without ripping up the floorboards. Its technology includes a survey robot that can be inserted into the underfloor cavity to inspect the area and produce a computer-aided-design model from the sensor array the robot carries. SurveyBot can enter inaccessible and hazardous areas such as crawl spaces, cable trenches and sewers. The robot creates accurate 3D textured maps with visual and thermal information, and can see in the dark. After SurveyBot has produced the model, the property can be assessed and a decision taken on whether to book a treatment.

If installation goes ahead, the company then deploys its Spraybot in the underfloor space. Spraybot consists of a sensor array, a spray turret that carries an automated spray-nozzle, chassis, drivetrain and supply tube, and can apply thermally insulating material to the underside of the suspended flooring. It uses powerful motors and independent suspension to climb over the kind of obstacles that might be found underneath suspended floors and enables the robot to pull the umbilical that supplies the materials for the spray.

The company experimented with different levels of autonomy for the robots, but eventually found that a blended approach was best suited to the application. The technology combines tele-operation, using camera vision, and human inspection with autonomous sensing, motion and material spraying. With support from the Royal Academy of Engineering's Enterprise Hub, the EU's Horizon 2020 programme and Innovate UK, the company has been able to scale up its high-tech construction,


A Mark 6.3 Q-Bot robot in action


Q-Bot Spraybot robots

robotics and retrofit business. The technology is completely manufactured in the UK, and each robot produced increases employment for each of the robot operating teams.

The company is working with housing associations and local authorities to install underfloor insulation in their properties across the UK as part of a drive to address fuel poverty. Each home that is insulated sees a 14% reduction in energy usage for heating, and a reduction of CO_2 emissions of 14,000 kilograms CO_2e over the 42-year nominal lifespan of the insulation.

HOW DOES THAT WORK?

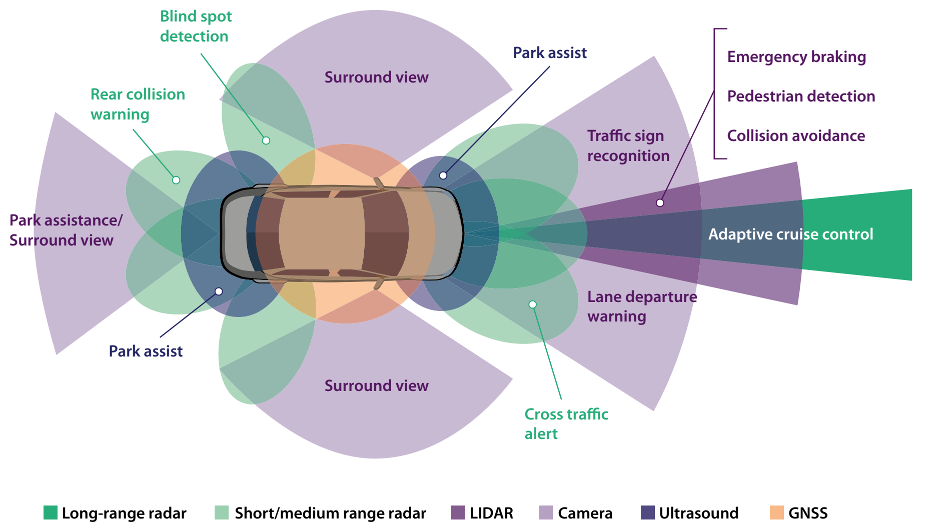
DRIVERLESS CARS

Self-driving cars have been a science-fiction staple for decades, but a wide range of onboard sensors and sophisticated data-processing tools are now supporting trials on public roads around the world.

Few technological goals are as dependent on innovation and engineering as attempts to create fully autonomous vehicles. The challenge of enabling vehicles to interpret endlessly changing environments has remained frustratingly beyond our abilities – until now. Thanks to recent breakthroughs in fields such as Lidar – which uses a pulsed laser to measure distance to a target – the prospect of what's known as level 5 autonomy finally seems achievable in the next few years.

Vehicular automation is graded on a scale from 0 to 5, where 0 is a process managed entirely by a driver. Level 1 involves standalone assistance such as radar-guided cruise control (capable of preventing frontal collisions), while level 2 automates individual processes as long as the driver is ready to take control at any point – such as computer-controlled braking on muddy descents. Level 3 automation lets a vehicle control all aspects of its movement in limited environments such as motorways, whereas a level 4 vehicle exercises self-governance throughout a journey, including parking and junctions. However, complex tasks including exiting a ferry onto a slipway may require human intervention.

The ultimate aim is to reach level 5: complete automation. At this point, human interfaces such as pedals and steering wheels are removed altogether, and every occupant becomes a passenger. To analyse whether surface or overhead obstacles are safely navigable, a level 5 autonomous vehicle requires multiple input streams to make sense of its surroundings:



The multiple input streams needed for a vehicle to achieve level 5 autonomy
(adapted from an image from NovaTel Inc)

- GPS: accurate localisation data is essential to prevent vehicles driving over pavements or cutting corners. The latest Global Navigation Satellite Systems (GNSS) deliver decimetre-level accuracy, combining signals from several satellites to mitigate potential reception issues caused by poor atmospheric conditions.
- Cameras: it is common for today's level 2 and 3 vehicles to have a trio of front-mounted cameras that capture 3D images of approaching terrain, which a computer can interpret. Side and rear cameras help with low-speed manoeuvres such as parking, but they struggle in low light.
- Radar: radio waves are beamed out of the vehicle in a variety of directions, bouncing off objects to determine their trajectories and velocities. Algorithmic software determines the likelihood of path interceptions, pre-emptively taking evasive action. However, radar cannot differentiate between objects of different mass or mobility.
- Lidar: reflected and received light pulses identify objects more accurately than radar, with the added benefit of 'seeing' lines on the road. Radar and Lidar both detect objects in what we think of as pitch darkness, although Lidar struggles to operate in adverse weather conditions such as heavy snow or fog.

In isolation, none of these systems provide sufficient environmental data for a vehicle to proceed safely. However, once they are fed into a multi-domain controller unit (and overlaid on real-time mapping and GPS positioning data), the vehicle should have enough input to set and follow its own route. Tomorrow's artificial intelligence (AI) platforms will combine deep learning with a 360-degree real-time environmental view, to anticipate and pre-emptively resolve threats posed by static and moving objects.

The advantages of level 5 autonomous vehicles include universal mobility for people currently unable to drive, and more time for 'drivers' to pursue other activities. Estimates suggest fuel economy could be boosted by up to 30%, although the biggest benefits relate to road safety. Over 27,000 people are killed or seriously injured on British roads each year, and 90% of these accidents are attributable to human error. Removing ourselves from the driving experience represents the best way to save millions of lives around the world.

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