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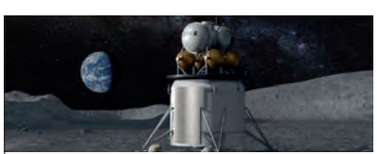

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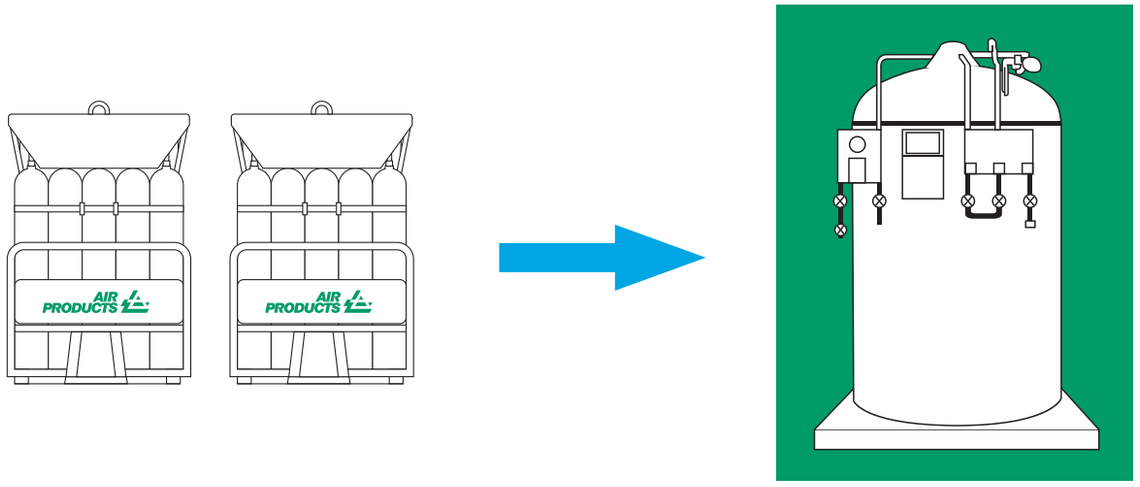

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Apollo 11 Buzz remains

In this special issue of *The Engineer* we're celebrating the 50th anniversary of what is widely regarded as one humanity's greatest achievements: the Apollo 11 lunar landing.

And what better way to do so than by actually talking to one of the people involved: Buzz Aldrin, the second man on the Moon, the subject of possibly one of the most famous photos ever taken (see front cover), and the only surviving Moonwalker from that legendary mission.

In our exclusive interview, Aldrin – who was the Apollo lunar module pilot – reflects on the backdrop to the mission, the technical challenges it faced and the personal impact of setting foot on the "magnificent desolation" of the Moon's surface.

As you might expect, the lunar landings were a major event for *The Engineer* magazine of the day, with its July 1969 cover captioning an image of the Saturn V rocket with the words: "The mightiest machine in the world".

The publication had followed the space race between the Soviets and Americans every step of the way, and in this issue we also take a look at how it reported on some of the key milestones of this epic battle of cosmic one-upmanship (p32) – from the launch of Sputnik, to Neil Armstrong's "small step".

> "UK engineers and scientists are at the forefront of space technology"

Elsewhere we take a look at some of the present-day technologies that are transforming access to space.

It is often remarked that had the awestruck observers of the Moon landings been told that the feat would still be the high point of manned exploration five decades later, they would have been somewhat disappointed. But while many of today's advances in robotic probes, rovers and satellites lack the human story of the Moonwalkers, they are no less technologically impressive. And as we report on p34, UK engineers and scientists are at the forefront of this fascinating area.

Meanwhile, for those who prefer their space technology with astronauts, efforts to return humans to the Moon are entering an exciting new phase. We take a look at some of the missions and technologies that could see the next generation of Aldrins and Armstrongs take their first steps on the surface of our nearest neighbour's barren surface.

***The Engineer* cover from July 1969**

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RAIL

Addressing the challenges of electrification

Project to investigate electrified network and integrate vehicle systems

HELEN KNIGHT REPORTS

Picture: Network Rail

The challenges of electrifying the transport network, including its impact on the National Grid, will be tackled as part of a research network being created in the UK.

The EPSRC-funded Decarbonising Transport through Electrification network plans to identify and address some of the challenges holding up the implementation of an integrated, electrified transport system across the automotive, aerospace and rail sectors.

The project, which is led by Dr Liana Cipcigan, co-director of the Electric Vehicle Centre of Excellence at Cardiff University, will investigate the developments that are needed to allow integration of the energy network with electric vehicle charging infrastructure, electric and hybrid aircraft, and an electrified rail system.

"We are trying to bring together automotive, aviation and rail, and consider the impact of all of these modes of transport on the power network, with electricity being used as a transport fuel," said Cipcigan.

The project includes Aston Martin, the National Grid, Transport for London, Transport for Wales, ABB, Ricardo, Safran Electrical & Power and the Welsh government, plus aerospace researchers from Bristol and Cranfield Universities, and rail specialists from Birmingham and Southampton universities.

The network will treat low-carbon road, rail and air transportation, alongside the associated electricity infrastructure, as one single, integrated system, Cipcigan said.

"The power network in one unique system, and all of this low-carbon infrastructure will take electricity directly from the Grid," she said. "So we will be looking at how the Grid will cope with the government's ambition to decarbonise the transport sector by 2040."

The project will investigate new technologies such as wireless charging systems and hybrid electric aircraft. It will also consider the mobility needs of individuals, as well as the economic, environmental and social demands of a future transport network, and the impact of government policies and regulations designed to reduce emissions.

The network will have three "work streams", covering vehicular technologies, charging infrastructure and energy systems.

"We have a particular interest in wireless charging technology, for example, including dynamic wireless on-road charging," she said.

"Fast charging and ultra-fast charging are potentially problematic, because they will create a big spike in demand over a relatively short stretch of time, so that will pose a new set of challenges for the Grid."

There are also likely to be a diverse range of charging technologies introduced, as one system is unlikely to meet the needs of all users, she said.

"It is also really important to have the roll-out of charging infrastructure, and public acceptance of the technology, keep pace with the development of electric vehicles," she said.

Alongside an investigation of these technologies, the researchers will also carry out large-scale data analysis and human factors studies to support the project.

The network will develop an interdisciplinary team to tackle the challenges of electrifying the transport network, and will seek funding from industry and the public and private sector, with the ultimate aim of becoming self-sustaining as a research centre.

The researchers also hope to establish an international conference.

"The project is aiming to build and expand the network, to allow us to bring together academics and other stakeholders to identify these very complex challenges, and then develop smaller projects as part of the work streams," Cipcigan said.

"With the money allocated in this project, supported by additional funding, we will issue calls for short-term projects to other participants to join our network, to reach out to those not already part of the consortium to take part in these short-term feasibility studies." ■

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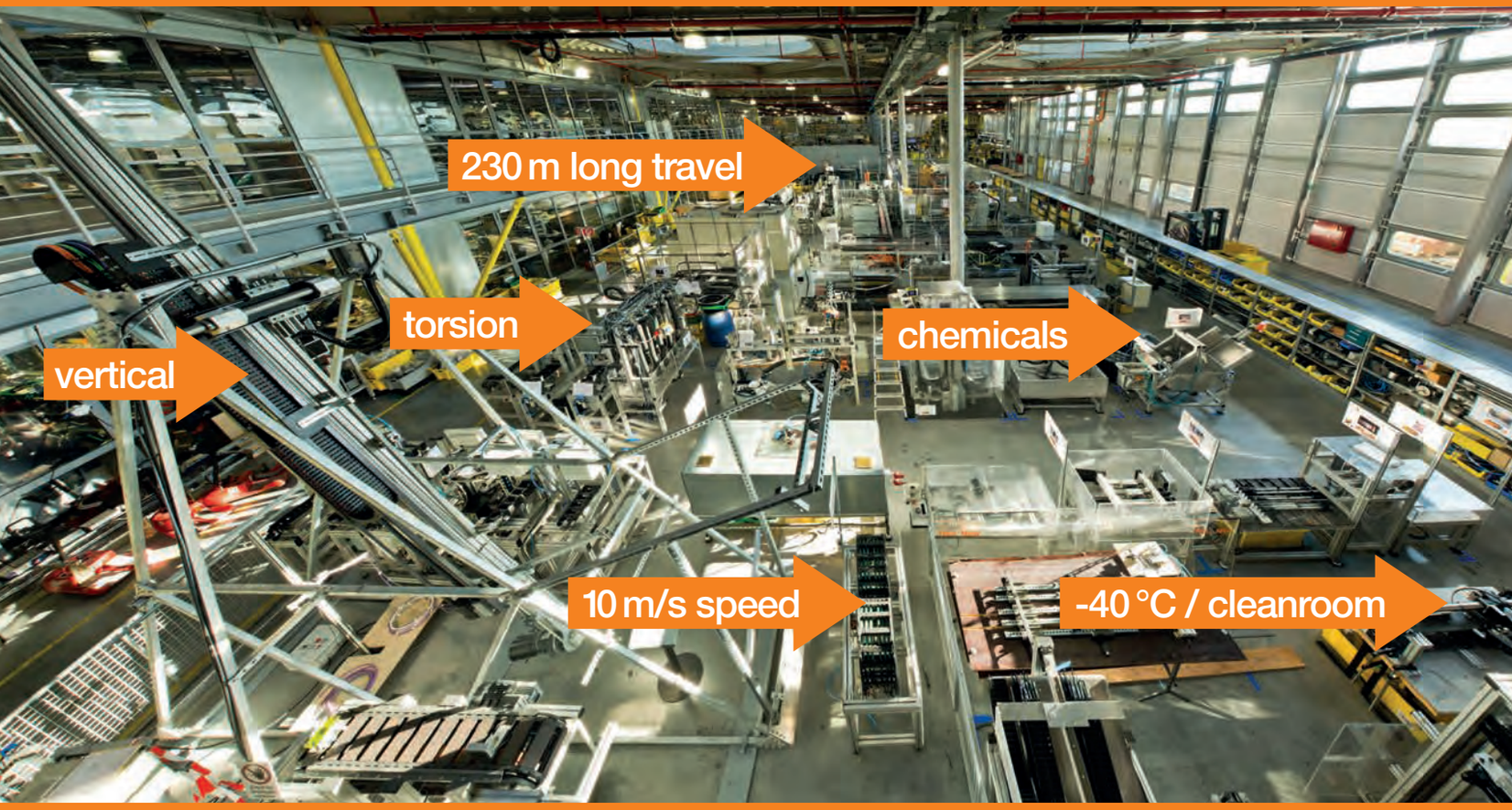

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AEROSPACE

Causes of turbine blade fault found

Context found for cracking

STUART NATHAN REPORTS

Rolls-Royce has shed light on the causes of turbine blade cracking in the Trent 1000 gas turbine engine, which powers the Boeing 787 Dreamliner.

Turbine blades were damaged by contact with polluted air, but the issue will not affect any other engines, said Dominic Horwood, Rolls-Royce civil aerospace chief customer officer.

Cracking problems in the intermediate pressure (IPT) section of the turbine have plagued the engine since early 2016, five years after its launch. Unscheduled groundings of Trent 1000-powered aircraft cost Rolls-Royce some £450m last year, and Horwood said that addressing the problem was "the single most important issue" facing the company.

One of Rolls-Royce's most important potential customers for Trent 1000, Air New Zealand, recently said it has opted for General Electric power plants for a new batch of 787-10 airliners, although its 787-9 fleets still fly with Trent engines.

According to Horwood, the cracking problem was caused by sulphurisation, a chemical process affecting the nickel alloy which comprises the IPT blades. "We are very confident that this problem will not occur in any of our other engines," Horwood said. "This is confined to component level in the Trent 1000."

The geometry around the root of the IPT blade is concentrated air sucked in by the engine's compressor system, which in some parts of the world contained higher levels of sulphur-containing pollutants than the engine had been tested with. The temperatures within the IPT and some of the specialised coatings on the blade may have exacerbated the problem, Horwood said, producing air turbulence and local temperature increases that led to fatigue-like behaviour in the metal which resulted in cracking.

Because of the way engines are tested – inside enclosed buildings called test beds where the engines are suspended from ceiling gantries and run on the ambient air from the surroundings – this problem could not be foreseen, Horwood explained.

"The issue is how to find such issues on the test bench, how to convince the engine it has been flying for years in, say, Asia," he said.

Such contextual issues are increasingly incorporated into Rolls-Royce's development and design programmes, as well as its maintenance operations.

"This is about learning," Horwood said, "and we are already applying that learning in our UltraFan future technology programme." UltraFan, the next generation of Rolls-Royce large airliner engines to follow the Trent series, is seeing the building of Rolls-Royce's largest ever test bed at Derby's civil aerospace campus. ■

Sulphurisation could be the cause of the turbine blade cracking problem

AUTOMOTIVE

Driverless car testing advance

JON EXCELL REPORTS

A new method for rapidly testing and validating autonomous vehicle technologies may help accelerate the adoption of driverless cars in the UK.

The technique was developed through the Bosch-led Move_UK initiative, a three-year government-funded project that also involves Jaguar Land Rover, telematics specialist The Floow, the Transport Research Laboratory, Direct Line and the Royal Borough of Greenwich.

During the trials, which have now completed their final phase, a fleet of five conventionally driven, but heavily instrumented, Land Rover vehicles completed 8,500 hours of driving around Greenwich gathering data on how human drivers and autonomous systems react to different driving events.

One of the key innovations was the development of an event-based triggering approach, which means that rather than recording everything, the system is only triggered by particular events such as harsh braking.

Because the data harvested in this way is more manageable than that gathered using conventional techniques, it can be fed back via Wi-Fi or 3G to a cloud-based system for instant analysis.

Project manager, Bosch engineer Simon Morley, said that the consortium's approach is up to 3,000 times less data-intensive than traditional methods, and represents a more efficient way to test automated driving technologies than more conventional approaches.

To give a sense of this, during 8,500 hours of driving, 450 highly relevant "event-triggered" video sequences were recorded. This amounted to around 150 minutes of video footage. ■

Newsinbrief

Zero emissions boost

Britain's journey towards its target of net zero emissions by 2050 has been bolstered with figures from National Grid, which suggest a greater reliance on low-carbon energy. The company's annual power generation data from the past decade shows Britain's reliance on wind, solar, nuclear, hydro power and storage overtaking fossil fuels in 2019. In May, Britain clocked up its first coal-free fortnight and generated record levels of solar power.

Institute's new member

Gerdau has become the sixth Tier 1 member of the Graphene Engineering Innovation Centre (GEIC) in Manchester. Collaboration with the Brazil-based steel company will see a portfolio of projects focusing on anti-corrosion coatings, composites for the automotive industry, membranes and energy storage devices. GEIC specialises in the rapid scale-up and development of graphene and 2D materials applications.

Flying taxis Down Under?

Melbourne is slated to become the first city outside the US where Uber will deploy its flying taxi service, Uber Air. Having previously announced Los Angeles and Dallas as its pilot cities in the US, Melbourne will now become Uber Air's gateway to the Australian and Asia-Pacific markets. According to the San Francisco-based company, test flights will start in 2020, with commercial operations kicking off in 2023.

Runway details revealed

Details of the project to build a third runway at Heathrow have been revealed, which include burying the M25 in a tunnel as it passes under the route of the new airstrip. The project – which is undergoing public consultation – will see the airport expanding in phases up to 2050, with later stages including the construction of new terminal buildings.

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MEDICAL

Tiny capsule to aid disease diagnosis

Sonopill will take ultrasound images and reduce need for painful surgery

HELEN KNIGHT REPORTS

A tiny robotic capsule that can be guided through the colon to take micro-ultrasound images of the gut is being developed by a UK-led consortium.

Diseases of the gastrointestinal tract, including some bowel cancers, account for approximately eight million deaths a year worldwide.

The Sonopill, being developed by researchers at Leeds, Glasgow, Edinburgh, Dundee and Heriot-Watt Universities, alongside Vanderbilt University in the US, could replace the need for patients to undergo a potentially painful endoscopic examination, in which a long, semi-rigid scope is passed into the bowel.

The robotic device, which has successfully completed feasibility studies, is based on a technique called intelligent magnetic manipulation, according to Pietro Valdastri, chairman in robotics and autonomous systems at the University of Leeds.

A robotic arm equipped with a series of magnets is passed over the patient. The magnets on the arm interact with a magnet inside the capsule, manoeuvring it through the colon without the need for a physical connection.

"We are trying to create a system that could replace colonoscopy with a painless alternative," Valdastri said. "Instead of pushing a stiff tube from the back, we are pulling this capsule with magnetic fields from the front."

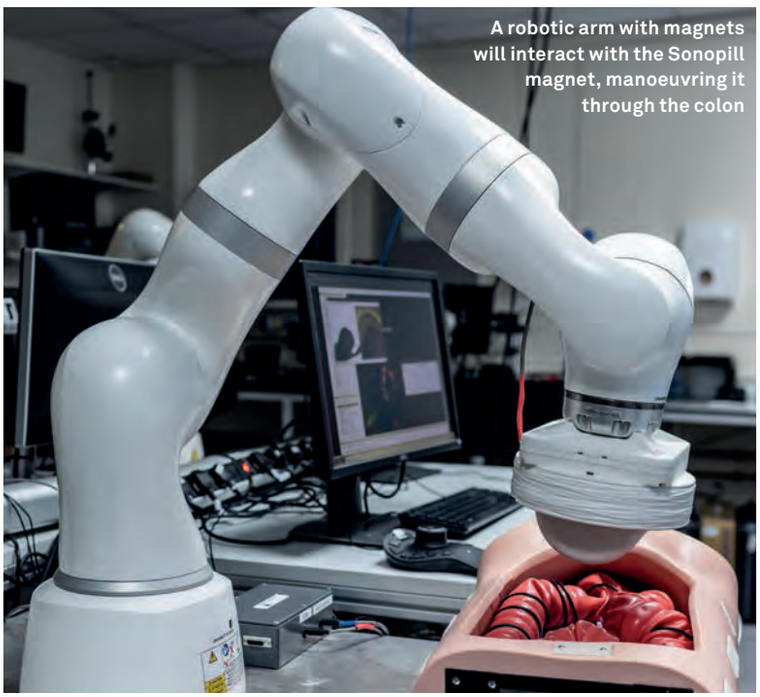
What's more, the use of micro-ultrasound means doctors will be able to tell immediately if the tissue is malignant or not, he said.

An artificial intelligence (AI) system ensures the capsule can position itself correctly against the gut wall, to allow it to take the best quality micro-ultrasound images. The AI system can also navigate the device back to the required location if it becomes dislodged.

The Sonopill consists of a small capsule, inside which is a micro-ultrasound transducer, an LED light, a camera and a magnet. A small, flexible cable is tethered to the capsule and sends ultrasound images to a computer.

The research, which also included Fujifilm VisualSonics, was funded by the EPSRC, the Royal Society, and the US National Institutes of Health.

Trials of the capsule without the micro-ultrasound transducer are due to begin in September, funded by Cancer Research UK, with the team hoping to start human trials in September 2020. ■



A robotic arm with magnets will interact with the Sonopill magnet, manoeuvring it through the colon

ENVIRONMENT

Agritech start-up shows growth by raising £5.4m in funding round

Scotland's Intelligent Growth Solutions (IGS), an agritech start-up focused on vertical farming, has raised £5.4m in its Series A funding round.

Founded in 2013, IGS uses a combination of internet-of-things-enabled lighting, automation and power management to grow fruits and vegetables indoors, with trays of produce stacked vertically to maximise space. The system is managed via a data platform that uses AI to help optimise the growing environment and maximise yields.

According to the company, its patented electrical, electronic and mechanical technologies allow it to deliver yields of 225 per cent compared to growing in greenhouses.

The system can also help reduce energy usage by up to 50 per cent and labour costs by up to 80 per cent versus other indoor growing platforms. The Series A funding round was led by US venture capital firms S2G and AgFunder, both of which are highly active investors in the agritech sector. **AW**

AUTOMOTIVE

Battery tech investment

£23m challenge to focus on electric vehicles

JON EXCELL REPORTS

Collaborative projects, which range from a new AI-based battery manufacturing approach to the development of safety systems to prevent overheating, have been awarded £23m by the government's Faraday Battery Challenge.

Established to supercharge the UK's electric vehicle (EV) expertise by driving collaboration across academia and business, the challenge will ultimately see £274m awarded to EV battery projects.

Among the latest winners are a Granta Design-led study looking into the use of AI in battery manufacture, and a project led by mining consultancy firm Wardell Armstrong which will work with experts at the Natural History Museum and mining firm Cornish Lithium to lead a new study looking to develop a UK supply of lithium.

Also successful is the Jaguar Land Rover-led Libris project which is looking to improve understanding of the causes of "thermal runway" events.

Meanwhile, an initiative that includes Oxford University spin-out Brill Power, Aston Martin, Delta Motorsport and Imperial College London will explore the development of new kinds of energy storage systems for hybrid electric vehicles that combine lithium ion batteries and supercapacitors.

"We are committed to ensuring our world-leading automotive sector can flourish," said business and energy secretary, Greg Clark. "These exciting new projects will build on the UK's reputation for excellence." ■

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ENVIRONMENT

Wireless sensing to test the waters

Cryoegg to study Greenland's ice sheets amid climate change concerns

HELEN KNIGHT REPORTS

The deep, high-pressure zones beneath Greenland's glaciers control how the arctic ice responds to the increasing temperatures caused by climate change, and contributes to the rising sea levels.

However, studying this deep, hostile environment is extremely difficult with existing technology.

Now, researchers at Cardiff University are developing a wireless sensing device, dubbed Cryoegg, to measure and characterise the liquid water beneath the ice sheets.

The EPSRC-funded project, led by Dr Liz Bagshaw, is developing and testing the sphere-shaped device, capable of collecting water measurements below 2.5km of ice and transmitting the data back to the surface via a radio frequency transmitter.

The environment beneath the glaciers is currently investigated using cabled sensors implanted into narrow boreholes. However, fast-flowing ice can stretch and eventually break these cables, meaning valuable data is lost, Bagshaw said.

In designing the Cryoegg, the team had to develop a device robust enough to collect measurements of water beneath the ice and be free to move around within the sub-surface meltwater.

"The Cryoegg is a sphere, about grapefruit size, and made of a very strong plastic," Bagshaw said. "It has a waterproof seal, and enclosed within the sphere is a radio transmitter, a microprocessor and a number of sensors."

The sensor device must also be able to operate at low temperatures and high pressures, with no external power supply for up to 12 months at a time, she said.

"We have done some trials in Greenland over the past couple of years, trying to understand the right radio frequency to use, and how to optimise the battery power underneath the ice, because we want it to operate for a long time, and we're working at very low temperatures which isn't great for battery performance."

In a 2017 trial, the team tested the Cryoegg at a site 500m below the ice. This summer, the team plan to test the Cryoegg in a 2km-deep borehole at the East Greenland Ice-Core Project (EastGrip) site, as well as a 1.2km borehole at Store Glacier, West Greenland.

"Then if all goes well, hopefully we'll be back to EastGrip next year to release an egg at 2.5km," added Bagshaw. ■

The Cryoegg will measure the liquid water beneath Greenland's ice sheets to gather important data

MEDICAL

Artificial nose to identify malignant brain tissue during electrosurgery

Finnish researchers have developed an artificial nose that analyses the smoke from electrosurgery in real time, detecting different types of cancerous brain tissue.

Electrosurgery devices let surgeons operate with limited blood loss, and vaporising biological tissue produces smoke that contains signatures of the underlying cells.

Using differential mobility spectrometry, the team from Tampere University analysed smoke from cancerous tissue almost instantaneously, detecting the digital fingerprint of various forms of brain tumour.

"Our new method offers a promising way to identify malignant tissue in real time and the ability to study several samples from different points of the tumour," said Tampere University researcher Ilkka Haapala."

The study used its artificial nose to analyse 694 tissue samples from 28 brain tumours and control specimens. The system's classification accuracy was 83 per cent when all the samples were analysed. **AW**

AEROSPACE

Drones to join air force

Device to lower aircraft maintenance times

ANDREW WADE REPORTS

The Spanish Air Force will become the first customer for a new advanced aircraft maintenance system from Airbus that uses drones and augmented reality (AR).

Drones equipped with sensors will scan an aircraft autonomously, securely transmitting data to tablets and AR devices on the ground. Airbus claims the platform could reduce maintenance times on military aircraft from around one week to just two hours.

The system has been trialled using a variety of different drones and sensor suites, according to Oscar Munoz, industrial innovation and digitalisation manager at Airbus.

"We can incorporate different sensors," Munoz said. "The most common is 4K HD cameras, but also other sensors like fuels and leak detection, thermographics, the different sensors used for non-destructive inspection by hand, these can all be installed in the drones."

The platform will be trialled on the Spanish Air Force's A400M military transport aircraft, with options to extend the technology to other platforms.

Airbus said the tests with the A400M will help it consolidate the algorithms for safe autonomous flight of the drone, while the terabytes of images and data will be used to create a deep learning library that will feed an AI-based defects detection system.

The system incorporates a digital workflow component that gives maintenance staff better visibility over operations and enables better governance. Munoz said military customers are the current focus for Airbus, although the platform will be rolled out for civilian airliners. ■

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MATERIALS

Silicon anodes to extend battery life

Coating technology could lead to faster-charging lithium ion batteries

HELEN KNIGHT REPORTS

Cheaper and faster-charging lithium ion batteries with increased lifespan could be made possible by a UK project to develop better coating technology for silicon anodes.

The project, known as Spice (Silicon Product Improvement through Coating Enhancement), is being led by Oxfordshire-based battery materials specialist Nexeon, and has been awarded £2m in funding through the Government's ISCF Faraday Battery Challenge by Innovate UK.

Silicon anodes are increasingly seen as the next stage in lithium ion battery development, as their ability to absorb more charge should lead to smaller batteries with a longer life.

However, to get the most from the use of silicon, battery makers typically have to use additional electrolyte additives, which increase the overall cost, according to Bill Macklin, chief engineer at Nexeon.

Adding a surface coating to the silicon reduces the need for higher-cost electrolyte additives, he said.

A coating can also slow down the degradation of the anode. "That means that you will get an increased cycle life, or more cycles before the capacity of the battery drops."

A carbon coating can also improve the anode's electronic conductivity, enhancing the ability to charge and discharge the battery, he said.

To develop the enhanced carbon coatings, the project team, which also includes Phoenix Scientific Industries (PSI), AGM Batteries, and researchers at the University of Oxford's Department of Materials, will use a vapour deposition process, he added.

"The [silicon] powder is placed in a gas stream containing a carbon precursor, for example, ethylene, at a certain temperature, and that breaks down the ethylene, resulting in carbon deposition," he said.

Nexeon has established a laboratory-scale coating process, which is being designed by PSI.

"But as you go up in scale, the challenge is to ensure you have uniform deposition on a bulk powder," said Macklin.

To this end, researchers at the University of Oxford will investigate what is happening at a molecular level during the process, to assess the uniformity, quality, and performance of the coating.

AGM Batteries, the UK's only cell manufacturer, will validate the performance of prototype cells incorporating Nexeon's coated silicon anode powder, as well as opening up potential routes to commercialise the technology. ■

Researchers will assess the uniformity, quality and performance of the coating

TRANSPORT

Electric container transporter Vera undertakes first assignment

Volvo's electric, autonomous container transporter, Vera, has taken on its first task at Gothenburg port.

With no cab, Vera resembles a four-wheeled sled designed to tow trailers and containers around ports and warehouses. Last month saw the powerful EV take on its first assignment, ferrying goods between the logistical centre of haulier DFDS and the APM Terminals port facility in Gothenburg.

"Now we have the opportunity to implement Vera in an ideal setting and further develop her potential for other similar operations," said Mikael Karlsson, vice president, Autonomous Solutions, at Volvo Trucks.

According to Volvo, the goal is to implement a connected system of several Vera vehicles monitored by a control tower, responding to logistical demands with greater efficiency, flexibility and sustainability.

The collaboration with DFDS is a first step towards implementing Vera in a real transport task on pre-defined public roads in an industrial area. Vera's speed will be limited to 40km/h during the pilot project. **AW**

MATERIALS

Bid to improve catalysis

Melting nanoparticles key to enhancements

HELEN KNIGHT REPORTS

Improvements to catalysis and additive manufacturing techniques could be possible following research into the way nanoparticles melt.

Although melting behaviour is known to change at the nanoscale, the way nanoparticles melt has remained an open question.

Now, in *Nature Communications*, researchers at Swansea University describe an experiment in which they imaged gold nanoparticles as they were heated.

The researchers imaged the nanoparticles using an aberration-corrected scanning transmission electron microscope, according to Prof Richard Palmer, who led the research.

They then carried out large-scale quantum mechanical calculations to simulate their results.

"We established that the nanoparticle melts from the outside in, so you have a liquid skin, which is floating around a solid core," said Palmer. "The melting point of the nanoparticles depends very strongly upon their size."

In catalysis, chemical reactions typically take place at elevated temperatures on small particles, which have a much lower melting point than their bulk metals.

"If you have a catalyst consisting of small particles, it may be that the molecules coming in to react are encountering a liquid surface, rather than the solid surface that you would have supposed," he said.

"So you may be able to tune the chemical activity by controlling the nature of the surface of these particles, by controlling the temperature at which the reaction takes place."

The research could also improve an additive manufacturing process called sintering, in which small particles are merged together to create a desired material.

The sintering process begins at a temperature at which the surface of the particles start to melt, said Palmer. ■

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SOLIDWORKS

MEDICAL

Valve treatment at heart of the matter

Diseased parts could be replaced with 3D-printed prosthetic devices

HELEN KNIGHT REPORTS

Degenerative heart valve disease is a growing problem among the ageing populations of Europe and the US, while in the developing world, valve failures caused by bacterial infections affect tens of millions of people.

As part of a research collaboration spanning over a decade, biomedical engineer Prof Neil Bressloff and interventional cardiologist Prof Nick Curzen, both based at the University of Southampton, have been investigating ways to use engineering to improve heart treatments.

In their latest research, the pair are looking into ways to improve heart valve replacement, particularly in TAVI (transcatheter aortic valve implantation), a procedure in which a metal cage, or stent, is passed over a catheter and into place within the opening of the aortic valve, Bressloff explained.

"When this replacement valve opens up, it pushes the [damaged] heart valve aside, and the prosthesis starts functioning as the native valve would have done," he said.

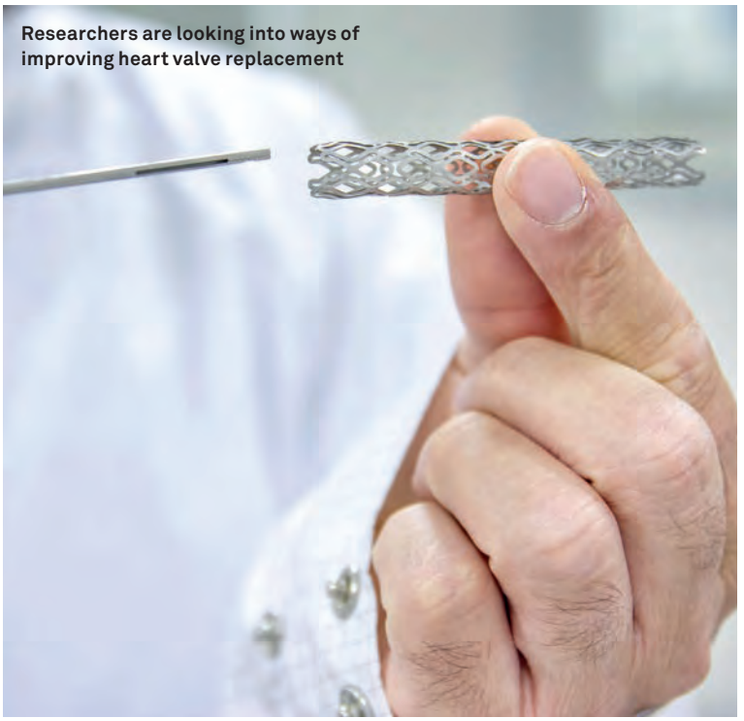
The researchers have previously carried out a successful pilot study to investigate the use of additive manufacturing to print these thin strut valve structures.

Now, in an EPSRC-funded project, they are hoping to optimise the direct metal laser sintering procedure and assess its effectiveness in producing replacement heart valve frames. The researchers will be working with Italian firm Sisma, which specialises in additive manufacturing of jewellery and dental implants.

Existing replacement heart valves are typically laser-cut from tubes, in the same way that stents are manufactured, which limits their design. By using additive manufacturing, the researchers hope to explore different design concepts, Bressloff said.

For example, the researchers will be looking into the design of valves for use in what is known as redo TAVI, in which the damaged TAVI valve is itself replaced with a new prosthetic valve.

"TAVI as a procedure was originally trialled on high-risk, frail patients who couldn't undergo open heart surgery, but because of its success, the method is being extended to low-risk and younger patients, leading to the need for long-term durability of replacement heart valves, as well as procedures such as redo TAVI," said Bressloff. ■



Researchers are looking into ways of improving heart valve replacement

MATERIALS

Wearable rehab devices will help disabled people gain more mobility

A new project based at the University of Bristol will develop soft, wearable rehab devices to help elderly and disabled people gain more mobility.

The research programme, known as Freehab, will see a range of soft materials and modern manufacturing methods used to create different products. Some of these devices will be used to aid physiotherapists in their assessments of patients' movements, while others will be used by the patients, helping them to stand up, for example. In those cases, the wearables will act like artificial muscles.

"There are over 10.8 million disabled people living in the UK today," said project lead, Prof Jonathan Rossiter. "Nearly 6.5 million have mobility impairments. These numbers are growing as the median population age increases and age-related mobility issues due to conditions such as arthritis and stroke become more prevalent."

According to Rossiter, a lack of proper tools is hindering progress for the millions affected. **AW**

AUTOMOTIVE

Supercar to be lightest ever

The T.50 will go on sale for more than £2m

HELEN KNIGHT REPORTS

The lightest supercar ever built is to be manufactured in the UK in a limited run (100 cars) that will see each car on sale for more than £2m.

The T.50 supercar will be built by Gordon Murray Group, the new manufacturing company established by Prof Gordon Murray, the designer of the McLaren F1.

The three-seater will be equipped with a new V12 3.9l, naturally aspirated engine, developed by Cosworth Powertrain, which will be capable of 12,100rpm and 650hp.

Built with a carbon fibre chassis, the T.50 will weigh 980kg, around a third lighter than the average supercar. This will give it a power-to-weight ratio of 663hp/tonne, greater than that of any other naturally aspirated sports car designed for the road.

T.50 will also make use of intelligent underbody airflow management, alongside a 400mm fan at the rear of the vehicle. The fan helps control the flow of air under the car.

"Our experienced team is applying the same uncompromising approach to design and engineering that shaped every facet of F1, and they are able to deliver substantial improvements over that car in every meaningful way," said Murray, chairman of Gordon Murray Group.

By housing the advanced aerodynamics beneath the car, it also allows the designers to keep the upper surfaces free of features such as wings, outlets, vents and bulges.

The company has established a partnership with an as-yet-unnamed Formula One team, allowing it to use the team's rolling-road wind tunnel to develop the T.50's aerodynamics.

The cars will be ready for delivery in early 2022. ■

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Return to the Moon may help earthlings

There's no need to rush, but going back to our celestial neighbour would achieve several worthwhile aims

Should humans return to the Moon? The arguments against are reasonably strong. The Moon has already been visited and nothing found there detained the visitors. Interesting lunar science could be done by people on the Moon, but much the same science could also be done by robots – and the world is full of interesting science that doesn't get done, because the world is almost infinitely interesting. Its wonders leave science spoilt for choice; as long as the science that gets chosen is good stuff, there's little point in worrying about the equally good stuff that doesn't.

Some claim that a return to the Moon will bring real, and possibly large, economic benefits. You should take that with a pinch of salt (one of many necessities with which the Moon is woefully under-stocked).

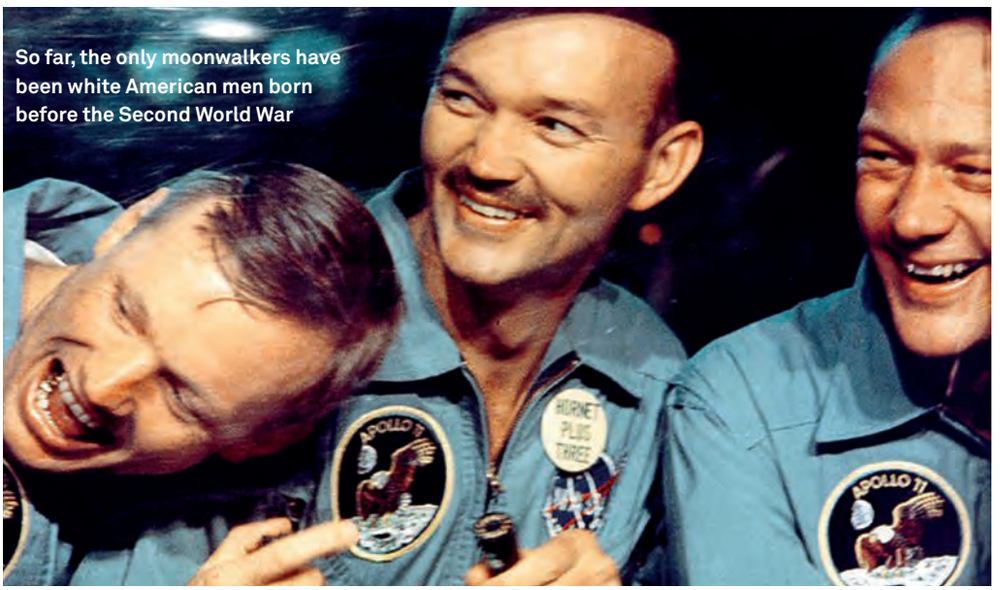
There may be some valuable platinum-group metals there – but unless they can be exploited on a large enough scale to change the way the economy uses such things, driving up demand even faster than costs drop, they don't look like a good prospect. Helium-3, which makes up a few parts per billion of the lunar regolith, has its boosters; but it is a fuel for a sort of fusion reactor no one has ever built, and which it is quite possible no one ever will build.

Far-fetched ideas

The frozen volatiles – water, ammonia, carbon dioxide and the like – that seem likely to lurk in the permanently shadowed craters near the poles might be usefully exploited by people building a moonbase. But the idea that they could be profitably exported to other parts of space for use as propellants, or in life-support systems, is far-fetched. Yes, it is cheaper in energy terms to send things to other orbits from the surface of the little Moon than from that of the big Earth. But there will probably only be a market for such things in orbit if getting from Earth to orbit is pretty easy – so why not ship them up from the Earth, where you don't have to mess around close to absolute zero in hazardous terrain to extract them?

And the sort of people trying to build an orbital economy will probably be the sort who wouldn't like the idea of being dependent on the goodwill of the Lunar Union of Mineworkers.

But this doesn't mean that there is no reason to return to the Moon. For the US, it is a matter of face. Going to the Moon in the 1960s was a big deal – it established the idea that no other country could compete with the US when it came to the very costly development of utterly unprecedented, even transcendent, technologies.



So far, the only moonwalkers have been white American men born before the Second World War

Going to the Moon in the 2020s would not have anything like the same effect. But if there is a chance that the Chinese might go in the 2030s, then the propaganda case for Americans having recently been there when they land – or actually greeting them – is quite strong. If it didn't, it would look like America had ceded something. It may well be that, in terms of national prestige, the hidden cost of having once gone to the Moon is the need to keep on being able to go.

Is there a chance that the Chinese may send people there in the 2030s? Sure. It's not a done deal, but if you want to send people into space, the Moon is the only feasible near-term destination other than a space station of your own devising.

It would not be the symbol it was when America did it in the 1960s. But it would still be something. And it would be way cheaper. Not truly cheap. But cheap enough for a big country to do it without the undue efforts that made Apollo possible. Cheap enough for a multi-billionaire or two to have a crack at it, too.

You might object that reasons based on national pride, or plutocratic ego, are not good reasons. But they seem good enough to make something happen. And when it does, there will be other advantages. The first time humans went to the Moon, it changed the way they looked at the Earth. The same may be true of their return.

And it would certainly change the type of humans who looked back. Women; non-Americans; non-whites; non-engineers, non-officers, non-test-pilots; artists; lottery winners. What they would see when they looked out over the never-living-not-even-dead Moon at the bright life in the sky? How they would think about it. How they would talk about it among themselves, would genuinely add to the sum of shared human experience.

That there should be a fundamental human experience that has only been undergone by a clique of white American men all born before the Second World War is something worth changing. ■

Oliver Morton is briefings editor at *The Economist* and author of two books: *The Moon, a History for the Future*, recently published by Profile Books, and *The Planet Remade: How Geoengineering Could Save the World*, which was shortlisted for the 2015 Samuel Johnson Prize and the 2016 Royal Society Science Book Prize

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Emission mission

Last month's cover story on technology for removing CO_2 from the atmosphere generated a lively debate

This is very encouraging technology. How can we speed up its implementation, to help avoid runaway climate change in the next 12 years?
John Kent

It is incorrect to assert that HVAC equipment provides 'free' air movement that you could piggyback a CCS filter on to. The fan is designed to provide a given air flow for a given pressure drop and if you double the latter, the motor power consumption also doubles – if the motor can draw the extra current without burning out. More likely scenario is that because of the higher ^P, air flow drops, reducing the performance of the HVAC; requiring the owner to increase the number of units, more energy consumption – and CO_2 emissions.
Trevor

Planting mechanical trees? Are we in la-la land? – why don't we just incentivise the planting of real trees which have been around a good deal longer?
John Armstrong

Such a lovely article. When I first read the title, a plethora of questions rose in my mind regarding the renewable/non-renewable source for the DAC and so on. This article answered all my questions. Great effort! I do appreciate it.
The idea with the HVAC systems is also quite creative. I doubt one thing. We produce around four gigatons of CO_2 every year. Let's take an example of the Klaus plant producing a ton of CO_2 every day. This amounts to around 10 million such trees to eradicate all the CO_2 produced each year. I am curious about the amount of energy and natural resources burnt to manufacture those 10 million trees. I guess, any activity on Earth requires some sort of expenditure of natural resource. Hence, we can never completely eradicate the loss of the resources. What we can do is give is more time to survive.
Tushar Girotra

Direct air capture is the most land-efficient means of capturing CO_2 from air, at upwards of a thousand times better than trees.

The Lackner tree has a two-stage capture process to produce concentrated (pipeline ready) CO_2, but single stage processes such as the global thermostat machine in Alabama (which removes 4,000 tonnes of CO_2 a year) can be coupled with solar power to make a highly efficient extraction system.

The CO_2 must then be stored or buried and there are several schemes for this involving above or below ground mineralisation to dispose of the liquified gas.

Enhanced oil recovery is clearly not a sensible use for DAC from the climatic mitigation point of view, but it attracts a subsidy in the US which is why (perversely) some DAC companies are looking at it so their tech can be scaled up.

Selling carbon offsets created by DAC looks like being an enormous new market and at least one of the existing DAC companies is on a path for CO_2 capture at $50/ton at scale.
Leon dimarco

Great article – it reminds me of a similar article I read from this magazine about 10 years ago that talked instead about storing the CO_2 that is captured and locking it away underground.

This article suggested that there was a better way of recycling captured CO_2 (other than for fizzy drinks or locking it underground in abandoned salt mines).

I believe a retired chemical engineer used wind and solar to capture CO_2 from air (like the recent article, although it sounded like his methods were less efficient than what was proposed here) and then, through proven industrial chemical processes, reconstituted the CO_2 into methanol and then larger carbon chain molecules that could then be used to power an internal combustion engine – like the helicopter he liked to file as a hobby. This closed the carbon recycling loop.
David Spiess

Using technology to fix the problems caused by our use of technology simply keeps the same wheel turning. What we need is not new technology, but a new relationship with technology. Without this we are headed over the same cliff, just a little later, travelling a little faster.
Steve Unwin

Thesecretengineer

Engineering outreach must target the late bloomers, not just school students, writes our anonymous blogger

While inspiring children to consider a career in engineering is critical, it's only one part of the skills puzzle. It's important not to close the door on those who discover their inner engineer later on in life.

A while ago I watched rather a good programme on the Devil's Lantern about schools through the ages. It was one of these "plonking a group from today within a historic environment and seeing how they get on" type of things and in this case the final programme dealt with the future. It included the use of cutting-edge technology to teach, as well as looking at the way the educational system may be structured in the future.

As a part of this, a group of students and teachers visited Silverstone UTC; putting it forward as an example of how in the future those emerging into the workplace may acquire more specialised skills before leaving school.

My initial reaction was that I was glad to see my own profession, one that we regularly think of as under-appreciated and neglected by the public as a whole, not only represented but put forward as the way ahead. However, I could not help but be concerned when I then considered how the establishment of such specialist colleges for school children as a national network, as suggested by the programme, would have affected my own career.

It is my duty to confess to you, dear reader, that I did not shine academically at school. It wasn't that I went off the rails or spent too much time chasing girls, rather that school and I simply did not click. I wonder then, if we'd had specialist engineering academies that fed into higher

education, how I would have fared? I wonder also just how many students, at an age where such a boost to their skills would matter, know what it is that they want to do with their lives – let alone what their true, realistic capability is?

I was looked on as being a little strange as a kid in that I always wanted to be a design engineer; well, either that or an astronaut. Most of my peers were hell-bent on pop stardom or being paid lots of money for kicking a ball about. As far as I'm aware none of them achieved those goals and most have followed careers they never even considered back in the days when we shared a classroom.

My own route into engineering was a tad unconventional but still essentially followed the established route of a smattering of qualifications from school followed by taking a more focused course within secondary education.

No high-flying degree course, but still a good way to follow my dream. If we'd had the mooted academy system I wonder if I'd even have had a look in? For me it was the different culture of college that unlocked the door to a certain amount of educational success and the first steps along the path towards a fruitful career.

Even back then, by the time I knew what I wanted to do and had shown a certain amount of natural aptitude (still a few summers shy of my 20s), I was too old for an apprenticeship.

My fear then is that an earlier specialisation within the education system, although benefiting some, would close the door to others. If this did become the way of the future, would those not lucky enough to have the self-awareness or innate ability to successfully apply for a place at the academies have missed their chance?

The education policies for the future are being formed even as you read this and, as a profession, we should decide what we need from them and try to influence the strategies put forward to our advantage. I believe that engineers are fundamentally born and not made, it being as much of a calling as nursing or teaching.

Some release their inner engineer late in life and I wonder if, in the ever more fluid marketplace we occupy, we should be looking to push for more emphasis on retraining in later years or even towards mature apprenticeships?

If we are to change anything, surely better to focus on those who arrive at our door late but backed by a lifetime of experience. Keeping options open for the young and creating opportunities for the older convert has to be a better way forward. ■

Inyouropinion

A third runway for Heathrow

Heathrow has reached its capacity and must not attempt to expand further. More use must be made of regional airports, and exactly the same is true for Gatwick.

Another Steve

Do all three of the runways need to be of equal length? Different aircraft have different take-off distances.

Make the third runway shorter and use it for the 33 per cent of aircraft that don't need the full length.

Ian Downie

It is lunacy to expand Heathrow. Apart from all the other reasons mentioned above we've just been told that we aim to be carbon-neutral by 2050. Expanding the pollution and CO_2 generator that is Heathrow is indeed like shooting yourself in the foot just before running a marathon.

John Armstrong

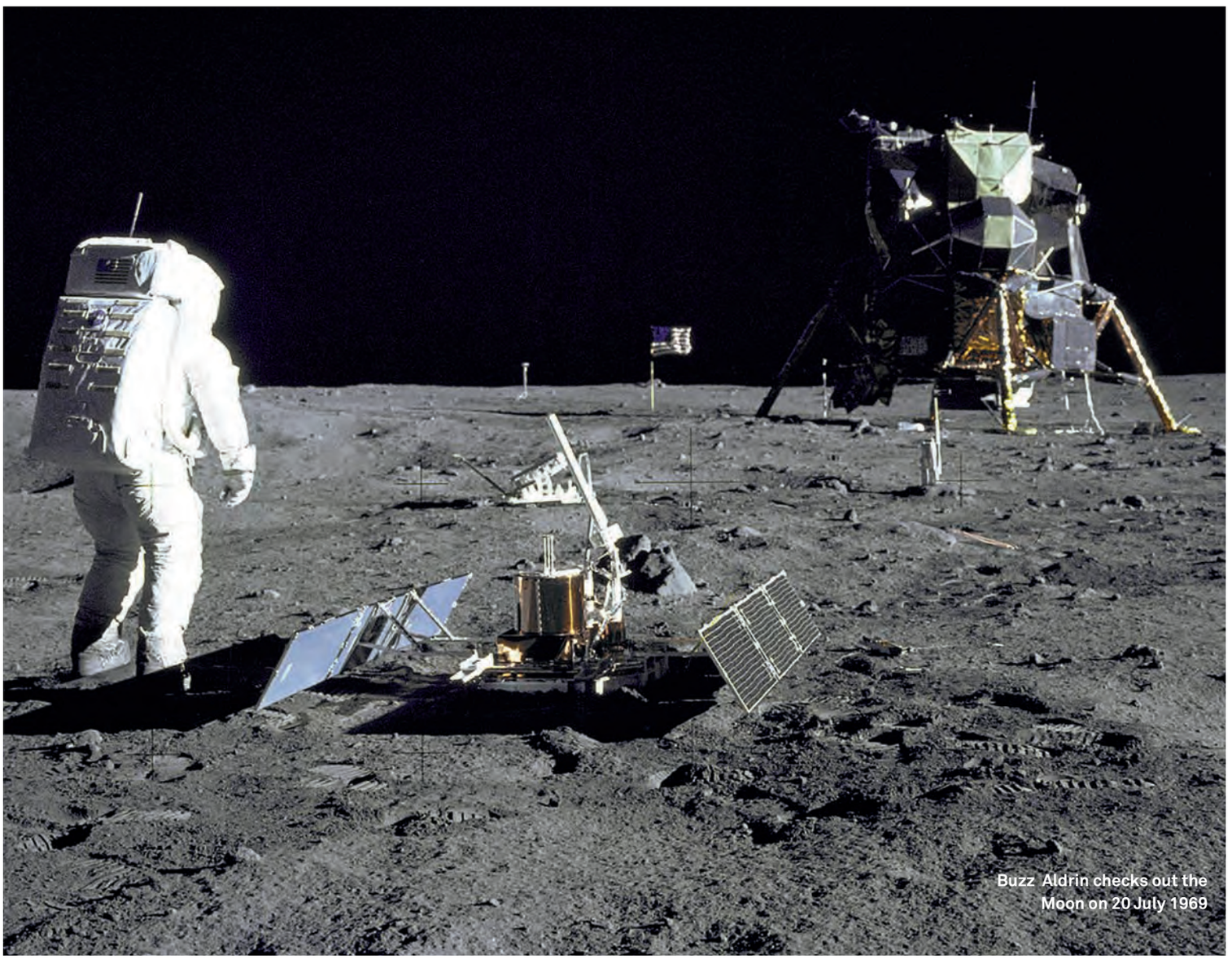
People forget that Heathrow has been asset-stripped by its foreign owners and is now billions in debt. How is it then going to find £14bn for this 3,500m-long runway over the M25?

I think it would be better to go back to the original idea of a shorter 2,000m runway, that would not go over the M25 and be much cheaper to build. Even a 1,900m runway could take turboprops, bizjets, regional jets and the smaller members of the Boeing 737 and Airbus A320 airliners. If the small airliners move to the new shorter runway, it frees up a lot of slots on the existing two main runways.

John Hartley

Join the debate theengineer.co.uk

Apollo 11: half a century on



Buzz Aldrin checks out the Moon on 20 July 1969

Fifty years ago this month, NASA put the first astronauts on the Moon. Nick Smith **talks to Apollo 11 Lunar Module pilot Buzz Aldrin, the second man on the Moon, and the only surviving moonwalker from that legendary mission**

On 20 July 1969, history was made when the first humans ever to set foot on another planetary body away from Earth opened the hatch of Apollo 11's fragile four-legged Lunar Module and took their "giant leap for mankind". The two men – described the following day in the New York Times as "Mr [Neil] Armstrong and his co-pilot Col. Edwin E. Aldrin Jr. of the Air Force" – were captured on a television camera that beamed their every move back to a global audience of 600 million. Their first actions on the Moon were to set up a further television camera, plant the American flag, collect rock samples, deploy scientific instrumentation and test their mobility in the unfamiliar, low-gravity environment.

While Neil Armstrong was a civilian aeronautical engineer, his lunar companion 'Buzz' Aldrin (who was to later legally change his name to his childhood moniker) was a military man who had served as a jet fighter pilot in the Korean War, flying 66 combat missions. With degrees in mechanical engineering (United States Military Academy) and astronautics (Massachusetts Institute of Technology), Aldrin had already been into space on the Gemini programme in 1966, when he clocked up five hours of extra-vehicular activity (EVA), as well as testing the docking procedures that would later become crucial to Apollo 11's success.

As well as being one of the most remarkable feats of exploration ever achieved, the Apollo 'Lunar Landings' were also something of an international political coup, played out against the backdrop of the Cold War. "You have to really have a very compelling reason to want to go there," says Aldrin.

That reason was not so much to do with the spirit of humanity, the thirst for scientific knowledge, or even the thrill of exploration. As early as 12 September 1962, President John F Kennedy had said: "We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard." But, what Kennedy – who was assassinated before Apollo 11 achieved its aims – was focused on was getting the upper hand in an increasingly tense Cold War, by beating the Russians to get there.

In 1957, America had been shocked by the Soviet Union placing the first artificial Earth satellite – Sputnik – into space. Later that year, the Russians sent the first dog – Laika – into orbit. In 1961, as part of the Vostok 1, Soviet cosmonaut Yuri Gagarin became both the first man in space and the first to orbit our planet. With America lagging in the Space Race, the quest to put a man on the Moon had become a proxy war. With the death of Kennedy, it became a debt of honour, and lunar success became central to the American national identity.

"Apollo 11 will probably go down in history as one of the major responses of two nations facing each other with threatening technologies," says Aldrin. "It was also our response to the apparent superiority of the Russians in putting objects into space before we could. Both nations gave assurances that it wasn't going to be just dogs and monkeys, but it was also going to be humans. In the case of the US, it was going to be very out in the open."

01 Iconic shot of the first footprint on the Moon's dusty surface

Aldrin states that this race forced the Russians to become less secretive about their technology: "even though they launched and recovered well inside their boundaries and didn't necessarily need to expose a lot of the technology, they became more open about what they were doing."

The story of how the Saturn V AS-506 left Earth on 16 July 1969 is one that has passed into legend. The rocket's cargo was essentially a Command Module (Columbia) that would remain in lunar orbit, piloted by a third astronaut (Michael Collins, "the quiet one"), while the Lunar Module (Eagle) descended to the Moon, later to rendezvous with the Command Module prior to return to Earth. As with Edmund Hillary's first successful ascent of Mount Everest in the preceding decade, this was an event that was to transfix the world and become a media circus on a previously unheard-of scale. In a press kit issued to the media a few weeks before Apollo 11's departure, NASA described the three-man crew as "astronaut-explorers".

Aldrin says that the entire mission was based on procedure and there was no room for improvisation. Upon landing on the Moon, "we

What follows is a transcript of a trans-space conversation between Lunar Module astronauts Neil Armstrong and Buzz Aldrin and the mission-control base at Houston, Texas. Armstrong is about to descend the ladder from the Lunar Module to take his first steps on the Moon.

ARMSTRONG: "OK, Houston, I'm on the porch."

HOUSTON: "Roger, Neil."

HOUSTON: "Columbia, Columbia [the command and service module]. This is Houston. One minute, 30 seconds LOS [loss of signal], all systems go. Over."

ALDRIN: "Halt where you are a minute, Neil."

ARMSTRONG: "OK, everything's nice and straight in here. OK can you pull the door open a little more? Right."

HOUSTON: "We're getting a good picture on the TV."

ALDRIN: "You've got a good picture, huh?"

HOUSTON: "There's a great deal of contrast in it and currently it's upside down on the monitor. But we can make out a fair deal of detail."

ARMSTRONG: "OK, will you verify the position, the opening I ought to have on the camera?"

HOUSTON: "The what? We can see you coming down the ladder now."

ARMSTRONG: "OK, I just checked getting back up to that first step. It didn't collapse too far. But it's adequate to get back up. It's a pretty good little jump."

ARMSTRONG: "I'm at the foot of the ladder. The LM [lunar module] footbeds are only depressed in the surface about one or two inches, although the surface appears to be very, very fine-grained as you get close to it. It's almost like a powder. It's very fine. I'm going to step off the LM now. That's one small step for man, one giant leap for mankind. The surface is fine and powdery. I can pick it up loosely with my toe. It does adhere in fine layers like powdered charcoal to the sole and sides of my boots. I only go in a small fraction of an inch, maybe an eighth of an inch, but I can see the footprints of my boots and the treads in the fine sandy particles. There seems to be no difficulty in moving around this and we suspect that it's even perhaps easier than the simulations on the ground. Actually no trouble to walk around. The descent engine did not leave a crater of any size. It [LM] has about one foot clearance on the ground. We're essentially in a very level place here. I can see some evidence of rays emanating from the descent engine, but a very insignificant amount. OK, Buzz, are we ready to bring down the camera?"

ALDRIN: "I'm all ready. I think it's squared away and in good shape. But you'll have to pay out all the LEC [lunar equipment conveyor]. Looks like it's coming out nice and evenly. It's quite dark here in the shadow and a little hard for me to see if I have good footing. I'll work my way over to the sunlight without looking directly into the sun..."

Moonwalking into the history books

The reason that Neil Armstrong is absent from virtually all of the classic Moon landing photos is because he took most of them. "Neil was an excellent photographer, and he took that great picture," says Aldrin, referring to the so-called 'visor' shot (above) of Aldrin staring straight to camera, with Armstrong clearly reflected in his visor. "I was walking along the lunar surface and he said: 'hey, stop.' And he just took it. People ask me why it is such an iconic shot. I've got three words: 'Location. Location. Location."

The camera used by Armstrong was a Hasselblad 500EL/M 6x6 medium format roll-film unit with a 60mm lens that had been modified for extravehicular activity: large buttons were added and the camera body was finished in silver to shield the film from solar radiation. The landing party had three fresh film magazines: two colour and one black and white. The magazines returned to Earth, while the Hasselblad remains on the lunar surface.

This wasn't the only camera the astronauts had with them. There were three Hasselblads in total – the other two being an IVA 'intravehicular' model with an 80mm lens, and a spare, left in the orbiting Command Module. While Aldrin was never meant to be the main photographer, he took the first exposure shot on the Moon. Aldrin's role was to take geological references on a Kodak stereo camera. The little crosses on the Hasselblad photos are fiducial markers created by inserting a Réseau plate between the shutter blades and film. This was a common method of producing reference points on photographs and to determine levels of image distortion in pre-digital scientific photography.

knew we were going to call ourselves Tranquility Base. But we never rehearsed that because we didn't want people to know. We hadn't inserted the historic announcement into our procedures checklist. So when Neil said 'Tranquility Base here. The Eagle has landed.' It struck me as, 'Gee, Neil, don't do that. We are in the middle of something.'"

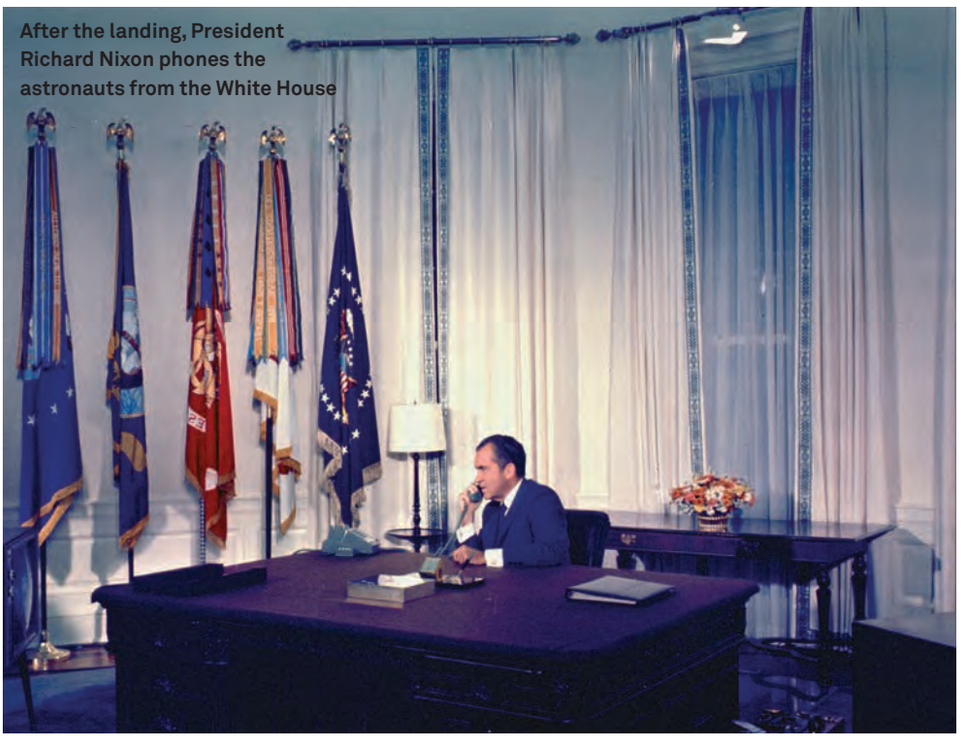
What they were in the middle of, says Aldrin, was "the most critical door-opening in all humanity. That was the moment of triumph. Seen from the Moon, every other human, except the three of us, was up there on that small object in the sky called Earth. We knew that the pressure was on us to make the landing. If you don't make the landing you can't go outside. But that's not the way the press saw it. For them, the most important thing was going down the ladder."

But that was the easy part, he recalls, describing what he saw as: "magnificent desolation. The magnificence was the achievement of humanity – for us to be able to get there. But the scene was so desolate, totally lifeless. It probably hadn't changed much in 100,000 years. It's not a hospitable place".

Aldrin reflects that there were two conditions "that assisted with the transition from not having a space programme to reaching the Moon." First, "when the president said we were going to the Moon, the air force had already been studying missions there – including manned flight – so it wasn't a totally unexplored area." Second, while the Russian space programme was disorganised and decentralised, NASA had just one aim: to get astronauts to the Moon. The US also had flexibility: they knew that the proposed Soviet Nova rocket could not be ready within Kennedy's

02 Saturn V rocket takes off from Kennedy Space Center, July 16 1969

02



After the landing, President Richard Nixon phones the astronauts from the White House

Buzz Aldrin in the Apollo 11 LM, prior to the historic landing

Earth and the Moon captured from Apollo 11

deadline, but there were two Saturn V rockets "that were the legacy of [space architect] Wernher von Braun. An engineer came along and said: 'wait a minute. If we optimise here and there, shed a little weight and send two more specialised spacecraft to the Moon, we can make do with just one Saturn V."

The plan formed for the orbiter-lander configuration which, with hindsight, "is the obvious way to go to the Moon, instead of direct there and back. The Russians looked at other shortcuts that we didn't evaluate very much. We chose flexibility".

Despite current talks at NASA about restarting the lunar programme in the near future, Aldrin has always been sceptical about the value of returning to our closest satellite, saying: "Going back to the Moon 50 years after we went there in the last century without having a clear development plan for what we're going to do – other than to say that it is a rehearsal for when we go to Mars – doesn't make much sense."

This point of view is only partially shared by NASA's new and 13th administrator, James F Bridenstine, who has been in his post since April 2018. The former US Congressman freely admits that he is "the first NASA administrator never to have seen humans walk on another world", which is all the more reason for stressing that now is "time to go back". When this happens, he says, we are going to do things differently.

According to Bridenstine, the next time we shoot for the Moon, our endeavours won't be in response to a Cold War race to put 'flags and footprints' on an unclaimed extra-terrestrial colony; it will be in the broader pursuit of science. He says: "We are the pioneers, the visionaries and the doers. We will add our names to history's greatest adventurers. The degree of excitement is as high as it has ever been. It is infectious. Everybody is ready to go back to the Moon."

> "As a project, going to Mars is much more advanced and we ought to be much more about doing that"
>
> Buzz Aldrin, Apollo 11 astronaut

These preliminary efforts, backed partially by corporate, rather than government, funds will be an intermediary phase leading to "the exploration of other worlds, such as Mars and beyond".

Broadly speaking, Aldrin agrees with this last sentiment, at least. "We learned quite a lot going to the Moon, and it is now appropriate to build on that and move on to a much bigger and grander objective by going to another planet. Not just to visit it a few times, but to set up a sustaining presence. As a project, going to Mars is quite a bit different, much more advanced, and I think we ought to be much more about doing that. Eventually humans will leave the Solar System and go to other stars. Not in my lifetime. But we will learn how to do that." ■

All images courtesy of NASA

Smartphone or Apollo Guidance Computer (AGC)?

It's passed into modern culture that there is more computing power on today's smartphones than what was available to the whole of NASA's Apollo 11 space programme. While this is beyond doubt and much of what was done on Apollo 11 in terms of navigation, life support, environmental monitoring and power management could be done via an app, Aldrin defends NASA technology as being revolutionary for the time.

"I can't quantitively give you the numbers, but there was no way you could possibly have had any kind of mechanical calculator to make the corrections needed to be able to get to the Moon. Our computers gave us the sophistication of mathematical smoothing techniques for the equations of motion and the perturbations. We were able to squeeze out of limited capacity some very, very remarkable achievements."

Apollo 11 also saw hand-off to manual at critical moments: "We chose to use humans to execute and aid things like re-entry, final closure braking and docking manoeuvres. We made use of humans there, rather than to try to automate everything. I think we made wise decisions when exploring how to do these things."

Lunar lift-off

National space agencies and private companies are preparing missions that will return humans to the surface of the Moon, 50 years on from the successful landing of Apollo 11. Why go back, and what might the new crewed lunar missions involve?
Stuart Nathan reports

The jury is out on whether Donald Trump believes the Moon is part of Mars. Recently, the most consistently puzzling US president in history tweeted that "We shouldn't be going back to the moon, we did that 50 years ago. We should be aiming for bigger targets like Mars (of which the moon is part)."

Charitable observers interpreted this as displaying Trump's understanding that plans to return crewed missions to the lunar surface are part of a larger goal of landing humans on the Red Planet. Others, more cynical, expressed glee at Trump seeming to display an alarming degree of ignorance.

Either way, half a century on from the Apollo missions, plans are indeed advanced to send men (and probably women as well, this time) to the Moon, with several organisations now trying to design missions.

The establishment of an office at NASA called 'Moon to Mars' confirms that the plan is to use new lunar missions as a stepping stone to our nearest planetary neighbour. The lure of humans on Mars – even if it's only as a romantic gesture rather than scientific – is a strong one, and visiting the Moon represents a perfect dress rehearsal. It's much closer than Mars (a week's return journey rather than two years, and therefore technically simpler), but it offers the chance to develop, test and optimise many of the systems that will be needed for the longer trip.

But proponents of Moon missions argue that Mars preparation and rehearsal is not the only reason for a lunar return. We have unfinished business with our satellite. Some of these new reasons are scientific – continuing the interrupted studies of the Apollo teams taking into account improved analytical capabilities developed over the intervening years and both investigating and developing theories about the Moon's origins, geology and composition.

If Donald Trump does believe the Moon is Martian, he's wrong; but it might be partly terrestrial. A current theory states that the moon was created when a large object collided with the still-molten Earth in the early stages of the solar system, ripping away a chunk of material. The Moon is composed of remnants from that ancient collision, the theory continues. If this is the case, it will contain the same mix of elements that is found on Earth and will provide clues to the subsequent development of the planet, as well as revealing how the solar system, and other planetary systems in the galaxy, developed.

Whatever the justification for the new lunar race, (see Viewpoint page 16), it differs from the 1960s version in one important respect: there is no plan on the horizon to send Russians to the Moon, or at least not one that has been made public. But, like the 1960s, the Americans seem set to lead the charge. In March this year, vice-president Mike Pence announced that NASA was being tasked with returning astronauts to the Moon by 2024.

Apollo to Artemis

While Apollo was the watchword for the first lunar missions launched by NASA, the second iteration of government backed crewed Moon journeys will carry a different name: Artemis. It's a fitting name; in Greek mythology, Artemis was the twin sister of Apollo. While Apollo was a solar deity, Artemis was always associated with the Moon.

It seems that NASA is determined to cement the Artemis name in the public eye early. It has redesignated the missions to be undertaken to test the Orion capsule, its new crew-rated module, from their original names of Exploratory Mission 1 (EM-1) and EM-2, the launch of the capsule for the first time with and without astronauts on board, as Artemis-1 and -2.

Artemis-1 is scheduled for July 2020: it will be the first flight of Orion atop the new space launch system (SLS) rocket, based on systems originally developed for the Space Shuttle. It will be a 10-day mission that will catapult an empty Orion capsule around the moon, returning directly to earth. Artemis-2, scheduled for 2022, will be another SLS launch, this time sending a crew on a lunar orbital trip (this would be the equivalent of 1968's Apollo 8 mission, which was the third flight of the Saturn V launcher).

There will then be a pause in the Artemis programme while the first units of the Deep Space Gateway (DSG) space station are placed into position. The initial plan is for only the power and propulsion modules, along with the key elements for a subsequent lunar landing – currently envisaged, initially at least, to be a three-module vehicle – a transfer module, a descent module and a return

01 How a NASA Artemis Moon landing might look

02 An ExoMars drill – likely to be the model for the drill for an ESA ISRU mission

module. All of these would be expendable.

These missions would be undertaken by commercial launch service providers, and once the modules are in position, Artemis will resume. Scheduled to launch in 2024, Artemis-3 will send a crew in an Orion module to rendezvous with the DSG, where its crew will transfer into the lunar modules. These will be launched to lunar orbit, from where the descent and return modules will detach to take the crew to the Moon's surface. The landing site is currently planned to be near the lunar south pole, a location of intense interest because it is believed to harbour water ice deposits in sections of craters that are in permanent shade, where temperatures drop are continuously below -100°C.

As with Apollo, the descent module will remain on the moon, while the return module will detach to dock with the transfer module in orbit. The return and transfer modules will fly back to the DSG. The crew will then disembark from their lunar shuttle back into Orion, which will return them to Earth. This differs somewhat from the Apollo approach, which used the conical command module and its attached cylindrical service module as the vehicle to go all the way from Earth into lunar orbit. For Artemis, the command and service modules for crewed missions will not go to the Moon, and there will be no need for the Artemis-3 SLS to also carry a LM (lunar module), as was the case with Apollo. This will save on its launch weight.

The Apollo LM is so far the only vehicle to have ever taken humans onto the moon and was developed and built by Grumman Aerospace, now part of Northrop Grumman. The company won the contract after 11 companies were invited to bid, with the process beginning in 1962. Once again, the builder of the Artemis LM (which might not be called that; it currently has no official designation) will be decided by a competitive bidding process. This began in May of this year, making the deadline somewhat quicker than in Apollo's case.

Again, 11 companies have been invited to conduct studies and select prototypes for a prospective lander. Each is looking at a slightly different project, and the scope of these projects indicates that NASA is intending missions after Artemis-3 to be somewhat different, as they include reusable modules that may be refuelled between missions back at the DSG. The 11 are:

- Aerojet Rocketdyne, a rocket and missile manufacturer based in Sacramento, undertaking a single transfer vehicle study;
- Blue Origin (the commercial space company owned by Amazon billionaire Jeff Bezos), carrying out studies of one descent element, and one transfer vehicle, and producing a prototype of a transfer vehicle, as well as planning its own missions to the Moon both with and without crews using its own New Glenn launcher system in the coming decades;
- Boeing, looking at a descent element study, two descent prototypes, one transfer study and prototype, and one refuelling element study and prototype;
- Dynetics, a Huntsville, Alabama-based company formed in the 1970s with close links to NASA, producing one descent element study and five descent prototypes;
- Lockheed Martin, undertaking one descent element study, four descent prototypes, one transfer vehicle study, and one refuelling element study;
- Masten Space Systems, a Californian company previously specialising in reasonable launchers, doing a single descent element prototype;
- Northrop Grumman, looking at one descent element study, four descent element prototypes, one refuelling element study and one refuelling element prototype;
- OrbitBeyond, a New Jersey-based specialist in lunar technologies founded only last year, producing two refuelling element prototypes;
- Sierra Nevada Corporation, an established electronics company heavily involved in satellite technologies, carrying out one descent element study, one descent element prototype, one transfer vehicle study and prototype, and one refuelling element study;
- SpaceX, Elon Musk's space company, which has been collaborating with NASA for some years on commercial launches, including resupplying the international space station, perhaps surprisingly only producing one descent element study;
- SSL, a Californian company specialising in building communication satellites, producing one refuelling element study and prototype.

The projects are taking place as part of NASA's NextSTEP (Next Step technologies for Exploration Partnerships) programme, a public-private partnership aimed specifically at commercial development of more extensive crewed missions between the Earth and the Moon and beyond. NextSTEP projects include advanced propulsion, such as electric systems, and habitation systems intended to be part of the ongoing DSG project, which will continue to be developed after Artemis-3 as it is intended to be the launch site for the vessel that will eventually take explorers to Mars, planned to be in a reusable 'cruiser' that will be assembled and possibly even entirely partially or manufactured off-planet.

The Engineer covered the background to, and the planning of, this project in depth in 2017.

The NextSTEP approach is intended to the process of developing equipment. "Our team is excited to get back to the Moon quickly as possible, and our public/private partnerships to study human landing systems are an important step in that process." said Marshall Smith, director for human lunar exploration programs at NASA Headquarters.

According to Greg Chalvers, human landing system formulation manager at NASA's Marshall Space Flight Center in Huntsville, Alabama, the philosophy behind Artemis is for NASA itself to not develop the details of how astronauts

will be taken to and landed on the lunar surface itself. "This new approach doesn't prescribe a specific design or number of elements for the human landing system," he said. "NASA needs our system to get the astronauts on to the surface and get them home safely, and leaving a lot of the specifics for our commercial partners."

The other contenders

The other nation states aiming to reach the moon with crews in the coming decades are China and India, but their plans are not as advanced as those of the US. The Chinese Chang'e Project has four well-defined phases – orbital missions, soft landers and rovers, sample-return and establishment of a lunar research station.

These in fact began in 2007 with a lunar orbiter (Chang'e 1). Three subsequent missions have seen a second orbiter, and two landers plus rovers successfully sent to the lunar surface. Chang'e 5, a sample-return mission, is planned for launch in December of this year, targeting the Mons Rümker volcano in the north-east of the Moon's near side. Looking forward, China does intend to undertake a crewed landing (in their case, the human explorers will be taikonauts), but the schedule does not see this happening until the 2030s, again near the south pole, where the plan is to establish a permanent outpost.

India, meanwhile, has the moon in its near sights. The Chandrayaan-2 mission is scheduled to launch between 9 and 16 July, taking an orbiter, lander and Rover to a site near the south pole with a landing scheduled in September, and explorations plans to ascertain the nature of the terrain and the composition of any minerals or compounds on the surface. In January of this year, the chairman of the Indian Space Research Organisation, Kailasavadivoo Sivan, stated that he aims to launch an Indian crewed lunar mission by December 2021, following an announcement by prime minister Narendra Modi last year. This would make it the first nation to return humans to the moon by some distance (in this case, the moonwalkers would be called vyomanauts).

Europe is not planning its own human voyages to the Moon, but is involved on the technology side. The main goals of European lunar projects are oriented towards in-situ resource utilisation (ISRU), the harvesting, refining and direct use of materials found in space for the furtherance of human exploration. James Carpenter, strategy officer in the directorate of human and robotic exploration and the European Space Agency, explained that the reasoning for this is purely practical. "We can't carry everything that we are going to need," he told *The Engineer*. "Especially as we aim to venture further into the solar system, ISRU is the only way we are going to be able to do it."

At the moment, the main goal of ISRU is to generate oxygen. "That has two immediate applications," Carpenter said. "It can be used as fuel, and astronauts can breathe it. We also already know that on the Moon there are compounds that contain oxygen: oxide minerals and water ice, although at the moment we don't fully understand where they are and in what precise quantities. ESA investigations are aiming to gather more information on both, as well as investigating the best ways of extracting the oxygen."

Much of the technological inspiration for these efforts is coming from the ExoMars programme, whose rover, named Rosalind Franklin, is currently under development. Rosalind will prospect for signs of past life and chemicals that might have supported it on the surface of Mars on a mission launching next year. The ExoMars drill, a percussive device designed to penetrate some 2m into the Martian surface, is the model for a similar instrument designed to go to the Moon in a project called PROSPECT (Package for Resource Observation and in Situ Prospecting for Exploration, Commercial exploitation and Transportation) which could fly to the Moon on a Russian mission, Luna-27, which aims to explore the south pole on the far side in 2024.

PROSPECT will consist of a lander incorporating a drill, called ProSEED, which will be designed to penetrate 1m below the surface to extract samples of water ice and volatile compounds that are solid at temperatures between -150°C and -200°C. These samples will then be passed to an on-board laboratory called ProSPA, that will heat the samples to extract the volatiles and will be able to carry out experiments involving heating up to temperatures of 1000°C, to test processes that might be used to extract oxygen in the future.

As well as utilisation by human missions, these experiments will provide information on the possible origins of compounds including water in the earth-moon system. Carpenter said: "We still don't know where the Earth got most of its water from.

"And if we understood that, we might know where else it might be found in the solar system. As it is a source of fuel, that would be extremely useful to help plan exploration into the outer planets and their systems of satellites, which are entire worlds of their own."

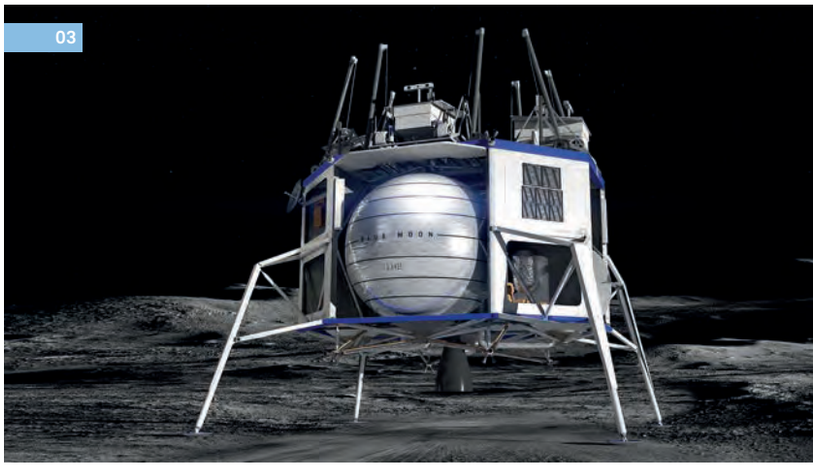
The possibility of using the Moon as a source of minerals that could be useful on Earth has been raised, but ISRU missions are likely to be confined to the use on the bodies where they occur, as transporting them back to Earth is a big task and very much dependent on the abundance and location of deposits.

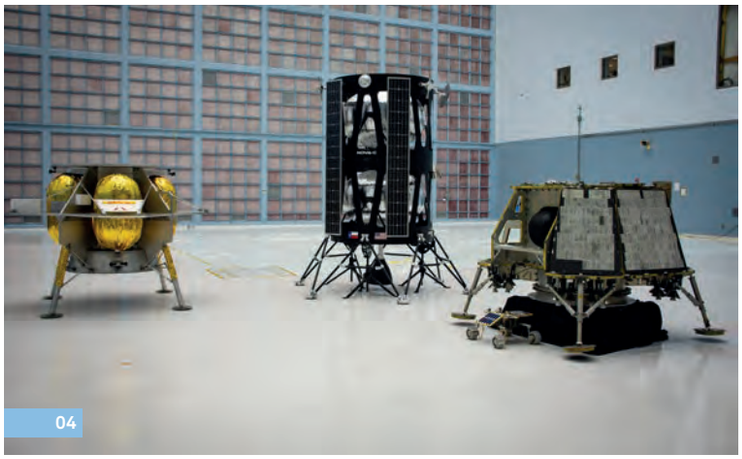
"We know that helium-3 occurs on the Moon, and has been suggested as a fuel for nuclear fusion, but as we haven't cracked fusion on Earth it seems foolish to be looking that far ahead just now," Carpenter said.

"One advantage for Europe in lunar missions is that there is now so much interest from different agencies that we are no longer dependent purely on the Americans and Russians to hitch rides on their missions."

"We know that powerful launchers, to which Europe does not have its own access, will be going there and we have a variety of established relationships with those operators. Knowing that ISRU is going to be vital as humans proceed beyond the Moon, to Mars, and possibly into the asteroid belt, we plan to use the expertise we will establish with our lunar ISRU missions to keep exploring."

As the UK is leading the ExoMars project, with Rosalind Franklin being assembled and its systems integrated in Stevenage, it seems likely that British institutions will continue to have a key role in this aspect of lunar exploration. ■





03 Blue Origin Blue Moon lander (cargo version)

04 NASA selects the first commercial Moon landing services for Artemis (left to right) from Astrobotic, Intuitive Machines and Orbit Beyond. All are scheduled to launch, carrying NASA payloads, in July 2021

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Made in space

Developments in 3D printing technology could make off-planet manufacturing a reality sooner rather than later. Stuart Nathan reports

Space, as Captains Kirk and Picard so memorably said, is the final frontier. And not just for exploration. As plans for human presence in the solar system become more developed, researchers are increasingly looking for ways to expand hitherto earthbound areas of human activity into space. As a recent conference at Coventry's Manufacturing Technology Centre explored, one area is manufacturing.

A very specific area of manufacturing is being studied: building spacecraft and items that human explorers might need on their missions (whether they last five years or even longer), such as shelters, habitats and tools, in space. The first stages of this are already beginning to be investigated: in-orbit assembly of spacecraft had notable success in the late 1980s and early 1990s, with the construction of the International Space Station (ISS) from modules transported by Russian launchers and the Space Shuttle, and assembled either by autonomous docking manoeuvres or astronaut crews.

The rationale behind off-planet manufacture is the same as the ISS build strategy: it's easier to construct awkwardly shaped and large items in situ than to build them on Earth and launch them into orbit. They don't have to withstand the vibration and rigours of launch, or be packaged for safe transport. The only thing that matters is the mass of the raw materials that need transporting.

This, of course, is theoretical. Easier it may be, but the task of actually building something still needs to be overcome and, until relatively recently, very few of the established manufacturing techniques were suitable (or practical) for a use in microgravity conditions. *The Engineer*'s previous forays into this sector looked at techniques such as extrusion of plastics to make long booms, but ability to build the major modules of spacecraft, for example, were completely lacking.

This has been changed by the emergence of additive manufacturing techniques, which take very simple forms of raw material, such as powder or wire, and turn them into relatively complex, three-dimensional geometrical shapes. These would allow complex structures to be built in space, with the need to transport raw materials in a compact form into orbit.

According to Tony Mears of the UK Space Agency, "[additive manufacturing] has the potential to shake up space manufacturing like nothing else. From wiping out the cost of traditional machinery, to making new designs, additive manufacturing is changing how we approach optical instruments, mirrors, even rocket engines. The UK Space Agency has funded projects across all these to mid-TRL (technology readiness level) and they all have a promising future ahead in commercial applications."

Not all additive techniques are suitable for use in space. The technique most commonly referred to as 3D printing, powder-bed additive layer manufacturing – where a laser is used to melt a metal or polymer powder to build up an item slice-by-slice – is not suitable. Prof Richard Hague, director of the centre for additive manufacturing at the University of Nottingham,

explained to *The Engineer* that in the absence of gravity, it would be impossible to consolidate a powder bed inside a 3D printer and, therefore, the technique would be impossible.

One technique that is showing promise, however, is wire + arc additive manufacturing (WAAM). Derived from welding, this uses an electric arc effector mounted on the robot arm to deposit metal from a wire, into whatever shape the effector arm is programmed to describe. As it is simple for such a system to move in circles, it is particularly well suited to making round-ended cylinders and spheres – both of which are shapes commonly used for space vehicles and habitats. Tanks designed to hold pressurised gases are very commonly shaped like this.

Cranfield University has played a key role in developing WAAM and is looking at space applications for the technique. Earlier this year, it collaborated with Thales Alenia Space and Scottish company Glenalmond Technologies, which is focusing on using the technique with high-grade metals, to build a full-scale prototype of a titanium alloy pressure vessel designed for space applications. Weighing 8.5kg and measuring a metre in length, the tank is made from the alloy Ti-6Al-4V, a high strength-to-weight ratio material commonly used for applications in the aerospace and biomedical sectors.

At the MTC conference, design engineer Abdul Haque of the Advanced Manufacturing Research Centre spoke about a project to build a spherical titanium propellant tank for a CubeSat, designed to hold ammonia to be used in a microwave-enabled electrothermal thruster system. This project, with industrial partner AVS Space, was undertaken as part of AMRC/Space, which was set up in September 2018 to explore opportunities in the UK manufacturing base to support the government's vision for a "great British space age". The tank met the internal pressure standards needed for such an application, Haque said.

Another application where additive manufacturing for space has attracted great interest is in building habitats for astronauts on the moon, with an eye to later application in crewed missions to Mars. Once again, the rationale is to remove the need to transport bulky and heavy items from Earth to targeted landing sites. The goal in these cases is generally to use in situ resource utilisation (ISRU) for the raw materials to build the modules: in other words, to use lunar (or martian) soil, known as regolith. ISRU is currently the object of much interest for lunar return missions (see feature on page 26).

With new lunar missions now firmly on the timetable, interest in additive habitats has intensified, and at the end of May this year, Laser Zentrum Hannover (LZH), a German independent research Institute, in association with the Institute of Space Systems of the Technical University of Braunschweig (IRAS), announced a new phase of a project called MOONRISE, which began in 2015. IRAS research leader Prof Enrico Stoll said that the project equipment, a low-weight laser that can melt lunar regolith to redeposit it in a robot-controlled additive extrusion system, will hitch a ride on an ESA-led lunar mission by the end of 2021.

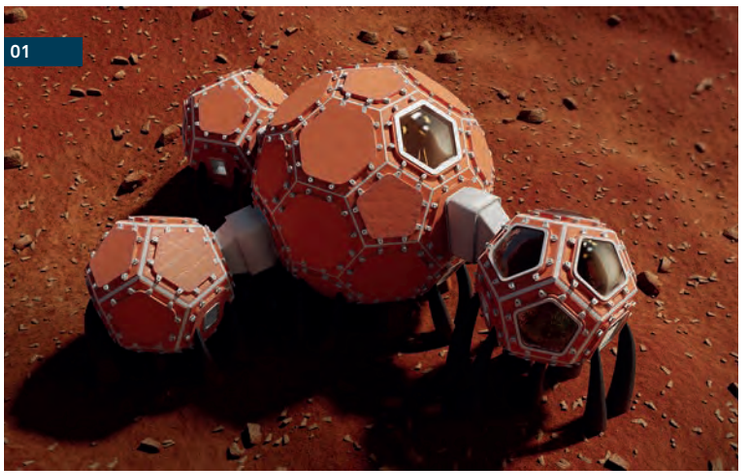
The MOONRISE laser weighs 3kg, and the team is currently adapting it to fit into a tunnel on the base of a lunar rover. Before the mission, the system will be tested to ensure that it can withstand the transit conditions and operate in the environment of the Moon. Testing has now been under way on the equipment for 10 months. LZH research leader Prof Ludger Overmeyer said that the challenge of ensuring the process is safe and equipment within the mass budget is considerable, but that progress is promising.

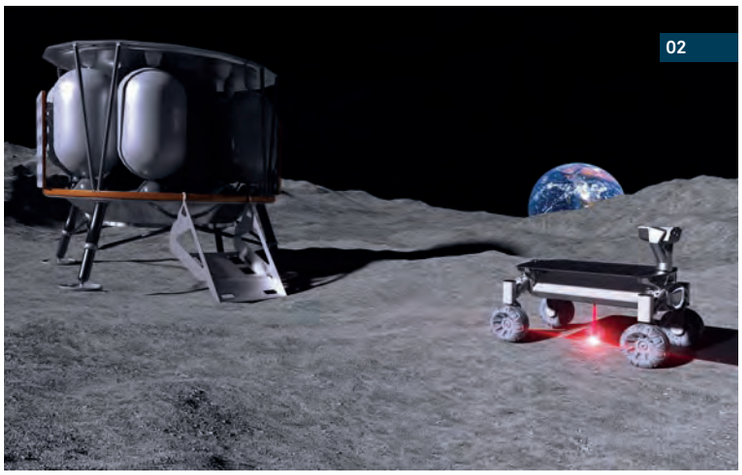
The project is being funded by the Volkswagen Foundation, Germany's largest independent funder of basic research, which grants awards for new projects at the rate of €100m (£89m) per year. Despite its name, it is not affiliated to the automotive giant.

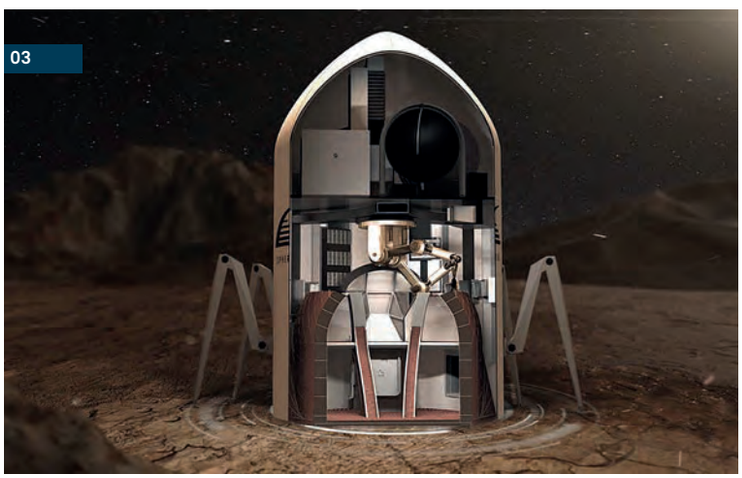
NASA, meanwhile, made construction of 3D-printed habitats on Mars the subject of a competition, which completed its penultimate and fourth phase in April. The top three teams to enter the competition, New York-based SEArch+/Apis Cor, Zopherus from Arkansas, and Mars Incubator of New Haven, Connecticut, shared a $100,000 prize purse based on short videos and miniature 3D printed models to show the interiors of their structures.

Each team took a different approach to the problem. SEArch+/Apis Cor developed a multi-storey design with continuous structural reinforcement, thanks to its spiral structure and ports along the side on top of the building to allow in light; Zopherus used a roving 3D printer that is designed to move from site-to-site building additional structures; and Mars Incubator's design consists of four separate volumes with different purposes, connected by bridges.

The final phase of the competition has been completed, with three finalists going head-to-head to build full-size models of their structures, but as this feature went to press, the winner (which will win an $800,000 prize), had not yet been announced. ■







01 Mars Incubator's design is connected by bridges

02 MOONRISE is on a mission to bring 3D laser printing to the lunar surface

03 Zopherus uses a site-to-site 3D printer

Giant leaps in the Space Race

The Engineer has reported on the technology behind many of mankind's most inspiring and significant efforts to explore and visit space. Jon Excell **visits the archives**

It is a somewhat depressing indictment of human nature that international conflict has proven to be one of the prime drivers of technological innovation. And though the US and the Soviet Union never quite came to blows, the Cold War-induced Space Race of the 1950s and 1960s is perhaps one of the most striking examples of this phenomenon in action.

From the launch of Sputnik to the technology that put man on the moon, *The Engineer* brought an enquiring – and often surprisingly sceptical – perspective to the technological leaps made during this unparalleled period of cosmic one-upmanship.

October 1957: The launch of Sputnik

The Soviets' launch of Sputnik – the world's first artificial satellite – was a key moment in the history of the 20th century that sent shockwaves around the world and was the catalyst for the Space Race.

Describing it as a "major scientific feat" and congratulating the Russians on their achievement, *The Engineer* pieced together technical details of the project from Russian newspaper *Pravda*, reporting that the satellite was a sphere, about 58cm in diameter and made of aluminium alloy. Reporting on its payload, the story said "the casing houses two radio transmitters and other equipment in an atmosphere of nitrogen gas, the whole assembly weighing 83.6kg. Four metal antennae are attached to the casing: 2.4m to 2.9m long, these rods folded back when the sphere was on its outward journey".

The signals from these antennae were monitored from Earth for the next 21 days until the transmitter batteries ran out. The satellite burned up on 4 January 1958 when re-entering Earth's atmosphere.

As *The Engineer* also reported, the launch of Sputnik was to be a key moment for the late Sir Bernard Lovell's Jodrell Bank radio telescope.

Until that point, the telescope had been a controversial project. Many astronomers were sceptical about the technology, whilst cost overruns and delays to the project had led to considerable negative media coverage.

However, on 11 September, although the facility wasn't even fully up and running, Sir Bernard's team managed to use the telescope to track Sputnik's launch rocket.

As Sir Bernard told *The Engineer* in a rare interview back in 2006, attitudes to the project changed almost overnight.

"I remember at 1am in a crowded lecture room showing them a slide of the echo, I said 'this is what no man has yet seen – a wonderful echo of the carrier rocket moving over the Lake District'.

"They knew that this was the echo from what could have been a ballistic missile, so then things began to turn in our favour."

> "We learn that the Russians have scored yet another remarkable first in space"

November 1957: Sputnik 2

Just a few weeks after the launch of Sputnik, *The Engineer* marvelled at the launch of Sputnik 2, a much larger satellite. Sputnik 2 was also the first spacecraft to carry a living creature – Laika the dog (who died shortly after the launch).

At the time of writing, very few details had emerged concerning the latest launch and *The Engineer* was hungry for details. "How very much we should like to have particulars of the rocket used, and more particularly about the propellants," it wrote.

January 1958: Explorer 1, America's first satellite

The successful launch of America's Explorer 1 satellite perhaps marked the moment when the Space Race began in earnest.

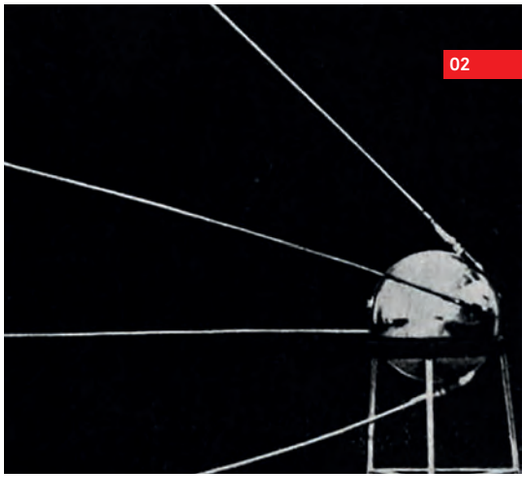
With a total mass of 13.37kg, the satellite itself was considerably lighter than Sputniks 1 and 2, and – after Sputnik 2 – was the second satellite to carry a scientific payload into space.

The Engineer wasn't overly impressed by the satellite, writing that "it is a fine feat on the part of the Americans, but it has in no sense demonstrated that American rocket development has caught up with that of the Russians".

Despite this scepticism, Explorer 1 did end up making a significant contribution to space science, becoming the first spacecraft to detect the so-called Van Allen radiation belt.

March 1960: Pioneer V

While the launches of Sputnik and Explorer were first and foremost political events, it wasn't long before the US and Soviet satellite programmes started



01 The launch of Sputnik was to be a key moment for the late Sir Bernard Lovell's Jodrell Bank radio telescope

02 Sputnik, the world's first artificial satellite, was described by *The Engineer* as a "major scientific feat"

doing some serious science. Pioneer V was one such mission. Launched to investigate interplanetary space between the orbits of Earth and Venus, the US probe earned the distinction of confirming the existence of interplanetary magnetic fields.

The Pioneer programme went on to see the launch of a number of other probes. Perhaps the most notable were Pioneer 10 and 11, which explored the outer planets, and are now thought to be on trajectories leading them out of the solar system. Last contact with Pioneer 10 was in 2003, while 11 hasn't been heard from since 1995.

April 1961: The first man in space

"As we go to press, we learn that the Russians have scored yet another remarkable first in space," wrote *The Engineer* in April 1961. "Last Wednesday morning, Mr Tovarich [sic] Gagarin was launched in a sealed capsule by rocket into an orbit that took him around the world in 108 minutes. The capsule was brought safely back to the Earth's surface. Congratulations to the Russians!"

The Engineer's coverage of the feat reported that the plan was for the entire mission to be controlled either by automatic systems or ground control – however, in case of emergency, Gagarin did have access to manual controls. Of particular note here is the description of the system used to orientate the ship manually. "In order to orientate the ship when steered manually, the cosmonaut uses an optical device to determine the position of the ship in relation to the Earth," wrote *The Engineer*.

May 1961: The first American in space

On 5 May 1961, just a month after the Soviets put the first man in space, commander Alan Shepard became the first American to complete the feat.

While acknowledging the psychological significance of the US's "first step toward manned exploration and military exploitation of space", *The Engineer* was less impressed by the technology, describing the mission as a "modest and belated jump into space" and meticulously outlining all of the ways in which it didn't measure up to Gagarin's mission.

July 1969: Apollo 11 puts the first man on the moon

By 1969, the Soviet technological superiority reported in *The Engineer*'s early coverage had fallen away, and the first lunar landing is widely regarded as the moment the Space Race ended.

While most of the coverage of this historic moment focused on the human story, *The Engineer* stuck admirably to its remit, and in a special issue of the publication, focused instead upon the machinery that took our first extraplanetary pioneers a quarter of a million miles from the Earth's surface to the moon's, and back again in safety.

October 2008: China's first spacewalk

In 2008, *The Engineer* reported on a key symbolic moment: China's first spacewalk, carried out from the country's Shenzhou VII spacecraft by taikonaut Zhai Zhigang.

China has been building up ever greater space capability in recent years, and in January 2019, successfully landed the first ever space craft on the dark side of the moon. Chinese engineers are putting the finishing touches to a three-module space station that it plans to have assembled in orbit by 2022.

February 2018: Private space takes off

Alongside the emergence of new space-faring nations, one of the defining characteristics of the 21st century space industry has been the emergence of a host of private space companies seeking either to kick-start a new era of space tourism, or to provide national space agencies' next-generation space exploration.

Arguably the most significant company here is Elon Musk's SpaceX, which is now thought to have a 65 per cent share of the market for newly awarded commercial satellite launches.

The company burnished its credentials in February 2018 with the maiden launch of the SpaceX Falcon Heavy, a heavy-lift launch vehicle that can put payloads into space at a fraction of the cost of Apollo-era technologies, which is currently the most powerful operational rocket in the world. ■

A new world of opportunity

With British engineers at the heart of efforts to reduce the cost of access to space, Andrew Wade and Jon Excell **look at some of the rising stars of the UK space sector**

The UK has more than its fair share of unsung engineering success stories, but there are perhaps few more striking examples of Britain hiding its industrial light under a bushel than its buoyant space sector. Despite a relatively low public profile, UK space is at the forefront of areas including the manufacture of telecoms satellites, the development of small systems that can be launched at a fraction of the cost of traditional technology, and the design of robotic probes and rovers for planetary exploration.

Meanwhile, with several proposed spaceports under consideration, alongside the development of innovative propulsion technologies such as Reaction Engines' SABRE engine, the UK is even beginning to take significant steps towards the development of its own domestic launch capability.

Now made up of nearly 1,000 separate organisations – with around 30 new companies joining the fold each year – and directly contributing almost £6bn to the economy each year, the sector has tripled in size since 2000, making it one of the UK's fastest-growing industries.

There are multiple drivers behind this success, not least the degree to which the UK has been able to draw on its existing research base, as well as the presence of established names like Airbus Defence & Space and Surrey Satellite Technology. Some credit should also go to the UK government for singling out the sector in its industrial strategy and planning the establishment of a National Space Council to oversee a joined-up approach to the sector's growth.

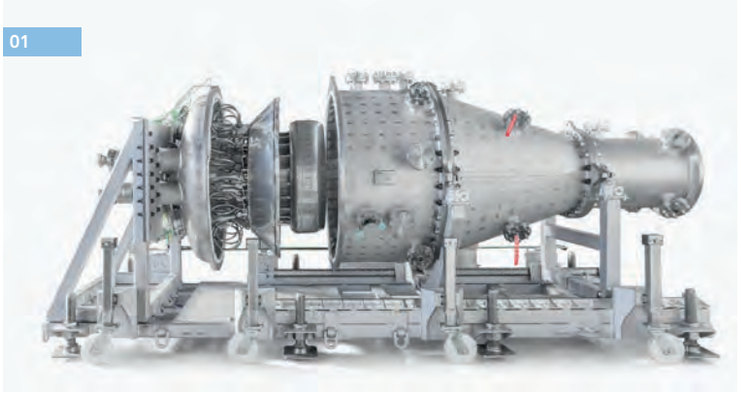
But perhaps what has really defined the sector in recent years is the emergence of a host of innovative SMEs that are grabbing a share of the lucrative 'new space' market opened up by organisations such as Elon Musk's SpaceX.

Nimble and small enough to react to a rapidly evolving marketplace, these rising stars of the space sector are applying new technologies in novel ways, helping reduce the cost of launching payloads into space and driving innovation across the sector.

Satellites

Perhaps the UK's best-known area of space technology is in the development of satellites. The sector's largest manufacturer, Airbus Defence & Space, has manufacturing bases in Stevenage and Portsmouth and UK engineers have played a key role in projects including Galileo, the Lisa Pathfinder mission and ESA's Solar Orbiter programme.

But in recent years it has positioned itself as perhaps the world's leading developer of small satellites. This began with Surrey Satellite Technology – now owned by Airbus – which pioneered the development of small satellites and paved the way for a new generation of innovative space spin-outs.



01 Reaction Engines' SABRE engine

02 The Lagrange mission

03 Oxford Space Systems' wrapped rib antenna

One of the most exciting emerging players in this area is Glasgow's Clyde Space.

Since its launch just over a decade ago, the company has become one of the world's leading developers of so-called CubeSats – miniaturised satellites (around the size of a loaf of bread) which are used for space research.

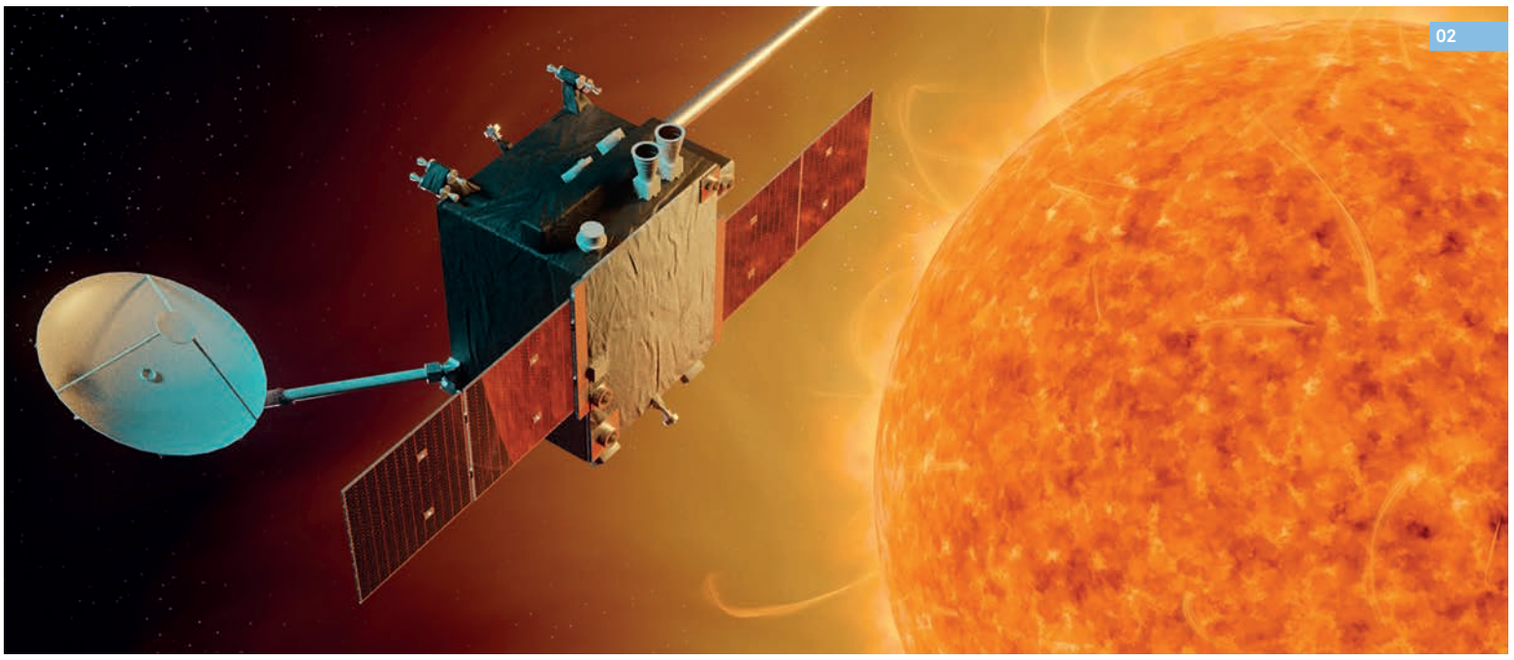
The firm – Scotland's largest space company – designed and manufactured Scotland's first satellite, the UKube-1, which was launched from Baikonur, Kazakhstan in 2014.

Another rising star of the UK space sector is Oxford Space Systems, which has commercialised technology for lightweight carbon fibre antennae that can be stored in small packages and which spring into shape when in orbit.

With a base at Oxfordshire's renowned Harwell Science and Innovation Campus among a cluster of more than 90 different space organisations including RAL space, Deimos Space UK, Rezatec and Neptec, the company has used 'origami engineering' techniques to develop a range of lightweight carbon fibre booms, antennae and panel arrays that boast the benefits of conventional satellite technology but can be launched into space at a fraction of the cost.

In 2015, the company was selected for the UK Space Agency's AlSat Nano mission, achieving a world-first with the longest-ever retractable CubeSat boom in orbit at 1.5m.

The company's AstroTube boom is being used as part of ESA's RemoveDebris mission, which is evaluating technologies that could be used to address the growing problem of orbiting space junk.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Science

Away from the commercial world, UK space is perhaps best known for its scientific research base.

Landmark moments in UK space science over the decades range from Ariel 1's solar observations in 1962 through to Tim Peake's mission aboard the ISS. Recent marquee projects with UK involvement include NASA's InSight Mars rover (landed November 2018) and James Webb Space Telescope (due to launch in 2021), as well as the lead role in ESA's upcoming ExoMars rover, newly named Rosalind Franklin in honour of the pioneering British chemist.

With no current launch capability of its own, it is perhaps not surprising that much UK space expertise has gravitated towards instrumentation. One fascinating project recently announced will see UCL's Mullard Space Science Laboratory (MSSL) develop a plasma analyser for ESA's Lagrange mission. Launched in 2024, the tool will be part of a sensor suite to monitor solar activity from the L5 Lagrange point, which forms an equilateral triangle with the Earth and the Sun.

"The plasma analyser is what is known as a 'top hat'-type electrostatic analyser," MSSL's Prof Dhiren Kataria told *The Engineer*. "It's going to be looking at the energy and angular distribution of solar wind ions."

Solar storms have the potential to cause widespread global chaos, knocking out satellites and power grids. As a result, monitoring the Sun's activity more accurately has long been a goal of the international space community, and the L5 mission will be complemented by a US spacecraft operating at the L1 point between the Earth and the Sun.

By dint of its location, the L5 mission will be privy to solar activity several days before that part of the Sun is aligned with Earth. L1 is directly between the two bodies, providing more up-to-date information, but also offering significantly less warning time for dangerous coronal mass ejections (CMEs). "If you can imagine, it gives you a kind of stereo view between L1 and L5," Kataria explained. "You have two views and you then have a better understanding of how the CME has evolved.

"By sitting at L5, you see the active regions well before they come into visibility for Earth. You get visibility of it at least four to five days in advance."

Other future UK missions to watch include Truths (Traceable Radiometry Underpinning Terrestrial- and Helio-Studies), an NPL-led project to enhance measurement capabilities in space; and Comet Interceptor, a bold new effort to study a pristine comet from the Oort cloud as it enters the solar system for the first time.

Spaceports and launch

Back in the commercial space, UK engineers are now looking seriously at the technology and infrastructure required to give the UK its own launch capability.

Recent years have seen a flurry of activity, with several British locations slated for both vertical and horizontal take-off, as well as new launch technologies gaining momentum.

Sutherland in northern Scotland was chosen in 2018 to be the home of the UK's first spaceport, providing vertical launch services from the wild, remote A'Mhoine Peninsula.

Plans for the complex will see Lockheed Martin use one pad for its Electron rocket, with a second pad likely to go to British spaceflight company Orbex, which recently raised £30m in public and private funding.

Some have questioned the suitability of the Sutherland site, and another site on North Uist in Scotland's Outer Hebrides is aiming to beat Sutherland to the punch. QinetiQ, which operates the nearby MOD Hebrides Rocket Range, is a partner in the project.

Horizontal launch has proved no less competitive, with both Glasgow Prestwick and Snowdonia's Llanbedr Airfield muted as potential spaceports, the latter having also been in the running for vertical launch. But Newquay Airport looks set to take the lead, with Spaceport Cornwall recently being allocated £20m in funding.

Virgin Orbit will operate from the facilities and assist with the development, potentially launching small satellites in the early 2020s. Further down the line, the UK's Reaction Engines is another possible customer. Development of the company's ground-breaking Sabre often feels glacial, but nobody said redefining spaceflight was going to be easy.

Reaction recently marked a major milestone, however, with SABRE's pivotal precooler heat exchanger passing hot ground tests replicating Mach 3.3, the speed record of the SR-71 Blackbird. The single-stage hybrid engine is designed to reach speeds of Mach 5.5 in air-breathing mode, before switching to rocket power to hit orbital escape velocities of around Mach 25. ■

SWIND E Classic: The power of retro

Old meets new, with this thoroughly re-engineered take on Sir Alec Issigonis's iconic design, writes Chris Pickering

The internal combustion engine's days may soon be numbered. At least that's the stark warning given by politicians who are seeking to ban the sale of petrol and diesel cars by 2040 (or possibly as early as 2030 under new proposals). It's a sentiment that's been steadily growing for a number of years, with car manufacturers ploughing vast amounts of money into developing new electric models. But recently, another trend has started to appear: electric conversions for classic cars.

At present, cars over 40 years old are protected against the ever-tightening emissions requirements directed at newer models. You can, for instance, drive through the London Ultra Low Emissions Zone in a 1948 Series 1 Land Rover, yet you can't do so in a 10-year-old Ford Fiesta. Whether or not that will still be the case in the future, though, remains to be seen. And there are also people out there who specifically want the retro style of a classic car combined with the guilt-free image of a modern electric drivetrain.

Enter the SWIND E Classic – a meticulously re-engineered take on the classic Mini, which substitutes the old four-cylinder BMC A-Series engine for an 80kW (110bhp) electric motor. It's coupled to a 24kWh lithium ion battery, which gives a real-world range of 125 miles (about the same as the fuel tank on the original Mini).

Many of the fundamental attributes have been carried over from the original car. At around 720kg, it does weigh slightly more than a classic Mini, but it's still far closer to the 1950s original than its modern namesake. It remains front-wheel drive too, albeit with a bespoke single-speed transmission, while the suspension is Alex Moulton's ingenious hydrolastic design, taken from the original Mini. The ride height has been lowered fractionally on this example, but it sits on period-correct 12-inch wheels. Even the charging socket is hidden underneath a replica filler cap.

> "You rapidly forget that it's powered by electricity"

As you can see, this is not an attempt at transport for the masses, but rather a toy for those with a passion for nostalgia. It had better be a pretty serious passion because the E Classic starts at £79,000. That's enough to buy you a new, all-electric Jaguar I-PACE and a perfectly usable classic Mini. But don't judge the E Classic too soon, because its price tag is about on par with the re-engineered petrol-powered Minis offered by David Brown (and indeed some of the more valuable original examples). The question is more whether it can deliver the same level of enjoyment for the lucky few able to afford it.

Step inside and the Sixties vibes are every bit as strong as you'd hope. At a glance, it's virtually indistinguishable from an original Mini cabin, albeit with a significant step up in fit and finish. Look closer, though, and you'll spot a few well-disguised mod cons. The fuel gauge has become a charge indicator for the battery, the oh-so-retro bucket seats are now electrically heated and there are

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01 The charging socket is hidden underneath a replica filler cap to retain some of the classic Mini's originality

02 The overall driving experience has a go kart-like feel

The SWIND E Classic allows you to step back into the Sixties with the classic Mini feel

even underfloor heat pads to further supplement the original Mini's notoriously inadequate heater. Options include a DAB radio with satellite navigation, Apple CarPlay and Android Auto, plus air-conditioning, power steering and an electrically operated sunroof.

Originality at the heart

In some respects, the most significant addition to the cabin is the enlarged transmission tunnel that runs down its centre. This contains part of the T-shaped battery pack, which extends out beneath the rear seats. SWIND had to modify the floor pan to accommodate this, which is a fairly significant undertaking. The battery pack itself is also a bespoke item, designed to slot in without impinging on the boot space. The position of the battery pack means that the centre of gravity has dropped by some 44mm compared to the donor car and the front-to-rear weight distribution has improved from 68:32 to 57:43.

This sort of thing is all in a day's work for SWIND's parent company, Swindon Powertrain; the Wiltshire outfit works with several major car manufacturers behind the scenes and currently builds the engines for more than half the British Touring Car Championship grid. As the company is at pains to point out, however, it's very different to the 'drop in' conversions offered for some other classics. Here, the engineers have gone out of their way to develop a solution that fits seamlessly within the original design.

Head out on to the roads around the company's Swindon HQ and the first thing that strikes you is the performance. It's certainly not Tesla-fast – and the initial slug of torque does fade away fairly rapidly – but there's a real kick in the back when you put your foot down. At the same time, the pedal response is progressive and easy to modulate, while the clutch-free transmission makes pottering around town an absolute doddle. The regenerative braking has been carefully calibrated too, giving just the right amount of retardation when you lift off the accelerator. This has also allowed SWIND to remove the brake servo, improving pedal feel without compromising the overall stopping power.

Much has been made of the Mini's go kart-like feel over the years and it's still very much in evidence here, with minimal body roll, bags of steering feel and an impressive sense of agility.

What I wasn't expecting quite so much was the soundtrack; the motor is far from silent and there's a distinct chatter from the transmission. The latter is a result of the so-called cogging torque that afflicts permanent magnet motors when they're off-load – a small spike of electromagnetic force as the magnets on the rotor pass the steel teeth on the stator. You can't feel this effect from the driver's seat – the torque it produces is only in the range of 2 or 3Nm – but it's just enough to set up an oscillation in the drivetrain. The SWIND engineers say they will be able to overcome this in the production models with careful control of the motors, but part of me wishes they'd leave things as they are. At the moment, it sounds like the straight-cut gearbox on a classic rally car.

In fact, perhaps the greatest compliment you can pay the E Classic is that you rapidly forget that it's powered by electricity. It handles, responds and, at times, even sounds like an original Mini. The secret to this is that the engineers have removed the weak link of the original design – the wheezy, arthritic BMC A-Series – but gone to great lengths to retain its other attributes.

Had this car been a 12-cylinder Ferrari or a rumbling V8 muscle car, I'm not so sure its character would have survived the conversion process. But here at least, the classic feel is very much alive and well, whatever the future may have in store. ■

magniX set for take-off towards the future of electric aviation with new motor designs

US-based firm uses ANSYS technology to test products at revolutionary speed

With its origins in Australia and a global HQ in Seattle, magniX wants to unite communities across the world using electric aviation.

To this end, the electric motor company is creating cleaner, quieter, lighter and more efficient motors at much lower operating costs. One of the ways it has done this has been to connect the propeller directly to the motor, which removes the need for a gearbox, while simultaneously bringing down weight, system complexity and maintenance costs.

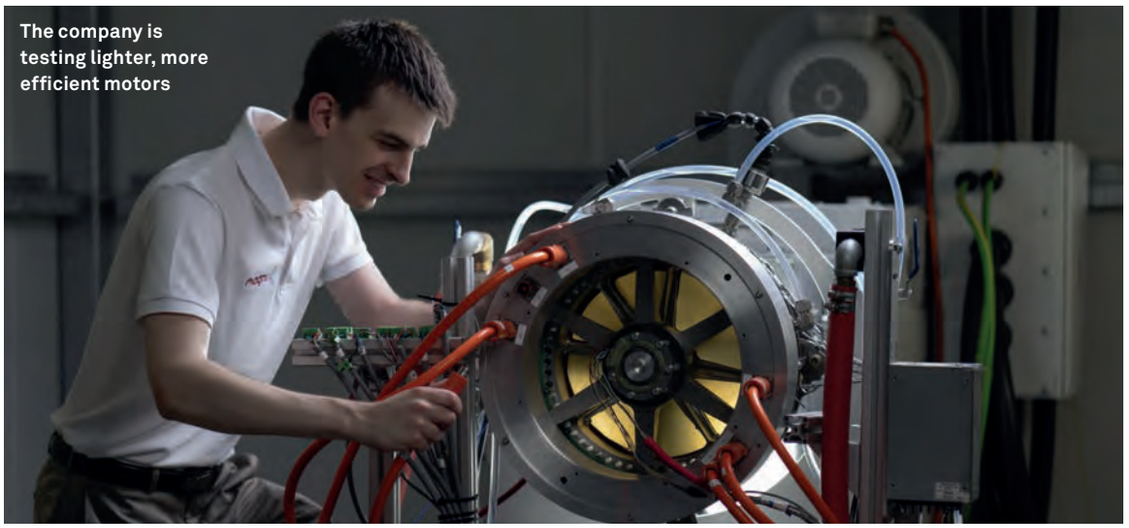
Despite many evolutionary developments in the past century, there have been few revolutionary leaps in aviation since the invention of the jet engine. Today's engines have between 30 and 40 per cent efficiency, but electric engines have the potential to be up to 95 per cent efficient, greatly cutting down on emissions and power consumption.

Furthermore, the aviation industry produces around 4.9 per cent of all carbon dioxide emissions globally and accounts for around 12 per cent of all carbon dioxide emissions within the transportation industry.

"Today, short-haul flights are relatively uncommon and more expensive than they should be," explains magniX CEO Roei Ganzarski. "A 100-mile flight could easily cost $400 (£314) in fuel, but an electric plane could do it for just $12. It's almost inconceivable that 20 people should fly from Cambridge to Coventry, Frankfurt to Würzburg, or Brussels to Antwerp, but electric planes have the potential to connect these and smaller towns together in ways that no one has ever thought about before."

The company may have a compelling technology solution, but it faces a multitude of challenges in changing the face of air travel. Primarily, most air travel innovations are based on improving existing designs, but it was important to magniX to start from scratch.

Manufacturing motors and inverters for aeroplanes is incredibly complex. Not only do they need to be lightweight, but they need to comply with multiple aerospace level requirements.



The company is testing lighter, more efficient motors

"Physically building and testing each potential motor and inverter design was out of the question," continues Ganzarski. "We're an agile company and don't want to waste time building each and every design to see if it will work – it's much better to focus physical testing on the most promising designs. We needed a tool that could help us to model new designs, understanding aspects like structural integrity and performance under different stress conditions.

"Above and beyond all of this is the safety question. We want to help to build aircraft that we would be happy for my kids to fly in. That's priority number one and thinking about what we do at a very personal level has helped everyone in our team really relate to the power and importance of this endeavour."

MagniX has selected ANSYS tools to simulate the structural properties of electric components and the impact of new configurations on motor parts. This allows it to rapidly prototype and evolve new products at a speed far beyond that of testing physical parts.

"We looked at other simulation vendors, but ANSYS gives us a proven experience level," says Ganzarski. "It allows us to simulate how the motors work, as well as looking at stress conditions, fluid dynamics, or individual structural properties."

Using ANSYS simulation tools allows magniX to test hundreds of parts and configurations in the same time that it would take to physically manufacture and test just one.

Simultaneously, magniX can use ANSYS to ensure that any new parts or configurations will meet common safety regulations across the aerospace industry, ensuring that the team do not waste time producing a component that will be forbidden by industry bodies but, more importantly, that components are safe and fit for purpose.

ANSYS technology is also recognised by industry bodies, including the FAA, EASA, Transport Canada and ANAC, giving the magniX team faith that their designs will be safe and can pass global regulatory requirements.

Although electric planes are limited to flights of up to 650 miles because of battery life, this distance still accounts for around 45 per cent of airline flights globally.

"It's really very simple," concludes Ganzarski. "Without simulation, we'd either have to compromise on reliability, quality, or speed, and that's unacceptable to us. Using ANSYS helps us to be first, faster." ■

AEROSPACE

Mixed reality takes to the skies

Airbus to team up with Microsoft to explore HoloLens 2, a reality headset that uses holograms to help speed up aircraft production

Augmented reality (AR) technology that enables users to manipulate holograms as if they are real physical objects is being used by Airbus to help drive the development of the next generation of aircraft.

Engineers at the aerospace giant are using Microsoft's latest mixed reality headset, HoloLens 2, to access and interact with production information, carry out training and speed up the design validation process.

Airbus has been exploring mixed reality for several years and started working with Microsoft on mixed reality solutions four years ago. But the latest version of the headset is claimed to open up a number of new applications for the technology. Indeed, according to Jean-Brice Dumont, executive vice president of engineering, Airbus has already identified more than 300 potential applications for the platform.

According to Dumont, the technology is expected to play an important role in helping Airbus meet a series of demanding targets. "Our challenge in the coming years is to manufacture more aircraft faster, and for that we need to enable our workers to be much better equipped and to be much more effective in what they do. We need to raise the bar," he said.

Airbus has already seen impressive results in its trials and deployment of the technology, Dumont explained. "Mixed reality can help us to increase quality, safety and security. The level of human error is significantly reduced, and in aerospace, increased quality is increased safety – and needless to say, security goes with that."

The latest HoloLens headset allows users to interact with holograms in physical space, meaning that they can view and manipulate holographic images on their own in the air or in combination with real physical objects, and also offers eye tracking that can sense when a user's eyes land on a particular location and produce relevant digital information.

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> "Mixed reality can help us increase quality, safety and security"

Among a number of different applications Airbus claims that the technology could be used for is to accelerate the design validation process by as much as 80 per cent. It can also be used to help workers on the production line access crucial information while keeping their hands free, one of several production environment applications that Airbus claims has allowed it to cut manufacturing time by a third.

Training is another key application area, with the technology enabling engineers to learn in an immersive virtual environment without the need for a physical aircraft or parts.

As well using Hololens in its own operations, Airbus is also partnering with Microsoft on the development of off-the-shelf solutions for its customers.

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One example of this is a mixed reality training programme first released with Japan Airlines that helps maintenance operators and cabin crews learn in a 3D holographic environment and access instructions, heads-up and hands-free, while on the job.

Airbus also plans to launch a collaborative map solution that allows participants from the defence and aerospace fields to virtually connect, quickly share space data and interact with complex virtual environments to plan and prepare ahead of missions.

Airbus is the latest in a list of industrial HoloLens users. As previously reported by *The Engineer*, both Volvo and Ford have been investigating its potential in the design lab, while German industrial giant ThyssenKrupp is trialling the technology for elevator repair.

Meanwhile, there is growing interest across the board in the industrial potential of AR. Speaking at PTC's annual LiveWorx conference, the software giant's chief executive James Heppelmann used his keynote address to extol the productivity enhancing benefits of AR.

The company's Vuforia product – one of the most widely used AR software tools – is integrated with HoloLens for industrial users. ■

01 HoloLens 2 will speed up the design validation process

02 Airbus has seen impressive results in its technology trials

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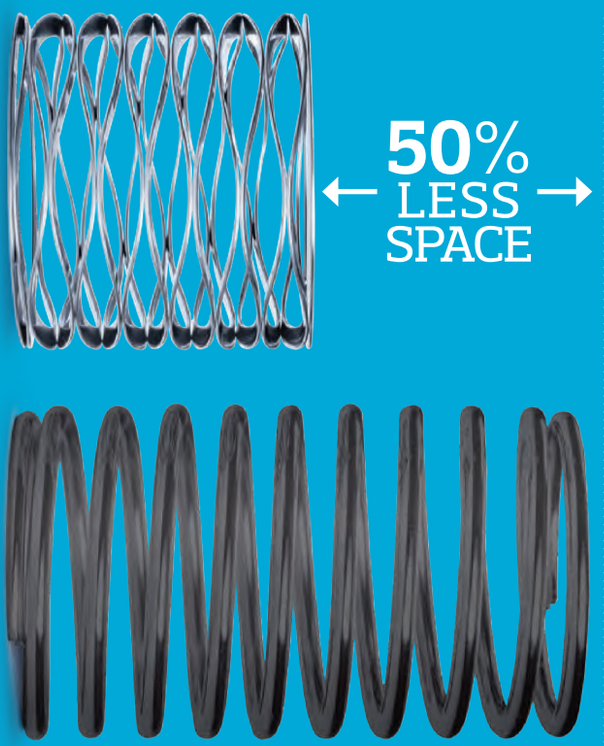

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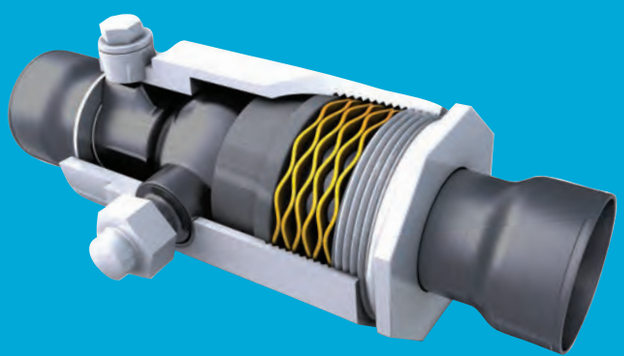

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Clean steam boosts food manufacturer Supplier: Spirax-Sarco

Spirax-Sarco Engineering has helped the Natural Fruit & Beverage Co enhance its packaging process with the introduction of a clean steam system.

There are four grades of industrial steam, ranging from bog-standard plant steam, up to filtered, clean and pure steam, which is the highest grade. While clean steam is widely used in the pharmaceutical and healthcare industries, many food manufacturers only use filtered steam for their processes.

When a baby food company came to the Natural Fruit & Beverage Co seeking to improve its product, manufacturing manager Jamie Walker investigated the use of different types of steam that could be used. The customer had up until that point been using CO_2 for purging and cleaning excessive residue before capping its baby food product, but CO_2 was an expensive resource and did not offer possibilities of improving the process.

A clean steam system will help the Natural Fruit & Beverage Co with its packaging

Having come to the conclusion that steam was the best solution, Walker then consulted with Spirax-Sarco on exactly what type of steam system would be suitable. The Spirax-Sarco team was invited to present to the management team at Natural Fruit & Beverage Co, where they explained the various types of steam, the concept of clean steam as an ingredient and how it applies in relation to a hazard analysis and critical control point.

The engineers explained that despite the tendency for food and drinks manufacturers to rely on filtered steam, consistency in taste, colour and quality of the end product could be achieved by choosing clean steam.

Generating and using clean steam within a process means controlling feedwater quality at the source. Rather than relying on a filtration process to extract particulates, the production of clean steam uses a secondary steam generator with the ability to control chemical-free feedwater quality.

Based on this explanation, Natural Fruit & Beverage Co introduced an electric compact clean steam generator at 50kW (50kg/h @ 3bar) with preheating capability and the ability to control feedwater quality.

"The Spirax-Sarco team gave me the confidence and security that they knew the subject well enough to introduce a clean steam generator rather than filtered steam," said Walker.

Since installing the new solution, Spirax-Sarco has supported the Natural Fruit & Beverage Co with regular site visits, which have helped Walker gain a better understanding of how the company's steam system is working. ■

MARINE

Ocean drive

Pumps show sea legs Supplier: Watson-Marlow

Pumps from Watson-Marlow have been proven seaworthy over extended periods of use in equipment for measuring ocean acidification.

Around half of global CO_2 emissions are absorbed by Earth's oceans, increasing their acidity. This has consequences for marine life. Keeping track of the level of dissolved CO_2 has become a key part of climate research, one that requires precision equipment that must often operate in challenging environments.

"Our Vindta 3C system can measure two carbon system parameters in a single sample," said marine chemist Dr Ludger Mintrop, founder of Marianda, a manufacturer of precision marine instruments. "It measures the alkalinity and total amount of dissolved inorganic carbon. Taking only 20 minutes, the system performs a titration process that measures two parameters from the same sample with an accuracy that no other product on the market can match."

Analysis is performed using a sophisticated system of sample holders, pipework and measurement cells, backed up by software. Liquid samples are transported to and from the measuring cells by two 400/R1 peristaltic pumps, supplied by Watson-Marlow.

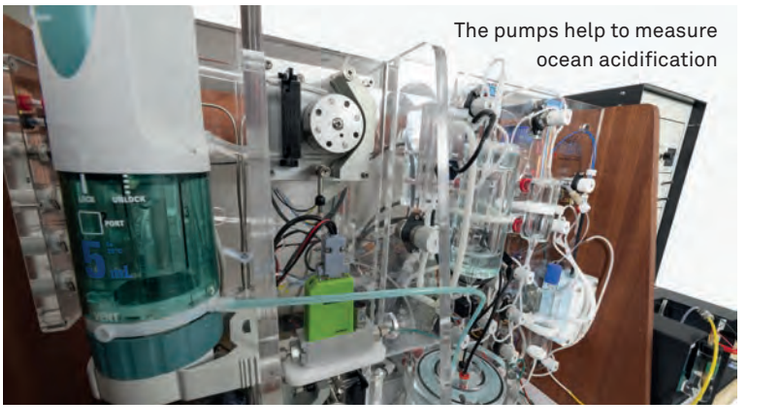
The first pump transfers sample liquid into pipettes and from there to the measuring cells, while the second pump empties one of the measuring cells after the analysis has been performed and cleans it with a rinsing solution.

"Our analysis equipment is used throughout the world, often under extremely challenging conditions," said Mintrop. "Many devices are deployed on marine research vessels and operate around the clock, often encountering saltwater exposure. In addition, the devices are sometimes put into storage for many months between expeditions, or transported to new research locations."

According to Mintrop, his previous experience as a researcher was helpful when selecting the ideal pump for the devices.

"I had already encountered Watson-Marlow OEM pumps during my work as a researcher, and come to value their performance and reliability," he explained.

"It's clear to see that only the highest quality components have been used in the drives and in the pump head. This is why the corrosion caused by exposure to saltwater just isn't an issue for Watson-Marlow pumps." ■



The pumps help to measure ocean acidification

Fast lane to the future

July 1960

The Engineer reported on early plans for autonomous vehicles

Many of today's cars roll off the production line with a myriad of safety features that help keep motorists safe in those moments when concentration wanes and traffic is dense.

Features such as lane-departure warning, automatic emergency steering, automatic emergency braking, and lane keep assist issue audible or tactile warnings to drivers deviating from their lane. However, good ideas like these have to start somewhere and in July 1960 a Mr LE Flory of the Radio Corporation of America (RCA) delivered a lecture at the Road Research Laboratory (or Transport Research Laboratory Ltd as it is known today) on a new system aimed at controlling cars electronically.

But where today's automotive manufacturers market driver assistance and greater autonomy in terms of preserving life, Mr Flory saw the prevention of accidents largely in terms of cold, hard cash.

"The cost of accidents in property damage and loss of time is, in the United States, equal to the cost of fuel consumed," he told his audience in a talk titled 'Some steps toward a system of electronic vehicle control'.

"In addition, from a strictly engineering standpoint, any method of increasing the efficiency of movement of traffic resulting in better loading of the highways is just so much money in the budget."

The big idea from Flory and RCA is standard now, but the way in which is has been implemented owes everything to ongoing technological advances that have negated changes to infrastructure proposed in the talk at Langley.

Introducing his lecture, *The Engineer* asked: "How many years will it be before a motorist, on approaching a main road, will be able to feed simple route instructions into some device in his car, and then leave the entire job of driving to automatic gadgets in the car and on the road?" Flory answered by describing how automatic control is achieved under the simplified conditions of single-lane traffic, namely keeping the car "in lane" and preventing it colliding with the car ahead.

This, said *The Engineer*, is a first step in developing a comprehensive system of vehicle control which might be introduced in stages, each stage "compatible" with existing traffic and the whole system strictly following the "fail safe" concept.

According to Flory, the stages went as follows: "First, a stage of improved communication with the driver to enable him to make decisions better and faster. Second, a stage where some of the decisions are made for him, and he is given a warning if he is approaching a dangerous condition; and third, a final stage where the system actually takes physical control of the car either on a continuous basis or only if the driver failed to respond properly to the warning system."

Focusing here on the first stage, Flory said that accomplishing lane guidance would require interaction between the vehicle and the highway lane, by laying down in or on the roadway a trail which a vehicle can follow.

"The most direct method is the insertion of a cable carrying an alternating current down the centre of the lane," Flory told his audience. "Simple detectors mounted on the car then provide control signals to the steering mechanism which will keep the car centred over the wire. This method permits the use of different frequencies for different lanes and route selection by change in frequency."

Echoing today's discussions around vehicle autonomy, Flory suggested that collision prevention is a more complex matter as it involves the interaction of two vehicles moving independently, only one of which can be assumed to have any special equipment.

"This situation suggests that the road must be the agent for transmitting a signal from the lead car, which may or may not be equipped with control devices, to the following car which is considered to be electronically controlled," he said. "Thus, the active source of the warning signal indicating the presence of the lead car must be within the road since a perfectly passive vehicle must make its presence and speed known to any equipped car following it.

"The road installation for collision prevention has thus the joint function of detecting vehicles at any point along the road, and of generating warning signals over a prescribed distance of road behind every detected vehicle". ■ JF

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and supporting services to be moved from A.E.R.E., Harwell, and a small team from A.W.R.E., Aldermaston, to that within four or five years the new laboratories at Culham should approach their planned size of 1000 total staff.

CHANGES IN MEMBERSHIP OF THE ATOMIC ENERGY AUTHORITY

Lord Plowden relinquished his appointment as chairman of the Authority on December 31, 1959. He was succeeded by Sir Roger Makins. Sir Ivan Stedeford relinquished his appointment as a part-time member on July 31, 1959.

The Atomic Energy Authority Act, 1959, increased the permitted membership of the Authority from eleven to sixteen. Sir Leonard Owen was appointed Member for Production and Sir Claude Pelly Member for Weapons Research and Development. Both appointments were effective from January 1, 1960.

Electronic Control of Road Vehicles

Last week a lecture entitled "Some Steps Towards a System of Electronic Vehicle Control" was given at the Road Research Laboratory at Langley by Mr. L. E. Flory of the Radio Corporation of America. Mr. Flory explained the system which is being developed by the R.C.A. at its laboratories at Princeton, New Jersey. Part of his lecture is reproduced here.

A SINGLE lane of traffic with no passing requires only two functions from a driver. First, he must stay in his lane, and second, he must be prevented from colliding with the car in front of him. In this oversimplified situation, if we provide automatically for keeping a car in its lane and for preventing collision with a car ahead under any conditions, we have the elements of a complete control system. One more operational requirement must be met, viz, any system must be capable of being introduced gradually and must at all stages be compatible with existing traffic.

Consider a system which could be developed in three stages. First, a stage of improved communication with the driver to enable him to make decisions better and faster. Second, a stage where some of the decisions are made for him, and he is given a warning if he is approaching a dangerous condition; and third, a final stage where the system actually takes physical control of the car either on a continuous basis or only if the driver failed to respond properly to the warning system.

It is obvious that to accomplish lane guidance there must be some interaction between the vehicle and the highway lane, by laying down in or on the roadway a trail which a vehicle can follow. The most direct method is the insertion of a cable carrying an alternating current down the centre of the lane. Simple detectors mounted on the car then provide control signals to the steering mechanism which will keep the car centred over the wire. This method permits the use of different frequencies for different lanes and route selection by change in frequency.

Collision prevention is a much more complex matter since it involves the interaction of two vehicles moving independently, only one of which can be assumed to have any special equipment. This situation suggests that the road must be the agent for transmitting a signal from the lead car, which may or may not be equipped with control devices, to the following car which is considered to be electronically controlled. Thus, the active source of the warning signal indicating the presence of the lead car must be within the road since a perfectly passive vehicle must make its presence and speed known to any equipped car following it. The road installation for collision prevention has thus the joint function of detecting vehicles at any point along the road, and of generating warning signals over a prescribed distance of road behind every detected vehicle.

Detection in the R.C.A. system is by a continuous sequence of wire loops embedded in the surface of the highway. The loops are about the size of a car and spaced only a few feet apart. As a vehicle passes over any loop the inductance of the loop is altered by the metal of the vehicle. This change is detected by an electronic circuit placed alongside the road.

In response to the action of the detector, a "flying tail" of electrical voltages is generated in the roadside circuits behind every detected vehicle. These voltages decrease in amplitude with the distance behind the vehicle. In the first stages of introduction of the system a tail of warning lights would be lighted in response to these voltages so that the driver of a following car would know that there was a car ahead. Different colours or patterns of lights could be used to indicate headway. By introducing a pattern into the series, motion of the lead car could be observed by the following car and his speed adjusted accordingly. Such a system might be installed immediately in areas of poor visibility.

In the second and third phases of the system, the roadside voltages would be used to activate transmitting equipment, which would generate a "flying tail" of the electromagnetic radiation which would carry the information concerning headway as well as a signal representing the speed of the leading car. These signals would be picked up by receiving equipment in the following equipped car, and the information regarding headway and speed extracted. In the second phase, this information would be used to sound warning signals or activate visual signals when either headway or closing speed approached a dangerous condition. In addition, pickup equipment could receive a signal from the guidance cable and sound a warning if the driver strayed from his proper position in the lane.

In the third phase, the received signals would operate the mechanical controls of steering, acceleration, and braking in a manner which would be predetermined by the design and adjustment of the control equipment in the car.

The Control System

The most conspicuous element of the detection system is the sequence of rectangular loops, comparable to a car in size, which are inserted into the pavement and form part of detection circuits whose active components are buried in capsules by the side of the road. The loops can then be installed quite simply in the roadbed during construction and have been installed in existing pavement by a simple and rapid diamond saw technique.

The loops are excited by a high-frequency current. When a vehicle passes over a loop it changes the inductance. This change in inductance causes a shift in the phase of the loop current which operates the phase sensitive detector unit. The unit in turn applies a gating potential to a signal generating unit which impresses a warning signal upon its associated antenna. Connecting all of the signal generators is a continuous one-way attenuating cable system. Thus, when a detector unit applies a gating potential to its immediately associated warning signal generator, it likewise impresses on all other generators a potential which decreases in magnitude exponentially as the distance from the car increases. This potential is used as a modulating signal by the generators to produce a warning signal which transmits distance information to the following car. The same decreasing potential can be used to operate visual warning lights, which change in colour or pattern with distance.

An additional pulsed signal is impressed on the antennas within the tail each time a car moves from one detector to the next. A following car picks up the warning signal which contains headway information; in addition it receives a pulse each time the lead car crosses a detector. By making a measurement of the time between these pulses a measure of the speed of the car is obtained. The detectors themselves are relatively simple, as they must be since they must be repeated many times for each lane of the highway. The tail signal generators are likewise relatively simple.

It must be stressed that the equipment in the vehicle generates no signal. A vehicle influences following vehicles only through its presence acting through the detectors to modify the signals radiated by the antennas buried in the road to the rear of the vehicle. It follows that the flying tail of warning signals, indicating both distance and speed, will be formed behind any car regardless of its equipment or the volition of the driver. Only the controlled car need contain any equipment.

The warning signal detector consists essentially of an antenna attached to the underside of the car and a receiver whose output contains the distance and speed information relative to a car ahead. This output can then be used in conjunction with the speed of the car itself to operate warning buzzers or lights, and, in a fully automatic system, the brakes and the accelerator of the car. Automatic gain control makes the output signal independent of precise location of the detecting antenna relative to the antenna in the road and makes it dependent only upon the modulation of the signal. Complete absence of a signal as in a power failure will be correctly interpreted by the car as an emergency and the car will be brought to a stop.

In experimental installations the guidance signal has been obtained from two tuned antennas mounted on the left and right sides of the front bumper. As the car deviates to the right or to the left from the centre of the lane, the current induced by the field of the guidance cable in the left antenna comes to exceed that induced in the right antenna and vice versa. The difference in the rectified signals from the two antennas may operate an indicator in the car or, acting through a hydraulic system upon the steering mechanism, tends to maintain a balanced condition

Word of the issue

Anothony Poulton-Smith explores the origins of the word 'torque'

For such a basic engineering term, describing the rotating force required to tighten a threaded fastener, it was not used prior to 1882. This is remarkably late considering the length of time threads have been used.

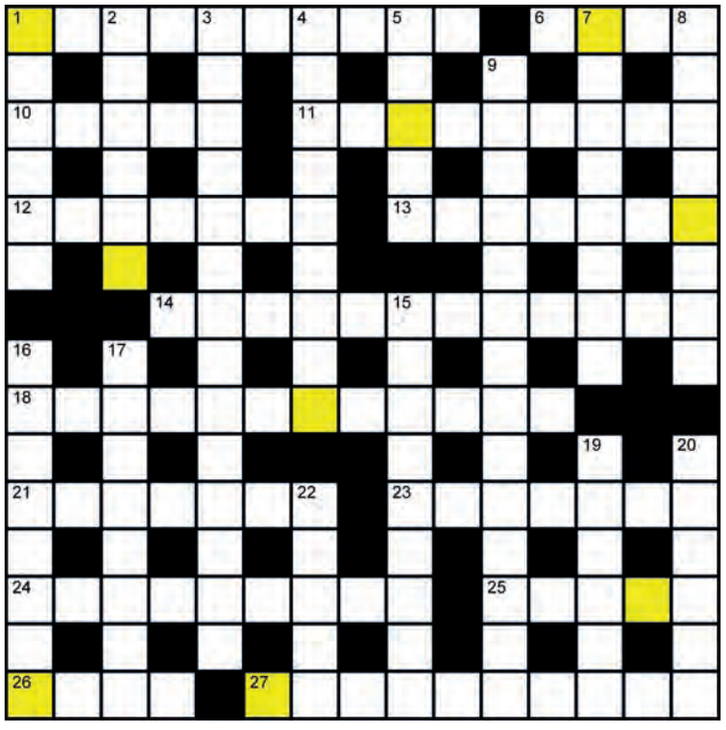
It does more or less coincide with the standardisation of thread forms but it does leave us wondering just how earlier engineers described the turning force.

However, the root of torque is ancient indeed. Coming from the Proto-Indo-European language of more than 8,000 years ago, we find the origin in terkw meaning 'to twist'. It was previously used in modern times (since 1834) to describe the twisted necklaces favoured by the Celtic peoples of around 2,000 years ago.

Also of interest are the many other words which have developed from the root terkw, and these include such varied words as contort, extort, nasturtium, thwart, retort, torment, torture, truss and the recent addition to the Oxford English Dictionary, twerk.

Bigpicture

Airbus has used Paris Air Show 2019 to host pitching sessions aimed at getting the FCAS – Future Combat Air System – off the ground. Selected European start-ups were given the opportunity to present their solutions for the FCAS, which is described as the largest and most ambitious development in European military aviation. Photo: ©Airbus



Prizecrossword

When completed rearrange the highlighted squares to spell out a type of flow control valve. The first correct answer received will win a £20 Amazon voucher. Email your answer to **jon.excell@markallengroup.com**

Across

1 Act of enclosing something in a box (10)
6 Come to a halt (4)
10 Crush or grind with a heavy instrument (5)
11 Apply an oil to aid movement (9)
12 Essential qualities (7)
13 Spear with three or more prongs (7)
14 Weakenings in force or intensity (12)
18 Structures separate from a main one (12)
21 Industrial plant for extracting metals with heat (7)
23 Protective structure of stone on a beach (7)
24 Star that explodes and becomes extremely luminous (9)
25 Signal going into an electronic system (5)
26 Set of questions evaluating skill (4)
27 Instep flattened so the sole rests on the ground (6,4)

Down

1 Act of reducing something unpleasant (6)
2 Marked by skill in deception (6)
3 Part of a ship above the main deck (14)
4 Metal with less than 0.15% carbon (4,5)
5 Swedish inventor of dynamite (5)
7 Friction between a body and the surface on which it moves (8)
8 Pastry used to hold in a filling (3,5)
9 Separation into component parts (14)
15 Remove software and associated files from a computer (9)
16 Stay and care for an empty dwelling (5-3)
17 Makes an effort (8)
19 Movable regulation plate in a furnace (6)
20 Lever that engages or disengages a rotating shaft (6)
22 Dry red table wine from Spain (5)

June's highlighted solution was: **TAILINGS.** The winner was: **Liz Lockwood.**

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