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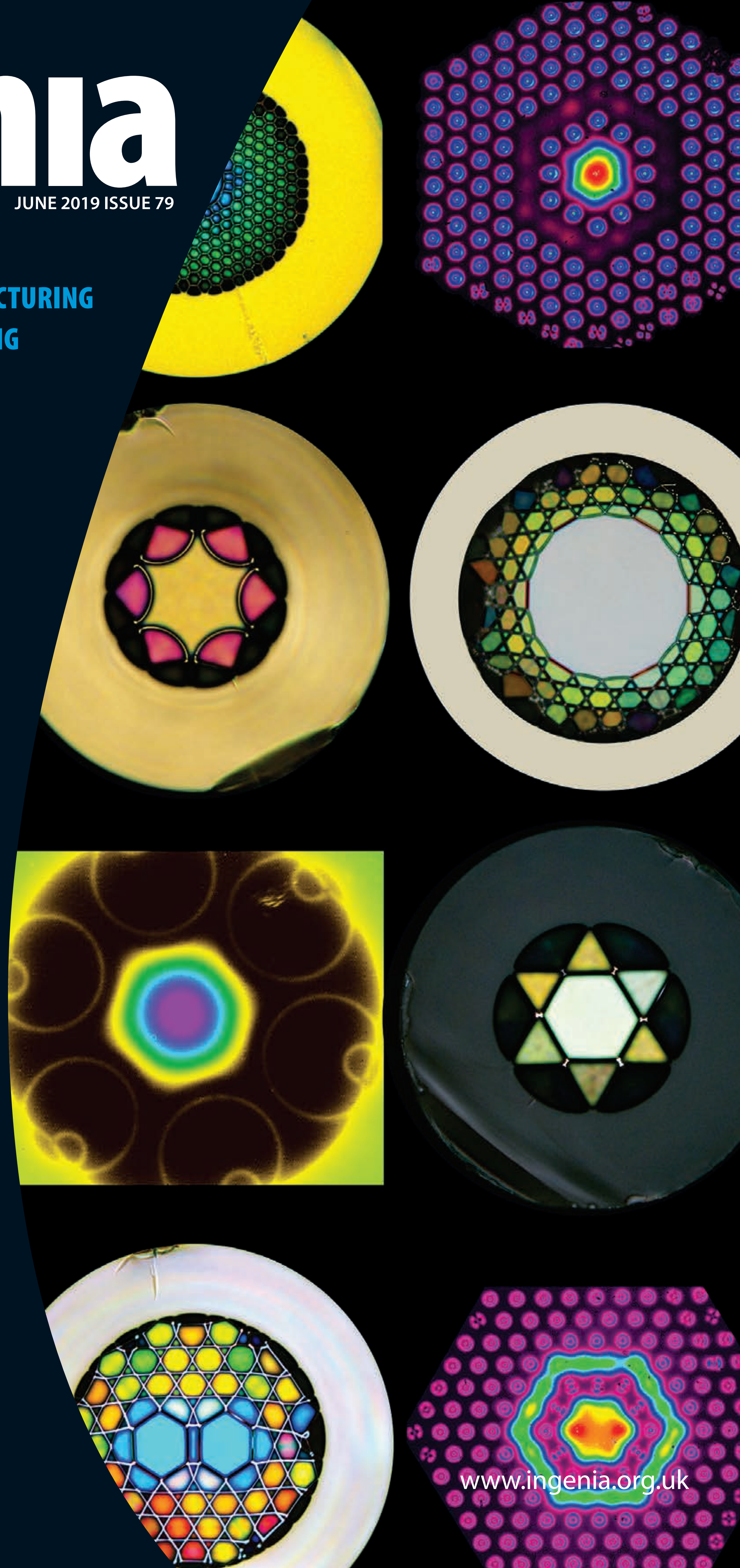

INNOVATIVE AUTOMOTIVE MANUFACTURING

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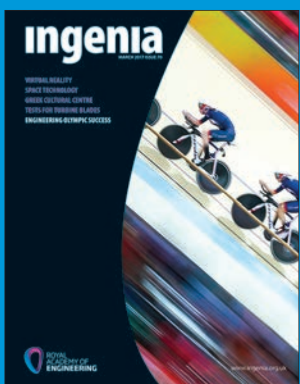
Ingenia is 20



Ingenia publishes stimulating and informative articles about all aspects of engineering and technology, from robotics and data to the latest in renewable energy and medical technologies. It produces authoritative yet accessible content, aimed at engineering enthusiasts from 10 to 110, including students, engineering undergraduates, engineers at all levels, and academics.

To subscribe to receive a free copy each quarter, please visit **www.ingenia.org.uk**

EDITORIAL

INGENIA AT 20


Scott Steedman CBE FREng

The pace of change in engineering since the turn of the millennium sometimes seems daunting, certainly from the perspective of *Ingenia*, which marks its 20th anniversary in July. So much has transformed in that time, but the growth and distribution of the world's population and the decline in poverty levels stand out as three key indicators when thinking about the impact of engineering on humankind. *Ingenia* has reflected these issues in articles published over the years.

First, most of the world's population now lives in an urban, not a rural, environment. This has stimulated global interest in smart cities, transportation and infrastructure. Second, the rate of population growth has peaked, thanks to clean water and medical advances, among other factors. Within the foreseeable future, the world's population will stabilise. Indeed, in some countries it is the prospect of population decline that has stimulated the development of robotics and artificial intelligence (AI). Climate change and population growth have driven renewed interest in how engineering will contribute to the UN's Sustainable Development Goals. Third, the proportion of the world's population living in poverty, as defined by the UN, has fallen from around a third to under a tenth.

As the Royal Academy of Engineering's flagship magazine, *Ingenia* has sought to celebrate the role of engineers and engineering in improving quality of life and in underpinning the global economy and sustainable development. Issue by issue, *Ingenia* has presented stories of tangible achievements that have made a real difference to the world, from innovation to wealth creation. As engineering has changed, *Ingenia*'s coverage has broadened to encompass software, digitalisation, robotics and AI.

Throughout, *Ingenia* has sought to share the advances made by UK engineers that affect the nation. Winners and finalists of the annual MacRobert Award, celebrating its 50th anniversary this year (see page 38), have provided a rich seam of material that demonstrates the breadth and depth of the UK's engineering successes.

As the Academy has worked to position engineering and engineers at the heart of society, *Ingenia* has followed by featuring the people and the projects that showcase the profession and its achievements. Every issue now includes the story behind an early career professional as well as a profile of an Academy Fellow.

Since 1999, *Ingenia* has published some 400 articles on virtually every facet of engineering. Every article is available free online, providing an invaluable archive, not least for the growing number of students who read the magazine. The magazine has become an important channel for the Academy to inform, enthuse and encourage students at school and university to consider a career in engineering. Of the nearly 12,000 copies of *Ingenia* distributed each quarter, over 5,000 go to schools, colleges, sixth forms, and universities for distribution to students.

It has been an remarkable journey made possible by the commitment of the members of the *Ingenia* Editorial Board, who have provided continuity and inspiration for the articles that have been painstakingly pulled together for each issue.

One major challenge faces the magazine if we are to leave *Ingenia* fit for the next 20 years. The magazine has the background and content of a hugely useful and stimulating online resource – its website at Ingenia.org.uk attracts on average 36,000 views per quarter – but it needs a refresh. We have plans to redevelop it so that *Ingenia* can better serve its growing audience of younger readers and offer readers a better online experience with more material that demonstrates the breadth and excitement of engineering.

As the only UK publication with free distribution that engages a broad, non-specialist audience in engineering, we see *Ingenia* as a valuable resource for future engineers. A more versatile online presence can act as a showcase for UK engineering that includes video and dynamic content to enrich our articles. Our sponsors have shown great commitment to the magazine over the years and we are deeply grateful to them for making *Ingenia* what it is today. Now, as *Ingenia* looks to the future, we hope that our sponsors, readers and the Academy will join us for the next great online development.

Scott Steedman CBE FREng
Editor-in-Chief

GUEST EDITORIAL

THE EVOLUTION OF ENGINEERING

As she approaches the end of her five-year term as President of the Royal Academy of Engineering, Professor Dame Ann Dowling OM DBE FREng FRS reflects on how the Academy – and engineering in general – has changed over the period.


Professor Dame Ann Dowling OM DBE FREng FRS

During the past five years, the Royal Academy of Engineering, and the engineering landscape in general, have seen some significant changes, including political and changes to funding as well as a focus on diversity and industry's relationship with academia.

In 2014, I was the first woman to be appointed as President of the Academy and this September marks the end of my five-year term. I am pleased to say that, since then, diversity and inclusion (D&I) within the profession has been high on the agenda. The Academy has led a D&I programme with the engineering community to support and inspire more women, those from minority ethnic backgrounds, lesbian, gay, bisexual and transgender individuals, and people with disabilities to start and advance careers in the field. To date, close to 100 businesses have engaged in this effort. In 2018, we gained our first female Chief Executive with the appointment of Dr Hayaatun Sillem, and I know that she and our new President will continue to drive our D&I efforts forwards.

D&I is critical in a profession that develops solutions for the whole of society, but it is also an important part of how we address the skills gap. The skills shortage in engineering has been persistent, but we are beginning to see some progress, particularly in engaging young people. The *This is Engineering* campaign, which the Academy launched in 2018 with several partners, has helped to open up engineering to a new generation and demonstrated the wealth and breadth of opportunities available in the profession. The films launched as part of this campaign have been viewed over 33 million times to date. Research carried out at the end of the campaign's first year has shown that consideration of engineering as a career option has almost doubled among teenagers who have seen the campaign films, and increased more significantly among females and black, Asian and minority ethnic students. It's great to see that this work is having such an effect and the campaign has even more ambitious plans for the future, which I hope many people will get involved with.

As well as addressing the perceptions of, and attitude towards, engineering careers among young people, we have also needed to focus on bringing engineering into the classroom. There are many excellent programmes aimed at doing this, but these are not having an effect at the scale needed, and the connections with schools are complicated, with more than 600 organisations involved in STEM education. So many options can make it difficult for schools to find out what is on offer and limits the opportunity to transfer best practice. The Academy and EngineeringUK have begun to explore how best to work together to simplify and streamline the whole engineering community's outreach to schools. No one underestimates the challenge that it might present but, if the engineering profession works collaboratively, the increase in our impact could be significant.

When I was appointed as President one of my first tasks was to lead a review, commissioned by the then Department for Business, Innovation and Skills, examining how government could support the development of more effective collaborations between business and university researchers, which are so crucial to the UK economy. I am pleased that the government fully endorsed the review's findings in 2016. As well as policy changes, the review has led to developments in how the government supports universities and businesses to build collaborations. Innovate UK immediately simplified its interface to business, making it easier for companies not already engaged in collaborative research to start, an approach that has subsequently been taken up by UK Research and Innovation (UKRI). The *Research Excellence Framework* (REF) 2021 will also bring welcome further recognition to business–university collaborations and make mobility between academia and industry easier.

The engineering research landscape has also benefited from a significant uplift in funding, towards the government target of an investment 2.4% of GDP in research and development by 2027. This began in 2016 with a £4.7 billion increase in government science and innovation spending announced in the Autumn Budget. Then, as part of the government's plan to develop a pipeline of highly skilled research talent, a £210 million National Productivity Investment Fund was announced in the 2017 Spring Budget. I was pleased to have been involved in shaping how some of the £4.7 billion commitment, through the Industrial Strategy Challenge Fund, would be spent, alongside the Department for Business, Energy and Industrial Strategy, the Research Councils and Innovate UK. The ambition was to bring together the UK's world-leading research base with business to tackle specific industrial and societal challenges where the UK can take a lead and drive economic impact. The Academy's own programmes have always encouraged business–university collaboration and I am delighted that we have been able to make a very significant increase in our support for researchers and innovators through winning additional funding as part of the government's Investment in Research Talent. I am also pleased to see engineering's critical role so well recognised, and I look forward to seeing how our influence and expertise will help inform government policy in the future. The Academy's establishment of the National Engineering Policy Centre, bringing together the expertise of all of the UK's professional engineering organisations to provide advice to policymakers, is a significant step forwards in growing that influence.

Just before my term began, the Academy launched the Enterprise Hub, which has become one of its success stories. It was originally developed to take the 'best of best' UK-based entrepreneurial engineering innovators and companies and provide them with pre-seed funding and a package of mentoring, training and bespoke support to encourage success, and therefore contribute to the UK's economic growth. While this still underpins the Hub's focus, it is increasingly partnering with like-minded organisations, including investors and corporates, to build a Hub community and introduce new initiatives to support aspiring and established entrepreneurs. However, one of its most important developments was the launch of the Taylor Centre – a physical home for the Enterprise Hub that provides professional working space and meeting rooms for Hub members. As well as beginning a new chapter in the Hub's story, the Taylor Centre is a space where members, mentors and supporters can connect, allowing it to act as a focal point for promoting excellence in engineering entrepreneurship and enabling us to unlock the wider value of the Academy and its Fellowship.

Of course, engineering is a global pursuit and the contribution and collaboration of engineers towards grand challenges on a global, as well as national, scale is vital. The Academy's international activities have gone from strength to strength over the past few years, supporting the training of hundreds of international entrepreneurs to help develop innovations that address local challenges, linking researchers with like-minded academics from other countries and building partnerships with engineering institutions across the globe. This year also sees the start of the second series of Global Grand Challenges Summits, with a two-day event hosted by the Academy in London that will bring together policymakers, innovators and the next generation of engineers from across the world to build collaborative solutions for our future. Back in 2013 I chaired the working group that developed the first London summit. In 2019, the world, engineering and technology all look very different, and a range of speakers on emerging technologies will attend the summit, as well as many more young engineers. I am looking forward to hearing their thoughts on engineering's role in such rapid transformation.

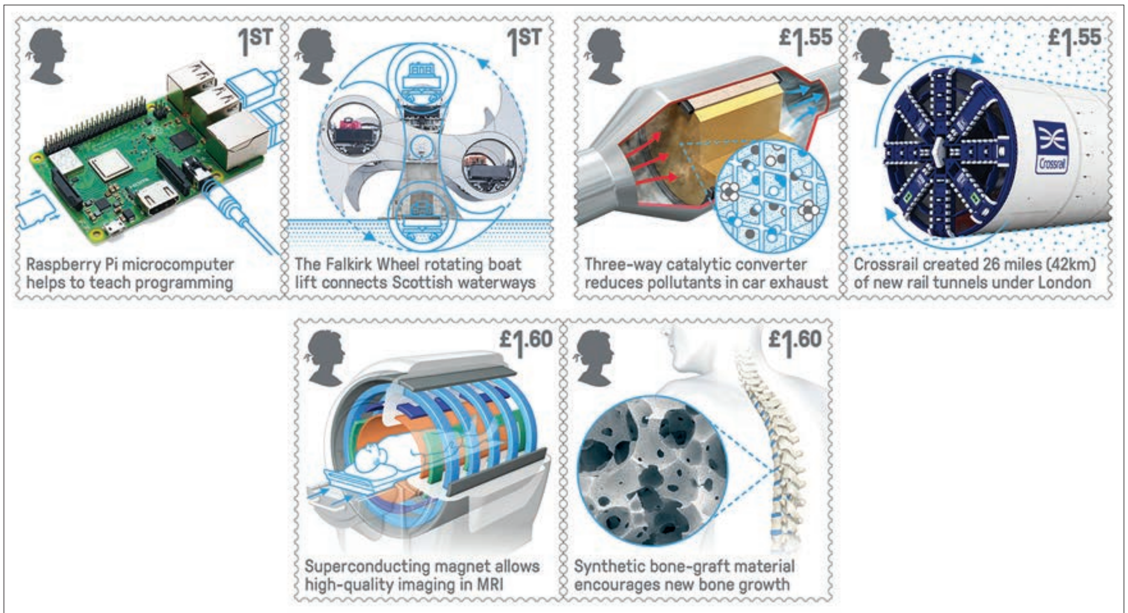
Engineering is playing an increasingly important role in society, and the engineering landscape has evolved significantly since I took up this post, progress that I believe the Academy's activities have contributed positively to. Collaboration, investment, a greater supply of skills, and D&I are all key to ensuring that the brightest minds can continue to innovate. There has never been a more important time for the Academy to advance and promote excellence in engineering so that our profession can continue to contribute to societal wellbeing and economic growth.

Professor Dame Ann Dowling OM DBE FREng FRS
President of the Royal Academy of Engineering

IN BRIEF

STAMPS CELEBRATE BRITISH ENGINEERING

The accompanying miniature sheet features the Harrier Jump Jet aircraft © Royal Mail



The set of six stamps celebrating British engineering © Royal Mail

Royal Mail has released a set of stamps that celebrate some of British engineering's greatest innovations from the past 50 years.

The set includes three previous MacRobert Award winners. The award is the Royal Academy of Engineering's prize for innovation in UK engineering, which celebrates its 50th anniversary this year. From the smallest of computers, the Raspberry Pi, to the three-way catalytic converter developed by Johnson Matthey, and Oxford Instruments' superconducting magnets that enable MRI scanning, the UK has a long and proud history of engineering.

The set is completed by stamps of the Falkirk Wheel, the world's only rotating boat lift, Crossrail's monumental tunnel boring project, and the synthetic bone-graft material developed at Queen Mary, University of London by Dr Karin Hing, who won the Academy's Silver Medal in 2011 for her work.

The Harrier Jump Jet appears in a miniature sheet of four stamps. Celebrating 50 years since it entered RAF service, the Harrier was the first operational jet fighter in the world to use revolutionary vertical short take-off and landing technology, powered by Rolls-Royce's Pegasus engine, which was joint first winner of the MacRobert Award in 1969.

Philip Parker, Head of Stamp Strategy at Royal Mail, said: "British innovation in engineering is world renowned. This stamp issue proudly celebrates the projects and inventions which showcase this, as well as demonstrating the extraordinary range of disciplines that British engineers excel in."

STUDENTS DESIGN, BUILD AND DRIVE RACING CARS

Formula Student teams line up at the starting line in 2018 © Institution of Mechanical Engineers

In July, more than 3,000 participants from over 25 countries will take part in the Formula Student event at Silverstone.

Organised by the Institution of Mechanical Engineers, the event challenges university teams to design and build a single-seater car, which they drive in a series of races over three days at the Silverstone track. This year will also include an artificial intelligence (AI) competition, where teams will programme a prototype autonomous vehicle, as well purpose-built vehicles, to undertake a series of on- and off-track driving challenges.

Teams from 59 British universities are taking part, as well as entrants from across the world, including a first entry from Hong Kong.

Andrew Deakin, Chairman of Formula Student, said: "Around 1,000 university teams have been involved in our Formula Student competition in the 20 years since its launch, which equates to roughly 40,000 students from across the world. This year we are really excited to have teams competing in the new FS-AI competition. Formula Student has always been proud of the work it does to prepare students for the real world of industry and FS-AI will help us achieve that in the ever-expanding area of autonomous vehicles."

Tickets for the event start at £10. To attend the race as a spectator, please visit **www.silverstone.co.uk/events/formula-student**

FUNDING AWARDED TO GLOBAL ENGINEERING VISIONARIES

The Royal Academy of Engineering has announced long-term support for nine world-leading engineers to develop areas of emerging technology. The Chairs in Emerging Technologies will focus on advancing technologies that have the potential to bring significant economic and societal benefits to the UK.

Supported by the UK government's National Productivity Investment Fund, the awards total over £20 million over the 10-year programme. The projects include next-generation cameras that can see round corners, human-centred robots that can adapt to an individual's assistive needs and light-powered retinal implants that can restore people's vision. The areas of research funded reflect the UK's wider technological priorities, with many of the projects directly aligned to the government's industrial strategy and designed to tackle some of the biggest industrial and societal challenges of our time.

Professor Dame Ann Dowling OM DBE FREng FRS, President of the Royal Academy of Engineering, said: "Engineering is critical to achieving the goals of the UK government's industrial strategy, and investment in emerging technologies means that we can secure our footing in important future markets. For these technologies to reach their full potential it is important to invest in the pioneering individuals who advocate for them, as without their vision and foresight it is difficult to identify the products and services of tomorrow."

To find out more about the chairs and their research, please visit **www.raeng.org.uk/emerging-technologies**

AIR-BREATHING ROCKET ENGINE PASSES FIRST TEST

The SABRE engine could power flights across the world at five times the speed of sound © Reaction Engines

An UK-built hypersonic engine that could power a plane from London to Sydney in around four hours has passed its first demonstration test.

The SABRE engine, developed by UK company Reaction Engines, is the world's first air-breathing part jet, part rocket engine, which relies on an innovative pre-cooler heat-exchanger technology. In March, this aspect of the engine was approved for testing, which recently took place at a test facility in Colorado, US.

The ground-based tests saw the pre-cooler successfully quench the 420°C intake airflow in less than 1/20th of a second. The temperature replicates thermal conditions corresponding to Mach 3.3 flight, or over three times the speed of sound. The tests are the first phase in an extensive test programme that will see the pre-cooler exposed to high-temperature airflow conditions of more than the 1,000°C expected during Mach 5 hypersonic flight.

The engine's core recently went through a preliminary design review, which was signed off by the European Space Agency and UK Space Agency. Testing of this section will take place at Westcott Space Cluster in 2020.

As well as powering rapid, point-to-point transport inside the atmosphere, the engine would allow reusable vehicles to enter orbit without the need for multiple propellant stages, which is the case with conventional rockets. The engine could take them from standstill to just over five times the speed of sound and then transition to rocket mode at high altitude at 25 times the speed of sound to enter space.

Following the testing in the US, Mark Thomas, Chief Executive of Reaction Engines, said: "This provides an important validation of our heat exchanger and thermal management technology portfolio, which has application across emerging areas such as very high-speed flight, hybrid electric aviation and integrated vehicle thermal management."

GET INVOLVED IN ENGINEERING

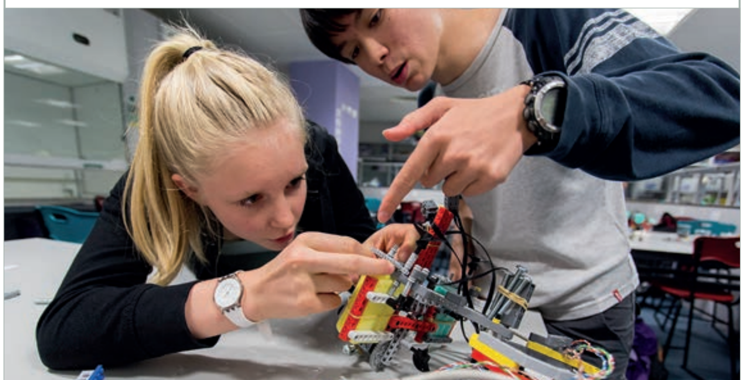
SUMMER EVENTS AT THE RI

The Royal Institution (Ri) has launched a series of summer events that focus on engaging the public with STEM topics.

Running until the end of August, the series will features events based on three themes: Who am I?; Science in our lives; and Great moments in science. Talks include: 'How batteries will change our lives', a discussion about how adoption of battery transport will affect the built environment and how the automotive and transport sectors will have to change; 'The conversation: a generalist AI', which will explore how artificial intelligence will be intrinsic to a range of future technologies; and 'Small steps and giant leaps', a day of hands-on activities and demonstrations about space exploration that marks the 50th anniversary of the Moon landing.

The Ri has also announced its Summer Schools programme for young people aged 7 to 18. Its range of hands-on workshops brings to life all areas of STEM, from designing and building robots, making explosive bath bombs and creating electrical circuits that drive an electric train to making their own speakers, trying their hand at mathematical origami and exploring 3D engineering.

To find out more about the events and workshops or book a place, please visit **www.rigb.org.uk**



Students at a Royal Institution Summer School © Royal Institution

UNTANGLING THE TRACKS AT THE LONDON TRANSPORT MUSEUM

The London Transport Museum has opened a new exhibition that explores the history of the Thameslink route. A display traces the route from 1866 up until the recent £7 billion engineering project to modernise it.

The display will include architectural models of Blackfriars station, which is the only station to span the river Thames. It has recently had an array of solar panels installed across its entire roof. Younger visitors can get hands-on with a untangle the tracks puzzle.

The exhibition also features the engineering behind the Borough viaduct, a 1,200-tonne, 72-metre bridge structure that gives Thameslink its own tracks into London Bridge station.

The exhibition runs from 24 May for a year. For more information, visit **www.ltmuseum.co.uk**

27 TO 29 JUNE 2019 LANCASHIRE SCIENCE FESTIVAL

Held across three days, Lancashire Science Festival will host a raft of shows and workshops for schools and families, ranging from building an overengineered mousetrap and learning about the science of *Star Wars* to an introduction to engineer Isambard Kingdom Brunel.

The first two days of the festival will be open to primary school groups from Key Stage 2 while the third day will cater for the general public. The programme is free of charge to everyone on a first-come-first-served basis and the workshops can be pre-booked at a cost of £1 per person, which will be donated to charity.

lancashiresciencefestival.co.uk

6 TO 16 JUNE 2019 GLASGOW SCIENCE FESTIVAL

One of the UK's largest science festivals, Glasgow Science Festival engages around 50,000 people in STEM through its June festival and community projects. Focused on the contributions of Glasgow and Glasgow-based researchers, the programme of events is suitable for all ages held at several locations across the city.

Visitors can attend an exhibition focused on the legacy of scientist, inventor and engineer James Watt, as part of celebrations marking 200 years since his death; listen to a talk about the achievements of women in engineering over the past 100 years; or enter a competition to be crowned 'Creating Engineers Grand Champion'. It also includes two events supported by the Royal Academy of Engineering's *Ingenious* scheme, Ingenious Circus, which explores the science and engineering behind the big top.

www.glasgowsciencefestival.org.uk

A volunteer helps a festival attendee © Glasgow Science Festival

HOW I GOT HERE

Q&A

ZOE DOBELL
SYSTEMS ENGINEER

Zoe Dobell is a systems engineer at Transport for London (TfL). She's currently working on the Central Line Improvement Programme (CLIP), where she is integrating new systems that are being retrofitted onto the trains.

WHY DID YOU FIRST BECOME INTERESTED IN ENGINEERING?

I have a few theories! When I was about five, I visited a railway depot with my dad who's an engineer. Exposure to that world from an early age made me aware that engineering existed and that it was interesting. I was also always involved in DIY around the house, so had an interest in 'fixing' things from a young age. My mum pushed me to join the Beavers as a child because she thought being active and outdoors was important. I was the only girl in the group, but I was always encouraged to do what I wanted.

HOW DID YOU GET TO WHERE YOU ARE NOW?

I was good at maths and science at school and my teachers always encouraged me, suggesting the subjects when I was choosing my A levels. I was lucky to be nurtured by great teachers and parents. I always knew I wanted to go to university as I've always quite liked academia, so I took A levels in the subjects I enjoyed: science, maths, and design and technology.

One of my teachers suggested that engineering was a good combination of all three subjects, which led to me studying materials science and engineering at Imperial College London. During my degree, I did a couple of summer placements: one with Angel Trains and one at Bombardier Transportation. These both taught me how to use my engineering knowledge to solve practical problems and taught me a lot about the challenges of railways. It was these challenges and the way they provide a service that excites me about railways. The practical experience really helped when I was choosing industries I wanted to apply for jobs in, and proved very helpful in the application and interview process for graduate roles.

I chose to work in transport because it helps people; it's good for society. I specifically chose railways because they're public transport rather than luxurious travel such as cruise ships or aeroplanes, and metros in particular help lots of people! I enjoy the challenge of working within constraints, such as being able to run a certain number of trains during rush hour. When I graduated, I joined TfL's graduate training scheme as a mechanical engineer, which gave me the opportunity to work all over the business. This gave me the knowledge that I needed to decide to work within rolling stock (train) projects and the Central Line Improvement Project.

Zoe at the London Transport Museum's Future Engineers exhibition

WHAT IS YOUR FAVOURITE THING ABOUT BEING AN ENGINEER?

I like the variety that being an engineer offers. For example, the London Transport Museum's Future Engineers exhibition asks visitors whether they are a fixer, a dreamer or a planner – I believe that as an engineer you get to be all three! There are days where you have to solve and fix a problem, days when you're thinking about the future and what could be done in 10 years' time, and other times when you're planning how to implement that dream. The variety means that I'm never bored and I'm constantly motivated to do something.

I also really enjoy finding solutions around the necessary constraints of jobs. Time and money are always constraints, but there are also technical constraints such as finding space for all the necessary equipment and the train still needing to be a certain size to fit through the tunnel. It's really satisfying when you find the solution.

WHAT DOES A TYPICAL DAY AT WORK INVOLVE FOR YOU?

My days are very varied. I work as part of a large team, and as a systems engineer I work closely with project engineers and various specialist engineers, as well as project managers and sponsors of the project.

At the moment, I'm office-based and we're doing the design work for CLIP. I have meetings with suppliers, often via Skype because they're located around the world. Some days I take suppliers to visit the depot and show them where their products might fit. I also go on trips to places such as Sweden and Finland to talk to suppliers about their designs.

It's my job to ensure that all the systems we choose can function and communicate with each other and will work as a group to deliver the required improvements. In a few months or so we'll be prototyping and fitting the products to a train, so then I'll be spending all my time at the depot, fixing the products and solving problems. It varies not only day to day, but year to year.

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

Keep your options and your eyes open! Look for the things that excite you and try to appreciate that everything around you has been engineered by someone. Look at problems that need to be solved: if you found something difficult to use, think about how you could improve it. James Dyson had problems with his vacuum cleaner, so he engineered a better one.

I would also emphasise the importance of studying science and maths throughout school, regardless of whether you choose to become an engineer through an apprenticeship or a graduate scheme route. Design and technology will also give you a great basis for engineering.

WHAT'S NEXT FOR YOU?

The beauty of engineering is that opportunities come around all the time, but because there's so much variety in individual jobs, you want to deliver the thing you set out to deliver – while continuing to learn and develop. In the future, I can imagine myself going into the management side of engineering – but we will see.

QUICK-FIRE FACTS

Age: **31**

Qualifications: **CEng MIMechE and MEng (Hons) Materials Science and Engineering, Imperial College London.**

Biggest engineering inspiration: **The natural talent and ideas of kids at STEM events.**

Most-used technology: **3D printing of parts – to aid space proofing and ergonomic assessments.**

Three words that describe you: **(unless someone knows better) creative, direct, logical.**

OPINION

CAN ELECTRIFICATION SOLVE AVIATION'S EMISSIONS PROBLEM?

A growing population and the efficiency and decreasing costs of air travel are leading to concerns about the aviation industry's green credentials. As focus increases on creating a more sustainable planet for the future, the industry is looking to make changes. Paul Stein FREng, Chief Technology Officer at Rolls-Royce, sets out why the industry and policymakers should be looking at electrification to address such challenges.

Paul Stein FREng

By 2030, 8.6 billion people will inhabit the Earth; six billion of those will be annual flyers and five billion will reside in cities. The increase in emissions of greenhouse gases (GHG) from human activity is likely to have been responsible for escalating global average temperatures in the last century. In 2019 alone, global annual emissions of CO_2 created by humans reached 33 billion tonnes, with aviation representing approximately 2%. Through the International Civil Aviation Organisation, the aerospace industry is playing its part in managing the environmental impact of growing aviation traffic and has set itself a target to reduce CO_2 emission intensity, with aspirations to drive to 2% annual fuel efficiency and carbon neutral growth from 2020 onwards.

To support the rising demand for air travel and achieve CO_2 emissions targets, the aviation industry is developing environmentally friendly technologies and practices. The aviation sector needs an overarching strategy that addresses aircraft and engine design, air traffic management and operation, development of sustainable aviation fuels and also market-based measures. In this direction, the industry has recently implemented a global market-based measure system called CORSIA (Carbon-Offsetting and Reduction Scheme for International Aviation).

Electrification is impacting many transportation systems because of its ability to create pure electric and hybrid machines with lower CO_2 footprints. For the first time, aviation is now exploring electrification for passenger-carrying aircraft to unlock environmental as well as many other benefits. While pure electric flight will power smaller aircraft, larger aircraft will need to rely on hybrid electric solutions for the foreseeable future, combining electrification with evolutions of the gas turbine. There are many challenges that lie ahead, in technology, systems engineering and skills, but electrification is set to have a similar impact on aviation as when gas turbines replaced piston engine propulsion. We are at the dawn of the third generation of aviation.

Rolls-Royce is embracing sustainability with an environmental strategy for aviation that has three strands: increasingly fuel efficient products; encouraging the development of environmentally friendly and sustainable aviation fuels; and pursuing the electrification of aviation. On efficiency, the Trent XWB has reduced CO_2 emissions by 15% relative to the first Trent engines (mid 1990s). The fuels industry is developing sustainable aviation fuels based on biomass, organic waste and fully synthetic processes and we expect to see significant scaling of these processes with time. While gas turbines will power large aircraft for the next 50 years or more, electrification will play an increasing role in propelling smaller aircraft and in enabling new approaches to large aircraft efficiency.

Regional hybrid aviation is set to revolutionise intercity mobility by 2030. It is possible that we will see a new type of regional air transport, being more fuel efficient and quieter than current turboprops, which will bring a new approach to mass transportation. The main challenges in this power class include the technology for very high power to weight machines, power electronics and batteries, thermal management, and systems integration complexity. But we are on a trajectory to solve these issues.

For larger aircraft, the gas turbine will remain the main source of thrust as only chemical fuels can deliver the energy density required for medium- to long-haul flights. Because of this, sustainable aviation fuels will become the cornerstone of environmental performance in these markets. However, electrification will enable simplification of gas turbine internal design, unlock new methods of managing aircraft drag, and open new benefits to aircraft at platform level.

However, to realise this exciting future, the entire aviation industry needs to coordinate with policymakers, regulators and governments internationally. Global standards are critical to the aviation industry as products are utilised around the world. Some do already exist but most areas need development to accommodate new technologies. This third generation of aviation will need governmental support in research and technology, test infrastructure, and legislation. Academia and industry will also have to join efforts to develop key knowledge, technology and a successful supply chain in:

- drop-in sustainable aviation fuels at required scale by the fleet in operation and viable economics, to ensure that aviation is environmentally sustainable and continues to bring social and economic benefits
- electrical machines, at multi MW-class and to aerospace standards with high performance and high integrity
- advanced controls, to manage and optimise electrical power usage across hybrid system including energy storage
- high-voltage lightweight electrical systems with advanced thermal management and cooling capacity
- high power density and highly efficient power electronics, which require low-loss advanced semiconductor devices and high frequency switching capable of operation at high voltage and high altitude
- energy-dense batteries that can withstand harsh thermal and electrical cycling.

As well as posing significant technical and systems integration challenges, these technologies also need to meet safety and certification standards, which are significantly higher than many other applications.

As a stepping stone to a more electric future, Rolls-Royce is leading an exciting challenge to build the world's fastest all-electric aircraft. This zero-emissions plane is planned to make a run for the record books with a target speed of more than 480 kilometres per hour. With our partners, we have support from the UK government to develop this all-electric aircraft from concept to flight test in just 36 months. Our aim is to stimulate the electrical supply chain and we hope to excite new electrical engineers to pursue a career in aviation. In hybrid electric propulsion, we are also leading the propulsion challenges in the E-Fan X project, which when flying will demonstrate hybrid electric propulsion at megawatt scale.

Rolls-Royce has a proud history powering aviation from the Eagle to the Griffon in piston engines and from the Welland to the UltraFan® in jet engines. We are now at the dawn of a new generation of aviation that will see new aircraft designs and the industry serving customers in many new ways. Aviation is now set to redefine transportation. Rolls-Royce is proud to be pioneering this challenge but for electrification to truly have an impact, the entire aviation industry needs to embrace it on a global scale.

BIOGRAPHY

Paul Stein FREng is Chief Technology Officer at Rolls-Royce. Prior to this role, Paul was Director General, Science and Technology, at the Ministry of Defence and Managing Director of Roke Manor Research Ltd. He is a Fellow of the Royal Academy of Engineering, the Royal Aeronautical Society and the Institution of Engineering and Technology.

Members of the Women's Engineering Society tour an early power station in the 1930s © Women's Engineering Society and the Institution of Engineering and Technology (IET) Archives

A CENTURY CELEBRATING WOMEN ENGINEERS

2019 marks the centenary of the Women's Engineering Society (WES). The society is marking the date by commemorating the women engineers who have been involved with WES over the last 100 years, from its founders to the women currently working in engineering. Portia Sale spoke to Ceryl Evans, Consultant Social History Curator to WES, about how the society is working to transform the engineering landscape, celebrating women as engineers, and campaigning to improve diversity and inclusion.

While women had been involved in engineering before the First World War, the new and expanding range of industries that arose during the conflict, such as munitions and aeronautics, created more opportunities for women to work in engineering. Some women went from doing poorly paid piecework to managing and training all-female teams in factories. In 1919, after the war had ended, the Sex Disqualification (Removal) Act was passed: "A person shall not be disqualified by sex or marriage from the exercise of any public function, or from being appointed to or holding any civil or judicial office or post, or from entering or assuming or carrying on any civil profession or vocation, or for admission to any incorporated society."

This law meant that women could join professional organisations, although there was a still a bar for married women. WES was legally recognised the day after the act was passed. While the act allowed the society to exist, the parallel 1919 Restoration of Pre-War Practices Act contradicted it in many ways, as it forced lots of women to relinquish their wartime roles to the men who returned from war. The society aimed to support the women who had worked throughout the war and did not want to go back to domestic work just because it was over.

Its first President was Rachel Parsons who, like many early women engineers, came from an engineering family – her father, Charles Parsons OM KCB FRS, invented the steam turbine. During the war Rachel replaced her brother as a director on the company's board and, along with her mother Lady Katherine Parsons, oversaw the recruitment and training of women munitions workers. Lady Katherine brought together the founders of WES – a group of inventors, engineers, campaigners and designers – to improve the rights of women in the workplace as traditional engineering societies continued to reject applications from women after the war.

EARLY YEARS

Many of WES's founding members had been involved in the suffrage movement, which in 1918 had contributed to women aged 30 being granted the vote. WES members recognised that although the vote had been given to some women, most of them working in the factories were under 30 and did not own property, so did

MARGARET PARTRIDGE, ELECTRICAL ENGINEER

Laura Willson, Dame Caroline Haslett DBE and Margaret Partridge, who all worked on electrifying rural England. This image was originally published in the *Leeds Mercury* newspaper on Saturday 17 September 1927
© WES and IET Archives

Margaret Partridge was a pioneer of electrical engineering and a member of WES and the Electrical Association for Women. She realised that electrification was the key to freeing women from domestic work and spent her life working to electrify England.

After completing a maths degree, she had a brief career as a teacher before deciding that it was not for her. Like many women, she trained as an engineering apprentice during the war and worked in munitions. After the war, she moved home to Devon where she set up her own electrical consulting business that provided electricity supplies for small towns and villages. In 1920, Margaret joined WES, where she advertised her new business in its journal with the slogan 'Women for Women's Work'.

Along with Dame Caroline Haslett DBE, she wrote *The Electrical Handbook for Women*, which taught women how to use appliances, do their own electrical repairs and teach the uses of electricity to other women.

Margaret's company brought electricity to many homes for the first time. In the 1920s, she wired four English villages for electricity and, with Dame Caroline, established Electrical Enterprise Inc to ensure that rural homes could access electricity.

She also offered apprenticeships for young men and women leaving school: Beatrice Shilling OBE, the aeronautical engineer and racing driver, became an engineer through Margaret's apprenticeship scheme.

Margaret also put on an exhibition of electric models and machines in Exeter to 'stir up the women of Exeter to demand the installation of electricity'. From 1943 to 1945 she was President of WES and founded a munitions factory during the Second World War.

MONICA MAURICE OBE, LIGHTING ENGINEER

Monica Maurice in 1939 © Wolf Safety Lamp Company

Monica Maurice OBE was a mine-lighting engineer who went on to become Managing Director and Chairman of the Wolf Safety Lamp Company. She joined WES in 1934 and was the first woman to be a member of the Association of Mining Electrical Engineers.

Monica was highly educated: she studied in Paris and Hamburg in the 1920s, before joining the Wolf Safety Lamp Company as secretary to the founder, her father, William Maurice. There, according to *The Woman Engineer*, she studied the techniques of electric mine lamp design, the manufacture of alkaline storage batteries, the methods of laying out colliery lamprooms and maintaining the efficient running order of installations.

During this time, Monica also trained as an apprentice engineer in Germany with the world's largest and most celebrated firm of mine lamp makers. Two years later, she was made a director with responsibility for the operation of lamps at collieries across the UK. She also played an active role in establishing an international standard of lighting for mines.

Monica had plans drawn up for a 'new model factory' and designed new machinery, based on the suggestions of an employee who had changed the way that battery electrodes were made. In 1936, she organised the 14th annual WES conference in Sheffield, and members visited and toured her new model factory.

During the Second World War, Monica served on the British Standards Committee, investigating wartime standardisation of mine lamp bulbs, personal safety and safety footwear.

Monica was a strong advocate for women in engineering, a keen motorist, a qualified pilot and practised advanced aerobatics for fun. Her wedding dress, which she designed herself and was, for the time, a daring red, is in the Victoria and Albert Museum. She was awarded an OBE by HM The Queen in 1975.

not benefit. The seven founders drew up a constitution for a society that would help women gain training, employment and acceptance in the world of engineering. The early members had diverse careers, spanning electricity, medicine, house-building and aeronautics.

Rachel Parsons was one of the first three women to study mechanical sciences at the University of Cambridge, although women could not graduate at the time. She campaigned for equal access to technical schools and colleges, and co-founded Atalanta Ltd, an all-women engineering company that produced machine models with Annette Ashberry, its Managing Director and another founder of WES. Parsons also set up Girl Guides groups in her area, teaching practical skills and community-mindedness.

Dame Caroline Haslett DBE was also one of WES's first members – she answered an advert for an organising secretary "with some experience of engineering". She went on to edit WES's journal, *The Woman Engineer*, and was later President of the society. She co-founded the Electrical Association for Women, an organisation that aimed to reduce women's domestic workload by encouraging the use of electricity. She became one of the most influential women in the first half of the 20th century, and even spoke alongside President Harry S Truman in front of the White House in her role as President of the International Federation of Business and Professional Women.

Other members included Dorothée Pullinger MBE, who managed 7,000 women munitions workers during the First World War, before becoming director of Galloway Motors, where she ran an innovative apprenticeship programme for women and built the first car engineered by, and for, women* ('An ingenious introduction to engineering', *Ingenia* 74).

In the mid-century, membership of WES continued to grow and attract women from a range of disciplines, from Dr Winifred Hackett, a computer pioneer, to metallurgists, nuclear engineers and the UK's first female railway engineer, among many others.

TODAY

WES is a charity and a professional network. Today, its work is needed more than ever – according to the Office for National Statistics, only 11% of professional engineers in the UK are women, one of the lowest rates in Europe. In technical roles, women's participation is even lower. The society continues to raise the profile of female engineers and shows girls that they can become engineers. It works to celebrate the present, remember the past and transform the future. WES runs STEM Returners, a programme for women returning to STEM after a career break, provides mentors for women working in STEM through MentorSet, runs the Top 50 Women in Engineering Awards each year, and runs International Women in Engineering Day every June [see *Marking the centenary*]. WES wants to see people embrace the idea that engineering is for everyone, by ensuring that while the world continues to change and develop, it opens opportunities to all, regardless of who they are.

A film about Dorothée Pullinger's life can be found at* ***https://bit.ly/2UnKXjG*

The Women's Engineering Society's 1923 conference © IET Archives

MARKING THE CENTENARY

Wikithons

Throughout its centenary year, WES is running Wikithons and inviting members of the public to help improve the gender balance of Wikipedia. Currently, women are underrepresented on Wikipedia in terms of both the number of women editors (less than 20%) and the number and length of articles written about them. Wikipedia is the fifth most visited website in the world, so the Wikithons help to train women to edit Wikipedia in the hopes of improving the gender balance of the site.

At a recent WES Wikithon, five new articles were published and 19 articles were improved. The volunteer editors made 61 edits that resulted in over 4,000 words being added to Wikipedia and the edited and new pages were viewed 750 times in the first week. The new articles included Monica Maurice OBE, an industrialist and the first, and for 40 years the only, woman member of the Association of Mining Electrical Engineers (see opposite); and Madeleine Nobbs, a building services engineer who was responsible for the re-provision of services to the Old Bailey in London after the Second World War, and was a President of WES.

WES Centenary Trail

The WES Centenary Trail is commemorating women engineers though an interactive online map (launching in June) that records and shares the history of WES and its members with the public. Combined with the new and improved Wikipedia entries, it hopes to build an audience for local and women's history, based on research into WES and other archives. Only 17.7% of biographies written in English are about women and a very small number of those entries are about women engineers. Wikipedia entries will be pulled through to populate the map with up to 200 pins to explore by the end of the project. The stories will be shared through local events, displays and social media.

Research for the WES Centenary Trail revealed the forgotten story of Jeanie Dicks, who undertook the electrification of Winchester Cathedral in 1934. At the time, the press was very interested in the novelty of a women taking on such a role and, as a result of the research, Jeanie now has her own Wikipedia page.

The Centenary Trail is funded by a grant from the National Lottery Heritage Fund. To find out more, visit **www.wes.org.uk/WESCentenaryTrail**, @WESCentenary on Twitter or @wes_centenary on Instagram.

International Women in Engineering Day

On 23 June, the sixth International Women in Engineering Day (INWED) will take place, a day that increases the profile of women in engineering. This year, it has a theme of 'Transform the future' and WES is encouraging participants around the world to demonstrate how they are transforming the future by encouraging more diversity in engineering. The celebrations will also include the announcement of the annual Top 50 Women in Engineering, which this year will focus on current and former apprentices.

INWED events have been planned around the world; from Madrid, to Canada and Panama. A group of female engineers from the University of Glasgow are working on a collaborative project with the University of Rwanda. In June, the engineers are travelling to Rwanda to deliver STEM workshops to the local community in Kigali to encourage local young people into careers in STEM.

WES encourages supporters to use its official hashtags #INWED19 and #TransformTheFuture to help raise the profile of women in engineering and highlight the career opportunities available.

The technology that allows people with diabetes to monitor their blood-sugar levels is well known, and now advances in technology are making this process and treatment easier © Photo Mix/Pixabay

ENGINEERING AN ARTIFICIAL PANCREAS

More than 4.7 million people in the UK have diabetes, with around a tenth of these having type 1. Diabetes can lead to serious health problems and the NHS spends £10 billion a year on diabetes treatments – 10% of its entire budget. Writer Geoff Watts spoke to Dr Julian Shapley from Cellnovo and Dr Pantelis Georgiou from Imperial College London about developments in technology that are making diabetes treatment more efficient.

TYPE 1 DIABETES

The patients with diabetes who need regular infusions of insulin are predominantly in the category referred to as type 1. This is caused by the body's immune system attacking and destroying the cells in the pancreas that produce insulin. The amount of sugar in the blood increases following a meal and a lack of insulin allows it to rise beyond the safe level. Prolonged periods of high blood sugar put type 1 diabetics at risk of heart disease, kidney failure, blindness and lower limb amputations. Regular infusions of insulin avoid this, but they must be administered with caution as an excess of insulin in the blood leads to low blood sugar (hypoglycaemia) and consequent unconsciousness: commonly described as a 'hypo'. Tight control of blood-sugar levels in both directions is therefore essential.

Type 1 diabetes is caused when the pancreas, a gland located behind the stomach, fails to make sufficient insulin, the hormone that controls the amount of sugar in the blood. The remedy is clear, at least in principle: replace the missing insulin. In practice this can be done with insulin injections, but technology has already moved beyond that. Years of technological development have produced ever-improving methods of monitoring blood sugar and increasingly sophisticated pumps for infusing the missing hormone. The ultimate aim has been to create an artificial pancreas that can monitor blood sugar and infuse insulin by itself, at the right time, and in the correct amount.

Although it may be appealing, the term artificial pancreas is misleading. It suggests either a large machine similar to an artificial kidney, or a smaller device, such as a pacemaker or artificial heart valve, that can sit inside the body. The artificial pancreas, as currently conceived, would be neither. Its components – a continuous glucose monitor (CGM) linked to an algorithm-controlled insulin pump – are relatively small, but are still worn outside the body.

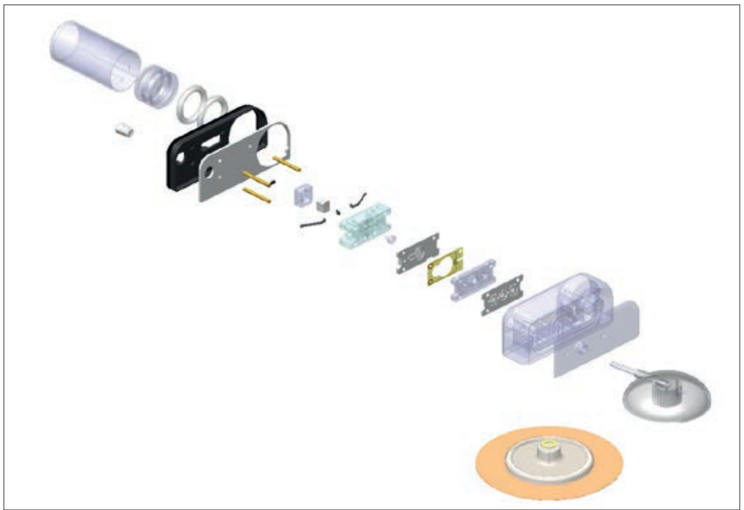
The individual components, the monitors and pumps, are already commercially available and current technology has much to offer. Pumps and monitors are making diabetes easier to manage with better results. However, doctors and medical engineers will not be satisfied until they can replicate the body's own control of its blood sugar exactly, for 24 hours every day, without any intervention by the patient.

This development will have been a century in the making. The first successful use of injected insulin for type 1 diabetes was in 1922. The early 1980s saw the first simple instruments for monitoring blood glucose at home, but it was not until late 1990s that technical advances enabled diabetic people to monitor their own blood levels continuously, and to take appropriate action. However, long before this scientists had recognised that, in principle, a CGM coupled with a pump could detect changes in blood sugar and respond automatically, 'closing the loop' as it's known in the trade.

CONVENTIONAL AND INNOVATIVE PUMPS

The first requirement of any blood-sugar control system is a means of infusing insulin into the body at the correct rate. There are many different designs of pump on the diabetes market, most of which rely on the same principle: a screw drive that advances a piston through the barrel of a syringe. That said, the most recent and radical innovation in this field has arisen from abandoning the conventional screw drive.

Dr Julian Shapley, a biochemist and microengineer who has spent time working for NASA, has developed a new kind of pump for delivering very small quantities of liquid. Dr Shapley originally designed his device for laboratory use, but re-engineered it when he realised that there



A breakdown of the components that make up Dr Shapley's insulin cartridge

Dr Shapley's wearable insulin pump attaches to a person's skin and allows them to monitor their levels via a smartphone

was a need for new pumps for the slow, controlled delivery of medicinal drugs.

Dr Shapley's pump relies on the way that wax behaves when it melts. Wax goes from solid to liquid when heated to about 60ºC and during the process its volume increases by 20%. That expansion is enough to drive a small pump. In his system, 21 microlitres (a microlitre is one millionth of a litre) of wax sit in a tiny square delivery chamber, with a flexible silicone membrane on one side. A piston shaft inside a barrel filled with insulin is on the other side of the membrane chamber. A diode embedded within the wax provides the heat needed to melt it. As the wax melts, the membrane bulges and pushes the piston forward in its barrel, expelling a small quantity of insulin into a delivery tube and into a needle through the patient's skin. As the wax cools, the piston retreats, drawing fresh insulin into its barrel. This insulin is stored in a reservoir that holds enough for several days. To control the flow of insulin from the reservoir in and out of the delivery chamber, Dr Shapley devised a novel pair of microfluidic one-way valves. A predetermined rise of pressure within the chamber closes the entrance valve and opens the exit valve; a fall does the opposite. Each complete forward movement of the piston delivers 0.5 microlitres of insulin.

To monitor the exact amount of insulin being delivered, the system incorporates a patented method of measuring the forward movement of a second, spring-driven piston that maintains the pressure in the insulin reservoir. A radial capacitor detects submicron movements of this piston and converts this piston's movement into a reading of the true amount of insulin leaving the reservoir and entering the patient's blood, which is displayed on the instrument's control panel. The insulin reservoir, along with the pump and needle, form an integrated, disposable device that is replaced every three days.

CONTINUOUS MONITORING

The technology for continuously monitoring a patient's glucose is well established and reliable. Self-testing originally used a spot of blood taken from a finger prick and dabbed on to a paper strip that the patient then inserted into a small handheld instrument. These mostly use an electrochemical cell primed with an enzyme such as glucose oxidase or glucose dehydrogenase, which, in the presence of glucose, generates a current proportionate to the concentration of glucose in the blood sample.

Most CGM devices use similar chemistry, but incorporated into a device with a needle-like sensor that penetrates the skin, and remains in situ. This sensor takes glucose readings every five minutes and transmits them wirelessly to a monitor. This automatically instructs the pump to infuse insulin at the rate required to maintain a basal level of activity (continuous supply) in the body's metabolism. The monitor also allows patients to read their blood-glucose level. They can then use controls on the monitor to begin infusing an additional amount of insulin, which is calculated to cope with any meal they are about to eat. The system will also alert them if, for some reason, their blood-sugar level leaves a predetermined range.

Overnight and for much of the day, these systems – some on the market, others still in clinical trials – routinely oversee the patients' disorder, giving them peace of mind and freeing them to attend to other matters. This is a valuable achievement, but not the end of the story. The next generation of diabetes control is now undergoing clinical trials.

ALGORITHMS GALORE

At first encounter, the exact control of blood sugar might appear to be a straightforward task of a kind long familiar to engineers. You eat a meal, your blood level sugar rises, the pancreas senses this and responds by producing the amount of insulin needed to restore the level to normal. Why have engineers found it difficult to develop algorithms that accurately mimic this control loop?

The first complication lies in the location of the glucose sensor. While the pancreas responds to glucose in the blood itself, CGM devices measure the sugar level in the fluid that permeates the tissues. There is a delay of around 10 to 15 minutes before the sugar concentration in this tissue fluid equals that in the blood. Moreover, the effects of an infusion of insulin are not immediate; there is a lag of up to an hour before the hormone takes effect and the blood sugar begins to fall. If an artificial delivery system fails to take account of this time lag, and goes on pumping out insulin, it will drive the blood sugar to dangerously low levels, causing the patient to suffer a hypo.

Another difficulty is the inherent complexity of the body's own control system, which uses not one hormone but two. Besides insulin, which drives down the blood-sugar level, the pancreas produces glucagon, another hormone that opposes insulin and increases blood sugar. The actual amount of sugar in the blood is a product of the interplay between these two hormones. Finally, there is natural variation. Different people respond differently to a quantity of insulin, so any algorithm must take account of the rate of change of the blood glucose reading in any one individual.

The bio-inspired artificial pancreas developed by Dr Pantelis Georgiou and researchers at Imperial College London links to wearable technology to capture lifestyle information and improve blood glucose control in diabetes

Engineers have been struggling for years to develop algorithms that take account of all these factors. The most advanced currently on the market can be relied on to take charge of insulin infusion overnight when the body's physiology is relatively stable, with no sudden food intake or bursts of physical activity. But during the day these systems still require users to forewarn them of a meal by pressing buttons on the monitor. Without this human intervention, any response to a sudden sugar load would be too slow to avoid the blood glucose level moving well outside the safe range.

MONITORING INTENTIONS

With a variety of satisfactory monitors and pumps available, the focus of engineers working on insulin control is now on improved algorithms. Dr Pantelis Georgiou and colleagues at Imperial College London's Bio-inspired Metabolic Technology Laboratory went back to basic cell biology in their research. They formulated an algorithm following a close examination of the behaviour of the cells in the pancreas that produce insulin. This resulted in what they describe as the world's first bio-inspired artificial pancreas, which is now undergoing clinical trials.

In common with others, their ambition is to achieve a closed-loop system that requires no human intervention: no button pressing to preannounce the

As we salivate in anticipation of a coming meal, we also start to make extra insulin. This is mediated by nerve signals from brain to pancreas that preannounce the arrival of food. Any artificial system needs to imitate this, so the next step towards a completely closed loop is to devise an insulin delivery system that can respond to our intention to eat

imminent intake of food. As we salivate in anticipation of a coming meal, we also start to make extra insulin. This is mediated by nerve signals from brain to pancreas that preannounce the arrival of food. Any artificial system needs to imitate this, so the next step towards a completely closed loop is to devise an insulin delivery system that can respond to our intention to eat. The researchers at Imperial College London believe that they can isolate a brain signal that correlates with this intention.

Detecting such a signal, and using it to trigger an anticipatory infusion of insulin, would be the most sophisticated advance yet in mimicking the body's own arrangements. If it succeeds, diabetics of the future might need one further component in their artificial pancreas, a brain electrode. The system might also use artificial intelligence to build profiles of the individuals using it: when they were most likely to eat and how much; and when they regularly exercised and might therefore need more blood sugar.

All this is for the future. Currently, many people with diabetes have yet to enjoy the benefits of the present generation technology, which already promises a reduced likelihood of the life-changing consequences of poorly controlled diabetes.

DIY THERAPY

Frustrated by what they see as the medical device industry's unduly slow progress in closing the loop, an increasing number of people with type 1 diabetes have taken a do-it-yourself approach to the task. To develop safe and satisfactory glucose monitors and pumps would be well beyond the skill of amateurs, but they have no need to do so. Existing devices can be made to suit their purpose. Devising the third component, the control system, certainly requires software engineering know-how, but it needs no equipment other than a suitably modified mobile phone.

The first people to try their hand at DIY loop closure were individuals with the computer engineering skills required to design their own algorithms. By hacking into the control systems of monitors and pumps they could apply new algorithms that, if so chosen, could be fully automated. They have since shared their knowledge on the internet, and even users with no computer skills have succeeded in following the instructions and downloading the necessary software.

The required information is all open access and, so long as these groups avoid offering medical advice and make no charges, they are not subject to standards, guidelines or official regulation. The hazards of this are self-evident, but the flexibility of the DIY brigade does confer obvious advantages in trying out new control arrangements. These amateurs may be taking risks, but are probably acting as a helpful spur to the industry.

BIOGRAPHY

Dr Julian Shapley is Founder and Chief Scientific Officer of Cellnovo, creative and technical lead behind its Mobile Diabetes Management System and inventor of its core pump technology. He is a multidisciplinary scientist and engineer focused on miniaturised systems for the pharmaceutical industry. His experience includes postdoctoral research on laboratory-on-a-chip technologies for healthcare, space and military research.

Dr Pantelis Georgiou is a Reader in the Department of Electrical and Electronic Engineering at Imperial College London and Head of the Bio-Inspired Metabolic Technology Laboratory in the Centre for Bio-Inspired Technology. In 2013, he received the Institution of Engineering and Technology's Mike Sergeant Award for outstanding contribution to engineering in 2013 and in 2017 was awarded the IEEE Sensors Council Technical Achievement award.

WHEELCHAIRS THAT ACCESS ALL AREAS

Trekinetic has engineered a wheelchair that gives users greater accessibility to many different terrains. The large front wheels allow users to push forwards rather than downwards, giving a better push propulsion over obstacles and soft ground © Trekinetic

Surprised by how little change there had been in wheelchair development over the years, former toolmaker Mike Spindle challenged himself to design and build a high-tech, lightweight wheelchair that could be created bespoke for each user. He spoke to Dominic Joyeux about the evolution of his game-changing design.

Twenty years ago, Mike Spindle's press toolmaking company was producing prototype components and precision tooling for Formula 1 teams at the cutting edge of their sport. He was running a business that was extremely busy from Friday to Sunday during the racing season and was looking for other work to occupy his workforce and high-quality CNC (computer numerical control) machining centre. While in an airport waiting lounge, Spindle saw a wheelchair that would transform his business and test his creative abilities to their limit.

The wheelchair was a standard one that had been sprayed metallic purple to make it stand out from the crowd and its owner was a young, stylishly dressed man. What Spindle saw was a disconnect between the man and his vehicle, modern versus old school. He says: "I thought, is that it? Is that the best they can do to update the chair, spray it purple!"

When looking at the wheelchair, Spindle saw a chair on a metal chassis, similar to a vintage car. He thought that a monocoque chassis, which is integral with the body of the structure as used in motorsport and most modern cars, would provide better stiffness and weight advantage. He also looked at the wheels and thought that having big wheels at the front rather than the back would expend less energy

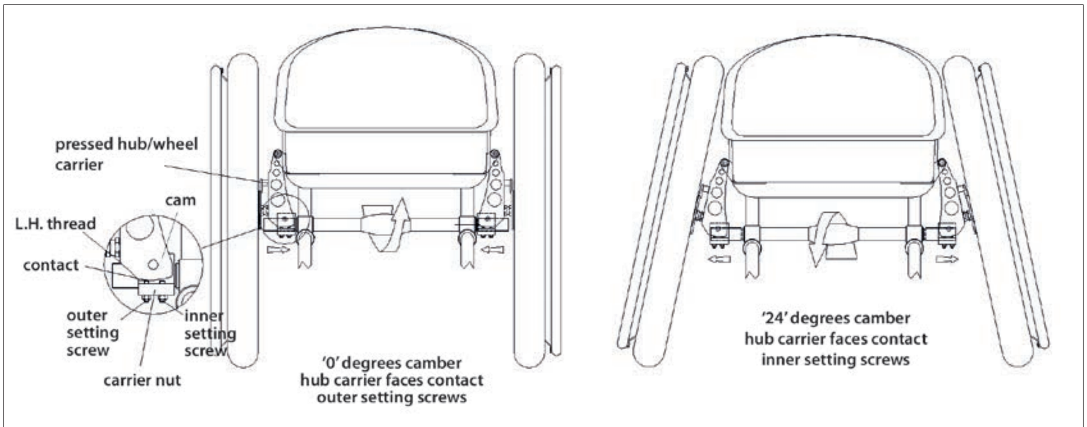
With these initial thoughts he started sketching designs on his holiday flight. His mission was to create a modern, more capable wheelchair that would be super-light and accommodate people with a range of disabilities, weights and ages. He wanted the chair to be suitable for both outdoor and indoor use and that any adaptations could be done by the owner without the need for tools or expertise. He set himself the extra challenge of designing the new chair himself without looking at how other wheelchairs, manual or powered, were made or had been developed.

The journey to reinvent the wheelchair was not straightforward. There were setbacks and complicated engineering hurdles that Spindle needed to overcome. Eventually, six years, 14 prototypes and with two worldwide patents in the application stage (later granted), in 2006, he launched a wheelchair that is tailored to each customer's personal needs using a standardised list of modular options. It is light years away from conventional wheelchairs and his company, Trekinetic, has won many awards for the chair design. It arguably creates the lightest powered wheelchairs on the market with the added bonus that all its chairs can be easily disassembled and fit into a standard, unadapted car.

STANDARD WHEELCHAIRS

Wheelchair design has improved only incrementally since the 1930s. Sporting wheelchairs have advanced somewhat but the vast majority of the UK's

VARICAM



Diagrams show the mechanism that enables users to reangle their wheelchair's wheel © Trekinetic

The aim of the Varicam innovation was to allow owners to splay the wheels of their chair via right-hand and left-hand screw threads situated under the seat and for it to lock at either end of its travel. There are four pivot points in the system that form a trapezium. At the top, there are two anchoring brackets attaching the seat to the two wheel hubs. At the bottom, the two pivot points are where brackets attach to the shaft, within which are a pair of hardened, steel-top locking screws that limit the movement of the trapezium at each extreme.

Without restraint, the trapezium would swing freely so Spindle created a curved cam that is rotated by adjusting the screw thread. The key design innovation was in shaping the cam so that it would allow enough travel when the adjusting screw thread was turned by hand, but also shaped to engage fully with the locking screws at each end of its travel.

When the adjusting screw is turned one way, the wheels are pulled upright to a wheelbase of 71 centimetres and form a 90° angle within the trapezium, the cam hits the outer locking screws (see diagram) and a rigid self-locking framework is achieved. This is the indoor setting that allows the wheelchair to be narrow enough to pass through door frames.

Fifteen seconds of turning the screw thread in the opposite direction will make the cam hit the inner locking screws, thus activating the friction lock again. This will lengthen the distance between the wheels to their 86 centimetre maximum – the outdoor setting. *Eureka* was so intrigued by this invention that it was featured as one of the magazine's famous 'Coffee Time Challenges' for readers.

1.2 million wheelchair users are sitting in chairs that were originated by US engineers 80 years ago. Everest & Jennings was the first company to mass-produce wheelchairs. One of its founders, Herbert Everest, had been injured in a mining accident and resented the bulky, rigid wheelchairs that were difficult to push. His friend, Harry Jennings, came up with a tubular-framed, lightweight, pliable chair with an X-frame in the middle that could fold and be placed in a car. Decades later came the innovation that allowed wheels to be removed by simply pressing a quick release pin – called a pip pin. The result is, pretty much, the model that we see today.

The four-wheel design, with two large ones at the back and two castors at the front, works well for most users but does have its limitations. It is 'tippy', meaning that the chair tilts backwards quite easily. The two small wheels at the front are impractical on gravel, beaches, or snow: they easily twist out of line, are pushed aside by small obstacles and sink into soft ground. Lastly, pushing the back wheels is inefficient and the movement of pushing downward causes users to lift out of the chair and also dip their heads down.

Spindle decided to bring the large wheels to the front so that the head remains upright and the arms are pushing forwards. This increases the push efficiency by around 30% and generates more power because the user is pushed against the back of the chair, instead of up in the air – for example, weightlifters can press much more weight on their back than they can standing straight without support. Having wheels at the front also means that the wheelchair can go through most soft ground and over obstacles. It can transform lives by enabling people to go across difficult terrain, such as countryside or a beach, without needing someone to push or drag them out of trouble.

Spindle saw an added advantage in being able to vary the wheels' angle (camber) and splaying them out. By letting out the two 60-centimetre-tall wheels by eight degrees, he could extend the distance between them. The negative camber improves grip when going around corners by transmitting forces through the negative plane of the tyre, while a wider wheelbase helps the wheelchair counter the risk of tipping over at speed. There were a dozen different engineering solutions available to vary the camber, but finding one that involved no tools, that non-technical users or carers could operate, and that could lock the wheels in their various extensions in a way that was quick and failsafe, required ingenuity. It also generated the wheelchair's first patent [see *Varicam*].

BEING DIFFERENT

Perhaps the most striking difference when looking at the Trekinetic wheelchair and what existed before is the monocoque (integrated) set-up. The chair is built around a carbon fibre seat that is moulded to the shape of the user so that the right-angle shape of a standard chair becomes curved, changing the pressure-loading and making it more comfortable. All the other main components are attached to this bucket seat via moulding during fittings.

The fact that the rear wheel is a small castor is another obvious difference, and at the early design stage this caused Mike Spindle one of his biggest headaches as the single castor at the back gave poor directional stability. At the front of a standard chair, two small castors run parallel to each other to maintain the trajectory set by the big rear wheels. However, at the back of a three-wheel set-up the castor is hypersensitive to direction change and would rather spin than go straight – rather like a rogue supermarket trolley wheel that fishtails uncontrollably.

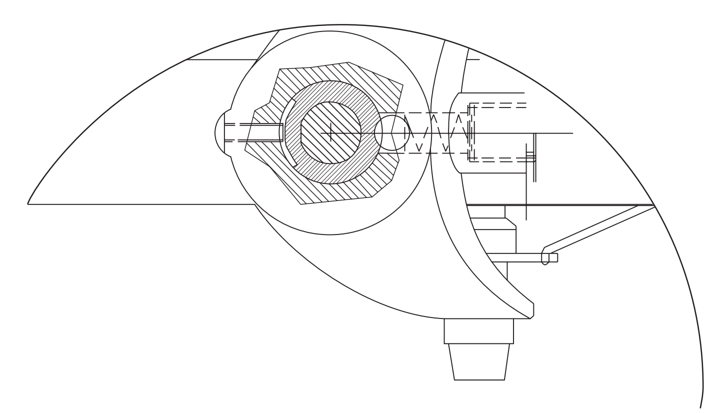
This problem set Spindle back around a year as he tried out various remedies. He wanted to maintain the three-wheel concept as it afforded a smaller turning circle and ensured that all wheels have contact with the ground at any one time. The deceptively simple solution is, in effect, a spring-loaded ball within a cam [see diagram].

Spindle had fashioned a way of effecting a gentle disengagement from the locked position into the rotating one. This innovation is not as vital for the powered version of the chair as the joystick will override this problem, but is crucial for the manual version.

LAST PIECES OF THE JIGSAW

One of the last major problems that Spindle had to solve during the prototype stage was regulating the chair user's weight distribution for slopes. Some people will have their seated bodyweight much nearer the front while those who are perhaps missing a leg will have more weight towards the back. During test runs down steep slopes, Spindle found that the wheelchair user risked falling out of a fixed position chair.

The solution came when Spindle sat and lowered the



When going forward, a ballbearing sits in a detent (a catch that prevents motion until released), which locks the wheel into a straight position. When enough lateral force is applied, the wheel can twist away from that detent position and steer. The twisting force necessary will be different for each person so an especially designed adjustable spring was made and the detent shaped to control the way the ball moves away from its locked position
© Trekinetic

positioning of his own office chair. When he lifted the lever of his gas-strut-supported chair, he activated the piston mechanism that expanded the nitrogen gas inside the chamber, which allowed him to alter its height. He contacted the specialist company Stabilus, which provided the gas unit, and then worked on incorporating an adjustable gas strut that would sit on top of the rear castor and support the seat at different adjustable and lockable angles when required.

As the Trekinetic chair has a short wheelbase the strut does not have to move much to enact a significant change in the centre of gravity; such as moving a load on a see-saw, the difference is magnified two-fold. The elegant mechanism that he invented enabled an adjustable but lockable system that could be operated by a non-engineer without an Allen key and secured Spindle another worldwide patent. It has the added benefit of acting as a shock absorber, which is helpful for wheelchair users with back or neuropathic pain.

Before launching the 'all-terrain' K2, the manual version of the Trekinetic wheelchair, Spindle added drum brakes. These had been used previously on some standard chairs as parking brakes but now a two-way lever system was added that meant they could be used on the move.

CUSTOMER RESPONSE

Spindle had spent hundreds of thousands of pounds on securing worldwide patents and had pushed himself to the limit both financially and creatively. He had reinvented the wheelchair and stripped it down as much as possible. He committed to the principle that if he added an extra feature to the chair he would not add another bracket to hang it on, but

PRODUCING A MONOCOQUE WHEELCHAIR

Most wheelchairs are four-wheel, metal-chassis-based designs made from standard wheelchair parts that are inexpensively produced at a large scale and used by most wheelchair manufacturers.

Almost none of these parts are designed for a monocoque wheelchair configuration. Therefore, the cost of moulds and bespoke parts and an unknown return on investment was a risk few companies were willing to take. Furthermore, the technology simply did not exist.

Spindle was aware that most modes of transport, such as cars, aeroplanes and boats, had already moved away from framework chassis configurations decades before and he was keen to update the wheelchair design. Monocoque is a popular choice with engineers as making one (normally the largest) component strong enough to carry all the other means that they can remove the entire weight and cost of the existing chassis.

Spindle designed a dual-carbon fibre skin that had all the strengthening features on the outside but a smooth inside, making the seat strong, comfortable, light and durable. Additionally, its fixings are precision moulded, which saves more weight and speeds up production.

The CAD-based design took many months, using thousands of pre-plotted data points. Spindle refers to it as "the world's worst 3D join-the-dots puzzle". The design was assisted by UK company Computool, which digitally massaged the final curves into place to perfect the original forms.

A significant issue was that it was impossible to know whether all the surfaces were smooth until the actual seat was manufactured. Fortunately, Computool's programme created a 3D model where surfaces could be rendered with a mirror finish that easily showed any lumps and bumps.

A significant benefit is that the seat is already internally moulded to a shape that mirrors the average human body. This means that minimal cushioning is needed to achieve comfort, although a range of dedicated pressure cushions is also available for more demanding medical applications. Spindle says that most users confirm the Trekinetic seat to be the most comfortable they have ever experienced. He adds: "This goes directly back to our Formula 1 roots. In a racing car, you mould the seat to the driver's body, so almost no cushioning is required. That is exactly what we have done here, but for a much wider audience."

would redesign the chassis to accommodate the new feature. The result was a sleek, super-lightweight and stylish chair.

The response and the rewards were immediate upon its launch. The BBC picked up on its originality and filmed a feature that was broadcast worldwide. He was complimented by architects, engineers and wheelchair users alike. He developed a stable of passionate component suppliers in 20 countries who believed in the product and kept their commissions to a minimum to help keep the price down.

The feedback also included requests for a powered version of the chair, which he placed on the market in 2014 and now accounts for four out of five sales [see *The Powered GTE*].

Because each wheelchair is bespoke the purchase cost is high compared to standard chairs, at around £4,000 for a manual and £10,000 for a powered one. Families often fundraise to obtain one while saving money by not having to buy a special adapted car or van to fit the wheelchairs in.

This year, Trekinetic will sell its thousandth wheelchair and its main publicity is word of mouth. All owners get stopped in the street by people struck by the futuristic design. The Science Museum has further helped raise the profile by having several K2s for visitor hire and main characters in both the 2016 film *Assassin's Creed* and the 2017 sci-fi film *MindGamers* used the chair.

Spindle says that he believes all wheelchair manufacturers will eventually adopt the monocoque template, as pioneered by Trekinetic. He is interested in pushing the new technology further and allowing the company to reach its full potential in mainstream markets. For him the most important element, apart from the kick of seeing new sales and new customers, is job satisfaction. He says: "When we were toolmakers and handed over to a car manufacturer an intricately designed fixture, gauge or tool that I had sweated blood and tears over, I often got in return a shrug and 'okay, thanks'. It was so frustrating. Whereas now, I can see the look on someone's face as they see how easy it is to push this chair, go anywhere and make things happen, sometimes for the first time in their lives!"

BIOGRAPHY

Mike Spindle is Managing Director of Trekinetic. He started his career as an apprentice toolmaker and was one of the youngest planning engineers at Zenith Carburettor Company, before becoming Chief Press Tool Designer. Mike then went on to own a toolmaking company, which designed and produced complex 3D forms for UK car manufacturers.

THE POWERED GTE

Mike Spindle likens traditional powered wheelchairs to 'dentists' chairs on wheels'. Usually made of mild steel, some have two car batteries in them and weigh between 70 and 150 kilograms. Launched in 2014, Trekinetic's five-speed GTE weighs 35 kilograms and has all the features of the K2 manual chair complete with additional hub motors, power pack, battery control unit and a joystick.

Trekinetic's powered GTE wheelchair, which has just three components and can easily be folded to fit in the boot of most medium-sized cars © Trekinetic

When Spindle had worked on the manual chair there had not been compact enough motors nor small enough batteries to produce a lightweight powered chair. A decade later, he saw that Yamaha had the sort of motor he could assimilate into the Trekinetic design. By placing the hub motors into the wheels, he could spread the chair's weight. The GTE has three fitted components – the two wheels and monocoque seat – which each weigh just over 10 kilograms, and can be easily placed into the boot of most medium-sized cars.

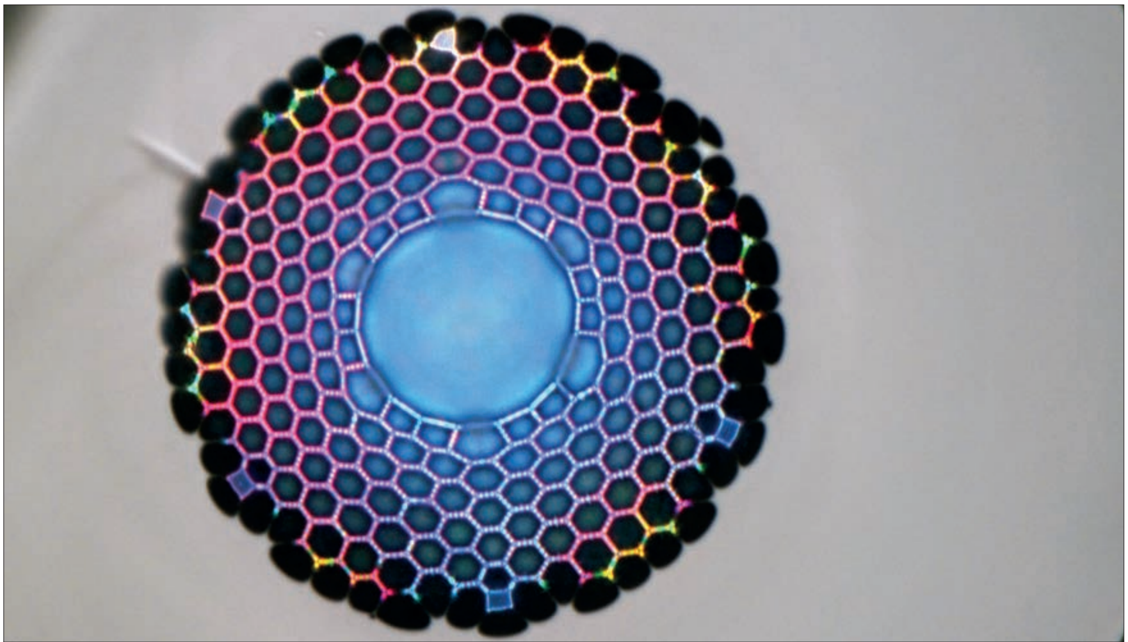
Trekinetic continues to push boundaries and a lot of its powered chairs have an add-on that makes it even more flexible. Spindle has sourced a body-formable vacuum seat liner that allows increased comfort for customers with conditions such a scoliosis. This innovation also allows young people to keep the same chair while growing into an adult. As a person's physical condition and posture changes, the owner can also simply pump up the bag into a different shape. This can save thousands of pounds compared to the traditional CNC-machined or moulded prescription seats that cannot be realistically altered.

The Hyperforma seat insert was originally invented by an occupational therapist and is filled with tiny polystyrene balls. Once the wheelchair user is in position, a hand pump is applied to a valve under the seat, air is expelled and the resulting vacuum makes the balls stay in their pre-set position © Trekinetic

Optical fibres incorporating a glass core are used in fibre-optic communications to transmit light and data over longer distances and higher bandwidths than electrical cables. A new generation of hollow core fibres is being developed to transmit data more efficiently © Joshua Kimsey/Pixabay

HOLLOWING OUT A FUTURE IN FIBRE OPTICS

Optical fibres are used in many settings, from computer networks to broadcasting and medicine, to carry information. The fibres are usually made up of strands of glass, each one thinner than human hair, but researchers have been working on fibres to transmit data that contain just air. Dr Matthew Partridge from the University of Southampton's Optoelectronics Research Centre discusses how these fibres were developed and the benefits they could have in communications.



A photonic bandgap type hollow core fibre with a large central core and honeycombed cladding
© Dr Seyed Reza Sandoghchi

Optical fibres are the foundation of the modern digital society. Since the first commercial cable was laid for the Dorset police in 1975, fibre optic communications has dominated telecommunications with estimates of around 325 million kilometres of fibre now being sold across the world every year.

The optical fibres in cables consist of thin strands of glass (around 125 micrometre diameter) surrounded by a thin polymer coating (around 250 micrometre diameter) and thicker plastic protective layers. These outer layers protect the fibres when they are in place and include, in some cases, metal armour to prevent external damage, for example from seabed disturbances and sea life.

However, the thin central glass strand is the important part for transmitting light. These solid glass strands transmit light via total internal reflection, which occurs at the interface between two materials of a differing refractive index. Light approaching the boundary from the higher-index region is totally reflected for all incident angles below a specific value (the critical angle). In the case of fibre optics any light that enters the fibre at or below this angle will be totally internally reflected along its length.

While ubiquitous, these solid-core fibres (essentially as first envisaged by the late Professor Sir Charles Kao KBE FREng FRS in the 1960s) have limitations. For example, the glass makes the light travel 30% slower than in air or a vacuum: this is how lenses bend rays of light and why solid fibres work at all.

Additionally, light travelling in solid glass leads to other unwanted effects, in particular so-called non-linear effects that cause the light to change its wavelength. In a system with closely packed wavelength channels these non-linear effects ultimately limit the achievable data rate of above 100 terabits per second.

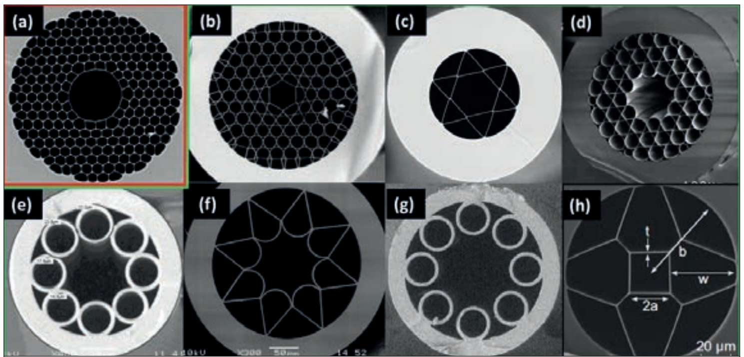
When looking at their use for higher power laser delivery, such as for cutting and welding metal, solid fibre can become damaged as the power of the light increases. A very small amount of light is absorbed and scattered by the silica; at kilowatts of power, this small amount causes damage to build up and can result in complete destruction of the fibre.

Given the limitations of existing solid glass fibres, it has been no surprise that many research groups have begun developing and deploying a new generation of optical fibres with air rather than glass cores. This new approach is called hollow core fibre optics.

HOLLOW CORES IN USE

Hollow core fibres are at the cutting edge of fibre optic technology currently in development and, as a technology, are in their infancy. However, this has not stopped their rollout into applications previously dominated by solid fibre optics.

One of the biggest fibre optic markets is the telecommunications industry and it is an area where innovative new fibre designs can have great impact. A significant amount of the research and development has focused on this market with the goal of developing a low transmission latency, high bandwidth, low-loss hollow core fibre. There have been considerable advances in fibre performance and data transmission experiments over recent years, with key demonstrations of these characteristics. Data rates of more than 50 terabits per second have already been transmitted over lengths of hollow core fibre, illustrating their potential for high



The range of hollow core fibre types available: a) Photonic band gap fibre; b to h) Various anti-resonant fibre designs (reproduced from Poletti F (2014) 'Nested antiresonant nodeless hollow core fiber', *Opt. Express 22*, 23807-23828)

capacity data communications. Development of a fibre with a signal attenuation below that of current solid silica fibres (0.2 decibels per kilometre (dB/km)) would allow for increased repeater spacings and improved system capacity. The lowest attenuation levels currently reported for a hollow core fibre are higher than the best solid silica fibres. However, recently the University of Southampton announced that it has produced a novel hollow core fibre design with a record low loss of 1.3 dB/km with clear scope for further improvement – at least theoretically to values well below 0.2 dB/km, which is the loss for silica fibres.

Beyond telecommunications, hollow core fibres are also being applied to various sensing and laser applications. They offer several advantages as sensors from their easily bespoke structure, tolerance of high powers and easily accessed internal gas paths. Early in 2018, GE Global Research announced the development of a hollow core sensor to detect leaks in oil pipelines. This sensor design consisted of using a solid core fibre to transmit laser light along the length of a pipeline. At several points the light from the solid core is coupled out and into a short section of open-ended hollow core fibre. This open-ended fibre is mounted inside sampling points in the pipeline where it can be purged and pumped with samples of surrounding gas. The light travelling through the hollow core can then be interrogated by spectroscopy (the absorption and emission of light) at the other end of the solid fibre. Methane has a clear spectroscopic fingerprint, which can then be used as an indicator of leaks.

The fibres' air-guiding properties also have an advantage in high-power laser delivery as the laser light is not travelling through glass but the hollow space in the core. An air-filled hollow core allows increases in power that can be delivered through a fibre, particularly for ultrashort pulses where the resulting high peak powers are a problem, caused by the dissipation of power into solid silica. In applications where ultra-high power is needed, it is possible to prepare a hollow core under vacuum rather than filled with air, allowing for an even greater level of power transmission for applications such as drilling and industrial materials processing.

HOW DO THEY WORK?

Hollow core fibres appear very similar to existing solid optical fibres; they are made from a thin strand of glass of around the same thickness. However, whereas solid fibre central cores are made from solid glass, a hollow core fibre has a core formed by microstructured hollow tubes.

In solid fibres the light is guided within the glass core. If this core was simply removed, then light launched into the fibre would not totally internally reflect and any light entering would refract out through the walls. In hollow core fibres the position and size of the surrounding microstructure provides conditions whereby the light is optically nudged by these thin membranes (as determined by a large number of variables including thickness, geometry and refractive index of the glass tubes) to keep it within the hollow central region. There are two main types of hollow core fibre microstructure that allow light to be guided this way.

Hollow core band gap fibre (or crystal fibre) surrounds the hollow core with a structure similar to honeycomb and the critical parts of this structure are the nodes or junctions between membranes. These nodes [see image above left] create a structure that will not allow certain wavelengths of light to pass, trapping them within the hollow core in the middle.

In the second type, hollow core anti-resonant fibre, the critical parts are the membranes themselves. When the thickness of these thin (around a micrometre or less) membranes is tuned correctly they act to reflect a wider range of wavelengths of light. There are many different structural types of anti-resonant fibre with a variety of benefits for bandwidth and loss. For example, the nested tubular variety is getting a lot of attention because of a recent record-breaking result of 1.3 dB/km for hollow core fibres (compared to the previous


A cane preform being prepared in the Optoelectronics Research Centre lab in the University of Southampton's £120 million cleanroom complex

record of 1.7 dB/km – a 25% improvement).

In both types the majority of the light travels in the centre of the hollow core and has very little interaction with the glass, making the light 'air guided' along the fibre (so called because of the air-filled core).

FIBRE OPTIC CORES

The production of hollow core fibre follows a similar approach to that of making solid core fibre, but with several additional controls over the final guiding structure. A typical hollow core fibre is produced in four stages: cane preform stacking, drawing the preform into a cane, construction of a fibre preform using cane and finally drawing this into fibre.

Cane preform stacking is where a large-scale version of the fibre is produced using capillary tubes. These typically have a diameter on the millimetre scale, and are about a metre in length. They are laid together in a capillary stack and inserted into a larger glass tube known as the stack jacket. A completed cane preform is typically around 25 millimetres in diameter and looks like a thick glass straw filled with intricate smaller glass straws.

Preparing a cane preform and positioning tubes into specific points to create the required spacing involves the use of various removable spacer rods, which hold each tube in the required position. This requires great precision and control as micrometre positioning errors can fatally effect the guiding properties.

The cane preform is then drawn down to form a cane that is similar to the final fibre but larger. The draw down process consists of pulling the cane preform through a furnace, which causes the glass to soften. As the preform is pulled it reduces to around 3 millimetres thick. During this stage the individual capillaries may be pressurised to allow for expansion or contraction of specific elements in the stack. This allows for some early control over the final fibre and splitting this in to two steps reduces the risk of problems such as movement, twisting or breakage of individual tubes.

Finally, the cane is inserted into a further glass jacket tube to form the final fibre preform, which is mounted at the top of a tower (known as the draw tower) that can be many floors tall. When the fibre preform is mounted, various elements are then pressurised using inert gas (either argon or nitrogen) and the fibre preform is attached to a gripping device, which can slowly move it up and down. During a fibre draw, the fibre preform is lowered into a furnace that heats it to around 1800°C. The first glass strands are manually pulled and attached to a tractor system that applies a constant controllable tension to the glass as it passes though the furnace.

As the fibre is pulled out of the furnace it passes through diameter monitoring equipment to allow feedback and variation of the draw speed, which in turn changes the diameter of the fibre produced. It also often passes through one or more coating dies, which uniformly coat the outside of the fibre with a protective polymer jacket. Finally, the fibre is spooled and ready for use. The intricacies and design of these fibres has only been possible through techniques learned from solid fibre drawing experience and the development of specialist glassware handling and drawing processes and facilities.

A fibre preform being fed into the furnace at the top of the fibre optic draw down at the Optoelectronics Research Centre fibre optic draw tower

SOLVING CHALLENGES

There are still several challenges to solve before wide-scale adoption can take place. The challenges include scaling up production of some of the more intricate designs and finding coatings that ensure that the fibres are as robust and flexible as their solid core counterparts. Previous work on coating and protection of solid fibres can help inform and facilitate rapid progress. The intricacies of the core designs are a unique problem to hollow core. Designing the stack layouts and then producing methodologies to achieve such layouts is one of the biggest challenges. However, as with solid core fibres these technical challenges are being solved alongside their commercial uptake.

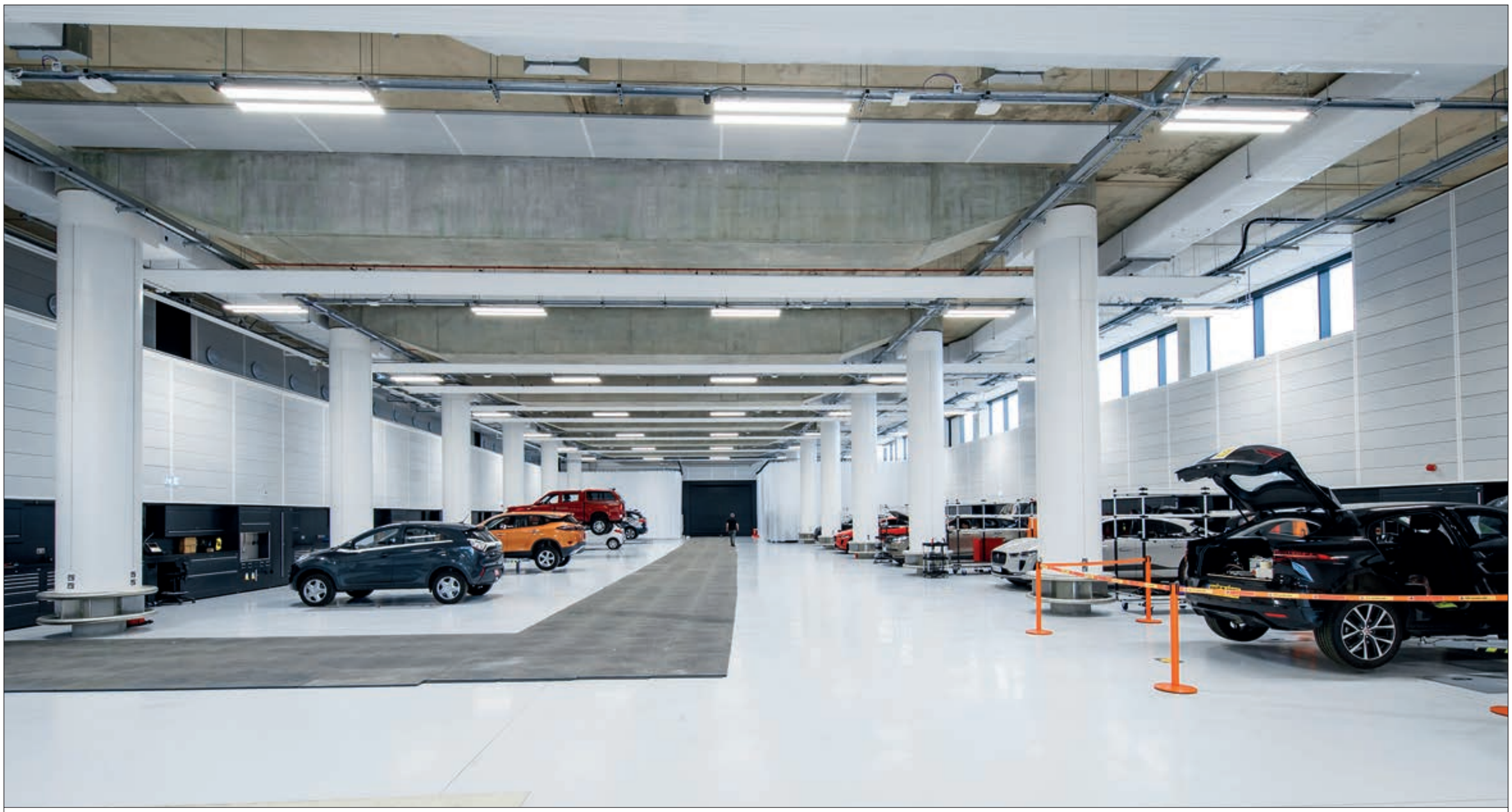
In the last year, two large-scale initiatives focused on hollow core fibre have been launched: the Engineering and Physical Sciences Research Council awarded the University of Southampton £6.1 million for its AirGuide Photonics project, which works with 32 collaborating companies. Second, Southampton-based spinout company Lumenisity Ltd has recently been formed to help commercialise the technology, with a focus on telecommunications and data communication applications.

Hollow core fibres are a technology that is poised to move from the lab into applications across the engineering industry. They are set to help solve some of the challenges and limitations of the current generation of solid silica fibre and expand fibre optics into new and exciting areas. While they are still evolving and developing, they are already showing significant promise. Anyone with an interest in telecommunications, 5G connectivity, high-power laser applications, fibre lasers and sensing should start looking at hollow core fibre as the future.

BIOGRAPHY

Dr Matthew Partridge is a Senior Research Fellow at the University of Southampton. His work focuses on the application of fibre optics to a wide range of real-world problems, from nuclear waste storage to medical diagnostics. In addition to his research, Matthew runs the popular research-focused blog and web comic ErrantScience.com.

A CENTRE FIT FOR FUTURE TRANSPORT



The engineering hall at the new National Automotive Innovation Centre at the University of Warwick. The centre will focus on research and development of future automotive technologies © Nick Dimbleby

As focus in the automotive industry turns to vehicles that are greener, safer and smarter, a new centre at the University of Warwick – a collaboration between WMG, Jaguar Land Rover and Tata Motors European Technical Centre – is addressing the challenges that are posed by their development. Professor David Mullins, Interim Head of WMG, discusses how the National Automotive Innovation Centre has been designed to be a collaborative research and education space with the facilities and scale so designers, engineers and researchers can come together and find a way forward for all of us.

Professor Dr Ralf Speth KBE FREng, Chief Executive of Jaguar Land Rover, says the centre's state-of-the-art facilities will offer a "critical mass of research capability in an environment designed to encourage cross-fertilisation of ideas on an unrivalled scale"

Mobility is fundamental to modern life. Our ability to move people and products from one place to another is essential to economic and societal success.

One of the UK government's Grand Challenge Missions in its industrial strategy is to become a leader in the development and manufacture of zero-emission vehicles. The ambition is for all new cars and vans to be effectively zero emissions by 2040, and not only greener, but also safer and smarter.

Developed as part of the industrial strategy, the Automotive Sector Deal has resulted in carmakers and their suppliers working together with government to support a significant increase in research and development (R&D): £225 million will be invested in automotive R&D from 2023 to 2026. This will focus on ultra-low and zero-emission cars and the next generation of connected and autonomous vehicles while improving the innovation of the UK supply chain.

These innovation areas are crucial if we are to reach what Jaguar Land Rover, Britain's largest car manufacturer, is calling 'Destination Zero' – zero-emission vehicles, zero congestion and zero accidents. Helping to address this challenge is the £150 million National Automotive Innovation Centre (NAIC) at the University of Warwick – the largest automotive research centre of its kind in Europe. A partnership between WMG, Jaguar Land Rover and Tata Motors European Technical Centre, it will focus on everything involved in the shift to autonomous, connected, electric and low-carbon vehicles. From looking at the design, testing and refining of batteries at scale and managing vehicle weights to compensate for the size of battery packs; to ensuring autonomous vehicles can identify and avoid danger and that connected vehicles are data-secure and error-free. Global automotive suppliers, such as Bosch and AVL, have already worked on these issues at the University of Warwick Science Park.

STATE OF THE ART

The 33,000-square-metre centre provides space for engineers, designers and academics to work together, from apprentices to senior managers. This joint investment has £15 million of support from the government's UK Research Partnership Investment Fund (UKRPIF), through Research England, to identity green, smart, safe solutions for future mobility.

There are already 700 designers, engineers and researchers located within the centre. It will eventually host 1,000 people working on a range of future vehicle and mobility projects. Design and engineering students and apprentices will also share the space and work alongside staff.

The centre features design studios; a vast engineering hall and laboratories for advanced powertrain, hybrid and chassis research; an immersive modelling and simulation suite; and an advanced propulsion research laboratory, all equipped with the latest technology such as engine dynamometers, virtual reality rooms and drive-in simulators. It has over 50 specialist areas, which include acoustic quiet facilities; noise, vibration and harshness testing equipment;

NAIC aims to encourage inspiration and collaboration on research projects between designers, engineers, manufacturers, academia, suppliers, customers and governments

and electrical development and high voltage laboratories.

To support the design modelling operations, NAIC has a three-axis milling machine to create the wooden structure (buck) that the clay models are constructed over, a paint shop consisting of three full-size vehicle paint booths and a wood mill, which will be used to make the buck.

RESEARCH

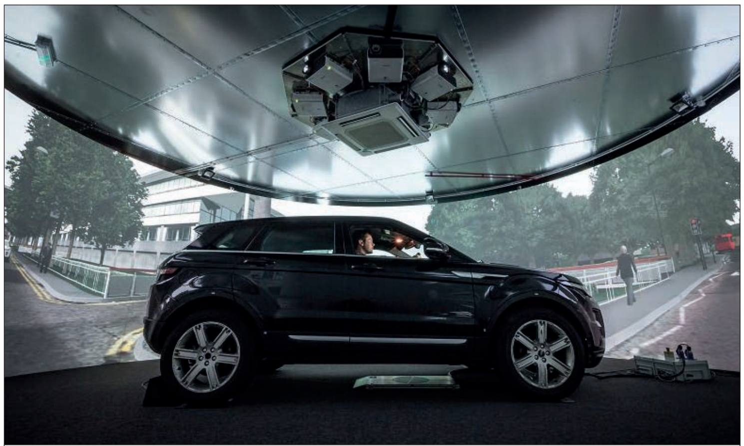
NAIC aims to encourage inspiration and collaboration on research projects between designers, engineers, manufacturers, academia, suppliers, customers and governments.

The Advanced Propulsion Research Laboratory at NAIC, which also benefits from UKRPIF support, is the UK's first complete and dedicated facility for the research, development and industrialisation of low-carbon automotive technologies in the UK. For these to be successful, researchers will need to develop propulsion systems that appeal to consumers and are profitable for manufacturers. Research will look at reducing the cost and improving the performance of electrified powertrains compared to conventional engines. To do this, engineers and academics will research ways to increase the integration of electrical and electronic components into system architectures; help suppliers scale up and manufacture parts in sufficient, cost-effective quantities; and ensure this is done while maintaining quality, performance and safety.

This research encompasses adapting internal combustion engines in the short term, alongside hybrid and electric systems, lightweight vehicle technology and advanced automotive control systems.

WMG's research team in advanced propulsion systems will address the technology needs that are critical to the future competitiveness of the automotive industry. These facilities will be available to manufacturers and suppliers so the whole supply chain can work together to make cars and commercial vehicles greener.

Key challenges include: energy storage and management; battery systems; power electronics; systems control and integration; lightweight materials; and fuels. This work will be done collaboratively and knowledge will be shared across the transport sector.



The 360° driving simulator allows testing of smart and connected vehicles in a safe, controlled immersive environment

One example of this collaborative approach is WMG's AMPLiFII (Automated Module-to-pack Pilot Line for Industrial Innovation) and AMPLiFII 2 projects, supported by the Advanced Propulsion Centre and Innovate UK. Both projects are developing battery systems for vehicles across a range of sectors including high-performance automotive, buses and off-highway vehicles. The low volume of very specialised battery packs needed for these sectors means that manufacturers have found it difficult to justify the high cost of developing electric vehicles.

Working closely with industry partners, Jaguar Land Rover, ADL, Ariel, Delta Motorsport, Potenza, Trackwise, HORIBA MIRA, and the University of Oxford, WMG's work has developed a scalable, modular pack centred around cylindrical cells. Looking initially at packs of 18,650 cells, the project has now entered its second stage – AMPLiFII 2 – and is now working with 21,700 cells.

This battery architecture supports both high-power and high-energy requirements, meaning that manufacturers will be able to aggregate demand for components and benefit from significant economies of scale.

The research will help create an electric vehicle supply chain that offers robust, low cost and quick-to-market mass production standards, while also informing the development of battery technologies for Jaguar Land Rover.

To reach 'Destination Zero', safer roads are needed as well as zero-emission vehicles. Engineers need to understand how vehicles communicate with each other and with the transport network, as well as how drivers interact with cars, giving them the right tools to drive safely. Testing these technologies on the road in real-world driving

Apprentices studying at the NAIC will have a real and immediate impact within the businesses they are placed with, as the courses include work on improving paintshops, refining aerodynamic features on vehicles and working with suppliers to reduce costs © Nick Dimbleby

situations is often complicated and potentially dangerous for early-stage development. It is also reliant on the production of costly physical prototypes.

To overcome this challenge, WMG created a drive-in, driver-in-the-loop, multi-axis, 360° cylindrical screen, high definition driving simulator – the world's first immersive, simulated environment for smart and connected vehicles. It fully reproduces wireless communications, putting a real car in an immersive virtual environment so that smart and connected vehicles can be tested and refined. It finds the problems that occur at the extreme and risk points for road safety and data security in a safe, controlled environment.

The next generation of the simulator, which is currently under construction in NAIC, will support the accelerated development and adoption of advanced technologies for next-generation vehicles. For example, research will be looking at how you can fool and confuse smart vehicles via their data sources and how they will deal with confusing or contradictory information.

The Midlands Future Mobility programme, where WMG works with Amey Consulting, AVL, Costain, Coventry University, MIRA, Transport West Midlands, and the Wireless Infrastructure Group, will also evaluate connected and autonomous vehicle technologies with support from the government's Centre for Connected and Autonomous Vehicles. These have been developed using simulation in NAIC, on test tracks and on roads in real-world driving situations. This will provide invaluable additional learning in development of the vehicles as commercially viable and desirable means of road transport.

ENGINEERING EDUCATION

The partners in NAIC are committed to delivering the skills to keep the UK globally competitive. The teaching facilities – such as workshops, collaborative learning spaces and a business incubator – support the education of tomorrow's engineers with degree apprentices studying in the centre and students from the WMG Academies for Young Engineers, university technical colleges where 14 to 19-year-olds work on real-world projects as part of their curriculum.

The new WMG Degree Apprenticeship Centre, which opens in September alongside the NAIC, will focus on apprenticeship courses for advanced engineering and manufacturing companies. It will provide training programmes up to master's degree level to 1,000 students each year. At undergraduate level these include engineering, applied engineering, digital technology solutions, and health, wellbeing, science and technology. At postgraduate level, they cover engineering business management, systems engineering and senior leadership.

While they study, the apprentices will be employed by companies such as Jaguar Land Rover, Airbus, Caterpillar, Aston Martin, GE and Lear. They will undertake their academic studies at the centre. All of the courses are tailored to meet the automotive industry's needs.

As they learn and work, the apprentices will benefit from NAIC's facilities, especially the state-of-the-art teaching workshop. Meanwhile all NAIC partners are developing curricula, including apprenticeships and lifelong learning, that will support emerging technologies in mobility at NAIC.

TRANSPORT IN FUTURE

The future of transport could well be one where zero-emission vehicles, public transport and self-driving pods form a single transport system, securely networked to each other and via digital platforms for maximum safety and minimal congestion.

People might drive – or be driven in – electrified, zero-emission vehicles, powered by an integrated smart-charging network using renewable and zero-emission energy.

These vehicles could be constructed with sustainable, self-repairing, stronger, lighter materials, which have been developed from technology advances in materials science, including natural fibres and recycled materials that reduce emissions in the production process.

Achieving greener, safer and smarter mobility requires partnership – between researchers, companies and government – and a workforce with the right skills, facilities and laboratories to find the answers together.

BIOGRAPHY

Professor David Mullins is Interim Head of WMG at the University of Warwick. He is involved in the design and implementation of WMG's research, education and knowledge transfer strategy, and has been responsible for the development of major WMG initiatives, including the NAIC. Before joining the university in 1997, he worked in UK Research Councils and was a regional coordinator for the ACME manufacturing directorate.

LORD BHATTACHARYYA

Professor Lord Kumar Bhattacharyya KT CBE FREng FRS, Regius Professor of Manufacturing, outside the centre that bears his name

The late Professor Lord Kumar Bhattacharyya KT CBE FREng FRS founded Warwick Manufacturing Group, now WMG, in 1980. For four decades, Lord Bhattacharyya led WMG, at the University of Warwick, on a singular mission: to combine academic excellence with industrial relevance, in both education and research.

WMG pioneered part-time modular courses relevant to real business needs, so staff could immediately contribute to their business while they learned. He saw engineering education as appropriate for all, offering teenagers the chance to become young engineers at WMG's two academies for 14 to 19-year-olds, right through to enabling experienced industrial engineers to innovate by earning research degrees

Lord Bhattacharyya saw innovation and collaboration as being at the heart of WMG. He led collaborative research partnerships on vehicle lightweighting, computer-aided design, powertrains and experiential engineering, each project with commercial partners and real-world impact.

The culmination of Lord Bhattacharyya's vision for Britain's automotive sector is brought to life in the NAIC, bringing together government, academia and business to address the great challenges of future mobility. As a tribute to his enduring vision, the research he championed will be conducted in the Lord Bhattacharyya Building.

ROYAL ACADEMY OF ENGINEERING
MACROBERT AWARD
50th ANNIVERSARY

50 YEARS OF ENGINEERING INNOVATION

Since 1969, the MacRobert Award has honoured the engineers behind the UK's most exciting engineering innovations. It is awarded annually for an outstanding example of engineering that has achieved commercial success and is of benefit to society, and seeks to demonstrate the importance of engineering and the contribution of engineers and scientists to national prosperity and international prestige. As the award celebrates its 50th anniversary, *Ingenia* looks back at some of the winners.

"For the last 50 years the MacRobert Award has celebrated groundbreaking engineering innovations that have established the UK as a global leader. Leading the judges for the MacRobert Award over the past five years, I have been privileged to see at first hand the engineering behind products that are changing our lives for the better." Dr Dame Sue Ion DBE FREng FRS, Chair of the judging panel

The MacRobert Award has recognised engineering achievements across the breadth of British engineering in the 50 years since it was first presented to Rolls-Royce for its Pegasus engine and to Freeman, Fox and Partners for the Severn Bridge.

The variety of the award's recipients reads like a 'who's who' of UK engineering expertise. The roll of honour has also proved to be an indicator of innovative advances in engineering. It all started in 1969 with a civil engineering achievement that heralded a new era of bridge building and the world's first short take-off and vertical landing aircraft. Rolls-Royce won a gold medal and its share of the prize for the Pegasus engine that powered the Harrier Jump Jet while Freeman, Fox and Partners picked up its share for the aerodynamic design of the Severn Bridge's deck.

Since then, the sheer diversity of the winning innovations has revealed how hard it can be to judge entries that range from sampling breath to diagnose diseases (last year's winner, Owlstone Medical) through superconducting magnets, catalytic converters, to a credit-card-sized computer that has revolutionised education, taking in wind power, robotic limbs and fibre optics along the way.

Originally founded by the MacRobert Trust, the award is now presented and run by the Royal Academy of Engineering, with support from the Worshipful Company of Engineers. An important task for the Academy is choosing judges for the award. At any one time, as laid down in the original 'Rules and Conditions', there are up to 10 judges, most of them fellows of the Academy. The current Chair is Dr Dame Sue Ion DBE FREng FRS – the first woman judge and chair.

The key to the award's success lies in the criteria that these judges apply when assessing entries. These criteria have changed over the years. The original remit was to reward "an outstanding contribution" made "by way of innovation in the fields of engineering or the other physical technologies or in the application of the physical sciences, which has enhanced or will enhance the national prestige and prosperity of the United Kingdom of Great Britain and Northern Ireland".

The original remit left the door open to entries that looked innovative in the first place, but then proved to be short-lived when it came to the marketplace. The first rule change was to include commercial success as a criterion. To reflect the way in which the Academy sees its own remit, the rules for judging entries for the MacRobert Award now hinge on three key issues: innovation, commercial success and benefit to society.

The MacRobert Award has grown to become the UK's leading prize for innovation in engineering. It has benefited from the beginning from the support and involvement of HRH Prince Philip, Duke of Edinburgh – the Academy's Senior Fellow. The award is now so well established that, to mark the 50th anniversary, the Royal Mail included three previous winners in a series of stamps that celebrate some of the achievements of British engineering from the past 50 years (see page 6). The Academy is also holding a reception at St James's Palace in July for past and present winners, finalists, judges and supporters. Later this year a photography exhibition will show the winners' innovations in a different light.

THE JUDGING PROCESS

The process begins with an invitation to companies to submit entries, by the end of January, that address the three key criteria: innovation; commercial success and benefit to society. The judging panel then selects a shortlist of six to eight candidates.

During March, two members of the judging panel visit each of the shortlisted organisations, with one member chosen for their expertise in the field. Guided by the visiting judges, the panel chooses the finalists. In May, the whole judging panel then visits all the finalists in turn, before choosing a winner.

The announcement of the winner of the MacRobert Award 2019 will be made at the Royal Academy of Engineering Annual Awards Dinner on Thursday 11 July 2019.

A BRIEF HISTORY OF MACROBERT AWARD WINNERS

1970

British Petroleum (BP)

Techniques enabling accurate surveying through permafrost in Alaska

Three BP geologists, led by Dr Peter Kent FRS, won the second MacRobert Award in 1970 for their role in driving BP's exploration of Northern Alaska, which enabled the discovery of the North Slope oil fields. This was the first MacRobert Award for BP, which is just one of two companies to have won three times. The second company is Rolls-Royce.

© British Petroleum

1979

© Post Office Telecommunications

Post Office Telecommunications

Prestel Viewdata software system

The 11th winner of the MacRobert Award in 1979 was Post Office Telecommunications for Prestel – the world's first viewdata service.

In the pre-internet days, Prestel was an early two-way system, with terminals connected to the telephone network. At its height in 1987 the service had over 75,000 terminals in the UK and overseas, increasing at 1,000 sets a month. The service finally closed in 1994.

This was the first time the MacRobert Award was given to an innovation in information technology.

1986

Oxford Instruments Group

Superconducting magnet systems for medical diagnostics

Oxford Instruments collected the 18th MacRobert Award for its research and commercialisation of superconducting magnet technology. The company developed a new generation of superconducting magnets that delivered a field strength and uniformity never achieved before. The technology gave the company an international lead in providing healthcare and research using nuclear magnetic resonance (NMR), a technology that continues to underpin the commercial activities of Oxford Instruments.

© Oxford Instruments Group

1992

© BP International

BP International

Advancing the application of hydraulic fracturing technology used in the exploitation of oil and gas reserves

There is no denying that hydraulic fracturing has changed the face of the energy industry. The technology won the 24th MacRobert Award despite the fact that Dr Tim Harper and Dr Paul Martins had to overcome initial scepticism within the industry when they set out to improve on existing methods of hydraulic fracturing.

Through extensive research and testing, Harper and Martins devised new approaches to fracturing and drilling, the biggest advancements in the field in 30 years, that significantly improved the flow of oil and gas and helped save oil firms hundreds of millions of pounds.

1993

ICI Klea

For the process and production technology for manufacturing the ozone-benign refrigerant KLEA 134a

ICI won the 25th MacRobert Award for a technology that addressed one of the key environmental issues of the day: depletion of the ozone layer caused by chlorofluorocarbons, refrigerant gases that were leaking into the atmosphere. Four engineers – including Rachel Spooncer FREng, the first woman to win the MacRobert Award – led the team that developed the hydrofluorocarbon KLEA 134a and a commercial production route for the new refrigerant in just five years.

© ICI Klea

Optos plc

The Optos scanning laser Panoramic 200(P200) ophthalmoscope has revolutionised eye care and the early detection of retinal defects with its ultra-wide retinal imagers

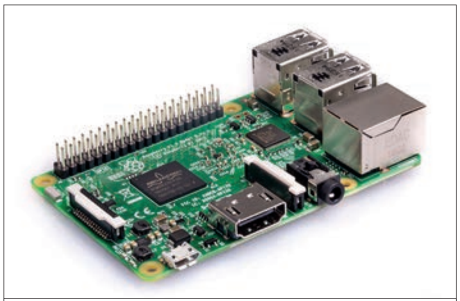
Douglas Anderson OBE FREng FRSE founded Optos in 1992 after his then five-year-old son lost sight in one eye due to late diagnosis of a retinal detachment. The P200 used low-powered lasers to create a 'virtual scanning point' inside the patient's eye. Proprietary software allowed the practitioner to capture, manipulate and enhance the image, enabling a detailed evaluation of the retina and producing a permanent clinical record of the examination.

© Optos plc

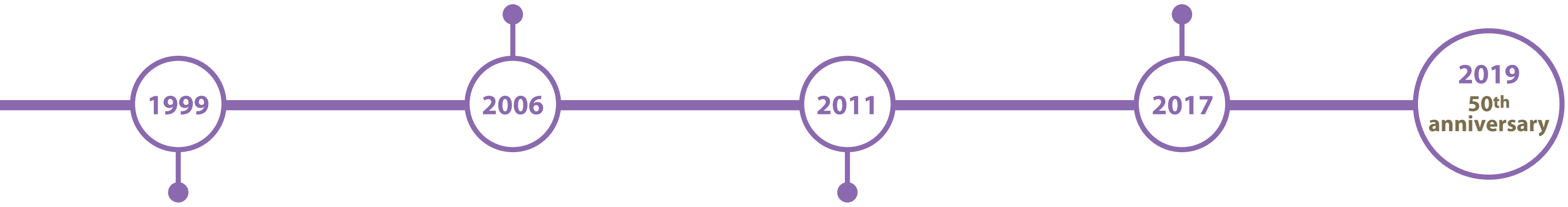
Raspberry Pi

A microcomputer the size of a credit card that set out to help increase the number of computer science applicants to the University of Cambridge

The Raspberry Pi started as an education aid but went on to create a new class of computer that has transformed how engineers design industrial control systems. As Dr Dame Sue Ion DBE FREng FRS, Chair of the MacRobert Award judging panel, said: "What sets Raspberry Pi apart is the sheer quality of the innovation, which has allowed the computer to be used far beyond its original purpose. By blending old and new technology with innovative systems engineering and circuit board design, the team has created a computer that is cheap, robust, small and flexible."



© Raspberry Pi Foundation



© Buro Happold

Buro Happold

For the roof structure of the Millennium Dome

At the time, the Millennium Dome, erected in Greenwich to host the Millennium Experience in 2000, was the biggest fabric building in the world but so lightweight that the structure weighed less than the air it contained. Supported by 12 steel masts, the dome was built as a set of modular components held together by 70 kilometres of cables.

Now known as The O2, the structure is visible from space as one of London's landmarks.

© Microsoft Research, Cambridge

Microsoft Research, Cambridge

Human motion capture in Kinect for Xbox 360

Five engineers from Microsoft Research in Cambridge won the MacRobert Award for their machine-learning work on the human motion capture in Kinect for the Xbox 360, allowing controller-free gaming.

The team applied machine learning to analyse depth images independently and to classify pixels in each image as belonging to one of 31 body parts. In the two months after its launch in November 2010, Kinect sold eight million devices, making it the fastest-selling consumer electronics device in history.

John Robinson CBE FREng, Chair of the MacRobert Award judging panel at the time, said: "Yet again, British engineers have solved a seemingly intractable problem that stumped the rest of the world – motion capture in real time has made Kinect hugely successful and what was originally developed as a game is now poised to revolutionise the way we use computers in the future."


Nick Rogers FREng

DRIVEN TO AN ELECTRIFYING FUTURE

Thanks to his own career progress from apprentice to Executive Director of Product Engineering at Jaguar Land Rover, Nick Rogers FREng takes a special interest in the car company's young engineers. He talked to Michael Kenward OBE about the challenge of simultaneously developing new car models, with the added complication of managing the transition to electric vehicles.

Engineers at Jaguar Land Rover (JLR) will tell you that, thanks to concerns about climate change, air pollution and the rise of self-driving cars, the automotive industry will change more over the next five years than it did in the previous half century. Nick Rogers FREng sees these issues as opportunities for the 10,000 or so engineers that he leads as Executive Director of Product Engineering at JLR. Then again, Rogers has already seen plenty of change in his 35 years in the industry. When he started work as an apprentice technician at British Leyland's (BL) Cowley works near Oxford, electronics was just beginning to make inroads into the car business.

Ironically, an electrical issue nearly killed Rogers's career as a carmaker before it had started. A careers tutor at school encouraged Rogers to apply for a job at BL, where his grandfather had worked. Rogers's experience maintaining tractors and mending other farm machinery at his family's dairy farm had prepared him well for an apprenticeship. BL offered him a job as a technical apprentice but the obligatory medical test confirmed what Rogers had said all along: he was colour blind. He wanted to work as an electrical engineer but couldn't tell the difference between the coloured wires. Rogers went home despondent and jobless, but this mood didn't last long. The next morning, he was out on the farm when his father told him that BL wanted him to interview for body engineering. They offered him a job although he confessed to not knowing what body engineering was about.

Now, as Executive Director of Product Engineering at JLR, Rogers leads a team of 10,000 engineers producing new models: everything from all-terrain Land Rovers to Jaguars, including Jaguar's first all-electric car, the Jaguar I-PACE, an instant hit. Body engineering is still a part of the remit, but is now accompanied by electrical and electronic engineering.

Rogers at the Land Rover 4x4 in Schools Technology Challenge, an annual competition led by Jaguar Land Rover to inspire, inform and develop the next generation of engineers © Jaguar Land Rover

ENGINEERS OF THE FUTURE

Rogers shies away from talking about himself and turns the interview into a seminar on engineering with a handful of JLR's recent graduates and apprentices, "the kids", as he affectionately calls them. "I'm not supposed to call them that," he admits to nods of agreement, and then goes on to explain that their role is to challenge him. "They are well behaved," he adds, "but they are very capable of questioning anything."

There is an important message behind Rogers's plan: to him the graduates and apprentices are an essential part of his approach to overseeing engineering at JLR. It is about staying grounded in the engineering and always challenging yourself. Rogers constantly returns to the role of apprentices as he describes his moves to embed engineering, and the science behind it, much more deeply into the mindset at JLR. Walking around rooms full of engineers at workstations, Rogers points to one end where apprentices work together. "If I ever have a bad moment," he says, "I go and sit with them for a half an hour and they cheer me up."

Most of today's intake of apprentices are studying for engineering degrees. Rogers was not able to study for A levels and then for a degree, so his career started not far from the bottom of the ladder. His traditional technical apprenticeship involved learning how to do just about everything in a mechanical workshop, for example making his own steam engine. Since then, Rogers has held various engineering roles, starting in body engineering, where he worked on the Mini Convertible and the Rover 200, fitting in the time needed to get his technical engineering degree. He ended up as head of Rover Group's body structure design team.

ENGINEERING EVOLUTION

The UK's car industry was going through interesting times throughout much of Rogers's earlier career. The brands that came to be JLR went through several owners, including Ford and BMW, so Rogers has seen different approaches to engineering

Rogers is a passionate advocate of staying grounded in practical engineering. This image was taken in 2015 on the production line of the two millionth Defender at Land Rover's manufacturing facility in Solihull © Jaguar Land Rover

leadership. In 2008, everything began to change when Tata Motors acquired JLR and the two brands finally came together.

JLR's current engineering time and effort is split equally between mechanical, electronic and electrical engineering. Of course, the complexity of electrical and electronic systems has increased over time so engineering time needs to be spent more efficiently. He brings up a chart showing that mechanical engineering consumes less engineering time than it used to. This does not mean, Rogers adds quickly, that mechanical engineering is less important, but moving into electric vehicles brings new challenges, not least being the management of batteries and electric motors. Today's automotive engineers have to bring together a constantly changing raft of technologies.

"When we started the journey four years ago, one of the key things that we were looking at was how did we put engineering back into the centre of what everybody did every day," Rogers explains. As a part of his plans to maintain the technical skills of JLR's engineers, Rogers has put in place what he describes as "a plan to get back to basic engineering". In part, this was a response to the rapid growth of recent years. Ten years ago, JLR employed just 2,000 engineers. "When you grow quickly, you have to learn continuously and it is so important to remember the basics," he explains. Now, JLR has created its own set of internal training modules following an analysis of industry changes, as well as relevant scientific theory and practical automotive applications that all JLR engineers need to know about. Rogers says that these are a key part of JLR's engineering transformation over the past three years: "They are the foundation of knowledge for our engineering product delivery and we have already witnessed improvements in our products as a result, such as in the handling and dynamics of the new Range Rover Evoque."

When Rogers became head of product engineering in 2015, he increased the annual intake of apprentices. He didn't like the idea that JLR took in just a handful of budding engineers each year, so encouraged his team to look at the skills and capabilities that JLR would need to meet its future needs. In particular, he wanted them to find technically curious, highly skilled and efficient engineers.

ELECTRIC TRANSFORMATION

A driving force behind the need for technically curious engineers is the rapid pace of change in the car industry. He says of his own time in the industry: "I think that the only constant has been building cars." Electric cars are increasingly popular and there is much talk of autonomous vehicles, a concept that already influences car designers and engineers. An immediate issue for JLR's engineers is managing batteries in electric cars. As a testbed for its own technology, JLR has one of the biggest arrays of electric charging stations in the UK.

The company's engineers also work with its Formula-E Jaguar Racing team. "We are using that as a testbed to prove technology. Batteries are incredibly expensive, so the battery management system is one of the most valuable commodities in the battery electric car. Any fraction of efficiency that you can get from optimising the energy going in and out of the battery is key intellectual property."

Another hot area of automotive engineering is in the 'infotainment' system. On a guided tour of JLR's facilities, Rogers points to a benchtop rig where engineers are testing hardware and software for future generations of such systems. The whole integration process of JLR's infotainment system was, Rogers says, "the biggest learning experience I have ever had in my life." The electronic side of cars is now so important that at the beginning of 2018 JLR

The Jaguar I-Pace is JLR's first all-electric vehicle © Jaguar Land Rover

set up its own Software Engineering Centre in Shannon, Ireland. Around 150 people work on new technologies to support electrification and self-driving features on future Jaguar and Land Rover vehicles.

Rogers says that the infotainment system has always been an example of the car's human–machine interface. In electric cars, the system brings together battery management and navigation. "When you plot a route, it knows when you're going to go uphill and downhill, making sure that you manage the energy within the battery to maximise so that every time you're going downhill you can regenerate as much energy as possible to then go back uphill. So it is actually planning the energy usage over your journey."

A feature that appeals to JLR's engineers is the ability to harvest data from various systems in the car, including infotainment, to understand vehicle usage. "This is really cool," says Rogers, "the engineers are actually using data from the car, to find out how people really use their vehicles." With its own fleet of electric vehicles, JLR has a growing flow of data from around 4,000 cars. "If there were software bugs, we might be able to proactively identify them before the customer sees them and find ways of fixing them."

The Shannon team has also recently launched 'smart wallet' technology that lets drivers earn cryptocurrency for sharing information about traffic jams and potholes, which is used to automatically pay for tolls, parking and electric charging. The data sharing service is optional and anonymous. Customers can opt in via their infotainment system and anonymously share data such as road surface conditions, without linking it back to their specific car.

Few areas of automotive engineering have been immune to the accelerating pace of technological change. Diesel engines, for example, went from hero to villain in what seems like the blink of an eye when other engine makers were caught cheating the testing regime for emissions. By good fortune, this happened around the time that JLR set up a production line to manufacture its own range of diesels – a facility that was nominated for the Royal Academy of Engineering's MacRobert Award in 2015 ('Designing and manufacturing world-class engines', *Ingenia* 67). "Engineering our own flexible engine architecture enables us to meet our bespoke needs, allowing JLR to adapt and stay ahead of changes in regulation and technology," Rogers says.

Rogers now has to plan for a world that may remove diesel engines completely. "If you look at the clean diesels that we make now, the level of nitrogen oxides (NOx) is hundreds of times less than it was a few years ago," he says. JLR's new engines already deliver the level of admissions and NOx reductions of 2020 regulations and have delivered a 90% reduction in NOx emissions since 2010. He then digs out a diagram of a diesel engine displaying exhaust technology that shows the "very efficient chemistry that we have inside the car". As Rogers sees it, ditching diesel engines does not make sense. "The engineering facts … are that every government across the globe that cares about health should be encouraging new, cleaner diesels."

The need to respond to political pressure has also done much to drive the development of electric vehicles. The need to do this while simultaneously developing new models with internal combustion engines has fuelled a revolution in how JLR's engineers develop new car models. Instead of working on new models sequentially, Rogers persuaded JLR that it should work on several models at the same time, while using a new computerised approach to engineering [see *Flexible, modular architecture*]. The response he got was "how can you do that?". As he saw it, this was the only way in which JLR could achieve its ambitions for delivering a series of new Land Rovers and Jaguars. "The truth is that you have to have the courage to do the whole lot at once," Rogers insists.

Rogers's pursuit of science does not stop at engineering. With human factors becoming increasingly important, he has recruited psychologists to work on such topics as car sickness. "I get dreadfully travel sick, so it is definitely a personal obsession. We are doing a lot of work, looking at cognitive load and the things that actually drive motion sickness." After all, you don't want to sell cars that make people feel queasy.

Rogers's interest in experiments doesn't stop with cars and their drivers. Ever the hands-on engineer, he has investigated alternative uses for some of the engineering that goes into JLR's electric cars. Rogers encouraged Stephen Boulter, Vehicle Engineering Manager for the I-PACE electric Jaguar, to take the car's batteries and match them to an integrated starter generator from one of JLR's hybrid vehicles. Run it in one direction and it generates electricity, reverse it and you have a generator, Rogers explains. Add some three-metre turbine blades and you get a three-kilowatt wind turbine.

As Rogers explains it, he was thinking of putting solar panels on the roof of his house "but if you look at the return you are much better putting up a wind turbine than you are solar panels". But Boulter gives the game away when he adds: "We are doing it for bit of fun aren't we?". Sure, says Rogers, but for him it all comes back to engineering, trying to spend time with the teams, being practical, thinking through ideas. Rogers admits that he is "obsessed about being curious". It is just an engineer's way of thinking. "If somebody says something can't be done, to most engineers that just provokes them into proving that it can be."

FLEXIBLE, MODULAR ARCHITECTURE

When Nick Rogers first suggested that JLR should develop different car models at the same time, the underlying idea was that engineers would build new cars using shared principles within a common architecture. Where possible, different models would share components put together in a common layout, but with the distinctive look and 'feel' that drivers expect when they sit behind the steering wheel of a Jaguar or Land Rover.

"We are very passionate that the driving experience and capabilities of our cars all fit into the brands," says Rogers. He thought that a common architecture could accommodate the variations needed to create cars that made the most of JLR's engineering expertise, especially its intellectual property.

An important catalyst for the new approach was JLR's promise that from 2020 all new models will offer a choice of 'drive trains', the part of a car that delivers power to the wheels. JLR's showrooms would offer three systems: the traditional internal combustion engine paired with the mild hybrid electric vehicle, the plug-in hybrid electric vehicle or battery electric vehicle.

The underpinning framework that will enable this efficient, concurrent engineering is in what Rogers describes as associative vehicle architecture (AVA), JLR's approach to digital engineering that is based in computer-aided design (CAD) and computer-aided engineering (CAE). "It is really about embedding our engineering knowledge base into our CAD and CAE tools and beyond," says Keith Rose, CAD and AVA Senior Manager.

The AVA system is a growing set of computer models of the different parts and subsystems in a car that "embeds the science as algorithms and parameter values based on our engineering strategy for that part or system," says Rose. "The vision is that the AVA is the live culmination of all the engineering knowledge that you have got," adds Rogers. "That is why it is so powerful. You continuously build and add to the previous strategy, or best-so-far knowledge, rather than reinventing it every time you start a new product, encouraging engineers to formally integrate the learning from last time."

The approach with AVA enables JLR to create results that may have previously taken days in hours, enabling the engineers to maximise their time on the most important part – using every minute to create the very best products possible for its customers.

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, **1967**. Apprentice Technician, British Leyland/Rover Group, **1984–1988**. Gained a degree in mechanical engineering from Coventry University, **1993**. Chief Engineer, Rover Body Structures Design, **1995–1998**. Chief Programme Engineer, Land Rover **2003–2005**. Lean Manufacturing Manager, Land Rover, **2005–2007**. Director of Global Architecture, Jaguar Land Rover, **2007–2015**. Executive Director, Product Engineering, **2015–present**. Fellow of the Royal Academy of Engineering, **2018**.

ULTRASONIC ARMOUR INSPECTION

A-Ultra is a portable device that uses sensors to check body armour for damage in just 10 seconds, saving time and money and making such inspections simple in even remote locations.

A-Ultra scans a helmet for damage © Microchip

To ensure that military personnel have uncompromised protection, the British military ships around five million armour units per year from around the world back to the UK to be inspected by X-rays. This can be a time-consuming and expensive process, and presented a need for a quicker, more efficient system.

Researchers at Cardiff University were working on an aerospace project when they saw a call-out from the Defence Science and Technology Laboratory searching for new techniques for inspecting armour. Their work focused on acousto-ultrasonics, an active inspection method that involves sending out ultrasonic waves at one location on a structure and receiving them in another. If the structure is damaged, the wave is interrupted and results in a different signal. The researchers realised that this technology could be applied to checking body armour and helmets.

They partnered with semiconductor company Microsemi to develop a handheld device that can conduct acousto-ultrasonic inspections and process the results to give a simple pass or fail answer. The A-Ultra uses existing sensors in new ways, with innovative formulas powering the detection system.

Four low-cost sensors are applied to the body armour. These can be retrofitted to existing armour, but new generations will be modified to include the system from the start, which will remain in the armour for its lifespan. The sensors are lightweight and unobtrusive within the armour. They are mounted on flexible circuits that can be easily installed and fitted to various shapes depending on the application. If one sensor fails, the remaining three will still be able to give a reading.

A handheld system then scans the four sensors by using low-profile, lightweight transducers to transmit ultrasonic waves across the armour surface, which the sensors receive. The system works by creating energy – similar to a miniature earthquake – releasing it through the structure. A-Ultra then analyses the waves received and assesses the ballistic protection before giving a pass or fail response. All of this occurs in under 10 seconds.

The device's simple pass or fail readout and one-button operation mean that unskilled workers can use it. The onboard memory can store data about inspections, and the battery-powered device is ideal for use in remote locations where power supplies can be unreliable.

In the future, the system could also have uses in protective clothing for sports, such as horse-riding helmets, or in monitoring larger structures such as aircraft, for example by carrying out quick and safe inspections of airplanes after a small runway collision. The team is currently working on making A-Ultra even smaller and building in wireless communication to make inspection in hard-to-reach locations a reality.

HOW DOES THAT WORK?

3D FACIAL RECOGNITION TECHNOLOGY

Facial recognition technology can identify or verify a person using information from a digital image or video. The technology is used in many different systems but has recently hit headlines as a feature of Apple's iPhone X.

There are several techniques in use for facial recognition but, essentially, it is a two-step process: feature extraction and selection, followed by classification. Many traditional processes use algorithms to identify facial features that are then used to search for other images with matching features.

Recently there has been increased interest in using 3D techniques for facial recognition. To understand this increased attention, we first need to understand how a task that all of us perform thousands of times a day, quickly matching faces we see to ones we know, presents such a challenge for a machine.

The first challenge comes from the 'sheep effect': the tendency of all sheep to look the same to you and me, while appearing quite distinctive to each other and the shepherd. Our vision is more accurate – sheep are all pretty much the same – but the shepherd's vision is clearly much more useful. Much the same applies to our own faces, which are really all very similar (as seen by sheep perhaps but 'really' too) but seem usefully very distinctive to us. However, differences in face shape are quite modest and can be confused by things such as glasses and changing facial shape in expressions that we easily discount. Machines find recognising such changes more difficult, which is why, for example, people are asked to look expressionless in passport photos that will be used for recognition by machines.

So, what has changed? Much of the interest is just the impact of ever-increasing, faster and less energy consuming, processing power being available. This

The iPhone X's 3D facial recognition technology projects over 30,000 dots onto a user's face to map their features and uses the information to unlock the phone in the future. The dots are invisible to the human eye but can be seen through an infrared camera, which captures the image and sends the data for confirmation. The flood illuminator is an invisible infrared light that identifies facial features even when it's dark
© Apple

makes the considerable data processing requirement for facial recognition in a device such as a smartphone more practical. The same effect has also driven the wide application of speech recognition, although this needs even more processing power and uses communications and remote 'cloud' processing ('How does that work? Speech recognition', *Ingenia* 77). But an even bigger gain has come from using better data, particularly a 3D image of your face rather than just an ordinary picture. In this respect, the machine is using better data than us; although, of course, we also see in 3D using our two eyes this is probably not so important for recognising people.

For a machine such as a smartphone, a 3D image of a face is much simpler to match reliably and this also solves problems with recognition when your face is slightly turned away, for example. Anyone with a recent iPhone or some gaming consoles will know that this also works in many lighting conditions, even in the dark, which is a problem for some other facial recognition technologies. This is typically done by 'structured lighting': the device projects a particular pattern of invisible infrared dots onto your face from several separated sources and analyses the video image these present. This reveals a 3D shape in much the same way as the angled shadows from a Venetian blind falling across a complex object. The information is then used to identify distinctive features on the surface of a face, such as the contour of the eye sockets, nose and chin. Although there is also much interest in laser radar (or 'lidar') for 3D imaging, for example for self-driving cars, it is currently far too expensive and not accurate enough to use for 3D identification of faces. However, the structured lighting approach, combined with faster processing and some extra techniques for ignoring hats and glasses for example, works well – although it is still imperfect and most likely not as good as humans. It is still probably the best of the biometric ID techniques, but the accuracy of recognition of 2D faces in sources such as CCTV feeds still needs much improvement. Some gaming consoles also successfully use similar techniques to analyse whole body movements. Expect the results to get better and be used ever-more-widely in the future as processing power and data capture improve further.

To watch a video that uses an infrared camera to show how face recognition works, please visit **www.youtube.com/watch?v=g4m6StzUcOw**