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the ENGINEER

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this**issue**

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news

opinion

features

our**opinion**

A storm on the way

Ahead of this summer's Farnborough International Airshow we ran a somewhat timely poll on *The Engineer*'s website asking readers whether they felt we might currently be seeing the last generation of manned military aircraft.

The response was fascinating, with just a third of those voting expecting the next generation of aircraft to have a pilot and the rest expecting them to be either fully autonomous or remotely operated.

Industry, though, had its own ideas. And just days later used Farnborough to take the wraps off 'Project Tempest', a £2bn effort to develop a new generation of fighter jet which, whilst bristling with all of the latest technology – including (potentially) directed energy weapons and a payload of drones – will still have a human pilot sitting in the cockpit.

Details so far are sketchy and it's unlikely that the eventual aircraft will look much like the hastily put together mock-up that graced BAE Systems' cavernous Farnborough display. But in this issue's cover story we glean what we can from the BAE engineers most closely involved in the project as well as a former RAF Air Marshal who talks candidly about what we might expect from a true 21st-century combat aircraft. We await with interest further details on a project that promises to dominate UK defence engineering in the years to come.

> "It's unlikely the eventual aircraft will look much like the hastily put together mock-up"

Elsewhere in this issue, we take a look at the final stages of a project that *The Engineer* has followed closely for almost a decade: the construction of London's new Elizabeth Line, aka Crossrail. In light of the much-publicised recent overrun, the project has had to abandon its once oft-repeated boast that it was on time and on budget, but it remains an incredible feat of engineering that we look forward to riding on when it opens at some point next year!

Finally, we profile those shortlisted for *The Engineer*'s 2018 Collaborate To Innovate awards (page 37). As in previous years, the sheer variety of projects on show is an inspiring reminder of both the UK's breadth of expertise and the many ways in which engineers are helping to address some of society's most fundamental challenges. The ultimate winners of this year's competition will be revealed in early November, and covered in detail in our November issue.

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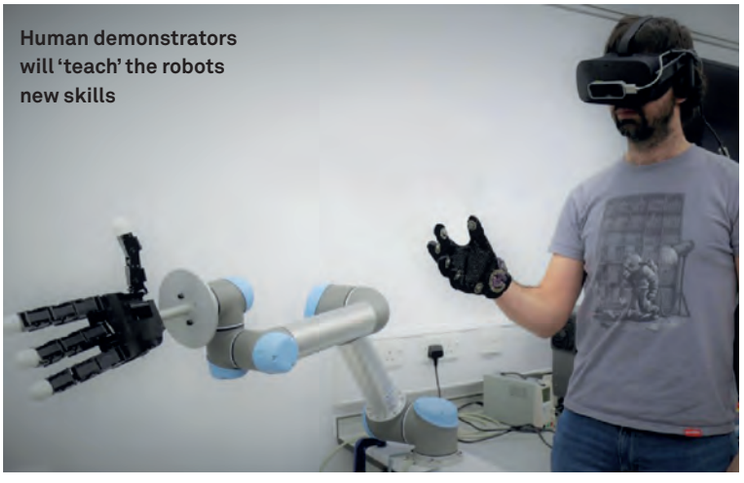
ROBOTICS

Taking robots to the next stage of evolution

Humans to pass on skills through gloves fitted with sensors HELEN KNIGHT REPORTS



Human demonstrators will 'teach' the robots new skills

The use of robots in global manufacturing has grown dramatically over the last decade.

However, despite this rise, robots are still typically limited to sectors such as the car industry, where they are used to carry out simple, repetitive tasks with solid components in carefully controlled conditions.

Now a team of EPSRC-funded researchers is hoping to teach robots to handle even delicate and irregular objects, expanding their use within sectors such as food and drink and consumer electronics industries.

The researchers, led by Dr Lorenzo Jamone at Queen Mary University of London, are developing a system based on virtual reality technologies and smart wearable devices, to allow robots to learn manipulation techniques by mimicking human demonstrators.

"Robots in industry today mainly deal with simple objects, so for example objects that are rigid, or those that are all identical, which allows them to use an analytical model," said Jamone. "Alternatively, robots are used for simple tasks such as picking and placing an object from the same position to another known position each time," he said.

Humans, in contrast, are adept at using their vision and sense of touch to adapt their grip when confronted with objects of a different shape or texture, or to perform different operations.

For robots to learn this skill from humans, the researchers plan to use teleoperation technologies, allowing the users to move a robotic hand just by moving their own. The human demonstrators will be equipped with gloves fitted with sensors, allowing the robot hand to detect and replicate their movements.

Simultaneously, the human will receive haptic feedback on what the robot is touching at any given moment.

Meanwhile, VR goggles will allow the human to 'see' through the robot's 3D vision system.

"The system will try to convey all of the sensory information to which the robot has access directly to the human, and give them the ability to move the robot," said Jamone. "In this way they can transfer their intelligence – in terms of what motions should be used to achieve certain manipulations – to the robot."

The robot will also be equipped with artificial intelligence algorithms to allow it to learn from the demonstrations, and from its own sensory information, he said.

The idea is that by using humans as demonstrators it will reduce the amount of time it takes for robots to learn these manipulation skills by themselves, by providing them with 'hints' that should cut down on the number of possible motions they need to try out.

The project, which includes robotic hand developer Shadow Robot Company, AI specialist DeepMind Technologies, and online grocer Ocado, should ultimately allow robots to develop intrinsic strategies for handling items such as food, said Jamone.

"We might teach the robot how to pick a banana and an apple, for example, and then it will be able to generalise that knowledge to decide how to pick up pears or avocado, because it will have learnt some consistent aspects of the fruits' structure," he said.

> "You need a way for the robot to learn from tactile and visual feedback"
> Dr Lorenzo Jamone, Queen Mary University of London

The approach could ultimately help to develop adaptable robots for other applications, such as nuclear decommissioning, remote infrastructure inspection, and space or deep sea exploration.

"These are all situations where a robot might need to manipulate objects, but you don't know what kind of objects it will face, or their properties," said Jamone.

"So you need a way for the robot to learn from tactile and visual feedback, and perhaps remotely from a human." ■

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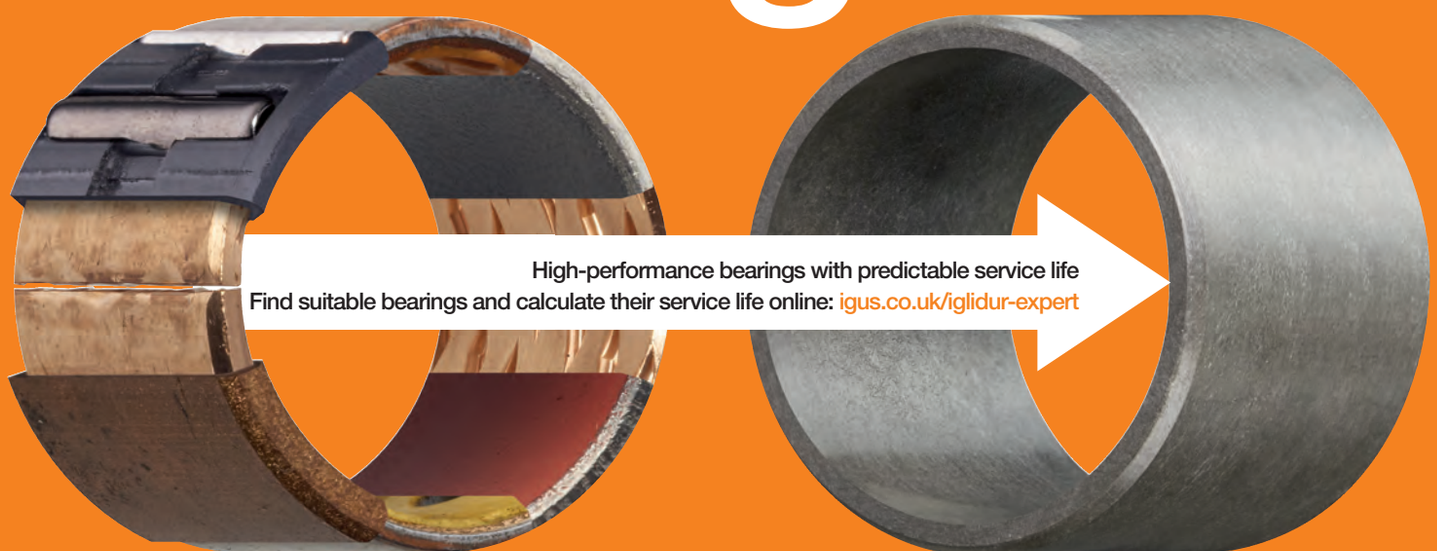

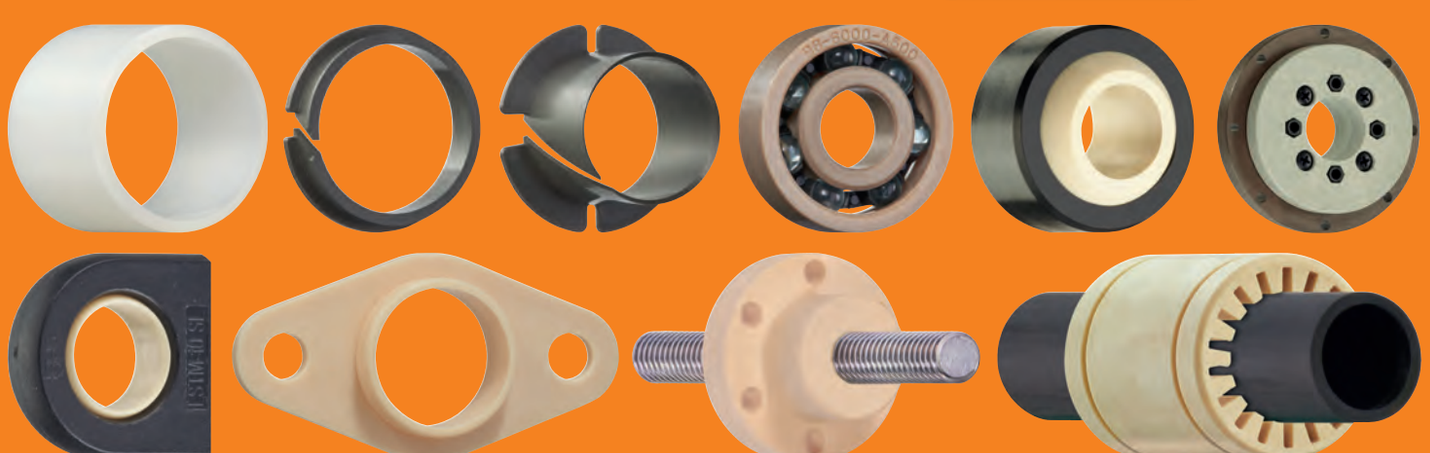

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AUTOMOTIVE

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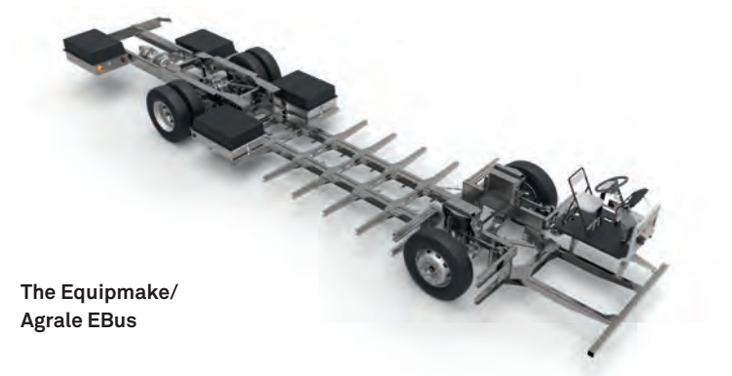
ANDREW WADE REPORTS



The Equipmake/ Agrale EBus

Equipmake has partnered with Brazil's Agrale on a new electric bus set to be rolled out across South America.

The Hethel-based firm will supply its new EBus drivetrain featuring the company's APM200 spoke architecture electric motor, claimed to be the world's most power/torque dense electric motor. The APM200 will be paired with Semikron SKAI inverters, alongside lithium-ion battery technology.

"Each bus system has two APM200s and they're mounted on a bespoke two-speed gearbox, which is part of the drivetrain system we're supplying," said Ian Foley, Equipmake MD. The spoke architecture [gives] a better use of magnetic flux, you get a higher torque density. In addition to that, we've also developed a system to directly cool the system with water because a limiting factor on the power density is the magnets getting too hot. A combination of those two things have enabled us to get the size and weight down."

Agrale will integrate the electric powertrain into its MT17 chassis, a 12m single-deck bus model capable of carrying 70 passengers. By optimising heating and cooling of the vehicle and maximising overall energy efficiency, the bus will have approximately 200 miles of range from a single charge. Overall weight will remain the same as the original diesel version. A prototype has already been built in Argentina, with full commercial availability expected by 2020.

"The key area for development with electric motors is really cooling," Foley said. "There's still a huge difference between the continuous power and the peak power of all electric motors. The more heat you get out the closer you can run it to peak power. All of our development is really focused on how to improve the cooling [of] the motor and that's the area we're going to see big developments in the next few years."

The motor relies on water and glycol circulating through the system, which has been designed for an inlet temperature of around 60°C. This is significantly cooler than an engine system, and allows the powertrain to operate at increased efficiency.

"The water and glycol is circulated through the rotor of the motor, around the stator of the motor and through the heat sink of the power electronics," said Foley. "There's a pump and a radiator in the circuit and it's continuously circulated and then cooled to keep to a maximum of 60°C."

The £2.5m development project is being supported by funding from Innovate UK. ■

EDUCATION

Inspiring engineers of the future

Museum offers hands-on experience

JON EXCELL REPORTS

A new exhibition at the London Transport Museum offers young people the chance to get "hands on" with transport engineering, and to appear on the front cover of *The Engineer* magazine.

The importance of inspiring and engaging the next generation of engineers is a regular topic for *The Engineer*, which is why the magazine is pleased to be involved in a new exhibit at the museum aimed at achieving precisely that.

Opening on 19 October, the museum's new Future Engineers gallery features a series of hands-on interactive exhibits aimed at helping young people explore the world of transport engineering and understand the range of jobs an engineer might do in the future.

Visitors will be able to experience 'driving' or operating a modern train inspired by one of the Bombardier Aventra trains that will be operating on London's new Elizabeth Line (Crossrail) while 'The Fix That Train' challenge will give a taste of how technology helps with train maintenance and safety. Another exhibit ,'Go With The Flow' will explore how ticketing has evolved.

Visitors will also be able to explore some of the future challenges around urban-planning via 'The Shape Your City' exhibit, a table-top game which will see them race against the clock to create a healthy and well-connected sustainable city.

Young people will also be able to see what type of engineer they might become, by working out what personality type they are and selecting a suitable future job – before taking the ultimate selfie with a photograph of themselves in their new engineering role on a digital cover of *The Engineer.* ■

Newsinbrief

JLR plant scales back

Around 1,000 workers at Jaguar Land Rover's Castle Bromwich plant will move to a three-day week following a review of the company's production schedules. According to JLR, the move will "ensure market demand is balanced globally". "In light of the continuing headwinds impacting the car industry, we are making some temporary adjustments to our production schedules at Castle Bromwich," it said.

Meanwhile, BMW is bringing next summer's planned maintenance shutdown of its Oxford Mini plant forward to ensure against potential Brexit supply chain problems. The halt in production will now shift to the beginning of April to coincide with the UK's departure from the EU, scheduled for 29 March, 2019.

Largest wind farm opens

The Walney Extension off the Cumbrian coast has officially opened, claiming the title of world's largest wind farm site. With 102 turbines already located on the site, the Walney Extension saw the installation of an additional 87. The 659MW wind farm now covers an area of around 145 sq km.

Vehicle battery facility

Williams Advanced Engineering and Unipart have joined forces to form Hyperbat Limited, a new UK vehicle battery manufacturer. The joint venture will see a high-tech manufacturing facility open in early 2019 that will produce batteries for future hybrid and electric vehicles. The first customer will be Aston Martin, which will be using the products on its limited production run Rapide E.

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CIVIL & STRUCTURAL

Making extra-long bridges a reality

UK researchers model how to safely span long distances in the future

HELEN KNIGHT REPORTS

New bridge designs that could ultimately span distances such as the Strait of Gibraltar, connecting Europe and Africa, could be made possible by UK research.

In an EPSRC-funded project, researchers at Sheffield University and Brunel University London, alongside long-span bridge expert Ian Firth of engineering consultants COWI, used a mathematical modelling technique to identify new bridge forms.

Most existing long-span bridges are either suspension bridges, such as the Humber Bridge, or cable-stay, such as the Queensferry Crossing.

However, as these bridge spans increase in length, more and more of their structure is needed just to carry their own weight, according to project leader Prof Matthew Gilbert at Sheffield University.

"There is a theoretical limit on how long a bridge span can be before the material fails," said Gilbert. So instead, the researchers set out to investigate whether new designs could lead to more structurally efficient forms, allowing longer bridge spans to be built.

The researchers developed a mathematical optimisation model, in which they incorporated a 19th-century mathematical theory by Davies Gilbert, who advised Thomas Telford on the design for the Menai Suspension Bridge in North Wales.

They found that the most mathematically optimal designs would contain regions resembling a bicycle wheel, with multiple spokes in place of a single tower.

However, since this would be difficult to replicate on a large scale, the team replaced these wheels with simpler split towers comprising just two or three spokes each.

"Very often there are slight variations on [the mathematically optimal] forms, which are only very slightly less efficient, in that there is very little extra weight, but they are much easier to build," said Gilbert.

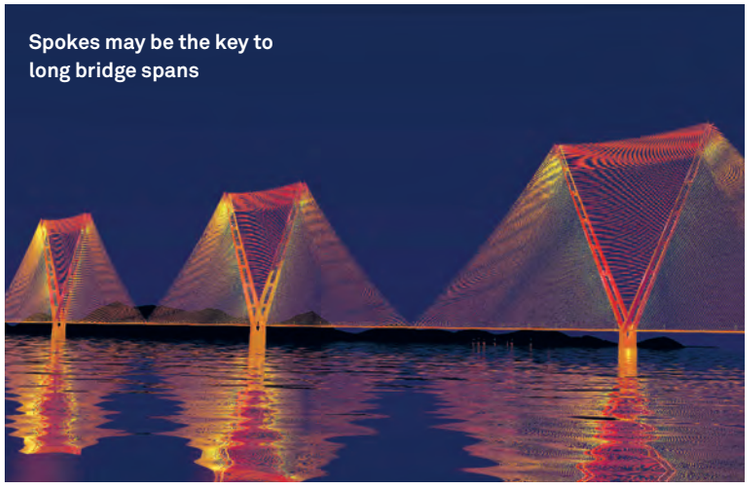
In the design, the forces from the deck are transmitted more efficiently through the bridge superstructure to the foundations, meaning less material is needed.

This is done by keeping the load paths short, and avoiding sharp corners between tensile and compressive elements.

> "We haven't yet looked at the lateral loading from wind"

More work is needed to ensure the new designs are practical, including how easy they will be to construct, said Gilbert.

"We haven't yet looked at the lateral loading from wind," he said. "So we'd like to work with experts in that field." ■



Spokes may be the key to long bridge spans

RAIL

First hydrogen-powered trains

Units that will travel up to 140km/h entering service on line in Lower Saxony

The world's first hydrogen fuel cell-powered trains have entered commercial service in the Lower Saxony region of Germany.

Travelling at up to 140km/h, the two Alstom Coradia iLint trains will serve a 100km route running between Cuxhaven, Bremerhaven, Bremervörde and Buxtehude. The line was previously served by diesel units.

The new trains will be fuelled at a mobile hydrogen filling station, where gaseous hydrogen will be pumped into the trains from a 40ft-high steel container at Bremervörde station. According to Alstom, one tank will provide enough fuel for 1,000km of travel.

A stationary filling station is scheduled to go into operation in 2021, when Alstom will deliver a further 14 Coradia iLint trains to Landesnahverkehrsgesellschaft Niedersachsen (LNVG) transport authority at a cost of €81m (£72m).

"The world's first hydrogen fuel cell train is entering passenger service and is ready for serial production," said Henri Poupart-Lafarge, chair and CEO of Alstom. JF

ENVIRONMENT

New device to tackle marine pollution

Dutch inventor in bid to clean up 'Great Pacific garbage patch'

JON EXCELL REPORTS

A giant device designed to remove plastic from the sea has begun a three-week voyage from San Francisco to one of the most heavily polluted areas of ocean on the planet.

Developed by Dutch non-profit organisation The Ocean Cleanup, the system is being towed to the 'Great Pacific Garbage Patch', a 1.6 million square kilometre area of ocean halfway between California and Hawaii that contains a concentrated accumulation of an estimated 80,000 tonnes of plastic waste.

Brainchild of Dutch inventor Boyan Slat, the technology consists of a 600m-long U-shaped floating barrier with a 3m skirt attached below. The barrier provides buoyancy and prevents plastic from flowing over it, while the skirt stops debris from escaping underneath.

The system – which has attracted over $32m (£25m) in funding – is propelled by the wind and the waves, allowing it to catch and concentrate plastic debris in front of it. Due to its shape, debris is funnelled to the centre of the system where it will be scooped up by ships.

Solar-powered and satellite-connected sensors, cameras and navigation lights communicate the position of the device to passing marine traffic and provide the Ocean Cleanup team with data on the system's performance.

The current trial follows a number of scale model tests, research expeditions, and a trial of a 100m segment of the barrier in the North Sea in 2016. The team claim its impact on wildlife will be negligible. ■

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AUTOMOTIVE

Graphene-enhanced body panels set for testing

20 per cent reduction in weight will mean decrease in carbon dioxide emissions HELEN KNIGHT REPORTS

Lighter, greener car body panels could be produced, without any reduction in strength, thanks to research into graphene-enhanced carbon fibre composites. Briggs Automotive Company (BAC), the UK-based manufacturer of the world's only road-legal supercar, the BAC Mono, has received funding from the Niche Vehicle Network to undertake research into the use of graphene in composite body panels.

In 2016, BAC became the first manufacturer in the world to develop a graphene-panelled car, when it created graphene-enhanced carbon fibre composite wheel arches for the Mono.

The new project, which includes Haydale Composite Solutions and Pentaxia Composites, is aiming to take this development further.

Graphene consists of one atom-thick sheets of carbon, and is stronger than carbon fibre and steel. Consequently, its use in automotive manufacturing could decrease the weight of body panels by around 20 per cent, reducing carbon dioxide emissions without affecting the car's strength.

Graphene has also been found to increase impact resistance, for example to stone chips and ultraviolet degradation, according to Neil Briggs, co-founder and director of product development at BAC.

To produce composite panels, graphene is added to the resin in powder form. The resin is then pre-impregnated into the carbon cloth, which is cut and placed in the mould, before being cured in an autoclave. "So the graphene mixes with the carbon cloth, to make the material stronger," said Briggs.

The team also plans to build a novel carbon fibre composite tooling system with improved thermal conductivity, allowing them to produce a new body panel system with improved mechanical and thermal performance. "By using graphene in the composite that is being used to make the mould, we match the co-efficient of thermal expansion of both the mould and the part, so that we get a better quality of part, a more consistent part," said Briggs.

This also means that the energy required to heat the tool in the autoclave, and the time taken for it to heat up and cool down, is reduced.

The team will test the body panels on the Mono in a bid to reduce weight by 10 per cent, and manufacturing cycle times by over 25 per cent. ■

Graphene offers important reductions in weight

COMMUNICATIONS

Farmers' eye in the sky

5G-connected drones will keep an eye on animals and detect problems with crops

UK researchers are exploring how 5G-enabled drones could be used to help create the smart farm of the future by monitoring crops and livestock.

The group, from Kingston University's Robot Vision team (RoViT) is looking at how drones could harness this technology to carry out real-time video monitoring and surveillance – potentially opening up new opportunities for increasing efficiency and productivity in the agricultural industry.

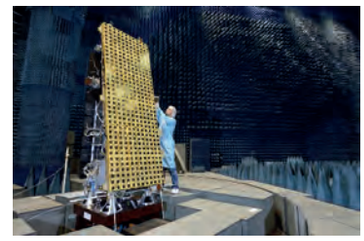
5G is set to become the industry standard for connectivity in the future with potential speeds of up to 10Gb/s. Kingston's Prof Paolo Remagnino said: "We're looking at providing a new method for monitoring livestock, grazing land and crops that would give farmers an eye in the sky over their fields. It would involve using drones with on-board visual and infrared cameras, supported by a computer vision system allowing them to detect when an animal is sick, trapped, injured or missing and also to monitor, count and control crops and spot signs of disease or weeds." JE

AEROSPACE

UK satellites launched

Two orbiters will improve observation of land and sea

STUART NATHAN REPORTS



The satellites were made in the UK

UK-made Earth observation satellites NovaSAR-1 and S1-4 have successfully launched from Satish Dhawan Space Centre in India.

The satellites were launched on board a PSLV (polar satellite launch vehicle) rocket on 16 September.

NovaSAR-1 is the first synthetic aperture radar (SAR) spacecraft to be built entirely in the UK and is the first of its type to occupy an orbit which crosses the equator at 1030 local time, which improves the diversity of radar operations. Capable of seeing through clouds and imaging the Earth night and day, SAR is often used for tracking ocean-going vessels, and this will be an important application for NovaSAR-1, which has been designed with a specific maritime mode of operation, monitoring a swathe of the earth's surface 400km wide.

The satellite's SAR payload was developed by Airbus Defence and Space in Portsmouth. Designed and manufactured by Surrey Satellite Technology Ltd (SSTL), its SAR technology is designed to be lower cost than other units.

The UK Space Agency's investment in NovaSAR-1 totals £2.1m, and its access to the spacecraft will "significantly boost the UK's sovereign Earth observation capabilities," SSTL said.

S1-4, also made by SSTL, is a visual imaging system capable of viewing the Earth's surface in several different wavelengths. It is expected to be used for urban planning, agricultural monitoring, land classification, natural resource management and disaster monitoring. ■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AI

Intelligent wheelchairs

Device will sense when users are tired or have problems with control HELEN KNIGHT REPORTS

Intelligent powered wheelchairs that adapt the level of support they offer users depending how skilled they are as a driver or how tired they become, could offer disabled people the opportunity for greater independence.

Researchers at Portsmouth University, led by Dr David Sanders and Dr Martin Langner, have previously developed low-cost analogue collision avoidance systems for powered wheelchairs, based on the use of simple proximity sensors.

Now, in an EPSRC-funded project with Dr Alex Gegov, the researchers are developing a digital sensor system for powered wheelchairs, which will use artificial intelligence to learn how well a particular user can drive, and adapt the level of support offered accordingly.

By reducing the effort needed to drive, the devices will allow some people to use a wheelchair by themselves for the first time, and make driving and steering far easier for many others, Sanders said. "The system can automatically adjust itself for the child that is driving the wheelchair," he said. "So for example, if the system knows, or very quickly learns, that a particular child is blind and has very little spatial awareness, then it can adjust itself to assist them in the best possible way."

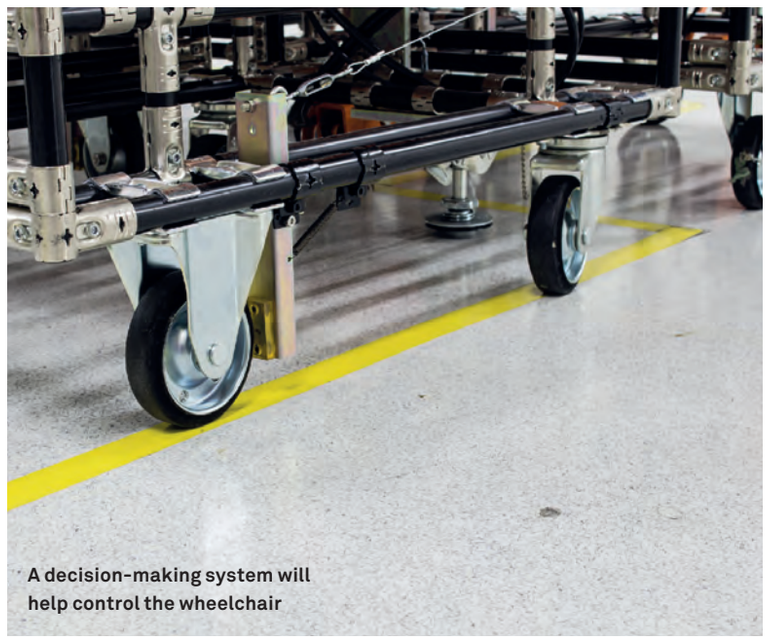
The sensors will be connected to low-cost microcomputers, such as the widely available Raspberry Pi devices, which will be equipped with AI software.

The system will be capable of interpreting hand movements and tremors, and will take into account factors such as skill, tiredness, and recent driving performance, to determine how much influence on the motion of the wheelchair it needs to have at any given time.

At least three different AI systems will be used to suggest a course of action, such as turn left or stop, for example, and a decision-making system (DMS) will decide which of these suggestions to follow, based on information from the sensors and the needs of the driver.

"We will have a decision-making system that sits above the AI systems, to decide which opinion is more valuable, and what are the risks of one [suggestion] over another," said Sanders.

The system, which will be developed with the Chailey Heritage Foundation, a specialist school in East Sussex, can be fitted to existing wheelchairs, to minimise the costs. ■



A decision-making system will help control the wheelchair

AEROSPACE

Fishing for space junk

Trials of European satellite designed to remove debris from orbit

A European group led by Surrey University's Surrey Space Centre has carried out the first ever successful demonstration of space waste removal technology.

Designed, built and manufactured by a consortium including Airbus, ArianeGroup and Airbus-subsidiary Surrey Satellite Technology, the so-called RemoveDEBRIS satellite used a specially developed net to capture a deployed target simulating a piece of space debris. During the trials, the net is detached from the satellite. However, the ultimate vision is that it would remain attached so that the satellite could drag the waste out of orbit.

The device was deployed from the International Space Station, having launched aboard the SpaceX Dragon spacecraft in April 2018.

Space debris is a growing problem, with an estimated 7,600 tonnes of 'space junk' orbiting the Earth. RemoveDEBRIS is one of a number of efforts worldwide to develop technology to address this problem. The broader aim of the mission if to trial a range of different active debris removal technologies. JE

CONSTRUCTION

Concrete use for plastic

Substituting waste product for sand is boost for environment

ANDREW WADE REPORTS

India has a shortage of sand, but there is a plenty of waste plastic that could replace it

Research from Bath University has demonstrated that some of the sand used in concrete can be swapped out for waste plastic, potentially leading to more sustainable construction.

The study, conducted in partnership with India's Goa Engineering College, was prompted by India's booming construction sector and a sand shortage the country is enduring as a result.

Sand typically comprises 30 per cent of any concrete mixture. By replacing 10 per cent of that sand with finely ground plastic particles, the Bath team estimates that over 800 million tonnes of sand could be saved. Published in the journal *Construction and Building Materials*, the research explored the impact of five finely graded plastics on the structural strength of concrete tubes and cylinders. It was found that sand-sized PET particles from recycled plastic bottles provided the best results, achieving a target compressive strength of 54MPa, similar to that of structural concrete.

"The research was focused on adding enough plastic so as to make the additions worthwhile in terms of providing a use for the waste, but at the same time not so much as to reduce the concrete strength to an extent which makes it too weak for structural applications," said Dr Richard Ball, from Bath's department of architecture and civil engineering. "10 per cent by volume additions of plastic could save 820 million tonnes of sand every year from being used in concrete mixes," he added." ■

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MEDICAL

New standards in cancer detection

AI to play part in helping urologists focus on better biopsies for diagnosis

ANDREW WADE REPORTS

A new advanced ultrasound imaging technique is being combined with artificial intelligence to improve the detection of prostate cancer.

The current standard-of-care ultrasound, which guides prostatic needle biopsies that help to diagnose prostate cancer, yields a 30 per cent false negative rate as the resolution of the ultrasound systems is insufficient to differentiate suspicious regions.

Operating at 29MHz, ExactVu is an imaging tool from Toronto-based Exact Imaging that harnesses ultrasound at a microscopic level. It provides a 300 per cent resolution improvement on conventional ultrasound, allowing urologists to better target biopsies for prostate cancer treatment. Exact Imaging has now teamed up with Cambridge Consultants, the UK technology firm developing AI to assist with identifying areas where cancer may be present.

"The AI was trained exclusively on ExactVu images," said Dominic Kelly, machine learning senior consultant at Cambridge Consultants.

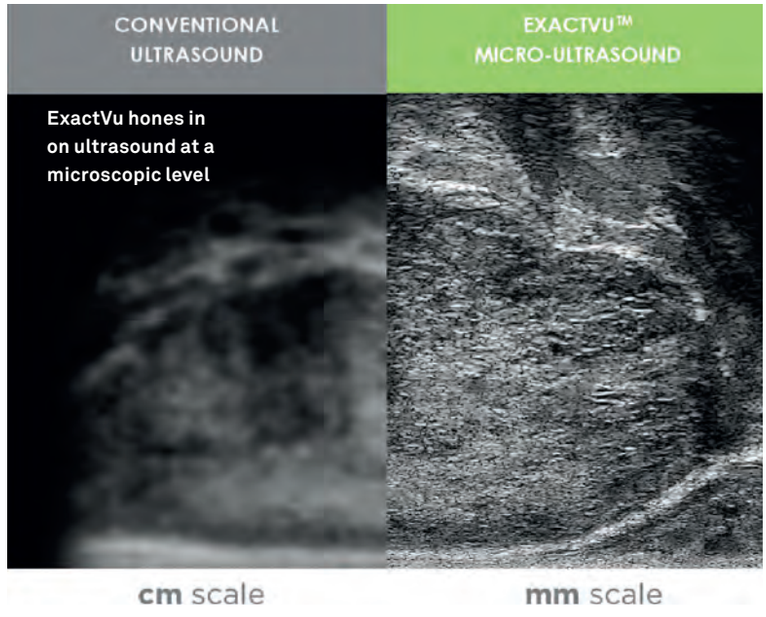
However, as the imaging technology is relatively new, a relatively small dataset of just a few hundred patients was available. This contrasts with the enormous datasets ordinarily used to train neural networks. According to Kelly, this is becoming increasingly common in healthcare, and AI techniques are evolving in order to adapt to constraints.

"Working with smaller datasets is a common requirement for AI in medical diagnostics and a challenging and important area for research," he said.

"From our experience developing AI for medical diagnostics we were able to architect an ensemble of deep neural networks, which was able to provide high specificity with a relatively small dataset of participant information."

Cambridge Consultants said the AI analysis should deliver improved accuracy and better characterisation of suspicious regions. The company also claims that its machine learning approach is faster and less computationally intensive than traditional statistical techniques. It said early testing on the proof-on-concept has shown "significant promise" and the system could go on to underpin a commercially-viable software application that enables urologists to make more informed decisions regarding which areas to biopsy. Furthermore, the system could have wider applications in oncology and beyond.

"The most exciting aspect of the system for us, and our research in this area more generally, is its ability to learn the features and characteristics of each problem being tackled," said Kelly. ■



ExactVu hones in on ultrasound at a microscopic level

ADDITIVE MANUFACTURING

New 3D printing system will mass-produce metal parts

ANDREW WADE REPORTS

HP Inc has unveiled its new Metal Jet additive manufacturing technology, a 3D printing system designed for the mass production of metal parts.

Similar in operation to the Multi Jet Fusion technology for plastics manufacturing, Metal Jet is a voxel-level binder jetting system that creates parts from a bed of metal powder. Six printer heads precisely print binding agent to the metal powder on each pass.

As layer upon layer is laid down to define the part, an energy source removes excess liquid and cures the part as it grows.

Once complete, the 'green part' is then removed and finished using a standard sintering technique, while the remaining metal powder in the bed can be reprocessed.

For now, the technology has been optimised for stainless steel, but the technology may be adapted for additional metals in the future.

The production bed of the machine measures 430 x 320 x 200mm and can accommodate multiple small parts or single larger components.

The technology is already being deployed via a partnership with GKN Powder Metallurgy, with customers so far including Volkswagen and Wilo. A Metal Jet Production Service is set to come online in the first half of 2019 which will allow users to upload 3D CAD files and have them manufactured in production runs.

Dr Tim Weber, HP Inc's global head of Metal 3D Printing, said the breakeven point for bulk runs of some parts will be as low as 55-65,000. The company says finished parts will meet or exceed ASTM and MPIF Standards.

Metal Jet hardware should become publicly available in 2020, priced at about $399,000 per unit. ■

AEROSPACE

Robot creation spreads its wings

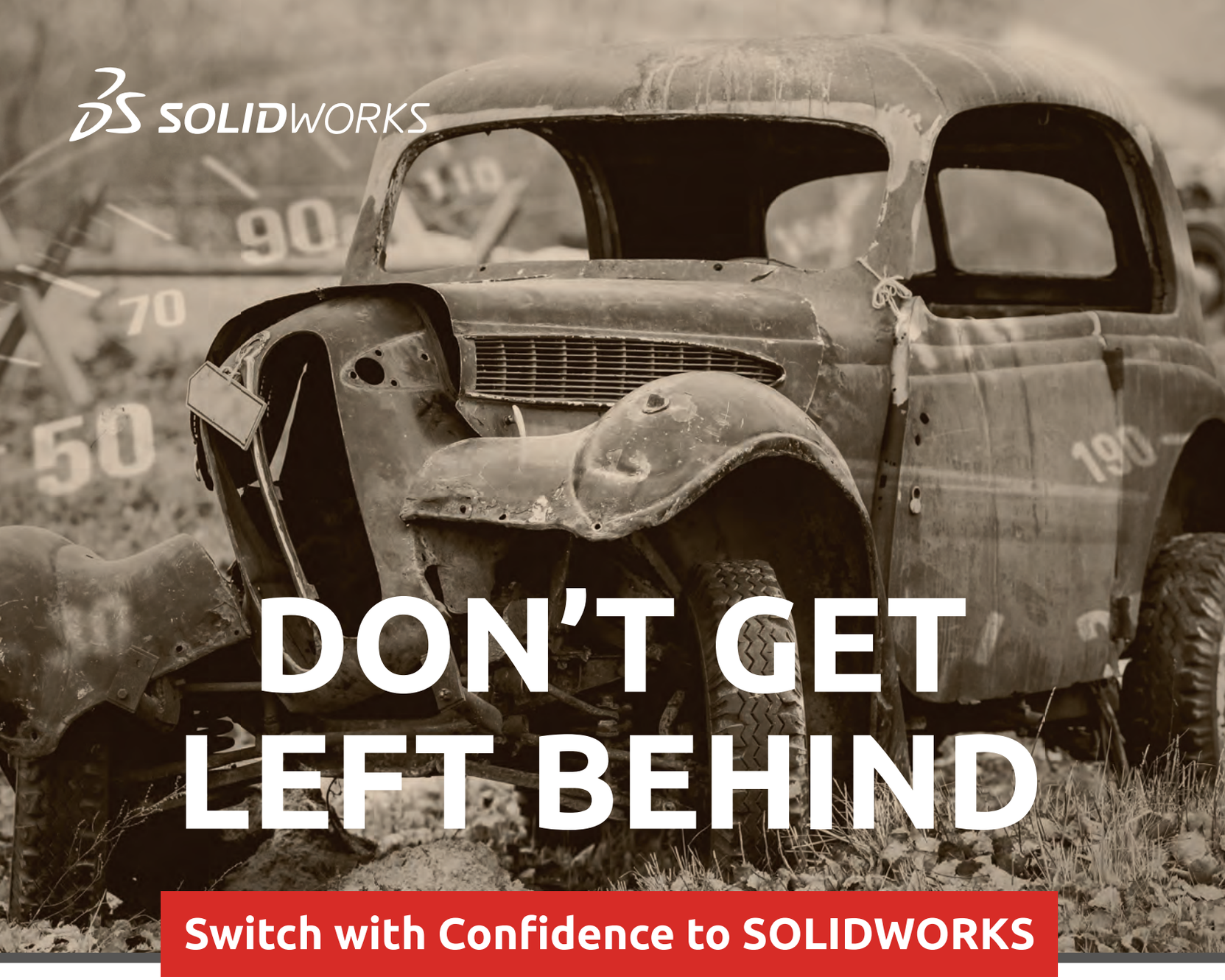
The new DelFly Nimble device will aid the understanding of insect flight

Engineers from TU Delft in the Netherlands have created an agile, autonomous flying robot that uses flapping wings to control its flight, similar to a fruit fly.

The DelFly Nimble robot is helping researchers to understand the mechanics of insect flight and has potential for new drone applications. Insects use their wings to power and direct their flight, allowing them to hover efficiently as well as accelerate and escape from danger rapidly. DelFly Nimble mimics this capability, beating its wings 17 times per second to stay airborne and control its flight through changes in wing motion.

"The robot has a top speed of 25km/h and can even perform aggressive manoeuvres, such as 360-degree flips, resembling loops and barrel rolls," said TU Delft's Matěj Karásek.

"Moreover, the 33cm wingspan and 29g robot has, for its size, excellent power efficiency, allowing five minutes of hovering flight or more than a 1km flight range on a fully charged battery." **AW**



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viewpoint | **heiko wildner**

Digitalisation and materials selection

Research from BCGDV and Matmatch has found that 80 per cent of materials research starts with Google. Heiko Wildner asks if this is this preventing engineers from being more innovative

Engineers can no longer rely on intuition and experience to solve design problems. With product life cycles continuing to shrink and trends like additive manufacturing rapidly evolving, the pressure for companies to bring cutting-edge products to market is at an all-time high.

When deciding what materials to use, the future of engineering heavily relies on companies being able to embrace digitalisation, especially when looking to create the next generation of products.

Material selection

In 2014, Apple was put under scrutiny following the eruption of 'Bendgate'. Just six days after the iPhone 6 and iPhone 6 Plus were released, reports claimed that the devices were bending as a result of the phones' 'weak' enclosures.

Many questioned the integrity of the company's engineering of the devices, but Apple published a statement defending the design and materials choice arguing that with regular use, customers would not find their device bending.

Not every company has an established reputation like Apple, which can help overcome any potential product backlashes like this. However, the release of the iPhone 6 demonstrates the care that must be taken when engineering new products.

Evaluating materials

The re-evaluation of materials is thought to be time-consuming, so many engineers have been hesitant to explore alternative options. By doing so, they have restricted their designs.

Most companies will request more than just a sample of a new material to move forward with a product's development. Procurement teams will often require various supporting documents, in particular materials data sheets, to endorse the material selection. This information is not always readily available or, in some cases, completely accurate, putting an additional block to thinking outside the box.

Through research of user behaviour on our own site, we found that a third of our visitors were simply looking for a material they already knew about. This suggests they had already decided what material they were planning to use. We have found this to be the result of mechanical and design engineers relying on their intuition and experience to speed up the research segment of the design process, dampening innovation.

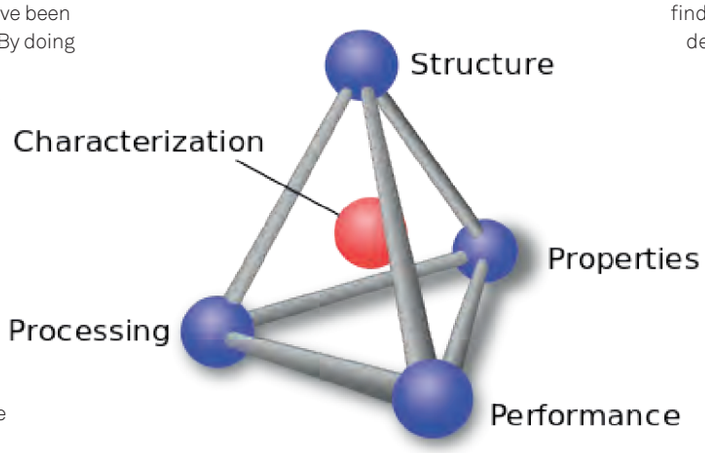
Reliability

Materials are often listed on internal databases without technical data sheets to support the claims of the described material. When manufacturing a new product, companies need to consider the practicalities of their choice and whether it is fit for purpose.

In principle, comparing different materials is simple, and digitisation has made it easier for engineers to access a vast amount of materials data. The issue for many engineers is that there is a wide-range of parameters used to describe materials, making research a longer process.

It is rare for a product to be completely manufactured from just one material. From our own research, we found that most products are created with two to five different materials. However, 7 per cent of engineers reported that their last project involved using more than 15 materials for just one product.

It is for this reason that many engineers do not have a single search criterion when sourcing materials for an application. Each product must be analysed independently with designers considering the use, target market and feature specifications it needs to fulfil to identify the materials requirements.



Changing design

Design techniques are changing and design tools advancing. Traditionally, engineers conducted 'classical design', where companies created a product that can evolve over time, as resources improve and consumer needs alter.

Designers then turned to 'design thinking'. This technique is driven by empathy for the customer and wanting to create something that will resolve a current issue. For example, creating an exoskeleton that is comfortable and light for the human operating it.

We expect computational design to become more prominent. This aims to enhance the design process by encoding design decisions using a computer language.

The goal is not to document the final result necessarily, but rather the steps that led to that result to assist future discoveries.

By encoding design rules in a computational framework, engineers can generate hundreds, if not thousands, of options that are more complex and may not have been discovered with classical design practices. The Disney research department adopted this approach to design more flexible structures for the robotics industry.

While Google may be the first point of call for finding a simple solution or a quick answer to a design question, mechanical and design engineers should make better use of the tools available to them.

Choosing the right material does not have to be a long, drawn-out process, especially if engineers extract the right data from frequently updated tools to support their decisions. Digitalisation presents a number of opportunities for engineers and designers to take a better scope of the materials industry and heighten innovation. ■

Heiko Wildner is chief operating officer at comparison database MatMatch

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Thehottopic

Is anyone listening to manufacturers?

JLR's latest Brexit warning sparked a debate on whether or not government is paying attention to industry concerns

Regardless of the position when we trade we always have to abide by a common set of rules or standards between the parties. So to sell our products to Europe we have to make them to their standards, as we do to every other country in the world, unless they adhere to ours already. In the old days of empire we could impose what we wanted to make on the dominions. Not possible nowadays of course. Those promoting Brexit fail to look at the wider picture.
Nick Cole

The government may well be taking the warnings of industry extremely seriously, but they don't have total control of the outcome. On the other hand, they may well be ignoring industry completely, just paying lip service to the industrial sector. There is not sufficient evidence available to say "Yes" or "No" to the question – so it's disappointing to find engineers apparently not bothering with evidence and voting with emotion. Perhaps a better question would be: "Is the Chequers proposal probably the best deal the politicians are likely to get for industry?" Or perhaps a question on whether the long term future for British industry in general is better off (or less worse off) with a "No Deal" or a "Chequers Deal" outcome?
Michael Bradley

Just because Chequers is a fudge doesn't mean it has no good points. By conceding ground on the rules governing the movement of "stuff", food can continue to come in and go out and the impact on manufacturing's cross-border supply chain is mitigated. At the same time the service sector – 80 per cent of UK's GDP – can take advantage of the free trade opportunities
Trevor

Many of those who promoted Brexit simply use bluster when faced with logic and inconvenient truths. Apart from promoting themselves and their interests, they've achieved little. Brexit is a con-trick which is paralysing the country. A hard-headed business leader would see it for what it is and stop it now. Anyone interested in Winston Churchill might know that he was a founder member of the European Movement, which is a network of organisations that has mobilised citizens and advocated for a democratic, federal and enlarged union.
Mark Harrison

I have yet to hear a single benefit of Brexit. This government couldn't care less about engineering, manufacturing or jobs in either sector and is arguing with itself about whether to kill them off slowly, via Chequers, or quickly through no deal. I am, however, amazed that they are also prepared to sacrifice our country's financial services industry rather than admit we have made a huge mistake!
John Petersen

It's right that JLR and others make their voices heard, but it's not right that they dictate the course of politics in this country. Politicians must not be subservient to them.
Mohammed Amin Abdullah

I doubt that anyone in government has much knowledge of how supply chains work. If there is a hard Brexit, deal or no deal, these will be decimated, putting UK manufacturing at a serious disadvantage. If the government cares about the welfare of the UK, it needs to listen when just about all of UK manufacturing is giving the same warning.
Alex T

Inyouropinion

Additive adoption

After having worked with 3D printers for the past eight years as part of my design engineer position, the overall cost and time reduction accrued, by using 3D printers to mock up potential mould tool changes, and to prove out their integrity, prior to cutting steel, has been invaluable. Yes they can be expensive, and sometimes temperamental, but they are quick and easy to set up, accurate and simple to use, and provide the answers one way or the other in a very efficient manner.

It has saved our business many hours of trial or guesswork, and has done so for reasonable asset payout. We are on our third iteration of desktop machine, and are still always impressed.
Mark Hemingway

Additive manufacturing does have its uses, but it's not a universal panacea. Just because a component can be drawn and therefore made doesn't mean that the finished component will be suitable for the stresses involved, without proper analysis. As ever, proper material specification and testing is vital.
Sandy

The future for AM is very bright. As the materials and software improve you can expect applications for the technology to continue to expand.
Graham Loxley

Driverless cars

I'd love a level 3 autonomous car. Should be very comfortable for long trips and relaxing in town traffic. Not so sure about the higher levels, I'm probably too old to accept having no control of the car. We also need to look at applications of this expensively developed control/AI technology to other areas of engineering. Security would look like a good application.
Jack Broughton

Who gets sued in an accident (driverless on driverless and also driverless on driven/propelled vehicles/pedestrians)? Systems designers, vehicle manufacturers, the occupant? This is going to be a happy hunting ground for the legal profession.
Phil Mortimer

Join the debate theengineer.co.uk

Thesecretengineer

Our unnamed correspondent has reached the end of the road with his employer, but should he/she challenge the boss or keep quiet?

Disillusioned with his (or her) employer's appetite for logical change, our anonymous blogger leaves. But should he (or she) have had one more crack at telling them where they were going?

If there is such a thing as a regular reader of these pieces then they will know that I've not been a happy bunny for a while.

It's a shame as Sleepy Hollow Electronics could have been my perfect workplace for any number of reasons. However, a dogged determination, by those few who inhabited the rarefied atmosphere above me, not to improve or even adopt the most basic current standard practices led to frustration; which in turn led to my leaving.

Context is all, as someone, possibly me, once said so I feel I must reiterate that some suggested improvements to the way the company works were basic late 19th-century stuff rather the latest fad or, indeed, cutting edge in any way whatsoever.

One or two members of the senior team felt as strongly about this as I and thought that on my day of departure I should have rather forceful words with the MD about it all – given that there could be no direct punitive backlash.

I did seriously consider it but in the end decided against. The main problem was, given my experience of those involved, I was certain it would make no positive difference. In fact, as my near-constant efforts to change things had been steadfastly rebuffed for three or four years, I could see such a manoeuvre making the opponents to change even more entrenched in their views. Therefore it would be counterproductive for those I left behind to fight the good fight.

Of course, the other aspect that crossed my mind is how it may have affected my references for a new position. Although I have been assured that it is now illegal to give a poor reference, inferences can be drawn from a fairly non-committal one. In addition, I have worked hard and diligently so would rather like that to be reflected in any comments made about me. It's difficult to see how deliberate torpedoing of future prospects can actually be avoided and, although I would not automatically expect a clash of industrial ideology to promote sufficient resentment as to initiate the intentional scuppering of my future, I was not so certain as to want to risk it.

Finally, I loathe and detest conflict, sincerely believing that it hampers work rather than aiding it. I know we're all different and some seem to thrive in the pseudo-soap opera environment of shouting and wild gesticulation but you risk creating an entrenched set of positions (hardly the optimum way to arrive at the best solution for a given problem) and/or get called something rude behind your back.

I will admit to having lost my rag very occasionally in the past and even deliberately employed the tactic of merely seeming to have lost it once or twice. However, I had to be very sure in my own mind that this was the best way of resolving the situation.

In relation to the subject in hand, it was difficult to reconcile the hard truths of what needed to be said with hope of a civilised conversation.

Although I am willing to admit to possibly displaying a lack of moral fibre with all this it does raise some pertinent points. If you cannot progress clearly needed changes (I cannot give details for obvious reasons but when I joined there was one particularly inefficient working practice that I hadn't seen since the mid-1980s and, after a number of years, I only managed to get it partially replaced by modern methods) – should you even worry about it? Should the fact things are so bad that I can see it taking only one of any number of plausible potential failures to sink the company cause me consternation?

I know I did my best to change things and was consciously scuppered by others in my attempts to improve the situation. Despite all the reasons that I cannot believe it was the right thing to do, I still wonder if I should have had that inevitably explosive conversation – if only for my own peace of mind? ■

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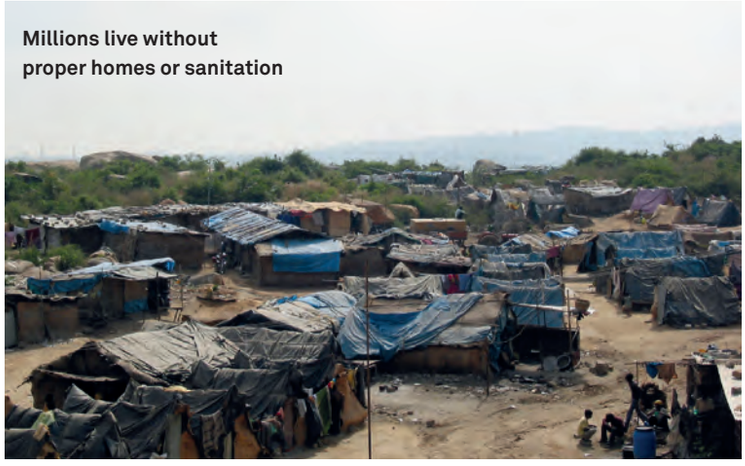
Engineers can improve the lives of millions

It's time to use our skills to give everyone in the world access to clean water, power and healthcare, says the president of the Institution of Civil Engineers

The ultimate objective of engineering is to meet people's needs. Whether that involves building homes for families, providing road and rail links for commuting workers, or producing consumer technology, our profession provides the solutions for every aspect of modern life.

Successful engineering directly correlates with a successful society. Inadequate infrastructure provision directly stifles the achievement of social and economic goals, leading to poorer quality of life. Across the UK, we still find communities in need of critical infrastructure, blocking access to markets, jobs, and information and training.



Millions live without proper homes or sanitation

The global picture is even bleaker. One in eight people live in extreme poverty and nearly 800 million suffer from hunger. Billions of people live in slum accommodation and cannot access clean water and sanitation. And this is all happening against a backdrop of increasing climate change and a rapidly growing population, placing unprecedented pressure on resources and the existing infrastructure.

The United Nations Sustainable Development Goals (UN SDGs) were created and adopted to address these issues, promoting prosperity for all while also preserving the planet. In 2015, the 193 UN member states agreed to adopt 17 international SDGs and achieve them by 2030.

It would be easy for many of us to overlook the relevance of the UN SDGs and assume that they are the purview of state governments or charities who work in less-developed countries. We agree that there are problems and we want to see them solved. But these problems can seem so large and formidable that they are for someone else to fix – surely someone with more power and ability than us.

But the truth is that our entire profession revolves around fixing problems and we engineers are uniquely placed to work towards meeting these goals. We are the ones who can deliver practical solutions to challenges such as resilient and clean energy, access to clean water, and sustainable urbanisation. We are the ones who can deliver real change.

Beyond the SDGs which are the most obviously relevant to our profession, engineering also lays the foundation for progress across all the goals. Better technology and infrastructure will enable and encourage better health, education and employment outcomes, and reduce inequalities.

This is why the Institution of Civil Engineers (ICE), working together with the World Federation of Engineering Organisations, is convening the Global Engineering Congress in London in October.

We will unite in an ambitious, combined and co-ordinated effort to tackle the five SDGs where we can make the most impact: clean water and sanitation; affordable and clean energy; industry, innovation and infrastructure; sustainable cities and communities; and climate action.

Top engineers, policy makers and experts from over 150 countries will meet to determine how to make the delivery of these SDGs a reality. Over five days, with an extensive programme of discussions and workshops, the congress will focus on how engineers can improve the lives of the billions of people around the world.

As the world's oldest professional engineering body, ICE has a duty to lead this global debate. Over the next two years, ICE will build a practical plan that enables the global engineering profession collectively to act. We will be working with like-minded partners across the world to create an engineering sustainable development route-map. The input from congress delegates will help to set out a pathway for the whole engineering community to enable economic success while delivering benefits for society and the environment.

This is a bold undertaking but given the scale of the challenges we face today, we can no longer afford to be complacent. There is already much detailed and informed research setting out the nature of the problem, but the time has come to turn words into action.

Engineers have always used their passion, creativity and problem-solving skills to tackle the pressing issues of the day. ICE has been celebrating its bicentenary throughout 2018 and we have taken pride in the impressive achievements of our members over the past 200 years. We can highlight the example of Joseph Bazalgette's creation of an sewer network for London – but we can also say that he effectively eradicated cholera and saved many thousands of lives. Our engineering predecessors delivered the seemingly impossible and achieved greater, far wider-reaching outcomes than could be first imagined.

There is no reason why we cannot follow in their footsteps and do exactly the same for people today. The challenges may seem greater but we have the talent, skills and technology to meet these demands head-on. We should be just as ambitious about what engineers can achieve today as we have ever been. Every engineering discipline has its part to play and every professional has a potential role. I am confident that we can and will make a difference. Billions of people around the world are depending on us. ■

■ For more information visit: www.ice.org.uk/events/global-engineering-congress

Beware: there's

Tempest is expected to carry swarming drones in its payload bay which its pilot will co-ordinate during missions

Stuart Nathan **tries to unravel some of the engineering aspects of Tempest, the UK's new combat aircraft announced this summer**

When BAE Systems and secretary of state for defence Gavin Williamson teamed up in July at the Farnborough Airshow to announce that a new combat aircraft would be developed for the UK, it came as something of a surprise. The RAF's main fighter aircraft, the Typhoon, still has the gloss of a relative newcomer. Tornado, its "older brother", is still in service, and the F-35 Lightning II has not yet become active. Surely it was too early to start developing yet another fighter aircraft?

Moreover, the way the announcement was made led to much of the mainstream coverage concluding that the new aircraft, which is to be named Tempest, was to be a purely UK venture. This also came as a surprise. The last combat aircraft in service with the RAF and Fleet Air Arm that was not an international collaboration was the Harrier, which made its debut in 1969.

Since then, the Jaguar was an Anglo-French production; Tornado involved the UK, France, Italy and West Germany; Typhoon these four partners plus Spain, and the development programme for Lightning II involves the US, Australia, Canada, Norway, Denmark, Netherlands and Turkey, alongside the UK.

The official line throughout these programmes has been that cutting-edge combat aircraft require such a complex set of technologies that no single country is capable of producing them, certainly not with limited budgets of European nations. So what has changed?

As ever, the true picture has been somewhat obscured by politics. For although the development of a combat aircraft would undoubtedly be the largest and most complex and highest-technology single engineering project starting in the UK for many

a storm coming

years – probably since the project to develop the Queen Elizabeth-class aircraft carriers – no defence-related technology programme can possibly be free of politics.

Arguably, the most important single factor behind the announcement and its timing is Britain's impending exit from the European Union. The government is very keen – if not desperate – to maintain the UK's image as a leading nation internationally, and defence is undeniably a tool to do this. Anxious that cutting ties with its closest international partners does not leave the country looking like a minor player, what better way than to flex its muscle? In the RAF's centenary year, demonstrating that we can still develop the primary way that nations project force in current combat situations is ideal.

The Farnborough reveal was not as simple as it seemed. Williamson and BAE Systems in fact made three announcements that were conflated into one by most of the coverage at the time. These were interlinked, so reporting the existence of 'Project Tempest' was the simplest way to report the story.

"The announcement came out like three legs of a stool," Andrew Kennedy, head of strategy for military air and information at BAE Systems, explained to *The Engineer*. "At the same time as the government made the announcement of the funding into 'Team Tempest', they then announced the establishment of a team to look at the combat air acquisition programme, which is effectively starting the process for the acquisition of a new aircraft.

The third element was the combat air strategy which effectively provides a framework for the government in which future decisions are going to be made. So all three of them are closely linked, but they are actually separate. It's a bit confusing."

The assumption that Tempest is going to be an all-British production is mistaken, Kennedy insists. Williamson's announcement sounded the starting gun for a series of year-long feasibility studies with potential partners to see whether requirements for a future combat aircraft could be aligned, along with investment plans and the industrial requirements to develop and build technologies that would be part of such a project.

This inevitably obscures any discussion of what technologies might find their way on to Tempest and BAE Systems is unwilling to dictate what technological solutions might be part of the future system. "We don't want to say 'this is the solution' and then try to force other people to come along with that," Kennedy said. "The whole point of these feasibility studies was to try to align requirements rather than to force our solutions on to other people, so it's a true partnership." At this point in the project, potential partners have not yet been revealed, if they have even been identified.

01 Defence secretary Gavin Williamson announcing Team Tempest at Farnborough

02 Some of the features expected to be seen in future virtual cockpit set-ups in both Typhoon and Tempest

The RAF and Ministry of Defence are unwilling to discuss an aircraft that does not exist yet, so to gain some insight into the role a future combat aircraft might play, *The Engineer* consulted Greg Bagwell, president of the Air Power Association, an organisation that brings together individuals, companies and bodies with an experience and interest in aerial combat. Bagwell, a former Air Marshal in the RAF, is well placed to provide such a view. As well as being air commander for RAF operations over Libya in 2009, earlier in his career he served as a Tornado pilot; he has also flown F-16 Fighting Falcons and Typhoons. His comments as reported here are his personal views, based on that considerable experience.

Harrier is a useful example to look at to see how the UK's approach to combat aircraft changed in the intervening half-century, Bagwell said. "By the time we had finished with Harrier, it looked a lot like an AV-8B which, of course, was very much a US product. In many ways the way the Harrier morphed from a UK to a US product is synonymous with the way the UK defence aerospace landscape has shifted."

He explained: "To be brutally honest, the UK home market is not big enough to be able to justify a completely new aeroplane, the numbers would not add up. So it has to be done with export in mind which almost undoubtedly means partnerships; and clearly there is competition."

That competition would include the US, which is hoping to sell the F-35 into additional markets; and France and Germany, which are also reported to be in discussions about developing a new combat aircraft. In fact, Bagwell said, countries including India, Korea and Turkey are all technologically "in the foothills" of generating new combat aircraft. These are all countries to which the UK might be hoping to sell Tempest, along with its existing export base which includes Qatar, Saudi Arabia and Australia, so these are countries which are probably among the potential partners with which Williamson, the Ministry of Defence and BAE Systems hope to be commencing discussions.

So what will they be discussing? Tempest will be a sixth-generation fighter – 'generations' being a somewhat slippery classification applied to aircraft of the jet era (see box on page 28). Such aircraft are inevitably designed to fill multiple roles. Typhoon, for example, is primarily designed to engage in air-to-air combat, and intercept other aircraft to ensure that its operator has the freedom to fly over disputed areas. The F-35, meanwhile, is optimised for ground attack. Despite this optimisation, however, both aircraft are capable of the other role as designed, and in any case over their service lifetimes aircraft are inevitably adapted for new jobs.

"Look at Tornado, for example," Bagwell said. "We designed that to fly low-level missions over Germany in a full-on war with the Warsaw Pact. Whoever would have thought it would be flying counterinsurgency missions over urban areas in Afghanistan and Syria? But we adapted it through the use of different sensors and weapon systems."

In a recent briefing at BAE Systems air combat development site at Warton in Lancashire, journalists were told that some air forces are becoming reluctant to use aircraft for too many different roles, because of concerns that if enemies developed a method for bringing down one aircraft, it could potentially seriously damage the capability to fly many different types of mission.

Bagwell agrees that the prospect of an air force flying only one type of aircraft for everything is ridiculous, but the cost benefits of a modular

The mock-up of Tempest on display at the Farnborough Airshow gave away few engineering details of the plans for the actual aircraft

approach with flexible aircraft are undeniable. "Anybody who thinks we can afford one-trick ponies is on the wrong track," he said. "Look at the F-22 Raptor, for example. It's very good at its one role – air superiority – but when you haven't been able to use it for 10 years, people started to doubt its value for money, which is why it got cancelled."

The combat air strategy document itself is quite vague: in summary, it states that the UK will retain the capability to carry out air-to-air and air-to-surface combat with the ability to carry out surveillance, reconnaissance, electronic warfare and command and control tasks concurrently. Details are thin, in line with Kennedy's comments about the evolving nature of the programme and desire to consult with partners and allies. However, it is made clear that the strategy rests upon F-35 and Typhoon for the near future, and commits the UK to continue to invest and upgrade Typhoon. This is an important point, Kennedy stresses, and represents a change in the way the UK has previously approached new aircraft development.

At Farnborough, Williamson announced that £2bn would be invested in the development of Tempest up to 2020, and BAE Systems would lead development with Rolls-Royce contributing engines, MBDA integrating weapons and Italian company Leonardo developing sensors and avionics.

The plan is to finalise design in the early 2020s, produce a flyable prototype by 2025 and have the aircraft entering service by about 2035. By that time, Typhoons are likely to have many flying hours still in reserve – the aircraft is still in production – and those in service will be phased out gradually over five to 10 years, in line with the RAF's existing practices.

In the meantime, many of the systems which will be developed for Tempest are likely to be first in service on upgraded Typhoons. "We're trying to make sure we can maximise the return on investment on Typhoon by rolling over those capabilities on to Tempest," Kennedy said.

"We could see it almost as just changing the skin on a current-generation system and then you gradually upgrade it as you go through, so it's an evolution rather than everything stops and we start again with the future combat air system."

This, he explained, is in part a reaction to a previous complaint that the RAF and other customers had about the evolution of aircraft and the way they are superseded. "We are requiring Tornado at the peak of its capability now, but we are also retiring it because the airframe really doesn't have any life in it any more. The change now is that we are seeing airframe as a system in the same way as we see radar, for example, as a system: it's something that can be upgraded."

This is a common approach in many other heavy industries such as automotive and civil aerospace, where features are introduced as "top-of-the-line" in existing models and then rolled on to their successors. "We have looked around and taken best practice from these other sectors," Kennedy said.

The hoped-for effect, he added, is that Tempest will be fully effective from the moment it enters service, as most of its key systems will already be tried and tested. The timescale for developing Tempest seems ambitious to Bagwell, but Kennedy stated that it was market-driven. "The mid-2030s is when we see the demand for this sort of aircraft beginning." It is not unusually long or short for this type of project, he claimed.

The aircraft itself – or at least a concept mock-up – graced the BAE Systems stand at Farnborough. However details of what the final aircraft will include are, understandably, sparse. Engine partner Rolls-Royce revealed that it is looking towards new, low-weight materials, such as ceramic composites in the turbine, and in one tantalising detail the new

03 Some of the roles and features being planned for Tempest

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Air superiority will be an important role for Tempest as it will supersede Typhoon, a dedicated air superiority fighter

aircraft is expected to need so much electrical power that generation capability will be integrated into the engine itself in the form of magnets directly bonded to the turbine shaft.

Among the list of possible features discussed in the initial documents describing plans for Tempest is the aspiration to use directed energy weapons. These are mentioned in the context of "non-kinetic attacks" implying they might be used, for example, to knock out enemy sensor systems rather than to shoot down other aircraft, but in either case a great deal of electrical energy will be needed to operate them.

Bagwell pointed out that a major advantage of directed energy weapons over conventional projectiles is that, as long as energy is available, there is no chance of running out of ammunition. "You are clearly going to need some serious power," he said. "It might replace a gun, it might replace a close-in missile, but the idea that you are going to use a laser to intercept something at 30, 40, 50 miles away, I think we are some way off yet." Fantasies of *Star Wars*-style dogfights are just that, he said. "But whoever designed the *Star Wars* scenes might turn out to be a visionary in 50 years' time."

According to Kennedy, any technologies mentioned at the Team Tempest launch event should be seen as an aspiration, rather than a concrete announcement; partly because everything is still subject to the feasibility studies with potential partners, and partly because in many cases they simply haven't been developed yet.

One example of this is stealth technologies. The Farnborough mock-up featured the sharp angles along the sides of the fuselage which are also a feature of the F-35 and are characteristic of the current design philosophy for confusing radar systems. However, according to Bagwell, "what is low-observable today almost certainly won't be low-observable in the future, because radar manufacturers are developing their products as well." Bagwell described this as a race between airframe makers and radar, but to Kennedy this is just a fact of life in the defence sector. "There's always a kind of competition, whether it's in stealth or any other air or military system: offensive and defensive capabilities tend to develop in parallel."

There are a few other hints that can be gleaned from the mock-up. Firstly, Tempest is, like Typhoon and F-35, a twin-engine aircraft, but likely to be slightly larger than both. This would give it greater flexibility in weapons load and possibly implies longer range. The twin tailplane configuration improves manoeuvrability and suggests a trade-off against stealth.

What's more, any observer would have noted that in recent years all new combat aircraft have looked very similar. "There are only so many ways you can design an aeroplane in a wind tunnel which has both stealth and basic kinematics built in," Bagwell said.

Gavin Williamson said that Tempest would be capable of flying as a piloted aircraft or in an autonomous mode. This is in line with discussions over whether future fighter aircraft will be piloted or drones, but to Bagwell this was an example of hedging bets. "Unmanned is clearly growing in utility, and there could be a time downstream where it is technically feasible that all combat will be conducted with unmanned vehicles. However, we haven't even cracked cars, trucks or ships yet, so why is the most difficult thing in the world (combat aircraft) something we are looking to solve or accept first?"

There are two potential problems with flying an aircraft like Tempest as a drone, he said. "I think there's a moral argument in there about keeping a human in the decision loop." The second reason is more practical: "If it's unmanned, is it controlled through remote means? And if that's the case, can you guarantee your satellite links?"

For Bagwell, there are advantages and disadvantages to both piloted and pilotless operation, but making an aircraft capable of both is likely to just end up costing more money and leading to compromises that blunt the advantages in both cases.

However, the use of an aircraft to control a swarm of drones in the battle space, which it might carry itself in its payload bay, is another matter and one which is likely to be a reality quite quickly. "The manned/unmanned mix is a thing of the future and if we haven't got there before Tempest I'll be amazed," Bagwell said. "There is effectively no difference between programmable decoys or swarm drones then firing eight missiles at different targets. It's not a big leap of faith, and they make the 'quarterback' aircraft more survivable and more lethal. The bigger issue is making cheap enough swarm drones."

This, and Bagwell's use of the term quarterback, implies that even in piloted mode, the actual job of the "pilot" will be less one of actively flying the aircraft, and more one of monitoring the battle space. "Aeroplanes are much easier to fly than they were 20 years ago," he said. "With flight control software, fly by wire, new sensors, collision warning directors and ground proximity systems, the idea that the pilot

dedicates the majority of his or her time to flying the aeroplane is just not true any more. In the past, we had to select Harrier pilots very carefully because it was so difficult to control the hover. That is not the case in the F-35B. But although aeroplanes are much easier to fly, they are much harder to operate. There is lots of data… lots of fusion, lots of things to think about; and you have to do it at greater ranges and higher speeds."

This is the thinking behind a system which will definitely find its way on to Tempest and will first be used in upgraded Typhoons: virtual cockpit. The idea is that instead of the huge array of dials and switches lining the cockpit, all of the indicators and controls will be projected on the monitor screen inside the pilot's helmet, as described in *The Engineer*'s recent feature on the new Striker II helmet. This will even extend to the use of haptic gloves so that when the pilot reaches for a "virtual switch", which he or she can see but does not actually exist, there will be a feeling of pressing the switch replicated using vibration devices mounted in the fingertip.

One feature of such a system will be that the display will be configurable by the pilot, so they can place the display wherever in their field of vision they feel it is most useful. For mid air-refuelling, for example, they might want to place a fuel tank display over the point in their vision where the refuelling probe docks with the trailing basket from the tanker. Another feature that is being tested is a "smartwatch"-type display that the pilot can pull out from their wrist, which might feature their own biometric data collected by sensors inside their flight suit. It might even display the biometric data of other pilots in their squadron.

"If you're detecting blood pressure, pulse rate or galvanic skin response, that can give you an indication that somebody is feeling particularly stressed," explained BAE Systems head of human factors Jean Page. "And if your squadron leader knows that, it will help distribute the workload around the squadron to ensure that everybody is working at the peak of their ability and nobody is overloaded."

Assessing the cognitive load on a pilot is essential to designing such a system. Page is working with psychologists to determine how much information a pilot can usefully process in the pressured atmosphere of a cockpit in a battle space. Such information will help to determine how virtual cockpit works in Tempest when it is ported over from Typhoon. One factor which the team already knows it will have to accommodate is the physical effect of G-forces. "The eyes are affected during a 9G manoeuvre, so we know, for example, that we wouldn't be able to reliably use gaze tracking under those circumstances," Page said. G-forces are already countered by inflatable pressure cuffs in flight suits which help keep blood circulating and prevent blackouts, and this is likely to be developed further.

> "Information flow and fusion is now more automated, and this is where I think artificial intelligence has a place"
>
> Greg Bagwell, president of the Air Power Association

One system that may be used in this environment is artificial intelligence to determine which information is likely to be most useful to the pilot. Bagwell believes this is more likely than the use of AI to actually fly the aircraft.

"Information flow and fusion is now more automated, and this is where I think artificial intelligence has a place – it's not to make autonomous decisions to pull the trigger or not, but provide you with fused information so you can decide more easily. It's more assisted intelligence than artificial intelligence."

As a self-confessed old-school combat pilot, Bagwell confesses he is sceptical about some aspects of virtual cockpit. "Flying an aeroplane can be quite a tactile thing," he said. "Replicating the level of feedback you get from actually pressing a physical button or handling the controls, getting that through gloves and without the use of simple sight and feel seems to me to be denying two fundamental senses – I can see the concept but I'm a little sceptical. But the idea of producing more and more information through different means, we are already there. The old analogue systems on aircraft now are the back-up systems, not the primary."

One thing that Bagwell was particularly keen to stress is that the notions of what is 'high-tech' have shifted, and today, military technology is likely to be somewhat more primitive than consumer technology: a complete reversal of the situation when he joined the RAF aged 18. "Today, there is probably more memory in your mobile phone than most combat aircraft flying, and a faster processor: the F-35 certainly doesn't have that much. Defence technology these days changes quite slowly. That's relatively recent, for a number of reasons. One is that digital technologies, processors and software are developing well inside the life cycle of an aircraft platform. Also, whereas before defence were the innovators because they had the resources to hand fast, now because commercial demand is high and the cost of R&D of some technologies has reduced, it is the commercial marketplace that demands volume and fast turnaround times. You are now seeing a Leviathan defence marketplace where, whether it be through design or test, we can't build these things very quickly any more." ■

Generations of fighters: from jet engines to directed energy weapons

The idea of fighter aircraft generations came into vogue in 1990, and only applies to aircraft of the jet era. The definition that most often holds sway today was devised in 2009 by the US publication *Air Force* magazine.

Generation 1: simple jet propulsion. Examples include the Lockheed P-80 Shooting Star and Messerschmitt 262 Schwalbe

Generation 2: swept wings, range radar, infrared-targeted missiles. Examples include the North American F-86 Sabre and the MiG-15

Generation 3: supersonic capability, pulse radar, beyond visual range missiles. Examples include the Republic F-105 Thunderchief, McDonnell Douglas F-4 Phantom, MiG-17 and MiG-21

Generation 4: pulse-Doppler radar, high manoeuvrability, look-down/shoot-down missiles: examples include McDonnell Douglas F-15 Eagle, General Dynamics F-16 Fighting Falcon, Mirage 2000, MiG-29

Generation 4+: high agility, sensor fusion, reduced radar signature. Examples include Typhoon, Sukhoi Su-30, Boeing F/A-18E/F Super Hornet

Generation 4++: active electronically scanned arrays; continued reduced signatures or some 'active' (waveform canceling) stealth; some supercruise. Examples include Su-35, proposed McDonnell Douglas 'Silent Eagle'

Generation 5: stealth with internal weapons bays, full-sensor fusion, supercruise. Latest generation currently are about to enter service, examples include Lockheed Martin F-22 raptor, F-35 Lightning II

A generation 6 fighter would include extreme stealth, morphing airframe capability, smart skins, networked sensors and directed energy weapons.

Action stations

Stuart Nathan **looks at the engineering challenges involved in the final part of Crossrail: fitting out the interiors of the Elizabeth Line stations**

The Engineer has followed Crossrail, the mammoth engineering project to connect London's outer suburbs to the east and west of the city, running through Essex and Berkshire, by driving a new tunnel under the city to connect the mainline stations at Liverpool Street and Paddington, from the moments the enormous tunnel boring machines began chewing at the Earth, to where the eastern and western tunnels met. We have also looked forward to it successor project, Crossrail 2, which will travel from the north of the city to the south. The first project is now nearing completion, with its final stages – installing the linings, furniture and other fixings that will make up the stations themselves – well under way.

These are large engineering projects in their own right by any standards, although dwarfed by the magnitude of the entire project. Underground stations are complicated places, the equal of any major building, but with the added complication of being tunnelled out of the ground and having highly restricted access. Among the complicating factors is the geometry: instead of the regular orthogonal planes of normal buildings, these are structures made up from cylinders of different diameters which frequently join at odd angles, some of which will be occupied by many thousands of people throughout the day, others only accessible to the staff who will operate the station at normal times, and then areas only open to the dedicated maintenance staff who will take over the spaces for a few hours each night.

Each category of people have different needs and will occupy the spaces in different ways. Other parts of the station will have to contend with the regular vibration of trains arriving and departing, and of course, the spaces also have to accommodate electrical systems, with all their associated safety features, mostly tucked out of sight and safe behind panelling, while in addition, increasingly complicated audio-visual systems – including both advertising boards, which are nowadays electronic display screens, and passenger information equipment – will be threaded through the confined tunnels.

The complicated machinery of escalators, lifts, entry and exit gates and ticket machines also have to be accommodated. Moreover, this is railway infrastructure, which means that a modern advanced signalling system also has to be installed and tested. This confluence of interconnected demands has led to the opening of the Elizabeth Line being delayed by a year, from December 2018 to 2019, much to the annoyance of the travelling public.

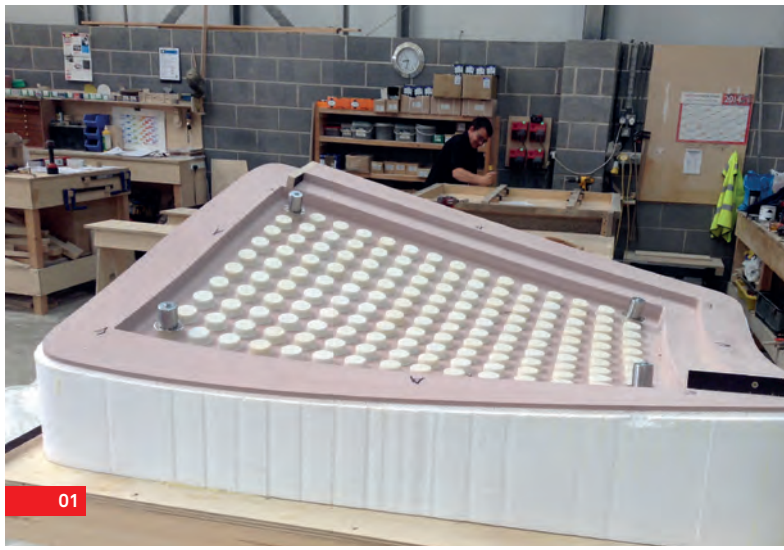
The task of fitting out three of the largest and most complicated stations has gone to Bryden Wood, a multidisciplinary civil and structural engineering company originally set up in the mid-1990s to explore how the concepts of design for manufacture could be applied to this sector. Increasingly, this has seen the company becoming involved in off-site modular manufacture, constructing the elements of the buildings it works on – which have included schools and units for Gatwick airport – off-site in factories to a high level of finish, generally using the 'flatpack' philosophy, and then transporting them to the site to be assembled into a finished building. "It's very much an attempt to improve the productivity of the construction sector, which is notably lower than that of the manufacturing industry and very dependent on specialised trades and their equipment arriving on site in sequence, which can often be disrupted by external factors such as traffic conditions and weather," explained Jaimie Johnston, director and head of global systems.

> "Every junction between tunnels has different geometry"
>
> Jaimie Johnston, Bryden Wood

Johnston is in charge of the project to fit out Liverpool Street, Whitechapel and Tottenham Court Road stations, which have the distinction of being some of the most complex on the line, tunnelled through areas with a high density of existing underground infrastructure which led to them having somewhat convoluted geometry. "One of the problems is that the tunnels we have to work in do not conform to very strict engineering tolerances," he explained. "The tunnels were made by drilling through the ground and spraying a cement mixture on to the walls to stabilise them as they were excavated, and it isn't possible to be completely accurate with that construction method." Whereas in a conventional building the walls would be perfect to millimetre tolerances and the angles would all be nearly exactly as specified in the architect's drawings, in the underground spaces of the Elizabeth Line, walls can waver along their designed route by a significant amount.

The consequence of this is that a standardised fixing system simply wouldn't be practical. Moreover, the usual way of working on a construction

A new system had to be devised to attach the cladding to the uneven walls



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01 The panels themselves were manufactured according to the digital models of the tunnel geometry and the architect's design for the station

02 Installing the cladding was more like an assembly operation in a factory than a traditional construction project

site, where communication is via drawings issued to the site team, would also not be practical; it would require far too many drawings to cope with the complex 3D geometry. Johnston's team, which was subcontracted by lead contractor Laing O'Rourke, therefore had to design a new system for making tunnel interior cladding that would be compliant with tight tolerances, but could still be installed into the awkward, non-compliant spaces left by the tunnel construction contractors.

The original design intent for the stations used a complicated steel fixing system that would be attached to the wall of the tunnel, and to which the panels that formed the cladding system would be attached. "This was highly complex, and the original design had cladding panels that were so heavy that they needed a complex superstructure behind them, and that required thousands of fixing bolts to attach it to the tunnel wall, which would have been expensive and complex to install," Johnston said.

"Every junction between tunnels has different geometry, which precluded standardisation. We realised that the design intent was effectively just the inner face, so anything between that and the sprayed concrete wall was effectively up for grabs. We did finite element analysis (FEM) on the support structures, we did FEM, physical testing and bomb blast testing on the panels to see how thin we could get them, because that would mean we could strip down the support structure we would need."

"We got the weight down by about two thirds, which reduced the parts count considerably. The concept we came up with, rather than fixing to the entire length of the surface of the tunnel, would fix to a single rail running along the wall that we would position with a laser line so it was precisely located in space, and do the same thing at the level of the platform itself, and indexed everything to those. That meant we could ignore the tunnel lining that was, in engineering terms, all over the place, and completely control the environment through those two fixed points which we created. That greatly reduced the number of fixing bolts we would need and allowed us to use a folding system to install a simplified fixing grid that unfolded between those two rails, and to which the cladding panels could be attached. As a result, the cladding installation is independent of the geometry of the sprayed concrete tunnels. It effectively meant we were working at zero tolerance."

Known as 'platforms', this system is used in conjunction with point-cloud scans of the interior of the station tunnels, and has been developed in collaboration with Autodesk to work with Solidworks. It means that the GRP cladding panels themselves can be standardised for a straight or regularly curved tunnel, and only need to be custom-manufactured for the junctions between tunnels, with their complicated geometry. In these sections, known as 'tasks', the original design intent was for each cladding section to have its own frame, made from steel. Johnston's team devised a way to make the support structure from GFRC as well as the cladding panel itself, greatly reducing weight and cost.

"One of the tests was that we had to be able to take panels off, so work could be done behind them, then replace the panels and readjust them within eight hours, which fits within the time available during the night shift for maintenance," Johnston said. "We actually found that we eliminated adjustment time – you just clip them on and you're finished. We got that eight hours down to 34 minutes. That all comes from eliminating any reliance on the tunnel geometry itself."

It's very likely that what we develop is working on Crossrail will come in useful for other types of project. In the Solidworks model, we literally have every nut, bolt, screw and washer in the digital to physical system, and that drives the whole assembly project. It's likely we will use that approach in other modularised construction projects, because it is that which means we don't need to use traditional drawings. We are almost finished on our original schedule for our three stations," he added. "We expect that the size we mothballed until after the budget when it becomes clearer when they will open. Whatever is delaying the start of operations, it isn't us." ■

An amazing time to be in automotive

Jon Excell **talks to JLR's chief product engineer about being at the heart of an industry leading a technological revolution**

As the over-used quote attributed to Henry Ford about the public asking for faster horses is often used to illustrate, the automotive industry has a deserved reputation for anticipating and second-guessing drivers' appetites.

And at a time of profound change for the sector, when car-makers are taking the lead on a range of truly game-changing disruptive technologies – Ford's words are perhaps as relevant now as they were when he alledgedly uttered them.

But while it's certainly true that the car industry is quicker than many other sectors to introduce new innovations, it would be wrong to suggest, as some critics of its eager adoption of change complain, that its approach to new products is some kind of top-down ivory tower exercise. Indeed, an often overlooked and increasingly important part of the automotive product development process is the time spent looking at cars that are already on the road, talking to the customers, and building the lessons learned from these vehicles into subsequent generations.

One person at the sharp end of this process is Jaguar Land Rover chief product engineer Elizabeth Hill, who – after a number of years leading the development and launch of major updates on the Range Rover – is now heading up the firm's "continual learning" on current cars.

Talking to *The Engineer* after winning one of *Autocar* magazine's 2018 British Women awards, Hill explained that while this has always been a key element of the firm's strategy, it's now become more important as a number of key technologies for the industry begin to hit the roads.

The obvious example here is electrification, which JLR – along with others – has pledged will be at the heart of all new vehicles by 2020. "We're moving more towards electrification in the future but we've still got many, many customers who still want IC engines as well," said Hill. "The architectures of the future will need to make sure they can do both." Unsurprisingly, another key issue here is that old EV bugbear, range. "Customers want more and more range," she added, "we'd like to get more for less in terms of package space."

Managing and acting on all of this feedback is a truly international effort, she explained. Lessons are learned from all of the 154 countries the firm sells its vehicles into, and the way in which these findings are built on has to be relevant to the entire customer base. "We can't design a car in Warwickshire for Warwickshire because if we did that we wouldn't be selling the volumes of cars we are currently," said Hill.

In general, she said, there are more commonalities than differences across all of these different markets.

> "We want to get to the place where like on your iPhone you get regular software updates"

Nevertheless, it's important to acknowledge that there are some key international differences. "The weather alone gives you different challenges: Russia compared to the UAE has very different conditions and terrains."

What's more, different parts of the world will inevitably have different relationships with technologies. For instance, she said, it's unlikely that autonomous vehicles – a key future area for JLR – are going to be enthusiastically embraced in chaotic busy cities like Sao Paolo. "It's so busy there are lots of parts of Sao Paolo where if you used autonomy you'd never get anywhere – it's only by sheer belligerence that you move through."

Taking sensible account of these regional differences is, she said, going to be increasingly important as the market becomes ever more diverse. "Obviously we can't design a car to suit every single individual customer, so

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you have to have a target for the masses, but you also need to have a number of regional differences to ensure that you hit the spot."

While many of the lessons learned by Hill's team feed into future vehicle plans, another element of her job is ensuring that improvements are rolled out to existing vehicles as quickly as possible. In an interesting reflection of the way in which the fast-moving world of consumer electronics is changing drivers' expectations," said Hills, this is largely a matter of software updates. "We want to get to the place where like on your iPhone you get regular software updates," she said.

Rapidly shifting technology trends such as this make it, said Hill, an "amazing" time for an automotive engineer. But anyone considering a move to the sector should be prepared to collaborate and step out of their

01 Jaguar Land Rover has a programme of continual learning to improve its current range

02 Electric is the future, but that is only part of the story

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comfort zone. "Engineers can no longer work in silos, they have to collaborate much more and take more of a systems approach," she said.

Hills pointed to the increasing levels of collaboration between JLR's four key centres of competence (powertrain, chassis, body, and electrical) as evidence of this in action. "More and more of that is getting blurred," she said, "so many things as we move forward have to work together. If you think about autonomy and what that means for the braking system, the engine, and the chassis module, there's a huge amount of interaction that gets driven out of that. Therefore, collaboration across those areas is absolutely key. Any barriers there might have been are coming down."

Hill's own entry into an engineering career was fortuitous rather than the result of a long-held ambition. Unsure of what path to take following a maths degree at Nottingham University, she took a temping job for automotive parts supplier LucasVarity deburring electrical stators, enjoyed the work, applied for a graduate trainee role and got it. After a brief stint at Rolls-Royce she joined Jaguar Land Rover in 2002 and hasn't looked back.

In light of her own experience, Hill would like to see more of a concerted effort to inform young people – and particularly girls – that engineering is a valid career choice for them. "I went to an all-girls school, was great at physics and maths but they never spoke to me about engineering. It was all a very happy accident," she said. "We need to get people into engineering by design rather than accident, we have to make sure at school we're talking to people about engineering."

JLR, she believes, has done a great job of doing just that, and by ensuring that its STEM efforts give equal encouragement to girls, has seen an increase in female apprentices from six to 36 per cent over the past five years. "There's no favouritism in that; they've got to go through the same application process. The issue before was that there were no girls applying. If you don't attract girls, they don't apply, and you can't employ them. If you attract lots, you get them applying and then they go through an application process just like everyone else."

It's exciting to ponder what technology trends and innovations will shape the careers of this future generation of engineers, but Hill's reluctant to indulge in too much crystal-ball gazing. "Twenty years ago, you probably thought you'd be able to predict 20 years head, but now you can't. Whatever we say we think is going to happen in 20 years I think it will be wrong. Every decade of my life the time that oil's going to run out has changed. In 20 years will there be no combustion? I don't know. We don't know what the clever people around us are going to discover to power cars and other things."

Flat out in the Ariel Nomad

This fun supercar is possibly the craziest idea to come out of the British car industry in recent years, but it's also one of the best, writes Chris Pickering

The Ariel Nomad is ideally suited to Exmoor's rugged landscape

Step into the Ariel Motor Company's Somerset HQ and the first thing you're greeted by is a 3HP Quadricycle built by the firm's namesake in 1901. In some respects there are parallels to its modern counterparts sat on the opposite side of the foyer. Both feature a lightweight construction, minimal bodywork and a mid-mounted petrol engine. But that's where the similarities end.

The original company is sometimes credited with having created the first commercially available bicycle. Although best known for its later motorcycles, it was also an early pioneer of the British car industry, with an Ariel Simplex listed among the vehicles on the grid for the first ever race at Brooklands in 1907. However, car production ceased in 1925 and the motorcycle business closed its doors in the late 1960s.

The name was revived in 1999 when former Porsche and Aston Martin designer Simon Saunders set about pursuing his dream of creating a lightweight, minimalist sports car. That design would go on to become the Ariel Atom and it has been evolving into progressively wilder iterations ever since (including one particularly bonkers example with the company's own 3-litre V8, loosely based on two four-cylinder motorcycle engines grafted together).

> "No other car is capable of driving from a race track to farm field via a B-road"

The Atom's defining feature has always been its steel-frame exoskeleton design. This is a glorious combination of form and function, with the sculptural aspect of the exposed tubes backed up by high torsional rigidity and low weight. Although very much a road and track toy, there was a hint of dune buggy about the Atom's appearance, which soon prompted enquiries about an off-road version.

To describe the Nomad that you see here as an off-road Atom would be doing a disservice to what is, in fact, a completely new design. Every single tube in the chassis is different and there are only a handful of components shared between the two cars. The philosophy, however, is very similar and there's the same overriding sense of quality that distinguishes Ariel from a lot of other low-volume sports car brands.

The cars are assembled on-site in Somerset, but the company draws upon the UK's rich automotive supply chain for its components and sub-assemblies. The chassis, for instance, are fabricated by Arch Motors in Huntingdon. They start life as a mixture of 12, 14 and 16 gauge cold drawn steel tubes that are joined using a combination of bronze, TIG and MIG welding before being phosphated and powder-coated. The brakes come from Alcon in Tamworth, while the digital dashboard display hails from Race Technology in Nottingham. Honda UK supplies the firm's engines, although the Nomad actually uses the 2.4-litre four cylinder unit from the US-spec Honda Civic Type S. This is torquier than the 2-litre engine from the previous-

01 A full-sized windscreen is an optional extra

02 You swing yourself in through the roll cage

03 The Nomad scythes through bends

generation Civic Type R that was used in the Atom until it made the switch to forced induction earlier this year. As standard, the Nomad remains naturally aspirated, but for around £4,000 Ariel will fit a supercharger kit that lifts its output to 300bhp and 300Nm of torque.

Those figures might not sound like much in an age of 600 bhp estate cars, but the Ariel's secret weapon is its power-to-weight ratio, and it uses it to devastating effect. With an all-up mass of 680kg, the Nomad is ferociously fast; its claimed 0-to-60 mph time of 3.2 seconds matches that of the McLaren 570S and the Lamborghini Huracán.

And this, don't forget, comes from a machine designed to negotiate muddy fields and rock-strewn tracks. We didn't do either of those things in our time with the Nomad, but we did head for the blissfully empty roads of Exmoor, where it proved to be more than up to the job of playing the road-going supercar.

You swing yourself in through the roll cage, *Dukes of Hazzard*-style, and prod a button to start the engine. It sounds gruff and a touch industrial at idle, but above about 4,000rpm the supercharger takes over with a banshee wail that's part buzzsaw and part divebomber. Lift off the throttle to change gear and the exhaust pipes turn into trumpets.

Come to a corner and the depth of engineering that's gone into the Nomad once again becomes apparent. In order to accommodate the wheel travel required for off-roading, the Atom's pushrod-operated inboard suspension has been dropped in favour of a more conventional outboard set-up. It's also a good deal more compliant than its track-focused sibling – even with the adjustable suspension in a relatively road-biased set-up. And yet somehow it still feels scalpel-sharp; scything through the bends in the way that only a lightweight mid-engined car can.

In some respects, the Nomad actually makes a better road car than the rather hyperactive Atom, but its real strength is versatility. That might sound like an odd comment for a car where even a full-sized windscreen is an optional extra, but consider it in the context of a Sunday afternoon blast and suddenly things start to make sense.

No other car on the market is capable of driving from a race track to farm field via a B-road and feeling equally at home in all three environments. Yes, it's a toy, but it's also beautifully engineered, exquisitely made and quite unlike anything else on the road. ■

A celebration of collaboration

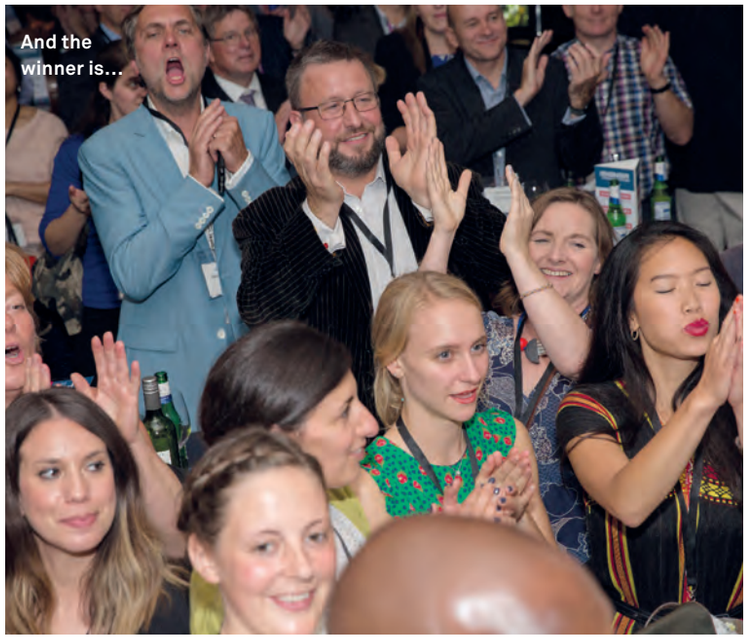
The shortlisted finalists for *The Engineer*'s 2018 Collaborate To Innovate awards highlight the strength and depth of UK engineering innovation

Now in its third year, Collaborate To Innovate (C2I) was launched to uncover inspiring examples of UK engineering collaboration and highlight the way in which engineers from different sectors and disciplines are working together to address some of society's most fundamental challenges.

It's fair to say that over the past three years it hasn't disappointed, and has helped showcase a host of truly groundbreaking projects: from medical innovations that will enable us to live longer, healthier lives; to transportation technologies that are helping to change the way we get from A to B.

And as the shortlisted projects for this year's competition – detailed over the next couple of pages – illustrate, UK engineering innovation is alive and well in 2018.

The ultimate winners of C2I 2018 will be announced at an awards party in London on 6 November and reported on in detail by *The Engineer*. For now, here's a brief taster of all of those hoping to walk away with one of our coveted C2I trophies. For a full list of all of the collaborating partners visit our C2I website: http://conferences.theengineer.co.uk



And the winner is...

Academic Innovator

Established to celebrate academic groups able to demonstrate sustained excellence in collaboration, the Academic Innovator award attracted a typically strong crop of entries spanning a range of specialist areas. On the shortlist were: The Institute for Advanced Manufacturing and Engineering, a long-term collaboration between Coventry University and Unipart; the South West Nuclear Hub, a University of Bristol-led effort to improve application of research and innovation to the nuclear sector; the SHEAR group, a University of Glasgow-led group exploring a range of innovations for challenging environments; and the Bristol Robotics Laboratory for its work helping over 300 SMEs with robotics and automation expertise.

> "At Frazer-Nash, we know that effective collaboration and the development of innovative solutions is vital in today's increasingly competitive markets. We recognise those talents in our own people, so we're delighted to support a competition that recognises the achievements of effective partnerships and the value that innovation delivers to the UK economy."
>
> Bill Hodson, board director

Automotive

Automotive is a new category for 2018, and the shortlisted finalists provide a great snapshot of a sector that's going through a period of profound technological change. Unsurprisingly, innovations related to low-carbon vehicles loom large: from the pioneering development of a road sweeper powered by hydrogen as well as diesel (ULEMCo and Aberdeen City Council), to an effort to grow the UK's electric powertrain manufacturing capability (the WMG-led High Volume E-Machine Supply (HVEMS-UK) project, and the recently completed Innovate UK funded CLASS project, which is demonstrating the manufacturability of lightweight composite chassis components. There's a nod to closer-to-market innovations courtesy of the AI-based Mercedes-Benz User Experience (MBUX) Infotainment System as well as the rapidly emerging field of driverless cars, which is represented here by the Arup-led UK Autodrive project.

Energy and environment

Finding ever more efficient ways to generate and use power is one of the biggest drivers of innovation. And the diverse group of finalists in the running for this award provides a compelling overview of some of the ways that engineers are rising to this challenge: from the Babcock-led work on power management systems for ships, to the OTHELLO project's claimed breakthrough in the solar energy arena.

Other shortlisted finalists are: Bristol STW, the UK's only co-located food-waste recycling facility and waste water treatment plant; the curiously named Elephants to Ants project, which is exploring the use of robots for nuclear decommissioning; the Balanced Energy Network (BEN) initiative, which is demonstrating an entirely new technology for sharing heating and cooling across a whole city; and a project in which Vestas, Airbus and a host of academic partners are working on reducing the aerodynamic noise generated by wind turbines.

Healthcare and Medical

Few fields are more dependent on cross-disciplinary collaboration than the healthcare technology sector. And from the blood filtering system developed through Sanguis (an initiative that promises to enable the availability of universal plasma) to the care robots developed through the Bristol Robotics Lab led Chiron project, the shortlisted finalists for C2I's Healthcare and Medical category provide a compelling illustration of how UK engineers are pioneering advances in this key area.

Other shortlisted entries include Eden 2020 (a pan-European effort to advance neurological diagnosis and treatment); a University of Sheffield-led project developing anti-microbial injectable bone grafts; an international effort to develop so-called bioelectronic drugs; and the University of Leeds-led SLIPS project, which is developing foot-sensing technology to treat diabetic foot disease.

Young Innovator

The Young Innovator award was established to spotlight excellence in STEM engagement and this year's finalists illustrate three differing approaches to inspiring the next generation: from the online format of 'I'm an Engineer, Get me Out of Here' (also a finalist in 2017) to the locally focused disaster-movie scenario of 'SmashFest' (which through its living in space programme has encouraged participants to engage with engineering by considering how they would live in space in the event of an earth-destroying disaster. Our third finalist, Transport Scotland's Academy 9 project, is a great example of how real-world engineering projects (in this case the A9 dualing programme) can be used as the basis of a host of engineering education activities.

Manufacturing Technology

In the age of Industry 4.0, the finalists in this year's manufacturing technology category provide some tangible examples of what this often-overused industry buzzword means in practice from the Laing O'Rourke-led Optimised project – which has built three industry 4.0 demonstrators, to the High Value Manufacturing Catapult's SitSki project, which has demonstrated the use of a host of factory-of-the-future technologies to build an advanced para-skiing system. The other shortlisted entries cover slightly more traditional ground with the Nuclear Advanced Manufacturing research Centre's (NAMRC) NNUMAN project exploring the techniques that could help re-invigorate the nuclear manufacturing sectors, while Gordon Murray Design's Carbon Aluminium Automotive Hybrid Structures project presents a new manufacturing technique for lightweight vehicles.

Defence, Security and Aerospace

Two separate aerospace projects, both led by Rolls-Royce, feature in this year's defence, security and aerospace category. One, in partnership with Strathclyde University, is developing a process for mapping residual stress patterns in compressor aerofoil components, while the other details the group's work with the University of Nottingham on new robotic technology for performing 'keyhole surgery' on jet engines. The other shortlisted entries are Kromek group's work for DARPA on the development of hand-held radiation detectors; and Delta f – a Worcester Scientific-led initiative exploring the use of bioMems (biologically inspired microelectromechanical systems) to develop next-generation biological and chemical sensors.

Information, Data & Connectivity – sponsored by Babcock International

babcock

The growing importance of connectivity and data are two of the defining trends of our current technological age, and shortlisted entries to this category provided a snapshot of how these trends are impacting a range of different sectors.

The energy sector is a case in point, with the Brunel-led WindTwin project – which has shown how digital twin technology could revolutionise wind turbine maintenance, and Limpet – an IOT approach to monitoring oil and gas pipelines, both showing how smart use of data can help improve efficiency and reduce downtime.

The automotive sector was also prominent here thanks to the Bosch-led MOVE_UK initiative, a multi-partner collaboration which is using an innovative approach to data management to validate driverless car technology. The other finalists in this category detail technologies that may underpin our data-rich future, from the Lancaster University-led Ultrawave project (which is exploring us of the mm wave spectrum to deliver high-speed Wi-Fi) to a UCL-led effort to develop novel transceiver technology aimed at enabling us to get more bandwidth out of existing infrastructure. ■

> "Babcock International is proud to support this year's C2I awards. Engineering is embedded in our DNA and technology underpins everything we do, and so does the way we collaborate with our customers. With our engineering expertise spanning across our four Sectors we have the ability to identify and integrate technology into our through-life support. That's why we are a partner trusted to deliver"
>
> Steve Penver,
> Head of data and analytics,
> Babcock International Group

What the judges said

The C2i 2018 judging panel was highly impressed with the standard of this year's shortlist:

■ **"The variety we had in the entries was quite inspirational – just seeing how many different domains the UK is pushing the boundaries in inspired me about the future of engineering**
Abbie Hutty, ExoMars Project, Airbus

■ **"As a first time judge I was taken aback by the amount of innovation, the high standard of the entries and the broadness of the applications across a range of different aspects."**
Steve Penver, Babcock International Group, head of data and analytics

■ **"An impressive range of entries, demonstrating the quality and depth of innovation that's ongoing in the country. It makes me feel optimistic about the future."**
Chris Guyott, engineering director, Frazer-Nash consultancy

■ **"I found the level of collaboration quite astonishing – the other thing that comes out is the cross-fertilisation of techniques and technologies from one sector to another**
John Halton – Director Business & Industry, Engineering UK

■ **"Really strong inputs, and strong signals in terms of AI coming to the front,"**
Andy Wright – director strategic technology, BAE Systems

■ **"Such a wide range of high-quality, Innovative and diverse entries really gives you confidence about the opportunities in engineering and what a fun place it is to work."**
Alan Newby, director aerospace technology and future programmes, Rolls-Royce Plc

Renishaw encoder helps slide scanner to hit its mark

High resolution position feedback with low cyclic error, noise and jitter. Supplier: Renishaw

Located in Budapest, Hungary, 3DHISTECH designs and manufactures one of the world's fastest and highest-capacity autonomous panoramic digital slide scanners – the P1000. The device is a highly accurate scanning microscope that enables large pathology labs to capture ultra-high resolution images of medical samples, while operating unmanned for up to two days. This new generation of digital slide scanner is the first to have integrated optical and magnetic position feedback encoders for enhanced throughput.

"The P1000 can digitise 1,000 slides in one work shift," said Viktor Varga, CTO of 3DHISTECH. "It has two main components: a digital slide scanner [microscope] and a high capacity slide loader. These components work in parallel to increase the throughput of the system. The microscope has three objective lenses, enabling both immersion and dry scanning. We designed the system to cover any need of a typical pathology or biological laboratory."

3DHISTECH specified a high resolution encoder, ultra-precise mechanics, and a fine-tuned process control system with a short control response time. These requirements are challenging in terms of mechanical and electrical engineering. Engineers had to minimise the stick-slip effect, and create a control loop with precise feedback for driving a piezomotor

with a 100nm step-size. The readhead's resolution and noise level (non-repeatable errors) were the most important performance parameters that influenced selection of the encoder system.

The engineers at 3DHISTECH decided to use Renishaw's VIONiC incremental encoders on the slide scanner to eliminate the latency associated with the conversion of absolute position into serial communication signals. They connected the encoder output directly to the microcontroller responsible for moving the axes to enable 'real-time' feedback. The chosen encoder is required to provide high resolution position feedback with low cyclic error (SDE), noise and jitter.

Ease of set-up and calibration is supported by an Advanced Diagnostic Tool (ADT), which includes user software that allows remote control and monitoring of VIONiC's set-up and calibration routines. The tool allows remote, advanced calibration features and is used by 3DHISTECH during readhead installation due to unavoidable obstruction of the line-of-sight to the set-up LED. With Renishaw's technical support, 3DHISTECH's engineering team was able to specify an encoder for each machine axis and find the appropriate encoder products for their applications. ■

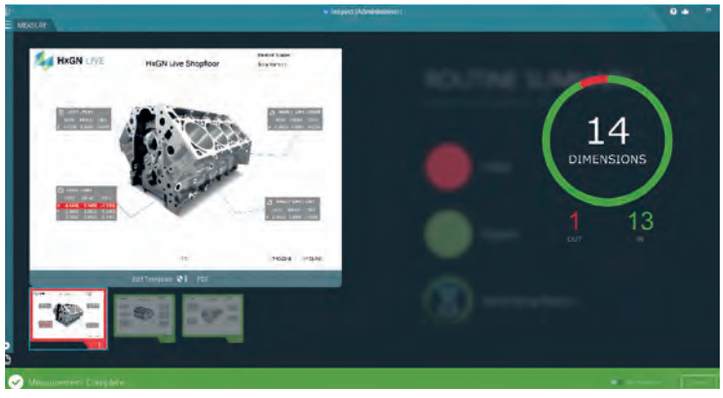
Major new software release

Many new features included Supplier: Hexagon

Hexagon Manufacturing Intelligence has launched PC-DMIS 2018 R2, the latest edition of the company's measurement software and the second of two major releases scheduled for PC-DMIS in 2018.

PC-DMIS 2018 R2 introduces a new reporting workflow, simplifying the creation of customised reports with simple 'drag and drop' and an intuitive slideshow-style interface. A new QuickPath tool expands on existing QuickFeature functionality to simplify feature creation with a safe path. PC-DMIS 2018 R2 also introduces the ability to add run charts from qs-STAT into the PC-DMIS report. Improved Probe Utility allows users to mark favourite tip configurations, create required tip angles by clicking on CAD, and buy replacements with Shopping Cart tools; a new e-Store is coming soon to hexagonmi.com.

Improvements in the use of lasers, specifically for path creation and



offline programming, are also featured in the new release, as are service pack updates to ensure maximum reliability.

"PC-DMIS 2018 R2 continues the recent trend towards maximising productivity in the three major metrology tasks: Creation, Execution, and Collaboration," said Ken Woodbine, product line manager for Metrology Software at Hexagon Manufacturing Intelligence. "Creating measurement routines is even simpler and more intuitive with the addition of both QuickPath for adding motion in 'walk up and measure' applications and the offline path visualisation and simulation for laser probes. Execution is also streamlined with improvements to our Inspect module, making it easier to control access to routines, and for operators to search and find routines and reports.

"PC-DMIS continues to add support to work seamlessly with even more measurement devices and sensors. The introduction of Q-DAS Run Chart integration and Shopshot offers a fuller picture of production processes. The addition of Inspect Slideshow dimensional display helps users call out key dimensions, giving operators a clear go/no-go in real time."

User experience has been improved with a smaller XactMeasure dialog window that consumes less space in the Graphics Display Window and improved FCF editor design with new icons for defining or adding datums and second single segment or composite FCF. Slideshow, the real-time dimensional reporting tool, is now free to use under a PC-DMIS Software Maintenance Agreement (SMA). Inspect 3.2 now gives more control over which routines are accessible, has improved search filters for routines and reports, and displays the last execution time and duration for each routine. ■

■ **PC-DMIS 2018 R2 is available to download immediately. More information is available through local Hexagon commercial operations and dealers.**

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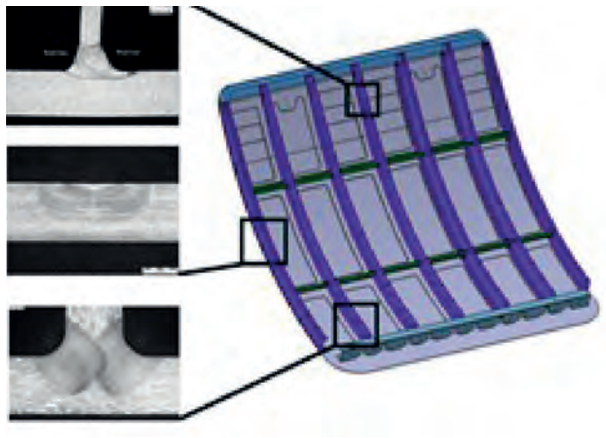
A better alternative for holding planes together

New technique may do away with rivets and give many benefits Supplier: TWI/Oasis



Traditionally, the aluminium structures that make up aircraft fuselages have been held together by rivets. A large commercial airliner will contain hundreds of thousands of these fasteners. But there are major drawbacks to riveting: it is time-consuming, expensive, and adds weight to the structure. Moreover, it involves drilling holes – which then have to be deburred – and places point-loads into a structure which is pressurised and de-pressurised cyclically. This can lead to long-term fatigue loading and corrosion.

Aircraft manufacturers would like to find new ways to hold aircraft together. TWI is leading a project to investigate new methods using the latest developments in friction stir welding and laser-beam welding. Known as the OASIS project, it is part of the EU's Clean Sky 2 research programme, funded under Horizon 2020 and involving six other European partners: welding equipment supplier ESAB, testing laboratory VZLU, process modelling and simulation provider Geonx, aerospace Tier 1 supplier Romaero, materials science and metallography RTD partner University West and virtual manufacturing and cost-modelling specialists at the Queen's University Belfast.

Friction stir welding was initially developed at TWI, and uses a rotating tool to generate friction on the junction of the items to be joined together. This creates a softened region near the tool, which joins the two pieces together without melting the material. As the tool moves along the junction, it mechanically intermixes the metals on either side, effectively creating a strong forged bond between the two pieces.

Initially, the project will look at developing techniques to manufacture two full-scale cargo door demonstrators for validation, with inspection in accordance with aerospace standards.

Eliminating rivets is expected to reduce the weight of an aircraft by up to 10 per cent, cut joining time by 40 per cent, reducing the use of sealants, and lowering the number of protective organic layers required to prevent corrosion. Moreover, it might improve stiffness and strength, as joined pieces will be attached together along their entire length rather than just at points, and will improve the aerodynamics of aircraft as their will be no holes, no protruding rivets and smoother surfaces. Reduction in the need for inspection and maintenance might also result. The project will run for 30 months with a total budget of €1.4m (£1.25). ■

3D printing technology enables dissolvable medical fasteners

Costs and risks lower Supplier: Optomec

Engineers at the University of Nebraska-Lincoln (UNL) in the US have demonstrated the use of metal 3D printing technology to produce dissolvable medical fasteners.

Led by Dr Michael Sealy, assistant professor of mechanical and materials engineering at UNL, the group, which attended September's IMTS event in Chicago, revealed that it has been using a LENS (laser engineered net shaping) additive manufacturing system supplied by Optomec to produce a range of dissolvable magnesium components.

The work is expected to have broad-reaching implications in the design and manufacture of next-generation medical implants as well as helping to eliminate the need for secondary surgical procedures, thereby reducing risks, costs and suffering for patients.

"Our research is focused on advancing the performance and functionality of dissolvable devices," explained Dr Sealy. "Using LENS, we are applying a hybrid additive manufacturing process to control the disintegration of medical fasteners and plates so they stay intact long enough to serve their purpose and then degrade away once the bone is healed."

Medical implants such as plates and screws are currently made of titanium or stainless steel, which are permanent structures that often have high complication rates and require a second surgery for removal.

"Two years ago, Dr Sealy and his team became the first customer of our LENS Hybrid Controlled Atmosphere system," said Tom Cobbs, LENS Product Manager at Optomec. "Now they are here at IMTS showcasing their ground-breaking accomplishments achieved with their LENS Hybrid system. Dr Sealy's pioneering work enables the design and manufacture of components with a combination of properties unobtainable using traditional metal working methods."

Powdered metals, such as magnesium, titanium and other reactive materials, must be processed in a controlled atmosphere where oxygen and moisture impurities are maintained below 10 parts per million. Dr Sealy and his team used the LENS System to process these materials in a way that addresses a key scientific challenge: how to maintain the strength and integrity of a degradable implant long enough for it to do its job.

As the technology is a hybrid system (combining additive and subtractive processes) the team was able to apply layered surface treatments that enabled controlled degradation of the magnesium components. The ability to control disintegration of a structure is a highly sought-after design capability – not only for applications in orthopaedics, cardiology, and urology, but also for other areas such as lightweight aerospace and automotive structures.

Electronics fair is a world leader

Munich is the venue for exhibitions, conferences, networking and setting free the imagination

Running from 13-16 November and filling 17 halls at the enormous Munich exhibition centre, this year's electronica show – the world's leading electronics trade fair – promises to be the largest ever iteration of the event, according to its organiser.

Showcasing components, systems, applications and services from more than 3,000 companies, electronica covers technologies, products and solutions from the entire electronics industry and attracts visitors from nearly every consumer segment and user industry imaginable.

New features for this year's event include electronica Experience which will give visitors the opportunity to get to grips with electronics, as well as showcase career opportunities in the sector; and IMPACT – Design for a Cause, an interactive forum that will look use a series of pitches, presentations and discussion panels to examine the future influence of electronics on communication, the environment and medicine.

The trade fair also runs in parallel with leading European microelectronics exhibition Semicon Europe 2018. Featuring over 450 exhibitors from the semiconductor manufacturing, printed and organic electronics sectors, the show offers exhibitors and visitors a unique platform to exchange and network with over 6,000 engineers, executives and decision-makers.

Away from the exhibition floor, the show also features a series of high-level conferences. Among these, the electronica Automotive Conference will look at how electronics are at the heart of technological change sweeping across the automotive sector. Presentations here will look at how electronics are shaping the future of mobility and, among other things, will look at emission-free driving.

Meanwhile, the electronica Embedded Platforms Conference will be dedicated to all things embedded: from MCUs and multicore to FPGA and tools and software for safety and security. Another conference, the electronica Wireless Congress, will explore technology trends such as the Internet of Things, Bluetooth standards and RF technologies.

This year's event will also see the introduction of a new Medical Electronics Conference, which will reflect the growing overlap between engineering and medicine.

Electronics are at the very heart of innovations within the medical technology sector. There are already plenty of examples of vital developments from the past, such as X-ray machines and pacemakers. And now, as health care becomes increasingly digitised with networking, smart data analysis and telemedicine, electronics have come to be an integral element.

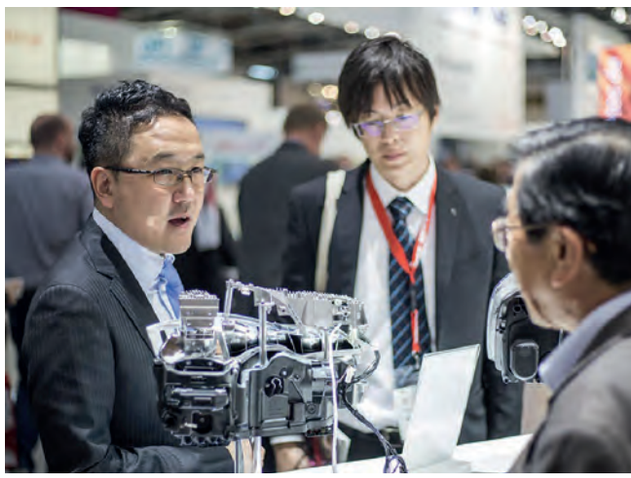
The result of this is further market growth, which is boosted by ageing and booming global populations as well as by a greater focus on individualisation within medicine.

Examining the opportunities and challenges of working in the health market, this event will see doctors and electronics engineers entering into discussions about the future of the medical sector. Issues covered will include smart medical devices, cloud computing, data security and sovereignty, blockchain technology, collaborative robots, smart contracts, usability, artificial intelligence, telemedicine and Medicine 4.0.

Meanwhile, back in the exhibition halls a number of companies will be showcasing medical electronics technologies that are already making a difference.

MEMS market leader Bosch Sensortec (Hall C3, Stand 522) will be showcasing a range of sensors for wearable applications that constantly measure vital parameters, whilst Analog Devices (Hall C4, Stand 111) will have implantable MEMS inertial sensors on display that consume very little energy and can be used to monitor patients at an increased risk of having a fall, for example.

Other innovations on display include the world's smallest differential pressure (Sensirion Hall B3, Stand 417) which is playing a role in state-of-the-art treatment in smart inhalers, and a microsensor system from Fraunhofer IMS (Hall C3, Stand 409) – patients with glaucoma can measure their intraocular pressure and temperature via an implanted sensor without the need for any contact to be made. ■



electronica will have several new features this year

A decade of showcasing great engineering

Organisers promise that 2018 will be the most ambitious yet with exciting new features and zones

Advanced Engineering, the UK's largest exhibition for advanced engineering professionals, is celebrating its 10th birthday by being bigger and better than ever, according to its organiser Easyfairs.

Running from 31 October to 1 November at the NEC Birmingham, Advanced Engineering 2018 promises to connect the entire supply chain of the UK's advanced engineering industry with R&D, design, test, production and procurement from large and small companies, through to top-tier industry players.

Bringing together over 700 firms and more than 15,000 engineers, the 2018 event is expected to build on the success of the 2017 exhibition, where attendance increased by 15 per cent on the previous year. Last year's event attracted some of the industry's biggest names, including Airbus, Boeing, Jaguar Land Rover, Hexcel and Dassault Systèmes, who met and did business across the supply chain, with visitors from a range of engineering specialisms including automation, design and test engineering, process control, machining and many more.

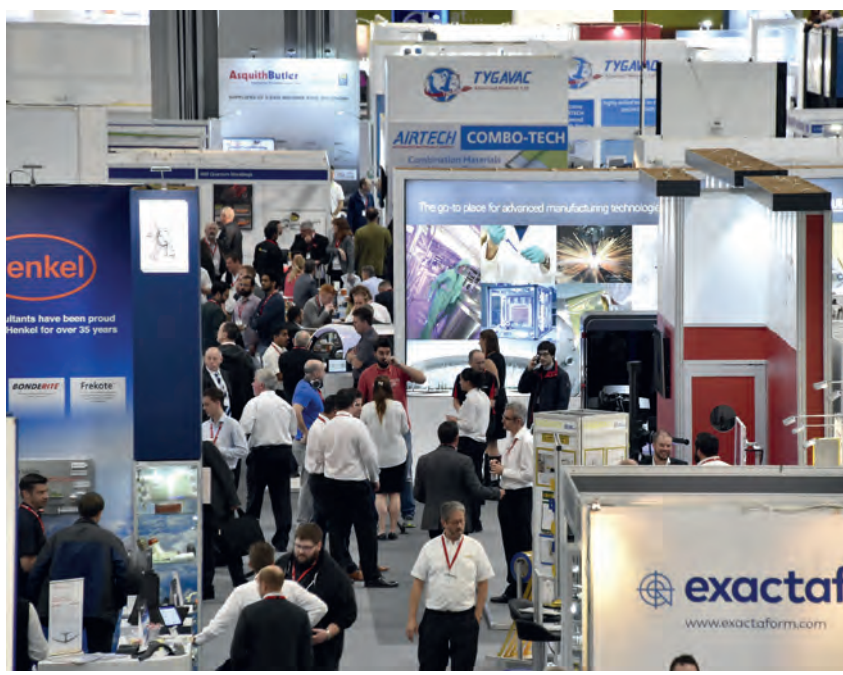
This year's exhibitors span a range of disciplines, sectors and areas of expertise and include major industry names such as Renishaw, Group Rhodes, Igus, Kawasaki Robotics, Mouser Electronics, National Instruments and Rockwell Automation.

The event is made up of six co-located zones: Aero Engineering, Composites Engineering, Automotive Engineering, Performance Metals Engineering, Connected Manufacturing and – new for 2018 – a Nuclear Engineering zone that will tap into the technical excellence of this high-growth sector, addressing nuclear energy new-build, operation and supply chain.

Another new feature is the UK Contract Manufacturing zone, a dedicated area for the UK's small engineering firms and subcontractors. "Britain's small engineering companies are the backbone of the country's manufacturing capability, a capability which is renowned around the world for its technical expertise and fantastic customer service," commented Alison Willis, industrial divisional director at Easyfairs. This year's show also features a return of Enabling Innovation, a feature that provides a unique opportunity for 50 start-ups and researchers to showcase the next generation of exciting new technologies.

Away from the exhibition floor, the event's two-day conference features six CPD accredited open forums featuring over 200 different sessions. Speakers include Sameer Savani, head of innovation and engineering at ADS Group, who will be talking about the aerospace sector's adoption of Industry 4.0 technologies; Mike Mychajluk, supply chain projects and external engagement manager at Jaguar Land Rover; along with Mike Wilson, business development manager at ABB Robotics. ■

■ For more information or to register for a free ticket visit: www.advancedengineeringuk.com



The exhibition is divided into several different zones

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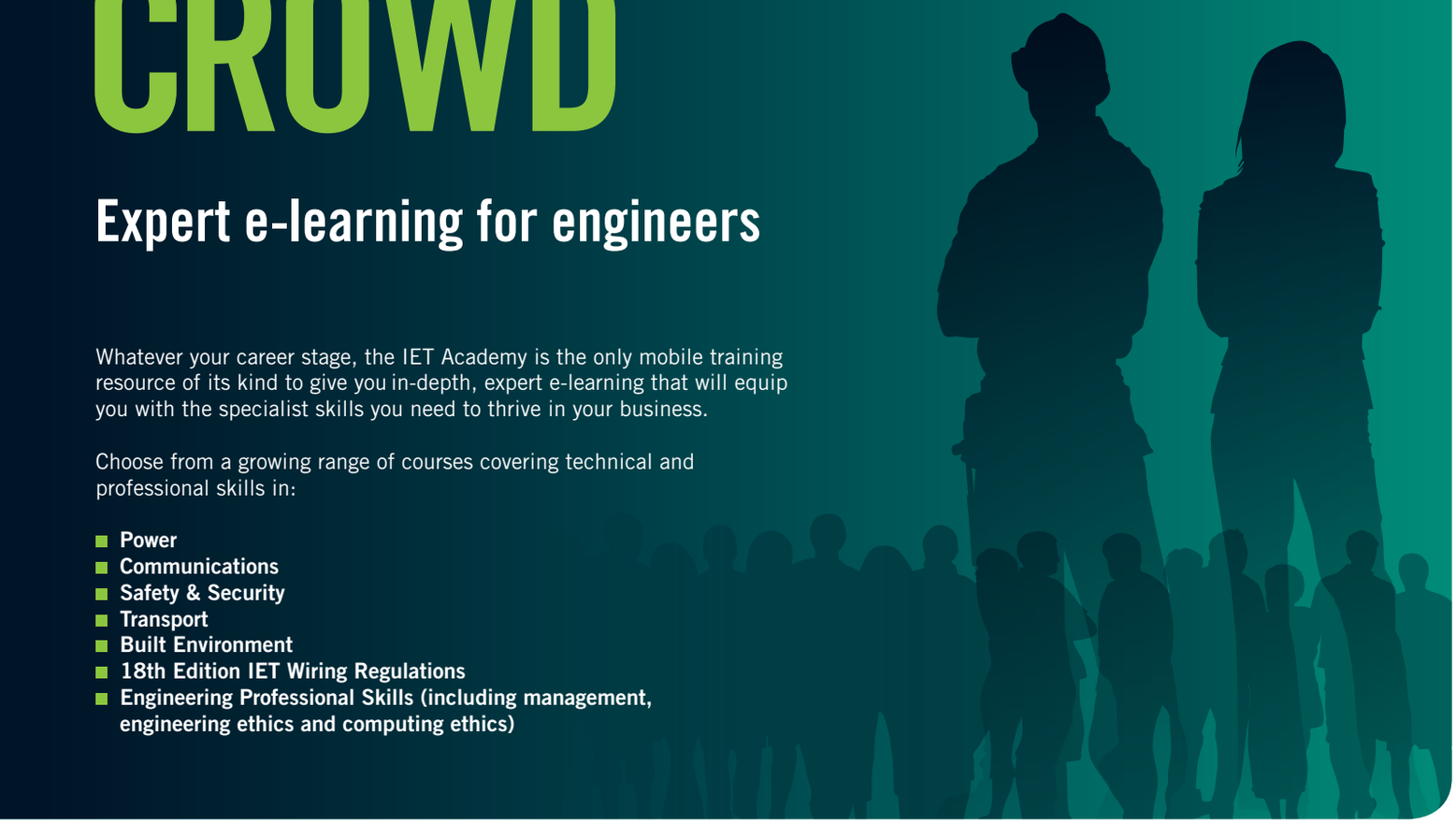

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September 1912

The mighty dreadnought

How *The Engineer* reported on Germany's naval build-up

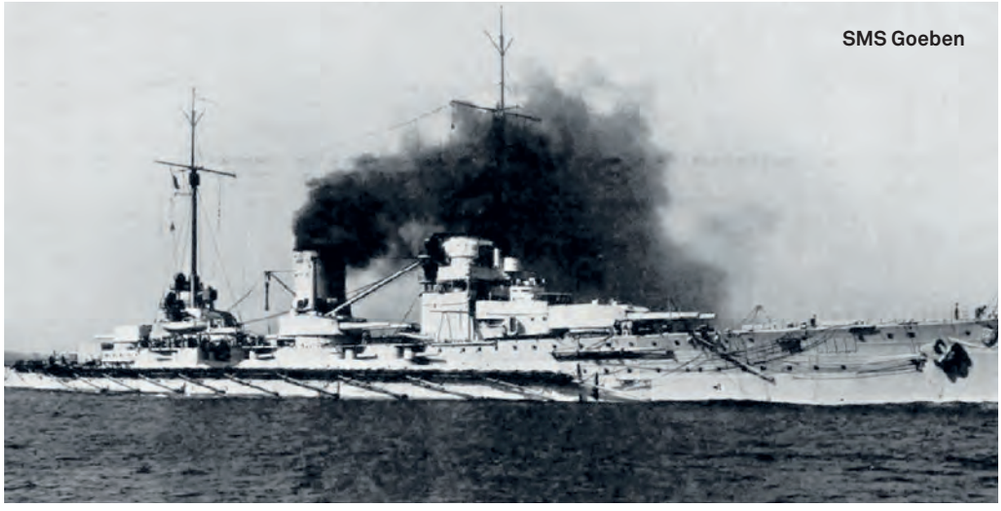
The approaching centenary of the conclusion of the First World War is as good a time as any to reflect on some of the engineering that preceded the conflict. Indeed, the respective antagonists' accumulation of military might is widely accepted as a significant contributing factor to the outbreak of the Great War, tensions ratcheting up in tandem with the naval arms race that unfolded. One of the most impressive ships to emerge from this pre-war period – and certainly one of the longest serving – was the SMS Goeben of the Imperial German Navy.

When the Royal Navy launched HMS Dreadnought in 1906, it completely changed the face of naval warfare. Dreadnought was the first capital ship to be powered by steam turbines, making her the fastest battleship in the world at the time, topping out at 21 knots. She was also fitted with a uniform main battery of ten 12-inch guns, rather than the conventional layout of fewer large guns supported by a smaller secondary armament. Her introduction heralded an entirely new class of warship, with those built before – the 'pre-dreadnoughts' – rendered virtually obsolete.

The German response was to lay down its own quartet of dreadnought-class battlecruisers, starting with the Von der Tann in 1907. By September 1912, the third vessel – the Goeben – had just been completed, joining its sister ship, SMS Moltke. Alongside an engraving that showed off the ship in all its glory, *The Engineer* cast its eye over the German efforts to date.

"All three of these vessels, together with the Seydlitz, now under construction... have been constructed by Messrs Blohm and Voss of Hamburg, and constitute a quartette which certainly reflects very highly on the ability of their constructors," our predecessors wrote.

According to *The Engineer,* the Goeben measured 610ft in length with a beam of 96.5ft, displacing 22,600 tons. It had a main armament of ten 11-inch 45-calibre guns dispersed in a five-turret arrangement that was replicated across all the German Admiralty ships under construction at the time. This big-gun battery was supported by 12, 6-inch guns on the main deck as well as an anti-torpedo boat armament of 12 3.4-inch guns and four torpedo tubes.



SMS Goeben

Like the Moltke, power was provided by Parsons turbines driving four shafts, "steam being supplied by twenty-four boilers of the Schulz four-drum type with 36 millimetre tubes." Goeben's sea trials had only just been completed and the results were not yet available, but *The Engineer* noted a maximum speed of 28.6 knots and subsequent information appears to bear this out.

This was a slight improvement on the Von der Tann, despite the Moltke and Goeben carrying increased belt armour. These incremental gains as the cruisers were rolled out were not overlooked.

"There is no doubt that in these two vessels German constructors have evolved on the whole a very successful design and one which is worthy of close attention in view of its wide divergence from the British practice of centre-line turrets and lack of heavy second armament," this publication said.

In practice, the Goeben barely served under direct German command, transferred instead to the Ottoman Empire upon the outbreak of war in 1914. It was renamed the Yavuz Sultan Selim – generally shortened to simply the Yavuz – and became the flagship of the Ottoman Navy, bombarding Russian positions in the Black Sea during the war. She also played a key role in the Battle of Imbros in January 1918, sinking a pair of British monitors on a sortie into the Aegean before suffering mine damage and beaching back in the Dardanelles. Despite being bombed by British light aircraft, she survived relatively unscathed and was towed back to Constantinople, but played no further significant part in the war.

"German constructors have evolved on the whole a very successful design"

The ship was due to be handed over to the British Navy as part of the reparations deal, but the Turkish War of Independence put paid to that. Yavuz would go on to become the naval flagship of the new Turkish state, carrying the remains of its first president, Mustafa Kemal Atatürk, from Istanbul to Izmit, upon his death in 1938. The ship continued in service throughout the Second World War, eventually decommissioned in 1950 and sold for scrap in 1971, by which point she was the last surviving dreadnought outside of the US. ■

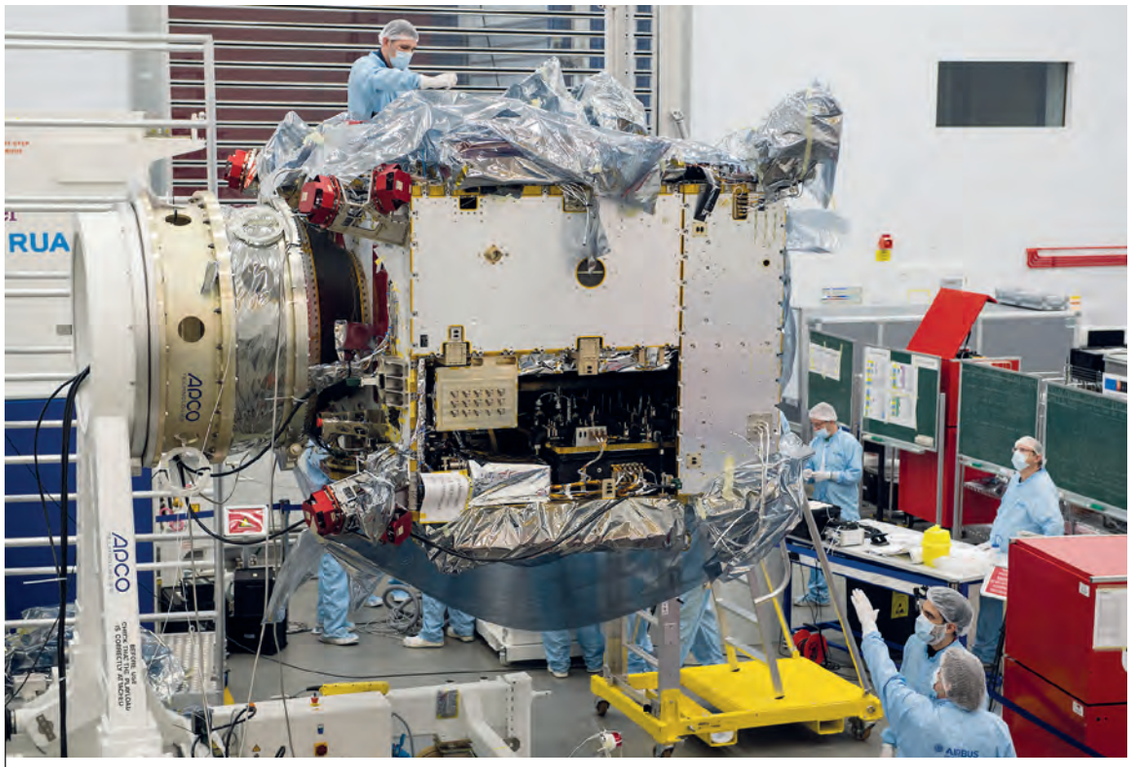
Word of the issue

Anthony Poulton-Smith explores origins of the word 'pressure'

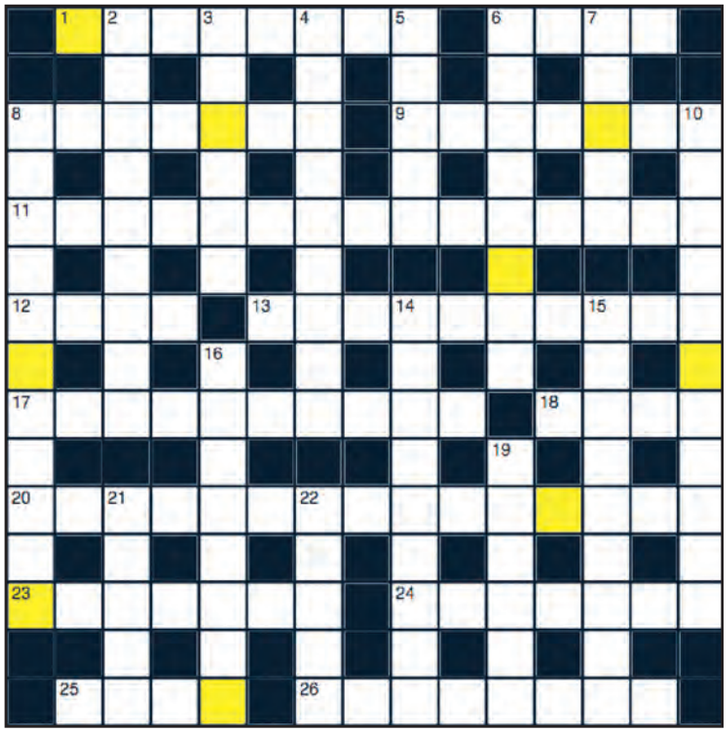
Pressure, to do work, has been in use for many millennia. The waterwheel uses the pressure from the head of water, the blacksmith the pressure of the hammer on the heated metal, and the first farmers pressed the ploughshare through the soil. Even early humanoids relied on pressure when banging two rocks together to produce stone tools.

Etymologically speaking the word is clearly derived from 'press', itself derived from the Proto-Indo-European per meaning 'to strike'. While it is tempting to think of an early human explaining the concept of creating a stone tool with the word per, it will never be proved. Yet we can take this even further back to a root kwel, used to mean several things but notably 'revolve' and 'turn around'. It has also been used in the sense of 'sojourn' as in 'to stay' and 'dwell' with the same meaning. These seemingly opposite meanings mean we can confidently suggest an earlier meaning – one which referred to a method of journeying, almost certainly for trade.

Bigpicture



The UK-built Solar Orbiter being readied to leave Airbus' Stevenage facility to travel to Germany for testing, ahead of its launch in 2020 from Cape Canaveral in Florida. The ESA mission will provide close-up views of the sun's polar regions, tracking solar storms and the solar wind which causes the Northern Lights. **Image: Airbus DS/Max Alexander**



Prizecrossword

When completed rearrange the highlighted squares to spell out the study of sound properties. The first correct answer received will win a £20 Amazon voucher. Email your answer to **jon.excell@centaur.co.uk**

Across

1 Substance that bonds surfaces together (8)
6 Showing care in execution (4)
8 Prevalent fashion of dress (7)
9 Of fabrics or fabric making (7)
11 Force of air around a transducer (7,8)
12 Strike sharply (4)
13 The act of gathering together (10)
17 Ancient Egyptian writing system (10)
18 Pole of wood or metal used for support (4)
20 Temperature standard where water freezes at 32 degrees (10,5)
23 Reduce in length (7)
24 Particular point in time (7)
25 Shortened word for one thousandth of a second (4)
26 Person who uses scientific knowledge to solve practical problems (8)

Down

2 Hydraulic system used to slow a vehicle with friction (4,5)
3 Released (a liquid) in drops (6)
4 Exactly alike (9)
5 Register formally as a participant (5)
6 A future manoeuvre made to progress towards a goal (4,4)
7 A farewell remark (5)
8 Parts of a reciprocating engine (11)
10 Emergency chair for a pilot (7,4)
14 Replacing a broken part (9)
15 Long stretch of ground for walking beside the seashore (9)
16 Of the home (8)
19 Invites to enter (4,2)
21 Sharp curves or crooks (5)
22 Flexible joint (5)

September's highlighted solution: **Clifton.** Winner: **Rita Mulley**

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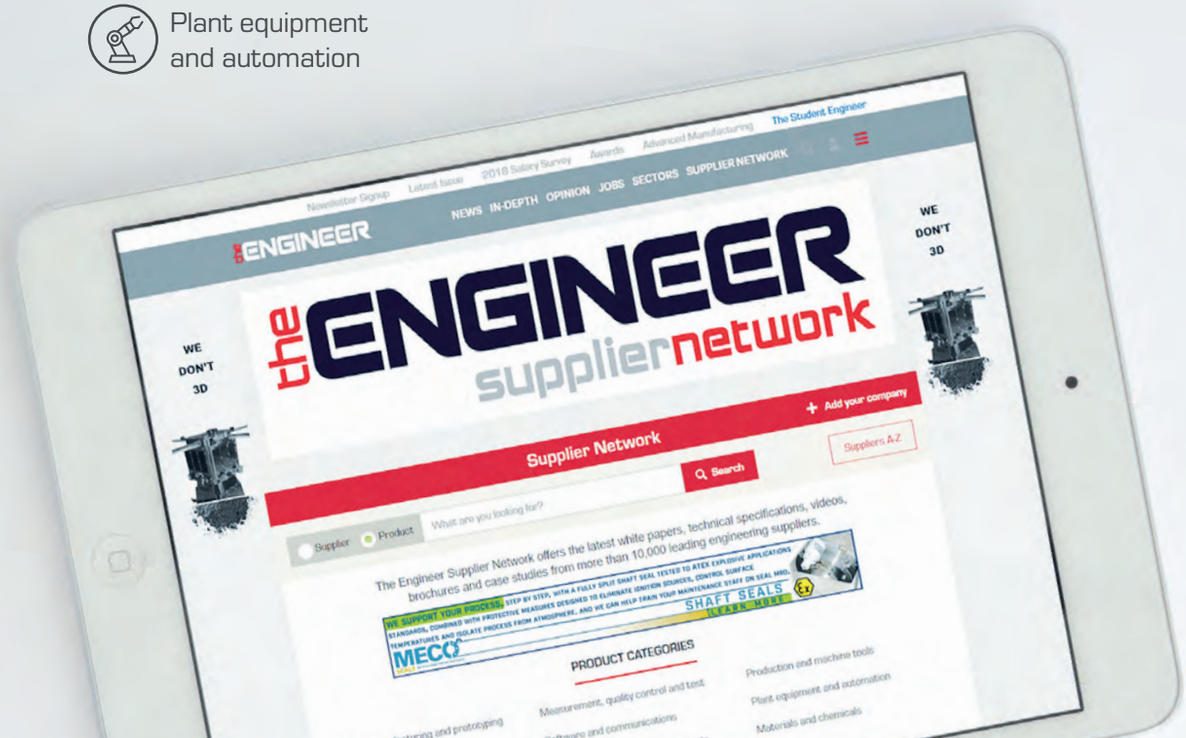

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