160 the ENGINEER

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September 2016

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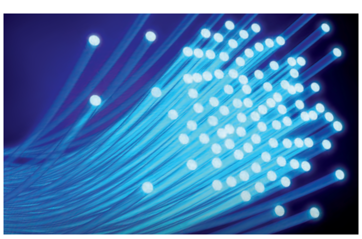

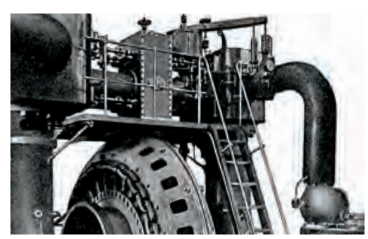


Anniversary edition

SPANNING FOUR INDUSTRIAL REVOLUTIONS

thisissue

160 anniversary issue
Established 1856

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Landmark moments

On 4 January 1856, just over 160 years ago, the first issue of *The Engineer* was launched into a very different world from the one we inhabit today.

It was the age of steam, empire building and Victorian innovation. Many of the figures who shaped our modern world – such as Brunel, Babbage and Faraday – were still alive. And some of the industries that dominate our coverage today, most notably aerospace and automotive, simply didn't exist.

When browsing through *The Engineer*'s coverage of this period, it's easy to be lulled into a rose-tinted view of the UK's industrial past by the sheer torrent of innovations coming forward.

But while our top-hatted predecessors undoubtedly had front-row seats for some of the sector's landmark moments, they would surely be every bit as impressed by the innovations that shape our world today: from the rise of autonomous systems and wireless connectivity, to the development of manufacturing machines able to print in one go components of almost unimaginable geometric complexity.

They would surely also be beguiled and excited by the possibilities of the digital world, and the way in which the Internet enables *The Engineer* of 2016 to instantly broadcast stories of note to a worldwide audience.

> "Our top-hatted predecessors would surely be every bit as impressed by innovations shaping the world today"

And they might recognise that, while the world has changed beyond recognition, *The Engineer* – launched, in the eloquent words of its founder, to report on the "bent of inventive genius to press continually forward" – remains true to its founding principles more than 16 decades on.

It's impossible to know where we will be in another 160 years. Will we have finally found a way to provide everyone on the planet with clean, plentiful energy? Will humanity have colonised other parts of the galaxy? Will we have been wiped out by artificial intelligence? And will *The Engineer* still be around in some form to report on it?

These questions are unanswerable. But one of the few certainties is that, whatever world comes about, engineers – and their timeless drive to invent, innovate and improve – will have played a major role in shaping it.

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foreword | **dame julia king**

Periods of change and upheaval can be times of great innovation – wartime, the transition to democracy in the former Soviet states and the rapid changes in the Asian economies, have all spawned generations of entrepreneurs and inventions. We are now facing a period of uncertainty and change here, brought on by the referendum vote for the UK to leave the European Union. Whether we voted for it or not, let's not waste the upheaval – how can we exploit this need for change to supercharge UK innovation?

There are plenty of challenges requiring engineering innovation – transport is now the largest sectoral contributor to CO_2 emissions in the UK as electricity decarbonises. How do we exploit digital to make our healthcare system affordable for the future? Can we really deliver the systems for 'negative carbon emissions' that will be needed to meet the Paris agreement's target of net zero carbon emissions in the second half of the century? How can we encourage more women to become engineers?

We are good at innovation in the UK, coming second to Switzerland in the recently published Global Innovation Index and second to the US in the Quality of Innovation metric, we are good at engineering, we have universities and companies, large and small, with people with ideas to address these problems in ways that could stimulate the UK economy.

> "*The Engineer* has been a constant through recession and recovery, world war and reconstruction"

Brexit, the new Industrial Strategy and low interest rates provide the opportunity to replace current European innovation support and to revitalise the UK system. Innovate UK and the British Business Bank could deliver a new, hassle-free and seamless portfolio of grants, loans, investments and other types of 'aid' to speed technologies from lab to launch – right through to 'first-of-a-kind' implementation. It needs serious government investment and some new thinking. It is a time to take some risks in engineering investment and it is an opportunity we mustn't miss.

The Engineer has been a constant over the past century and half. Through Industrial Revolution, recession and recovery, world war and reconstruction, it has covered the changing times and the technologies that have characterised them. It has seen bigger upheavals than this one, and reported on how we have weathered them. Whatever the outcome, we can be sure that its pages will reflect how we meet the upcoming challenge, and the ingenuity and flexibility we will need in the coming years. ■

Dame Julia King, Baroness Brown of Cambridge, is chief executive and vice-chancellor of Aston University. She has a PhD in fracture mechanics, and was the first senior research fellow of the Royal Academy of Engineering. Before re-entering academia as principal of the engineering faculty at Imperial College in 2004, she held several senior positions at Rolls-Royce

partner foreword | keith lewis

MATCHTECH

From the design and manufacture of single components, to the assembly of a complete product, engineers touch everything that exists in the world. Their innovations filter into unlimited avenues and influence everything we see, hear and touch. To celebrate *The Engineer*'s 160th birthday, I wanted to reflect on and celebrate some examples of the revolutionary impact engineers have had in this world over the past 160 years.

Let's start with travel. Today, people, particularly in the developed Western world, think nothing of hopping in the car to get to work or jetting off on a plane for a long weekend abroad; but this is only possible as a result of the innovations and developments engineers have made over the past 100 years. American Henry Ford is credited as the man who brought cars to the masses in the 1920s. While previous motor car models had been created before this time, Ford's mass production techniques made cars more affordable as he was able to increase productivity, make more cars and sell them for less money. In 1913 there were 606,124 motor vehicles in the world. Now, it is estimated that there are 1.2 billion and this figure could more than double to 2.5 billion by 2050.

> "I strongly believe that the industry will continue to rely on traditional skills"

Since then, engineers have developed the safety, fuel efficiency, power and technological capabilities of cars. The creation of headlights, seatbelts, wing mirrors and air bags, among many other features, have contributed to significantly improved levels of safety while clean diesel and direct-injection methods have increased the power and fuel efficiency of cars. Today, the automotive industry is focusing on the concept of the connected car and the development of autonomous vehicles that can effectively drive themselves. As for the future, BMW anticipates that "the next 10 years are probably going to involve more change and more dynamics than we have seen in the last 100".

In the aerospace industry, the past 160 years has seen people successfully travel into space to conduct scientific research, the launch of satellites to aid navigation and the take-off of the jumbo jet, which continues to dominate the airline world. Today, the global demand for new aircraft is at record levels with 27,000 passenger aircraft and 40,000 commercial helicopters predicted to be needed by 2032. On top of this, existing aircraft are being re-engineered and upgraded to be faster, quieter and more fuel-efficient in response to a more environmentally aware world. Airbus foretells that the industry will be disrupted by more technological advancements, which could see concepts of "using body heat for power, luggage floating on a bed of air and aircraft running on methane gas" become a reality.

As the world has become more environmentally aware, investment in renewable sources of energy has increased. As well as the huge infrastructure and power developments made during the Industrial Revolution, the era also brought with it the unwanted by-products of air and noise pollution. This new-found pollution combined with the realisation that our natural resources were depleting led to the birth of the renewable energy industry, which now supports more than 7.5 million jobs worldwide. With estimations that renewable energy sources will account for 26 per cent of the world's energy supply in 2020, the future of the renewables industry looks strong.

Another exemplary industry that engineering has revolutionised is defence. In relation to naval defence, 160 years ago shipbuilders were beginning to experiment with iron and later steam, and captains relied on charting and celestial navigation to find their way. Now, the Royal Navy is using unmanned boats that are fitted with a complex array of sensors, a navigation radar, 360-degree panoramic infrared camera and laser range finder to support missions with remote surveillance.

Many people have said we are now experiencing a fourth industrial revolution as developments in technologies fuse connections between the physical, digital and biological worlds. These technological advancements have caused the gap between traditional engineering skills and IT skills to decrease and within industry employers are increasingly seeking engineers with skill sets in technology to design, implement and manage application systems, among other tasks, within the evolving telematics and connectivity space. While you cannot deny the significant shift towards this convergence of skills, I strongly believe that the industry will continue to rely on the traditional skills that engineers have been using for the past 160 years to complement the more contemporary skills that have started to emerge.

While the last 160 years of engineering has been impressive to say the least, I believe that future years will be just as significant, with the advent of driverless vehicles, further space discovery and tourism, and possibly even the manufacture of 3D-printed houses, ready to buy 'off the shelf'. If the industry continues to dream big and invest in innovation, there is no limit to what engineering can achieve in the future.

Keith Lewis, chief operating officer of Gattaca and managing director of engineering recruitment specialist Matchtech

Blazing a trail for diversity

The history of women in engineering is full of inspirational attempts to break down barriers in a notoriously male-dominated landscape. Dr Sally Horrocks reports

In the years between 1637, when Amye Everard Ball was the first woman to apply for an English patent and 1898, when Hertha Ayrton became the first female member of a British engineering institution, numerous women took out patents, developed and adapted technologies and contributed to innovations. Ayrton's membership of the Institution of Electrical Engineers (IEE, now Institution of Engineering and Technology, IET) in 1898 marks not the start of women's contributions to British engineering, but an important step in their efforts to take their place alongside men in the engineering profession.

Although she was already a patent holder before she married her former teacher William Ayrton, Hertha's research career benefitted from the marriage and she established her reputation through work on the 'hissing' of the electric arc and on ripples and vortices. These were the topics when she became the first woman to deliver a lecture at the IEE in 1899 and at the Royal Society in 1904. The award of the Hughes Medal by the Royal Society in 1906 cemented her reputation and she continued her work after William's death, as well as being an active campaigner for women's suffrage.

The first women engineering students entered British universities during the years shortly before the First World War. Many of these pioneers, such as Rachel Parsons, came from families with strong engineering traditions and benefitted from their support and access to practical experience in the family firm. Others, such as Dorothée Pullinger, used family connections to secure more hands-on training, in her case starting in the drawing offices of a car firm managed by her father. Employment prospects were initially limited to those that could be secured through personal contacts, but during the Second World War they improved dramatically when the influx of women into munitions factories brought a demand for women with engineering expertise to train and supervise them.

At the end of the conflict these women industrial workers were expected to return to the home or to domestic service, enforced in many sectors by the Restoration of Pre-War Practices Act. Prospects for professional women also looked bleak, despite the passing of the Sex Disqualification (Removal) Act in 1919. This prompted a group to establish the Women's Engineering Society (WES), with Caroline Haslett as the first secretary and Rachel Parsons as president. This was a campaigning organisation with a practical approach to feminist activism through efforts to maintain and enhance opportunities for women in engineering, to develop support networks for women engineers and to use engineering expertise to reduce the burden of women's domestic labour. The 1921 census


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recorded 46 women professional engineers and during the 1920s women were admitted for the first time to many of the established engineering institutions, including Dorothée Pullinger, Institution of Automobile Engineers, 1920; Rachel Parsons, Institution of Naval Architects, 1922; Verena Holmes, Institution of Mechanical Engineers, 1924; and Dorothy Buchanan, Institution of Civil Engineers, 1927.

When Vera Brittain wrote *Women's Work in Modern England* in 1928 she told her readers that engineering was second only to advertising in offering "the finest opportunities to enterprising women" but warned that "the best openings for women are provided by new businesses and professions capable of alteration and expansion, rather than by the older and more circumscribed vocations with a long tradition of masculine authority". The biographies of prominent members of the WES during the interwar period bear this out. Margaret Partridge, for example, established an electrical contracting business that installed power systems in the south west and encouraged female engineers by providing apprenticeship opportunities and practical experience.

Individual entrepreneurship was one solution to the difficulties of finding employment. Another was working in one of the government's research establishments. Beatrice Shilling, Partridge's most successful apprentice, took this route and studied at the University of Manchester before securing a post at the Royal Aircraft Establishment in Farnborough. Here she joined Frances Bradfield, a mathematics graduate who ran the wind tunnels. The inter-war civil service required women to resign when they married, unless their expertise was irreplaceable. When Shilling married George Naylor, a fellow RAE employee in 1938, she was one of only a very few women allowed to retain her position. Her case was no doubt helped by the expectation that aircraft would play a vital role in the upcoming conflict. The decision was rewarded by her contributions to a variety of projects, the most well known of which was a modification to the Merlin engine, which prevented it stalling, affectionately known by pilots as 'Miss Shilling's orifice'.

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"The best openings for women are provided by new businesses and professions capable of alteration and expansion"

Vera Brittain

The wartime demand for engineers provided an opportunity for some women to access training and expertise in engineering, but there was no concerted attempt to encourage them. Female school leavers with qualifications in mathematics were recruited into government research establishments or trained as radio mechanics after joining the services.

Universities were discouraged from increasing their recruitment of women students to fill places left empty by men, but those women who did study during the war were rapidly pressed into service. Beryl Myatt (later Platt, Baroness Platt of Writtle) was one of just five women studying mechanical sciences in her year at Cambridge. After completing an accelerated wartime degree in two rather the usual three years, she worked for Hawker

03

01 Beatrice Shilling improved the safety of the Spitfire

02 Hertha Ayrton, first female member of a British engineering institution

03 Dorothée Pullinger of the Institution of Automobile Engineers

on wartime aircraft. Her later career was typical of many in this wartime generation who worked on immediately after the war but, despite the formal removal of marriage bars, eventually chose to leave engineering for marriage or motherhood before distinguishing themselves in voluntary roles.

Those who stayed on were joined by new graduates, but the dramatic expansion of provision for engineering in higher education did not lead to an increase in the number of women studying engineering. In 1956, out of a total of 1,034 engineering degrees awarded, only three went to women. Despite sustained government anxieties about a >>

> "Industry will have to shake itself out of the habit of mind that thinks of girl engineering graduates as freakishly improbable"
>
> Willis Jackson

>> shortage of scientists and engineers there were no central efforts to encourage women to fill the gaps.

Encouraging girls into engineering was left to independent organisations such as the WES and the British Federation of University Women. They identified several barriers, including inadequate provision for mathematics and physical science in girls' schools, and lack of awareness among careers advisors, as well as the reluctance of firms to employ women because they believed they could not supervise men and were likely to stay only a short time before marrying and leaving. Leading engineering educators such as Willis Jackson added their voices to the debate, arguing that "industry must lose its inhibitions and start chasing girls" and "will have to shake itself out of the habit of mind that thinks of girl engineering graduates – where it thinks of them at all – as freakishly improbable, like female rugby footballers". Regular references were made to the example of the Soviet Union, where women made up a high proportion of engineering graduates.

04 Rachel Parsons was first president of the Women's Engineering Society

After the launch of Sputnik, anxieties about the potential consequences of Soviet superiority in science and engineering finally pushed the government to consider the issue. The Social Survey investigation into the employment of women scientists and engineers in industry reported in 1961, and disappointed campaigners who had hoped for official endorsement. Instead it suggested the reluctance of firms to employ women engineers was justified and the national interest would be best served if they used their talents to teach the next generation of technical experts.

Within less than a decade this position had shifted dramatically and in 1969 the Department of Education and Science under Shirley Williams, lent its support to Women in Engineering Year. The WES hosted a major international conference and the Central Office of Information produced a film, *The Engineer is a Woman*, to promote careers in engineering to girls in schools. The number of women studying engineering and technology at British universities started to rise significantly and there were efforts to open up more employment opportunities for these graduates. A sustained parliamentary campaign to open up scientific and technical posts in the civil service to women was mounted from 1971, spearheaded by Edward Bishop, Labour MP for Newark, and a former aircraft design engineer. Speaking to a House of Commons Committee in 1972 he argued: "Sex discrimination can no longer be explained away by tradition, no longer excused by custom and no longer ignored."

Women in Engineering year marked the start of a sustained series of educational efforts to encourage girls and women to follow careers in engineering by raising awareness of the opportunities available to them and seeking to create a more feminine image of technology. Networking groups, including women's groups within the major professional institutions, emerged during the 1980s alongside the existing activities of the WES. In contrast to feminist initiatives to teach women craft skills in engineering and construction, professional engineers tended to concentrate on helping women cope with rather than challenge the male-dominated and masculine cultures of engineering. In the 1990s, skill shortages in engineering led to the prominence of arguments for recruiting women based on potential economic benefits. More recently there has been a shift to a broader emphasis on enhancing the diversity of the engineering workforce not just with respect to gender, but also race and socio-economic background.

The number of women graduating in engineering and applied science from British universities passed 1,000 for the first time in the early 1980s. In 1982 the Royal Academy of Engineering elected its first female fellow, Dr Elizabeth Killick, an expert in novel radar and sonar systems who was head of the Weapons Department at the Admiralty Underwater Weapons Establishment at the time of her election. By the 1990s the optimism that had accompanied these developments had dissipated as the proportion of women studying engineering reached a plateau and in some fields showed signs of falling. At the same time, the visibility of women engineers was enhanced by their service in high-profile public roles, including as presidents of engineering institutions: Pamela Liversidge at The Institution of Mechanical Engineers, 1997; Jean Venables at the Institution of Civil Engineers, 2008; Jenny Body at the Royal Aeronautical Society, 2013; and Naomi Climer at the Institution of Engineering and Technology, 2015. In 2014 Ann Dowling was elected president of the Royal Academy of Engineering. It remains to be seen whether this visibility will begin to undermine the resolutely masculine image of the profession.

Dr Sally Horrocks lectures in modern British history at the University of Cambridge

Why diversity is good for business

Mixed teams, whether of race, gender or age, are naturally more creative and better able to come up with solutions to problems

There has never been a better time to be an engineer: demand that far outstrips supply, competitive graduate salaries and fantastic career prospects characterise the engineering profession today.

And yet there is a huge shortage of engineers in the profession and the proportion of women working in UK engineering has remained at less than 10 per cent during my three decades in the industry.

The lack of gender diversity is contributing to skills shortages that are damaging the economy. The shocking reality is that the UK is missing out on half of its potential engineering and technology workforce by failing to attract women into the industry.

The IET's most recent Skills and Demand in Industry Survey showed that over half (57 per cent) of businesses in the UK do not have gender diversity initiatives in place and 41 per cent have acknowledged that they could do more to recruit staff from diverse backgrounds.

Why are there so few women in engineering and what do we need to do to show that engineering isn't just a job for men? If there was just one issue here I think we would have fixed it by now, but it's not as simple as that. It is everything from the subtle ways that boys and girls are encouraged to play with different toys or study different subjects at school, to the information that the decision makers they turn to – parents and teachers – have about engineering. There is also the image and perception that many people have in this country, of engineering as 'dirty' and 'messy'. Research we carried out showed that half of parents felt that engineering careers are more for boys, and children's views were largely similar.

If we could get better at showing girls and women, and other minority groups, that engineering is a career for them, I feel pretty sure we could improve the overall pipeline of engineers.

The IET, like many other professional institutions and businesses, is very active in this space. For example, we have recently jointly published with the Prospect trade union *Progressing Women in STEM Roles*, some practical guidance to support employers working in the industry in taking action to improve their gender diversity and inclusion.

The new guidance gives employers suggestions and best-practice examples of how they can not only take steps to attract more female candidates, but also ensure that women in their organisation have a fair and even playing field to develop and to progress their careers.

In addition, the guidance gives managers tips on how to ensure promotions are fairer among workforces of different genders – and on how their organisations can implement effective return-to work programmes to re-integrate women coming back from career breaks.

We know that many employers acknowledge that the lack of women in their organisations is a real problem for them, and so we hope this guidance will prompt them to take practical action to address this – both in terms of how they recruit more women and how they nurture the talent of those that they already employ.

We also need to fix the misconceptions some people have of engineering. It's about giving engineering a makeover and highlighting it as exciting, modern – showing how it can lead to an international career with the chance to solve some of the world's biggest challenges.

Women engineers I know are working on everything from the Mars Rover to developing new drug-delivery techniques that could transform the treatment of major diseases such as cancer.

> "It's about giving engineering a makeover and highlighting it as exciting and modern"
> Naomi Climer

We need to do more to position engineering as creative, modern and diverse, and show people that engineers make a difference. Engineers enhance our lives.

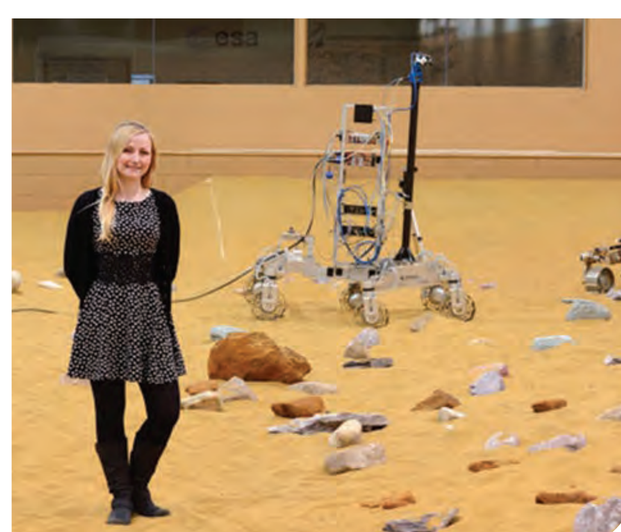
Finally, we need to think more drastically about how we solve this problem. Perhaps more could be done to encourage engineering employers to be more transparent about how they measure their efforts to boost the number of female engineers. Publishing data on the number of female engineers in the workforce would be one way of doing this.

Companies know that diversity is good for the bottom line because mixed teams, whether of race, gender or age, are naturally more creative and therefore better able to come up with solutions for the problems engineers face.

There are so many big, global, as well as small, local challenges for engineers to crack that we need all the talent we can get. This is not about doing the right or fair thing for women – it's a compelling economic and societal issue to train as many talented engineers as we can.

And if parents, educators and the engineering industry as a whole join forces to help tackle the issue of female under-representation in engineering, perhaps we will see that nine per cent figure start to change.

Naomi Climer, IET president



Airbus defence and space engineer Abbie Hutty

SKILL DEMANDS OVER THE NEXT DECADE

MATCHTECH

OVER THE LAST 160 YEARS WE HAVE SEEN A BIG SHIFT IN THE NEED FOR DIFFERENT SKILLS – FROM THE KINAESTHETIC MECHANICAL SKILLS NEEDED TO DESIGN AND CREATE NEW TYPES OF ENGINE, THROUGH TO THE ELECTRICAL SKILLS REQUIRED TO WIRE UP THE JUMBO JET AND THE SOFTWARE-BASED SKILLS FOR MODERN, CONNECTED VEHICLES.

Today engineers need to harness a range of skills, processes and technology to have the same impact on the future as their predecessors have had over the last 160 years. The successful engineer of the future will of course need attributes like strong analytical skills, good communication skills, problem solving skills and attention to detail but what new and developing skills will companies be looking for in the next decade? I would like to consider just a few trends in engineering that I believe will have an impact on future skill demands.

ADVANCED MATERIALS

With companies striving for better, faster, stronger products and services to fend off the competition and keep up with consumer demand there are many opportunities available for engineers with advanced materials skills to work on the latest innovative materials.

In manufacturing, additive manufacturing carries huge opportunities as the sector evolves towards highly efficient logistics and large-scale manufacturing. In the automotive, aerospace and medical industries, among others, companies are increasingly using 3D printing technology and additive manufacturing for prototypes and some production parts, shrinking supply chains. The recent progress made with 3D printing is expected to continue to the point where entire houses will be bought 'off the shelf' and available to print. Those engineers who have the skills to work on advanced manufacturing techniques can expect to be in demand.

In similar vein, engineers with knowledge of complex lightweight materials are expected to continue to be in high demand. Aerospace and automotive companies are increasingly looking for ways to become more fuel efficient, whether through lower weight and higher temperature resistance aircrafts or through the development of porous polymers and new steel alloys that prove to be stronger and lighter than steel.

CONNECTIVITY AND SMART DEVICES

As the demand for connectivity and smart devices increases, we see a shift from embedded to application technology and the skills associated with designing, implementing and managing these systems. This gap between traditional engineering skills and IT skills has been decreasing for some time now and we are increasingly seeing requests from engineering companies for candidates with skill sets from the technology sector which wouldn't have been needed a generation ago. For example, automotive companies will require traditional engineering design capabilities combined with evolving telematics, network design/ security and software.

Whilst opportunities will always remain for engineers with traditional skills, such as those within mechanical and electrical engineering, the ever-expanding influence of technology means engineers also have the chance to evolve their careers by learning new skills.

ROBOTICS AND AUTOMATION

Today, robotic and automated solutions are widely used across many manufacturing and material handling environments but arguably, this is just the beginning. Robots and intelligent systems are two key examples of technological advancements within the Industry 4.0 era which will influence the evolving skill sets required in many sectors of engineering. Opportunities for employment within this field appear vast as employers operating in aerospace, healthcare, agriculture and transport increasingly look at new ways to introduce smart automated processes. It seems the demand for engineers who can design, program, commission, simulate and test automated machinery and processes can only increase.

Our clients see first-hand the changes in automation. Speaking to Stuart Brown, Airports Director of AAC Ltd, a rapidly expanding global baggage handling automation specialist, he is seeing an increased demand for airports to work smarter and with it a shift in the skills needed to deliver their projects.

Whilst traditional electrical and software controls skills remain core to their business, the increasing demand for intelligent interconnected systems is causing new requirements for engineers with higher level software understanding.

ENVIRONMENT

For some time, there has been an increasing focus on engineering the solutions to environmental problems and this trend looks set to continue across numerous sectors. Whether it's the creation of floating and underwater cities to solve the problem of inner-city crowding or the development of smart cities to better connect communities and vital services, innovative, sustainable and environmentally-friendly engineering solutions are needed to address key social and environmental issues.

We are already seeing an increasing numbers of jobs related to making products and services less harmful to the environment - from the rise of electric vehicles increasingly adopted by big car manufacturers, to the emergence of smart grids connecting smart meters, smart appliances and renewable energy resources. The future engineers of the world have a large task on their hands to solve global concerns surrounding the environment and they will need the passion, ingenuity and creativity to do it.

FINAL THOUGHTS

Whilst the demand for engineers with traditional skills will continue, employers are increasingly looking for engineers that will take it upon themselves to learn new techniques and new technologically advanced pieces of equipment in order to perform their job to the best of their abilities. For any engineer, the ability to demonstrate that you know the current state of the engineering industry and that you can work effectively within it is of course beneficial to your future, however those who can anticipate the future problems and solutions can only expect to thrive above the crowds. Here's to the next decade of innovation in engineering.

Keith Lewis
Managing Director of engineering recruitment specialist Matchtech

Driven personalities and cutting-edge technology

Breaking the land speed record is about much more than just covering a set distance in minimum time.
David Tremayne reports

Distance versus time sounds so simple when speed record breaking is distilled to these three words.

But they omit so much of what lies behind such endeavours that they sell it short. Since Frenchman Count Gaston de Chasseloup-Laubat and Belgian Camille Jenatzy went head to head in their battle to become the fastest man on Earth in 1898, it has been about so much more than building a vehicle with the greatest possible power output, then inserting a driver with instructions to keep his right foot nailed to the floor.

World speed record attempts have never been just a story of cold scientific research, development and execution; far from it. Until the 1970s, the intuitive mechanical opportunism and attitude of the hot rodder was often as much a part of some of the stories as the complex amalgam and application of engineering skill. But the underlying foundations have always embraced pure human courage, passion and indefatigable endeavour.

Driving a record car at full speed on narrow, tree-lined public roads, on the sands of Pendine in North Wales and Daytona in Florida, or on the vast expanse of the Bonneville Salt Flats in Utah is one of the loneliest pursuits in the world. Yet, paradoxically, it also requires a supportive team effort borne of brains, camaraderie, mutual respect and reliance.

And it isn't just the driver who requires courage. The late Ken Norris, who with his brother, Lew, created Donald Campbell's famed Bluebird CN7 car and K7 boat, once revealed the burden that the designer must also carry: "When we first considered doing the boat I knew we had to accept the responsibility, and the challenge, from the design standpoint. I said you first have to convince yourself that you are capable, because you have this man's life in your hands. You've got to say: 'Can I do it?' And that is always a pretty difficult question."

Within such human and technological elements, together with the underlying and endless battle with an often-disgruntled Mother Nature, lies the true challenge of record attempts.

In the beginning, the electric car

Indepth
Electricity and steam

In life, what goes around tends to come around. So it has been with both electricity and steam, which, while no longer strong enough to create outright record holders, have had fresh moments in the spotlight since the earliest attempts.

In tune with the world's burgeoning interest in electric cars, students at Ohio State University's Center for Automotive Performance have allied with Venturi to produce a series of Buckeye Bullet electric battery/hydrogen fuel cell-powered land speed cars, the fastest of which in Roger Schroer's hands achieved 307.905mph (495.526kmh) at Bonneville in 2010. Their ultimate aim is 400mph (643kmh).

Steam hasn't been left behind, either. In 2009 Charles Burnett III achieved 139.843mph (225.049kmh) through a mile, and Don Wales 148.166mph (238.443kmh) through a kilometre, in the British Steam Car.

The diesel-fuelled internal combustion engine, too, has made headlines. In August 2006 supersonic record breaker Andy Green earned his salt spurs with 350.092mph (563.403kmh) in JCB's twin-diesel-powered Dieselmax at Bonneville.

01 Bluebird-Proteus CN7, which achieved 440mph with Donald Campbell at the wheel in 1964, was the last wheel-driven record holder was the king. In his Jeantaud fitted with a vertical chisel-shaped nose to cheat the wind, Chasseloup-Laubat recorded 39.24mph (63.15kmh) on 18 December 1898, on a straight piece of road near Achères in France. In January the following year, Jenatzy and his bespoke cylindrical-shaped electric racer, appositely named La Jamais Contente – The Never Satisfied – beat that with 41.42mph (66.66kmh) before Chasseloup-Laubat replied with 43.69mph (70.31kmh) later the same day. Ten days later Jenatzy's response was 49.92mph (80.34kmh) before his rival hit back with 57.60mph (93.724kmh) in March. Jenatzy had the last word with 65.79mph (105.904kmh) in April.

Electricity was soon supplanted by steam when Léon Serpollet's Ouef des Pâques – Easter Egg – recorded 75.06mph (120.771kmh) on the Promenade des Anglais in Nice in April 1902. And steam, in turn, was beaten by the internal combustion engine when the wealthy American, William Vanderbilt Jr, took a Mors racing car to 76.08mph (122.431kmh) in August that year and set in train a series of improvements as fellow racers Henri Fournier and Georges Auger (racing as 'Augieres') boosted the mark to 76.60mph (123.249kmh) and 77.13mph (124.102kmh) that November.

Racer Arthur Duray took a vast Gobron-Brillié to 84.73mph (136.353kmh) a year later, but it was Louis Rigolly who achieved the big breakthrough with 103.55mph (166.628kmh) at Ostend in 1904.

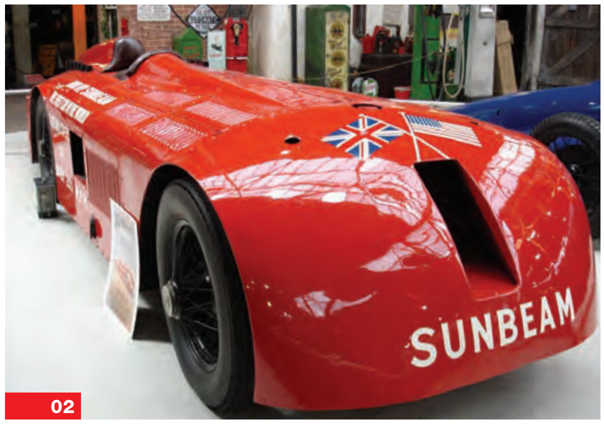
Racing cars continued to increase the record until the First World War bequeathed the aircraft engine. Sunbeam boss Louis Coatalen shoehorned a surplus Manitou aero

Racing cars continued to increase the record, until the First World War bequeathed the aircraft engine. Louis Coatalen shoehorned a Manitou aero engine into a car

engine into a racing car; where the Gobron had 13.6 litres of horizontally opposed four-cylinder engine and 130bhp, the Sunbeam boasted 350bhp from its 18.3-litre V12 and rewrote the script.

In 1922, Kenelm Lee Guinness took the car to 133.75mph (215.25kmh) – a speed beaten by René Thomas's 10.6-litre V12 Delage with 143.31mph (230.634kmh) in 1924 and Ernest Eldridge's 21.7-litre six-cylinder FIAT Mephistopheles with 146.01mph (234.986kmh) six days later. In subsequent years Captain Malcolm Campbell would helm the Sunbeam, albeit modified and painted to reflect its new Bluebird name, to 146.16mph and 150.766mph (235.217kmh and 242.80kmh) before Major Henry Segrave intervened with a 4-litre Sunbeam racing car at 152.33mph (245.149kmh) in 1926.

That was the racing car's swansong, however, as the



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02 Henry Segrave's Sunbeam 1000HP broke the record in 1927

03 Segrave's 1926 Sunbeam

04 Louis Coatalen used an aero engine for the first time in 1922

05 Léon Serpollet's Easter Egg

06 The first record holder, the electric La Jamais Contente

British racing drivers George Eyston and John Cobb waged a gentlemanly battle on the Bonneville Salt Flats

late 1920s ushered in the era of the monster. Welsh engineering genius John Godfrey Parry-Thomas made a silkier purse out of Louis Zbrowkski's brutal Higham Special and beat the record twice on Pendine Sands in 1926, with a big jump to 169.30mph (272.458kmh) and then 171.01mph (275.229kmh), before Campbell returned with a bespoke Bluebird in February 1927 to record 174.883mph (281.447kmh). Thomas became speed record breaking's first fatality while seeking to beat that a month later.

That same month, Segrave became the first man to exceed 200mph (321kmh) with 203.79mph (327.981kmh). His big red Sunbeam broke much new ground: it was the first land speed car with a full-width streamlined body, and mounted one 22.5-litre V12 435bhp Matabele engine ahead of the driver and another behind, the resultant power conveniently rounded up to 1,000hp for publicity.

Segrave also initiated European usage of Daytona Beach, which became the new mecca for speed seekers. In 1928 they included Campbell, whose modified Bluebird reclaimed the record at 206.956mph (333.062kmh). Two US ventures met with varying success, however. Flame-haired giant Ray Keech wrestled the crude Triplex Special – a behemoth powered by three 26.9-litre Liberty V12s – to 207.55mph (334.022kmh) to beat Campbell; and rival Frank Lockhart crashed his beautiful and scientific 3-litre V16 400bhp Black Hawk Stutz at 200mph (321kmh) yet survived, only to lose his life in a second accident two months later. And after Segrave had smashed America's record with 231.446mph (372.340kmh) in March 1929 with his beautiful Golden Arrow, Keech's successor, Lee Bible, died when he lost control of the Triplex.

Thereafter Campbell owned the record, boosting it on a further five occasions in increasingly modified Bluebirds until he broke another barrier with 301.129mph (484.818kmh) in September 1935.

In turn, Campbell was supplanted by fellow British racing drivers George Eyston and John Cobb, who waged a gentlemanly battle on the Bonneville Salt Flats, to which a desperate Campbell had decamped gratefully for his final attempt after a wheelspin at Daytona had robbed him of crucial speed. Eyston's self-designed Thunderbolt was powered by two 36.5-litre 2,350bhp Rolls-Royce R engines, had eight wheels (the front four doing the steering) and weighed 7 tonnes; Cobb's Reid Railton-designed Railton Special ingeniously mounted two old 1,250bhp Napier Lion engines in a lightweight S-shaped chassis clothed with a beautifully streamlined bodyshell, and was the first record car to use four-wheel drive. Each broke the record three times: Eyston's best was 357.500mph (575.217kmh), Cobb's a dramatic 394.200mph (634.267mph), with a fastest one-way run of 403mph (648kmh).

That mark would last for 17 years and in 1960 resulted in the Great Confrontation at Bonneville when technical ingenuity knew no limit. Art Arfons and Athol Graham had 'conventional' aircraft piston-engined contenders; hot rod genius Mickey Thompson drove a brilliant pukka automobile with four Pontiac engines and four-wheel drive; Donald >>

The Blue Flame really was rocket science: powered by a bespoke rocket motor designed to run on hydrogen peroxide and liquefied natural gas

>> Campbell's Bluebird CN7 introduced the turbine engine, also driving all of its wheels; and Dr Nathan Ostich's Flying Caduceus was the first land speed record car powered by pure thrust, via a General Electric J47 turbojet that did away with the need for a transmission.

All of them failed. Graham and Campbell crashed, the American fatally; Arfons' Anteater was too slow, as was Ostich's jetcar; and Thompson hit 406.60mph (654.341kmh) on Challenger's first run but blew an engine on his return. Four years later the recovered Campbell averaged 403.10mph (648.728kmh) on Australia's Lake Eyre, but by then that counted only as a wheel-driven record and would be beaten a year later by Bob Summers' Goldenrod at 409.277mph (658.636kmh). The jets had taken over.

Craig Breedlove's 407.45mph (655.709kmh) run in 1963 was not ratified by the FIA (although the FIM accepted the tricycle Spirit of America jetcar's mark as a motorcycle and sidecar record) but, after Tom Green had briefly set the record in Walt Arfons' Wingfoot Express at 413.20mph (664.95kmh) in October 1964, the race became a perilous war of Russian roulette between Breedlove and Walt's estranged brother, Art. Arfons won 1964 with 536.71mph (863.710kmh) as Breedlove crashed into a brine lake; in 1965 the latter returned with a new car, Spirit of America-Sonic 1, ending the year on top with 600.601mph (966.528kmh). In 1966 it was Arfons' turn to walk away from an accident – at 600mph (965kmh).

There things stalled until 1970 when Reaction Dynamics' The Blue Flame really was rocket science. Powered by a bespoke rocket motor designed to run on hydrogen peroxide and liquefied natural gas, the four-wheeled pencil encountered teething problems before Gary Gabelich broke through with 622.407mph (1,001.639kmh), beating 1,000kmh for the first time. Later that evening, winter snow came to Bonneville. Literally and figuratively, the hot-rod era had been superseded by the age of cold science.

07 The Blue Flame held the record from 1970 until Richard Noble's Thrust 2 in 1983

08 Craig Breedlove broke the record several times, with this car succeeding in 1963

Indepth

Ron Ayers, chief aerodynamicist for Bloodhound SSC

For almost a century, world land speed record (WLSR) cars were designed using the technologies of their day – for example, drawing boards, slide rules, hand computations and (in some cases) wind tunnels. By the 1990s, electronic computers had taken hold. Thus:

1. CAD systems introduced enormous flexibility into the design process by enabling many design options to be considered before cutting metal. Thrust SSC was perhaps the first WLSR vehicle to benefit from this.

2. Computational fluid dynamics (CFD), after being validated by our Pendine rocket-sled experiments, could be used to explore transonic ground effect and define the outside shape of the vehicle.

3. Spreadsheets enabled very detailed analyses of vehicle performance that could be constantly updated to incorporate the latest design changes and environmental factors. We demonstrated this with our driver (Wing Commander Andy Green) taking Thrust SSC up to sonic velocities and then bringing the car to a stop with the wheelbase spanning the designated turn-around point 13 miles from the start.

4. Thrust SSC logged readings from more than 120 instruments, enabling detailed analysis of the factors influencing performance and contributing to increased safety.

5. Bloodhound SSC will have between 500 and 600 instruments and up to 30 onboard cameras, recording every aspect of vehicle operation. Five hundred HD channels will transmit this data live even when travelling at supersonic velocities.

Going for the record

Aerodynamicist Ron Ayers explains how he became involved with Richard Noble's speed record-breaking exploits

I first met Richard Noble in 1992. He was then the holder of the world land speed record, having achieved a figure of 633mph in 1983. On learning that I had an aeronautical background, and specialising in high-speed aerodynamics, he asked me to help him create a car to travel at supersonic speeds. My initial reaction (caused by ignorance of the effects of shockwaves at ground level, and the impracticability of having 800mph rolling roads in wind tunnels) was a strongly negative one. It was only after considerable thought that I told Richard that these problems could just conceivably be overcome. Even this modest reduction of pessimism was sufficient for Noble to introduce me to Glynne Bowsher, an experienced mechanical engineer who had previously worked on Thrust II, and we commenced designing. The team was subsequently augmented by Jeremy Bliss, who had extensive experience as a systems and suspension designer for the McLaren F1 team.

Having no automobile engineering experience, I needed to find a starting point so I looked at world land speed record history. Clearly there are two separate records – wheel driven and jet/rocket driven.

In the half century from 1898 to 1947, when John Cobb reached 400mph (albeit in only one direction) the WLSR had increased by a factor of 10). In the seven decades since then, the wheel-driven record has increased only by a modest percentage, appearing to approach an asymptote. A similar asymptotic limit can be observed with jet cars.

From the first jet car record (407.45mph in 1983) to the breaching of 600mph took only 833 days. The percentage increase over subsequent decades has been very modest indeed. This curve looked to me like a barrier to further progress. In short, my target of 800mph did not look achievable by simply using a 'jet on a trolley'.

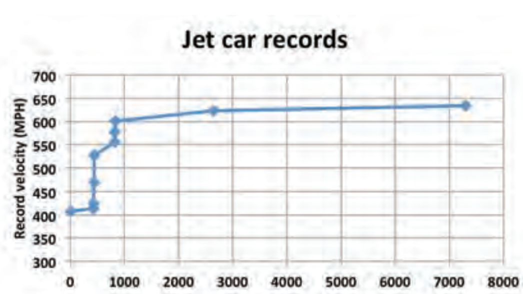
Two other possible solutions looked more promising. The first was using rocket propulsion. The Blue Flame car clearly had not achieved its full potential so this was a possibility. Unfortunately I did not have access to rocket technology at that time

The second was using two jet engines. A pair of Rolls-Royce Spey 202s was available for a few thousand pounds, so this was our chosen solution. These amazing engines ran 66 times, often ingesting sand, and never once presenting us with the slightest problem.

The layout of a single-engine jet car presents the problem of where to locate the driver. He can hardly sit astride the engine like a jockey, so the unattractive choice is between driver-out-front as with Spirit of America (driver very exposed), and driver-on-one-side as with Thrust II (big vehicle frontal area). With two jets the solution is obvious. The driver can be located at the vehicle's centre of gravity and protected by the enormously strong steel structure holding the two engines. The ratio of jet intake area/total frontal area is also much greater than for single-jet layouts, with obvious benefits for performance.

01 Ayers examines a model Bloodhound
Image: Stefan Marjoram

02 Thrust SSC broke the sound barrier in 1993



For structural reasons the engine mass had to be supported either by the front wheels or the rear wheels. Benefits, and problems, could be seen for both layouts. As our design team was so small, two unfunded people at that stage, we could only explore one option and had to make a choice. Our chosen layout, of mounting the engines over the front wheels, had immediate benefits with regards to stability but necessitated the use of rear-wheel steering. It also exposed the rear body panels to the jet efflux from the two jets. These problems did, indeed, subsequently prove to be severe. Rear-mounted engines have avoided these problems, but would we have encountered stability or other difficulties instead? We will never know.

The problem we had to explore was that of transonic ground effect. We could not do that using a wind tunnel as such tunnels could never be fitted with an 800mph rolling road. Swansea University agreed to use computational fluid dynamics (CFD). Its Cray computer, state of the art at that time, could process one million space elements, which proved to be just sufficient to handle symmetric configurations in inviscid flow. The following is a pressure picture produced in 1993 – long before anyone else was using CFD for design purposes. The strong shockwave visible across the middle of the body immortalised itself on Black Rock Desert.

My problem in 1993 was that no one else had ever trusted CFD for design purposes. Indeed, the opinions I received were of the type: 'Oh yes, we tried it once, the results were rubbish so we have ignored it since.' As Thrust SSC was the ultimate safety-critical project, I had to find some method of validating the CFD or we could not proceed. We designed and made a 1/25th scale model and instrumented it with high-frequency pressure sensors.

This model was accelerated from rest to 800mph in 0.8 seconds, using a battery of rockets.

Amazingly, the results of this pioneering CFD correlated very well with the pressure readings from these rocket tests. Independent experts confirmed that the accuracy of CFD had been reasonably established so we could use it for design work.

Ron Ayers is chief aerodynamicist for the Bloodhound SSC

Crossing the great divide

The triumphs and tragedies behind great feats of bridge engineering.

Stuart Nathan reports

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Bridges are icons of engineering, and with good reason. They're an undeniable example of what engineering can do, allowing passage across rivers or voids that would otherwise be insurmountable barriers. Their forms are mathematics made solid, their supports, curves and towers showing, often in a stripped-down form, exactly how the forces that allow vehicles and people to cross them are distributed through their structures. And often they have stories of overcoming challenges, ingenuity, triumph, and sometimes tragedy.

There isn't space here for an exhaustive study of bridges and their place in civil engineering; such a thing could fill many volumes. This article will confine itself to some highlights and milestones in bridge technology.

Britain's history with bridges goes back millennia. London, for example, owes its existence to the bridge technology available to the Romans; the city grew up around the lowest bridging point of the River Thames when Emperor Claudius's invasion forces established their encampments in 44AD.

Onward through the centuries, the development of new materials and methods of working with them drove bridge design, with notable examples being the world's first arch bridge made from cast iron, crossing the River Severn near Telford in Shropshire, which opened in 1781.

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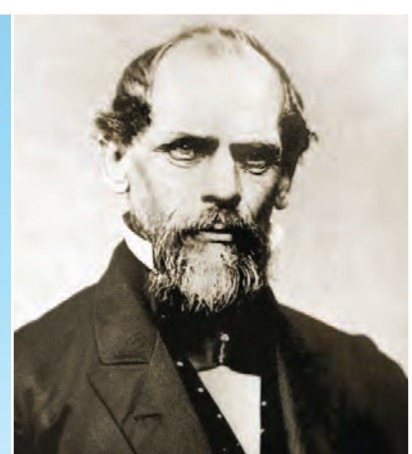

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01 Brooklyn Bridge, New York City

02 John Augustus Roebling

03 Emily Warren Roebling

Now an icon of the Industrial Revolution and a World Heritage Site, the Ironbridge was designed by architect Thomas Farnolls Pritchard and includes design elements of stone and wooden bridges.

When *The Engineer* was first launched in 1856, the state of the art in bridge technology was the suspension bridge, and one of the most famous examples of the design was in gestation. The city of Bristol had decided that the gorge formed by the River Avon in Clifton, in the west of the city, needed to be spanned, and had initiated a competition to select a design. Victorian Britain's best-known engineer, Isambard Kingdom Brunel, submitted four entries, but the competition collapsed after none of the designs were thought feasible. Another design, by the chief judge, another eminent Victorian engineer, Thomas Telford, could not be funded. In a second competition in 1831, Brunel was declared the winner after a private meeting with one of the judges. The span required for the bridge, a little over 214m, was so wide that even Brunel's father, civil engineer Marc Isambard Brunel (best known for the first Thames tunnel), thought it couldn't be crossed with a conventional suspension bridge; he advised his son that a central support would be needed, but the younger Brunel ignored him.

One reason for this may have been that Brunel had been granted permission to use a technology that had been patented by Sarah Guppy, a Bristolian woman whose eldest son had worked on the Great Western Railway, and become friendly with Brunel. Guppy patented a method for making safe pilings for bridge towers in 1811, which were particularly useful in sites where the foundations of the towers were in danger of being washed away. Guppy had already granted Telford permission to use


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this technology on his Menai Suspension Bridge linking Anglesey to the Welsh mainland in 1826, and did Brunel the same favour. By contemporary account, a shy woman who put great store by modesty, Guppy's contribution to the UK's bridges is still little known.

The Clifton Bridge is an early example of recycling in engineering. The chains that support the bridge deck (which, to the surprise of many, is made of wood reinforced with asphalt) were those from one of Brunel's earlier bridges, the Hungerford footbridge in London, which had been dismantled to make way for a new railway bridge into Charing Cross Station. The triple chains, specified by a revised design to strengthen the structure, devised by William Barlow and Sir John Hawkshaw, were of wrought iron, lower in carbon content, stronger than cast iron and more readily available than steel, which at that time was not yet made in sufficient quantities to be cost-effective. The chains are anchored in blocks of brickwork secured at the end of 25m-long tunnels at either end of the bridge, and the deck itself hung from vertical suspension rods. The bridge was completed in 1864, and opened in the same year.

By the 1880s steel had become more readily available and was the material of choice for another iconic bridge, the Forth Rail Bridge in Scotland. A cantilever bridge whose construction uses beams projecting horizontally but secured only at one end to support central bridge modules and carry the stresses of the structure and trains passing along it into granite piers on the bed of the River Forth, it was designed by railway engineers John Fowler and Benjamin Baker to replace an earlier design by Thomas Bouch, which was abandoned after his Tay Bridge collapsed in 1879.

The Forth Bridge has a near-twin across the Atlantic in Quebec with an ill-starred history. Built some years later than the Forth, the Quebec Bridge (which consists of one double-cantilever, rather than the Forth's three) collapsed twice during its construction. The first time, in 1907, resulted from mistakes made during the design calculations that meant the weight of the bridge was far in excess of its carrying capacity. The construction teams were warned of this, but the warnings only reached the site after the bridge had collapsed, killing 75 of the 86 workers on the site at the time.

A team, including Maurice Fitzmaurice, an engineer who had worked on the Forth Bridge, drafted a different and more massive design. Construction restarted, but in September 1916 a problem with lifting equipment caused a failure as the central section (between the two cantilever diamonds) was being moved into place, and it fell into the Quebec River, killing 13 workers. The fallen section is still on the riverbed. The bridge was finally competed in 1917, and, with a central span of 549m, remains the longest cantilever bridge span in the world.

The next major advance in bridge technology is also in the Americas, and is one of the world's iconic engineering structures. The Brooklyn Bridge in New York City, connecting Manhattan Island to the Outer Boroughs, embodies several innovations, probably the most of important of which are in its cables.

Although the Brooklyn Bridge resembles a suspension bridge, it isn't one – it's a hybrid. Between its two towers, the deck is supported like a suspension bridge, but on the landward side of the towers the cables form the distinctive fan-shape of the bridges that now dominate construction, the cable-stayed bridge. This means there was no need for the cables to be anchored some distance away on the landward side to carry the stresses into an anchor, such as on the Clifton Bridge.

The main engineering figures on the Brooklyn project were John Augustus Roebling, a German immigrant and steel maker, who had previously designed other >>

04 The Millau Viaduct, designed by Michel Virlogeux and Norman Foster

Britain's history with bridges goes back millennia. London's bridge technology, for example, came from the Romans


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05 Ironbridge, near Telford

06 Clifton Suspension Bridge

07 Clifton's recycled chains

08 The Quebec Bridge

09 The second Quebec collapse

>> suspension bridges in the US, and his family. Before emigrating to the US, Roebling had become interested in rope making because he believed the ropes that had been used to tow barges could be improved. He developed a method for making a rope from seven strands of steel wire, and later refined this into a system to spin the ropes into cables in situ during the bridge construction itself. Cables had been demonstrated as superior to chains for suspension bridges as early as 1830, but the technology had not at that point been available to make them.

Roebling's technique starts by stringing a 'pilot line' between the highest points of the support towers. A large spool of wire is placed at one end, and anchored in place. The free end is looped around a spinning wheel on the pilot line, and is sent to the other end, where it is again anchored (components called 'strand shoes' are used for this; they are basically eye bolts attached to a steel channel). This is continued until the desired thickness of cable is reached, which can be 125 up to 400 wires. Extra cables are added to make the entire structure, which is then compacted into a cylindrical shape using radial jacks, and the whole structure wrapped in more steel wire. Roebling also designed a steel reinforcing system to prevent the deck of the bridge twisting.


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Spinning the cables for the Brooklyn Bridge began in 1877 under the direction of Roebling's son Washington. In an early example of the bad luck that would dog the family's involvement in the project, Roebling senior's foot was crushed between a ferry and a piling while he was surveying the bridge site, and he died of tetanus contracted as a result of his injuries less than month after the accident.

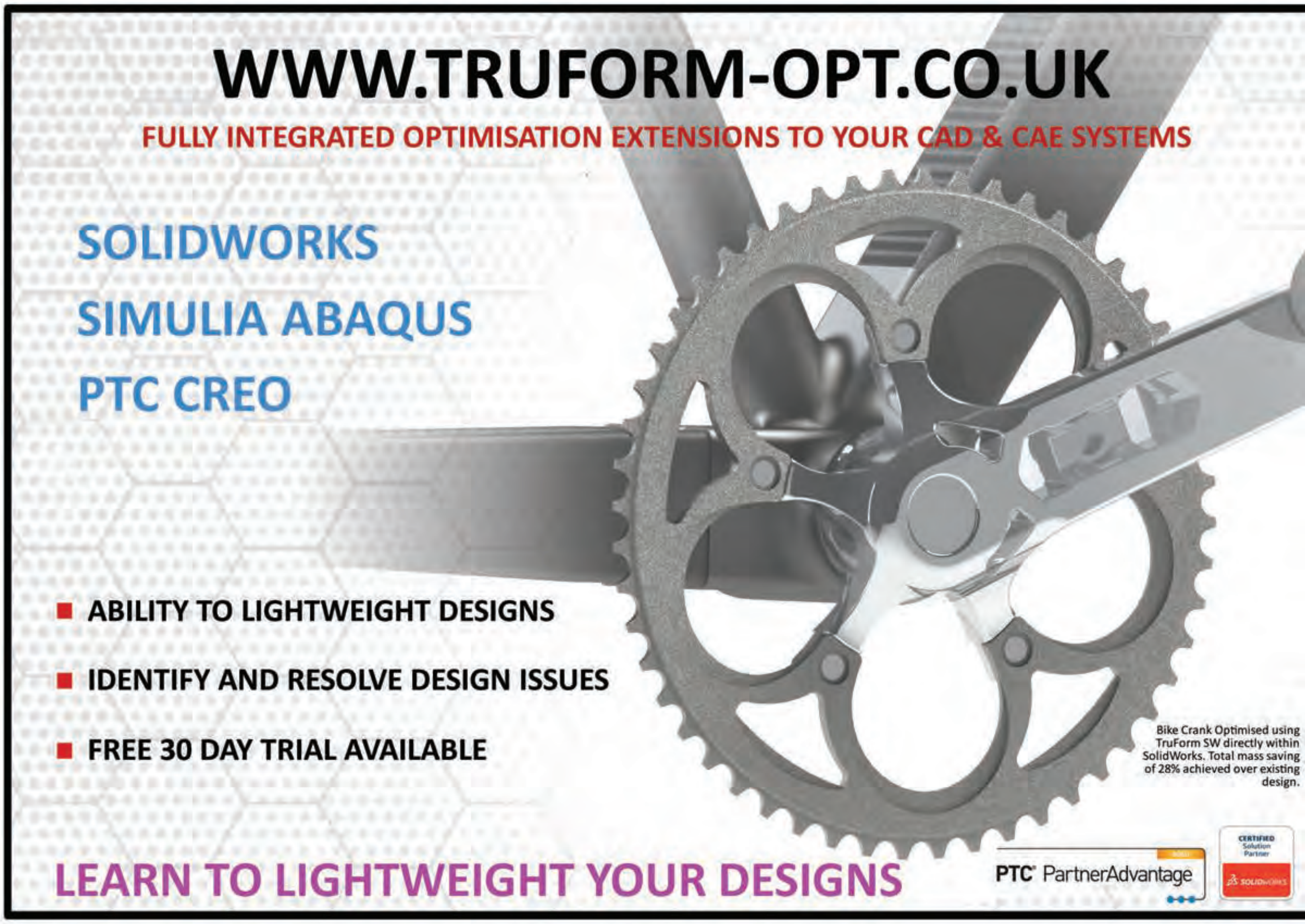
Misfortune was also to strike Washington. The bridge-supporting towers were built using caissons – upside-down cylinders that were placed on the river bed, inside which workers would excavate to sink the structure into the bed and form the foundations for the tower. Because of the water depth, the air inside the caissons had to be pressurised, and emerging from this pressurised environment was hazardous. Washington directed efforts to fight a fire inside a caisson (safety was poor, with dynamite used in the confined space), and, like many other bridge workers, he contracted decompression sickness, where nitrogen forced into solution in the blood in a high-pressure environment returns to its gaseous state as pressure is relieved, causing injuries, particularly to joints and lungs. Today it is known as 'the bends' and mainly affecting scuba divers, in the 19th century it was known as Caisson disease and also affected many workers on the Forth Bridge.

It left Washington paralysed and unable to supervise work in person, so his wife, the remarkable Emily Warren Roebling, learned higher mathematics, bridge construction and cable fabrication, and acted as day-to-day supervisor and project manager, although Washington remained formally chief engineer (Emily was the first person to cross the bridge when it opened in 1883). The Roebling family's unlucky relationship with engineering icons continued into the next generation, with Washington's nephew killed on the Titanic.

With its 486m span, making it 50 per cent longer than any other bridge when it was completed, Brooklyn remained the longest in the world for decades. Longer suspension bridges succeeded it, most of them using variations of Roebling's cable-spinning system, including the Golden Gate Bridge in San Francisco and in the UK, the Severn and Humber bridges. In more recent years, drawbacks in the technique have become apparent; on the Forth Road Bridge it is believed that moisture inadvertently incorporated into the cables during spinning in the damp and rainy environment of the Forth Estuary caused internal rusting of the wire strands that has led to subsequent breakages; this dramatically reduced the lifetime of the bridge (which was built in the 1960s) and led to it now being replaced by a new structure, currently under construction.

The new Forth crossing is, like many large bridge projects today, a cable-stayed bridge. In these, the stresses are transferred to the bridge towers and carried downward, rather than being transferred transversely by suspension cables that need to be anchored in the ground. This allows the deck to be built in sections, outward from the towers, rather than having to wait until the cables are fully constructed before hanging the roadway from them. Other notable cable-stayed designs include the QEII Bridge east of London, the Pont de Normandie across the Seine in Northern France, and the lofty Millau Viaduct in southern France.

All these constructions share a frugality of materials: typically using only two – steel and masonry, often concrete, which combines strength and versatility with cheapness. For this reason, major structural innovations are thought unlikely unless other materials are developed that can challenge the existing ones in value, as steel did with cast and wrought iron. Innovations in monitoring are likely throughout bridge structures to give earlier warning of component failure, as happened with the Forth Road Bridge. Self-healing concrete is also being considered for towers and decks.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A revolution in bridge design

There needs to be a radical re-think in relation to how bridges are constructed, inspected, maintained and replaced

Since the 1990s there has been considerable development in the design and construction of bridges, ranging from boutique footbridges to long-span bridges and large sea crossings. Widespread use of computers and involvement of architects has improved both the engineering quality and aesthetic appeal of bridges.

In many parts of the world waterways, whether wide rivers, bays and estuaries, have meant large detours and/or use of ferries, thus severely hindering the movement of people and goods and limiting socio-economic development. This has led to the bridging of these waterways with road and rail bridges, and, since the 1990s, several large sea-crossing bridges have been built, mainly in the Far East. In North America, many large bridges are reaching their service life, which has been as short as 70 years, and these need replacing. In the next few decades this trend is set to continue with more aesthetically appealing bridges and very large sea crossings such as between Java and Sumatra; between Hainan Island and the mainland in China; between China and Taiwan; the Bering Strait linking Russia and Alaska; the crossing across the Red Sea linking the Arabian Peninsula to Africa; and the Gibraltar crossing.

In engineering terms the major development has been the increase in span of cable-stay bridges that are set to replace suspension bridges up to a span range of 1,500m. Beyond 1,500m it will invariably be suspension bridges and, in both types, multi-span bridges will make large sea crossings possible.

But whatever type of long-span bridges are used there needs to be and will be a radical re-thinking on how bridges are constructed, inspected, maintained and replaced. Bridge technology will need to adapt techniques and materials being used in the off-shore, shipping and aircraft industry. Over-reliance on traditional materials such as steel and concrete will be replaced by use of lightweight composites for parts of the structure and use of synthetic materials such as kevlar for cables, will enable longer spans to be realised. Just like in the automobile and aircraft industry, parts of the bridge will be designed to be replaceable. It can even be foreseen that robust foundations with a life span greater than 300 years will be designed and built, while other parts of the bridge can have lower design life and be replaceable. This will increase the longevity of the bridges and lead to more sustainable bridges.

> "Structural monitoring is now a norm in bridges but wireless technology will enhance this"
>
> Naeem Hussain, Arup

> New materials and construction processes will enable longer spans on bridges to be achieved

A major development in sea crossings across deep water will be the use of offshore technology such as is being considered for the pioneering design and construction of the E39 motorway across the deep fjords in Norway. Suspension bridges with spans in excess of 2,500m with towers supported on floating tension-leg caissons are in an advanced stage of study and realisation. This technique, along with use of composites, will be the revolutionary breakthrough in bridge engineering.

The return on capital expenditure on large bridges can and will be increased by enabling foundations of long marine viaducts to also support wind turbines. Political will is required to enable this to be realised but public pressure for renewables and sustainability will force procuring agencies to invest in multi-use large crossings.

Fast-evolving digital technology will be increasingly adopted in the design and construction of bridges. Structural health monitoring is now a norm in bridge engineering but wireless technology will enhance this and, along with drones, will enable more focused inspection and maintenance to be carried out. The 3D printing of parts, offshore fabrication in factory conditions and use of robots in assembly will lead to safer work, reduction in capital expenditure and longer useable life.

In terms of bridge technology, the transformation of academic ideas into reality is within reach.

Naeem Hussain is global bridge design practice leader at Arup

On the evolving struggle for power

Technology, business, politics and personalities combined in the energy sector more than in any other industry. Stuart Nathan reports

The Engineer's founding in the midst of the Industrial Revolution gave our predecessors front-row seats on the start of many developments that have shaped our modern world, whether they realised it or not. Less than 20 years before Charles Healey put the first issue of the journal together from his offices on the Strand, Michael Faraday was in the basement of the Royal Institution, a few hundred yards away, laying the first foundations for the revolution that would see electricity become our primary source of energy for many of the activities that make up our lives.

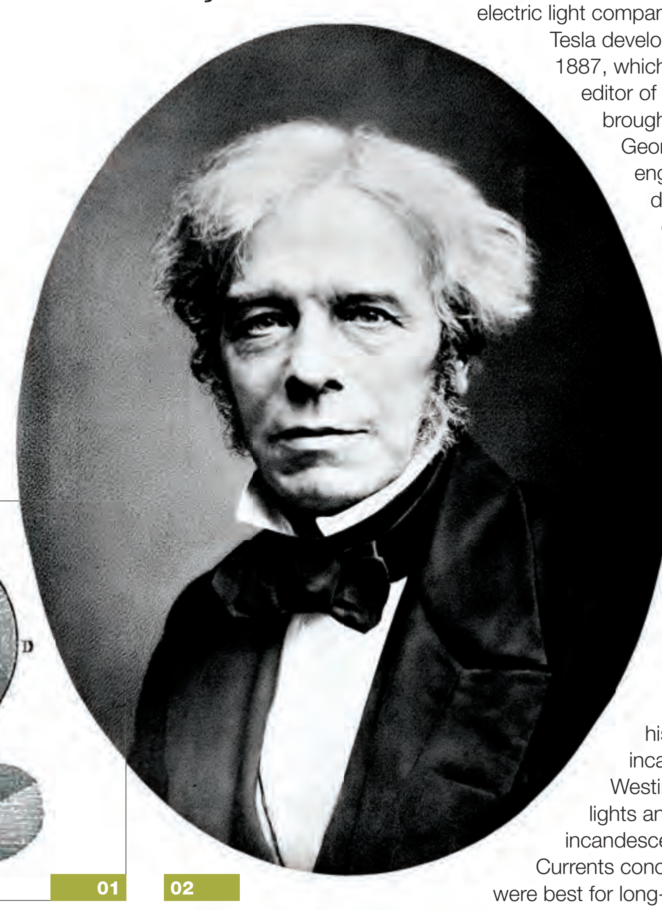
Faraday was a polymath, as involved in chemistry as he was in physics. His most significant discovery for the energy sector was that of electromagnetic induction in a series of experiments beginning in 1831; these demonstrated that moving a small coil of wire through which an electric current is circulating into or out of a larger coil causes a current to flow in the larger coil. Faraday's realisation that a changing magnetic field produces an electric field is at the basis of field theory, which underpins much of our understanding of the fundamental forces of nature, but its significance for the energy sector is that it led Faraday to build the first electrical generator, a simple piece of equipment with a metal disc rotating in a plane perpendicular to a static magnetic field. Although not a practical method for generating useful electricity, the Faraday wheel contains the vital elements that continue to form the basis of generators in every form of energy generation used today apart from photovoltaic solar.

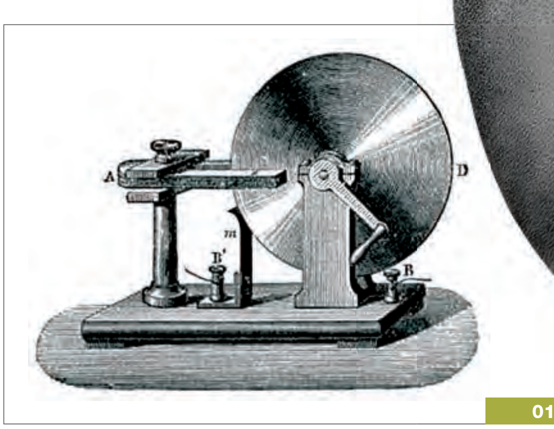
Such was the interest in electricity from the mid-to-late 19th century that Faraday's discovery remained a source of inspiration even after it became obvious that, in itself, it was not especially useful. Subsequent improvements on the design incorporated magnets into the rotating component and, in 1883, A Floyd Delafield of Connecticut patented a simplified version of a dynamo that did not require a commutator (a moving switch that reverses the direction of current flow between the rotor and external circuit). Delafield and Faraday's work inspired the Serbian-American genius Nikola Tesla, who patented his own design of dynamo in 1889. Tesla had moved to the US in 1884 to work for Thomas Edison, where he completely redesigned Edison's motor and generator, an event that seems to have led directly to the two men falling out, as Tesla thought Edison had promised him $50,000 if he could complete the task. Edison claimed to have been joking, and offered Tesla a $10-per-week raise on his $18-per-week salary; the Serb promptly resigned and founded his own electric light company.

> The War of the Currents concerned whether DC or AC were best for long-distance distribution of electricity

Tesla developed an induction motor in 1887, which (via his friendship with the editor of the journal *Electrical World*) brought him to the attention of George Westinghouse, whose engineers had been trying to develop an alternating-current motor and power system. Electricity was spreading through cities by that time, thanks to the near-simultaneous invention of the electric light bulb by Edison in the US and Thomas Swan in the UK; Westinghouse took Tesla on as a consultant and set him to work on developing an AC system to power streetcars in Pittsburgh.

This period led to a conflict known as the War of the Currents, where Edison tried to promote his DC technology (and incandescent light) over Westinghouse's AC (with arc lights and a different design of incandescent light). The War of the Currents concerned whether DC or AC were best for long-distance distribution and





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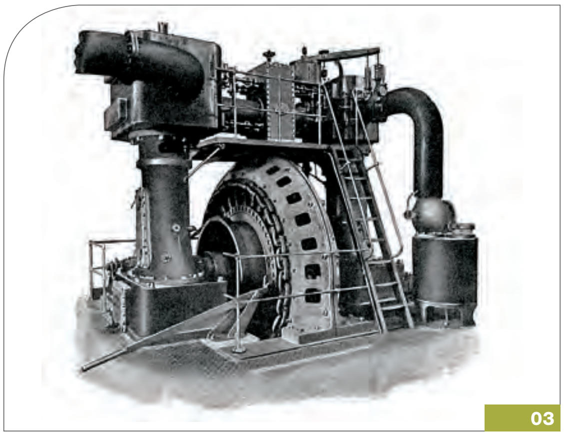
01 Michael Faraday discovered electromagnetic induction

02 The Faraday wheel contains vital elements still used in generators today



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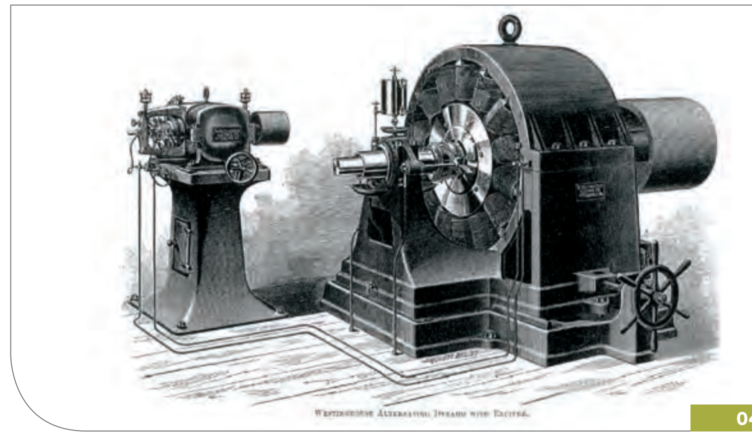

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03 The UK's first power station in Deptford was designed by Sebastian Ziani de Ferranti

04 Nikola Tesla developed this AC turbine for Westinghouse

which was safer; the simultaneous introduction of the electric chair as a method of execution in the US lent the whole farrago a lurid air. The 'War' came to an end with a series of scandals over executions, accidental electrocutions and a merger that sidelined Edison, who had been a vocal opponent of AC and led to him choosing to abandon the electrical business. But the crucial factor was probably technological: the adoption of a practical transformer that had been developed by the Hungarian team of Károly Zipernowsky, Ottó Bláthy and Miksa Déri in 1884. The ZBD high-efficiency closed-core shunt transformer allowed AC to be sent at high voltage along relatively small cables, then reduced in voltage to a level that could be used by consumers (DC, by contrast, had to be distributed at the voltage used in homes along large, expensive wires, and needed generating plants to be near to loads).

The UK was largely an onlooker in these events; the D'Oyly Carte theatre on the Strand became the first public building to be lit electrically when it opened in 1880, the House of Commons was lit with electric lights in 1881, and the Electric Lighting Act, passed in 1882, allowed supply systems to be established.

The country's first AC power station opened in Deptford in 1891. This was designed by Liverpool-born Sebastian Ziani de Ferranti, a prodigy who designed an arc-light system at 13 and a generator at 16; he patented a generator with the US patent office in 1886. Deptford, coal-fired and regarded as the world's first high-voltage power station, supplied electricity at the then unheard of voltage of 10,000V. It operated until 1957 (its sister plant, Deptord West, was demolished in 1991).

The National Grid started operating in 1933, allowing the spread of electricity across the UK; the post-war Labour government established the nationalised Central Electricity Generating Board in 1947, by which time the research that was to lead to the UK's pioneering place in the next major phase of power generation technology was well underway.

The UK was involved in the Manhattan Project to build the first nuclear weapons, with Britain's own nuclear weapon research (known cryptically as the Tube Alloys Project, and triggered by work on nuclear fission of uranium at the University of Birmingham by German refugees Otto Frisch and Rudolf Peierls, working under Australian physicist Mark Oliphant) subsumed into the larger endeavour.

After the war, the UK continued with its own nuclear weapons programme (hindered by the US making all Manhattan Project results classified, even from allies, which necessitated the repeating of some experiments). The first UK nuclear reactors were built at the Atomic Weapons Research Establishment in Harwell, and work began on the first civil nuclear reactors at Windscale in Cumbria in 1953. The first, Calder Hall, was a dual-purpose Magnox station; both producing plutonium for weapons and commercial power (Calder Hall stopped making military plutonium in 1964). Similar scaled-up Magnox nuclear stations were built across the country in the first civil nuclear programme; a new type of reactor, the Advanced Gas-Cooled Reactor (AGR) was developed at Windscale with a prototype plant coming on stream in 1963. Seven twin-reactor AGR power stations were built between 1963 and 1989, but a combination of technical problems, financing and changing political philosophies meant that an adapted version of the Westinghouse pressurised water reactor (PWR) was the last reactor to be built in the UK – at Sizewell in Suffolk – until the reactivation of the nuclear-build programme in the late 1990s that has led to the continuing controversy over the Hinkley Point C project.

Meanwhile, the UK has continued to be active in the development of renewable energy, particularly in the marine environment, with the contribution of Stephen Salter at Edinburgh University in wave power particularly notable, along with tidal stream energy. Nuclear fusion research has been most successful in the UK, with the Joint European Torus experiment at Culham leading the way for the design of ITER, planned to be the first reactor to demonstrate the feasibility of fusion controlled by electromagnetism on a large scale. Michael Faraday, equally at ease with conceptual atoms and practical electromagnets, would have approved.

The UK was involved in the Manhattan Project to build the first nuclear weapons

05

05 Calder Hall was a dual-purpose Magnox station

The shape of things to come

Mr HG Wells, author of popular scientific romance *The Time Machine*, turns the pages of *The Engineer* for clues as to the shape of our future

It is with trepidation that I approach my new commission: to consider the engineering marvels of the moment and speculate on their application in this approaching 20th century. The great minds of the age, from Baron Kelvin and Monsieur Eiffel to Messrs Tesla and Bell, may well peruse these pages as a matter of course, and what if such men were to look upon my suppositions and find them objectionable? The enterprise could be deemed disrespectful, the equivalency of an astrologer lecturing professionals. Yet I persevere, for I believe such minds are as much afflicted by an impatient curiosity as is my own.

The engineer may look upon the works of the past century with satisfaction, his rate of achievement ever more precipitous. Yet his advances have not come without cost. Well lamented are the depravations to which our working people are subjected in the service of mass production; much felt too is the depression of the past few decades. We can be sure that what we invent in the coming century has as much potential for destruction as progress. Here the speculator finds his purpose, as an enthusiastic but cautious force – a man calling to his friend perched on a cliff, reminding him to judge not only the plunge to the sea, but the powerful tide too.

We might look to the Paris skyline for a beacon of the potential change that confronts us. Monsieur Eiffel's tower suggests a future where man solves overcrowding by living at height, stacked in layered towers. We might well imagine a world where the workforce is moved about entire neighbourhoods of such lattices and platforms, like parts in a machine, ascending and descending between home and factory via Mr Reno's escalators and Mr Ferris's great wheels. We might create a terrible future London, where towers are so densely packed that street level is a choking maze of smoke, and ruling classes perch on the city's luxuriant rooftop, where the air is clear. Monitoring their restive population via Kinetoscopes and electric sound telegraphs, the rulers fail to notice a new form of communication forged in the volcanic heat of the city's core. A code tapped on metalwork, developed from Morse's, allows a new Guy Fawkes plot to succeed – detonating a tremendous eruption of molten steel and iron, burning away the upper crust and levelling society once again.

Still, if our present century were dedicated in honour of a singular profession, the designer of bridges may well consider himself the pre-eminent candidate. His ability to overcome the most daunting challenge has inspired and amazed; Napoleon's Dutch engineers improvised crossings of the Berezina in a matter of days, saving an army. Fowler and Baker's Forth Railway Bridge took eight years to erect, yet leaves a mark as immortal as the pyramids. Now the Channel Bridge and Railway Company proposes a 21-mile crossing over the English Channel, composed of 73 piers, supporting a deck 46ft above the highest tides!

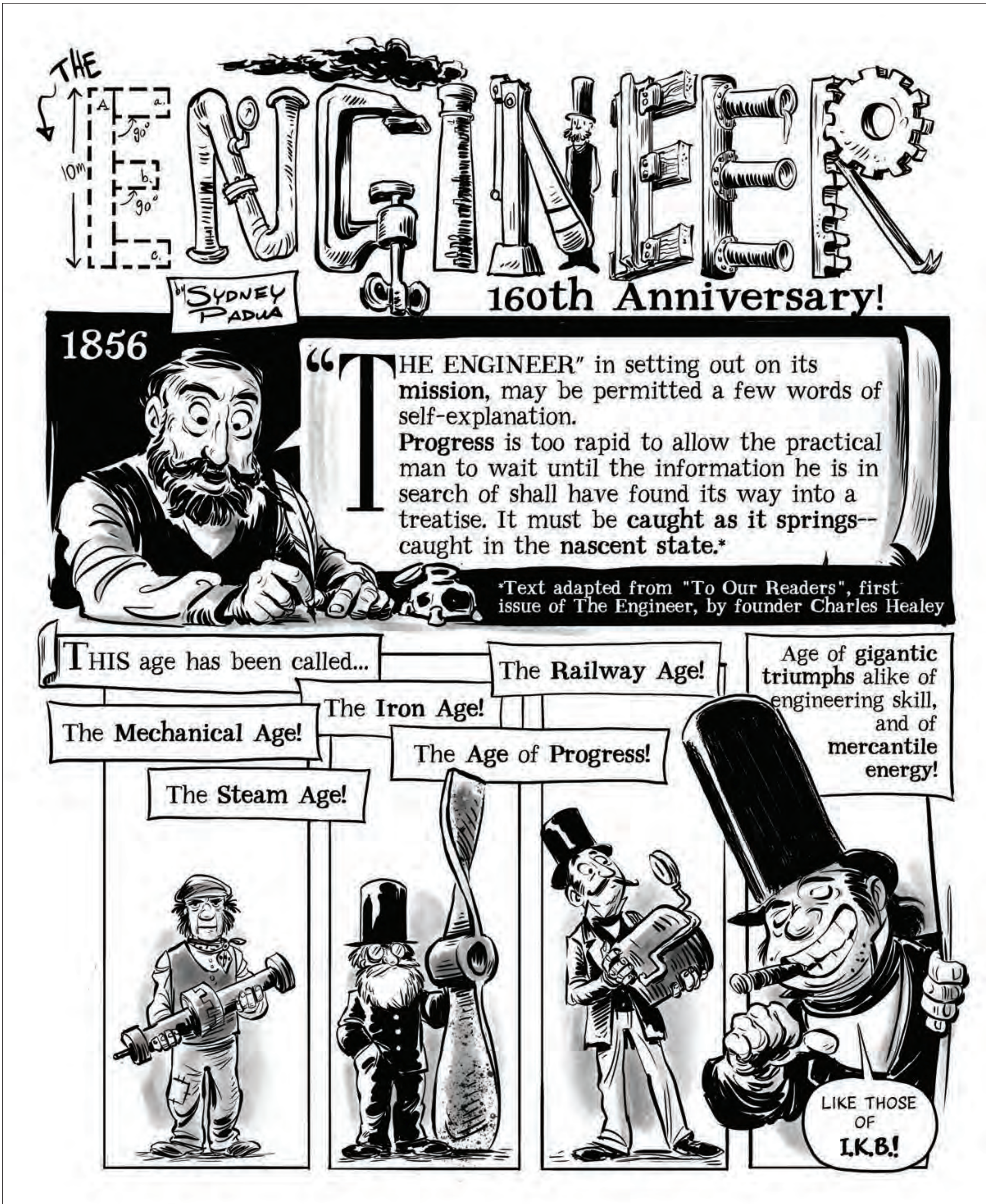
Here I cannot help but think of Messrs Tesla and Westinghouse's hydroelectric power station at Niagara, and its remarkable alternating current. This is a revolution that promises, by subjugating nature's forces, to unite both north and south of that nation through abundant, affordable power. Why, then, should the Channel Bridge not serve similar ends? We might imagine future engineers fixing turbines in the Channel Bridge piers, harnessing tidal power for France and England alike, forbidding conflict through shared interest in a structure too precious to risk.

Might such colossi spread peace across our entire troubled continent? What of a dam erected at Gibraltar, lowering the Mediterranean and making vast new tracts cultivatable? Such huge undertakings might become quasi nations in themselves, growing myriads of balconies, buttresses and turrets to house an innumerable multitude of peoples dedicated to its maintenance. Interconnected by new railways and telegraphs, the sea ribbed by new causeways, powered by abundant hydro-electric power, the old borders could dissolve entirely into one great, Eurican body, the dams and bridges their main arteries.

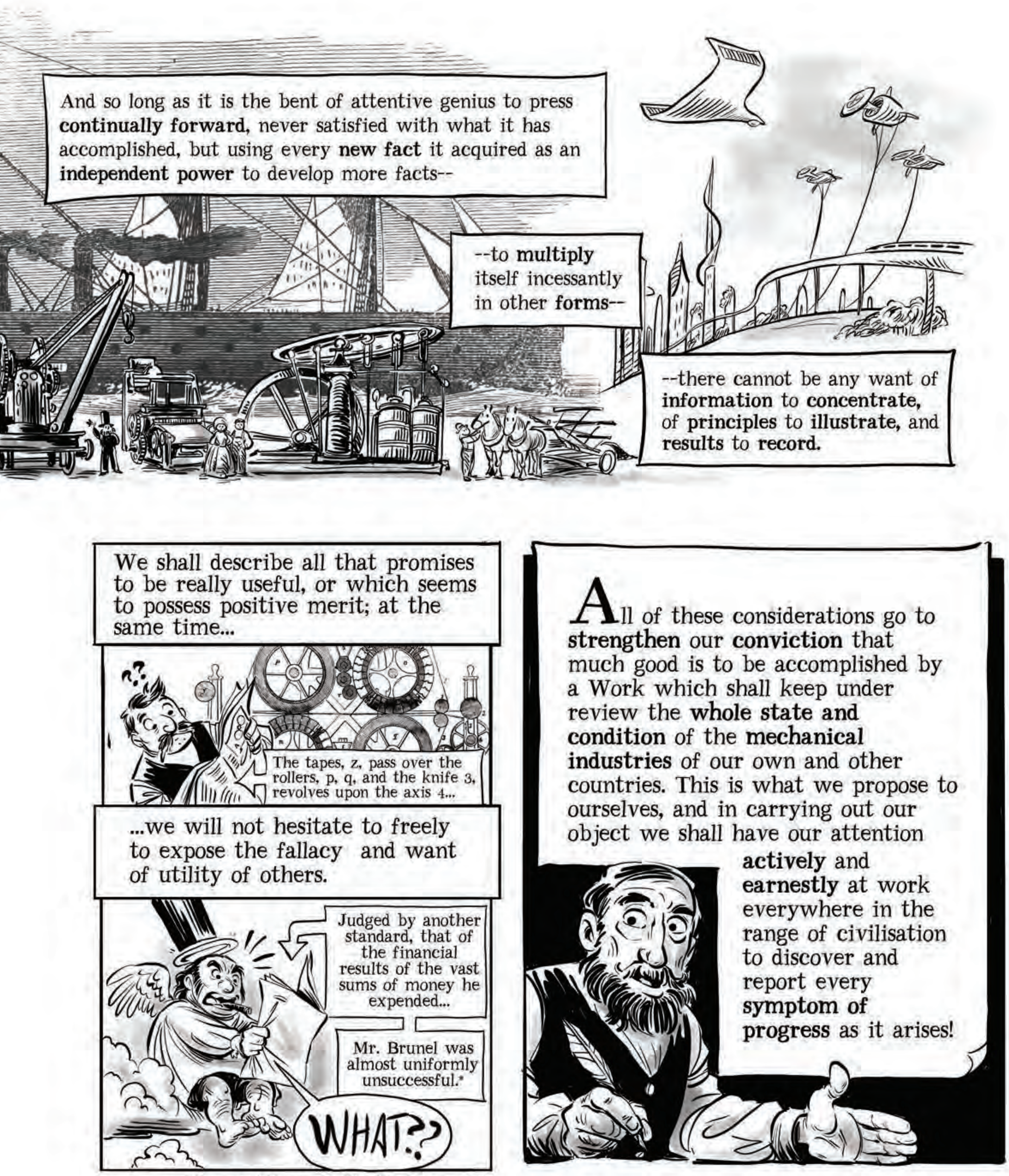
Human prejudice, I fear, may still intercede – even at a time of plenty. For though borders fall and travel eases, we cannot say that Mau Mau, Pole and Turk would find welcome in Kentish pub or Bavarian beer hall. We may imagine the tale of a band of English confederates, dedicated to the destruction of Eurica, and the restoration of borders both physical and social. Turning Herr Kroehls' ingenious submarine craft to their purpose, they torpedo the Gibraltar Dam, unleashing a biblical flood, and plunging Europe into a new dark age.

Hark! I can hear my new readers' dismay: "yours is a gloomy future". Well, it may not be so. Our capacity for invention has the promise to eliminate need, and unify mankind. Yet, we should not forget our capacity for corruption. Westinghouse's electricity brought us the electric chair, as well as the Niagara Power Plant. Engineers' power may serve the best and the worse of man; an alternating current indeed.

Mr Wells requests the Editor to state that those who have enjoyed his column might consider the work of Mr Jon Wallace, who is also much inclined to idle speculation on the nation's future


THE ENGINEER
by SYDNEY PADUA
160th Anniversary!
1856
"THE ENGINEER" in setting out on its **mission**, may be permitted a few words of self-explanation.
Progress is too rapid to allow the practical man to wait until the information he is in search of shall have found its way into a treatise. It must be **caught as it springs**-- caught in the **nascent state**.*
*Text adapted from "To Our Readers", first issue of The Engineer, by founder Charles Healey
THIS age has been called...
The **Railway Age!**
The **Iron Age!**
The **Mechanical Age!**
The **Age** of **Progress!**
The **Steam Age!**
Age of **gigantic triumphs** alike of engineering skill, and of **mercantile energy!**
LIKE THOSE OF I.K.B.!


Industrial progress seems to have become a necessary condition of our social state: we cannot be permitted to look back with satisfaction on what has been achieved, without being reminded that there are yet demands of comfort and convenience unsatisfied.
When the great burden of hard work and manipulation is turned over upon the iron hand and fingers of machines, which we have taught to carry for us...
TO DRAW FROM THE BOWELS OF THE EARTH ITS OWN ELEMENT, AND THE MATERIALS FOR ITS REPRODUCTION!
TO DIG AND DRAW WATER FOR US!
SOW AND REAP, GRIND AND BAKE FOR US!
WHEN WE EMPLOY WIND AND WATER AS A POWER AND AS A PATHWAY, MAKE THE TIDES TO WORK FOR US!
FORGE AND BLOW, WELD AND RIVET!
TO SPIN, WEAVE, KNIT AND SEW!
WHEN WE HAVE TAUGHT IRON TO FLOAT AND SUPPLIED IT WITH AUTOMATIC ORGANS OF LOCOMOTION--
NO LESS GIGANTIC AND NOT LESS WONDERFUL FOR BEAUTY OF ADAPTION THAN FOR MAGNITUDE AND POWER!
...there is certainly no want of scope for our exertions.



*Brunel obituary in The Engineer, 1859

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In pursuit of an efficient future

Sustainability and not speed is driving innovation in aerospace.
Andrew Wade reports

Flight as we know it today can be traced all the way back to Sir George Cayley, often referred to as the 'father of aviation'. Born in Scarborough in 1773 (a place he would go on to represent as a Whig Party MP), Cayley devised the first recognisable aeroplane concept in 1799 when he proposed a fixed-wing flying machine with separate systems for lift, propulsion and control.

The Yorkshireman was also the first to identify the four core aeronautic forces of weight, lift, drag and thrust. These forces – and the cambered wings that Cayley devised to help master them – still underpin aviation today. Indeed, without Cayley's scientifically rigorous approach to aerodynamics, it is doubtful the Wright brothers would have enjoyed their much-lauded success at Kitty Hawk, almost 50 years after the Englishman's death.

Another fine testament to Cayley's legacy in Britain can be found at the Royal Aeronautical Society, an organisation founded in 1866, just 10 years after *The Engineer*. As part of its 150th celebrations, the RAeS recently held a conference entitled 'What Price Speed?', which provided both a fascinating retrospective on aviation innovation, as well as a glimpse of what the future might hold.

While speed has always captured the imagination of aviation's pioneers, the RAeS conference looked at how economic and environmental factors are shaping today's aircraft. Among presentations on the possibilities of hypersonic flight and advanced engine technology, there were also talks on new British airship Airlander (which will soon take to the skies for UK test flights), as well as the future of turbo-props. But in the context of passenger flight, perhaps the most intriguing contribution came from Rolls-Royce, an icon of British aviation for more than a century.

The presentation was delivered by Phil Curnock, chief engineer for Civil Large Engines Future Programmes at Rolls-Royce. With the company since 1996, Curnock is Rolls through and through, his father having also spent 40 years there as an engineer. His affable manner is underpinned by a keen technical insight, alongside an ability to clearly frame the challenges that passenger flight now faces.

"I work in the large civil business, and we've been pretty much flying at the same speed for a long time now," Curnock explained. "We're not drastically going to alter that in the near future. When I talk to Boeing and Airbus at the moment, they don't talk about going faster, they talk about flying cheaper and with less fuel."

Since the dawn of the passenger jet age with the de Havilland Comet, engine fuel consumption has been reduced by around 40 per cent. When combined with the larger planes of today, overall fuel burn per seat has fallen by about 70 per cent. These efficiency gains have predominantly been made in two areas.

"There's two things we can do with a gas turbine fundamentally," said Curnock. "I've got propulsive efficiency and thermal efficiency. I can make my cycle more thermally efficient, run higher temperatures, smaller cores, higher pressure ratio – I can really drive that route if I want.

"The other route is propulsive efficiency. From a turbojet to a turbofan to a very high bypass-ratio turbofan to an open rotor, I can really drive up the propulsive efficiency… what we've basically been doing for the past number of years is both."

Over the near term – which Curnock identifies as the next 10 years – Rolls is launching two new engines that will help drive efficiency and reduce emissions. The first, called the Advance, will involve new core three-shaft architecture that redistributes the workload between the intermediate-pressure (IP) and high-pressure (HP) shafts, resulting in fewer parts and lower weight. It will have a bypass ratio of 11, a pressure ratio of 60:1, and overall efficiency gains of around 20 per cent compared with Rolls-Royce's Trent XWB, the current efficiency leader in the large engine market.

While the Advance should hopefully enter service around 2020, beyond that Rolls is also making plans to bring its UltraFan concept to fruition. Building on technology that should be ready to enter service in about 2025, the UltraFan will marry the Advance core technology with innovative high-temperature materials to push the overall pressure ratio to more than 70:1, with a bypass ratio of 15. Compared with today's engines, the UltraFan should offer a 25 per cent improvement on fuel burn.

And make no mistake, gains such as these will be absolutely essential if air travel is to have a sustainable **>>**

"When I talk to Boeing and Airbus at the moment, they don't talk about going faster, they talk about flying cheaper and with less fuel"

Phil Curnock, Rolls-Royce

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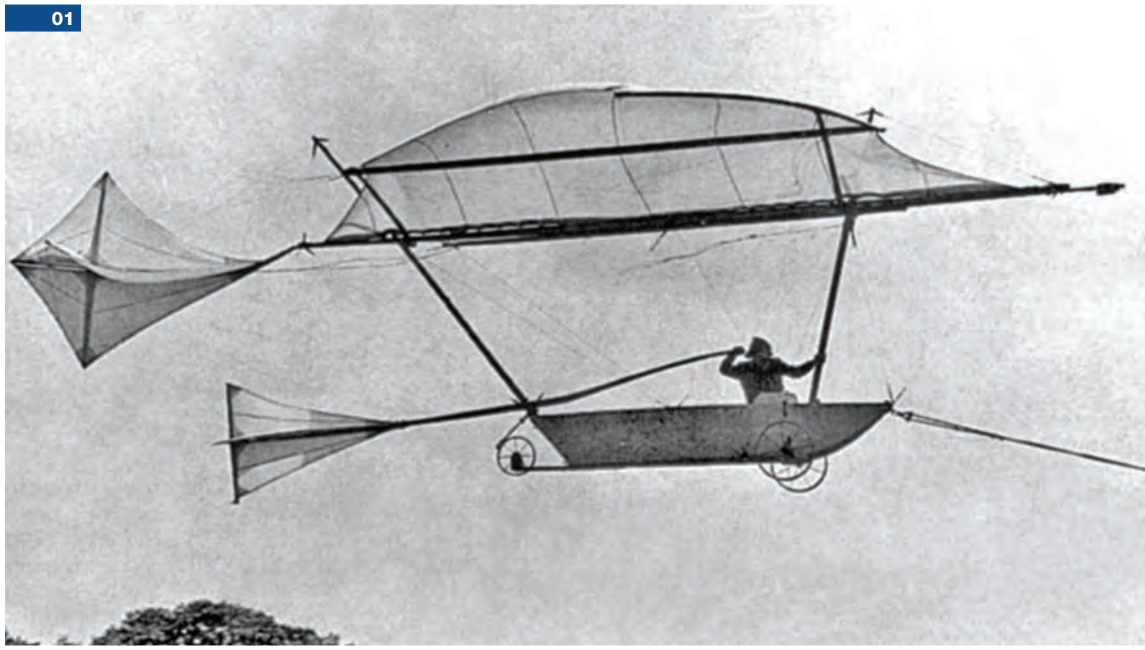

01 A replica of Cayley's glider flown in 1973

>> future. In 2015 there were approximately 22,500 passenger jets in service. That number is expected to double to over 45,000 over the next 20 years. Growth will be driven by a year-on-year increase in passenger numbers of around five per cent, with Asia's demand for single-aisle aircraft almost trebling between now and 2035. Over the next 20 years China's domestic traffic is expected to overtake North America, currently the largest single market.

Meanwhile, growing amounts of freight are also being moved by air, pushing demand for wide-bodied aircraft. High-value commodities such as perishable goods and consumer electronics are increasingly being moved via the skies, making the need for greener flight even greater.

But the push for efficiency doesn't tell the whole story. As Curnock points out, there is a small but growing percentage of the population for whom speed and comfort are paramount, with economy little more than a footnote. The number of billionaires in the world has trebled over the past 15 years, with many of them already travelling on private jets. If we are to see supersonic passenger travel re-emerge in the coming years, it will almost certainly come from this segment, perhaps supported by some travellers already willing to pay a premium for first- and business-class seats.

"For a billionaire owning a business jet, or maybe even a supersonic business jet, it's probably the same percentage of his annual wealth as you or I owning a family car," said Curnock. "About one in 20 people are already willing and able to pay a premium for service, comfort, convenience (in first and business class)."

02 Jet-efficiency gains have reduced fuel burn per seat by 70 per cent

03 Rolls-Royce's latest engine should bring 25 per cent fuel gains by 2015

04 A return to supersonic could reduce demand for first-class flight

02


03


A return to supersonic passenger flight would in all probability be bad for the *hoi polloi* who fly economy

04


Airlines make the vast majority of their profit from the customers willing to pay that premium for better-class seats. If those flying first and business are lost to a burgeoning supersonic jet sector over the coming years, the impact on the economy traveller could be dramatic.

"They make considerably more profit from the front of the aircraft than they do from the back," Curnock said. "So if that value stream is being taken away… does the economics of existing aircraft still work as well?"

So a return to supersonic passenger flight would in all probability be bad for the *hoi polloi* who fly economy – the author included – with airlines potentially losing out on the inflated fares that subsidise the cheap seats.

Those who pine for a return to the glory days of Concorde should be careful what they wish for. Unless, of course, they're used to turning left when they step on board, and could potentially stomach the supersonic price tag.

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The road to sustainability

The Mini was the herald for a new era of environmental sensibility in automotive engineering. Jason Ford reports

In 1959 *The Engineer*'s editorial staff were no more acquainted with a crystal ball than the current team, so it's little wonder that a modest fanfare accompanied one of the greatest automotive triumphs of all time.

In its 28 August 1959 feature titled 'Simplified Small Car', an unnamed author wrote: "There has been announced by the British Motor Corporation a new small car which will be included among both the Austin and Morris ranges, under the names of 'Seven' and 'Mini Minor' respectively. The designer is Mr A Issigonis."

In 1995, the Mini was voted Car of the Century by readers of *Autocar* but it wasn't until 1969 – when production was concentrated at BMC's Longbridge Plant in the West Midlands – that both models were streamlined and Mini as a standalone brand came into being.

In the interim, Issigonis' masterpiece had sold over a million units in its first six years, a period in which the marque was joined by the Mini Van, Mini Pick-Up, Morris Mini-Traveller and Austin Seven Countryman estate.

Issigonis' brief was to develop an affordable four-seat car that would be able to cope with increasingly dense inner-city traffic and gain mass appeal in an age of oil shortages brought on by the Suez Crisis in 1956.

The result – a prototype of which was being driven within seven months – was a front-wheel-drive concept with the engine fitted crosswise at the front.

As our editorial predecessor wrote: "In assessing the performance and handling qualities, it is important to bear in mind that the car is essentially a minimum-cost design, and any shortcomings should not therefore be regarded as inseparable from the use of those features, such as rubber suspension, that are distinctive."

Measuring 3.05m in length and selling at a retail price of £496, the Mini was designed for small parking spaces and low budgets. By 4 October 2000 the classic Mini had ceased production, but had achieved global sales of over 5.3 million units by the time BMW stepped in to resurrect the brand in 2001.

For many, Issigonis and his colleagues at BMC had redefined the small, compact car and now – decades later – automotive engineers at the world's major OEMs are reinterpreting personal mobility in terms of powertrain and fuel efficiency, sustainable manufacturing, and the very act of driving itself.

One such entity is Ford Motor Company, whose Fiesta model celebrated 40 years of production in July 2016, and is the UK's best-selling car, with over four million sales.

Globally, Ford sold around 6,635,000 vehicles in 2015 and the company, in common with its competitors, is driven by profitability and sustainability.

Ford is delivering its Blueprint for Sustainability through a holistic approach to integrating sustainability in all life-cycle stages of its products, and in its manufacturing processes.

According to John Cangany, manager, corporate social responsibility communications at Ford, it has been working with industry leaders and brands to find pioneering uses for different waste streams. This, in turn, has led to seat fabrics made from at least 25 per cent post-industrial or post-consumer recycled content, plus rice-hull reinforced wire harnesses and kenaf-reinforced door interior panels.

A recent tie-up has seen Ford partner with tequila manufacturer Jose Cuervo to explore the use of agave fibres in vehicles and research projects include creating foam and other plastics from captured carbon dioxide, as well as testing algae, tomato peel, bamboo and guayule shrubs for future vehicle applications.

"We are substituting lightweight materials – such as advanced high-strength steels, aluminium, magnesium, natural fibres and nano-based materials – to reduce vehicle weight," said Cangany. "Some of our advanced engines, such as EcoBoost, further reduce overall vehicle weight.

"Our F-150 highlights not only our sustainability strategy to improve fuel efficiency through the use of lightweight materials, but also a partnership with [aluminium specialist] Novelis to promote a circular economy within the automotive industry through closed-loop recycling," he added. "We created a supply chain that allowed us to replace our steel body parts with recycled aluminium, effectively reducing the weight of the entire truck by about 700lb. As part of the closed-loop manufacturing process, we recycle enough aluminium to build 30,000 F-150 bodies every month." >>

Issigonis' brief was to develop an affordable four-seat car that would be able to cope with inner-city traffic

01/02
Unheralded at its launch, the Mini represented a major milestone in automotive lightweighting

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>> Another company working with Novelis is Jaguar Land Rover, a company that came into being via the numerous machinations that saw Issigonis' BMC merge with Jaguar Cars Ltd in 1966. Ford bought Jaguar in 1989 and by 2000 the US automaker had acquired Land Rover before selling both to Tata Motors in 2008 for £1.15bn.

Currently the UK's largest automotive business, the luxury sports and SUV producer has a target of 75 per cent recycled aluminium materials in its vehicles by 2020 and is making lightweight advances through the REALCAR (Recycled Aluminium Car) project.

Like Ford, JLR has reclaimed over 50,000 tonnes of aluminium scrap – or the weight of 200,000 XE body shells – back into the production process during 2015–16.

Around Britain, 11 press shops are realising a closed-loop segregation of waste aluminium scrap so that it can be sent back into production to be re-melted into recycled aluminium sheet for use in JLR's vehicles.

The structural grade of recycled aluminium – which requires up to 95 per cent less energy than primary aluminium production – has been introduced in the bodies of the Jaguar XF and F-Pace models and a key part of the project – part funded by Innovate UK – was the development of Novelis RC5754, a recycled aluminium-based alloy that can accept a higher percentage of the recovered scrap.

JLR produces vehicles at three plants in the UK but Formula One luminary Gordon Murray proposes placing manufacturing facilities in the heart of the markets they will serve with iStream, a process developed at Gordon Murray Design that borrows from motorsports to bring a raft of environmental and business benefits to consumers and manufacturers.

The iStream process – which stands for stabilised tube-reinforced exoframe advanced manufacturing – replaces stamped steel with a composite monocoque bonded to a tubular steel frame.

Specifically, in the two-step iStream process, low-cost composite sandwich sections (iPanels) are bonded to a combination of thin-walled, manipulated steel tubes (iFrames) to form a stiff, impact-resistant structure.

In practice, a facility employing iStream requires 80 per cent less capital investment, uses 60 per cent less energy, produces cars that are 20 to 25 per cent lighter and more fuel-efficient than conventional cars in a factory footprint that is typically 70 per cent smaller than a traditional automotive plant.

This 'cradle-to-grave' philosophy ensures low energy and a high-efficiency approach at every stage, with the potential to pass on savings to the consumer and environment alike.

Another company adopting a 'clean-slate' philosophy is Riversimple, which plans to offer its Rasa FCEV (fuel cell electric vehicle) to consumers in a sale of service model that aims to capture 100 per cent of the revenue generated by the car. Company founder Hugo Spowers envisages similar flexibility in production, albeit at low volumes, so that small plants can be established to truly customise for much smaller niches.

The mantra at Riversimple is "to pursue, systematically, the elimination of the environmental impact of personal transport" but the future of automotive looks likely to take this further in its quest to eliminate deaths and injury altogether through vehicle autonomy.

The list of OEMs working on vehicle autonomy is considerable with the 2020s slated as the decade in which autonomous vehicles make their breakthrough.

Despite the hugely complex nature of such platforms, it is professions much older than *The Engineer* that could potentially hinder their progress, with debates centred on insurance and liability taking precedent over the engineering challenges that lie ahead.


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03/04 The Ford Fiesta is the UK's best-selling car

05/06 JLR is making lightweight advances through its REALCAR project

07/08 Riversimple's Rasa FCEV vehicle

Digital Britain

The UK has been a pioneer in the domain of fibre-optic communications and digital technology. Stuart Nathan reports

"There was a big pool of technically skilled talent around – people who had worked in telecoms, signalling and especially radar in the war"

Richard Epworth

Britain's contribution to digital technologies is not particularly well known; they're more associated with the US – the birthplace of the transistor and the home of many of the most influential hardware and software developers of recent years; or the Far East, which flooded markets with low-cost consumer electronics in the 1980s and 1990s. But Britain gave rise to important technologies, without which two of the most influential and pervasive aspects of the digital world – mobile telephony and computing, and the success of the Internet – would not exist. And innovations in digital technologies still abound in Britain, which may help computing to become even faster and advance our understanding about the most mysterious computer of all – the squishy organic one we all carry in our heads.

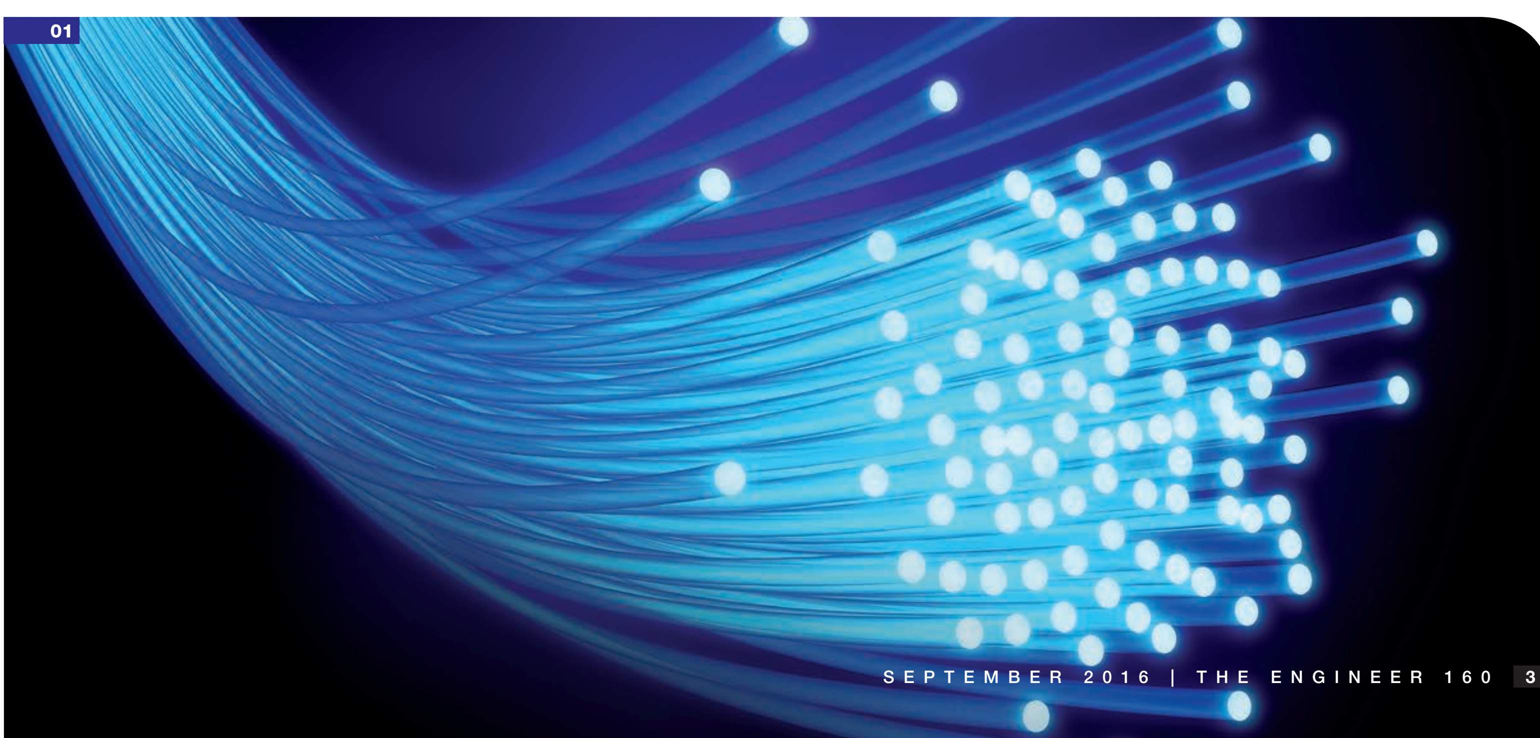
Of course, the invention of the World Wide Web by British computer scientist Tim Berners-Lee at CERN and his subsequent donation of the concept to the public domain is well known. But what's more obscure is that fibre-optic communications, the technology that allows the rapid, error-free transmission of vast quantities of data around the world, had its origin in the UK. "The Internet is only possible because the cost of communicating is very low, and independent of distance," said Richard Epworth, a member of the original team at Standard Telecommunications Laboratories (STL), where optical fibre was first developed in the 1960s.

Research into data transmission along optical fibre began because of the potential for low-loss communication offered by digital communication, Epworth told *The Engineer*. "The success of television led to a belief that in the following decades everyone would have a videophone, so there would be a need to transmit much more data," he explained. "And there was a big pool of technically skilled talent around – not necessarily graduates, but people who had worked in telecommunications, signalling and especially radar in the war, who were still young and looking for employment."

Optical communication was a popular choice because even then it was seen as being a good choice for digital technology, although not necessarily for electronics. "If you're transmitting an analogue signal electrically, by manipulating a current along a wire, then as soon as you have any interference or loss of signal quality, you have problems; you don't need much distortion at all before the signal becomes incomprehensible," Epworth said. "But if you're transmitting digitally, the signal is either on or off, and any distortion doesn't matter at all." It's exactly the same idea that made Morse code signalling so successful, he added; all that matters is whether there is any signal or not; and visible light Morse works at the speed of light. What fibre optics promised, Epworth said, was simply increasing the range of the visible light Morse idea and sending it around corners, plus the increase in speed compared with electrical signalling through copper. "The invention of the laser increased interest, and transmission through free space was studied, but it's too affected by weather, so some sort of guide for the light was obviously needed."

The principle underlying fibre optics was first demonstrated in 1842 in Paris, when Daniel Colladon and Jacques Babinet showed that light could be 'bent' inside a stream of water falling from a horizontal spout; the shallow angle of the light striking the interface between water and air caused it to be reflected inside the curved stream of water. This technique was used with glass fibres to provide illumination for dentistry and other medical examinations as early as the 1920s. This approach wasn't investigated >>

01 Fibre optics, invented in the UK, underpins much of the technology of the modern world

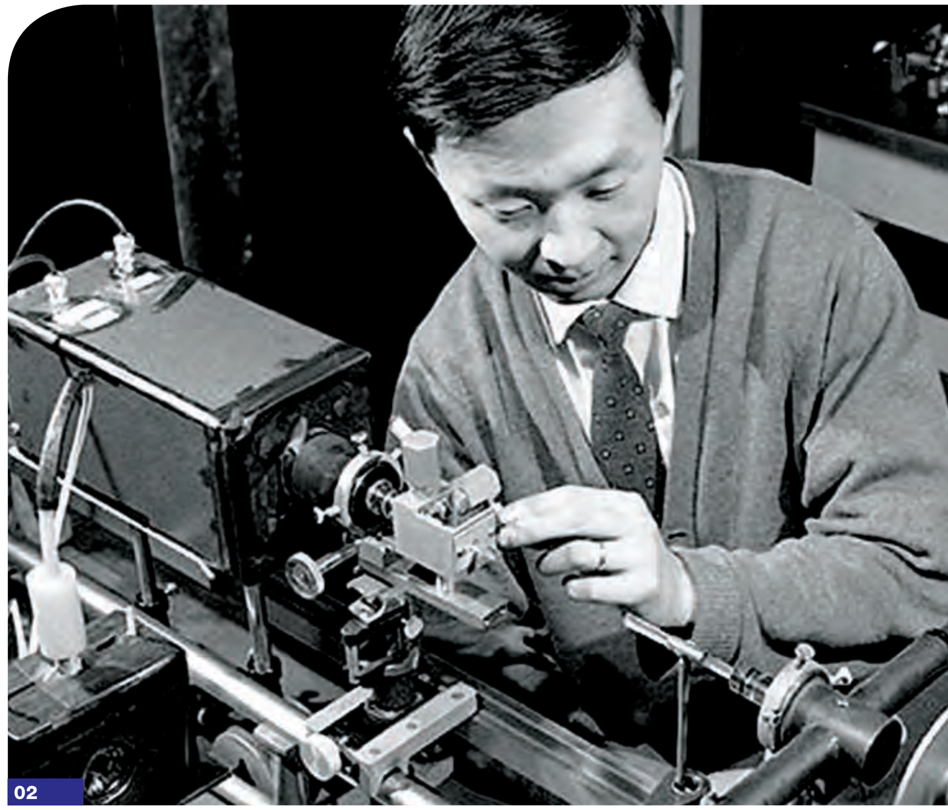


>> seriously initially, Epworth said, because the glass attenuated the signal too much.

Harlow-based STL was one of several research organisations trying to make optical communication work in the 1960s, he added, and the field was wide open with many avenues being explored. Initial research took the term 'light pipe' seriously – it used a hollow, air-filled tube with mirror-finish walls as the transmission medium. "We also did a lot of work around planar thin-films, and with using optical waveguides where the majority of the signal would actually be outside the transmission medium," Epworth said. "And for a while, it looked like the winning technique would be one using microwaves."

The breakthrough came courtesy of a researcher from Hong Kong, Charles Kuen Kao, who, working with microwave expert George Hockham, theorised that a purer glass than was currently available would be suitable for visible light transmission; his key realisation was that it was the purity of the material that was the problem, rather than the fundamental physics. Kao and Hockham's paper on the light transmission in a cladded glass-fibre carrier, published 50 years ago this year in the *Proceedings of the IEEE*, is recognised as the beginning of practical optical fibres, and was instrumental in winning the pair a share of the 2009 Nobel Prize for Physics.

Subsequently Kao toured the world trying to get other institutions interested in the technology, but it wasn't until Bell Labs succeeded in synthesising a very pure, ultra-transparent silica from elements that it was taken seriously commercially. The UK retained involvement in the early application of the technology, setting up the first transmission system between Hitchin and Stevenage, but the fact that it was a multi-national project, and that no commercial remnant of STL exists, means that its status as a UK innovation has slipped from the public consciousness, Epworth said. With Kao now suffering from advanced Alzheimer's disease, Epworth is keen to bring him and his work back to public knowledge.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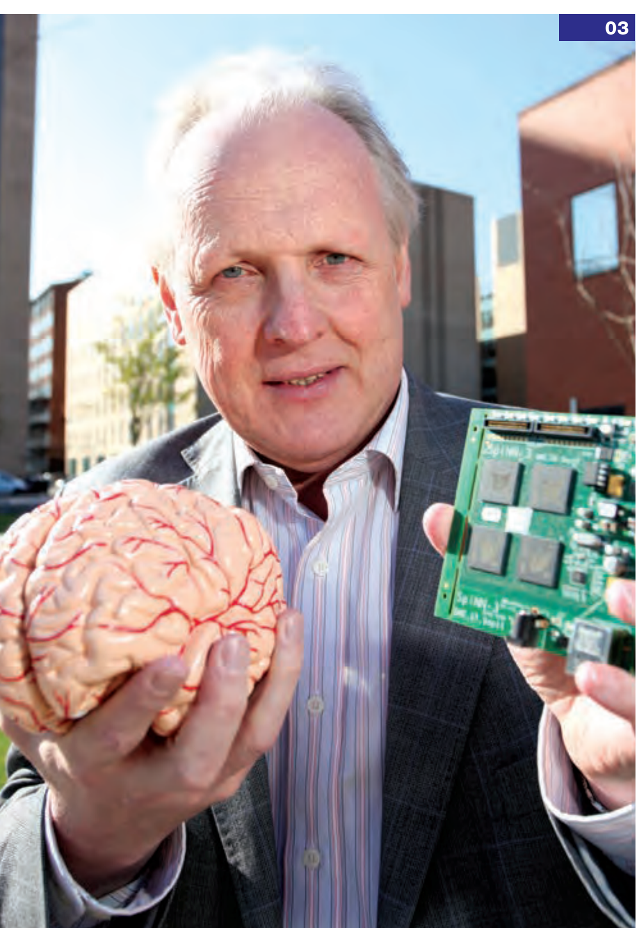
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The work of the optical fibre pioneers continues through optical computing research

02 Charles Kuen Kao, shown here working on the first fibre-optic apparatus at STL in 1956

03 Stephen Furber is now using RISC chips to model the human brain at Manchester University

Another major digital innovation is more in the public eye owing to commercial machinations. The RISC (Reduced Instruction Set Computing) microprocessor was developed by ARM (Acorn RISC Machine), by a team led by Stephen Furber. Talking to *The Engineer* in 2010, Furber explained that at the time, chip-making was dominated by US giants such as IBM, which had very set ideas on how chip architecture should work.

The ARM team's key breakthrough was in realising that it needn't be bound by these ideas and could design a chip without manufacturing it themselves. The result was a processor that consumed much less power than its competitors, an advantage that has seen its successors dominate the market for mobile phones, tablets and laptops. This success recently saw ARM bought by Japanese firm SoftBank for $42bn.

The work of the optical fibre pioneers continues through optical computing research, which uses light and quantum states to design processing systems that function at the speed of light. Optalysys, a Cambridge-based spin-out, is using diffraction, low-power lasers, liquid crystals and similar data processing techniques to those used in computational fluid dynamics to make a computer that works at exaFlop speeds (a billion billion calculations per second), and expects to unveil its prototype this year.

Meanwhile, Furber is using arrays of RISC chips (up to a million in total) in a project to simulate the calculating operations of the human brain by building silicon-based systems that can use fuzzy logic in the same way as neurons. The goal of the Spinnaker (Spiking Neural Network Architecture) project at Manchester University is to bridge the gap between the understanding of neurons and that of the whole brain. One outcome of this might be new treatments for Alzheimer's disease, along with more advanced, but lower-power, brains for robots.

Autonomy takes to the waves

The development of unmanned systems looks set to redefine the world of marine warfare.

Helen Knight reports

Causing the most damage to enemy forces and infrastructure, while limiting the risk to your own troops, has been at the heart of all military operations since the birth of warfare.

And one of the most effective ways of ensuring the safety of a nation's troops is to avoid putting them in harm's way in the first place.

To this end, naval forces around the world are increasingly looking at the potential for using unmanned marine vessels, which can carry out surveillance, search and rescue, and mine countermeasure operations, for example, without putting a human crew at risk.

But the use of autonomous systems in maritime warfare is nothing new. Indeed, the first such system, known as a Programmed Underwater Vehicle (PUV), was developed in the 19th century.

The PUV, which is better known as the torpedo, was the brainchild of British engineer Robert Whitehead.

Whitehead was working for marine boiler and engine maker Stabilimento Tecnico Fiumano in Fiume, now known as Rijeka, in Croatia, when he was contacted by Captain Giovanni Luppis of the Austro-Hungarian navy.

01 The US Navy funded work on the CURV ROV in the 1960s

02 BAE's PAC 450 driverless RIB

03/04 British engineer Robert Whitehead invented the torpedo

Luppis had come across papers written by an unknown officer in the Austrian Marine Artillery, which detailed an idea for a small boat steered by cables. This would be laden with explosives and used to target enemy ships.

Unhappy with his own attempts to build such a device, Luppis turned to Whitehead and the pair formed a partnership to develop a weapon based on the idea.

Rather than using a small boat launched from shore and controlled by ropes from the land, as Luppis had envisioned, Whitehead began to experiment with the idea of a ship-launched weapon that could be fired in a straight line at an enemy vessel.

The result was the world's first self-propelled underwater torpedo, known as the Minenschiff, or mine ship, which was presented to the Austro-Hungarian navy in December 1866.

The Minenschiff was 3.3m long, and capable of travelling at a speed of 13km per hour, driven by a small reciprocating engine powered by compressed air. It carried an explosive warhead, and could hit an enemy ship up to 640m away.

To improve the stability and control of the torpedo, Whitehead later added a hydrostatic valve and pendulum balance, connected to a horizontal rudder, to keep the device at a constant preset depth. A gyroscope mechanism, developed by Ludwig Obry, kept the torpedo running in a fixed direction.

Navies around the world quickly saw the potential of such a weapon and began adopting the technology. The speed, range and power of the torpedoes grew as their use increased, particularly during the two world wars.

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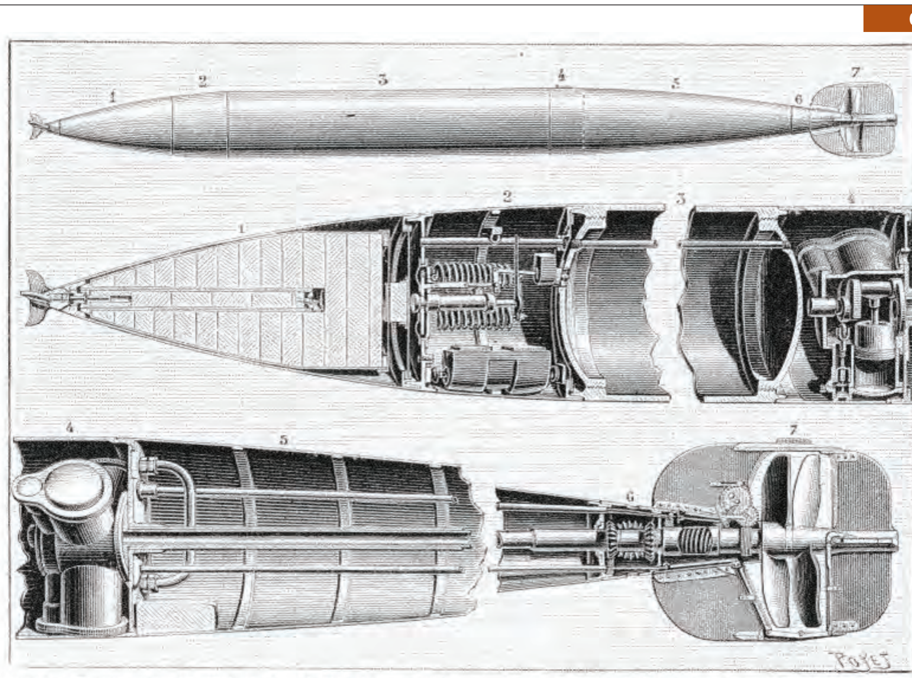
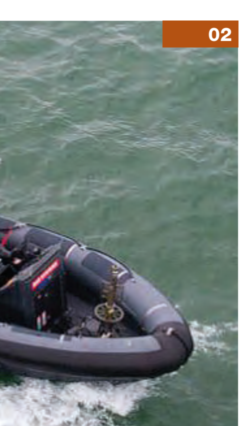


Fig. 1. — Torpille automobile Whitehead. — 1. Magasin. — 2. Chambre à secret. — 3. Réservoir d'air comprimé. — 4. Chambre des moteurs à air comprimé. — 5. Flotteur ou chambre de flottaison. — 6. Mécanisme de commande de rotation des hélices. — 7. Hélices et gouvernails.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However, while self-propelled torpedoes had become an extremely effective weapon by the end of the Second World War, human crews were still needed to carry out other, potentially dangerous operations. There were also operations that were simply not possible with a human crew. The US Navy, for example, wanted a way to recover ordnance lost during tests carried out in deep seas.

In 1953, Frenchman Dimitri Rebikoff developed the first remotely operated vehicle (ROV), which he christened Poodle. ROVs are unmanned vehicles, capable of performing deep-sea operations while connected to a surface vessel by a tether.

Rebikoff, who was also a keen diver and underwater photographer, had built an underwater scooter, the Torpille, in 1952, to help move through the ocean more easily. The following year he converted this into a ROV, capable of being controlled from the surface.

ROVs were further developed during the 1960s, when the US Navy funded work on a Cable-Controlled Underwater Recovery Vehicle (CURV), designed to perform deep-sea rescue operations, and recover objects from the ocean floor.

The CURV system made headlines in 1966 when it was used to recover an atomic bomb lost off the coast of Spain in an aircraft accident. It was later used to save the pilots of the Pisces submersible, with only minutes of air remaining, when the vehicle sunk off the Irish coast in 1973.

ROVs are still used today for mine clearance and inspection, and many deep-sea recovery operations, but their tethers tend to limit their speed and range.

Autonomous Underwater Vehicles (AUVs), in contrast, are not tethered or remotely controlled, and can operate independently of their surface vessel for hours or even days at a time. The vehicles follow a preset course, and can navigate using acoustic beacons on the sea floor, GPS, or inertial navigation with depth, inertial and velocity sensors.

The first AUVs were developed in the US in the 1960s and 1970s. Like ROVs, AUVs such as the US Navy's Swordfish Unmanned Underwater Vehicle are now used for operations including reconnaissance, mine countermeasures and mapping.

AUVs follow a pre-set course and can navigate using acoustic beacons on the sea floor, GPS or inertial navigation

The next stage in the development of autonomous systems technology for defence is likely to be the use of swarms of these unmanned vehicles, including both undersea and surface vessels, acting together to perform a given task.

The US Office of Naval Research (ONR), for example, has developed a kit that can be installed on almost any boat, to allow it to operate autonomously. The system, called Control Architecture for Robotic Agent Command and Sensing (CARACaS), allows boats to operate in tandem with other vessels, choose their own routes, and form a swarm to protect naval ships from enemy vehicles.

And in an ONR-sponsored demonstration at the Naval Air Station Patuxent River in Maryland in the US last year, unmanned undersea vehicles from the UK, Canada and the US worked together with an unmanned surface vehicle to search the ocean and sea floor for mines.

In the UK, the Royal Navy will hold a similar exercise this October. The Unmanned Warrior trials, which will take place off the coast of Scotland, will see aerial, underwater and surface vehicles undergo a series of challenges designed to test their capabilities.

One such vessel will be BAE Systems' autonomous rigid inflatable boat (RIB) the PAC950. The boat, which was developed with ASV, was recently tested successfully in Langstone Harbour, Portsmouth, where it autonomously intercepted a 'threat' boat.

The exercise will also test a mission planning and command-and-control system, known as Maritime Platform Exploitation (MAPLE), which is capable of integrating unmanned systems developed by different suppliers. In this way, the system, developed by a consortium involving BAE Systems and Qinetiq, will allow multiple operators to control multiple autonomous vehicles in unison.

So, the autonomous defence systems of the future will not just be simple weapons, but vehicles capable of cooperating with each other to perform a wide range of tasks, such as surveillance and fleet-protection operations.

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Making the future

The UK is leading the way in many areas of manufacturing technology.

Will Stirling reports

British manufacturing once meant making high-volume goods trying to compete on price, product development that lacked ambition, and heavily unionised and inflexible workforces. Today, things are very different. Manufacturing and the ecosystem that supports it is now built around a focus on advanced technologies and high-value products.

'World class' is a hackneyed phrase with no hard definition but the UK has some manufacturing expertise that can claim to be among the world's best. One is photonics. The Optoelectronics Research Centre (ORC) at the University of Southampton is a world-leading research centre for photonics research. This technology is both a UK-manufactured and exported product – consider laser machines, optical lenses and fibre optics – and, as centre leader Prof Sir David Payne said, a key enabling technology. "Photonics navigates airlines, it helps assemble aircraft, it cuts metal, it manufactures your smart phone. It is even found on the Moon, on the International Space Station and on Mars." The centre has created 11 spin-out companies to date, the largest, SPI Lasers, at £23 million turnover, has 248 employees and is now owned by Trumpf. In 2015 ORC won a £10 million bid to become one of two EPSRC Future Manufacturing Hubs, proving the importance of lasers to the UK economy.

FLITES (Fibre-Laser Imaging of gas Turbine Exhaust Species) is a now completed pan-European project to develop specific laser solutions for monitoring the efficiency of jet engines. The technology monitors how a Rolls-Rolls engine is performing in real time, so that its engineers are able to improve both the engine efficiency as it operates and the manufacturability of the engine. "The engineering challenge is huge because these have a near 2m diameter and operate in very harsh physical conditions," said Dr John Lincoln, industrial liaison manager at ORC. The specific technologies harnessed were the development of new lasers at new wavelengths, and using fibres to deliver light all the way around the engine's output. "We had to make the lasers themselves and get the light to where it was needed, in an extremely hostile environment, to probe that jet output in all three dimensions," added Lincoln.

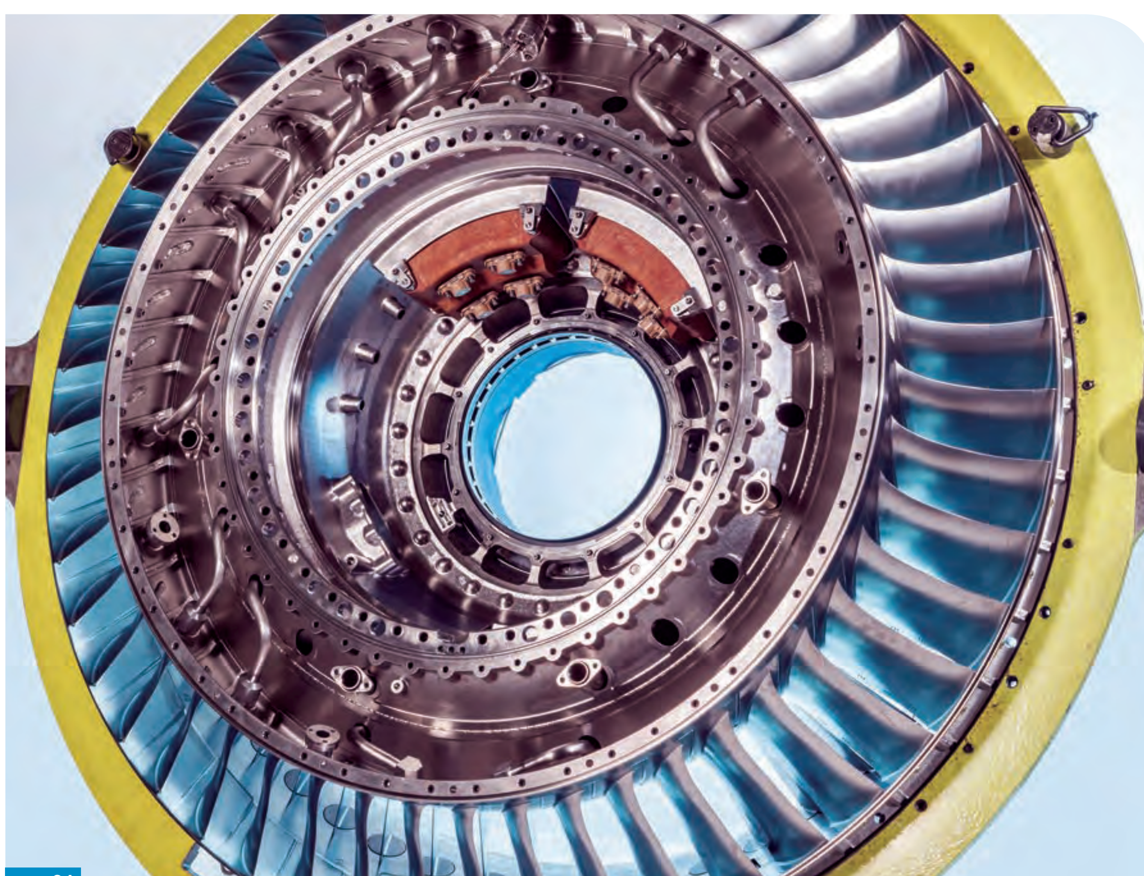
> "Photonics navigates airlines, it helps assemble aircraft, it manufactures your smart phone"
>
> Prof Sir David Payne, ORC

01 Rolls-Royce used AM to produce a 1.5m diameter bearing housing for the Trent XWB-97 engine

As well as developing a process, with industry partners, to manufacture a continuous fibre measuring 14km, research at the centre has created a new type of glass. It allows lasers to transmit into the infrared spectrum but with hitherto unachievable levels of purity. It means ORC's partners can manufacture these highly consistent lenses. This has garnered interest from the chemical detection industry, life sciences, the oil and gas industry, and from those involved in infrared imaging. "Without these lenses you cannot do the imaging and therefore you cannot do remote chemical detection economically," said Lincoln.

The Brits have a strong reputation for additive manufacturing (AM) expertise, even though – as is often the case – technology providers such as Stratasys (US), EOS (Germany) and Canon (Japan) are overseas companies. Some better-known breakthroughs in AM in the fabrication of large structures include the world's largest aeroengine component to be additively manufactured: a 1.5m-diameter load bearing housing for the Rolls-Royce XWB-7 engine programme. But UK engineers are finding applications for AM right across industry, including pharmaceuticals.

The Centre for Additive Manufacturing at the University of Nottingham is running projects funded by pharma company GlaxoSmithKline to design an AM process for manufacturing respiratory devices and to print tablets. Pharma companies wish to understand what advantages AM has over traditional tablet-making techniques, and the centre specialises in >>



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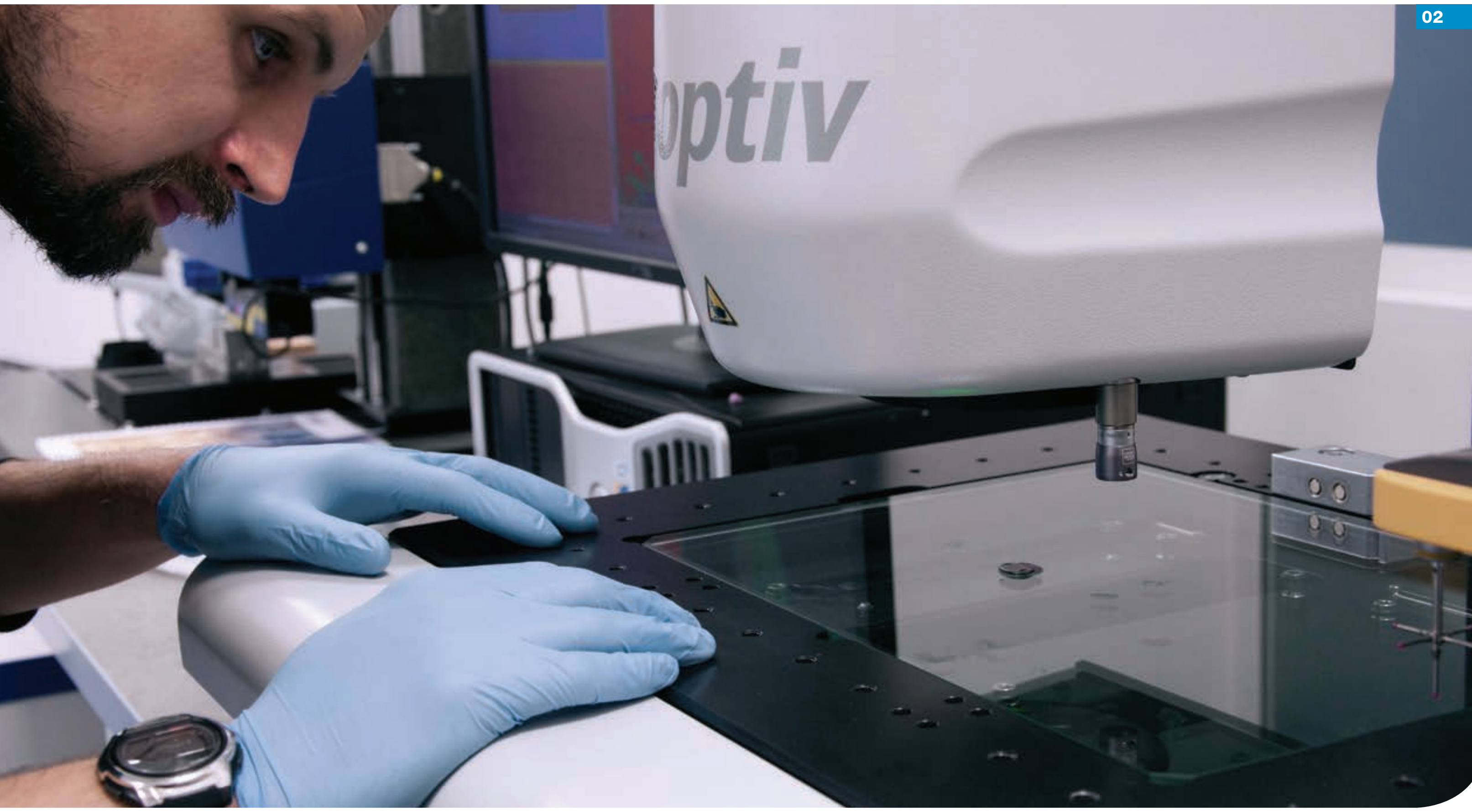

>> developing multi-material AM processes. "For pharma, you can grade a drug through a tablet and tailor the release profile, for example, and you can have more than one drug inside," said doctoral researcher Prof Ricky Wildman, director at Additive Scientific, a spin-out from the centre. "Then there are other benefits around distributed manufacturing and personalised medicine."

So AM is being used in the UK to realise the potential of personalised manufacturing – a Holy Grail in the next industrial revolution – to customise a drug without the normal costly changes to manufacturing process, such as retooling. "Modern medicine is providing analysis on a genotypical level at the moment, meaning you can start to individualise a diagnosis much more than previously," said Wildman. "To take advantage of this diagnosis you need a process to personalise the medicine. You could have the analysis in a hospital and within a few hours have that specific tablet ready for consumption."

To date, there have been no trials 'in-man' of AM or 3D-printed tablets with the exception of Aprecia Phamaceuticals' ZipDose, according to Wildman. Personalised AM drugs will move from the laboratory to the factory, the hospital, the pharmacy and will finally be printed in homes. He said: "It's conceivable that within five to 10 years, 3D printers for drugs will appear within hospital pharmacies." A new Additive Manufacturing Strategy is being prepared by the Manufacturing Technology Centre (MTC) and partners, and will feed into the government's National Innovation Plan.

Metrology is an area where the UK has strong R&D and an international technology provider with Renishaw. Better in-process metrology, where a component is measured and verified during the machining process, can affect a step change in productivity (a national obsession as the UK lags behind our peers). At the Advanced Manufacturing Research Centre with Boeing in Rotherham (AMRC), head of core research Tom McLeay said a typical project from an industry partner would request halving the cycle time for a process and halving the amount of manual intervention in that process, referred to as "double productivity". "For example, a part that takes 10 hours today also has an additional two hours' manual intervention, we would have to turn that 12-hour process into five hours of machining time and 30 minutes of intervention that might currently rely on rare skills and an ageing workforce," said McLeay.

"You could have analysis in a hospital and within a few hours have that specific 3D-printed tablet ready for consumption"

Prof Ricky Wildman, Additive Scientific

02
Photonics manufacturing is key to electronics

Working with Prof Andrew Longstaff at the University of Huddersfield, with support from the National Physical Laboratory and Renishaw, on-machine inspection techniques using new sensor types, such as ultrasonic thickness measurement of casings and shaft components, have been developed to reduce manual intervention. "On-machine inspection with probes is limited by access, so ultrasonic waves is a new technique to avoid this," McLeay said. But the improvements are also about machine tool calibration and verification, where these tasks are done autonomously in the process rather than taking the machine offline.

Renishaw's Sprint scanning probe, launched two years ago, is its on-machine measurement system. While hard numbers are under non-disclosure agreements, "during independent evaluation and testing of generic applications we typically expect a minimum of 75 per cent reduction compared to conventional probing measurement times and possibly more depending on application requirements", said Paul Maxted, director of industrial metrology applications at Renishaw.

High Value Manufacturing Catapult centres are focused on 'lights-out' processes, where stoppages, to check and measure parts and to remove swarf or burrs that interfere with the cutting tool, are removed. Machining is also a key area of productivity improvement where the UK shines. For example, the AMRC-assisted Boeing Portland in proving out new carbide cutting-tool technologies, providing a potential 67 per cent increase in metal-removal rates.

The list of high-value UK manufacturing techniques is growing, but needs investment for Britain to remain in the top-seven manufacturing economies globally.

Looking forward to a seamless journey

The likely future of rail will be created by a raft of near-invisible changes to our existing rail networks. Stephen Harris reports

Shooting across the landscape at top speeds of 760mph, the proposed vacuum tube train known as Hyperloop would supposedly be the fastest, safest, most efficient mass-transit system the world has ever seen. If it ever gets built. While several organisations are developing technology to make Elon Musk's proposed Hyperloop system a reality, the slow-moving nature of the rail industry and the government departments that fund it mean such ultra-fast travel on a mass scale remains a very distant possibility. The more likely future of rail travel for most people in the next few decades will be created by a raft of near-invisible changes to our existing networks that provide a smoother experience while meeting increased demand.

"The biggest impact for train users will be knowing they can get a seamless journey," said Colin Stewart, global rail leader for Arup and lead author of the consultancy's recent *Future of Rail 2050* report. "The user leaves their house and gets to where they're going in the fastest way… If I stop to get a coffee I want to know if I will miss my train and that, if I do, I can still run my journey smoothly from one end to the other."

Making this possible will partly rely on outside technologies that are already coming into use. This includes smartphone apps that translate real-time data from the transport network into simple, up-to-the-minute travel instructions. And others that automatically charge travellers for their journey without the need for tickets or even electronic travel-pass cards. Network operators will even be able to use the location information generated by passengers' phones and other wearable technology as they move around to better predict and respond to changes in demand in real time.

But adding such services to existing network capabilities won't be enough. Rising populations – particularly in cities and in the global middle class – and the need to reduce carbon emissions from transport mean demand for rail travel is expected to soar in the coming decades. The UK is already facing a serious capacity crunch on significant parts of its rail network.

"We have around 1.5 to 1.6 billion passenger journeys a year in the UK, and that is expected to double in the next 25 years," said Mark Ferrer, new technology director at Siemens Rail Automation. "We've got to do something about the capacity issue now. You can build new lines – HS2 and the rest – but at huge expense and it takes a long time. There are additional ways of also increasing capacity on the network we've got."

This means automation, not just in terms of self-driving trains but also of large swathes of operation, control and maintenance of the rail network. Replacing physical, track-side signals with digital instructions sent to onboard computers on every train means trains can run closer together, safely increasing the number of passengers transported in a given time.

This kind of technology, known in Europe as the European Train Control System, is already being installed, particularly in metropolitan railway systems. Siemens estimates that current upgrades to the Thameslink route through London will increase the number of trains that can run on the line from 16 to 24 an hour, with space for a further six if delays mean more vehicles are needed to catch up with demand. The next step will be to roll it out to other parts of the network. Network Rail's Digital Railway programme aims to increase capacity by 40 per cent in this way.

These systems also include automatic train operation, which mean trains will be able to calculate exactly when they need to use the accelerator or brake to travel between two points on a line in the fastest, most efficient way. Many modern metro systems already use this kind of driverless technology, such as those in Copenhagen and Dubai.

01

01 Dubai's driverless metro

02 New Delhi station *(credit: Ministry of Railways)*

03 Mercury concept train

04 Germany's CargoCap *(credit: Priestman Goode)*

03

A big concern for rail, as with all transport, is using less energy and moving to low-carbon sources

Eventually, however, we could see computers take over complete running of trains on national networks, opening up the possibility of virtual coupling, where separate trains can run in convoys without being physically joined in order to get even more vehicles on the line.

There are two key technologies needed to run these automated networks. One is artificial intelligence that can not only plan the most efficient timetables but also update them in real time and re-route trains in response to breakdowns, accidents and other delays. "Rerouting is all done by humans at the moment but that takes a lot of time and process, by which time the delay may have moved on and become much bigger," said Prof Clive Roberts, director of the University of Birmingham's Centre for Railway Research and Education. "Instead of relying on gut feelings you can use precise data and information… Dealing with minor perturbations can already be done automatically but the bigger issue is when a whole line goes down for several hours."

The other is the sensing technology needed to gather the real-time information about every train and section of track, which will also enable automatic maintenance. This could be done with embedded sensors, robotic wheelsets or even monitoring drones that fly around the network for closer inspection of problems and transmit information back to base. This will help operators spot signs of problems before they become serious and enable maintenance to be planned as needed at the most convenient times. Add to this technologies such as self-healing materials and you have a system that requires far less time when routes are out for repair work.

What about the physical design of the trains themselves? One big concern for rail, as with all transport systems, is using less energy and moving to more low-carbon sources. This means more focus on aerodynamic design and greater use of now-established technologies such as regenerative braking. It seems likely Britain will see many of these come into greater play when the high-speed line HS2 eventually opens from 2026.

There may also be greater electrification of existing networks, but Arup's Colin Stewart argued that isn't inevitable. "Electrification is actually pretty expensive, which is why it's not rolled out everywhere," he said. "Diesel trains are so much more efficient now they can almost compete with electric ones. We could see trains on less-used routes having a smarter propulsion system." He pointed to the prototype hydrogen-powered locomotive built by Birmingham University a few years ago and even suggested nuclear power may be an option.

Might a new form of mass transit such as mag-lev or Hyperloop ultimately be recognised as the smartest way to go? There's certainly a lot stacked against it, not least the question of whether it would provide enough benefit for customers and businesses to be worth the huge investment costs. "With such new technology you have the potential to introduce all sorts of new problems," said Birmingham University's Clive Roberts. "The mag-lev in Shanghai today looks rather tired and isn't running at top speed."

But Stewart argued there's a place for many different forms of rail travel in the future, each catering to the different needs of the part of the country or city they are covering. "In a dispersed city such as LA you could even envisage a system of mini pods that enter a major artery, connect until the other end and then come off." Together these will work with other new technologies such as driverless cars, all connected by masses of data to create the kind of seamless journey that customers are looking for.

02

04

the engineer timeline

theengineer.co.uk/the-engineer-160-3/

1856 *The Engineer* A new journal is born, promising that "little will escape our notice worth placing before our readers".
1856 Bessemer's steel Henry Bessemer explains his new process for "the manufacture of malleable iron and steel without fuel".
1859 The Great Eastern *The Engineer* reports from the deck of Brunel's mighty steamship on her first trial trip from moorings in Deptford.
1859 Isambard Kingdom Brunel "He seldom lost an opportunity for decrying against inventors and inventions." *The Engineer* publishes an unflattering obituary of the most famous engineer of his age.
1867 Bazalgette's sewers Abbey Mills pumping station, an integral part of Joseph Bazalgette's sewerage system for London, which helped rid the city of cholera, is examined by *The Engineer*.
1868 Traffic lights The first "street signals" are unveiled with much fanfare at Westminster, allowing MPs and lords to cross the road safely.
1871 Charles Babbage "A certain somnolence of temperament." *The Engineer* publishes its obituary of the inventor of the computer.
1877 The telephone *The Engineer* predicts the latest "wonder" invention will change the world and bring benefits to the whole "human family".
1880 The Tay Bridge disaster "We have no intention of going again over the harrowing details." *The Engineer* is in shock over the collapse of the Scottish bridge, which led to the deaths of up to 75 people.
1880 Edison's light What are we to make of the most recent claims of Mr Edison, a "comparatively uneducated" man with bold ideas?
1880 The Forth Bridge The world's first steel bridge is built across the Forth Estuary in Scotland.
1883 Brooklyn Bridge The Brooklyn Bridge opens in New York City; de facto chief engineer Emily Warren Roebling is the first to cross.
1893 Daimler's petrol motor Here is Mr Daimler's "ingenious and interesting" oil motor. It uses the lighter oils, also known as petrol. Will it catch on?
1894 Rollason's wind motor A new type of generator that uses wind to generate power. According to *The Engineer* its inventor is "on the right track".
1896 X-rays The remarkable story behind new rays detected by Prof Roentgen. Initially seen as a hoax, X-rays are now creating waves of their own.
1904 The first Rover The motorcycle company of Coventry has constructed a small motorcar, which *The Engineer* is pleased to show its readers.
1909 Passenger flight Samuel Cody pilots the first flights carrying passengers in his own aircraft, the Cody British Army Aeroplane No. 1, at Aldershot Aerodrome.
1909 Marconi's wireless Mr G Marconi recounts experiments in wireless telegraphy that won him the Nobel Prize for physics.
1912 The Titanic *The Engineer* considers the lessons to be learned from one of the great tragedies of the 20th century.
1923 Wembley Stadium The full story and pictures of the new Wembley Stadium.
1926 The new refrigerator This apparatus, placed on the market by Electrolux Ltd, has no moving parts whatsoever.
1926 Television *The Engineer* attends a demonstration of Mr JL Baird's invention, and finds that the results "leave a good deal to be desired".
1936 Alexandra Palace A television station is about to be tested for the BBC in North London. *The Engineer* tours the site of the new transmitter.
1942 The Merlin engine The inside story of how Rolls-Royce has made his legendary Spitfire engine even better, to the Luftwaffe's dismay.
1942 The Lancaster bomber *The Engineer* is invited to see Bomber Command's latest aircraft.
1945 The story of radar With the war won, the veil can be lifted from the remarkable new technology that gave the Allies a crucial edge.
1945 The Whittle jet engine Another wartime secret is free to grace the pages of *The Engineer* as Frank Whittle describes his work.
1954 Radiotherapy The technology behind the world's most advanced radiotherapy equipment, newly installed at Christie Hospital, Manchester.
1955 Colour TV The BBC's experiments with colour camera equipment herald a further historic leap in the story of television.
1955 The automatic factory Automation is the new industrial buzzword. What will the age of the industrial robot mean to business and workers?
1956 Calder Hall The opening of the world's first nuclear power station to generate electricity is a new era in Britain's energy policy.
1957 Sputnik "There is no question. The Russians have sprung a major surprise." *The Engineer*'s view of the world's first artificial satellite orbit.
1956 CERN The first particle accelerators are completed at the physics experiment in Geneva.
1966 Fibre optics Charles Kuen Kao and George Hockham publish the first paper on fibre-optic communications.
1967 Concorde unveiled Britain and France are united in pride as Concorde 001, the first of the new supersonic aircraft, is rolled out of its hangar.
1969 Apollo 11 *The Engineer*'s tribute to the unparalleled technical endeavour that made the moon landing possible.
1974 The micro computer Motorola assures *The Engineer* that a computing revolution is on the way. And the journal sees no reason to doubt it.
2008 Large Hadron Collider *The Engineer* marvels at the subterranean magnificence of the most complex machine ever made, as it begins work on unlocking the secrets of matter.
2014 HMS Queen Elizabeth The biggest ship ever built in Britain, the Royal Navy flagship aircraft carrier, is floated out of the dock where it was assembled.
2015 Crossrail The most ambitious civil engineering project in London for many years reaches a milestone with the completion of tunnelling.
2015 Rosetta mission The first successful landing of an unmanned probe on a comet.
2015 Bloodhound SSC The newly completed car is revealed to the public for the first time ahead of its attempts on the world land speed record.
2016 Gravity waves A landmark discovery in physics, as ripples in space time from the merging of two black holes are detected.

01 SS Great Eastern

02 The Merlin Engine

03 The Large Hadron Collider

04 Samuel Cody's aeroplane

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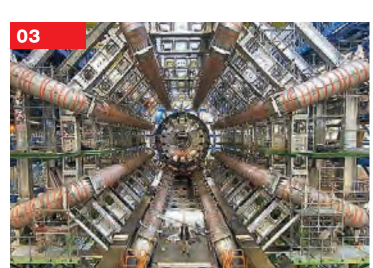
02


03


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