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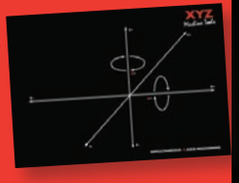

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this**issue**

Volume 299
Issue No. 7908
Established 1856

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Powering innovation

There is a long and colourful history of sporting competition driving broader real-world innovation.

Perhaps the best-known example of this is the race-to-road dynamic of motorsport, a phenomenon that's been strongly reinforced in recent years, most notably through the Formula E competition, which has driven the development of electric vehicle powertrain technology and arguably done much to shift public perceptions of electric vehicles.

In this issue's cover story, we turn our attention to Formula E's airborne equivalent: Air Race E, the world's first all-electric manned aircraft racing competition, which – when it launches in 2020 – will see eight all-electric planes racing around circuits at speeds of up to 400km/h.

It promises to be a truly exciting sporting spectacle. But as we report, the team behind the Airbus-backed competition also has broader ambitions for the project, and hopes that it will mimic Formula E's automotive impact and supercharge the development of electrification technologies for tomorrow's commercial aircraft.

> "Electrification is becoming increasingly key to the sector"

Just a few years ago, this would have been a barely credible aim. But, thanks to the continued advances in battery and powertrain technology, electrification is becoming increasingly key to the sector's strategy for meeting ever-more ambitious emissions targets, with companies including Rolls-Royce, Airbus, Siemens and Boeing all actively developing electric aviation technologies. Just as electric car technology has become a key area of *The Engineer*'s coverage, we look forward to reporting on the torrent of electric aerospace innovations that will surely follow in the coming years.

Electric flight is just one of the topics that you can find out more about at *The Engineer*'s annual conference, when we will be joined by Rolls-Royce plc's chief project engineer for hybrid-electric propulsion Riona Armesmith, who will be talking about her company's work on the E-Fan X project.

As in previous years, the conference, which takes place alongside *The Engineer* Expo, Subcon and AMS exhibitions from 4-6 June at the NEC, Birmingham, boasts an exciting mix of presentations covering some of engineering's hottest technology trends and most exciting projects.

Two of our key speakers are profiled in this issue: BAE Systems technology director Dave Short (page 24) and additive manufacturing pioneer Jeremy Pullin (page 55).

Finally, there's still plenty of time to get your entries in for our annual awards competition Collaborate to Innovate, which now has an extended deadline of 21 June.

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ISSN 0013-7758. Printed by Precision Colour Printing, Haldane, Halesfield 1, Telford, TF7 4QQ. **Visit www.theengineer.co.uk for constantly updated news, products and jobs and to sign up for our FREE weekly email newsletter and tailored job alerts**

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ENERGY

Solar grids set to transform lives in sub-Saharan Africa

Project to build sustainable and affordable means of generating electricity HELEN KNIGHT REPORTS

Photovoltaic solar panels would bring electricity to off-grid communities

Around 588 million people in sub-Saharan Africa have no access to electricity, meaning they lack basic services such as lighting, heating, and communication. A new solar project aims to change that.

Expanding the existing electricity grid in Africa would be hugely expensive for both governments and communities. Meanwhile, more than 80 per cent of the continent's existing electricity supply is generated by fossil fuels, causing damaging pollution and climate change.

In a bid to increase access to electricity in sub-Saharan Africa without harming the environment, researchers at Ulster University are developing a distributed energy network, based on solar power and battery storage. The SolaNetwork project, funded by EPSRC and Innovate UK, will develop and trial an interconnected network of standalone solar systems, according to lead researcher Dr Jayanta Mondol of the Centre for Sustainable Technologies at Ulster University.

Each system will consist of photovoltaic solar panels to generate electricity for lighting, heating and powering appliances; a solar thermal collector (called SolaCatcher) to provide hot water; a battery to store excess electricity; and a platform that uses mobile, cloud, and blockchain cryptographic technology to provide energy services to the community.

"The idea is that when the sun is shining electricity is produced by the photovoltaics, and is fed to DC appliances," said Mondol.

"Any excess electricity is then stored within the battery."

The work builds on a previous project, known as SolaFin2Go, in which the researchers developed and tested individual solar systems for off-grid households in Botswana. They will now scale-up the technology, connecting together 20 systems to form a virtual and physical node-to-node network. A monitoring and control system comprising sensors and a two-way communications connection will manage the delivery of energy services and provide business data.

"We have developed a mobile network for the village that can be used to monitor the system performance remotely," said Mondol.

The project will also aim to help users to finance the system. For example, the researchers are investigating the use of a battery rental programme, to avoid users having to buy the system upfront. Households will also be able to use excess electricity to pay for the service, through a battery trading system.

"Usually, this kind of system would be expensive, but instead users can pay their costs through their electricity generation, so they don't have to pay upfront," he said.

The solar network will be operated and maintained by a not-for-profit distributed energy service company (DESCO), formed of members of the local community and project stakeholders. The DESCO will manage electricity trading between individual consumer-producers, and provide training to the local community in using and maintaining the technology. In this way, the project will also help to develop skills and employment in the local area.

In particular, the researchers hope to have a positive impact on the lives of women in sub-Saharan Africa. They will hold information forums to consult directly with female villagers, disseminating information on the project and its implications for households.

"We would like to focus particularly on the employment of women, to improve their quality of life," said Mondol. "Women (in sub-Saharan Africa) spend a lot of time cooking over open wood fires, but our technology can give them electricity and hot water, so it could also improve their lifestyles and health."

The solar project includes researchers from the Botswana International University of Science and Technology, as well as Ulster University spin-out SolaForm." ■

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AEROSPACE

Airlander 10 set to go all-electric

UK project to power giant

HELEN KNIGHT REPORTS

An all-electric version of the world's largest aircraft, Airlander 10, could be a step closer as a result of a UK project.

Hybrid Air Vehicles (HAV), the developer of the Airlander 10 aircraft, in partnership with Collins Aerospace and Nottingham University, has been awarded a grant of £1.1m from the UK Aerospace Research and Technology Programme, to develop electric propulsion technologies.

The project, E-HAV1, will develop a prototype 500kW electric propulsion system, with the ultimate aim of replacing Airlander 10's fuel-burning forward engines, in a first step towards an all-electric version.

Airlander 10 is a hybrid aircraft that relies on a combination of buoyant lift from helium like an airship, aerodynamic lift like an aeroplane and vectored thrust like a helicopter. In this way it already consumes significantly less fuel than conventional aircraft, but the addition of electric forward propulsors will improve this even further, according to Nick Allman, executive director at HAV.

"The aircraft is already a low-carbon aerospace product, but we have our sights set more ambitiously in that we're trying to be zero-carbon," said Allman. "There are inherent features of our aircraft that we believe position us to be at the forefront of moving in that direction."

The amount of power needed by the aircraft is substantially lower than it would be on a traditional fixed-wing aircraft, for example, meaning the electric propulsion systems needed are intrinsically smaller, he said.

"We also have quite a modular design. We have four engines that are independently attached to the vehicle, so its relatively straightforward for us to model in simulation a change from our current diesel cycle engines to electric."

As part of the three-year project, the team will carry out extensive ground-testing of the full-size prototype propulsion system, once it is built.

"We will be using test rigs that we have used to test the propulsion systems on the Airlander 10," said Allman. "That will allow us to understand areas like its efficiency, noise levels, and how the new motor interacts with the propeller."

A hybrid-electric and, ultimately, an all-electric version of Airlander 10 would represent a major achievement for the aerospace industry, said Marc Holme, motor drive systems engineering director at Collins Aerospace.

"Electric propulsion has the potential to revolutionise aircraft by providing significant reductions in carbon emissions, noise, fuel consumption, and operation and maintenance costs," Holme said. ■

Airlander 10 is the world's largest aircraft

AUTOMOTIVE

Speed limiters for all new cars

ANDREW WADE REPORTS

The EU is aiming for all new European vehicles to be equipped with Intelligent Speed Assistance (ISA) by 2022, inhibiting speed in accordance with local limits.

The technology uses cameras and GPS to detect the speed limit for a given stretch of road, then inhibits engine power to ensure drivers do not stray over the limit. ISA can be overridden temporarily, for example when overtaking, by pressing the accelerator hard to the floor. The system can also be disengaged, though it will be operational by default every time a vehicle is started. It is estimated widespread adoption could reduce EU road fatalities by around 20 per cent.

ISA is just one of several safety features the EU plans to introduce under its revised General Safety Regulation. According to the Department of Transport, the UK will also adopt the measures, regardless of the outcome of Brexit. Other mandatory systems for cars under the new regulation will include a warning for driver distraction and drowsiness, cameras/sensors for reversing, advanced emergency braking, lane keeping assistance and a 'black box' data recorder for incident reporting.

"Every year, 25,000 people lose their lives on our roads," said Poland EU commissioner Elzbieta Bienkowska. "The vast majority of these accidents are caused by human error. We can and must act to change this."

The General Safety Regulation is now subject to ratification by the institution's parliament and council. According to the EU, it expects that the proposed measures will help save lives and avoid at least 140,000 serious injuries by 2038. ■

Newsinbrief

Good year for deals

Research from AT Kearney has found that the total value of deals in the industrials market rose to $680bn (£525bn) in 2018, an increase from $662bn the year before. 2018 saw over 100 individual deals worth over $1bn, with seven of those transactions topping $10bn, including United Technologies' takeover of avionics supplier Rockwell Collins and the $12bn deal between Melrose Industries and GKN.

Phoenix rises

A new UK-built endurance aircraft called Phoenix has made its public debut following indoor flight testing at the Drystack facility in Portsmouth. Designed to operate at high altitudes for extended periods, the prototype has a 15m-long fuselage filled with helium and a wingspan of 10.5m. It propels itself using variable buoyancy, constantly shifting its weight to be lighter or heavier than the surrounding air, which creates thrust.

'Marsquake' detected

NASA's InSight lander has recorded its first possible 'marsquake'. Seismic vibrations of the Martian surface were detected by silicon sensors developed in the UK. The signal was detected by InSight's Seismic Experiment for Interior Structure (SEIS), which the lander placed on the Martian surface in December.

Cubesat first

A cubesat containing the first commercial microwave radiometer and 3D-printed antenna for space has launched from the US. Dubbed IOD-1 GEMS, the miniaturised weather observing and forecasting technology is the first of the Satellite Applications Catapult's In-Orbit Demonstration (IOD) Programme, which is funded by Innovate UK. It is also the first satellite in Orbital Micro Systems' Global Environmental Monitoring System (GEMS) constellation.

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AUTOMOTIVE

New high-energy batteries tested

Conversion reaction system could mean cars going further per charge HELEN KNIGHT REPORTS

Electric vehicles could travel 1,000km on a single charge, thanks to a new type of lithium-based battery, its developer claims.

The device is the world's first 1,000Wh/kg rechargeable battery, according to developer Innolith, based in Basel, Switzerland.

The Innolith Energy Battery, which does not contain expensive exotic materials, is based on an inorganic electrolyte, according to the company's chairman, Alan Greenshields.

Unlike the organic electrolyte in conventional lithium-ion batteries used in electric vehicles, this inorganic electrolyte is non-flammable. In this way it could eliminate the main cause of battery fires that plague electric vehicle manufacturers, Greenshields said.

"The core of what we're doing is to [eliminate] the undesirable properties of lithium-ion batteries, in that they catch fire, or even explode, and don't last very long," he said.

In traditional intercalation-based batteries, the lithium ions shuttle back and forwards between the two electrodes, but do not chemically react with the material, said Greenshields. Instead the lithium ions slide into gaps within the crystalline structure.

"When you charge a lithium-ion battery, you force lithium ions out of the positive electrode, through the electrolyte and they intercalate into the negative electrode, and when you discharge it the reverse happens," he said.

In a conversion reaction system, in contrast, the lithium reacts with a material at the electrode to form a compound, storing energy in the process.

When this compound dissolves into its constituent parts it releases energy again, said Greenshields.

"As a result, at the electrode level, you have at least ten times higher [energy] storage per unit of mass, because you're using an actual chemical reaction rather than the intercalation storage of lithium ions," he said.

Innolith is planning to commercialise the high energy density battery through an initial pilot production in Germany, followed by licensing partnerships with battery and car companies, said Sergey Buchin, CEO of Innolith.

The company anticipates development and commercialisation of the battery will take between three to five years.

"We believe this battery will be suitable for all sorts of transport applications, including electric cars and buses, and with its high energy density we can also use it in drones and other aircraft," said Buchin. ■

Experiments have been taking place to improve the capacity of batteries

HEALTH

Real-time sweat monitor could help diabetics and fitness fanatics

UK start-up Sweati has launched its non-invasive real-time sweat monitor, a wearable patch capable of tracking glucose, lactate and hydration.

Developed in collaboration with Imperial College London, the fabric patch uses a combination of microfluidics and chip technology to measure minute levels of sweat. This means the wearer does not have to be engaged in strenuous activity for it to function, although athletes and leisure users are a target market. Other potential users include soldiers in the field and diabetics seeking to monitor glucose levels non-invasively.

"Imagine a device that will be able to tell you when to fuel, when to hydrate and what pace to run at," said Sweati founder and CEO James Mayo. "That means no more hitting the dreaded 'wall' while running a marathon. Sweati will make working out enjoyable and efficient. For diabetics, it would mean no more blood draws interrupting their day... For members of the military, we have the ability to save lives with no more heat casualties." **AW**

MARINE

Propeller noise breakthrough

Quieter blades will protect marine life

HELEN KNIGHT REPORTS

A new technology capable of reducing the underwater radiated noise generated by ships' propeller cavitation has been developed at Strathclyde University and West Sussex-based Oscar Propulsion.

Cavitation occurs when tiny bubbles form in the water as a result of the propeller moving through it. When these bubbles collapse, they create an audible shock wave.

Propeller cavitation can generate as much as 180dB of underwater radiated noise and can be heard by – and cause distress to – marine life 100 miles away. It can also damage the propellers.

The new PressurePores system reduces propeller tip vortex cavitation by applying a small number of strategically bored holes in the propeller blades. This reduces the sound produced by the propellers, without significantly reducing their efficiency, according to David Taylor, CEO of Oscar Propulsion.

The team first tested the idea in a cavitation tunnel at Newcastle University, said Taylor. "We made some relatively randomly-placed holes in different propeller models, and compared these with propellers without holes, and with that relatively crude test we managed to get about a 14dB reduction in noise," he said.

After this success they carried out CFD modelling at Strathclyde University, which confirmed the result of their physical tests. They then used the CFD model to analyse the effect of more specifically targeting the location of the holes. ■

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MEDICAL

Dementia care to be closer to home

New research and technology hub to look at ways of easing NHS pressure

ANDREW WADE REPORTS

A new research and technology centre will explore a range of innovations for monitoring and treating dementia in the home, potentially easing the burden on patients and the NHS.

Based at Imperial College London's White City campus, the £20m centre is a multi-partner collaboration that includes the University of Surrey, with financial backing via the Medical Research Council, Alzheimer's Research UK and the Alzheimer's Society.

Using a combination of sensors, AI, robotics, sleep trackers and infection testing, it is hoped that a system can be developed to aid the 850,000 people with dementia.

"Latest figures suggest one in four hospital beds are occupied by people with dementia – and 20 per cent of these admissions are due to preventable causes such as falls, dehydration and infections," said the head of the new centre, Prof David Sharp, a neurologist at Imperial.

"The new technologies we develop will improve our ability to support people in their homes. They will allow us to intervene at an early stage."

According to Prof Sharp, some of the technologies that will be explored include miniaturised radar and off-the-shelf sensors that could either be purchased by patients or potentially prescribed by the NHS. An earpiece sensor being developed in-house at Imperial will provide information on gait and sleep, as well as acting as a mobile EEG, delivering a consistent stream of data over many hours.

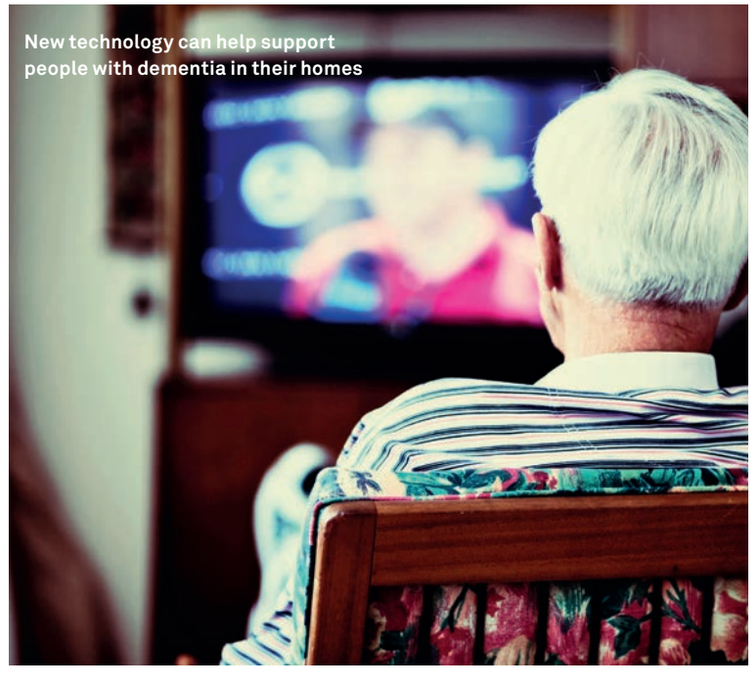
This holistic monitoring will allow medical staff to better understand the effect of drug treatments and patient wellbeing. AI systems will help detect ailments such as urinary tract infections earlier, something that could reduce stressful and costly hospital admissions.

"Working with the latest machine-learning capabilities means the technology we're using will be able to get better at spotting warning signs and events that require intervention," said Payam Barnaghi, professor of machine intelligence at the University of Surrey and deputy director of the UK Dementia Research Institute Care Research and Technology Centre.

"Doctors will be able to have confidence in their ability to monitor people remotely and to react quickly to any worrying changes."

Scientists involved in the project have already developed safe and robust data storage technologies.

The new centre is due to open on 1 June. ■



New technology can help support people with dementia in their homes

MEDICAL

New breast cancer scanner aims to give more precise tumour diagnosis

Radiation detection specialist Kromek and Denmark's DTU Space are developing a breast cancer imaging device based on tech from high-energy astronomy.

Kromek is contributing its cadmium zinc telluride (CZT) detection technology to the project, which aims to develop a 3D molecular breast imager (3D MBI) scanner capable of more precise diagnosis of small breast cancer tumours than is possible today.

CZT is a room-temperature semiconductor that directly converts X-ray or gamma ray photons into charge carriers inside the crystal which is already used in medical devices and for studying high-energy phenomena in space.

The 3D MBI project is funded via a £321,000 grant under European scheme Eurostars through Innovate UK and involves a DTU Space research team at the Technical University of Denmark.

The main focus of the project is making the electronics used around CZT detectors smaller, lighter and more power-efficient. **SN**

AEROSPACE

Project 804 is on The Grid

Flight demonstrator to test hybrid engines

JASON FORD REPORTS

Collins Aerospace has revealed details of The Grid, a new facility in Rockford, Illinois, claimed to be industry's most advanced electric power systems laboratory.

Collins Aerospace is a unit of United Technologies Corp, which recently launched an advanced projects group and is developing Project 804, a hybrid-electric flight demonstrator predicted to yield average fuel savings of 30 per cent.

Project 804 will re-engine and fly a regional turboprop aircraft – a Bombardier Dash 8 Series Q100 – powered by a 2MW-class hybrid-electric propulsion system. Collins Aerospace will use The Grid to help design and test a 1MW motor, motor controller and battery system in support of the project.

Collins Aerospace said the 1MW motor will be the aerospace industry's most power-dense and efficient to date, and the new motor and motor controller will be used to assist the demonstrator's fuel-burning engine as part of its hybrid-electric propulsion system.

Work on the 25,000 sq ft lab is under way and is expected to be fully operational by 2021. The $50m (£39m) investment in the lab is part of a larger $150m investment Collins Aerospace expects to make in electric systems over the next three years.

"The Grid positions us to remain the world leader in the electrification of aircraft for decades to come," said Collins Aerospace CEO Kelly Ortberg. "Hybrid-electric and fully electric aircraft will revolutionise air travel as we know it. They will help support a greener planet by reducing carbon emissions, and will help our airline customers by reducing operating costs and fuel consumption." ■

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ENERGY

Phosphorene could make tech a reality

Tiny crystalline ribbons could help with energy storage and electronics

HELEN KNIGHT REPORTS

Fast-charging high-capacity batteries and flexible devices that scavenge electricity from waste heat are just some of the technologies that could be made possible following a world-first development by UK researchers.

A team at University College London (UCL) have made flexible nanoribbons of crystalline phosphorus, which they claim could have a wide range of applications in energy storage and electronics.

In a paper published in the journal *Nature*, the researchers, alongside team members at the University of Bristol, Virginia Commonwealth University, USA, and École Polytechnique Fédérale de Lausanne, Switzerland, describe how they produced the tiny ribbons of phosphorene by accident.

They were attempting to produce 2D sheets of phosphorene – the phosphorus equivalent of graphene – by mixing black phosphorus with lithium ions dissolved in liquid ammonia at -50C. After 24 hours, they removed the ammonia and replaced it with an organic solvent.

But instead of creating sheets, they found they had made ribbons of the material, according to UCL's Chris Howard, one of the paper's authors.

"In the meantime, we noticed that papers kept coming out in the literature about really interesting, useful, and exotic properties that might be possible if only someone could make phosphorene ribbons," said Howard.

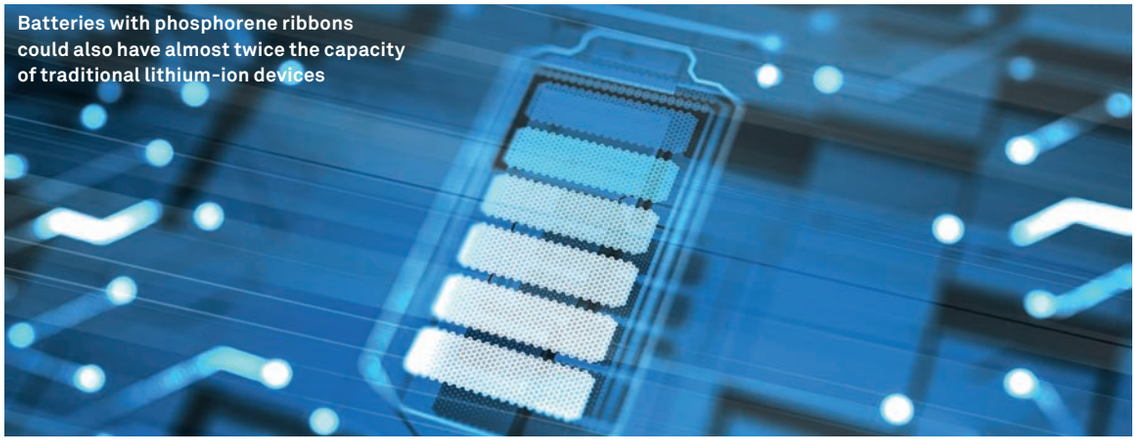
So the researchers set about fine-tuning their process until they could produce samples in which most of the contents were ribbons.

The ribbons form with a typical height of one atomic layer, widths of 4-50nm, and are up to 75µm long. They are extremely flat, crystalline and unusually flexible, said Mitch Watts, the paper's first author.

"What's more, by changing the width or the number of layers of the ribbon, you can actually tune the electronic properties for specific applications," said Watts.

The use of phosphorene ribbons within batteries could lead to devices with extremely rapid diffusion of lithium ions, resulting in fast charging. Batteries with phosphorene ribbons could also have almost twice the capacity of traditional lithium-ion devices, said Howard.

The material has also been calculated to have a very high figure of merit as a thermoelectric, meaning it can convert waste heat into electricity, and its flexibility means it could be used to power wearable devices, he said. ■



Batteries with phosphorene ribbons could also have almost twice the capacity of traditional lithium-ion devices

AEROSPACE

New wing design that can change shape mid-flight set for take-off

Researchers in the US have built and tested a radical new wing design that can change shape mid-flight to enhance performance and boost efficiency.

Developed primarily by engineers from NASA and the Massachusetts Institute of Technology, the wing is made from thousands of triangular components with matchstick-like struts, bolted together in a lattice framework. This lattice is then covered in a thin layer of polymer material similar to the struts. The resulting wing structure is comprised mostly of empty space, forming a mechanical metamaterial that combines the stiffness of a rubber-like polymer with the lightness and low density of an aerogel. The wing has a density of just 5.6kg per cubic metre, the researchers say.

The shape of the wing reacts passively to its environmental forces, with the stiffness in different struts carefully calibrated to achieve the desired effect. Sections of the wing bend in response to the various phases of flight, delivering a more optimal performance at take-off, cruise and landing. **AW**

AEROSPACE

Engineers to use VR tech

Virtual reality courses successfully piloted

HELEN KNIGHT REPORTS

Aircraft engineers are to be trained using virtual reality (VR) technology, following a successful pilot project between Rolls-Royce and Qatar Airways.

In a trial of the technology, engineers with Qatar Airways received VR training on Rolls-Royce's Trent XWB engine, according to Stuart Moss, an IT innovation strategist at Rolls-Royce.

The Trent XWB is so large that it must be separated before engineers can transport it for maintenance and repair, said Moss. "This process takes a couple of days, to ensure that you can put it back together again in exactly the same alignment."

Engineers will often receive training in how to carry out this complex task a few years before they have to do it in practice. So the team decided to use VR as a way to offer a refresher course in the technique.

Using HTC VIVE VR equipment, the engineers were immersed in the process, using sight, sound and touch to separate parts of the engine in a virtual setting.

"We developed a fully immersive VR version of the engine," said Moss. "In fact, everything that you can do in real life is remodelled in the engine, so you can take the engine to pieces and re-do the entire training course in VR."

Previously, an engine would have been transported to Doha, Qatar, for the training, or alternatively Qatar Airways would have provided an engine in service, with the risk of damage to equipment and the loss of valuable flying time. ■

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MEDICAL

New implant to track brain trauma

Glutamate spike measurement could determine if drugs are working

STUART NATHAN REPORTS

Debilitating migraines are a common consequence of spinal cord injuries, triggered by a chemical messenger in the brain that spikes very quickly to toxic levels.

It has previously been impossible to detect such a fast change in the level of the responsible neurotransmitter, glutamate. Now, biomedical engineers from Purdue University have now developed an implant that can detect a glutamate spike and help track the damage it causes, which may find future use as a method for determining whether drugs for brain trauma or diseases are working.

In healthy people, glutamate is associated with functions such as learning and memorising. Damage to the spinal cord can cause it to leak into spaces outside cells, over-exciting and damaging them. This tends to occur very rapidly, with glutamate levels suddenly spiking.

An implant has been developed that can detect a glutamate spike in the brain

"When you feel like you're running a fever, it doesn't matter when you check your temperature – it will probably be the same for several hours. But a glutamate spike is so fast that if you don't capture it at that moment, you miss the whole opportunity to get data," said Riyi Shi, a professor of neuroscience and biomedical engineering in Purdue's Department of Basic Medical Sciences, College of Veterinary Medicine and Weldon School of Biomedical Engineering.

In a paper in *Biosensors and Bioelectronics*, Shi and the Purdue team explain how they produced a flexible sensor from platinum nanoparticle-based nanocomposite ink, using 3D printing and laser micro-machining.

"We wanted to create a low-cost and very fast way to build these sensors so that we can easily provide researchers with a means to measure glutamate levels in vivo," said Hugh Lee, a Purdue assistant professor of biomedical engineering, who focuses on implantable microtechnologies.

Using these two techniques allows the researchers to rapidly change the size, shape and orientation of sensors and test them in animals with no need for expensive microfabrication methods.

In an animal test, with the implants mounted in the spinal cord, the researchers were able to capture the glutamate spike immediately, while previous sensors have taken approximately half an hour to return the data.

Shi hopes that the sensor will help determine the mechanism behind glutamate leaks and migraines, which is currently unclear. ■

AEROSPACE

Spacecraft's orbit and moon-land attempt to be awarded $1m prize

The first privately funded spacecraft to orbit the Moon and attempt to land on its surface is to be awarded a $1m (£0.8m) Moonshot Award by XPRIZE.

SpaceIL's ill-fated Beresheet robotic lander failed to soft-land during its final descent to the Moon on April 11. As it prepared for landing, Beresheet experienced a main engine failure and lost communication with mission control in Tel Aviv, Israel.

Beresheet was launched on 21 February atop a SpaceX Falcon 9 rocket from Cape Canaveral, Florida. Nammo Westcott in Buckinghamshire developed and built Beresheet's LEROS 2b rocket engine.

Founded in Israel in 2011 by Yariv Bash, Kfir Damari and Yonatan Winetraub, SpaceIL was set up to compete in the $30m Google Lunar XPRIZE. In 2015, SpaceIL became the first team to announce a launch contract.

"[SpaceIL's] ability to build a lunar lander for $100m and less than 50 engineers is a leap forward towards affordable and accessible space exploration," said Peter H Diamandis, executive chairman of XPRIZE. **JF**

PHYSICS

Holographic development

'Maths is the key' to creating 3D projection

STUART NATHAN REPORTS

Physicists at Bilkent University in Ankara, Turkey, have solved a long-standing conundrum in developing holographic projection.

Creating a 3D holographic projection relies on back-to-back stacking of a large number of 2D images. However, the images tend to interfere with each other, making the projection fuzzy, a phenomenon known as cross-talk.

While previous attempts to solve this problem have focused on optical technology, the co-leader of the Ankara project, Prof Ömer Ilday, says this is not the best approach.

"The reason for this cross-talk is the maths, not shortcomings of the physical components," he said. "Any pair of high-dimensional mutually random vectors tend to be orthogonal. This is a consequence of the central limit theorem and the law of large numbers. We use this property, and a straightforward wavefront engineering trick, to add random phases to each image, to eliminate cross-talk without using any additional optics."

The key to this development lies in the work of Joseph Fourier, who developed the 'Fourier transform' used in high-speed spectroscopy, and Augustin-Jean Fresnel, who originated the flat lens used in lighthouses.

"It was not possible to simultaneously project a 3D object's back, middle and front parts," said Prof Onur Tokel. A connection between the equation developed by Fourier and Fresnel helps to solve this issue. ■

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Capital Projects – too complex to change?

Yen-Sze Soon, Managing Director, Accenture Digital - Industry X.0, Engineering & Capital Projects

Across the world, there is surging demand for new infrastructure. Rising global populations and concerns about economic slowdown are making infrastructure investment a top priority for government. In the UK, capital projects like Crossrail, HS2 and new nuclear power generation plants are all high-profile – but not always for the right reasons. Capital projects, such as these across industries, not just infrastructure, typically overrun cost and time projections by significant margins. The Financial Times recently reported that Crossrail is expected to require further cash injections of almost £2.5 billion and is likely to start operations nearly two years behind schedule[1].

Critical challenges

Crossrail is far from being the only capital project that's run into difficulties. So, why is this happening and what can be done to overcome these issues? While there is no single solution, a more concentrated focus on ecosystem collaboration, workforce and digital transformation can combine to have major, lasting impact.

Making sense of a complex ecosystem

By nature, capital projects are hugely complex. They involve large goals within the overall plan and require many parties to deliver them. Across industries, there are owners, EPCs (Engineering, Procurement and Construction) and sub-contractors, third-party logistics providers, expediters, quality assurance organisations and other service providers. These parties manage multiple functions individually or collectively: from project planning to supply chain and logistics, execution and commissioning. These groups all have different commercial objectives, ways of working and measures of success, which makes coordinating them a huge task.

These differences also often lead to a lack of transparency, which limits collaboration. That means:

- An absence of cross-functional insights and analytics leaves integrated project planning and execution unsupported. After financial services, capital projects generate more data than any other industry. But most of it is poorly managed, misplaced or discarded during execution. This means little value is extracted from historical data. And the lack of information symmetry, intelligent insights and access to lessons learned can result in sub-optimal decision making.
- Design and engineering often do not span the lifecycle of a capital project. Designs that do not incorporate cost, design and scheduling data, lead to scope growth and/or rework. Typically, across the industry, around 10% of a project's value is lost due to rework. Inefficiencies can arise owing to incorrect material selection and construction methods, which in turn often lead to excessive waste (in fact, some studies suggest capital projects generate approximately 40% of the world's waste). And all these issues are exacerbated by changes to original designs not being effectively communicated across all parties involved.

Lack of diversity and an ageing workforce

There is limited diversity in the capital projects workforce. In the UK construction industry, women[2] make up only 13% with BAME workers accounting for only 5.7%[3]. A lack of diversity means that there is a bias towards doing things the way they have always been done. With few alternative voices, there is less chance of sparking innovation.

Additionally, there's still relatively limited use of intelligent machines that can augment human workers, enhancing project safety and upskilling people throughout the value chain. That's particularly pertinent for the construction sector, which is challenged by an ageing workforce and the sustainability of skills coming through the next generation.

So many moving parts and inter-dependencies, limited collaboration and an inability to drive change, mean most large projects are almost destined to fall short of expectations before they've even begun. The statistics paint a bleak picture. In construction alone, the average is 80% overspent on original budget and less than 60% of projects completed on time. And with this sector contributing up to 6.5% of Gross Value Added to the UK economy, any improvements will have a decisive impact on the country's performance.

Value left on the table

While the industry faces some formidable challenges, solving them could deliver massive gains. According to a recent Accenture study, in the UK alone, almost £90 billion of value over 10 years is waiting to be unlocked through efficiency gains and environmental benefits by improving how capital projects in construction are planned, managed and run.

The construction industry has been slow to implement digital technologies as transformation tools to drive value. That has to change. Advances in various digital technologies such as edge computing, Industrial IoT, AI, robotics, additive manufacturing and mobile can support transformational solutions for capital project

delivery. Rather than seeing these as standalone, individual technologies, it's essential that industry players harness their combinatorial impact to support decision-making, enhance productivity, integrate business functions and improve safety. So how can the industry start to realise the gains available from adopting digital technologies?

Monetise existing data to incentivise collaboration

First, there is a need to encourage more collaboration and sharing of the vast amounts of valuable data across the industry. Each party could monetise their own data by trading it with others in return for better contractual terms and/or financial gains to incentivise collaboration. Overall this could help to enable and be funded by the collective prize of on-time and on budget delivery. This will require enabling technologies such as a trusted collaboration platform, but most importantly a change in mindset and a redesign of incentive structures based on the data available and its potential value to the industry. External collaboration will have limited value if it is hindered by internal organisational barriers. Hence, within each organisation, operating models also need to be modified to encourage more cross-functional collaboration through redesign of individual and team measures of success and ways of working.

Obtain real-time supply chain and construction execution data

Speeding up the feedback loop for monitoring execution progress against plan will enable faster issue resolution and more effective risk mitigation. This can be achieved with the IoT. Collecting real-time location data for people, equipment and valuable materials will support actions to ensure everything's in the right place, at the right time in line with the project plan. Edge technologies in combination with cloud enable data from the most remote location to be collected, aggregated and analysed.

For example, connecting up a construction site in this way provides unparalleled insights into productivity. Ask a construction company what they estimate their productivity (outputs over inputs) to be and they typically put it at around 60%. Our analysis shows it's likely to be nearer 35%. One reason? It can take workers 90 minutes to get on and offsite every day. But it's only possible to prove that and have meaningful conversations across parties to do something about it, with connected technology that can provide actual information.

Build a 'Control Tower' to process data and optimise decision-making

Data collected as described, can be combined into a trusted digital platform in the form of a 'Control Tower' with up to date engineering designs and documentation, enabling real time end-to-end supply chain visibility and progress of execution against plan. This visibility combined with complex algorithms, available on a platform incorporating artificial intelligence, can process and optimise proposed solutions, accurately predict and mitigate risks and reduce the time it takes to resolve issues. Digital Twins, or representation of the physical site and assets with associated engineering properties, can be created and used to simulate decisions and redesigns further increasing efficiency and certainty.

Automate and diversify the workforce

Adopt robotics to augment humans for repetitive tasks, increasing productivity and safety, especially in challenging environments such as restricted facilities. Adopting all these technologies will attract a different type of talent, including digitally native workers, to the industry. That will increase diversity, driving innovation, continuous improvement, and act as a catalyst effecting change in the existing workforce in terms of behaviour and skills; ultimately transforming the workforce in capital projects.

Big challenges, bigger opportunities

The challenges in capital projects are massive. But the potential opportunities are even greater. The key to unlocking them? Combining the right technologies with the right talent. To discuss practical examples of how these challenges can be turned into opportunities, please contact IX.0-Zone@accenture.com.

If you would like to learn more about how Industry X.0 can help a business thrive in the digital revolution, please read our report Combine and Conquer: Unlocking the Power of Digital – accenture.com/combine-conquer.

[1] https://www.ft.com/content/6e63cfe6-20bc-11e9-b126-46fc3ad87c65
[2] http://www.infrastructure-intelligence.com/article/may-2015/infrastructure-insider-power-diversity
[3] http://www.constructionmanagermagazine.com/insight/diversity-are-these-our-true-colours/
[4] European Contech Summit London 2018
[5] Made Smarter Review 2017 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/655570/20171027_MadeSmarter_FINAL_DIGITAL.pdf

Decisions must be made without delay

The principal associate of structural engineers Thomasons explains the restoration challenges facing the fire-damaged Notre-Dame cathedral

What happened to Notre-Dame cathedral in Paris on 15th April is a grim reminder of the sheer destructive power of fire when it takes hold, especially in an old building where wall panelling and much of the structure, floors and furnishing is timber. In normal use it is reasonably safe, but behind ceilings, partitions and panels there are innumerable voids, nooks and crannies where rubbish can accumulate over the centuries. A hidden fire can start in one of these areas and take hold before anyone even sees it.

The danger is particularly prevalent during building work: these concealed areas may be opened up or disturbed and new inflammable materials brought in, such as plastic, paper materials, packaging, or solvents. Building work also introduces possible new ignition sources: sparks from a disc cutter, a blowtorch burning off paint, faulty electric wiring, power tool batteries, or a stray cigarette end.

Image: Wandrille de Préville (Creative Commons Attribution-ShareAlike 4.0 International)

Planning and restoration headaches

The first challenge for restoration is to assess the condition of the remaining structure and identify those precarious parts which need to be removed before people can work safely in the area. To extinguish the fire, a vast amount of water was sprayed into the building and unless this is removed quickly, it could cause untold further damage to plasterwork and timbers. Therefore, as soon as it is safe to do so, the most urgent task is to pump water out of the basement, start drying the building and protect it from the weather with a temporary roof.

Once this roof has been erected, there will then be time to think and plan. Engineers and architects will first identify areas that need to be rebuilt or strengthened to support the new roof and they also have to decide how it will be constructed. The original roof structure ('the Forest') was constructed from a vast number of oak trees felled in medieval times, so 'like for like' replacement is probably not possible: parts of the new roof structure may have to made with modern materials. Difficult, sensitive decisions about the design will need to be made quickly so a new permanent roof can be constructed as soon as possible to protect the precious interior from the weather and allow the building to be heated, to assist drying out. This initial phase will be critical, as any delay in drying and protecting the structure and finishes could lead to major further deterioration.

> "Initial progress is likely to be limited by the number of skilled workers available"

It is essential to assemble a team of people who are knowledgeable and experienced in working on historic buildings: architects and engineers to assess the damage inflicted on Notre-Dame, design reinstatement work and checks to ensure it is done correctly; project managers to arrange contracts and control finances; and builders and craftsmen to carry out the work itself.

The first challenge will be assembling this team as soon as possible and companies have to identify key people so they can be released from other commitments. Progress in the early stages is likely to be limited by the number of skilled workers available to work on the rebuilding, so a push to get work started needs to be followed with a recruitment and training programme to swell the workforce and accelerate the project.

Solutions need to be found to cut through the bureaucracy and standard procurement policies, so work can get off the ground. As work progresses, more people will become involved, and this expansion needs to be managed properly so design, construction quality, cost and the programme are all kept under control. A huge challenge lies ahead: all that is certain is it will take many years and a large amount of money to complete. ■

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Thehottopic

Taking the wrong track?

News that the Government is to review the HS2 project triggered a debate on the UK's future rail strategy

HS2 is a notable success for the construction lobby. It will benefit few (certainly not many between the main destinations) and cause immense environmental and social destruction – all for a reduction of 20 minutes at best. Any economic improvement for business would be better served by an electrification and modernisation of existing lines, together with modern rolling stock, and by replacing the ripped-up lines of the 60s. Once we have a comprehensive rail network, businesses and employees will be able to devolve away from main centres and thus create wealth and benefit the whole country, not just the principal cities. If done right, this would reduce commuting, and the resultant pollution.
Bob Sheppard

Hyperloop is the optimum public transport system, with no drivers and no strikes, 24 hours a day, 365 days a year, ensuring distance is dead. A section could be laid between existing stations on one track initially, creating a fast hyperloop between strategic centres, bypassing slow stations. The hyperloop would go back and forth between its stations within a few minutes, ensuring the hyperloop is available within five minutes of arrival at a station.
Paul Booker

I have always thought high-speed links are crucial to a modern society, either for digital or transport. The problem I have with the current HS2 is it does not push any boundaries of speed or building methods. Maglev trains may be a better option, making at least an attempt to push the envelope in Europe. The other issue I have is the focus on the North and Midlands. I would much rather it was on the South West or East Anglia. Better still, let's be talking about HS4 and HS5 to these destinations.
Darrian Lilley

It should never have been called HS2, but IC2 instead – increased capacity. Rail use continues to grow rapidly and we have not built a new north-south line for over 100 years. Building this line will release the current infrastructure for more freight transport by rail, which surely could ease some of our road congestion.
Andrew Smith

We were misled over HS2. The speed of HS2 will be slower than stated, the time savings will not be achieved and it will go no further than Birmingham. The project is, and will continue to be, over budget and late. HS2 is a disaster for the railways, sucking up all the funds and preventing the much-needed investments elsewhere in the rail system.
Another Steve

Regarding all these fancy hi-tech, high-speed solutions, I'd challenge anyone to draw a 10-mile straight line on a map of Britain that doesn't pass through an ancient monument or a site of natural interest. The last people with effective powers to do this were the Romans
Trevor

Why are we persisting in installing pantograph systems? This is particularly pertinent to HS3 as there are hills in the way east-west and the Victorians built the incredible tunnels we still use. They are not tall enough for pantographs. Why are we not investing in hydrogen or other self-contained propulsion systems?
Sandy

Capacity and connectivity are the problems. Existing lines need either longer trains or more of them and the old rail network should be looked at for new light rail transport systems to connect to the main lines.
Roger Newnham

I am interested in and excited by the technologies (which range from tunnelling to maglev) – and hope that they will be developed to be affordable. Regrettably, there is no sign of any innovating. And without innovation it is likely to be expensive both in time and money. I am not convinced that making one link very fast and leaving all the slow ones in place makes much sense.
Julian Spence

Thesecretengineer

Our anonymous blogger ponders the possible reasons behind Boeing's 737 MAX troubles and what this might mean for the future of civil aircraft design

I feel it only fair to point out at the start that I am commenting on this matter from a position purely based on what has been reported in the media so far; undoubtedly there is more still to come to light.

As you are all no doubt aware there has been a crash involving a Boeing 737 MAX, sadly with no survivors. This is the second involving this type of aircraft within five months, both reportedly initiated by the same cause.

From what I have seen, this is a multi-layered problem – in fact, most major accidents are caused by multiple failures – but I wonder if this one strikes at the heart of the way civil aircraft are currently brought to market?

On the surface there is a simple cause and effect: a new anti-stall system on the aircraft is dependent on a sensor and this was giving false information leading to an ultimately fatal nose-down attitude for the aircraft.

The first cause for concern is that the pilot could not override the system. Apparently there was a set procedure for just such a situation as this, but what it didn't do was permanently lock the anti-stall out. Therefore, if the problem persisted there was no way to stop it taking you into the ground.

Take this a step further and you have to ask: if there is no way to permanently disable the system why was there only one sensor?

When I worked on the design of an aircraft we had redundancy in every critical system. Cost and weight are ever more important with

A Boeing 737 MAX-8 (the same variant as that involved in the Ethiopia crash) takes off

Image: Boeing

airliners but surely one more sensor, on something like this, should have been designed in? In fact, I even wonder if the system should have been purely a notification device, warning the pilot so that he or she could respond.

Look a little deeper and you come to wonder why this system was needed in the first place. The Boeing 737 made its maiden flight in 1967 and has been subsequently developed through a number of upgrades on its way to becoming the most numerous jet airliner.

In the push for greater efficiency, the 737 MAX has been re-engined, but because of this there is now a danger of it pitching nose-up in flight; a danger sufficiently worrying for the anti-stall system to have been introduced.

We have lived for a long time with airliners that need computer intervention to fly in their operational envelope and mainly this has been very safe. However, there is, I would suggest, at least a partial precedent for this sort of failure in the loss of Air France flight 447. In that case it is believed a pitot tube on the Airbus A330 became obstructed with ice, causing a cascade of events which ended with the loss of 228 lives – a devastating accident that you would think is still actively referenced in the civil aviation world.

Boeing is full of very clever people and I seriously doubt any of them take the potential loss of life that may come from any of their decisions lightly. So how have we come to what, admittedly with hindsight, seems like an inherently dangerous situation built upon a number of questionable decisions? Answer: the extension of a design over 50 years old that introduces a known risk, trying to negate that risk with an automated system that directly affects the aircraft's flight without the ability to lock it out and the reliance on one sensor for input and enforced response.

Whether we have arrived here through hubris, misplaced confidence in technology or financial pressure, I cannot help but think it may be a watershed moment for aircraft design. It's a reminder too that as engineers we have a duty to maintain our professionalism and stand guard against any inappropriate dilution of standards. ■

Inyouropinion

Maiden flight of Stratolaunch

Stratolaunch is quite old technology just looking to lift more. With a take-off weight, including payload, of 540 tonnes, a 117m wingspan and requiring over 3.5km of runway, it can't exactly use your local airport. I don't know what the end purpose is.

John Logsdon

I would be interested to know what weight could be put into, say, LEO orbits – using the 225-tonne load of the Stratolaunch, and how this compares with other (reusable) launchers. If my memory serves me correctly, the Bell X15 used to be taken up to a height and then, presumably, a ramjet and air-breathing rocket would take it the rest of the way. So it does beg the question of what sort of payloads this vehicle would carry.

Peter Spence

Ultra Low Emissions Zone

A forthright approach is required from the outset and Sadiq Khan has done this. It will make individuals reassess their vehicle choice and increase the number of EVs in the capital. This will also generate a new business culture around low-carbon alternatives. This is the future.

Pete

Seems to be a sticking plaster 'solution' based more on politics than real action. It does nothing to remove polluters from the roads. London doesn't exist in a vacuum, so what about the pollution drifting in from the M25 and Heathrow ?

Another Steve

The greatest polluter of London's air space is Heathrow and they are expanding that.

John Bibby

Considering the weight of evidence from multiple countries, it would be wilfully ignorant not to urgently tackle NOx and particulate pollution.

As to just how effective the solution will be, that's harder to pin down. You can't blame government for choosing to charge motorists. Simply banning the worst cars would have constituents gathering pitchforks and torches.

J Eyre

Join the debate theengineer.co.uk

Always looking for a competitive edge

BAE's technology director talks to Jon Excell **about the engineering challenges of keeping one step ahead of a constantly evolving range of military threats**

While they may sound like the ingredients of an action movie, AI-enabled cyberattacks, hypersonic missiles, laser cannons and robot swarms are just a few of the potential real-life threats being anxiously contemplated by the world's top defence researchers.

In fact, at a time of rapid technological change and increasing geopolitical uncertainty, the range of threats facing countries is perhaps broader and more challenging than at any time in history.

To gain a greater understanding of the engineering challenges presented by all of this, *The Engineer* sat down with Dave Short, technology director of one of the firms at the forefront of innovation in the sector: UK defence giant BAE Systems.

Disarmingly affable and relaxed given the sobering nature of the day job, Short is nevertheless clearly passionate about the task at hand: ensuring that no stone is left unturned in the search for technology. "We're looking at anything and everything to do with technology," he said. "Anything that can give us greater capability or competitive edge."

Prior to taking on his current role in January 2018, Short's career was spent predominantly within the military air sector. Most recently he was engineering authority for the Typhoon and Tornado, and before that was chief engineer for BAE's involvement in the F-35. But, despite this focus on aerospace, interfaces in the firm and a keen interest in competitive environments have, he claims, set him up well to take on a broader tech brief.

This is important, because encouraging collaboration across a company where expertise has historically been a little 'siloed' is a key element of the role. "I'm trying to ensure that from a collaboration point of view we understand what we've already got, ensure that we maximise the technologies we already have, and ensure that we don't duplicate," he said.

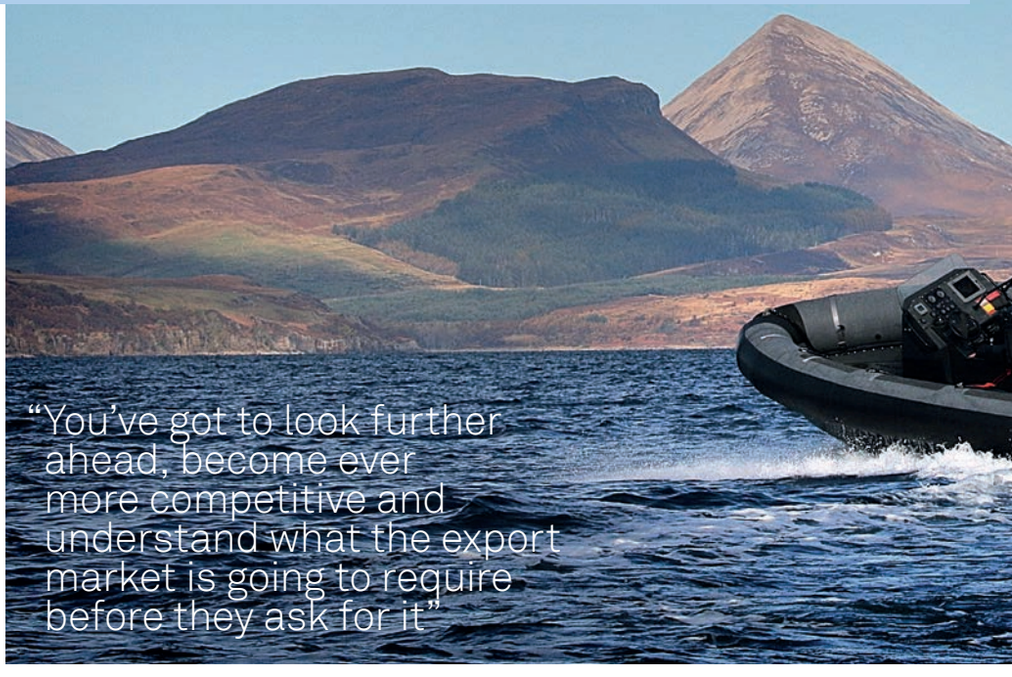
One of the ways that the CTO organisation for which Short works achieves this is with a ring-fenced pot of 'seed-corn' funding that can be used to overcome some of the bureaucratic hurdles that sometimes hold up innovation.

This approach enables the firm to be a little more speculative than is often the case and to second-guess future capability requirements. "You've got to look further ahead, become ever more competitive and understand what the export market is going to require before they ask for it," explained Short. A good example of this bearing fruit is the Unmanned Warrior project, in which BAE worked with other partners to develop autonomous capabilities for the Royal Navy. "This was a more risky project when it started than was comfortable for the maritime business to take on without some backing from the centre," he said. "But now that's matured into something that's progressing into bringing in customer funding."

Another case of the firm looking to the future is its £20.6m investment in Oxfordshire's Reaction Engines, which is developing SABRE, a new class of aerospace engine that combines jet and rocket technologies.

Short said that while BAE's interest in the project is "very much based around opportunities for space", the capabilities the team is developing – notably the ability to sink vast amounts of heat – could be applied to a number of other applications.

Short's team is looking beyond BAE for inspiration, whether through its strategic relationships with universities such as



"You've got to look further ahead, become ever more competitive and understand what the export market is going to require before they ask for it"

02

01 Developed in collaboration with the University of Manchester, Magma represents a new breed of aircraft without any moving surfaces

02 Artist's impression of Tempest, BAE's proposed next generation fighter jet

A trial of an unmanned RIB during the Unmanned Warrior project

Manchester (which is playing a key role in its development of unmanned aerial vehicles (UAVs) with characteristics such as non-moving surfaces) or by working with other companies. This often involves working with specialists from other sectors, and Short singled out motorsport, famed for its ability to move rapidly from prototype to finished product partner.

The firm has a longstanding relationship with McLaren and last year announced a tech sharing partnership with Williams with whom it is reported to be collaborating on cockpit designs and battery technology.

The company also frequently finds itself collaborating with competitors – an essential dynamic, he said, given the sheer range of challenges the sector faces. "When I started back in the 80s, almost everything was done in-house, but as the world moves on and there's more technology available, you want to bring in as much as you can."

In a sector where emerging technology areas frequently call for non-traditional skill-sets, collaboration is also at the heart of the company's approach to people, with it often making more sense to tap into skills which exist elsewhere rather than develop an in-house capability. A case in point is the gaming sector, which is proving to be a valuable source of in-demand data expertise. "Some of the capabilities which have been developed in the gaming industry and the engines which drive those are quite suitable for some of the things we want to try and do going forward," said Short.

One of the threats driving this requirement is the growing issue of cyberattacks. "This wasn't even mentioned in defence policy going back to 2007/08. Now it's a major topic," said Short, citing the 2018 WannaCry ransomware hack (which cost the NHS £92m) as an example of the havoc that can be caused. And while he wouldn't be drawn on details of BAE's work in this field, his thoughts on how the technology might evolve are chilling. "The thing I'll be interested to see evolve personally is the use of AI in conjunction with cyber.

"The AI will keep learning from what didn't work and you might find it learns more quickly than the human hacker."

But despite justified concerns over the threat of cyber, Short rejects the notion that conventional defence projects are no longer relevant in the age of digital warfare. "The fact that you've got cyber doesn't suddenly supersede the need for being able to have a really significant force on the back of an aircraft carrier somewhere, for other threats and other reasons."

One such threat is the emergence of hypersonics, and, in particular, growing concerns over the technology being developed by Russia and China. "You've got intercept missiles which can take things out at Mach 3 and 4 but if something's coming in at Mach 6, 7, and 8, what do you do about it?" he asked.

He said a key project for BAE is the Boeing-led HIFIRE programme which has been developing and trialling experimental hypersonic vehicle technology.

Elsewhere, perhaps one of BAE's most publicised areas of activity is its work on UAVs.

From the development of the Taranis unmanned combat aircraft, to its ongoing work on flapless flight (which recently saw the firm's Magma UAV become the first aircraft to perform manoeuvres using supersonically blown air), the pace of development has led some to speculate that the current generation of military aircraft will be the last to feature a pilot.

But while UAVs will undoubtedly play an ever-greater role, Short thinks that there will be a "man in the loop" for some time to come. "It's a mandatory aspect of engagement anyway, but also humans still provide a flexibility that is very difficult to truly replicate through the use of autonomous systems," he said.

He suggested the next generation will see an optionally manned capability – something being considered with Tempest, the next generation fighter concept unveiled by the firm at the 2018 Farnborough Airshow.

Tempest, a real showcase for emerging defence technologies, may also be the recipient of another system more readily associated with the movies: the directed-energy weapon. Short confirmed that this technology is an area of great interest for BAE, adding that having an infinite magazine (i.e. a weapon that doesn't run out of bullets) would be useful for dealing with threats such as swarm attacks.

Rather than developing the actual weapons, the prime focus here, he said, is understanding the challenge of integrating this kind of technology on future platforms. "If you think about the amount of energy, the amount of heat that can be generated and some of the peripheral aspects of having that kind of capability, you need to have a design case that allows that to be part of the thought process right from the very start."

Ultimately, this view on integration, and designing platforms to cope with future technologies, is one of the key challenges. Obsolescence has been a longstanding issue across the military environment, with numerous cases of capabilities being developed which are obsolete before they've gone into service.

But Short believes technology is enabling the sector to become better at future-proofing its systems. "Computing, communications, data backplanes and the way you can make things more modular means we're in a better position to make things more future-proof even though the cycles are picking up pace all the time." ■

Dave Short will be talking at Day One of *The Engineer*'s 2019 conference (4-6 June, NEC, Birmingham) – see Page 52 for more details.

Electric air racing looking to take flight

01

Stuart Nathan **looks at the development of Air Race E, a new motorsport involving electrically powered air racing, and the effect this might have on the future of air transport**

Those Magnificent Men in their Flying Machines used to be a television fixture on bank holidays in the UK, seemingly on rotation with *The Great Escape* and *Chitty Chitty Bang Bang*. With a huge cast of such 60s stalwarts as Terry-Thomas, Robert Morley and Sarah Miles, it was an Edwardian-set madcap comedy depicting an air race between London and Paris with a fiendishly catchy theme song: They go up-tiddly-up-up, they go down-tiddly-down-down. It directly influenced the immortal cartoon character Dick Dastardly (who memorably took to the air himself in a never-ending and never-explained quest to stop a carrier pigeon. Cue another theme tune).

However, air races were no laughing matter in the early 20th century. They have a long tradition in aviation, and made important contributions to aerospace development. The Schneider Trophy, a prestigious competition for seaplanes, was a testing ground for the development of aerodynamics and aircraft engines, and its winners were the forerunners of such famous fighter aircraft as the British Spitfire (whose development from a seaplane was immortalised in another bank holiday favourite film, The First of the Few), the American Mustang and Italian Folgore. And air racing is still going now.

Today, the best-known air race event is probably the Red Bull Air Race World Championship, where small single-engine aircraft fly through a slalom course featuring sharp turns at high speed against the clock. However, the Formula One Air Racing series in fact predates this event, and was first proposed in 1936 with its first event in 1947. The biggest air race event in the world, the US National Championship Air Races in Reno, Nevada, attracts some 150,000 spectators annually.

In contrast to the Red Bull championship, Formula One events are full multi-entrant races, where eight aircraft compete virtually wingtip to wingtip around a 5.13km oval course at an altitude of about 10m. As with all motorsport, racing vehicles must comply with detailed entry criteria.

Aircraft must have a minimum wing area of 66ft² (6.1m²), a minimum empty weight of 500lbs (227kg) and a maximum engine displacement of 200in³ (3.28L). They can reach speeds above 200mph (322km/h) and the spectators are seated 150m from the course.

> "It's not just replacing fuel tanks and batteries and an engine with an electric motor; the power electronics are crucial"
>
> Glenn Llewellyn, Airbus

Formula One events comprise eight laps of the circuit.

Jeff Zaltman, chief executive of Air Race Events, which sponsors the Air Race 1 World Cup and is launching a new all-electric series, Air Race E, told *The Engineer* that electrification in aviation is 20 years behind automotive because it is focused on large aircraft that can carry a number of passengers. "For an air race, the situation is quite different. You're only talking about small aircraft going a short distance over a short time, so you don't have to worry about the limitations of battery size and weight balance which are so important for passenger airliners. But small aircraft like these are going to be very influential in the development of bigger ones, particularly in the testing and proving of the engine and energy management systems."

Formula One Air Race forms the model for Air Race E, with the same course layout and eight-lap races, and the aircraft will be of similar size and envisaged as having comparable performance. The raison d'être of Air Race E is similar to that of the Formula E road motorsport series: to use the galvanising effect of a sporting competition to concentrate and accelerate development of electrical flight.

However, there will be differences, notably that Formula E is deliberately focused on development of a high-performance electric powertrain rather than car aerodynamics, unlike in Formula One where powertrain and aerodynamics are equally

important to the Constructors' Championship.

For aircraft, the challenge of installing an electrical propulsion system is very much more bound up with the design of the plane than it is with cars. So while the early Formula E series saw all the teams competing with essentially the same car, and teams have gradually been allowed to develop more of the powertrain themselves, for Air Race E, teams will be developing their own airframes from the beginning. Entrants will, of course, not be limited by gender, so it should be a case of those magnificent men and women in their flying machines. Initially, Zaltman plans to run Air Race E events as an 'undercard' to Formula One races, but he hopes the electric event will become more important than conventional fuelled races over time.

The open design regime is in keeping with the air racing culture, where the 'maker community' is heavily involved in designing and building aircraft. Some of the teams are made up of aeronautical engineering students, often representing their university. Others are archetypal 'men in sheds' (women can and do also have sheds): hobbyists who simply enjoy the challenge of making their own planes (sometimes, but by no means exclusively, from kits). In order to continue to fit in with this culture, entrants will have to conform with the specifications set down by the governing body (likely to include wing area, empty weight, maximum motor power rating and battery capacity and/or weight, closed cockpit, fixed undercarriage and propeller design), but will otherwise be free to build and fly their own designs.

The industrial drivers are also somewhat different. While the automotive industry is focused on producing electric cars that, although not single-seat racers, are not all that different from the Formula E vehicles, the aerospace industry is not interested in developing small single-seat aircraft, but larger passenger airliners to fly city-to-city routes. The environmental rationale is also different. Both automotive and aerospace industries want to reduce their fossil fuel burn and therefore their carbon emissions, but aerospace is also very concerned about the noise that aircraft make, and the desire behind the switch to electric propulsion is concerned with losing the jet engine scream. For both industries, the carbon emissions question is one of emissions in use: if the electricity to power the vehicles comes ultimately from fossil fuel power stations, then overall emissions are not reduced at all (although reducing emissions from large-point sources like power stations is simpler than reducing them from a large number of smaller sources, such as fossil-fuelled vehicles).

Both the land-based and air-based racing series are very much concerned with the development of battery technology – cramming more energy storage into as small and light a package as possible – and with the management of that battery system to ensure the most economical use of its stored power. For electric aircraft, the separation of energy production from propulsion (that is, removal of the need to actually burn fuel) has significance for design of the vehicle. "It's not just a matter of replacing fuel tanks and batteries and an engine with an electric motor; the power electronics are also crucial, and new airframe configurations are possible even within the stipulations of the formula," commented Glenn Llewellyn, general manager and chief technology officer of Airbus's electrification programme.

01 Formula One aircraft are not identical, as the inverted gull-wing configuration on this aircraft shows. Other aircraft have straight wings

02 Aircraft remain close and low throughout the race

03 Wingtip-to-wingtip racing

"We are very interested in how competitors in Air Race E tackle that issue, and how they integrate batteries and motors into their designs. We think that might well give us some inspiration for how we might look at that in our larger aircraft. It really is an integration issue as much as it is an engineering design one."

But Llewellyn stressed that because this project is within the context of a motorsport formula, the airframe innovations possible with electric aircraft will not be seen in Air Race E; Airbus is considering options such as tilt-rotors for vertical take-off urban mobility vehicles, and is likely to make use of hybrid technologies with an on-board generator for cruise flight, but Air Race E will be strictly all-electric, fixed-wing and front-engine.

Despite this, Zaltman said: "We are very much hoping the design freedom we are allowing in our competition will give rise to some interesting solutions to these kinds of problems. You probably wouldn't see that variety of solutions if we were a single manufacturer series like Formula E was in its earlier years."

Although the first race is currently scheduled for 2020, the series is still in its infancy technologically.

A prototype aircraft is being developed with Airbus's help at the University of Nottingham, where hybrid propulsion systems research fellow Richard Glassock is converting a current Formula One aircraft by retrofitting an electric motorbike engine to power its propeller, and by replacing its fuel tanks with batteries. This prototype will be used to help set the specifications for future aircraft (particularly in terms of weight), and it is expected to make its maiden flight (probably at Cranfield) within the next couple of months.

"I've been working on electric and hybrid systems for aircraft propulsion for about 15 years and we can see now in the world that electric propulsion is really a growing industrial application, so this is a perfect fit," Glassock said. As electric motors allow faster acceleration than kerosene-powered engines because of their instant torque, they are well-suited for racing aircraft.

The aircraft Glassock's team is working on is a Cassutt III airframe which, he explains, is an older model but still popular in air racing. It has a welded tube steel fuselage with wooden wings which are fabric-covered with some composite fairings and

nose cowling. The fuel tanks sits right behind the engine, so the substitution is direct: the batteries occupy the space where the fuel tanks were.

The original engine is a 0-200 4-cylinder piston design, the cylinders arranged in a horizontally opposing configuration. As electric motors are cylindrical, the characteristic "side cheeks" of the aircraft will disappear.

The major challenge in engineering terms, Glassock said, is concerned with weight and its distribution. "The electric motor has the potential for relatively high 'power density' or power-to-weight ratio compared to the original piston engine," he explained. "The engines used in racing can be modified in some limited ways, and typically operate at much higher RPM than as certified, which enables considerably more than the standard power output.

"Some racers claim around 150kW from their piston engines (originally certificated at 75kW rating), and the weight is around 110kg. A good presently available technology electric motor installation should give the same power at about half this weight, when the necessary ancillaries (mainly cooling system, heat exchangers, pumps fluid, etc) and power electronics are included. Whereas the old internal combustion engine in this case was pretty well at the limit of power to weight, the electric propulsion systems still have a lot of development potential."

A bigger problem is the batteries. For presently available battery technology, the energy required at 150kW may require batteries that "imply excessive weight for the Formula One-type aircraft in current use", Glassock said. "This will be an interesting problem for the overall design. It may be necessary to increase the wing area, or introduce high lift devices (flaps, spats, etc) to enable higher gross weights. Alternately it may be better to use lower power and therefore less energy, if the overall speed can be made competitive."

These are typical aircraft engineering, racing and strategy design problems, he added. "Also, the battery technology will improve over time along with motor and power electronics so that it is likely within some years that the 150kW Air Race E platform will be of similar gross weight to the present-day units."

The electric motors are commercially sourced, although at least one model being considered was designed and built at the University of Nottingham. These racing motors are rated at "continuous" and "peak" power, Glassock explained. "The e-bike motors are in the order of 200kW peak and 120kW continuous rated, however the motorcycle race duty cycle is much different from the air race conditions.

04 Richard Glassock and Jeff Zaltman

05 Air Race E will focus on electric flight development

Also, the motor power is of course limited by the ratings and operational conditions for the power electronics and battery."

In many types of aircraft, fuel tanks are located in the wings. Racing aircraft tend to locate them in the nose, and the retrofit project will follow suit with batteries behind the motor, to ensure that the centre of gravity is in the right place. If future designs locate them in the wings instead, some mechanical reinforcement would be needed, Glassock speculated, as the batteries and associated equipment weigh some 100kg.

Glassock's project has two phases. "The first phase is to retrofit the aircraft with mostly commercially available components and replicate the original performance as far as possible," he said. "The second phase will be to design a bespoke propulsion system including custom-built power electronics, motor and integration systems. The aircraft we are using was fitted with a relatively standard engine. We believe it would have been developing approximately 80kW and so we are aiming at replicating this for Phase 1. We would like to keep the gross weight as close as possible to the original aircraft too, and so we expect equivalent performance, handling and manoeuvrability."

In the second phase, things may change. The goal of this part of the project will be to optimise the aircraft and its systems. "This will involve the motor and power electronics design primarily, but as with all aircraft design, and racing in general, the whole system including the airframe, propulsions system and the environment have to be considered."

In the future, as teams develop their own aircraft, Glassock believes that the noses might become longer and thinner, with differences in the cooling requirements of the motor leading to differing approaches to aerodynamics.

Glassock believes that the Air Race E project will be very significant for development of commercial electric aircraft. The main reason for this, he says, is that the 150kW power level needed in racing aircraft is the same as the engine rating that will be needed commercially.

"Electric motors are suitable for relatively easy 'stacking', so that multiple motors can easily drive a single load, propeller or fan," he said. "These properties make the technical development of Air Race E propulsion systems highly relevant to broader commercial use such as in eVTOL, PAV and even regional and sub-regional transport.

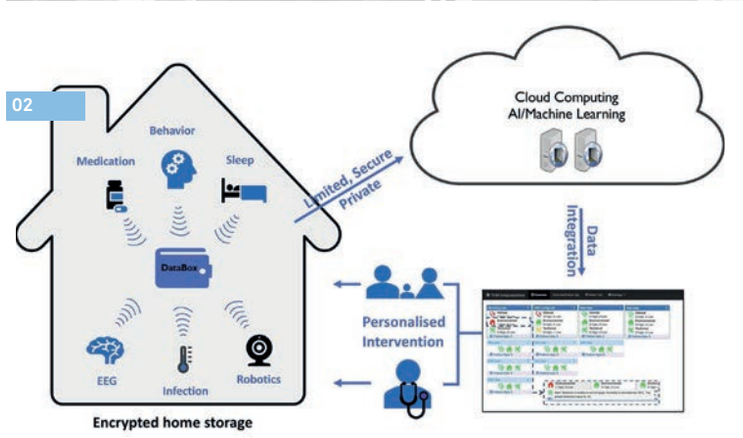
"I can see this racing becoming very exciting, both in terms of the flight environment but also in the technical design and operations. And the human potential, social interaction and innovation environment can be spectacular. We want to encourage younger generations to positively embrace the ambition at all levels too. I think these factors align with the sort of future thinking and spirit necessary to solve many complex problems facing the aerospace industry, transport and environmental issues and within educational, commercial and industrial engagement."

So, while some harbour doubts about the transfer of technology from Formula E to commercial road cars, there seems to be agreement that the world of air racing will be of definite influence to the coming generation of electrically powered commercial aircraft.

And although problems still remain to be cracked, such as low-carbon energy to charge the aircraft's batteries, and the batteries themselves (although the imminent launch of 1kWh per kilogram batteries may well change this, as we will see in coming issues of *The Engineer*), it seems certain that the way we fly – for short distances at least – is on the verge of a significant change. ■

Homing in on technology

A new £20m research centre will explore home-based technology to help people living with dementia.
Andrew Wade reports



It is estimated there are 50 million people on the planet living with dementia today, a number the World Health Organisation predicts will treble over the next 30 years as average life spans increase. The issue has been described as a time bomb – the biggest healthcare challenge of the 21st century. Although there is no known cure for the disease, technology is playing an increasingly important role in helping people live with dementia, particularly in their own homes.

"Dementia is now the biggest killer in the UK," said Prof David Sharp, a neurologist at Imperial College London and head of a new £20m dementia research centre. Located at Imperial's West London campus near White City, the facility will apply AI, robotics, sensors and software to create dementia-friendly homes when it opens in June this year.

"We've got 850,000 people living with dementia today," Sharp told media at a recent event to launch the centre. "We've got an ageing population. By 2050, we're going to have about two million people living with dementia.

"From my perspective, I think the system for caring for patients with dementia is broken. I think most patients and carers come into contact very infrequently with healthcare professionals. What that means is that preventable problems develop. One of the facets of that is around hospital admissions. So around 25 per cent of all the NHS beds are occupied by people living with dementia, and we estimate that about 20 per cent of those admissions are potentially preventable."

Preventable admissions can be the result of anything from dehydration and falls to things like urinary tract infections (UTIs), which are particularly common in dementia patients and often result in lengthy hospital stays. Cutting the number of these admissions would reduce the strain on both the NHS and dementia patients themselves, for whom hospital visits can be distressing. According to Sharp, technology in the home could have a major impact on how dementia's effects are detected and how the disease is treated.

"We have treatments for UTIs, we're just not implementing them quick enough," he said. "We think that technology and new engineering advances are going to help us to do that. What we propose is that the centre will develop an intelligent environment, so really a cost-effective home that uses advanced engineering solutions and artificial intelligence to support and protect patients living in their own home, which is where people want to stay for as long as possible."

At the heart of the system will be a suite of advanced sensors deployed throughout the home, recording the most relevant information for patients who are living with dementia. This includes things like sleep assessment, detailed behaviour assessment, medication effects, brain activity changes and infection monitoring. The information from these systems will feed into a system called Databox, which will essentially be a small home-server that will give patients control over their own data, while also providing access to approved healthcare professionals.

As well as evaluating technology that is already available, the centre will test completely new hardware designed specifically for the project. An earpiece sensor developed in-house at Imperial will provide information on gait and sleep, as well as acting as a mobile EEG, recording brain activity over extended periods of time. Elsewhere, low-cost miniaturised radar technology will generate detailed data on patient movement and behaviour.

"We have a prototype of an ear EEG system that can be used to track brain activity over long periods of time, so we'll be evaluating that," Sharp explained. "We're also going to be developing new biosensors to measure infection state as well as the earliest signs of the development of dementia from the blood."

AI and machine learning will help identify patterns in the data and guide decision making. Crucially, the system should provide a more rounded view of the disease and its impacts, in comparison to the brief patient snapshots garnered from medical appointments. This will help healthcare professionals to evaluate the effectiveness of treatments in real time as well as enhance patient safety.

"We want to use robotic devices and other ways of changing the environment to try and improve safety and to try and support people to live for

01 Prof David Sharp

02 The various technologies that could help dementia patients remain longer in their homes

as long as possible in the home," said Sharp. "We think the system overall will have a number of benefits. We think it will personalise care, it will improve health autonomy, it will improve communication across healthcare teams and it will improve safety by allowing us to identify problems that might be developing in the home environment."

In a bid to ensure that the research is practical and relevant, the centre will work with Imperial's design centre, Helix, to get early feedback on prototypes from patients and carers. The most promising technology will then be trialled in the homes of around 50 people affected by dementia, with a new group of 50 rotated in every six months. This model will enable the team to assess different combinations of technology to find out what blends well for the best overall benefit. While certain devices are already commercially available, Sharp expects some of the newer developments to reach the market within the next five years, with the aim of keeping the tech small, low-cost and scalable.

"I think we're close to having something that's really usable in a wide context," he said. "I think the wins will be across a wide range of things. I think we'll be targeting reducing that 20 per cent figure of unnecessary hospital admissions.

"We're very interested in the use of smartphone apps, for example, for monitoring certain aspects of disease progression. We've already funded that and we have a system for monitoring memory and attention and how people are affected. And that will be free to download.

"So there'll be an element that anyone will be able to access, from anywhere in the world.

"Of course some of the more complicated technology will come at a cost."

The vision is that someone diagnosed with dementia in the near future could be prescribed a package of hardware and software, perhaps via the NHS. GPs might have a dashboard of different apps suited to individual needs, while specialists might kit out homes in the same way internet and TV providers do today. Ultimately, the system should enable healthcare professionals to engage with dementia patients more effectively, but also much more meaningfully.

"We think the technology will transform the efficiency, the use of the resources available, improve the way GPs are operating, reduce hospital admissions, keep people out of care homes and out of hospital for as long as possible," said Sharp.

"That has major economic wins, and people also want to stay in their homes with their loved ones as long as possible. They don't want to be in a nursing home or sitting for three months in a hospital bed because they had a UTI but we couldn't treat it. That's the target. That's a win all round." ■

F-Pace SVR: The Magnificent Beast roars to life

The latest creation from JLR's Special Vehicle Operations department is the Jaguar F-Pace SVR – a luxury SUV that offers other-worldly performance, writes Chris Pickering

"We call this thing The Magnificent Beast," jokes Ross Restell, lead engineer for vehicle dynamics at JLR's Special Vehicles Operations department. He's referring to the new Jaguar F-Pace SVR that sits waiting for us across the car park. Just then, one of the cars starts up, its 5-litre supercharged V8 roaring into life like an angry lion woken from its slumber. I swear you can feel the ground shake.

We've been here before, of course. Luxury SUVs are big business and that means premium manufacturers are scrambling to outdo each other in the world of super-fast, super-sized off-roaders. Alfa Romeo has the Stelvio Quadrifoglio, Porsche has the Cayenne Turbo and even Jaguar's sister company Land Rover has an indirect rival in the form of the Range Rover Sport SVR.

But while the Range Rover Sport SVR is a gloriously silly hot rod that blends laugh-out-loud performance with Land Rover's traditional mud-plugging capabilities, the F-Pace SVR is an altogether more serious attempt at a performance car. It has a very credible base in the standard F-Pace – already one of the best handling SUVs on the market – and a lot of work has gone into creating a civilised, well-rounded package.

"We inherited a great car to start with," comments Restell. "The F-Pace is already extremely rigid so we were able to get the performance and the handling characteristics we wanted without having to make any changes to the fundamental structure. It's mainly aluminium so it's also comparatively light and the suspension already has a suitable layout with double wishbones at the front and an integral link setup at the rear."

> "It's these systems that give the F-Pace SVR its remarkable ability"

The most obvious change is the addition of the vast supercharged V8 that's currently causing the air around us to pulsate. It's essentially the same unit as you'll find in top-of-the-range versions of everything from the F-Type to the Range Rover.

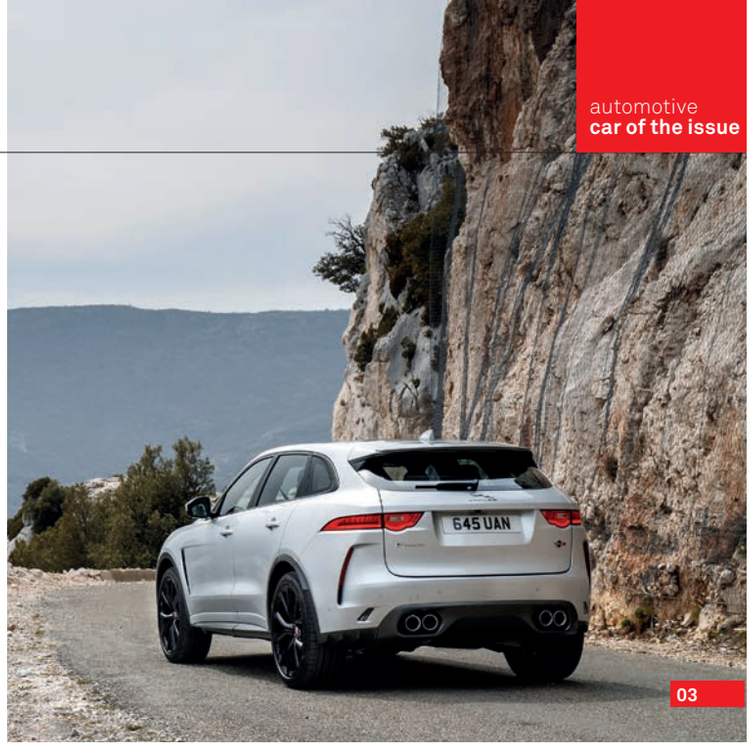
However, this marks the first time that this engine has been installed in the F-Pace. The results are startling. Despite an unladen weight of more than two tonnes, the 542bhp (550PS) V8 is capable of catapulting the F-Pace SVR from 0 to 60mph in just 4.1 seconds. That's faster than a Ferrari 360 Modena in a car with ample room for five people and a boot large enough for a pony. Top speed is an almost equally barmy 176mph.

01 The steering is well-weighted

02 This is the first time a V8 engine has been installed in the F-Pace

03 The F-Pace goes from 0 to 60mph in an impressive 4.1 seconds

You can feel the ground shake with this Jaguar F-Pace SVR



03

Other changes include a set of giant alloy wheels (21-inch as standard, with optional 22-inch wheels fitted to our test car). Inside those you'll find an equally gigantic set of brake discs (396mm at the rear and 396mm at the front) charged with hauling this beast back to a standstill.

The calm before the storm

We climb into the beautifully appointed interior and point the F-Pace SVR's nose north from St Tropez towards the Route Napoleon and the Southern Alps. Aside from a flare of revs when the engine starts, it's a very refined experience. The V8 dies down to a distant rumble, the eight-speed ZF automatic shuffles gears seamlessly in the background and the ride – even on those monster truck wheels – has that classic Jaguar blend of compliance and composure.

We find ourselves stuck behind a truck as the road starts to snake its way up into the mountains. A short straight opens up ahead so I flick the drive selector over to Dynamic and pin the accelerator to the bulkhead. A wall of sound erupts from the SVR's tailpipes. With no turbochargers to worry about, the response is instant, the torque delivery is unswervingly linear and the thrust is seemingly never-ending. It's as if the road ahead has been compressed by magic.

A few corners later, I'm even more convinced that the SVO engineers have turned to voodoo. Whereas some fast 4x4s squat down on their haunches when you accelerate hard and roll around in the corners, the F-Pace stays level and composed. The same applies to braking, with more than enough retardation to haul this two-tonne projectile down from the somewhat alarming velocities it is able to achieve. You never entirely lose that sense of mass, but at no point does it feel like an impediment. There's a real sense of involvement here too, with well-weighted steering that responds faithfully to your inputs and a chassis that seems to pivot directly about your hips.

But what's remarkable about this car is the way it combines the mild-mannered Dr Jekyll and the savage Mr Hyde into one coherent package. As Restell explains when we catch up later on, it's this elusive balance between ride and handling that proved the biggest challenge for the SVO engineers.

"We would sometimes spend a week at the Nürburgring developing an incredible track set-up. It would seem OK driving back on the continental motorways, but as soon as we rolled off the train into the UK we'd realise that it had become too track-focused," he comments. "We'd then spend two or three weeks driving around the roads of the UK to wind that back out before we'd have to return to the track to ensure we'd got the balance right."

Part of this transformation lies with the hardware. The springs are now 30 per cent stiffer on the front and 10 per cent stiffer on the rear. There have also been revisions to the bushes, the spring aids and the anti-roll bars, along with the internal components used in the Bilstein Continuously Variable Damping system. Elsewhere, there's a new electronically controlled rear differential, capable of varying the locking torque to strike a balance between traction and stability (for instance, allowing the rear inside wheel to spin on a damp corner to prevent excessive oversteer). Meanwhile, the fore-and-aft split can also be constantly adjusted, with anywhere from 50 to 100 per cent of torque sent to the rear wheels. On top of all this, there's a brake-based torque vectoring system that can occasionally be felt helping the car to pivot into the corners. It's these systems that give the F-Pace SVR its remarkable breadth of ability.

No less than 250 different software calibrations were apparently tested before the SVR was finally signed off. Earlier on in the process, JLR's driver-in-the-loop simulator in Gaydon had been used extensively, allowing the ride and handling engineers to drive a virtual model of the car. The roads around the development centre were digitised using a laser scanning process to capture every bump and camber. Similar techniques were used to create virtual representations of test facilities such as the Nürburgring. This helped the engineers to narrow down the hardware choices before they moved on to physical prototypes for the fine-tuning.

Given all the performance and technology involved, the F-Pace SVR actually starts to look like quite good value at its starting price of £74,835. Of course, there are those who will tell you that an SUV capable of hitting 176mph is excessive. And they're not wrong. But there are a few things to consider: It's a stunning engineering achievement that acts as a halo product in an industry where SUVs are big business and this particular variant will only ever account for a tiny percentage of F-Pace sales. A lot of the lessons learnt on this project will translate well to other areas of the business (particularly when it comes to engineering dynamism into electric vehicles laden with batteries).

And finally, it seems that the days of big, loud combustion-engined cars like this may soon be numbered, so we should enjoy this magnificent beast while the opportunity still exists. With that in mind, I'm heading back up into the mountains. ■

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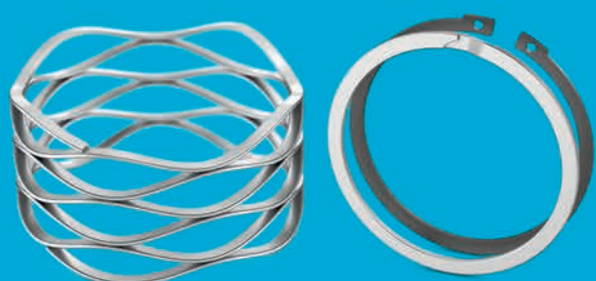

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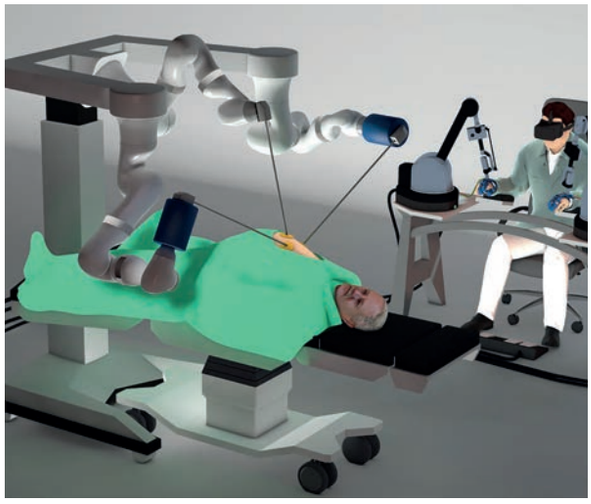
Maxon gives robotic surgeons a helping hand

A collaboration between Bristol Robotics Laboratory (BRL) and Maxon is enabling greater precision in assisted keyhole surgery Supplier: Maxon Motors

Robots are becoming ever more prevalent in the healthcare sector, no more so than in the demanding world of surgery. Bristol Robotics Laboratory (BRL) is developing a system known as RAMIS (robotic-assisted minimally invasive surgery) that uses Maxon DC motors and controllers to drive and position a three-finger surgical instrument that goes inside the body.

The instrument will be controlled by exoskeletons that fit over the surgeon's hands, with smart glasses providing the surgeon with a realistic view of what's taking place inside the patient. RAMIS is part of a wider Maxon project – SMARTsurg – that is developing an advanced system for robotic keyhole surgery procedures.

Prior to RAMIS, Maxon worked with BRL on several projects, while the latest endeavour involves a team of 10 institutions across Europe, featuring highly experienced clinical, academic, and industrial partners.



BRL and Maxon are enhancing keyhole surgery procedures

"While the popularity of RAMIS is steadily increasing, the potential for improving patient outcomes and the potential for other procedures is not fully realised, largely because of serious limitations in the current instrumentation, control and feedback to the surgeon," explained Sanja Dogmadzi, professor in medical robotics at BRL.

"Specifically, restricted access, lack of force feedback, and use of rigid tools in confined spaces filled with organs pose challenges to full adoption. The development of robotic surgical platforms has introduced 3D vision and significant improvements in the levels of dexterity.

"RAMIS will reduce the demand on the surgeon, shorten training time and deliver accuracy, safety and reduced procedure time."

BRL used Maxon's online Configurator to select and configure the DCX 19 S brushed DC motor, GPX 22 gearbox and ENX 10 encoder used on RAMIS. The online platform enabled the best fit in terms of output torque, speed and encoder feedback. Physical dimensions could also be realised, including technical details of the package published, such as the 3D CAD model, at the touch of a button.

The Maxon EPOS2 positioning controller and CAN communication protocol were used to ensure each axis responds to commands from the master controller in terms of position, speed and torque. ■

HVAC systems boost hotel's energy savings

Installation helps Madrid hotel achieve 40% reductions in energy Supplier: ABB

It isn't just manufacturing industries that can make savings using smart instruments.

The InterContinental hotel in Madrid has achieved 40 per cent reductions in energy use by installing variable-speed drives and high-efficiency motors from ABB on its heating, ventilation and air conditioning systems. The total reduction exceeded 445,000kWh per year. The installation was part of a project by InterContinental Hotels Group (IHG), of which the Madrid hotel is a 65-year-old flagship.

The hotel has eight pump groups that serve its HVAC systems and hot water supply to guestrooms, kitchens and other facilities. Although these were in good condition, IHG was concerned their efficiency levels were below best practice, which a study confirmed. "The study showed that 40 per cent of energy could be saved by decreasing the frequency of the motor by 10 per cent," stated Enrique Bernad Lillo, quality and financial manager at Exel Industrial.

ABB's recommendation was that the system should be upgraded with variable speed drives with the IE3 energy efficiency classification that is now mandatory for compliance with EC regulations.

As well as saving energy, they also produce less noise than the previous system because of their smoother start-up characteristics. Also, they eliminate the risk of pump cavitation, increasing the equipment's lifespan and reducing maintenance costs.

"Our ABB intelligent motion solutions enable energy savings of around 40 per cent, helping IHG exceed its Green Engage goals. Over a year that adds up to 445,000kWh, cutting the hotel's annual energy bill by more than £28,000 to deliver a projected return on investment in less than two years," said Morten Wierod, president of ABB's Motion business.

Variable-speed drives and high-efficiency motors have been installed on HVAC systems

He added: "This is a great example of how our variable speed drives, combined with our high-efficiency motors, are providing the most affordable, effective and sustainable means of saving energy and optimising operations for our customers." ■

Advanced Manufacturing

Component production cycle could speed up

Delay between production and a component's measurement checks could be reduced, boosting efficiency

HELEN KNIGHT REPORTS

Manufacturers could significantly reduce the delay between production of a component and precision measurement checks, thereby improving productivity and efficiency, thanks to UK research.

When a component is manufactured, it typically leaves the CNC machine at an elevated temperature, and must be cooled before it can be precisely measured in a coordinate measuring machine (CMM).

But since engineers have no way of knowing precisely when the part will drop to the desired temperature of 20°C, they typically wait for eight to 24 hours before checking it in the CMM, according to Dr Naeem Mian at the University of Huddersfield.

This creates a logjam in production and means that expensive CMMs stand idle.

Now Mian and his colleagues have found that this wait time could be slashed, potentially to just a few minutes.

Their research is expected to give engineering firms a technique for calculating how long it takes for a component's temperature to be stabilised so that it can safely be measured by a CMM.

Delay of a component production cycle could be reduced to just a few minutes

"We can commence measurement after just six or seven minutes"

The researchers carried out a series of experiments to determine the thermal contact conductance values of different components, or their ability to conduct heat to a surface, to calculate how long it takes for the temperature to stabilise. Mian then used finite element Analysis to validate his findings. When experimenting with a heated venturi he found it could cool enough to be placed in a CMM in minutes.

"We heated up the venturi to around 33°C, while its base was around 40°C," said Mian. "But instead of leaving it for an eight-hour shift pattern, or even up to 24 hours, we conducted our research and found that we can commence measurement after just six or seven minutes."

Funding gap preventing firm growth

Mid-sized firms miss out on new contracts

HELEN KNIGHT REPORTS

Research from Wyelands Bank has found that nine out of 10 mid-sized manufacturers, turning over £10m to £300m, are being held back because of a lack of finance.

Difficulties raising finance to support their growth have stopped them from winning new contracts and that has stifled new job creation.

Each firm said that the difficulties raising finance meant they had missed out on an average of £20m in revenues and an average of 11 new contracts, which would have enabled each firm to create 10 new jobs.

These figures suggest that the 23,000 mid-sized manufacturing businesses in the UK have collectively missed out on 163,000 contracts and 175,000 new jobs.

The research found also that difficulties in raising finance prevents 70 per cent of firms from investing in new equipment or technology.

Half have also been held back from entering new markets and 45 per cent are said to have been prevented from moving to a new site or premises due to funding issues. **JF**

Contents

PRODUCTION

Getting smart with new production techniques

New capabilities in MEMS designs can provide more sensors and bigger batteries for electronic devices

HELEN KNIGHT REPORTS

Smart devices, including wearable electronics and internet of things (IoT) technology, could be equipped with more sensors and bigger batteries, thanks to a new production technique.

Micro electro mechanical systems (MEMS) are a vital component in most electronic devices, as they provide the sensing capabilities that make the technology smart. However, since every MEMS sensor design is unique, each needs its own specially-developed manufacturing process, making it difficult to quickly ramp up to large volume production.

Now, London-based Nanusens has developed a technique to use the same standard production process used to make electronic chips, known as the complementary metal oxide semiconductor (CMOS) process, to build MEMS sensors.

In this way, the devices can be produced in any fabrication plant, in large volumes, according to Dr Josep Montanyà, CEO of Nanusens.

The new technology is likely to be initially applied to earbuds

In the CMOS process, silicon dioxide is etched away to produce the mechanical structure. In the new MEMS process, these structures can include nanoscale moving parts such as springs, which then form the sensor.

"You need empty space to allow the movement [of the MEMS device]," said Montanyà. "So we etch away the silicon dioxide very quickly, and leave the metal. In this way we generate the empty spaces we need in order to allow the metal to move."

The use of the CMOS process also allows Nanusens to take advantage of Moore's Law of electronics, meaning it can build smaller, nanoscale sensor devices. Existing MEMS devices, in contrast, are typically one micron or larger in size.

The nanoscale MEMS (NEMS) structures can be built on the same chip as the electronics needed to control them, with the entire package 1mm³ in size. In contrast, packages consisting of chips containing conventional MEMS structures, alongside a separate chip for the control electronics, are typically around 4mm³ in size.

> "You need empty space to allow the movement [of the MEMS device]"

The technology is likely to be initially applied to earbuds, where they will free up space for larger batteries with improved operational life. It could also be used in smart phones and wearable devices.

However, the company believes the sensors will ultimately have the most significant impact on the IoT, which has so far been limited by the lack of cheap, mass-produced MEMS sensors, said Montanyà. ■

PRODUCTION

New software breakthrough

X1 Grid to enhance AI and tech connections

Software designed to turn production facilities into smart factories, by more quickly and easily connecting industrial robots and machinery with different business applications, has been developed in Germany.

Munich-based RoboticsX, which specialises in industrial robotics and automation software, has developed the platform, called X1 Grid.

The software platform is equipped with IBM Watson Internet of Things (IoT) and IBM Cloud technology.

The system extracts and translates industrial hardware data into information suitable for use by business applications. This information is then analysed by the IBM Watson IoT platform to identify ways to improve production, according to Peter Boras, CEO and co-founder of RoboticsX.

"These days, industrial systems tend to be quite complex, you need to study for 100 years to know how to work the machines, so we are trying to offer very simple solutions," said Boras. "So if there is a problem, I want to know how I resolve it."

The Watson system includes AI software designed to predict and prescribe any maintenance. In this way it can allow manufacturers to make the best use of their equipment, and reduce downtime.

The AI system can recommend steps to improve the quality of manufactured goods, reduce costs, and increase production speed. The AI can also be used for quality control, to reduce scrappage, and to improve supply chain management.

"Other systems need to be programmed manually, so it takes a lot of effort, time and cost, but our system is really easy to use, making it cheaper and faster," said Boras.

The software is suitable for use with advanced machinery, but also with older devices such as PLCs. **HK**

MATERIALS

Breaking tensions to see through sheets of strength

A new processing technique can turn transparent polythene into a stronger material than aluminium, with implications for several industrial sectors

STUART NATHAN REPORTS

A new processing technique aims to enhance the mechanical properties of HDPE to the point where it competes with glass

Prof Ton Peijs of the Warwick Manufacturing Group and Prof Cees Bastiaansen of Queen Mary, University of London, have devised a method of making transparent polythene sheets that have tensile strength greater than aluminium.

They have tuned the process of drawing sheets of polymer from a solid in such a way that the material's strength is enhanced whilst transparency is not compromised.

Engineers have been trying to develop a material that can replace glass – which is heavy and brittle – in vehicle glazing applications.

Transparent polymers have lower density but scratch and fog easily.

The researchers claim their new technique, which orientates strands of polymer molecules within the sheets, enhances the mechanical properties of high-density polyethylene (HDPE) to the point where it competes with glass and outperforms metals.

Drawing involves pulling the material under tension, generally at an elevated temperature to allow the molecules to be reoriented. When drawing polyethylene, defects and voids in the bulk structure are introduced which destroy the polymer's transparency and reduce its strength.

The researchers started with HDPE sheets and drew them out at a temperature below the polymer's melting point. They found that by drawing at temperatures between 90 and 110^{0}C, they achieved the best balance between strength and transparency.

"We expect greater polymer chain mobility at these high drawing temperatures to be responsible for creating fewer defects in the drawn films, resulting in less light scattering by defects and therefore a higher clarity," said Prof Peijs.

The films possessed a Young's modulus of 27GPa and the maximum tensile strength of 800MPa along the drawing direction, both of which are 10 times higher than those of PA and PMMA plastics.

Aluminium, meanwhile, has a Young's modulus of 69GPa and aerospace grades have tensile strengths up to 500MPa.

However, the density of HDPE is less than 1,000kg/m^3 while aluminium is 2,700kg/m^3 and glass is around 2,500kg/m^3. The transparent aluminium-based ceramics have densities approaching 4,000kg/m^3.

"It is anticipated that these HDPE films can be used in laminates and laminated composites, replacing or strengthening traditional inorganic or polymeric glass," said Prof Peijs. ■

INDUSTRY 4.0

How Wi-Fi 6 can work

New tech applications may be made possible

The use of augmented reality and real-time video monitoring of equipment within the manufacturing industry could be among the applications made possible following the world's first trial of Wi-Fi 6 internet of things (IoT) technology.

The UK trial, the first in a series of global trials, is being held at Mettis Aerospace's 27-acre facility in the West Midlands, in collaboration with the Wireless Broadband Alliance (WBA).

The Mettis Aerospace site was chosen for the trial as it provides a number of technical challenges to the wireless system, covering a large geographical area and with industrial radio interference that can disrupt signals, according to Tiago Rodrigues, general manager of the WBA.

During the trial, the team will select two or three areas of the

manufacturing plant in which to install the Wi-Fi 6 network, consisting of several antennae.

"We are going to run a series of tests to address Mettis Aerospace's requirements, so for example, the use of augmented reality," he said. "We want to verify that Wi-Fi 6 can deliver those types of applications in an industrial environment."

Other challenges the technology faces is in juggling the competing needs of the different applications. Some applications, such as multi-stream video, will require high bandwidth, others require low latency, while mission critical applications will need to be prioritised, said Rodrigues.

"So particularly for Mettis' maintenance team, it is very important that they can have critical information as soon as possible, so that they can take whatever actions are required," he said. HK

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Customers are the key to innovation

Demand for change comes from your client base, says Alan Mucklow, MD, UK & Ireland, Mazak

Where does the desire to innovate come from? Most companies will tell you it is in their DNA, that there is a deep inherent need to push the boundaries of the possible; a restless urge to create a new product that is faster, stronger, better or cheaper.

But, in my experience, while the best organisations do have a relentless commitment to innovation, the initial spark often comes from market forces, more specifically customers, demanding some, or all of the above.

This initial spark convinces the organisation to point the full resources of its research and development capability at the fulfilment of this latent demand, providing customers with the answer to their conscious or unconscious problems, before marketing the new product more widely.

Make no mistake however, it is customers who have provided the initial spark and rightly so, because innovation without potential demand is a recipe for waste and unfocused effort towards an undefined goal.

The organisation needs to know that there is a potential market ready and willing to buy, providing the correct parameters are in place, such as price, application suitability, distribution, training and aftersales service, to name but a few.

There are plenty of high-profile examples of investments that have been wasted on product or service innovations that were never able to find a market. More difficult to recall, because in hindsight their success appears to have been preordained, are the product developments that were driven by market demand and customer insight.

At Mazak, we have long believed that our customers are the starting point for innovation. It was the demand from customers for platforms that could undertake multiple tasks that led to the development of the INTEGREX range of multitasking machines.

Similarly, the VTC-800 series of machines, which are manufactured in the UK, were developed after customer demand for a vertical travelling column machining centre. The 1,000th machine for the European market rolled off our production line at Worcester earlier this year.

We are very sensitive to market and cultural distinctions across the world, which lead our customers to use machines in alternate ways and in different applications. This, in turn, encouraged the development of the European Product Group, which was a direct recognition that the demands of European customers were significantly different to that of Japanese or North American machine tool users.

Without people on the ground, visiting customers, standing on production lines, asking the right questions and listening to the answers, our product development in Europe would have been much more limited, generic and unable to focus on the demands of individual sectors.

> "For me, the message is that we need to continually invest"

The VARIAXIS i-300 AWC, which stands for Auto Work Changer, is a direct example of this approach. The i-300 is a compact, simultaneous five-axis machining centre that was initially specifically developed for the aerospace sector. The aerospace supply chain was demanding high-accuracy machining on small prismatic parts, along with expanded tool capacity and a highly rigid construction to improve accuracy. The AWC is an innovative solution for the aerospace sector that has, subsequently, also found a role in medical and automotive work.

The next big innovation leap in the machine tool sector will not be confined to merely new products, however. The ability to better understand asset utilisation and put in place more proactive maintenance practices, such as remote monitoring as part of a predictive maintenance programme, will be an integral part of the new connected factory, or what we call the 'iSmart factory'.

All of this will result in major changes to how we operate and interact with customers but, ultimately, we will benefit from deeper customer relationships which will, in turn, fuel further innovation.

History tells us that the great leaps forward were not made by organisations that looked inward and remained in their comfort zones as markets left them behind. Rather, the great leaps were made by those who were in tune with their markets, sensitive to the changing needs of consumers and brave enough to seize the opportunities that were presented.

For me, the message of Collaborate to Innovate is that we need to continually invest, not only financially, in terms of R&D expenditure, but also invest further in our customer relationships. It is here that the sparks of creativity and innovation can be identified and nurtured, sparks that ultimately have the potential to turn into something new, exciting, inventive and genuinely groundbreaking. ■

01 The VARIAXIS i-300 AWC, which stands for Auto Work Changer, is a compact simultaneous five-axis machining centre that was initially specifically developed for the aerospace sector

02 The VTC-800 series of machines, which are manufactured in the UK, were developed after customer demand for a vertical travelling column machining centre

Continuous improvement

Engineering subcontractors continue to exploit advances in automation and process improvement from production equipment suppliers. Mike Excell reports

Despite ongoing political turmoil, the machine tool-related sectors continue to adopt a positive approach. "We are seeing companies taking matters into their own hands and relying on skills and abilities to secure the future of their businesses, by making them more competitive through investment in technology" says Steve Finn, managing director of DMG MORI UK.

He's observed a swing in order book make-up over the past two years, with subcontractor business up from 35 per cent to 68 per cent. "The fact that these orders are not for machines which we hold in stock, but are for machines to be delivered in seven to nine months, demonstrates the confidence in the marketplace to proceed with capital investment despite the potential uncertainty."

Automation, he believes, is an increasingly important driver for investment decisions. "At our last Open House in 2018, 80 per cent of the machines had automation featuring, for example, robots and gantry loaders; all these machines were sold at the event. The key demand was for solutions which addressed the requirements of low-volume, high-variety applications. With these relatively simple automation systems, machines can be run 24 hours and at a rate of £7-£8 per hour and still be profitable."

Investment delivers results

Subcontractors illustrating that investment in advanced manufacturing technology underpins sustainability include Silverstone-based Alitech Precision. The company, which supplies motorsport and automotive customers, installed its first 5-axis VMC in 2017 – an 'entry-level' machine – and this was joined by a Hermle C 400 in December 2018. Subcontractors generally benefit by progressing from 3/4-axis machining to fully interpolative 5-axis cycles.

> "This demonstrates confidence in the marketplace"
>
> Steve Finn, DMG MORI

Advantages include raising the complexity of free-form surfaces that can be profiled, higher component accuracy and reduced cost of manufacture. Fewer set-ups are needed, as a part can be positioned automatically with the two rotary CNC axes before being milled and drilled using the three linear axes. Alitech's investment was prompted by capacity problems. It had been doubling turnover every year, progressing from producing mainly prototypes and limited batches of components to larger runs of typically 20 off-complex parts such as race car uprights. This meant that work queued for up to a month, which is an unacceptably long lead time in this sector.

Glasgow-based Auld Valves also embraces an investment-based strategy. Established in the early 19th century, its global customer base covers the oil and gas, nuclear and shipbuilding sectors. A full foundry service, offering four to six weeks lead times on made-to-order valves, is enhanced by new machining technology.

Historically, the company preferred to sub-contract machining, or use manual lathes and radial-arm drills; but growing business, exemplified by valve orders for aircraft carriers and planned work on BAE Systems' Type 26 frigates, prompted investment in two XYZ SLX 425 ProTURN lathes.

"Having the two machines has enabled us to bring more work back in-house, enhancing our service to customers," said technical engineer Tom McLarnon. The machines enabled inexperienced operators to move from manual to CNC, and the ease of use of the ProtoTRAK control has seen them programming most jobs at the machine.

"This has made it much more practical to manufacture one-offs and small batches quickly," said McLarnon. "The set-up and cycle time savings we are seeing are in the order of 60 per cent over highly-skilled operators using manual machines. And as a lot of our valves are made to order, we can keep stock to a minimum while still being able to deliver to short lead times."

Systematic improvement

Productivity-boosting technology comes in many forms, as Senior Aerospace Weston will testify. The company makes complex components and sub-assemblies for commercial aviation; output from its Lancashire machine shop includes Airbus wing and mainframe components – 50mm cube parts, up to

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01 Inlet manifold required eight operations on a 3-axis VMC, two on Hermle C 400

02 XYZ's ProtoTRAK enables Auld Valves operators to programme jobs at the machine

03 Yamazaki Mazak celebrates a decade of success for its European Technology Centre in Worcester which has hosted more than 33,000 visitors

engine pylon brackets and landing gear fittings. Some complex items were taking up to 10 minutes to inspect using existing CMMs, causing production bottlenecks. Manual inspection methods did not solve the problem; the solution would be in-cycle measurement.

"Renishaw proposed the Equator gauge, another level up from a traditional 3-axis CMM in terms of speed," explained Weston's CMM programmer Andy Wright. The Equator system is a flexible gauge designed for speed, repeatability and ease of use. "We have 70 part-numbers that could fit on the machine, so there is high potential," said Wright. "No special skills are required – the operator simply loads the part in to the fixture, lets the cycle run and receives an easy-to-read report."

Parts inspected in this way include a titanium wing flap track component. "Over the years we have gone through several process iterations and various equipment solutions trying to measure this part quicker with the required accuracy, but inspection would regularly fail due to component complexity and tight datum tolerances," explained Wright. "However, using the Equator gauge, we have been able to achieve a process that delivers accurate gauging and repeatability. The Equator gauge measures around 25 different features on this particular part, taking just 90 seconds in total."

Another specialised technology which can profoundly affect productivity is Citizen Machinery's LFV (low frequency vibration) chipbreaking system. Available on a number of the company's machines, it can be applied to

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different parts of a cycle. It avoids a 'bird's nest' forming around the sub-spindle, which inhibits synchronous component pick-up for reverse-end machining; and entanglement of a tool leading to breakage or compromised component accuracy and surface quality.

LFV works by rapidly oscillating the tool in two axes in synchronisation with the rotation of the spindle. This is in contrast to the intermittent chipbreaking action being programmed into a cycle as a macro, which can generate heat and cause tool tips to wear prematurely.

LFV is not necessarily applied continuously to a whole programme as the technology is designed to slightly extend elements of the cycle by repeated periods of air cutting lasting microseconds. This action breaks the swarf into short chips and also improves penetration of coolant to the cutting zone, extending tool life.

If a job is price-sensitive, LFV's use can be minimised or switched off during manned operation, but the system is so flexible it can be reintroduced for lights-out running to ensure a full shift's production in the bin the next day, without fear of stringy swarf impairing turning and drilling efficiency and possibly recycling from the conveyor back into the working area (and jamming the machine).

04 Renishaw's Equator system delivers speed, repeatability and ease of use

05 Sandvik Coromant's Silent Tools Plus delivers real-time information

Inside information

When considering connected solutions for enhanced productivity, another perspective comes from Sandvik Coromant. The cutting tool specialist observes that manufacturers of large and expensive components – such as those used in the aerospace or oil and gas sectors – sometimes need to slow down internal turning processes in order to protect the workpieces.

One way of preventing errors, while speeding up machining, would be to introduce regular checks on what is taking place inside the component. Sandvik Coromant's Silent Tools Plus enables manufacturers to do this; benefits include better process security and machining efficiency and avoidance of damage to the machine tool and component.

This latest solution in fact springs from established Silent Tools technology, but the new development features a damped adapter with embedded connectivity. This makes it possible to extract accurate information from the machining process and share it in real time with the operator via easily understandable, intuitive graphical displays. Information can include vibration levels or the temperature in the damping system.

The display instantly alerts the operator to any incident outside set parameters, such as excess shaking or increased harmonics, enabling action to be taken to stop or adjust the machining process and avoid damage to the component. In addition, because the centre height setting functionality provided by Silent Tools Plus displays the level of the cutting edge, operators can quickly and easily set the height of the insert to the correct level before machining begins. This enhances machining performance and insert life.

The rise of newer manufacturing processes such as additive methods and 3D printing can distract us from the fact that machine tool technologies are still developing. The latest offerings from suppliers of 'conventional' production equipment are providing users with new ways of achieving improved and sustainable productivity. ■

How CAL takes liquid to solid in minutes

Hayden Taylor **talks tomographic reconstruction, concurrent printing and the serendipity behind successful collaboration**

Science and serendipity are not always concepts that fit well together, but when it comes to the idea behind Computed Axial Lithography (CAL), it has certainly played a role. About three years ago we had the idea to adapt the principles underlying the 3D imaging technique of computed tomography to create a rapid new 3D printing technique that could fabricate objects all at once.

The idea might initially have seemed a little crazy, but when graduate student Brett Kelly brought a group of disparate experts together from the University of California at Berkeley and Lawrence Livermore National Laboratory, we realised it could actually work.

Introducing CAL

Our team was inspired by the widely used imaging technique of computed tomography, in which X-rays are projected through solid objects from many angles and software interprets the transmitted signals to build up a 3D image of what lies inside the object. We started to experiment with how we could use related principles to create tangible 3D objects by projecting patterns of light from many angles into a volume of photosensitive material.

CAL was therefore, in a sense, conceived by turning the principles behind computed tomography on their head. It works by projecting a dynamically evolving pattern of light into a rotating volume of photosensitive material to form an object based on the cumulative dose of the illumination.

The process takes anywhere between 30 seconds and a couple of minutes to print an object. We have printed structures ranging up to between 5 and 10cm in diameter, and with features down to about 0.3mm.

Existing methods would take hours to print similar objects.

CAL uses commercially available digital video projection hardware to achieve these fast build times. Its sophistication lies in its software, which translates a digital model of the desired object into a series of images that are shone, in sequence, all the way through the material in the rotating print volume.

The rotation, coupled with the rapidly changing light pattern, allows the light dosage to be fully controlled in three dimensions. When the total amount of light energy received at a given point in the material exceeds a threshold, the liquid solidifies and the part is formed.

To produce sharp features, the thresholding response of the material needs to be strong, and this is provided by uniformly dissolved oxygen which initially inhibits solidification but is consumed as the light dose accumulates.

Re-using resin

Another positive about oxygen inhibition is the clear route it provides to regenerating unused resin. Following the printing process, any unused resin can be drained out of the volume and exposed to air to allow the oxygen content to reach its original equilibrium state once again. The thresholding behaviour is reliably recovered and the resin can be reused, reducing material wastage.

Scaling up

We are investing a lot of effort into scaling up the process to larger printing volumes. In CAL, light passes all the way through the printing volume and is absorbed at a far gentler rate than in traditional light-based printers. We anticipate that this property means that we will be able to scale up the size of printed objects by increasing the power of the illumination source, without necessarily greatly increasing the printing time. Using a simple model that extrapolates from our existing experiments, we anticipate being able to print a 0.5m diameter part with features down to 0.1-0.2mm, while processing material at several litres per minute.

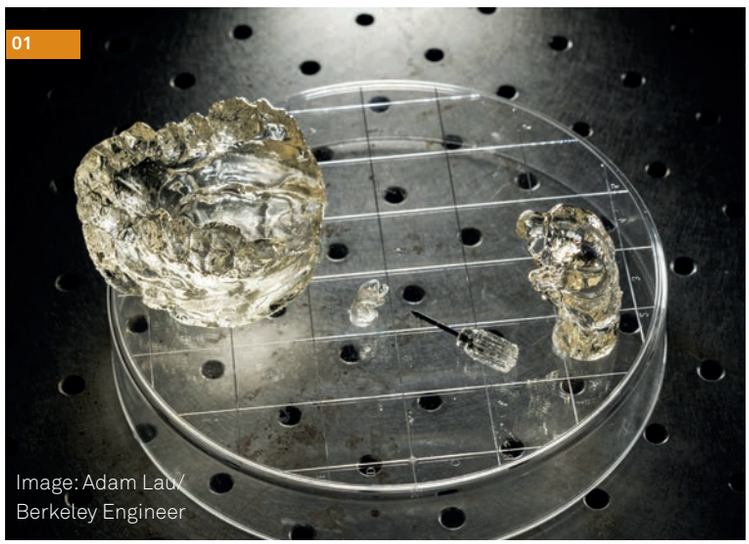


Image: Adam Lau/ Berkeley Engineer

Another important step in scaling up the printing volume may be to move to a configuration in which the rays of light fan out from the projector rather than travelling parallel to each other as at present. Making this change would enable us to print objects much larger than the projector. Another important consideration is that as common resins solidify, they undergo shrinkage which manifests itself as a change in optical properties, potentially scattering light inside the printing volume. We will need to think more about these effects as we scale up in size and complexity.

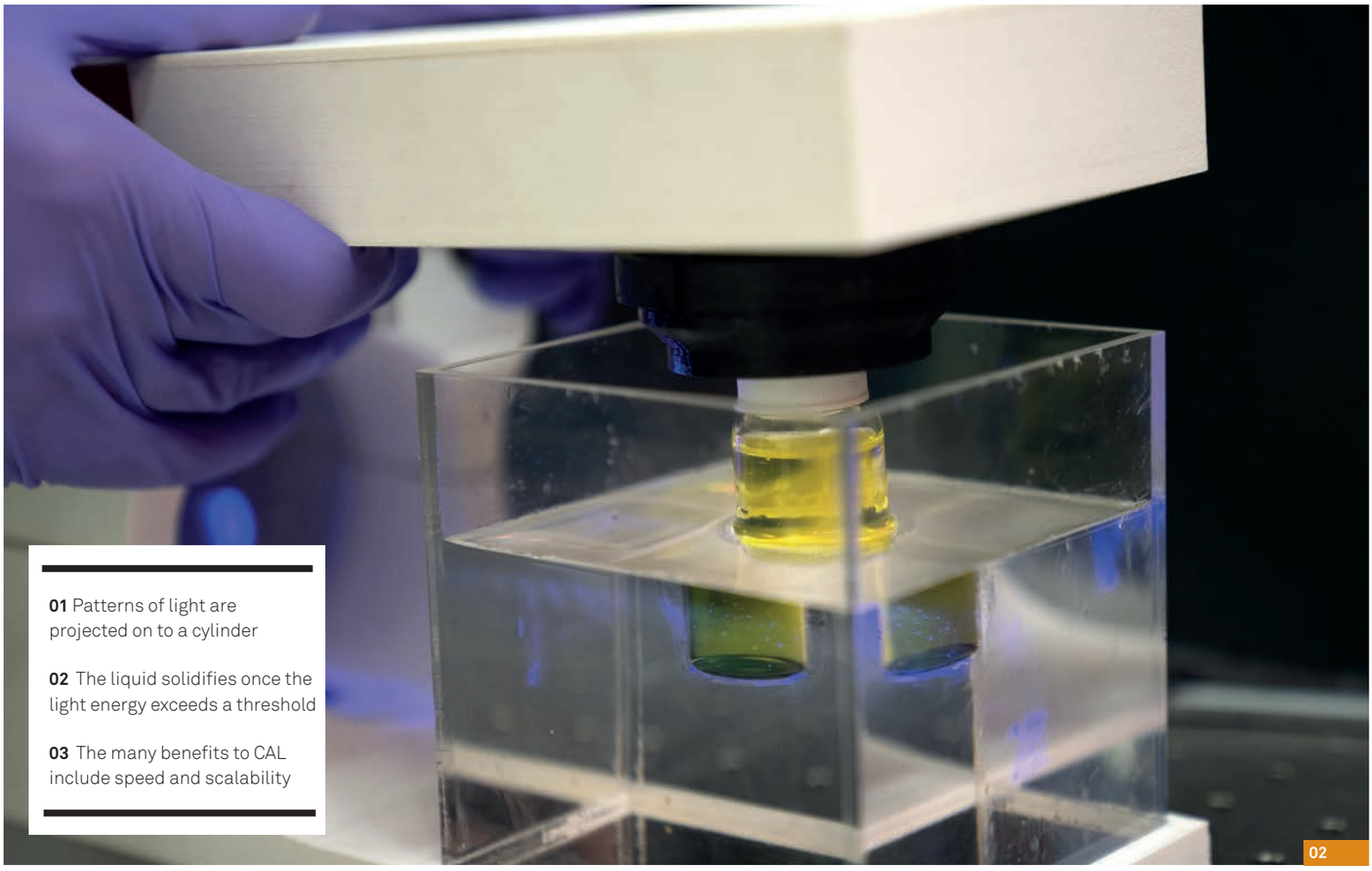
Smoothing out the rough edges

Speed and scalability are not the only advantages of CAL. The rough edges associated with the layer-by-layer printing of standard additive processes are literally smoothed out.

By essentially printing whole objects in one go, no layering is needed, which translates to no ridges and smoother builds, which are ideal for consumer products.

We've printed soft structures with exceptionally smooth surfaces into gelatin methacrylate hydrogel. By printing an object concurrently, our method also eliminates the need to design and build solid support systems or scaffolding, even for overhanging features. We can print into high-viscosity fluids which support the object being printed, translating to less post-processing time in the removal of supports.

As the object is not moving relative to the liquid during printing, it is not



01 Patterns of light are projected on to a cylinder

02 The liquid solidifies once the light energy exceeds a threshold

03 The many benefits to CAL include speed and scalability

02

limited by fluid flow, which means that we are able to use CAL to print into materials that have a higher viscosity, broadening the range of material properties that can be accessed. By avoiding fluid flow during printing, we can even print into very soft and delicate materials, like the gelatin methacrylate, which may open new applications in bioprinting of soft tissues.

Overprinting for customisation

In addition to the smooth nature of prints using CAL, the method also enables you to print an object around a pre-existing object, for example, printing a plastic handle on to a steel screwdriver. This 'overprinting' capability provides the opportunity to 'mass-customise' consumer products, such as personalised grips for tools or sporting equipment as well as user-designed ergonomic features. It also lays the groundwork for easier multi-material fabrication.

Projecting carefully crafted patterns of light on to a rotating cylinder of liquid solidifies the shape "all at once", as opposed to traditional 3D printers which must produce objects layer by layer.

The speed, material range and versatility that can be accomplished with CAL can potentially be translated into a vast range of real-world applications – from medical, dental and biomaterials to consumer products. What we have achieved so far has only been possible because of the diverse expertise of our team: in optics, photochemistry, computation and mechanical design. The team came together quite serendipitously through some chance interactions on campus, and there was a real joy in watching the team and the technology take shape.

Hayden Taylor is an assistant professor in the Department of Mechanical Engineering at the University of California, Berkeley.

Find out more about CAL and hear from Hayden at this year's Additive International Conference on 10-11 July at Nottingham Belfry. Visit www.additiveinternational.com ■

03

3D PRINTING

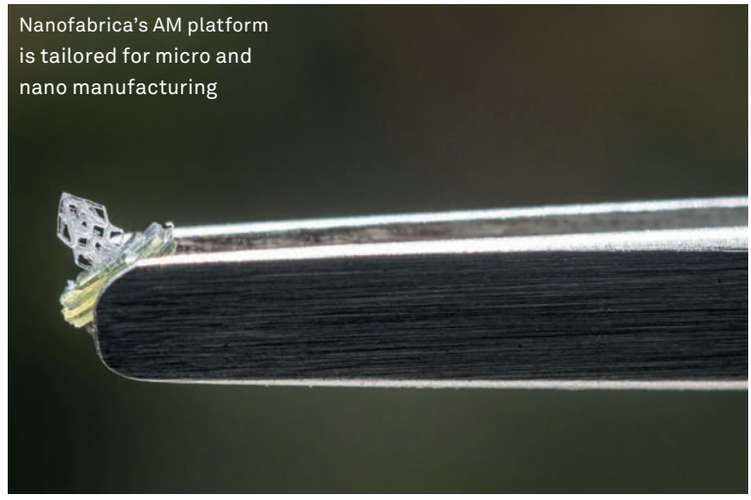
Tiny triumph for Nanofabrica

Launch of a micron-level 3D printing platform offers speeds up to 100 times faster than other micro AM products

New technology at the intersection of micro and additive manufacturing (AM), will let manufacturers take advantage of the inherent advantages of AM, while achieving micron and sub-micron levels of resolution and surface finish, over a build envelope of 5x5x10cm.

AM platform developers have so far struggled to get resolution under 50 microns and those that exist tend to be slow, expensive in terms of machine costs and cost per part, or can only print parts that are restricted in size. AM platform developers need to focus technological advances in areas that open up innovation and manufacture of products and components hitherto impossible using AM.

It is here that Nanofabrica, a Tel Aviv-based developer of precision AM technologies, has been particularly successful. The first breakthrough of



Nanofabrica's AM platform is tailored for micro and nano manufacturing

Nanofabrica's technology enables high precision at a cost required for industrial manufacturing. Secondly, Nanofabrica's process is based on a digital light processor (DLP) engine that combines with adaptive optics to achieve repeatable micron levels of resolution. This tool, in conjunction with an array of sensors, allows for a closed feedback loop. Where other AM platform developers achieve precision through great hardware, Nanofabrica uses software.

Another unique aspect of Nanofabrica's AM platform is the ability to achieve micron resolution over centimetre-sized parts, made possible through a combination of technologies. Specifically, the company has taken its use of adaptive optics and enhanced this imaging unit with technology used in the semiconductor industry.

> "The whole process is based on a digital light processor engine"

By working at the intersection of semiconductors and AM, Nanofabrica is able to build large 'macro' parts with intricate micro details. It can also do this at speed by introducing a multi-resolution strategy, meaning that the parts where fine details are required are printed relatively slowly, but in the areas where the details aren't so exacting, the part is printed at a speeds 10 to 100 times faster. This makes the entire printing speed anything from five to 100 times faster than other micro AM platforms.

In addition, for original equipment manufacturers (OEMs) requiring small parts, thousands can be printed in a single build on the Nanofabrica platform, making it a true mass manufacturing technology for micro product or component manufacturers. ■

FORMING

Driving force

Pressure vessel built for exploring space

Cranfield University's additive manufacturing specialists have fabricated a full-scale prototype of a pressure vessel, intended for use on crewed space missions for Thales Alenia Space. Scottish company Glenalmond Technologies was a partner in the project.

The pressure vessel is made out of the titanium alloy TI–6Al–4V and is 1m high, with a mass of 8.5kg. It was made using the wire arc additive manufacturing (WAAM) process, which Cranfield has developed over the past years. The process, which is derived from welding, allowed a conventionally two-part structure to be made in a single piece and required 200kg less alloy than conventional manufacturing techniques. Cranfield believes that further weight savings are possible.

The vessel was sent to Glenalmond's East Kilbride works, where it was stress-relieved, laser-scanned, machined further and inspected using an ultrasonic method. Tests confirmed it fulfils technical and quality requirements and Cranfield and Glenalmond are working on a second prototype to demonstrate the reliability and repeatability of the processes.

"We were looking for an innovative manufacturing solution for the tanks, which typically suffer from long lead time, with the conventional production route based on subtractive machining," said Eng. Massimo Chiampi, study manager for additive manufacturing projects at Thales Alenia Space. "Thanks to this project, we have demonstrated that the adoption of WAAM technology enhances the competitiveness of our product. A near-net-shape item is fabricated in a few days – compared to several months needed for the procurement of the standard wrought products – and also the amount of machining operation is consistently reduced.

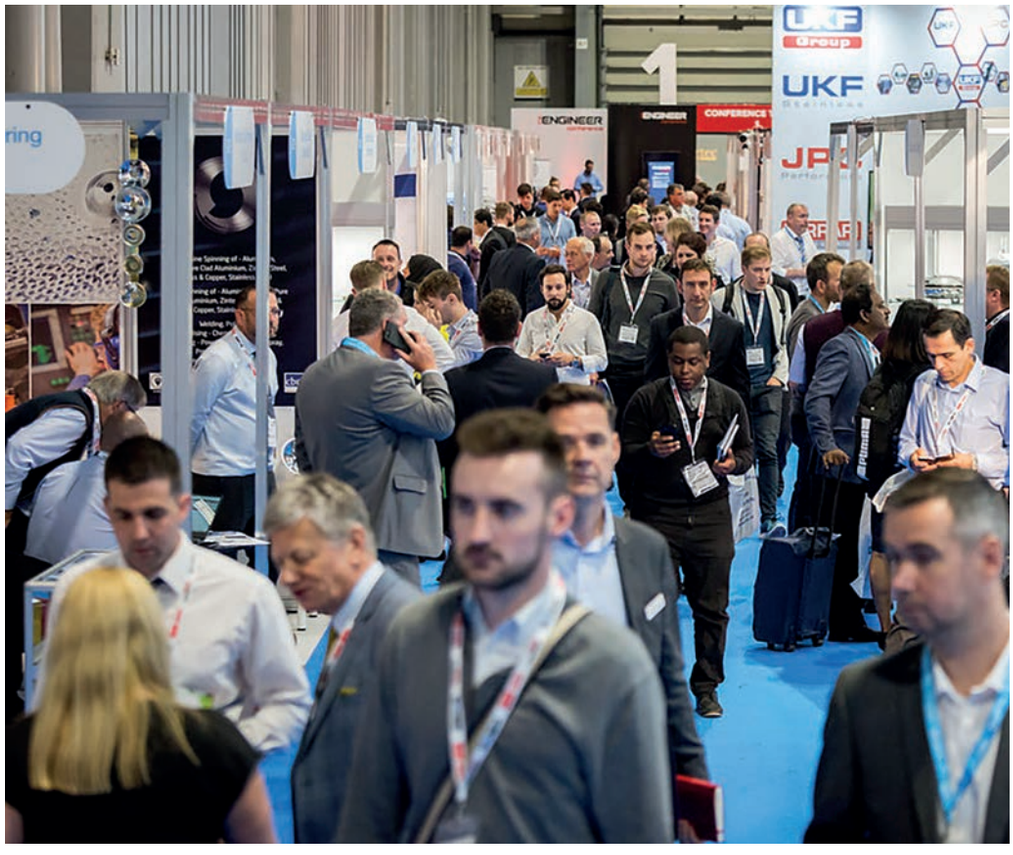
"We have achieved a 65 per cent reduction on the overall lead time and this provides a benefit also in terms of design flexibility, making it possible to answer customer needs at a late stage of the project."

Dr Jialuo Ding, principal research fellow at Cranfield University and chief scientist at WAAM3D, said: "We have been developing WAAM technology for more than 10 years and it is very satisfying to see it reach this level of commercial maturity. We are very excited about rolling out the technology through our new spinout company, WAAM3D."

Dr Filomeno Martina, senior lecturer at Cranfield University and CEO of WAAM3D, added: "This part has given us the opportunity to test WAAM3D's innovative solutions on a high-profile user case, with a very aggressive timescale. We are very proud of the level of automation achieved at Cranfield University. WAAM3D will make all these tools available to industrial communities in the next couple of months and we are looking forward to the impact on industrial large-scale additive manufacture this will have." ■

Innovation, partnership and excellence: Subcon is back

Opportunity to form new partnerships and see how areas of industry are innovating



Subcon returns on 4-6 June 2019 and is once again set to take place at the NEC, Birmingham. Now in its 43rd year, Subcon remains the UK's only dedicated event to enable subcontract manufacturing buyers to source suppliers, benchmark capabilities and form new manufacturing partnerships.

Against a backdrop of profound uncertainty and change within the engineering and manufacturing industries, Subcon 2019 will show how the industry continues to innovate and deliver maximum value, with three events in one venue.

Supporting innovation: The Launchpad and Launchpad Awards

For 2019, Subcon has unveiled a new opportunity to support engineering entrepreneurs. The Launchpad and Launchpad Awards will showcase cutting-edge innovations from across the industry with dedicated space at the event for specially selected start-ups.

The Launchpad aims to propel manufacturing and engineering-based start-ups by giving these entrepreneurs an opportunity to share their innovations with thousands of professionals with the power to guide them to success. The showcase and awards will deliver an unrivalled platform for eight engineering start-ups and a £10,000 prize package to the winner.

Enabling partnerships and driving business: The Subcon exhibition

As with every previous year, Subcon will deliver the contacts, connections and content that engineering and manufacturing businesses in the UK need to succeed. Visitors will be able to harness new innovations from over 300 world-class suppliers to help increase capacity, optimise productivity and improve flexibility, while driving down costs to stay competitive in a global market.

Subcon exhibitors span a massive range of engineering businesses. Ahead of the event this year, Subcon hit the road and spoke to exhibitors across metal fabrication, 3D printing, measurement and other sectors. As this diversity of exhibitors shows, there will be huge opportunities to forge strategic partnerships and improve existing processes.

To maximise the value of the event, Subcon is once again co-locating with *The Engineer* Expo and Advanced Manufacturing Show. *The Engineer* Expo delivers the innovation, inspiration and insight businesses need to optimise future engineering and manufacturing strategies. From an exhibition of next generation design and technology solutions from the UK's most ground-breaking suppliers, to an unrivalled conference programme featuring industry leaders responsible for some of the UK's most inspiring engineering and manufacturing projects, *The Engineer* Expo will keep visitors abreast of the biggest issues around, from Brexit and Industry 4.0 to the challenges of diversity and skills.

The Advanced Manufacturing Show will showcase live demos and the latest efficiency-boosting innovations from hundreds of world-class suppliers. This is an unparalleled opportunity to review outsourcing and procurement decisions and bring tools and technology up to speed, to reduce costs, cut lead times and increase productivity to stay competitive in a global market.

Shaping the future: *The Engineer* Conference

Following the success of the conference programme in 2018, Subcon will also feature presentations from industry pioneers such as Siemens and Rolls-Royce, as well as thought leadership from organisations including Make UK, the Manufacturing Technology Centre (MTC) and WMG (formerly the Warwick Manufacturing Group). A total of 34 sessions will be announced in the run-up to the event.

The conference programme will deliver insight on industry issues, with presentations from industry leaders responsible for some of the UK's most inspiring and ground-breaking engineering and manufacturing projects. Speakers confirmed this year include:

- Ian Warhurst, the engineering entrepreneur behind the rescue of the Bloodhound car, will talk about his plans for this iconic UK project
- Brian Holliday, managing director, **Siemens Digital Industries**, delivering a keynote address, covering the latest developments and momentum around Industry 4.0
- Mark Ireland, chief engineer, **MTC**, speaking on the MTC Sit Ski project and the role of collaboration
- Stephen Phipson, CEO, **Make UK**, covering the impact of Brexit and the changes felt throughout the manufacturing supply chain
- Riona Armesmith, chief project engineer, **Hybrid Electric Propulsion**, Rolls-Royce talking about the development of electric/hybrid aircraft and the E-Fan X project
- Lina Huertas, head of technology strategy, digital manufacturing, **MTC**, covering the technologies set to transform manufacturing
- Jeremy Pullen, **Sartorius**, on what is next for additive manufacturing
- Steve Banton, channel manager, **ABB Robotics**, on the development of cobotics and where it will make its impact felt
- Nick Hawker, CEO and co-founder, **First Light Fusion**, on the commercial application of nuclear fusion
- Martin Little, commercial director, **Rail Alliance**, on the overlooked opportunities within rail

Gordon Kirk, event director for Subcon, points out that this wide range of opportunity and the chance to see so many diverse companies is no accident: "We are even more aware than ever of the pressures on UK engineering and manufacturing businesses, so we have crammed as much value into the event as we can. From the 34 sessions of *The Engineer* Conference to the showcase of new start-ups and co-locating with Advanced Manufacturing Show and *The Engineer* Expo, Subcon 2019 will deliver huge value to visitors throughout the three days. We are incredibly excited to include so much new material and look forward to opening the doors at the NEC!" ■

GOODMAN METALWORKS

Goodman Metal Works is a Nottingham-based, full-service metal fabrication company returning to Subcon. Director Richard Goodman explains what keeps them coming back: "It is a very compact event, spread out over three days, so it is a very easy way to meet the critical people you need to meet."

LASER LINES

3D printers and additive manufacturing systems reseller Laser Lines is based in Banbury. This year at Subcon it is debuting not only new machinery but also new materials. Mark Tyrtania, sales director, explains that for Laser Lines, "Subcon is the right mix of visitors from varied industries... my top tip is to arrive early and leave late".

METPRO

Based in Smethwick, Metpro has grown to become a leading supplier to the mechanical and electrical market in the UK. Marketing manager Jacob Rudge says the value of Subcon is the quality of people that attend: "The majority of our conversations have been with key decision-makers... some of the most successful outcomes we have had throughout the years have been from just striking up these conversations."

Thinking outside the box with a game-changing innovation

The Manufacturing Technology Centre's state-of-the-art Factory in a Box initiative promises to revolutionise manufacturing. Stuart Nathan reports

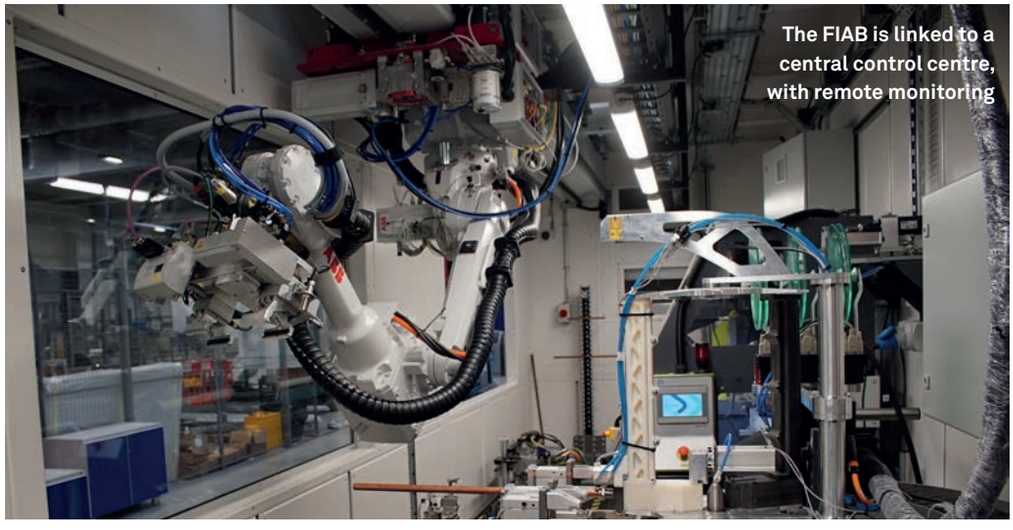
Shipping containers are the red blood cells of industry. Identical and standardised, they carry all the elements needed for manufacturing around the world. They circulate through shipping lanes, railway lines and motorways between the suppliers, manufacturers and assemblers that make up the organism that generates income for businesses and nations alike.

But now, those same containers will be able to form part of the organism itself. The Factory in a Box (FIAB) initiative, part of the Smart Manufacturing Accelerator launched in March at the Manufacturing Technology Centre (MTC) in Coventry, turns these ubiquitous steel cuboids into manufacturing units in their own right. This represents an ideal opportunity to use the latest Industry 4.0 technologies, supplying all the equipment in the box with connected sensors that allow their operation to be controlled from anywhere in the world via a digital twin.

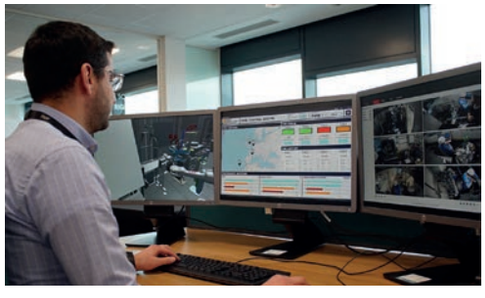
There are several reasons why a manufacturer might want to investigate FIAB. It could act as a "taster" of Industry 4.0 for wider operation, said Dr Hannah Edmonds, a technical specialist in the digital engineering group at the MTC. It can modularise manufacturing, so it can be located at remote sites. Assembling the units at a remote location allows the systems to be tested before the modules are transported to their final operational site, allowing them to be productive soon after installation. "It's of particular interest to companies who want to spread their manufacturing around the world, but keep their IP," said Edmonds.

Part of the inspiration for FIAB came from Elon Musk, who commonly refers to factories as products in and of themselves. Speaking about the manufacture of the Tesla Model 3 at the company's 2016 shareholders' meeting, Musk said: "We realised that the true problem, the true difficulty, and where the greatest potential is, is building the machine that makes the machine. In other words, it's building the factory." Tesla has the ambition of packaging the production system for its lithium ion batteries into a product that can be reproduced anywhere: in a way, a Gigafactory in a box.

The Smart Manufacturing Accelerator and FIAB initiatives are supported by a variety of collaborators and partners, including ABB, which has supplied robots; Autodesk, whose design software is integral to packaging all the equipment and machinery necessary to carry out production inside the confines of a shipping container; GE; sensor specialist Senseye; Beckhoff, whose fieldbus helps to link up the sensors to control systems; predictive simulation software and modelling specialist Lanner; and Siemens.



The FIAB is linked to a central control centre, with remote monitoring



Other partners include Wonderware and Unison, whose robot path planner software helps guide the automated systems which carry parts from one manufacturing station to another.

Unison's input has been helpful for one of the first projects to be completed by the FIAB team, a modularised system for building cryogenic pipe assemblies for Croydon-based Dearman. The assemblies are part of its transport refrigeration unit (TRU), built around a piston engine driven by expansion of liquid nitrogen or liquid air and capable of replacing diesel-powered refrigeration systems for trucking refrigeration that produces no carbon dioxide or air pollutant emissions. Using FIAB will allow Dearman to create TRUs internationally, co-locating production with overseas vehicle manufacturers and integrators.

The cryogenic assemblies are made from 15.87mm pay 65 copper pipe with 1.05mm wall thickness. Each assembly can enter up to two T-pieces with threaded end fittings. The FIAB unit contains several working stations, served by a robot which runs along a gantry installed in the container ceiling: at one end is racked storage for copper pipe pieces and next to this is a computer numerical count (CNC) pipe cutter, which cuts pipe with stock-use optimisation to minimise wastage.

The cut pipes are then carried to a brazing station where end and T-fittings are attached. The end-fittings are attached to pneumatic testing connections at this point. The assemblies then move on to a CNC bending machine with a robot mounted end effector to set the correct geometry. Pneumatic testing of the assembly follows and a machine vision station inspects the geometry. The installation is mirrored by a digital twin, which allows a real-time simulation of the process in schematic form to be viewed, while CCTV cameras remotely observe the robot and other equipment.

Toby Peters, chief executive of Dearman, said: "Getting innovative, responsive new technologies into international markets quickly relies upon a new model for manufacturing which can be established here in the UK, allowing us to export not just technology, but manufacturing know-how. At Dearman, we see this as a way to produce a game-changing technology, at the right price, that can be tailored to local demands, while establishing an international presence in fast-growing economies." ■

Dr Hannah Edmonds will be talking about FIAB on Day Two of The Engineer's annual conference (5 June, 12-12.30pm).

Has additive entered the manufacturing mainstream?

Jeremy Pullin, **head of AM and design to manufacture at Sartorius Stedim, reflects on the technology's widespread use and scope for future use**

Additive manufacturing has changed in many ways – 20 years ago, for example, the term 'additive manufacturing' was not commonly used at all. The additive layer technologies at the time were most commonly called rapid prototyping, because that's what they were mostly used for.

Over the past 20 years, the number of technologies has grown, as well as materials. The biggest growth by far has been in manufacturers and users – this is mostly due to the expiry of many key patents registered in the 80s and early 90s, thus allowing new players to enter the market.

In 1999, you could not buy a fused deposition modelling (FDM) printer for less than £10,000 and they were only manufactured by one company (Stratasys). Now you can buy FDM printers for a few hundred pounds, with start-ups popping up on an almost daily basis. The appearance of cheaper systems has led to more users and wider adoption generally, which in turn has led to the growth of associated revenue streams, such as system support, materials and sub-contract services.

Another big change generated by market expansion is the entry of third parties, such as material companies. Twenty years ago, the big ones were not interested as the marketplace was too small for them. Chemical company BASF, for example, has now released materials for all of the main polymer AM technology processes and it will continue to do so, being joined by others such as 3M. The same is true for the powdered metals markets, with entries by companies such as Sandvik and Carpenter Technology.

How far down the road have we come in relation to AM's adoption into the manufacturing process?

The growth in the sub-$5,000 desktop machines – that were incorrectly predicted by some to be in every home by now – has slowed. The fastest-growing area is in larger, more expensive equipment. At one time, AM machines for metals were very much the underground indie band at AM festivals. They are still not the headlining act, but are appearing lower down the order on the main stage. This is partly due to smaller companies being bought by larger concerns such as 3D Systems, Renishaw and GE, with much larger knowledge pools and research and development facilities being available, compared to where they were as they first stumbled out of university labs and start-ups, from where they were spawned.

Metal AM machines are now one of the additive sector's biggest areas of growth

Adoption is now at an early, yet credible stage and for several years now, there have been parts fitted in both military and civilian aircraft. These have been produced in their millions for markets such as hearing aids and dental implants and we are now seeing custom 3D-printing parts being offered in the automotive field, such as the 'MINI Yours' project by BMW, to name but one. I say adoption is early, because although these are all credible real-world use cases, we have barely begun to scratch the surface of where we are going.

Which trends are here to stay?

Predictions are a funny game, but we can consider a few trends that are almost certain to continue. One of the shifts in the AM world is towards series parts. It is too often now said that AM will only ever be a good fit for custom parts. Yes, they are, which is precisely why they are being so widely adopted in the medical world. The geometries that they are capable of producing, however, also mean that there are times where they can add functional advantages that have nothing to do with lead times, or reduced economic batch quantities.

Aerospace is a great example of this, where parts can be produced with internal lattice structures rather than solid volumes, resulting in lighter weight parts. Lattice structures also give increased surface areas, making them ideal for thermal exchange, so we are seeing heat exchangers/cooling structures being printed with extremely high efficiency rates. The cost per part may be higher when compared with technologies such as casting, moulding or machining, but the ability to reduce part counts and add value though inherent functionality can more than justify this.

We have already seen this in examples such as the fuel nozzle developed by GE for the LEAP engine. Here, GE is ramping up its production volumes of around 38,000 parts per year, with the part count being reduced from 27 per assembly to three. To be clear, additive manufacturing is not going to replace other manufacturing technologies, such as injection moulding, but its adoption will grow as a mainstream complementary technology.

AM technology is strong in areas where injection moulding is weak, such as initial investments (for tooling), lower economic batch quantities and design flexibility. Conversely, AM is weak in areas where injection moulding is strong, such as amount of available materials, cycle times and cost per part. For this reason, the two technology groups will coexist quite happily.

Another big change is the move to automation in AM, such as material and part-handling. We are already starting to see automated cells, where parts flow from printing to post processing and inspection. The automated cells of today will turn into the mass production automated lines of tomorrow.

As more companies enter the field, the number of materials available will not simply grow, but explode, which is what happened in other manufacturing industries before. Right now, there are a lot of commercial releases of reinforced and flexible materials, as well as metal alloys, but in the labs are smart materials such as colour-changing and so-called programmable polymers.

Some of the major changes are down to bigger companies entering the field. Well-established groups such as Renishaw and Ansys have already made their moves through a combination of acquisitions and incorporating their own expertise, but we are now seeing true industrial giants active in the area. I've already mentioned companies such as GE, BASF and 3M, but others, such as Autodesk, Siemens, Hewlett-Packard, DMG Mori and Ricoh, have also moved in.

The R&D capacities of these companies will accelerate the maturing and adoptions of AM in ways that have not been seen in its history. ■

Jeremy Pullin will be talking about additive manufacturing on day one of *The Engineer*'s annual conference (4 June, 1.30-2pm).

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May 1949 Right plane, wrong time

The Engineer saw the versatile Balliol put through its paces

The Boulton Paul Balliol had just about everything the RAF and Fleet Air Arm could want from an advanced trainer.

Specifications defined by the Ministry of Supply asked for an all-purpose Service training platform with high performance and good manoeuvrability. It had to be suitable for training in day or night – flying, gunnery, navigation, bombing, photography, or glider towing. Finally, the new aircraft had to be "readily adaptable for deck landing".


Boulton Paul "Balliol" Advanced Trainer

Some Operating Results at British Power Stations

Boulton Paul Aircraft Ltd delivered on the specs with the design of three Balliol variants, namely the Mk l with an Armstrong Siddeley Mamba or Rolls-Royce Dart gas turbine engine; the Mk 2, with a Rolls-Royce Merlin 12-cylinder vee engine; and the Pl08, with a Bristol Mercury engine.

By the time *The Engineer* visited the company's facilities in Wolverhampton, six prototypes had been built and a small-scale pre-production order for 17 Mk 2 aircraft had been received.

In the air, the aircraft was said to perform as well as the British fighters that took part in the Battle of Britain.

"Some twenty years ago a machine with this performance and wing loading would have been considered only suitable for an exceptionally skilled pilot, yet the Balliol can, we understand, easily be flown by pilots who have just completed their primary training," our correspondent noted.

Boulton Paul Aircraft Ltd was acutely aware that an advanced trainer was only as good as the flying time it afforded trainee pilots, so the company ensured that the Balliol would give aircraft maintenance teams easy access to all parts of the aircraft.

Of particular note was the Balliol's folding wing, which gave access to "the inside of the wings, the fuel tanks, guns and other parts".

"In the hands of pupils, aircraft are likely to become damaged through violent landings, collisions and other accidents, and to reduce the work of repair, the Balliol is made in a large number of replaceable units," said *The Engineer*.

One example of this could be found in the centre section of the wing, which on similar aircraft would have carried straight across the fuselage but was made in two separate parts so that they could be replaced independently.

"Another example is the design of the undercarriage, where the cantilever leg is unsupported by any external struts and is removable complete with all its locking mechanism and with a piece of the wing that houses it," our correspondent reported. "It is attached to the main spar by four dowels, and each leg is interchangeable from port to starboard. If it is necessary to replace one of these assemblies, the whole unit is immediately available, with all adjustments already made to the locking mechanism and other parts. Finally, interchangeability has been studied to the extent that the tailplanes, elevators, ailerons, and wing tanks are respectively interchangeable from port to starboard, and, in addition, the rudder fin is interchangeable with the tailplane. Problems of replacement stocks, storage and transportation are thereby considerably eased."

For naval use, the Balliol was fitted with easy folding outer wings (secured by a simple latch gear), a shock-absorbing undercarriage for deck landing and an arrestor hook. But for all its versatility and utility, the Balliol was an aircraft that was in the right place but very much at the wrong time.

At the time of writing, a pre-production Balliol had completed tests at Boscombe Down and was undergoing "tropical trials" at the Ministry of Supply's facilities in the Sudanese capital Khartoum. Others, our correspondent said, were set for service trials at squadrons and maintenance crews in the UK and Rhodesia (Zimbabwe).

Balliol aircraft were, however, only delivered in meaningful numbers to the Flying Training School at RAF Cottesmore where they replaced the North American Harvard. The Sea Balliol served 781 Squadron at Lee-on-Solent but by 1951 the curtain was coming down on propeller-driven advanced pilot training as the RAF transitioned to jet-powered trainers.

The weather conditions were very poor when *The Engineer* visited Boulton Paul Aircraft Ltd, but our correspondent was thrilled by what the company had achieved, reporting that despite poor visibility "the firm's chief test pilot gave a very spirited demonstration of the flying qualities of the Balliol". ■ JF

Word of the issue

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

We may think of 'drive' as a modern word, for instantly we associate this with the motor car. Yet pause to think what else this verb can be applied to. For example, we drive a golf ball, a cricket ball, when raising money, in computing, with a horse and carriage (hence the use of 'drive' as a road name), and in antiquity livestock and ploughs.

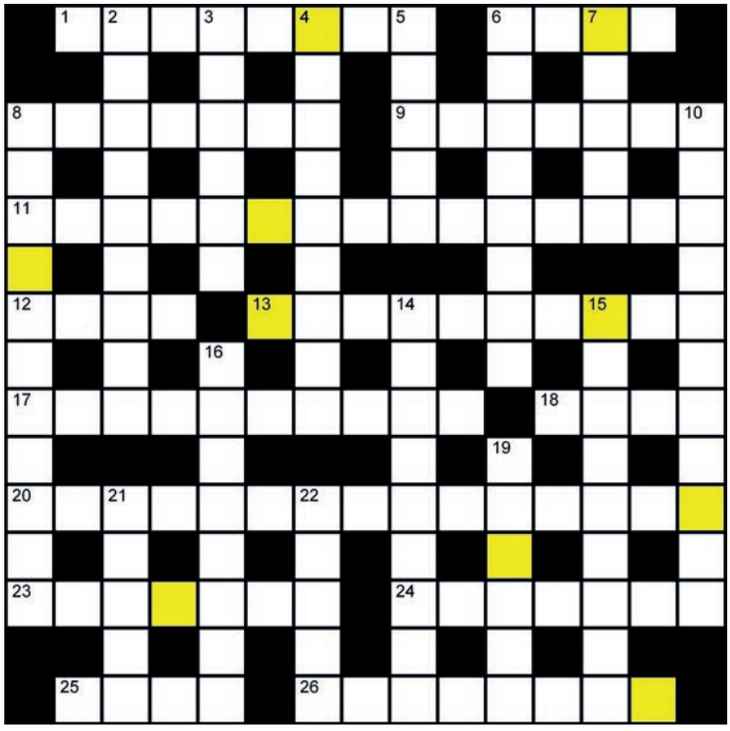
While we see the act of driving as manoeuvring our cars, what we are really doing is impelling our vehicle and using 'drive' in a transitive sense first seen in 1660.

Etymologically it is a Germanic word, used in Western Europe from the earliest Proto-Germanic 'dreibanan' and used to mean 'impel, drive away' and 'I lead'. In turn this can be traced to the Proto-Indo-European 'dhreibh', which not only meant 'drive' but 'push'.

Perhaps a clue lies in the use of 'drive' in the hunting sense, for hunting clearly predates engineering. If 'drive' first referred to steering prey to an area where they are trapped and can be picked off, then historically 'drive' and 'push' are interchangeable.

Bigpicture

The first of 10 hydrogen fuel cell heavy duty trucks has been revealed in Los Angeles by Toyota and the Kenworth Truck Company. The new truck provides an estimated driving range of over 300 miles and the fleet will perform freight duties in and around the ports of Los Angeles and Long Beach in California.



Prizecrossword

When completed rearrange the highlighted squares to spell out a mechanical device that regulates movement. The first correct answer received will win a £20 Amazon voucher. Email your answer to **jon.excell@centaurmedia.com**

Across

1 Destructive sea waves (8)
6 Having low density (4)
8 Instrument for scraping the skin after a bath (7)
9 Convert information into a cypher (7)
11 Typesetting equipment (8,7)
12 Compound formed by replacing hydrogen in an acid by a metal (4)
13 An invention that is not protected (10)
17 Event to get rid of unwanted household goods (6,4)
18 Repetition of a sound due to reflection (4)
20 System that keeps an area cool (3-12)
23 Document received for the completion of a course of study (7)
24 Something unusual – perhaps worthy of collecting (7)
25 Flow in a circular current, of liquids (4)
26 Speculate about (8)

Down

2 Mechanical device that sprays water on a fire (9)
3 Show to be false (6)
4 Pools used for powering a water wheel (9)
5 Water at boiling temperature diffused in the atmosphere (5)
6 Used again after processing (8)
7 Lines from the centre of a circle to it's edge (5)
8 Protection against splattering liquids (6,5)
10 Battleship with big guns (11)
14 Structurally different form of an element (9)
15 Property of being cohesive and sticky (9)
16 Application of soil and plant sciences to land management (8)
19 Fuse with a metal alloy (6)
21 Characterized by speed (5)
22 Draw up an outline or sketch for something (5)

We'd like to apologise for the printing error that rendered our April Crossword trickier than usual. Congratulations to all of the readers who managed to complete it regardless!
April's highlighted solution was: **SUPERHEAT.** The winner was: **Pete Hawkins.**

Awards Entry Deadline **21st June 2019**

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